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# Centennial Mandalong Pty Ltd

# Subsidence Predictions and General Impact Assessment for the Mandalong Southern Extension Project

## DGS Report No. MAN-001/1

**Date: 12 August 2013**

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12 August 2013

Mr Peter Cook
Project Manager
Mandalong South Project Office
Mandalong Road
Mandalong NSW 2264

DGS Report No. MAN-001/1

Dear Peter,

**Subject: Subsidence Predictions and General Impact Assessment for the Mandalong Southern Extension Project**

This report has been prepared in accordance with the brief provided on the above project.

Please contact the undersigned if you have any questions regarding this matter.

For and on behalf of
**Ditton Geotechnical Services Pty Ltd**

Steven Ditton
Principal Engineer

## Executive Summary

This subsidence assessment has been completed to meet the Director General's Requirements for an environmental assessment for the Mandalong Southern Extension Project (Project). See **Section 2** for the subsidence specific requirements.

The Project proposes to extend Mandalong Mine's existing underground mining operations into the area covered by EL 6317 in order to access, develop and extract the additional coal reserves identified within the West Wallarah (WW) Seam and Wallarah-Great Northern (WGN) Seam at a rate of up to six million tonnes per annum (Mtpa) of run of mine (ROM) coal. Among other things, the Project also proposes to continue the utilisation of existing surface infrastructure integral to the mining operation in terms of coal delivery, handling and transport, and install new surface infrastructure to service the extended mining operation.

The area proposed for mining within the Project Area comprises a surface area of approximately 2,839 hectares. The proposed mine plan within this area encompasses a total of 40 longwall panels (LWs 25 to 64) ranging in length between approximately 1,000 and 3,500 metres (m), depending on seam conditions and site constraints.

Numerous mine plan options and variations were considered for the Project during the planning phase. The proposed mine plan was developed and selected as the optimal option in light of the following constraints:

- Alluvial and sub-surface groundwater sources;
- The existing surface environment, including creeks, ecology, steep slopes and archaeology items (**Sections 5.2, 5.3, 5.4, 5.5 and 5.6**);
- The alignment of major service infrastructure, including TransGrid's 330 kV power lines (**Section 5.7**);
- The location of privately-owned residences (**Section 5.8**);
- The Wyong Shire Council's Buttonderry Waste Management Facility (**Section 5.11**);
- The structural geology of the West Wallarah and Wallarah-Great Northern Seams identified during the exploration drilling program (**Section 7**); and
- Mining efficiency, operational and economic considerations.

Development of the main headings (seven roadway configuration) is proposed to be aligned through the middle of the mining area along the north-south line where the WW Seam splits into the WGN Seam. These headings will be permanent tunnels for access and services throughout the mine life.

The Project aims to maintain similar levels of impact to built structures and the environment as the existing Mandalong Mine. The longwall panels are planned to have sub-critical to critical widths of 160 m, 180 m or 200 m to minimise subsidence impacts for the following key features:

- Residences – there are 114 houses located within the Project Area;
- Power transmission lines – four TransGrid owned power lines traverse the Project Area suppling 330 kV electricity to the western and northern suburbs of Sydney, as well as links between Eraring and Vales Point power stations. In addition, there is one 132 kV Ausgrid owned power line traversing the eastern portion of the Project Area;

- Creeks – the main creeks within the Project Area are Morans Creek, Wyee Creek, Mannering Creek and Buttonderry Creek, which are all 3rd order streams (according to the Strahler System, DIPNR 2005);
- Archaeology – 113 Aboriginal and six European heritage sites, including grinding grooves, rock shelters, scarred trees and logging stations, have been identified within the Project Area.

**Assessment**

Subsidence effect and impact predictions (**Section 10**) for the features above the proposed longwalls have been based on **ACARP, 2003** (see **Section 9** and **Appendix A**) and subsidence effect data from the Mandalong Mine to-date (LWs 1 to 12). At the time of report preparation, Mandalong had extracted (and reported on) four 125 m wide and eight 160 m wide longwalls in the West Wallarah Seam.

Based on experience from the Mandalong Mine and other longwall mines in the Lake Macquarie Area, it is likely that the development of subsidence will be reduced by the spanning potential of massive conglomerate and sandstone units that exist within the overburden. Borehole data indicates that the Project Area is situated within the Triassic Narrabeen Group and upper sequences of the Newcastle Coal Measures.

Whilst it is not possible to guarantee the spanning behaviour of the conglomerate units, the overall design philosophy of the Mandalong South longwall panels has been to limit surface impacts to levels similar to the existing Mandalong Mine. Statistical inference techniques have been applied to estimate confidence levels for the predicted values and allow a probabilistic assessment of the potential range of impacts to the environment and man-made developments. Credible worst case (CWC) predictions have been based on Upper 95% Confidence Levels in this study.

Based on the predicted maximum panel subsidence, tilt and strain values for the longwall panel layouts, the potential for the following subsidence related impacts and their likely effect on natural and man-made features have been assessed:

- **Surface cracking (Section 12.2)**
  Surface cracking will be controlled by the panel geometries and the 'strain absorbing' properties of surface alluvium along 3rd and 4th order streams. It is therefore considered 'very unlikely' that surface cracks will develop along the creek beds.

- **Height of sub-surface fracturing above the panels (Section 12.3)**
  Heights of continuous cracking are very unlikely to interact with the surface cracking zone within 15 m from the surface. It is assessed that the Constrained Zone above the Fractured Zone in the overburden is likely to provide adequate protection to watercourses and near surface ground waters. Spanning Munmorah Conglomerate units have limited Fractured Zone development heights above the workings.

- **Surface gradient changes (Section 12.5)**
  The potential for terrain adjustment where steep slopes are subjected to tilt or gradient increases of up to 20 millimetres per metre (mm/m) or 1 degree ($^o$). Significant erosion

and deposition of soils is expected to occur in areas with exposed dispersive/reactive soils and steep slopes greater than 18°.

- **Ponding (Section 12.4)**
  Existing ponding depths range from 0.0 m to 3.3 m along existing watercourses. Potential ponding depths may range from 0.15 m to 2.8 m (i.e. an increase or decrease of up to 0.6 m) after LWs 25 to 64 are completed. Based on Mandalong Mine's impact experience to-date, it is assessed that the proposed subsidence beneath the watercourses and Groundwater Dependent Ecosystems (GDEs) is unlikely to cause significant long-term impacts due to the presence of strain absorbing alluvium and low levels of surface cracking expected.

- **General slope stability and erosion (Section 12.5)**
  The steep slopes in their current, pre-mining condition are assessed to have a 'low' sliding potential over an extreme range of climatic conditions (i.e. dry to saturated).

  The subsided slopes for the same climatic conditions and range of expected tilts and strains are also assessed to have 'low' sliding potential during worst-case conditions, which may include unrepaired, water filled cracks. Occasional rock falls along minor cliff lines and movement of detached sandstone boulders down steep slopes (i.e. rock fall roll out) could occur due to mine subsidence development or natural weathering processes.

- **Valley uplift and closure (Section 12.6)**
  Valley closure and uplift movements across valley floors are considered an unlikely phenomenon above the proposed longwalls due to the lack of thick, massive beds of conglomerate and sandstone units at the surface along the broad creeks and valleys.

- **Far-field horizontal displacements and strains (Section 12.8)**
  Far-field displacements (FFDs) are horizontal movements outside the angle of draw and generally only have the potential to damage long, linear features such as pipelines (e.g. Telstra and Nextgen infrastructure), bridges and dam walls. TransGrid tension towers may also be vulnerable to far-field movements and strains. This phenomenon is dependent on (i) depth of cover to the coal seam, (ii) distance from the goaf edges, (iii) maximum subsidence over the extracted area, (iv) topographic relief and (v) horizontal stress field characteristics.

  It has been assessed that far-field strains are likely to be less than 1 mm/m at 0.5 x cover depth and less than 0.3 mm/m beyond an angle of draw of $45^{o}$ or a distance equal to 1 x cover depth outside longwall extraction limits. Measureable horizontal displacements are likely to be < 20 mm beyond a distance of 1 x the cover depth. The above displacements and strains are unlikely to cause damage beyond an angle of draw of $26.5^{o}$ to sensitive features.

Based on the observation that a finite range of subsidence effect values can occur at a given location above an extracted longwall panel of known mining geometry and geology, it is possible to provide a range of predictions that are likely to occur within a nominal confidence limit (i.e. usually 95%). This approach will allow specialist consultants and stakeholders to apply risk management principles in a practical way. On-going monitoring and review of subsidence effects and associated impacts will be conducted during mining in order to implement the proposed impact management strategies for the Project Area.

Each of the key features of the Project Area have been assessed and provided with impact management strategies as follows:

- **Surface cracking (Section 12.2)**
  Surface crack repair works may need to be implemented around the affected areas of the site, and in particular, if public roads, watercourses and steep slopes are impacted. Crack repairs in the flatter areas may involve ripping, backfilling and top dressing works or the pouring of cement-based grout or crushed rock into wider, deeper cracks. Crack repairs should not be attempted until the majority of active mine subsidence has occurred.

- **Steep Slopes (Section 12.5)**
  Subsidence that results in cracking on steep slopes that needs to be repaired, will probably require the use of tracked equipment to back fill or re-grade affected areas with erosion resistant materials, such as imported crushed rock or low strength, sand and cement-based grout. Impact management strategies for steep slopes should include surface monitoring and visual inspections, with placement of signs along public access ways warning of mine subsidence impacts.

- **Watercourses (Sections 12.2 and 12.4)**
  Extraction Plans will need to include Trigger Action Response Plans and remediation strategies for the unlikely occasions when cracking does occur along creeks and streams. Surface piezometers will be necessary to monitor ground water level adjustment and recovery for several years after each panel undermines a creek.

  Based on Mandalong Mines impact experience to-date, it is assessed that the proposed subsidence beneath the watercourses and Groundwater Dependent Ecosystems (GDEs) areas above the proposed mining layout is unlikely to cause significant, long-term impacts due to the presence of strain-absorbing alluvium and low levels of surface cracking experienced to-date.

  Surface flows between sections of creek that have become ‘disjointed’ due to ponding impacts, may require engineered channel earth works. Local experience to-date suggests that if increased in-channel ponding occurs it can either remain as an ‘additional’ pond along the creek or be remediated in consultation with the relevant government agency.

- **Sub-surface Fracturing (Section 12.3)**
  The Constrained Zone acts as a ‘barrier’ to drainage of overlying water bodies and its thickness is a very important element in surface to seam connection control. At Mandalong, the Munmorah Conglomerate defines the upper limit of the A-Zone, and acts as a barrier to significant water flow from overlying strata into the workings.

  Sub-surface fracture height measurements (through installation of deep borehole extensometers and pairs of shallow stand pipe piezometers along creeks to depths ranging from 5 m to 15 m) above the proposed longwalls should be considered during the Project at representative locations as part of the Extraction Plan TARP requirements. Consideration of further deep borehole extensometers in the low lying eastern areas of the project area would allow a more comprehensive review of groundwater interaction with the extracted longwall panels.

Inspections and monitoring of underground workings stability, groundwater makes and goaf air entry should continue to be recorded and included with subsidence monitoring data.

- **Residences (Sections 12.13 and 12.14)**
  The majority of residences and structures (i.e. >95%) will remain within safe, serviceable and repairable (SSR) impact limits. However, it is also likely that approximately 5% of houses and structures could experience 'moderate' impact from mine subsidence and may require additional repairs to restore the structure. This is likely to occur if there are non-flexible features and detailing inherent in older or non-articulated masonry structures.

  Mandalong Mine currently manages the undermining of residences via a Property Subsidence Management Plan (PSMP) process. This process has been successful and will be continued into the Project Area.

  A register of impacts to residences that have been subsidence by longwalls 1 to 12 indicate that buildings have remained safe, serviceable and repairable. It is therefore unlikely that properties will become structurally un-safe during subsidence to justify the vacation of residents prior to undermining; however, underground vibrations that occur during subsidence development may be detected by the occupants and/or their livestock (and pets). There is an existing network of MSB owned vibration monitors over the existing Mandalong Mine workings. It is expected that this would continue in the southern extension area.

  Three houses out of 114 (2.6%) may have their floor levels subsided below the minimum free board of 0.5 m above the 1 in 100 year flood level after mining is completed.

  Six houses have been identified as requiring a detailed risk assessment prior to commencement of mining in order to ascertain if rock roll out control measures will be necessary.

- **Archaeology (Section 12.9)**
  It is assessed that 13 of the 113 known Aboriginal Heritage sites (12% of known sites) may be impacted by cracking and erosion damage by mine subsidence above the proposed longwalls. It is possible that another 15 other sites (13% of known sites) could also be impacted by the proposed longwalls, with all other sites considered 'unlikely' or 'very unlikely' to be affected by cracking or erosion damage.

- **Power lines (Sections 12.10 and 12.11)**
  Five TransGrid tension towers along TL 24 are within the proposed limits of the longwall extraction with two towers inside a 26.5$^{o}$ angle of draw from the panel limits.

These towers are likely to be subjected to cumulative tensile or compressive strains in excess of 1 mm/m. It is understood that this section of the line will be relocated (following application and approval) prior to mining impacts.

Four of the five TransGrid tension towers along TL25.26 are located outside a 26.5$^{o}$ angle of draw and assessed as unlikely to be subject to strains greater than 1 mm/m. The tension tower No. 32 along TL22 is likely to experience strains of +/- 1 mm/m above LW54.

Thirteen of the 56 TransGrid suspension towers within the Project Area are estimated to have strains ranging from +/- 2 to 5 mm/m above the proposed longwalls, with the remainder estimated to have strains of less than 2 mm/m.

Power lines should continue to be managed in accordance with the Mine's Public Safety Management Plan in consultation with TransGrid, Ausgrid and the Mine Subsidence Board.

- **Communications (Sections 12.15 and 12.16)**
  Telstra and Nextgen have infrastructure throughout the Project Area. Mandalong Mine currently has an effective Telstra Management Plan, which is revised for each Subsidence Management Plan. This plan outlines the expected impacts, inspection regimes and potential or proposed mitigation measures. It is expected that a similar Management Plan would be prepared for the Nextgen infrastructure.

- **Roads (Sections 12.12 and 12.19)**
  Public Roads, fire trails and access tracks may be impacted by surface cracking of widths ranging between 20 mm and 50 mm. Public Roads should continue to be managed by the Mine's Public Safety Management Plan to provide signage and traffic control measures to affect repairs and maintain safety for road users during active subsidence periods.

- **Buttonderry Waste Management Facility (Section 12.20)**
  The Buttonderry Waste Management Facility will be located well outside a 26.5$^{o}$ angle of draw to the proposed longwalls and is very unlikely to be impacted by vertical subsidence or far-field displacements and strains.

- **F3 Freeway (Section 12.21)**
  The F3 Freeway will also be located well outside the 26.5$^{o}$ angle of draw to the proposed longwalls and is very unlikely to be impacted by vertical subsidence or far-field effects.

- **Yambo Survey Trigonometry Station (Section 12.22)**
  The Yambo Survey Trigonometry Station is located within the Project Area and is likely to be affected by mine subsidence. The new location of the station will be surveyed after the completion of mine subsidence in consultation with Land and Property Information (Department of Finance & Services NSW).

Overall, it is concluded that the assessed range of potential subsidence and far-field displacement impacts after the mining of the proposed longwall panels will be manageable for the majority of the site features, based on the analysis outcomes and discussions with the stakeholders to-date.

Impact management plans and strategies (**Section 12**) can then be developed that allow appropriate Trigger Action Responses and mine planning adjustments or mitigation measures necessary to deliver satisfactory outcomes to the feature and the stakeholders.

Surface and sub-surface monitoring recommendations are detailed in **Section 13**.

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**Glossary of Terms**

## Glossary of Terms

**Angle of Draw (AoD)** The angle to the vertical from the sides or ends of an extracted panel and the line drawn from the limits of extraction at seam level to the 20 mm subsidence contour at the surface. The 20 mm subsidence contour is an industry defined limit and represents the practical measurable limit of subsidence.

**Barrier Pillar** The pillar of coal left beneath sensitive surface features (e.g. TransGrid Tension Towers) and adjacent longwall panels.

**Chain Pillars** The pillar of coal left between adjacent longwall panels. The pillars form a barrier that allows the goaf to be sealed off and facilitates tailgate roof stability during longwall panel extraction. The height of the chain pillars is usually the same as the *development height*.

**Compressive Strain** A decrease in the distance between two points on the surface. Compressive strains may cause shear cracking or steps at the surface if > 3 mm/m and are usually associated with concave curvatures near the middle of the panels.

**Confidence Limits** A term used to define the level of confidence in a predicted *Subsidence Effect* (see definition below) subsidence impact parameter and based on a database of previously measured values above geometrically similar mining layouts.

**Cover Depth (H)** The depth (H) from the surface to the mine workings roof horizon.

**Critical Panels** Longwall panels that are almost as deep as they are wide (W) (i.e. 0.6 <W/H < 1.4) and is the point where 'bending' of the overburden starts to occur. If there are no massive strata present, significantly higher magnitudes of subsidence start to occur (i.e. panel geometries are transitional between sub and super critical panels, where the overburden does not span).

**Curvature** The rate of change of tilt between three points (A, B and C), measured at set distances apart (usually 10 m). The curvature is plotted at the middle point or point B and is usually concave in the middle of the panel and convex near the panel edges.

i.e. curvature = (tilt between points A and B - tilt between points B and C)/(average distance between points A to B and B to C) and usually expressed in 1/km.

Radius of curvature is the reciprocal of the curvature and is usually measured in km (i.e. radius = 1/curvature). The curvature is a measure of surface 'bending' and is generally associated with cracking.

**Credible Worst-Case** The Credible Worst-Case (CWC) prediction for a given *Subsidence Effect* and is normally the Upper 95% Confidence Limit determined from measured data and the line of 'best fit' or mean used to calculate the mean value. The CWC values are typically 1.5 to 2 times the mean values.

**Design Angle of Draw (Design AoD)** The 'practical' angle of draw (AoD) used to define minimum or allowable distances from the sides and ends of an extracted pillar panel to sensitive surface features. It is considered to be an effective impact management tool in which to minimise impact from differential subsidence effects parameters such as tilt, curvature and strain, which may cause cracking or instability. A Design AoD of $26.5^{o}$ has been used with negligible impact to surface features at the Mandalong Mine to-date.

**Development Height (h)** The height at which the first workings (i.e. the main headings & gateroads) are driven.

**Dry-schlerophyll Forest** Multi-aged stands of eucalypts with a forest floor dominated by hard leafed shrubs such as banksias, wattle and tea trees.

**Extraction Height (T)** The height at which the seam is mined or extracted across a longwall face.

**Extraction Plan** The current approval system that has formally replaced the **Subsidence Management Plan** (see below) and incorporates Director General Requirements and Project Approval Conditions that are used to define performance criteria and develop subsidence impact management plans.

**Factor of Safety (FoS)** The ratio between the strength of a pillar divided by the load applied to the pillar.

**Far-Field Displacement** Horizontal displacement outside of the AoD, is due to horizontal stress relief in the strata above an extracted panel of coal. The strains due to these movements are usually < 0.5 mm/m outside a $26.5^{o}$ AoD and do not cause damage directly.

**First Workings** The tunnels or roadways driven by a continuous mining machine to provide access to the production panels in a mine (i.e. main headings and gate roads). The roof of the roadways is generally supported by high strength steel rock bolts encapsulated in chemical resin. Subsidence above first workings pillars and roadways is generally < 20 mm.

**Full Tributary Area Load** Refers to the full weight of the prism of rock directly above the pillar of coal supporting it. The prism area is defined by the line drawn half-way between the pillar and the adjacent pillars surrounding it. The volume

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| | of rock above the pillar is then determined by multiplying the Tributary Area by the depth of cover. The load is then determined by multiplying the volume by the density of rock (normally assumed to be 2.5 t/$m^3$). |
| **Goaf** | The extracted void behind a retreating longwall that the immediate roof of the overburden collapses into soon after the coal has been extracted. The overburden above the ‘goaf’ then sags down and compresses it, resulting in a subsidence 'trough' developing at the surface. |
| **Horizontal Displacement** | Horizontal displacement of a point after subsidence has occurred above an underground mining area within the AoD. It can be predicted by multiplying the tilt by a factor derived for the near surface lithology at a site (e.g. a factors of around 7 to 15 are normally applied in the Newcastle Coalfield by DgS). |
| **Inbye** | An underground coal mining term used to describe the relative position of some feature or location in the mine that is closer to the working coal face than the reference location. |
| **Inflexion Point (d)** | The point above a subsided area where tensile strain changes to compressive strain along the deflected surface. It is also the point where maximum tilt occurs above an extracted longwall panel. It is typically located between 0.25 and 0.4 x cover depth from the panel sides, depending on panel W/H ratio. |
| **Longitudinal Subsidence Profile** | Subsidence measured (or predicted) along a longwall panel centre line. |
| **Mean Values** | The average value of a given *Subsidence Effect* (i.e. of subsidence, tilt, curvature or strain) predicted using a line of 'best fit' through a set of measured data points against key independent variables (e.g. panel width, cover depth, extraction height). |
| **Outbye** | An underground coal mining term used to describe the relative position of some feature or location in the mine that is closer to the point of mine entry than the reference location. |
| **Outlier** | A data point well outside the rest of the observations, representing a presumed anomaly (e.g. a measurement related to a structural discontinuity or fault in the overburden that causes a compressive strain concentration at the surface, in an otherwise tensile strain field). |
| **Panel Width (W)** | The void width of an extracted longwall between chain pillars. |
| **Primary Subsidence** | Subsidence that is caused directly by second workings or longwall mining due to the sagging of overburden after coal is extracted and the immediate roof collapses into the void left behind by |

the retreating longwall. Primary subsidence usually occurs soon after the undermining of a given surface location and continues for several weeks as the longwall retreats further along the panel.

**Project Area** The area that will be affected by mine subsidence and far-field effects from the extraction of the proposed longwall panels associated with the Mandalong Southern Extension Area. Centennial Mandalong have adopted an area defined by a line drawn 600 m from the limits of proposed longwall extraction for the DA Submission.

**Residual Subsidence** The last 5% to 10% of subsidence that occurs after primary subsidence is complete, and is due to the re-consolidation or re-compaction of goaf and overburden. It is a time dependent component of the subsidence and is unlikely to cause further impact to surface features.

**Secondary Subsidence** Indirect subsidence that is likely to occur above an extracted longwall panel if another longwall is extracted adjacent to it. The additional subsidence is caused by chain pillar compression and load transfer mechanisms to the goaf. These events can occur several times (at an exponentially decreasing rate) after the passing of at least three or four longwall panels.

**Second Workings** Refers to the removal of coal between first workings pillars and usually results in goaf formation as spans between pillars are significantly increased. Second workings are therefore performed on retreat in a longwall panel that will no longer be required to provide access or ventilation to a given section of mine.

**Shoving** The shortening and distorting effect of compressive strains and shear strains due to mine subsidence on surface terrain, which results in localised shear failures or movements and uplift of soils and rock.

**Strain** The change in horizontal distance between two points at the surface after mining, divided by the pre-mining distance between the points.

i.e. Strain = ((post-mining distance between A and B) - (pre-mining distance between A and B))/(pre-mining distance between A and B) and is usually expressed in mm/m.

Strain can be estimated by multiplying the curvature by a factor derived for the near surface lithology at a site (e.g. a factor of around 7 to 20 is normally applied in the Newcastle Coalfield).

Discontinuous overburden behaviour however, can result in local strain and curvature concentrations at cracks, making accurate predictions difficult. A rule of thumb is normally applied to allow for these effects, which is to increase smooth profile strains (and curvatures) by 2 to 4 times occasionally at a given location. The increase in strain also usually develops at locations with exposed rock profiles, as opposed to areas with deep soil profiles.

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| **Sub-critical Panels** | Longwall panels that are much deeper than they are wide (i.e. W/H < 0.6) and cause lower magnitudes of subsidence than shallower panels, due to natural arching or catenary action within the overburden across the extracted coal seam. |
| **Subsidence** | The difference between the pre-mining surface level and the post-mining surface level at a point, after it settles above an underground mining area. |
| **Subsidence Control Zone** | Reducing the impact of subsidence on a feature by modifying the mining layout and set back distances from the feature (normally applied to sensitive natural features that can't be protected by mitigation or amelioration works). |
| **Subsidence Effect** | The term used to define the subsidence and differential subsidence parameters (i.e. subsidence, tilt, strain and horizontal displacement) that may or may not have an impact on natural or man-made surface and sub-surface features above a mining area. |
| **Subsidence Impact** | The impact that a subsidence effect has on natural or man-made surface and sub-surface features above a mining area. |
| **Subsidence Management Plan** | Refers to the approval process for managing mine subsidence impacts, in accordance with the Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS) Guidelines.<br><br>The mine must prepare an Extraction Plan with Subsidence Management Plans (SMP) to the satisfaction of the Director-General, Resources and Energy before the commencement of operations that will potentially lead to subsidence of the land surface. |
| **Subsidence Mitigation/ Amelioration** | Modifying or reducing the impact of subsidence on a feature, so that the impact is within safe, serviceable, and repairable limits (normally applied to moderately sensitive man-made features that can tolerate a certain amount of subsidence). |
| **Subsidence Reduction Potential (SRP)** | Refers to the potential reduction in subsidence due to massive strata in the overburden being able to either ‘bridge’ across an extracted panel with sub-critical or critical geometry, or have a greater bulking volume when it fails above super-critical panel geometry. The term was defined in an **ACARP, 2003** study into this phenomenon and is common in NSW Coalfields where massive sandstone / conglomerate units exist. |

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| **Super-Critical Panels** | Longwall panels that are not as deep (H) as they are wide (W) (i.e. W/H > 1.4) and will cause failure of the overburden and maximum subsidence that is proportional to the mining height (i.e. 0.5 to 0.6 T). |
| **TARP** | Trigger Action Response Plan. |
| **Tilt** | The rate of change of subsidence between two points (A and B), measured at set distances apart (usually 10 m). Tilt is plotted at the mid-point between the points and is a measure of the amount of differential subsidence.<br><br>i.e. Tilt = (subsidence at point A - subsidence at point B)/(distance between the points) and is usually expressed in mm/m. |
| **Tensile Strain** | An increase in the distance between two points on the surface. Tensile strains > 2 mm/m are likely to cause cracking at the surface with shallow soil profiles over rock and are usually associated with convex curvatures near the sides (or ends) of the panels. Tensile strain also usually develops above chain pillars. |
| **Transverse Subsidence Profile** | Subsidence measured (or predicted) across a longwall panel or cross line. |
| **Valley Closure** | The inward (or outward) movement of valley ridge crests due to subsidence trough deformations or changes to horizontal stress fields associated with longwall mining. Measured movements have ranged between 10 mm and 400 mm in the NSW Coalfields and are usually visually imperceptible. |
| **Valley Uplift** | The phenomenon of upward movements along the valley floors due to **Valley Closure** and buckling of sedimentary rock units. Measured movements have ranged between 10 mm and 400 mm in the NSW Coalfields and may cause surface cracking in exposed bedrock on the floor of the valley (or gorge). The uplift due to valley closure is usually 0.5 to 1 times the closure magnitude. |

## 1.0 Introduction

This report presents a mine subsidence impact assessment for forty (40) additional longwall panels (LWs 25 to 64) in the West Wallarah (WW) Seam and Wallarah-Great Northern (WGN) Seam at the Mandalong Mine, Mandalong.

The Project Area is located to the south of the existing mine, which is currently extracting longwall 13 of a possible 24 longwalls (i.e. LWs 1 to 24).

The report will be used for the purpose of preparing an Environmental Impact Statement under Part 4 of the *Environmental Planning and Assessment Act 1979 (EP&A Act)* for State Significant Development to the Department of Planning & Infrastructure (DP&I).

The subsidence assessment has considered the Department of Mineral Resources (now Department of Resources and Energy (DRE) of the Department of Trade & Investment, Regional Infrastructure & Services (DTIRIS)) *Guideline for Applications for Subsidence Management Approvals (December 2003).*

The report has assessed the proposed mining layout of LWs 25 to 64, as shown in **Figure 1**. The proposed longwalls will have panel widths of 160 m, 180 m or 200 m, with cover depths ranging from 180 m in the north-east to 480 m in the south-west (average of 300 m). Longwall extraction heights will vary between 1.8 m to 4.6 m, depending on seam thickness.

The panel geometries have been designed to control mine subsidence effects to tolerable or appropriate levels in accordance with stakeholder and government agency requirements.

The surface and subsurface features of interest that exist within the Project Area include:

- 1$^{st}$ to 3$^{rd}$ Order Streams associated with Morans, Wyee, Mannering and Buttonderry Creeks.

- Steep slopes (18$^{o}$ to 35$^{o}$) and discontinuous sandstone cliff lines (outcrops) between 2 m and 5 m high with talus boulders of a similar size.

- Dry schlerophyll forest (eucalypts and hard leafed shrubs).

- Groundwater dependent ecosystems (GDEs) associated with unconfined alluvial aquifers along the water courses.

- Riparian vegetation and shallow alluvium along the flatter reaches of the creeks.

- One hundred and thirteen (113) Aboriginal Heritage sites, including 11 Artefact Scatters or Finds, 58 Grinding Grooves, 11 Scarred Trees, 3 Stone Arrangements and 28 Rock Shelters with Art and/or Potential Archaeological Deposits (PADs), 1 water supply location and 1 open campsite.

- Three TransGrid 330 kilovolt (kV) easements with 56 suspension and 13 tension towers.
- Ausgrid 132 kV easement and domestic power lines (suspended on timber poles).
- One hundred and thirty-six (136) private rural residential land holdings with 114 houses, 175 associated out-buildings, access driveways, fences, dams, swimming pools, tennis courts and livestock. The land is used for residential, horse training, farming and grazing purposes.
- Six (6) commercial businesses (Toepfer; Aradlay; Gibsons; Vaughans; Leighton Kesteven; Saunders).
- Fifteen (15) public roads (Wyong Shire and Lake Macquarie City Councils).
- Unsealed gravel fire trails and infrastructure access roads.
- Telstra and Nextgen fibre-optic and Telstra copper cabling (buried and suspended) to residents.
- Buttonderry Waste Management Facility (BWMF / Wyong Shire Council).
- Yambo Survey Trig Station.

The locations of some of the above surface features are shown in **Figures 1** and **2a** to **2c**.

The F3 Freeway is > 0.6 km or >2.5 times the cover depth to the east of the proposed longwalls.

Subsidence effect and impact predictions for the proposed project longwalls have been based on **ACARP, 2003** and subsidence effect data from the Mandalong Mine. Mandalong Mine has extracted 125 m and 160 m wide longwalls and has similar geological conditions. The southern extension area however, is deeper than the current Mandalong mining area, which has cover depths ranging from 150 m to 370 m. The mining height (T) in the current Mandalong mining area has ranged from 3.5 m to 4.8 m, with final maximum subsidence ranging from 0.26 m to 1.24 m (7%T to 26%T).

Based on experience from the Mandalong Mine to-date, and other longwall mines in the Lake Macquarie Area, it is likely that the development of subsidence will be affected by the spanning potential of massive conglomerate and sandstone units that exist within the overburden. Borehole data indicates that the Project Area is situated within the Triassic Narrabeen Group and Upper sequences of the Newcastle Coal Measures.

There are numerous sandstone channel and conglomerate members within the Narrabeen Group and Newcastle Coal Measures that have reduced subsidence significantly where it has been able to span across voids left in the extracted coal seams. The units are typically braided channel deposits with a bedding thickness range from 15 m to 80 m. The conglomerate beds are laterally persistent and often separated into horizontal or wedge-shaped sub-units by thin mudstone and siltstone beds. The Munmorah Conglomerate Member has several massive conglomerate and sandstone units that range in thickness from 10 m to 40 m and are 30 m to 100 m above the proposed mine workings.

Statistical inference techniques have been applied to determine confidence levels for the predicted values and allow a probabilistic assessment of the potential range of impacts to the environment and man-made developments.

## 2.0 Director Generals Requirements (DGRs) and Stakeholder Requests

As part of the Mandalong Southern Extension Project, Centennial Mandalong will develop and implement impact management plans to satisfy the expectations of the relevant government departments, agencies and stakeholders and meet the performance measures required.

The following impact assessment and management requirements (that have relevance to this report) have been requested:

| Agency, Department or Stakeholder | Project Impact Assessment Requirements | Sections of Report |
|---|---|---|
| Planning & Infrastructure (DP&I) (20/03/12) | Subsidence - including a detailed quantitative and qualitative assessment of the potential conventional & non-conventional subsidence impacts of the development that includes: | |
| | - the identification of the natural and built features (both surface and subsurface), including Wyong Council's Buttonderry Waste Management Facility and high voltage power transmission line and towers (particularly angle tension towers), within the area that could be affected by subsidence, and an assessment of the respective values of these features using any relevant statutory or policy documents; | 5, 7 |
| | - accurate predictions of the potential subsidence effects and impacts of the development, including a robust sensitivity analysis of these predictions; | 10, 11 |
| | - a detailed assessment of the potential environmental consequences of these effects and impacts on both the natural and built environment, paying particular attention to those features that are considered to have significant economic, social, cultural or environmental values; and | 12 |
| | - a detailed description of the measures that would be implemented to avoid, minimise, remediate and/or offset subsidence impacts and environmental consequences (including adaptive management and proposed performance measures); | 12, 13 |
| | Land Resources - including a detailed assessment of the potential impacts on landforms and topography, including cliffs, rock formations, steep slopes, etc; | 12.1 - 12.8 |

| Agency, Department or Stakeholder | Project Impact Assessment Requirements (Cont…) | Sections of Report |
|---|---|---|
| Planning & Infrastructure (DP&I) (20/03/12) | Heritage - including an assessment of impacts on Aboriginal cultural heritage and Historic heritage, including:<br>- an Aboriginal cultural heritage assessment (including both cultural and archaeological significance) which must:<br>• outline any proposed impact mitigation and management measures (including an evaluation of the effectiveness and reliability of the measures); and<br>- a Historic heritage assessment (including archaeology) which must:<br>• include a statement of heritage impact (including significance assessment) for any State significant or locally significant historic heritage items; and,<br>• outline any proposed mitigation and management measures (including an evaluation of the effectiveness and reliability of the measures); | 5.5, 12.9<br><br>5.6 |
| Primary Industries - Minerals Resources (DRE) (16/03/13) | Subsidence - the proposed mine layout should be designed and management systems be developed, taking in to consideration identified subsidence, existing surface structures and stakeholder and community issues.<br><br>The EIS should provide assessment of subsidence levels associated with underground mining, using best available predictive formulae.<br><br>The EIS should identify if the predicted subsidence will result in fracture connectivity to the surface, and the environmental consequence to the ground surface, groundwater aquifers and groundwater dependant ecosystems of the predicted subsidence. Baseline assessment of the surface features above the proposed mining areas must be sufficient to identify environmental features at risk, and appropriate setback or protection zones if necessary for sensitive features.<br><br>The following significant issues relating to subsidence impacts/management for the Mandalong Southern Extension proposal have been identified by DRE:<br><br>**1. High Voltage Powerlines**<br>The site is traversed by two 330kV powerlines. DRE understands from discussions with the Proponent that one links two power stations and the other services Western Sydney. DRE also understands that there is limited redundancy in these powerlines.<br><br>Both Lines include a number of angle towers, i.e. where powerlines change direction. Industry experience indicates that it is generally not possible to manage subsidence of angle towers (with exception of very slight angles) | 5<br><br>10<br><br>12<br><br>12.10 |

| Agency, Department or Stakeholder | Project Impact Assessment Requirements (Cont…) | Sections of Report |
|---|---|---|
| Primary Industries - Minerals Resources (DRE) (16/03/13) (cont…) | without the implementation of barriers sterilising coal and creating operational difficulties.<br><br>The presence of such towers which require protection will affect the mine layout potentially sterilising coal. Conversely adverse subsidence impacts to such towers may cause interruptions to power supply potentially affecting large numbers of people and business activities.<br><br>DRE understands from discussions with the proponent that it is proposed to mitigate against mine subsidence impacts to the angled towers through a combination of:<br>a. Mine design to avoid subsidence of selected towers;<br>b. re-routing of part of the affected powerlines to where subsidence would be negligible.<br><br>The latter is currently subject to consultation with the infrastructure owner. It is understood from discussions with the proponent that without relocation of the angled towers the project viability may be affected.<br><br>It is expected that other subsidence impacts to towers, i.e. non-angled, and on the powerlines in question can be managed by existing technology.<br><br>DRE consider that the proposed relocation of relevant angled towers is an important measure for managing potential impacts to high voltage powerlines. This will provide a balance between protection of power supply and coal resource utilisation at the site.<br><br>The proponent should address the potential subsidence impacts to high voltage powerlines in the EIS, including assessing options to protect angled towers, i.e. mine layout and feasibility of re-routing powerlines, in consultation with the infrastructure owner. | |
| | **2. Private Properties**<br><br>The proponent should address the potential subsidence impacts to private properties in the EIS, including:<br>• Adequate characterisation of potentially affected private properties;<br>• Mine layout options optimised to manage subsidence impacts to meet the performance criteria determined during the planning process. | 12.13 |

| Agency, Department or Stakeholder | Project Impact Assessment Requirements (Cont…) | Sections of Report |
|---|---|---|
| LMCC | Council Infrastructure - The EA is to consider the impact of subsidence on Lake Macquarie City Council infrastructure, inclusive of local roads, lands, buildings and infrastructure. Where this is likely to impacts upon Council and community infrastructure the supporting documentation is to consider ameliorative measures inclusive of monetary contribution to the maintenance, monitoring and lifecycle of existing and planned infrastructure. | 12 |
| Wyong Shire Council (1/03/12) | 3. The potential impact of subsidence on the built environment also needs to be considered. This includes residences/buildings, infrastructure and the Buttonderry Waste Management Facility (BWMF). | 12.10 - 12.22 |

In summary, the following impact performance measures have been adopted based on the government departments and stakeholder requests:

Minor or negligible impacts are required in regards to:

- Land use capability and operating businesses or land users.
- Buttonderry Waste Management Facility.
- Landform aesthetics.
- High Angle TransGrid Tension Towers (in lieu of their re-location outside of subsidence affected areas).

Manageable or agreed impacts with subsidence impact control measures (based on stakeholder consultation) to:

- Steep slopes, cliffs and rock formations.
- Water courses, biodiversity and flood plains.
- Residential structures, which are to remain Safe, Serviceable and Repairable (SSR) during and after mine subsidence effects.
- TransGrid Towers and conductors (including low-angle tension and suspension towers).
- Ausgrid infrastructure.
- Telstra and Nextgen infrastructure.

- Aboriginal and Non-indigenous Heritage sites.

- Transport routes and public safety.

Centennial Mandalong will implement an adaptive management approach to ensure the above impact assessment requests are achieved for the Mandalong Southern Extension Project.

Adaptive management will involve the monitoring, remediation and periodic evaluation of the consequences of mining, with possible adjustment of the mining layout and/or methods through the Extraction Plan process to achieve the required measure of performance.

## 3.0 Methodology

This report includes an assessment of subsidence effects and potential impacts of LWs 25 to 64 on the surface and subsurface features present within the Project Area, based on the following methodology:

(i) The development of a geotechnical model of the overburden and immediate roof-pillar-floor system using available borehole log and testing data.

(ii) Prediction of maximum subsidence effect parameters for the proposed longwalls.

(iii) Review of Mandalong Mine's subsidence data and impacts associated with LWs 1 - 12.

(iv) Prediction of first and final subsidence effect profiles and final contours and assessment of the potential impacts to existing and proposed features or developments.

(v) Prediction of post-mining surface levels.

(vi) Potential surface cracking widths and their general location.

(vii) Prediction of sub-surface heights of continuous and discontinuous fracturing above the proposed longwall panels.

(viii) Potential ponding depth locations.

(ix) Potential surface gradient changes and erosion / slope stability impacts.

(x) Valley Closure and Uplift potential along watercourses.

(xi) Far-field horizontal displacements and strains.

(xii) Predicted impacts and management strategies required for the environment, developments and Aboriginal and European Heritage sites.

The predictions in this study have been based on two empirically-based models developed for the Newcastle and US Coalfields (refer to **ACARP, 2003** and **SDPS, 2007**).

Pre-feasibility studies of appropriate panel widths and set-back distances required to minimise or limit surface impacts to manageable levels have been undertaken by Centennial Mandalong and Ditton Geotechnical Services (DgS) prior to the preparation of this report. The outcomes of the preliminary analysis have resulted in the mining geometry and layout presented herein.

Based on regression analysis techniques, curves of 'best fit' have been used to estimate Mean and Credible Worst-Case (Upper 95% Confidence Limits) for the subsidence effects due to the proposed longwalls. The curves are based on measured subsidence data in the NSW Coalfields and key mining geometry parameters (refer **ACARP, 2003**) and Mandalong experience to-date.

The prediction method will allow specialist consultants to assess the potential range of impacts to a given feature in a probabilistic manner.

Impact Management Plans and strategies can then be developed that allows appropriate Trigger Action Responses and mine planning adjustments or mitigation measures necessary to deliver satisfactory outcomes to the feature and the stakeholders.

## 4.0 Available Information

The following information was provided by the mine to prepare this report:

(i) The proposed mining layout for LWs 25 to 64.

(ii) Cover depth contours to the West Wallarah (WW) and Wallarah-Great Northern (WGN) Seams and seam thickness isopachs.

(iii) Borehole log and core testing data from the proposed mining area.

(iv) Geophysical logging (in-situ wire-line sonic velocity, gamma and neutron profiling, insitu horizontal stress testing).

(v) Inferred geological structure (fault and dyke) locations.

(vi) Surface levels and existing drainage regime, including 1% Annual Exceedance Probability (AEP) flood levels.

(vii) Locations of surface developments and infrastructure in the study area.

(viii) Location and significance of Aboriginal and European heritage sites.

(ix) Subsidence results from Mandalong Mine's longwall panels LW1-12.

(x) Previous geotechnical and subsidence prediction reports by Seedsman Geotechnics.

Plans of the proposed mining layout with cover depth contours, pre-mining surface levels, built and heritage features are presented in **Figures 1** to **2a-e**.

Seam thickness isopachs and seam gradients are shown in **Figures 3a** and **3b** respectively.

Data from 90 boreholes in the project area have been referred to in the study to develop a geotechnical model of the mining area. The location of the boreholes are shown in **Figure 4a** and summarised in **Table 1**.

The proposed longwall panels will be located where seam thickness contours range between 1.6 m and 4.6 m (see **Figure 3a**).

## Table 1 - Borehole Log Summary

| Borehole Number | Easting (MGA) | Northing (MGA) | Surface Level (AHD) | Workings Cover Depth* (m) |
|---|---|---|---|---|
| B500W900 | 348624.24 | 6329321.51 | 42.40 | 324.6 |
| B600W800 | 349802.70 | 6328319.82 | 57.00 | 322.8 |
| B600W900 | 349599.00 | 6329250.87 | 56.80 | 327.4 |
| B700W700 | 350324.00 | 6327134.86 | 122.60 | 395.7 |
| B700W800 | 350675.82 | 6328533.12 | 178.80 | 434.4 |
| B700W900 | 350448.35 | 6329441.06 | 104.20 | 366.9 |
| B700X000 | 350915.63 | 6330408.28 | 72.50 | 306.4 |
| B800W500 | 351681.17 | 6325379.63 | 35.00 | 338.9 |
| B800W600 | 351564.46 | 6326384.49 | 49.30 | 332.1 |
| B800W700 | 351462.93 | 6327269.93 | 181.00 | 454.6 |
| B800W800 | 351391.55 | 6328398.87 | 192.80 | 437.0 |
| B800X000 | 351462.70 | 6330548.00 | 31.20 | 272.7 |
| B900W400 | 352502.00 | 6324398.63 | 39.80 | 341.0 |
| B900W500 | 352751.51 | 6325246.88 | 36.40 | 320.3 |
| B900W600 | 352826.00 | 6326513.51 | 104.80 | 357.3 |
| B900W700 | 352545.66 | 6327362.23 | 178.40 | 422.9 |
| B900W800 | 352734.93 | 6328584.05 | 131.30 | 360.8 |
| B900W900 | 352632.72 | 6329453.38 | 119.60 | 351.2 |
| B900X000 | 352596.84 | 6330441.88 | 34.80 | 262.8 |
| C000W400 | 353689.38 | 6324567.25 | 37.00 | 294.9 |
| C000W500 | 353872.29 | 6325388.61 | 74.90 | 314.1 |
| C000W700 | 353590.26 | 6327303.98 | 137.50 | 365.5 |
| C000W900 | 353630.33 | 6329530.93 | 50.50 | 253.4 |
| C000X000 | 353599.54 | 6330399.22 | 124.90 | 330.2 |
| C000X100 | 353393.17 | 6331344.96 | 28.20 | 245.9 |
| C050X000 | 354144.84 | 6330454.53 | 64.40 | 257.7 |
| C100W600 | 354707.85 | 6326576.37 | 59.10 | 281.2 |
| C100W800 | 354673.42 | 6328430.86 | 40.80 | 247.5 |
| C100W900 | 354615.59 | 6329458.19 | 46.60 | 228.7 |
| C100W950 | 354587.04 | 6329926.68 | 36.30 | 216.4 |
| C100X000 | 354546.72 | 6330378.30 | 66.30 | 247.2 |
| C200W700 | 355622.32 | 6327403.11 | 68.90 | 253.0 |
| C200W900 | 355627.84 | 6329469.97 | 56.20 | 232.6 |
| B850X070 | 352070.37 | 6331147.12 | 26.17 | 260.3 |
| B800W850 | 351462.57 | 6328860.99 | 90.01 | 337.2 |
| B900W950 | 352613.77 | 6329834.47 | 101.47 | 330.0 |
| C000W800 | 353509.40 | 6328547.84 | 107.18 | 328.6 |
| B950W650 | 353118.76 | 6327131.28 | 147.80 | 390.6 |
| B800X000 | 351462.71 | 6330547.94 | 31.20 | 337.6 |
| B950X000 | 353057.79 | 6330464.66 | 109.46 | 336.2 |
| B950W950 | 353139.69 | 6329925.29 | 124.26 | 280.0 |
| C050W750 | 354161.77 | 6327713.01 | 50.01 | 271.7 |
| C100W700 | 354630.83 | 6327430.99 | 49.33 | 324.6 |
| C100W500 | 354857.484 | 6325335.336 | 67.3 | 265.40 |
| C075W975 | 354362.949 | 6330161.423 | 42.8 | 231.63 |
| C050W950 | 354129.106 | 6329905.187 | 58.4 | 254.39 |
| C000W600 | 353495.346 | 6326336.285 | 55.7 | 300.85 |
| B800W900 | 351624.26 | 6329415.113 | 69.7 | 312.11 |
| B700W600 | 350628.448 | 6326369.701 | 54.4 | 349.28 |

# Table 1 (Cont…) - Borehole Log Summary

| Borehole Number | Easting (MGA) | Northing (MGA) | Surface Level (AHD) | Workings Cover Depth* (m) |
|---|---|---|---|---|
| B650X000 | 350153.386 | 6330249.308 | 144.2 | 420.92 |
| B600X100 | 349466.329 | 6331370.056 | 124.8 | 398.30 |
| B650W750 | 349988.864 | 6327995.45 | 123.168 | 387.79 |
| B650W800 | 350248.2081 | 6328178.51 | 175.7055 | 435.69 |
| B650W850 | 350149.858 | 6328850.647 | 85.571 | 353.62 |
| B700W750 | 350360.124 | 6327721.37 | 141.357 | 403.24 |
| B700W850 | 350682.155 | 6328940.149 | 136.923 | 392.26 |
| B700W950 | 350569.72 | 6329969.066 | 94.567 | 343.61 |
| B700X030 | 350584.463 | 6330664.744 | 121.293 | 381.79 |
| B725W900 | 350768.222 | 6329265.511 | 121.573 | 376.60 |
| B750W750 | 351227.358 | 6327875.129 | 182.256 | 437.81 |
| B750W900 | 351057.0032 | 6329411.155 | 93.1683 | 340.71 |
| B750W950 | 350930.596 | 6330082.796 | 40.6789 | 283.31 |
| B750X050 | 350996.516 | 6330807.147 | 115.166 | 345.79 |
| B775W900 | 351253.4332 | 6329316.752 | 45.9863 | 295.86 |
| B800W650 | 351703.229 | 6326950.227 | 165.811 | 435.00 |
| B825W725 | 352010.2358 | 6327646.51 | 206.191 | 459.97 |
| B850W500 | 352295.299 | 6325371.943 | 36.78 | 331.90 |
| B850W550 | 352186.068 | 6325810.901 | 44.314 | 329.07 |
| B850W600 | 352217.876 | 6326321.328 | 102.672 | 372.95 |
| B850W650 | 352078.9732 | 6326782.968 | 105.5208 | 369.42 |
| B850W700 | 352071.334 | 6327292.954 | 116.322 | 379.43 |
| B850W750 | 352243.8221 | 6327711.168 | 191.1898 | 438.60 |
| B850W800 | 352068.69 | 6328422.55 | 61.8 | 307.22 |
| B850W850 | 351946.999 | 6328879.578 | 46.463 | 289.67 |
| B850W900 | 352083.049 | 6329412.368 | 42.785 | 282.72 |
| B850W950 | 352048.9875 | 6329875.173 | 62.8332 | 296.71 |
| B850X000 | 352087.855 | 6330502.039 | 66.192 | 300.70 |
| B850X030 | 352103.6877 | 6330773.895 | 38.3228 | 274.10 |
| B850X050 | 352123.5336 | 6330891.727 | 36.3009 | 270.99 |
| B875W800 | 352415.081 | 6328417.331 | 106.668 | 343.96 |
| B875X060 | 352263.2326 | 6330986.723 | 37.3356 | 270.44 |
| B900W750 | 352644.883 | 6327952.346 | 121.069 | 357.22 |
| B900W850 | 352601.1511 | 6328942.965 | 142.2462 | 370.97 |
| B925W925 | 352820.883 | 6329792.826 | 102.923 | 325.40 |
| B950W500 | 353140.1479 | 6325390.975 | 106.1725 | 373.66 |
| B950W850 | 353082.831 | 6328911.246 | 147.195 | 375.14 |
| B950W900 | 352991.68 | 6329504.12 | 139.697 | 363.79 |
| C050W550 | 354162.822 | 6326062.706 | 50.38 | 280.56 |
| C050W650 | 354197.439 | 6326839.058 | 56.49 | 283.91 |
| C050W850 | 354078.741 | 6328840.458 | 126.594 | 330.15 |
| C150W850 | 355017.8946 | 6328843.863 | 54.3305 | 239.65 |

* - Workings are located in WW and WGN Seams

# 5.0 Surface Conditions

## 5.1 General Surface Conditions and Land Use

Topographic relief ranges from RL 23 m AHD to RL 250 m AHD above the proposed panels. Surface slopes range from $1^{o}$ to $5^{o}$ in the flat, low lying areas in the east and from $15^{o}$ to $35^{o}$ on the ridges in the south-west (see **Figures 2a** and **2b**). There are several discontinuous (< 20 m in length) sandstone rock outcrops along the steep slopes of the western ridges that range between 2 m and 5 m high. Sandstone talus boulders were noted on the slopes below the ridge crests.

The majority of the surface of the proposed mining area is private land holdings with some Forest NSW (Olney State Forest) and Crown Land areas.

The flatter, eastern portion of the Project Area has private rural residential properties (2 - 200 ha lot sizes) and 7 businesses. Several of the eastern lots are used for farming / orchards, livestock grazing and horse training purposes.

The western portion is located in steeply undulating terrain and is largely undeveloped with several rural residential lots.

There are four TransGrid 330 kV and one Ausgrid 132 kV Transmission Line easements, fire trails, access tracks and 15 bitumen-sealed public roads present within the Project Area.

The Buttonderry Waste Management Facility is owned and operated by Wyong Shire Council and is located at the southern portion of the Project Area.

## 5.2 Watercourses

There are several 1$^{st}$ to 4$^{th}$ Order Streams (Strahler System, **DIPNR, 2005**) associated with Morans, Wyee, Mannering and Buttonderry Creeks, all of which drain the site towards Lake Macquarie and Tuggerah Lakes to the north, east and south-east. Pond chains are known to exist along some of the creeks.

The streams above the proposed mining area include numerous 1$^{st}$ and 2$^{nd}$ Order Streams and five 3$^{rd}$ and 4$^{th}$ Order Streams with alluvial sediments and pond chains. Shallow incised stream sections and intermittent sandstone rock bars exist in the elevated ephemeral gully reaches or creek tributaries. The creeks are assessed as Schedule 1 and 2 Streams in accordance with Office of Environment and Heritage (OEH) Guidelines and do not require buffer zones against subsidence effects (**Umwelt, 2013**).

### 5.3 Rock Outcrops and Steep Slopes

The rock outcrops above the south-western ridges of the Project Area are discontinuous and between 2 m and 5 m high. The slopes are moderate to steep, ranging from $15^o$ to $35^o$. The location of the steep slopes is shown in **Figure 2a**.

The lithology is predominately sandstone with minor mudstone (shale) units of the Triassic Narrabeen Group and identified as being within the Terrigal and Patonga Claystone Formations.

*Note: A discontinuous cliff face infers the cliff or rock features are broken up into segments < 20 m in length and are likely to respond independently of adjacent features during mine subsidence development. A discontinuous cliff line has greater in-built articulation than a continuous face and is therefore likely to tolerate higher magnitudes of subsidence without significant cracking damage, compared to a continuous cliff face.*

The rock outcrops comprise 0.5 m to 3 m thick beds of pebbly sandstone, fine to coarse grained, grey brown with open vertical joints spaced between 2 m to 5 m. The cliff faces are bedding and joint controlled with 1 m to 5 m diameter boulder-sized talus observed on the slopes below them.

Light grey mudstone or shale beds exist along the bases of the cliffs with undercutting of sandstone beds apparent. Some localised honeycombed weathering had formed overhangs or rock shelters that are 2 m to 10 m deep with 3 m to 5 m length spans. The rock strength on the cliff faces was estimated to range from 20 to 50 megapascals (MPa) with some low strength beds of 2 to 15 MPa associated with mudstone and weathered sandstone units.

Natural instability is primarily due to the undercutting of mudstone beds and the release of overlying sandstone blocks along existing orthogonal joint patterns. Tree-root wedging is also likely to be a contributing factor to rock face instability. The presence of mature trees on the steep slopes however, will provide significant natural reinforcement of the soils and reduce the likelihood of landslip development during and after mine subsidence.

### 5.4 Vegetation

Vegetation on the site consists of dry schlerophyll forest (eucalypts and hard leafed shrubs) on the steep slopes and ridges with dense riparian vegetation and melaleucas along the watercourses. A more detailed assessment of the existing ecology is provided by RPS.

### 5.5 Indigenous Heritage Sites

The results of the Cultural Heritage inspections have identified one hundred and thirteen (113) Aboriginal Heritage Sites within the vicinity of the proposed mining area (refer to **RPS, 2013**). The sites are mainly located on the steep slopes and ridges or at the rock bar locations along the watercourses.

The sites consist of scattered archaeological finds (11), scarred trees (11), an open camp site (1), grinding grooves (58), stone arrangements (3), rock shelters (16) and rock shelters with art and/or Potential Archaeological Deposits (PADs) (12) and one (1) water supply location (see **Figure 2d**).

There is also a possibility that other sites exist within the Project Area that have not been detected yet.

### 5.6 Non-Indigenous Heritage Sites

Desktop research and survey (**RPS, 2013**) for non-Indigenous heritage sites found no sites of state or local significance recorded in the area. However, the survey did record six items associated with early timber getting in the Study Area, as follows:

- Simpsons Track (Mandalong Rd).
- Brisbane Water to Wallis Plains Rd.
- Four log landing sites.

It is understood that the sites have low historical value due to their poor condition generally.

The location of the sites is shown in **Figure 2e**.

### 5.7 Services Easements

The three TransGrid 330 kV transmission line easements (TL22, TL24 and TL25/26) consist of 51 suspension towers and 13 tension towers (see **Figures 1** and **2a-b**). One of the easements (TL24) has up to 5 tension towers that are proposed to be relocated, based on preliminary discussions between TransGrid and Centennial Coal.

A fourth easement (TL21) traverses the mining lease across the BWMF. The easement is located between 0.9 and 1.4 km to the south of the proposed longwalls and where the cover depth is approximately 300 m. It is assessed that the towers are likely to be outside the limits of measureable movement due to the proposed longwalls and should therefore, not require management measures to be implemented.

The tension towers generally exist at changes in easement direction, at the top or bottom of a ridge or where the easements intersect. The tension towers are significant in regards to mine subsidence effects as they cannot be fitted with reinforced concrete cruciform footings to protect the structures from strain or tilt. The subsidence effects at the tension towers must therefore be controlled to tolerable levels by moving the longwall panels away from the towers. Based on measured subsidence data for the Mandalong Mine, a minimum set back distance equivalent to 26.5$^{o}$ Angle of Draw from the longwall extraction limits has been assumed for mine planning purposes.

The suspension towers however, may be protected with cruciform footings and may therefore be undermined by a longwall panel generally.

The Project Area also has an Ausgrid 132 kV easement that traverses the site and consists of conductors supported on pairs of timber poles. Other site utilities include Ausgrid 11kV and 440V domestic power lines (also suspended on timber poles), Telstra and Nextgen Optical Fibre Cable (buried) and Telstra copper (buried and suspended), which run alongside the council roads.

A summary of the TransGrid easements and tower types are presented in **Table 2**.

**Table 2 - TransGrid Tower and Easement Summary**

| Easement | No. of Tension Towers | No. of Suspension Towers | Comment |
|---|---|---|---|
| TL22 | 1 | 9 | Tower No.s 29 - 38 (No. 32 is a Tension Tower) |
| TL24 | 7 | 26 | Tower No.s 23 - 55 (27, 28, 35, 37, 38, 40 & 43 are Tension Towers). Towers above LWs 23 - 32 are proposed to be relocated. |
| TL25/26 | 5 | 16 | Tower No.s 27 - 47 (32, 34, 38, 43 & 46 are Tension Towers). |
| *TL21* | *0* | *5* | Tower No.s 29 to 33 (none are tension towers or within 600 m from proposed longwall limits). |
| **Totals** | **13** | **56** | All 69 Towers are within EL6317 or <600 m distance from proposed LWs 25 to 64. |

### 5.8 Private Lots and Existing Structures

There are 135 privately owned Lots within the Project Area that range in size from 2 ha to 200 ha. A total of 114 residences and 7 businesses exist on the Lots with a total of 289 structures identified on the Buildings Register prepared by Centennial Coal.

The structures on the private properties include a range of dwelling types (i.e. single/double storey, masonry/weatherboard) with sheds, swimming pools, tennis courts, on-site effluent disposal systems, fencing, driveways and small to medium-sized farm dams (1 ML to 10 ML capacity).

Based on a drive-by inspection and Google Earth review of the properties within the Project Area, a register of the existing structures on each lot has been prepared by Centennial for the purposes of a broad subsidence impact assessment.

A total of 289 structures were registered as follows:

- 24 brick houses (residential)
- 90 non-brick houses (residential)
- 175 out buildings (non-residential)

The locations of the residential buildings (i.e. houses) are shown in **Figure 2c**.

### 5.9 Flood Levels

Approximately 18 houses are located within 3 m distance of the 1% Annual Exceedance Probability (AEP) Flood Levels along the creeks (see **Figure 2c**).

The maximum allowable subsidence for the houses has been estimated and summarised in **Table 3** for mine planning purposes.

The maximum allowable subsidence for the existing houses with ground levels <3 m above the 1% AEP flood level ranges from 0.0 m to 2.0 m, based on the minimum floor level freeboard of 0.5 m.

It is noted that the actual floor levels have been estimated from the drive by survey and available surface level contour maps and should therefore be checked by a proper level survey prior to mining.

**Table 3 - Maximum Allowable Subsidence for Existing Houses within 3 m of the Current 1% AEP Flood Level**

| House No. | Location | Existing Floor RL (AHD, m) | Estimated 1%AEP RL (AHD, m) | Maximum Allowable Subsidence* (m) |
|---|---|---|---|---|
| 6 | Dyce | 30.2 | 29.2 | 0.50 |
| 7 | Dyce | 29.9 | 29.2 | 0.20 |
| 8 | Dyce | 29.7 | 29.0 | 0.20 |
| 22 | Wyee Farms Road | 28.5 | 27.5 | 0.50 |
| 23 | Wyee Farms Road | 30.3 | 29.3 | 0.50 |
| 24 | Wyee Farms Road | 31.8 | 30.8 | 0.50 |
| 29 | Wyee Farms Road | 45.5 | 43.0 | 2.00 |
| 30 | Wyee Farms Road | 44.5 | 43.0 | 1.00 |
| 31 | Wyee Farms Road | 45.5 | 44.0 | 1.00 |
| 39 | Wyee Farms Road | 31.5 | 30.0 | 1.00 |
| 45 | Wyee Farms Road | 37.0 | 35.0 | 1.50 |
| 47 | Wyee Farms Road | 49.0 | 47.5 | 1.00 |
| 51 | Wyee Farms Road | 41.0 | 39.8 | 0.70 |
| 52 | Wyee Farms Road | 41.5 | 40.5 | 0.50 |
| 53 | Wyee Farms Road | 47.5 | 45.0 | 2.00 |
| 96 | Woods Rd | 48.3 | 47.8 | 0.00 |
| 101 | Manhire Road | 29.5 | 27.0 | 2.00 |
| 111 | Dyce | 30.4 | 29.2 | 0.70 |

* - Maximum Allowable Subsidence = Existing Floor RL - (1% AEP Flood RL + 0.5)

### 5.10 Prescribed Dams

There are no Dam Safety Committee (DSC) Prescribed Dams within the Project Area.

### 5.11 Public Roads and Fire Trails

The following fifteen roads are within the Project Area and part of the Wyong Shire Council and LMCC local government areas (see **Figure 2c**):

- Mandalong Road
- Dyce Road
- Toepfers Road
- Hue Hue Road
- Woods Road
- Crooks Road
- Bushells Ridge Road
- Wyee Farms Road
- Little Valley Road
- Binalong Way
- Kiar Ridge Road
- Eagle Place
- Manhire Road
- Bloomfield Road
- Buangi Road

The roads are either bitumen sealed or unsealed, gravel dual carriageways with reinforced concrete pipe culverts at watercourse crossings. The fire trails, and private access and infrastructure access roads are un-sealed, gravel carriageways.

The current condition of the roads and culverts has been assessed as good by mine site representatives and summarised in **Table 4**.

**Table 4 - Description of Roads in the Project Area**

| Roads | Sealed | Unsealed | Culverts | Bridge | Condition | Speed Limit | Comments |
|---|---|---|---|---|---|---|---|
| Crooks | **X** | | **14** | | Good | No Signage | 3 culvert causeways on Road |
| Chapman | | **X** | **1** | **1** | Good | No Signage | |
| Mandalong | **X** | **X** | **18** | | Sealed Good. Unsealed Average due to busy use of road and poor maintenance | 80km | 4 culverts on sealed and 14 on unsealed. |
| Binalong | **X** | **X** | **7** | | Good | No Signage | Unsealed section of road is very narrow. One car space. On the edge of ridge line |
| Buangi | **X** | | | | Good | No Signage | |
| Hue Hue | **X** | | **12** | | Good | 80km | |
| Woods | **X** | **X** | **4** | | Good | 60km | End of the road goes into 4WD track and comes around to join up with Toepfers Rd |
| Toepfers | **X** | **X** | **4** | | Good | 60km | End of the road goes into 4WD track and comes around to join up with Woods Rd |
| Wyee Farms | **X** | | **12** | **1** | Good | 80km | |
| Manhire | **X** | | **3** | | Good | 80km | |

Note: All pipes under road are about 500mm

## 5.12 Buttonderry Waste Management Facility

The Buttonderry Waste Management Facility consists of several clay lined waste disposal cells with a network of gas and water drainage pipelines, leachate treatment ponds / dams, access roads and administration / storage / machinery buildings.

Wyong Shire Council have requested that current and future development areas within the site boundary limits are not impacted by mine subsidence due to concerns regarding the safe operation of the facility and environmental hazards that exist within the landfill cells (i.e. leachate).

Centennial has considered this concern and the assessed mine plan has been developed so that no longwall panels sit directly under this facility or within a distance likely to cause significant impact to it.

## 6.0 Mining Geometry

The following mine workings details have been used in this assessment:

- The longwalls will have panel widths of 160 m, 180 m or 200 m.

- The cover depth of the longwalls range from 180 m in the north-east and increases to 480 m in the south-west. The average cover depth is approximately 300 m.

- The WW seam thicknesses in the western area will range from 3.4 m to 4.6 m.

- The WGN seam thicknesses in the eastern area will range from 1.6 m to 3.6 m.

- The longwall extraction height will range from 1.8 m to 4.5 m and depend on the seam thickness.

- The first workings roadways will be nominally 5.2 m wide by 2.5 m to 3.4 m high (depending on seam thickness).

The panel width to cover depth ratio (W/H) for the proposed longwall panels will range from 0.41 to 1.14 with an average of 0.63, indicating ‘sub-critical’ to ‘critical’ subsidence behaviour is likely to occur (refer to **Glossary**).

The proposed longwall panels have been grouped into 5 areas for this study (see **Figure 4b**):

- Group 1 – North-west Area Longwalls (LWs 25 - 31) in the WW Seam

- Group 2 - South-west Area Longwalls (LWs 32 - 37) in the WW Seam

- Group 3 – South-east Area Longwalls (LWs 38 - 54) in the WGN Seam

- Group 4 – North-east Area Longwalls (LWs 55 - 61) in the WGN Seam

- Group 5 – North-north-east Area Longwalls (LWs 62 - 64) in the WGN Seam

A summary of the mining geometry in each area is presented in **Table 5**.

## Table 5 - Proposed Longwall Mining Geometry in Groups 1 to 5

| **Panel Group No: Location** | **Panel No.** | **Panel Width W (m)** | **Cover Depth H (m)** | **W/H** | **Chain Pillar Width $w_{cp}$ (m)** | **Seam Thickness (m)** | **Mining Height T (m)** |
|---|---|---|---|---|---|---|---|
| Group 1: NW Area in WW Seam | 25 | 180 | 270 - 380 | 0.67 - 0.47 | 46.0 | 3.8 - 4.6 | 3.8 - *4.5* |
| | 26 | 180 | 270 - 380 | 0.67 - 0.47 | 43.4 | 4.0 - 4.3 | 4.0 - 4.3 |
| | 27 | 180 | 275 - 340 | 0.65 - 0.53 | 43.4 | 4.0 - 4.2 | 4.0 - 4.2 |
| | 28 | 180 | 275 - 340 | 0.65 - 0.53 | 43.4 | 3.9 - 4.1 | 3.9 - 4.1 |
| | 29 | 180 | 277 - 360 | 0.65 - 0.50 | 43.4 | 3.8 - 3.9 | 3.8 - 3.9 |
| | 30 | 180 | 278 - 310 | 0.65 - 0.58 | 43.4 | 3.8 - 3.9 | 3.8 - 3.9 |
| | 31 | 180 | 280 - 320 | 0.64 - 0.56 | 43.4 | 3.4 - 3.8 | 3.4 - 3.8 |
| Group 2: SW Area in WW Seam | 32 | 200 | 300 - 420 | 0.67 - 0.48 | 46.0 | 3.4 - 3.6 | 3.4 - 3.6 |
| | 33 | 200 | 300 - 460 | 0.67 - 0.52 | 48.6 | 3.5 - 3.5 | 3.5 - 3.5 |
| | 34 | 200 | 310 - 480 | 0.65 - 0.42 | 48.6 | 3.5 - 3.5 | 3.5 - 3.5 |
| | 35 | 200 | 320 - 460 | 0.63 - 0.43 | 45.3 | 3.4 - 3.6 | 3.4 - 3.6 |
| | 36 | 200 | 340 - 440 | 0.59 - 0.45 | 45.3 | 3.4 - 3.7 | 3.4 - 3.7 |
| | 37 | 200 | 335 - 420 | 0.60 - 0.48 | 45.3 | 3.5 - 3.8 | 3.5 - 3.8 |
| Group 3: SE Area in WGN Seam | 38 | 180 | 195 - 360 | 0.92 - 0.50 | 39.7 | 1.6 - 2.2 | *1.8* - 2.2 |
| | 39 | 180 | 200 - 350 | 0.90 - 0.51 | 39.7 | 1.6 - 2.3 | *1.8* - 2.3 |
| | 40 | 160 | 210 - 340 | 0.76 - 0.47 | 39.7 | 1.7 - 2.3 | *1.8* - 2.3 |
| | 41 | 160 | 220 - 340 | 0.73 - 0.47 | 39.7 | 1.8 - 2.3 | *1.8* - 2.3 |
| | 42 | 160 | 230 - 390 | 0.70 - 0.41 | 39.7 | 1.8 - 2.4 | *1.8* - 2.4 |
| | 43 | 180 | 250 - 440 | 0.72 - 0.41 | 39.7 | 2.0 - 2.4 | 2.0 - 2.4 |
| | 44 | 180 | 260 - 440 | 0.69 - 0.41 | 39.7 | 2.0 - 2.45 | 2.0 - 2.5 |
| | 45 | 180 | 250 - 420 | 0.72 - 0.43 | 39.7 | 2.0 - 2.5 | 2.0 - 2.5 |
| | 46 | 180 | 260 - 380 | 0.69 - 0.47 | 40.7 | 2.0 - 2.8 | 2.0 - 2.8 |
| | 47 | 180 | 270 - 370 | 0.67 - 0.49 | 40.7 | 2.0 - 3.0 | 2.0 - 3.0 |
| | 48 | 180 | 265 - 400 | 0.68 - 0.45 | 40.7 | 2.0 - 3.2 | 2.0 - 3.2 |
| | 49 | 160 | 250 - 400 | 0.64 - 0.45 | 40.7 | 2.0 - 3.3 | 2.0 - 3.3 |
| | 50 | 160 | 250 - 360 | 0.64 - 0.44 | 40.7 | 2.0 - 3.4 | 2.0 - 3.4 |
| | 51 | 160 | 240 - 360 | 0.67 - 0.44 | 40.7 | 2.0 - 3.4 | 2.0 - 3.4 |
| | 52 | 160 | 240 - 360 | 0.67 - 0.44 | 40.7 | 1.8 - 3.4 | 1.8 - 3.4 |
| | 53 | 160 | 240 - 360 | 0.67 - 0.44 | 40.7 | 1.9 - 3.2 | 1.9 - 3.2 |
| | 54 | 160 | 250 - 360 | 0.64 - 0.44 | 40.7 | 1.9 - 3.0 | 1.9 - 3.0 |
| Group 4: NE Area in WGN Seam | 55 | 160 | 175 - 340 | 0.91 - 0.47 | 41.8 | 1.6 - 3.8 | *1.8* - 3.8 |
| | 56 | 160 | 180 - 360 | 0.89 - 0.44 | 41.8 | 1.6 - 3.2 | *1.8* - 3.2 |
| | 57 | 200 | 190 - 330 | 1.05 - 0.61 | 41.8 | 1.6 - 2.6 | *1.8* - 2.6 |
| | 58 | 200 | 195 - 340 | 1.03 - 0.59 | 41.8 | 1.7 - 2.6 | *1.8* - 2.6 |
| | 59 | 200 | 190 - 380 | 1.05 - 0.53 | 41.8 | 1.6 - 3.0 | *1.8* - 3.0 |
| | 60 | 160 | 190 - 420 | 0.84 - 0.38 | 41.8 | 1.6 - 3.4 | *1.8* - 3.4 |
| | 61 | 200 | 195 - 400 | 1.03 - 0.50 | 144 | 1.6 - 2.6 | *1.8* - 2.6 |
| Group 5: NNE Area in WGN Seam | 62 | 200 | 220 - 320 | 0.91 - 0.63 | 37.5 | 2.1 - 3.4 | 2.1 - 3.4 |
| | 63 | 200 | 180 - 300 | 1.11 - 0.67 | 37.5 | 2.0 - 2.6 | 2.0 - 2.6 |
| | 64 | 200 | 175 - 320 | 1.14 - 0.63 | 37.5 | 1.8 - 2.2 | 1.8 - 2.2 |

*Italics* - mining height inside seam thickness range.

# 7.0 Sub-Surface Conditions

## 7.1 Geological Setting

Reference to the 1:100,000 Geological Sheet for Newcastle - Gosford (**DMR, 1995**), indicates the mining lease is located within the Triassic Narrabeen Group and Permian Newcastle Coal Measures.

The lithology within the mining lease consists of thinly to massively-bedded sedimentary strata that belong to the Triassic Clifton Sub-group (Terrigal, Patonga Claystone, Tuggerah Formation, Munmorah Conglomerate and Dooralong Shale) and Late Permian Moon Island Beach Sub-group (Vales Point Seam, Karignan Conglomerate, Wallarah and Great Northern Seams and Awaba Tuff) strata. Quaternary Alluvium (sands, silts and clays) to depths of up to 15 m exist along several of the creeks within the mining lease.

The typical site stratigraphy is summarised in **Table 6A**.

The surface geology, based on the investigation boreholes, comprises the Terrigal, Patonga Claystone, Tuggerah Formations and the extent of each formation is shown in **Figure 5**. The low height rock outcrops on the south-western ridges within the Project Area are associated with the sandstone beds of the Terrigal Formation. The Patonga Claystone is dominated by mudstone and siltstone with few sandstone beds. The Tuggerah Formation comprises interbedded sandstone and shale with minor conglomerate.

**Table 6A - Typical Site Stratigraphy for the Mandalong South Area**

| GROUP | FORMATION | COAL SEAMS / SIGNIFICANT UNITS |
|---|---|---|
| **NARRABEEN** | | MUNMORAH CONGLOMERATE |
| **NEWCASTLE COAL MEASURES** | MOON ISLAND BEACH | VALES POINT<br>WALLARAH<br>TERALBA CONGLOMERATE<br>GREAT NORTHERN<br>WEST WALLARAH (a) |
| | AWABA TUFF | |
| | BOOLAROO | FASSIFERN<br>UPPER PILOT<br>LOWER PILOT<br>HARTLEY HILL |
| | WARNERS BAY TUFF | |
| | ADAMSTOWN | AUSTRALASIAN<br>MONTROSE<br>WAVE HILL<br>FERN VALLEY<br>VICTORIA TUNNEL |
| | NOBBYS TUFF | |
| | LAMBTON | NOBBYS<br>DUDLEY<br>YOUNG WALLSEND (b)<br>YARD<br>BOREHOLE<br>WEST BOREHOLE (c) |
| | WARATAH SANDSTONE | |

(a) The West Wallarah seam is the combination of the Wallarah and Great Northern seams.
(b) The Young Wallsend seam is the combination of the Nobby’s and Dudley seams.
(c) The West Borehole seam is the combination of the Nobby’s, Dudley, Yard and Borehole seams.

### 7.2 Lithology

The overburden strata generally comprises interbedded sandstone, siltstone, mudstone, and pervasive conglomerate units (Munmorah Conglomerate).

Sandstone, siltstone, carbonaceous mudstone and coal form the immediate roof, while the floor will consist of tuff, sandstone and siltstone.

The Wallarah and Great Northern Seams are wholly combined in the western portion of the site and known as the West Wallarah (WW) Seam. The West Wallarah Seam has been split into the Wallarah + Great Northern A (WGN) Seams and Great Northern C Seam by the over the eastern portion of the site.

The Awaba Tuff generally exists immediately below the WW Seam only, and has been responsible for several time-dependent subsidence development events around the Lake Macquarie Coalfields in the recent past (i.e. Awaba, Cooranbong and Newvale Collieries).

There have been no time-dependant subsidence developments below chain pillars at the Mandalong Mine, which indicates that the Awaba Tuff is likely to be durable in the Project Area. The borehole core logs indicate that the Awaba Tuff comprises moderately hard claystone with minor soft, puggy units < 100 mm thick. Laboratory test results demonstrate the tuff has Moderate to High UCS strength with low moisture sensitivity.

### 7.3 Structure

The mine is located to the west of the Macquarie Syncline, with bedding dipping towards the south and south-west at $1^{o}$ to $3^{o}$; see **Figure 3b**.

Regional structure comprises normal faults striking NW-SE with throws of 1 m to 2 m and low angle thrust faults are known to exist in the region on a NE strike. No significant structure with displacements > the seam thickness have been detected by the exploration boreholes to-date.

Aeromagnetic surveys have identified several igneous dykes striking mainly NW with some NE features. Two sub-vertical diatremes (i.e. sub-vertical igneous plugs) have also been identified.

The above structures are plotted on **Figure 5** and are approximately 500 m to 2000 m apart. **Lohe & Dean-Jones, 1995** describe similar normal faulting in the Central Coast region with fault planes dipping at $55^{o}$ to $75^{o}$ with curved profiles and south-western block down throws.

Several NE/SW striking faults were presented in **Mauger et al, 1984**, however, the exploration boreholes within the project area have not detected any of these to-date. Despite this, the orientation of the proposed longwalls will be at a high angle (>$30^{o}$) to both sets of NE and NW structures, so that if significant structure is encountered during development (or longwall extraction) the effect of these in regards to spanning capability of massive lithology will be minimised.

Joint patterns in the proposed mining area were measured using acoustic televiewer profiling techniques and identified orthogonal, sub-vertical ($80^o$ to $90^o$ dip) joints striking NE-SW and NW-SE. The joint sets are considered to be widely spaced, planar, rough and persistent.

A dolerite sill at seam level precludes mining to the west of the proposed mining area. The location of the sill is based on exploration boreholes only at this stage, and will be further assessed as the mine is developed towards the sill.

### 7.4 Horizontal Stress

Horizontal stress directions have been determined through acoustic televiewer borehole breakout analysis and in-situ over-coring in Borehole No.s C050W650 & B850X000. The major and minor horizontal stresses are orientated towards the NE-SW (045/225) and SE-NW (135/315) respectively.

### 7.5 Geotechnical Characteristics of Rock Mass

As mentioned previously, it is considered likely that the development of subsidence will be affected by the spanning potential of massive units or 'beams' within the Triassic Munmorah Conglomerate Member. Similar behaviour has been observed at numerous underground coal mines in adjacent mines around Lake Macquarie and the Newcastle Coalfield generally.

The mines are overlain by numerous sandstone channel and conglomerate members within the Permian Newcastle Coal measures and Triassic Narrabeen Group. The units are typically braided channel deposits with a bedding thickness range from 15 m to 80 m. The conglomerate beds are often separated into horizontal or wedge-shaped sub-units by thin mudstone and siltstone beds.

In-situ geophysics data (sonic velocity profiling below steel casing, neutron and gamma logs) has been applied to identify thickness, strength and stiffness of massive conglomerate and sandstone beams using established relationships with laboratory testing and lithology (**McNally, 1990**).

Gamma logs record natural radioactive emissions from potassium, and therefore indicate the quantity of clay minerals present in the rock mass. The gamma response is generally lower in massive conglomerate and sandstone strata units compared to mudstone and claystone.

The neutron logs indicate variations in hydrogen ion content (and hence water content) and generally highlight stronger and weaker strata.

Sonic velocity logs record variations in compressional wave velocity along a borehole wall, which is also a measure of the rock mass strength and stiffness. The bore hole must be full of water to allow coupling of the sound waves with the probe sonde and this may be difficult to achieve in a dry hole with fractured strata. The sonic velocity profiles are also significantly affected by steel casing.

Neutron logs are generally unaffected by either a dry borehole or the presence of steel or PVC casing, so they can be used in lieu of sonic logs if data gaps occur between the seam and surface.

The thickness of the conglomerate beams that were estimated from the gamma and neutron log profiles based on the measured *insitu* trace ranges presented in **Table 6B**.

**Table 6B - Geophysical Profile Characteristics for Stratigraphy Identification**

| Log | Units | Lithology | Unit Range (mean) | Relative Magnitude across Lithologies |
|---|---|---|---|---|
| Gamma | API | Sandstone/Conglomerate | 50 - 100 (75) | Low |
| | | Mudstone/Claystone/Siltstone | 150 - 200 (180) | High |
| Neutron | API | Sandstone/Conglomerate | 1500 - 2000 (1700) | High |
| | | Mudstone/Claystone/Siltstone | 750 - 1500 (1000) | Low |
| Sonic Velocity | m/s | Sandstone/Conglomerate | 3500 - 4500 (4000) | High |
| | | Mudstone/Claystone/Siltstone | 3000 - 3500 (3200) | Low |

Examples of the unit thickness measurement technique are presented in **Figures 6a** to **6d**.

The available borehole data for Mandalong South include descriptive logs and testing (eg. UCS, Youngs Modulus, Poissons Ratio, and Slake Durability) on Munmorah Conglomerate and Awaba Tuff core samples.

A summary of the laboratory testing is presented in **Tables 7** and **8**.

### Table 7 - Laboratory Test Results on Munmorah Conglomerate

| BH# | Depth (m) | UCS (MPa) | E (GPa) | E/UCS | Lithology | f.m.c. (%) | Density (t/m3) | Sonic Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|
| C050W750 | 151.8 | 45.3 | 16.7 | 368 | SAST | 4.6 | 2.38 | 3658 |
| C050W750 | 156.9 | 35 | 15.3 | 437 | CONG | 4.4 | 2.4 | 3781 |
| C050W750 | 166.75 | 54 | 21.1 | 391 | CONG | 3.3 | 2.457 | 4206 |
| C050W750 | 177.99 | 58.3 | 21.0 | 360 | PESAST | 2.9 | 2.423 | 3936 |
| B950W950 | 194.58 | 55.1 | 17.3 | 314 | PESAST | 3.6 | 2.437 | 3936 |
| B950W950 | 212.8 | 38.8 | 12.6 | 326 | PESAST | 5.2 | 2.373 | 3930 |
| B950W950 | 226.5 | 47 | 16.7 | 355 | CONG | 3.6 | 2.415 | 4091 |
| B950W950 | 229.7 | 61.1 | 23.7 | 387 | PESAST | 2.7 | 2.506 | 4264 |
| B950W950 | 243.3 | 105.9 | 20.3 | 191 | SAST | 1.6 | 2.612 | 4187 |
| B950X000 | 211 | 43.6 | 17.1 | 393 | PESAST | 4.5 | 2.429 | 3858 |
| B950X000 | 219.4 | 50 | 22.1 | 443 | PESAST | 2.9 | 2.466 | 4065 |
| B950X000 | 226.26 | 67.7 | 22.2 | 328 | PESAST | 3.2 | 2.474 | 4170 |
| B950X000 | 231.3 | 102.4 | 20.0 | 195 | PESAST | 1.5 | 2.598 | 3979 |
| B950X000 | 244.4 | 80.2 | 22.4 | 280 | PESAST | 3.5 | 2.474 | 3955 |
| B950X000 | 264.5 | 55.7 | 20 | 368 | SAST | 3.6 | 2.449 | 4080 |
| **Statistics** | | | | | | | | |
| Mean | **210** | **62** | **19** | **342** | | **3.4** | **2.46** | **4006** |
| Min | 151.8 | 35 | 13 | 191 | | 1.5 | 2.37 | 3658 |
| Max | 264.5 | 106 | 24 | 443 | | 5.2 | 2.61 | 4264 |

Lithology Key: SAST - Sandstone; PESAST - Pebbly Sandstone; CONG - Conglomerate.; f.,m.c – field moisture content.

**Table 8 - Laboratory Test Results on Awaba Tuff**

| BH# | Depth | UCS (MPa) | E (GPa) | E/UCS | Lithology | f.m.c. (%) | Density (t/m3) | Slake Durability (%) |
|---|---|---|---|---|---|---|---|---|
| B700W850 | 402.58 | 46.5 | 16.2 | 348 | Tuff | 4.5 | 2.458 | - |
| B700W950 | 353.12 | 82.9 | 20.3 | 245 | Tuff | 2.2 | 2.573 | - |
| B750W750 | 445.53 | 75.9 | 16.1 | 212 | Tuff | 3.5 | 2.507 | - |
| B750W900 | 348.8 | 29.6 | 7.3 | 247 | Tuff | 4.6 | 2.462 | - |
| B800W850 | 342.15 | 39.3 | 12.8 | 326 | Tuff | 3.9 | 2.475 | - |
| B850W800 | 313.4 | 72.7 | 17.8 | 245 | Tuffaceous Sandstone | 2.4 | 2.512 | 95.2 |
| B850W900 | 291.32 | 57.3 | 15.1 | 264 | Tuff | 2.6 | 2.493 | 95.2 |
| B850W900 | 292.4 | 36.6 | 12.4 | 339 | Tuff | 3.5 | 2.533 | - |
| B850X000 | 307.16 | 66.4 | 17.1 | 258 | Tuff | 3.5 | 2.483 | 99.4 |
| B850X030 | 274.10 | 114.9 | 22.8 | 198 | Tuff | 2.5 | 2.5 | 98.9 |
| B900W850 | 378.28 | 54.8 | 13.7 | 250 | Tuff | 2.9 | 2.491 | 95.9 |
| B900W950 | 335.4 | 69.6 | 16.1 | 231 | Sandstone | 3.4 | 2.55 | - |
| B950X000 | 343.44 | 54.5 | 20.6 | 378 | Tuff | 4.1 | 2.476 | 98.5 |
| **Statistics** | | | | | | | | |
| Mean | **346.13** | **62** | **16** | **272** | | **3.4** | **2.50** | **97** |
| Min | 274.10 | 30 | 7 | 198 | | 2.2 | 2.46 | 95 |
| Max | 445.53 | 115 | 23 | 378 | | 4.6 | 2.57 | 99 |

Lithology Key: Tuff - Tuffaceous Claystone.

Good correlation was apparent between the laboratory derived and *in situ* sonic UCS results for both the Munmorah Conglomerate and Awaba Tuff, and are presented in **Figure 7a**.

Sonic velocity profiles have subsequently been converted into unconfined compressive strength (UCS) profiles, with representative results for the Munmorah Conglomerate presented in **Figures 7b** to **7d**, and the Awaba Tuff in **Figure 8a**.

UCS profiles of the immediate roof and floor strata to the east and west of the seam split, have been derived using the above technique and are presented in **Figures 8a** and **8b**.

Based on the laboratory test results in **Table 8**, the borehole lithology and geophysical logs the Awaba Tuff consists of interbedded claystone, mudstone and siltstone layers with an average strength of 30 to 60 MPa at field moisture content; see **Figure 8c**. The Slake Durability test results in **Table 8** indicate that the Awaba Tuff strength (UCS) is only 'slightly' sensitive to moisture content increases.

The experiences to-date with Awaba Tuff at Mandalong Mine indicate only minor floor heave has occurred in development headings around geologically structure affected areas, which are usually associated with wetter conditions. It is therefore considered unlikely that large areas of floor heave and unexpected subsidence increases will develop across the mine if some of the tuffaceous claystone units in the floor soften over time.

Estimates of the range of material thickness, strength and stiffness properties present in the roof and floor of the WW (Western longwalls) and WGN Seam (Eastern Longwalls) are summarised in **Table 9**.

**Table 9 - Thickness, Strength and Stiffness Estimates of Stratigraphy**

| **Stratigraphy** | **Thickness (m)** | **UCS Range+ [Mean] (MPa)** | **Elastic Moduli Range* [Mean] (GPa)** |
|---|---|---|---|
| Munmorah Conglomerate | 90 - 120 | 48 - 80 [60] | 13 - 24 [19] |
| Interbedded mudstone, sandstone and siltstone | 17 - 36 | 20-80 [*20*] | 6 - 24 [6] |
| West Wallarah / Wallarah + GNA Seams | 1.6 - 4.6 | 11 - 13 [12] | 2 - 4 [3] |
| Awaba Tuff | 0.5 - 12.5 | 30 - 115 [62] | 7 - 23 [16] |
| Laminite | 0.3 - 5 | 20-50 [30] | 6 - 10 [7] |
| Teralba Conglomerate | >10 | 60 - 80 [70] | 18 - 25 [21] |

\+ - Unconfined Compressive Strength derived from Laboratory UCS testing on bore core samples and /or correlations with Sonic Velocity profiles.
* - Laboratory Young's Modulus (E) derived from laboratory and sonic UCS data, E = 342 x UCS (units are in gigapascals [GPa]).
*Italics* - Design value based on lower bound values from laboratory testing.

### 7.6 Geotechnical Model of the Overburden

Based on the available geotechnical data, the following key subsidence model parameters are required to estimate the likely behaviour of the overburden during subsidence development:

- Cover Depth (H)
- Mining Height (T)
- Maximum unit (i.e. beam) thickness (t) within the Munmorah Conglomerate formation
- Distance (y) of the massive conglomerate or sandstone 'beam' above the proposed mine workings
- Thickness of the various mudstone floor units (including Awaba Tuff) that exist immediately below the floor of the proposed mine workings in the west and east of the seam split respectively

Contours of the above parameters are presented in **Figures 1**, **2b**, and **9** to **11** and are discussed further in the following sections.

Other secondary parameters that also form part of the geotechnical model of the overburden include:

- Overburden depth or potential load acting on the Munmorah Conglomerate Beam (D)
- Thickness of the Munmorah Conglomerate Formation
- Distance the Munmorah Conglomerate Formation is located above the West Wallarah or WGN Seams (i.e. the thickness of the Dooralong Shale)
- Thickness of seam split interburden between the WGN Seam and Awaba Tuff (i.e the Teralba Conglomerate and Great Northern C Seam)
- Interpreted soil cover thickness contours (i.e. alluvium and residual soils)

Contours of these parameters are presented in **Figures 12a** to **12e** respectively.

## 8.0 Description of Subsidence Development Mechanism

After the extraction of a single longwall panel, the immediate mine roof usually collapses into the void left in the seam (i.e. the caving zone). The overlying strata or overburden then sags down onto the collapsed material, resulting in a subsidence trough developing at the surface. Further fracturing and bedding shear failures may also develop in the overburden above the caved zone, the extent and severity of the fracturing will depend upon the mine geometry and geology (see **Section 12** for further discussion on sub-surface fracturing).

The maximum subsidence usually occurs in the middle of the extracted panel and is dependent on the mining height, panel width, cover depth, overburden strata strength and stiffness, and bulking characteristics of the collapsed strata in the caving and fractured zones. For the case of single seam mining, the maximum subsidence usually does not exceed 60% of the mining height in the Newcastle and Central Coast Coalfields, and may be lower than this value due to the spanning or bridging capability of the strata above the collapsed ground (or the goaf).

The combination of the above factors determines whether a single longwall panel will be *sub-critical, critical* or *supercritical* in terms of maximum subsidence.

In the Australian coalfields, *sub-critical* (or natural arching) behaviour generally occurs above the caving zone when the panel width (W) is <0.6 times the cover depth (H).

The Panel W/H ratio indicates whether a panel is likely to be *sub-critical, critical or supercritical*. Sub-critical panels have W/H ratios < 0.6 and likely to have low levels of subsidence due to natural compressive arch action (i.e. catenary) within the overburden.

*Critical* panels generally have W/H > 0.6 and are too wide for a natural arch to develop, thus resulting in ‘bending’ action in the overburden strata. The magnitude of subsidence depends upon the span and characteristics of the overburden. If massive conglomerate or sandstone channel units exist in the strata then subsidence magnitudes may still remain relatively low if they continue to span above critical panel geometries.

*Supercritical* panels have W/H > 1.4 and unlikely to have spanning strata, with subsidence magnitudes controlled by the mining height and bulking characteristics of the goaf.

If relatively thick and strong massive strata exist in the *critical* width range, then *sub-critical* spanning behaviour can occur for panel W/H ratios up to 0.9 in the Newcastle Coalfield, see **Figure 13a** and **13d**. The maximum subsidence for this scenario is usually significantly < 60% of the longwall extraction height and could range between 10% and 30%.

In the case of *super-critical* panels, maximum panel subsidence does not continue to increase significantly with increasing panel width. The maximum subsidence however, will be strongly influenced by the depth of cover and the magnitude of vertical stress acting on the collapsed roof material in the caved zone.

A summary of the range of overburden behaviours is shown in **Figure 13b** to **13d**.

The surface effect of extracting several adjacent longwall panels is dependent on the stiffness of the overburden and the chain pillars left between the panels. Usually, ‘extra’ subsidence occurs above a previously extracted panel and is caused primarily by the compression of the chain pillars and adjacent strata between the extracted longwall panels, see **Figure 14a**.

A longwall chain pillar undergoes the majority of life-cycle compression when subject to double abutment loading (i.e. the formation of goaf on either side, after two adjacent panels have been extracted). Surface survey data indicates that an extracted panel can affect the chain pillars between three or four previously extracted panels.

The stiffness of the overburden and chain pillar system will determine the extent of load transfer to the preceding chain pillars. The load on the chain pillars will be mitigated to some extent by load transfer to adjacent fallen roof material or goaf. The proportion of load that is transferred to the goaf from the overburden and chain pillar system is also reflected in the measured final subsidence profiles above a series of extracted panels.

After the development of subsidence above a longwall panel, the surface subsidence trough extends outside the limits of extraction for a distance assumed equal to half the depth of cover (or an angle of draw to the vertical of $26.5^{o}$) in the Newcastle and QLD Coalfields, see **Figure 15**.

The subsidence prediction models used in this study consider the abovementioned processes and will be further described in **Section 9**.

## 9.0 Subsidence Prediction Methodology

### 9.1 Maximum Subsidence Predictions for Multiple Longwalls

Multiple-panel subsidence effects are determined by the DgS modified **ACARP, 2003** model (see **Section 9.3** for details) by adding a proportion of the chain pillar subsidence to the predicted single panel subsidence. Estimates of first and final subsidence above a given set of longwalls use this general approach. The definition of First and Final $S_{max}$ is as follows.

First $S_{max}$= the maximum subsidence above a longwall panel after it is first extracted, including the effects of previously extracted longwall panels adjacent to the subject panel.

Final $S_{max}$= the final maximum subsidence over an extracted longwall panel after at least three more panels have been extracted, or when mining has been completed.

First and Final $S_{max}$ above a longwall panel are normally predicted by adding 50% and 100% of the predicted subsidence over the respective tailgate side chain pillars ($S_p$) under double abutment loading conditions (i.e. the pillars between the previously extracted and current panel), less the goaf edge subsidence ($S_{goe}$) above the Maingate of the current panel.

The equations for maximum panel subsidence for multiple panel layouts are as follows:

$$\text{First } S_{max} = \text{Single } S_{max} + 0.5(\text{First } S_p - \text{Single } S_{goe})$$

$$\text{Final } S_{max} = \text{First } S_{max} + (\text{Final } S_p - \text{First } S_{goe})$$

The Final $S_{max}$ includes the loading effect on the adjacent chain pillars (and goaf) when subsequent panels are extracted. It is calculated by adding the First $S_{max}$ to the Final $S_p$ less the First $S_{goe}$.

A conceptual model of the subsidence development mechanism for multiple longwall panels is shown in **Figure 14a**.

The reliability of the model has been assessed using regression analysis techniques and estimates of mean and standard deviation or error of curves of ‘best fit’ through the data base sets. The mean and Upper 95% Confidence Limits (U95%CL) of each prediction can then be provided.

The above methodology supersedes the subsidence prediction methodology of **DMR, 1987** which only provides single panel subsidence predictions in the Newcastle Coalfield.

The subsidence above chain pillars has been defined in this study as follows.

First $S_p$ = subsidence over chain pillars after longwall panels have been extracted on both sides of the pillar for the first time.

Final $S_p$ = the total subsidence over a chain pillar, after at least another three more panels have been extracted, or when mining is completed. The Final $S_p$ is equal to 1.2 times the First $S_p$ value.

When local subsidence data is available for multiple longwall panels, the relationship between the multiple and single panel subsidence predictions can be determined as follows:

First $S_{max}$ = Single $S_{max}$ + 0.5b(First $S_p$ - Single $S_{goe}$)

Final $S_{max}$ = First $S_{max}$ + b(Final $S_p$ - First $S_{goe}$)

The 'b' factor may be estimated from measured subsidence profiles, and allows the load transfer effect between the goaf and the chain pillars to be included in the model (as described previously in **Section 8**). It has been observed at deeper NSW Coalfield Mines (i.e. the Western and Southern Coalfields) where the proportion of subsidence over the chain pillars that should be added to the single panel subsidence decreases as the cover depth increases. The 'b' factor for Mandalong South has been estimated from LW 1- 12 data at Mandalong Mine as shown in **Figure 14b** and ranges from 0.6 to 1.0 for the given panel geometries.

Secondary and residual subsidence above chain pillars and longwall panels tend to occur after extraction and caving of the immediate roof due to (i) increased overburden loading on the pillars and goaf as subsequent longwall panels are extracted and (ii) on-going goaf consolidation. The residual movements can increase subsidence by a further 10 to 30% above chain pillars. A subsidence increase of 20% after double abutment loading occurs (i.e. First $S_p$) has been adopted in the **ACARP, 2003** model to estimate long-term loading effects (i.e. Final $S_p$). Secondary and residual subsidence magnitudes above longwall panels will decrease exponentially as mining moves further away from a given panel.

### 9.2 Maximum Tilt, Curvature and Horizontal Strain

Tilts and curvatures magnitudes have been assessed using the empirical techniques presented in **ACARP, 2003** and by also taking first and second derivatives of the predicted subsidence profiles for comparative purposes. The expected distribution of tilt, curvature and horizontal strain across a total extraction panel is presented in **Figure 15**.

Predictions of strain and horizontal displacement were made based on their respective relationships between the measured curvatures and tilt (refer to **ACARP, 1993** and **ACARP, 2003**). Details of the relationships are re-presented below.

Structural and geometrical analysis theories indicate that strain is linearly proportional to the curvature of an elastic, isotropic bending 'beam'. This proportionality actually represents the depth to the neutral axis of the beam ($d_n$), or in other words, half the beam thickness. **ACARP, 1993** studies returned strain over curvature ratios (i.e. $d_n$) ranging between 6 and 11 m for NSW and Queensland Coalfields. Near surface lithology strata unit thickness and jointing therefore dictate the magnitude of the proportionality constant between curvature and strain. Similar outcomes are found for tilt and horizontal displacement (refer to **Figure A28, Appendix A**).

**ACARP, 2003** continued with this approach and introduced the concept of secondary curvature and strain concentration factors due to cracking. The mean peak strain / curvature ratio or $d_n$ for the Newcastle Coalfield was assessed to equal 5.2 m with strain concentration effects increasing the 'smooth-profile' strains by 2 to 4 times. On-going review of the database has led to a value of 10 being adopted as a more appropriate value for impact prediction purposes. Based on the measured curvature and strain data for the adjacent Mandalong Mine's LWs 1-12, a strain / curvature ratio of 10, with a strain concentration factor of 2 has been applied to the 'smooth profile' values in this study; see **Figure 16**.

A $d_n$ value of 10 m has also been applied to the predicted 'smooth' curvature and tilt profiles to conservatively estimate strain and horizontal displacement above the proposed Mandalong Southern Extension Area panels. These values may then be doubled to estimate localised, concentrated strain effects due to cracking, which are really only expected to occur in zones of peak tensile (or compressive) strains when they exceed 1 to 2 mm/m in magnitude and where surface rock exposures are present within 2 to 3 m of the surface.

Surface crack widths (in mm) may subsequently be estimated by multiplying the predicted strains by 10 (assuming a 10 m distance between survey pegs). *Note: The above crack width estimation method assumes all of the strain will concentrate at a single crack between the survey pegs. This can occur where near surface bedrock exists, but is more likely to develop as two or three smaller width cracks in deeper soil profiles. Therefore, the crack widths are expected to be wider on ridges than along sandy-bottomed creek beds.*

### 9.3 Subsidence Profiles and Contours

Two empirically based prediction models (**ACARP, 2003** and **SDPS®**) have been used to generate subsidence profiles and contours above the proposed longwall panels after mining is complete. **Surfer 8®**software has then been used to generate subsidence, tilt, horizontal displacement, and strain contours above the panels from the **SDPS®** output files.

The subsidence predictions models used in this study are summarised in **Appendix A** and below:

- **ACARP, 2003** - An empirical model that was originally developed for predicting maximum single and multiple longwall panel subsidence, tilt, curvature and strain in the Newcastle Coalfield. The model database included measured subsidence parameters and overburden geology data, which have been back analysed to predict the subsidence reduction potential (SRP) of massive lithology in terms of 'Low', 'Moderate' and 'High' SRP categories.

  The model database also includes chain pillar subsidence, inflexion point distance, goaf edge subsidence and angle of draw prediction models, which allow subsidence profiles to be generated for any number of panels and a range of appropriate confidence limits. The

Upper 95% Confidence Limit (U95%CL) has been adopted in this study for predictions of the Credible Worst-Case values.

The model has been updated by DgS since 2007 to allow the original **ACARP, 2003** model to be applied to other Australian Coalfields and improve its robustness over a greater range of mining geometries and geologies.

- **SDPS®, 2007** - A US developed (Virginia Polytechnical Institute) influence function model for subsidence predictions above longwalls or pillar extraction panels. The model requires calibration to measured subsidence profiles to reliably predict the subsidence and differential subsidence profiles required to assess impacts on surface features.

  The model also includes a database of percentage of hard rock (i.e. massive sandstone / conglomerate) that effectively reduces subsidence above super-critical and sub-critical panels due to either bridging or bulking of collapsed material. This is consistent with the **ACARP, 2003** models prediction methodology.

A summary of the development of the **ACARP, 2003** and **SDPS®** models and terminologies used are presented in **Appendix A**.

The modifications to the **ACARP, 2003** model included adjustments to the following key subsidence prediction parameters, which were made to improve compatibility between the two prediction models used.

- Chain pillar subsidence prediction is now based on pillar subsidence/extraction height ($S_p$/T) v. pillar stress (under double abutment loading conditions - see **Figure A16** of **Appendix A**.).

- Distance of the inflexion point from rib sides and inter-panel pillars in similar terms to **SDPS®** software (i.e. d/H v. W/H) - see **Figure A27** of **Appendix A**.

- The horizontal strain coefficient ($\beta_s$) is the linear constant used to estimate strain based on predicted curvature and is equivalent to the reciprocal of the neutral axis of bending ($d_n$) used in **ACARP, 2003**. Based on Newcastle Coalfield data, a value of $d_n$= 10 m or $\beta_s$ =0.11/m has been applied successfully to predict ‘smooth’ profile strains using the calibrated **SDPS®** model - see **Figures A28** and **A29.1** of **Appendix A**. *Note: the Karmis model does not improve on the correlation between the curvature and strain due to discontinuous strata behaviour. The* **DMR, 1987** *method shows similar variation between strains and curvature as was identified in* **ACARP, 2003***; see* **Figure A29.2** of **Appendix A**).

# 10.0 Subsidence Predictions for Mandalong Southern Extension Area LWs 25-64

## 10.1 General

Subsidence effect predictions for proposed Mandalong southern extension area longwalls 25 to 64 have been assessed across the study area after:

(i) each longwall block has been extracted (i.e. First $S_{max}$), and

(ii) after mining of all of the proposed longwall panels are complete (i.e. Final $S_{max}$).

The assessment requires the consideration of the following:

- The subsidence reduction potential (SRP) of the overburden and the influence of proposed mining geometry on single panel subsidence development (i.e. whether the panels are likely to be sub-critical, critical or supercritical);

- The behaviour of the chain pillars and immediate roof and floor system under double - abutment loading conditions when longwalls have been extracted along both sides of the pillars;

- The combined effects of single panel and chain pillar subsidence to estimate Final subsidence profiles and subsidence contours for subsequent environmental impact assessment.

The outcomes of the subsidence assessment are presented in the following sections.

## 10.2 Geological Model and Subsidence Reduction Potential of Massive Units

### 10.2.1 Empirical Model Assessment

The Subsidence Reduction Potential (SRP) refers to the subsidence reducing effect that massive conglomerate / sandstone / igneous units may have above longwall panels, due to their inherent spanning or arching behaviour. The SRP is a function of the cover depth; the width of the panel (or span); the thickness of the massive unit and the distance of the unit above the workings.

A conceptual model of the spanning potential of a massive strata unit and key parameters used in the assessment are presented in **Figure 13b**.

Based on reference to the Subsidence Reduction Potential (SRP) prediction lines presented in **ACARP, 2003**, the thickness and location of the massive units within the Munmorah Conglomerate Member above the proposed panel widths have been plotted with the ‘High’ and ‘Moderate’ SRP lines for the appropriate cover depth categories on **Figures 17a** to **17b**.

The outcomes of the empirical model analysis for the massive units within the Munmorah Conglomerate are summarised as follows:

- The thickness of the conglomerate beams most likely to span range from 17 m to 35 m (mean of 27 m).

- The beams are located 82 m to 110 m distance above the proposed mine workings roof (mean of 97 m)

The minimum beam thicknesses likely to have 'High' and 'Moderate' SRP are presented in **Table 10**.

**Table 10 - Minimum Beam Thickness Required for High and Moderate SRP**

| Cover Depth, H | Minimum Beam Thickness t (m) | | |
|---|---|---|---|
| | W = 160 m | W=180 m | W=200 m |
| **High SRP** | | | |
| 185 - 250 | 19 | 22 | 24 |
| 250 - 300 | 29 | 33 | 36 |
| 300 - 380 | 39 | 43 | 48 |
| **Moderate SRP** | | | |
| 185 - 250 | 18 | 20 | 22 |
| 250 - 300 | 22 | 25 | 27 |
| 300 - 380 | 34 | 39 | 43 |

The results of the SRP analysis for the individual panels are summarised in **Table 11**.

**Table 11 - Summary of Empirical SRP Analysis Outcomes**

| LW# | XL# | Interpreted Unit Thickness (m) | Massive Unit Distance above Workings y (m) | Workings Cover Depth, H (m) | Unit Location Factor (y/H) | Panel Width W (m) | SRP |
|---|---|---|---|---|---|---|---|
| 25 | 1 | 29 | 97 | 290 | 0.33 | 180 | Moderate |
| | 2 | 35 | 100 | 270 | 0.37 | 180 | High |
| 26 | 1 | 27 | 98 | 290 | 0.34 | 180 | Moderate |
| | 2 | 30 | 105 | 270 | 0.39 | 180 | Moderate |
| 27 | 1 | 27 | 98 | 285 | 0.34 | 180 | Moderate |
| | 2 | 27 | 105 | 270 | 0.39 | 180 | Moderate |
| 28 | 1 | 27 | 98 | 300 | 0.33 | 180 | Moderate |
| | 2 | 27 | 100 | 270 | 0.37 | 180 | Moderate |
| 29 | 1 | 27 | 98 | 340 | 0.29 | 180 | Low |
| | 2 | 25 | 98 | 275 | 0.36 | 180 | Moderate |
| 30 | 2 | 25 | 96 | 280 | 0.34 | 180 | Moderate |
| 31 | 2 | 24 | 95 | 280 | 0.34 | 180 | Low |
| 32 | 3 | 24 | 95 | 400 | 0.24 | 200 | Low |
| | 4 | 30 | 90 | 360 | 0.25 | 200 | Low |
| 33 | 3 | 24 | 98 | 420 | 0.23 | 200 | Low |

**Table 11 (Cont…) - Summary of Empirical SRP Analysis Outcomes**

| LW# | XL# | Interpreted Unit Thickness (m) | Massive Unit Distance above Workings y (m) | Workings Cover Depth, H (m) | Unit Location Factor (y/H) | Panel Width W (m) | SRP |
|---|---|---|---|---|---|---|---|
| 33 | 4 | 30 | 95 | 440 | 0.22 | 200 | Low |
| 34 | 3 | 24 | 102 | 470 | 0.22 | 200 | Low |
| | 4 | 30 | 97 | 480 | 0.20 | 200 | Low |
| 35 | 3 | 24 | 103 | 420 | 0.25 | 200 | Low |
| | 4 | 30 | 98 | 450 | 0.22 | 200 | Low |
| 36 | 3 | 23 | 107 | 380 | 0.28 | 200 | Low |
| | 4 | 30 | 102 | 430 | 0.24 | 200 | Low |
| 37 | 3 | 23 | 107 | 410 | 0.26 | 200 | Low |
| | 4 | 30 | 102 | 430 | 0.24 | 200 | Low |
| 38 | 5 | 32 | 99 | 255 | 0.39 | 180 | Moderate |
| | 7 | 30 | 94 | 350 | 0.27 | 180 | Low |
| | 13 | 31 | 93 | 205 | 0.45 | 180 | High |
| 39 | 6 | 32 | 99 | 235 | 0.42 | 180 | High |
| | 7 | 30 | 94 | 325 | 0.29 | 180 | Low |
| | 13 | 31 | 93 | 210 | 0.44 | 180 | High |
| 40 | 5 | 31 | 98 | 255 | 0.38 | 160 | High |
| | 7 | 28 | 96 | 290 | 0.33 | 160 | Moderate |
| | 13 | 31 | 93 | 210 | 0.44 | 160 | High |
| 41 | 5 | 29 | 98 | 250 | 0.39 | 160 | High |
| | 7 | 27 | 98 | 280 | 0.35 | 160 | Moderate |
| | 13 | 30 | 93 | 230 | 0.40 | 160 | High |
| 42 | 6 | 31 | 98 | 275 | 0.36 | 160 | High |
| | 8 | 25 | 99 | 320 | 0.31 | 160 | Moderate |
| 43 | 6 | 28 | 98 | 310 | 0.32 | 180 | Moderate |
| | 8 | 24 | 100 | 345 | 0.29 | 180 | Low |
| 44 | 6 | 25 | 98 | 345 | 0.28 | 180 | Low |
| | 8 | 22 | 105 | 350 | 0.30 | 180 | Low |
| 45 | 6 | 25 | 97 | 310 | 0.31 | 180 | Moderate |
| | 8 | 18 | 110 | 385 | 0.29 | 180 | Low |
| 46 | 6 | 26 | 97 | 295 | 0.33 | 180 | Moderate |
| | 8 | 17 | 110 | 360 | 0.31 | 180 | Low |
| 47 | 6 | 28 | 96 | 315 | 0.30 | 180 | Moderate |
| | 8 | 17 | 110 | 315 | 0.35 | 180 | Low |
| 48 | 6 | 26 | 98 | 300 | 0.33 | 180 | Moderate |
| | 8 | 17 | 110 | 320 | 0.34 | 180 | Low |
| 49 | 7 | 25 | 96 | 295 | 0.33 | 160 | Moderate |
| | 8 | 17 | 108 | 325 | 0.33 | 160 | Low |
| 50 | 6 | 24 | 97 | 288 | 0.34 | 160 | Moderate |
| | 8 | 17 | 107 | 315 | 0.34 | 160 | Low |
| 51 | 6 | 24 | 97 | 300 | 0.32 | 160 | Moderate |
| | 8 | 18 | 106 | 320 | 0.33 | 160 | Low |
| 52 | 8 | 20 | 105 | 350 | 0.30 | 160 | Low |

**Table 11 (Cont…) - Summary of Empirical SRP Analysis Outcomes**

| LW# | XL# | Interpreted Unit Thickness (m) | Massive Unit Distance above Workings y (m) | Workings Cover Depth, H (m) | Unit Location Factor (y/H) | Panel Width W (m) | SRP |
|---|---|---|---|---|---|---|---|
| 53 | 8 | 21 | 103 | 355 | 0.29 | 160 | Low |
| 54 | 8 | 22 | 102 | 355 | 0.29 | 160 | Low |
| 55 | 5 | 20 | 87 | 205 | 0.42 | 160 | High |
| | 7 | 33 | 90 | 340 | 0.26 | 160 | Low |
| | 13 | 25 | 90 | 185 | 0.49 | 160 | High |
| 56 | 5 | 20 | 88 | 205 | 0.43 | 160 | High |
| | 7 | 35 | 90 | 355 | 0.25 | 160 | Moderate |
| | 13 | 26 | 92 | 195 | 0.47 | 160 | High |
| 57 | 5 | 22 | 88 | 217 | 0.41 | 200 | Moderate |
| | 7 | 34 | 89 | 300 | 0.30 | 200 | Low |
| | 13 | 27 | 93 | 205 | 0.45 | 200 | High |
| 58 | 5 | 25 | 88 | 227 | 0.39 | 200 | High |
| | 7 | 30 | 89 | 285 | 0.31 | 200 | Moderate |
| | 13 | 28 | 93 | 220 | 0.42 | 200 | High |
| 59 | 5 | 28 | 92 | 265 | 0.35 | 200 | Moderate |
| | 7 | 27 | 91 | 270 | 0.34 | 200 | Moderate |
| | 13 | 29 | 93 | 205 | 0.45 | 200 | High |
| 60 | 5 | 30 | 92 | 238 | 0.39 | 160 | High |
| | 7 | 27 | 92 | 305 | 0.30 | 160 | Moderate |
| | 13 | 30 | 93 | 205 | 0.45 | 160 | High |
| 61 | 5 | 31 | 95 | 238 | 0.40 | 200 | High |
| | 7 | 28 | 93 | 330 | 0.28 | 200 | Low |
| | 13 | 31 | 93 | 210 | 0.44 | 200 | High |
| 62 | 9 | 34 | 85 | 275 | 0.31 | 200 | Moderate |
| | 10 | 34 | 93 | 305 | 0.30 | 200 | Moderate |
| 63 | 9 | 33 | 85 | 225 | 0.38 | 200 | High |
| | 10 | 32 | 93 | 280 | 0.33 | 200 | Moderate |
| 64 | 9 | 32 | 85 | 198 | 0.43 | 200 | High |
| | 10 | 30 | 93 | 270 | 0.34 | 200 | Moderate |

### 10.2.2 Analytical Voussoir Beam Model Assessment

Voussoir Beam theory allows a quantitative assessment of a jointed rock beam’s spanning capability by arching action over an extracted longwall panel. The **ACARP, 2003** empirical model of the subsidence reducing effect of spanning strata units was developed with reference to the Voussoir Beam analogue.

The Voussoir Beam model assesses the factor of safety against instability of the rock beam due to (i) abutment crushing, (ii) shear failure and (iii) buckling. The analytical model presented in **Diedrichs and Kaiser, 1999** also provides a statically admissible solution for the deflection of the spanning unit to be calculated for a given set of material strength and stiffness properties. The uncertainties inherent in the model include the effective span of the unit within the overburden, the uniformity or persistence of the ‘beam’, and the effective loading height acting on the beam.

Analytical models therefore allow the geo-mechanical properties of the mine site strata to be used to (i) predict subsidence, and (ii) compare the outcomes to the empirical model, which has been based on measured subsidence data for a wide range of mining geometries and geomechanical properties in the Newcastle Coalfield.

The rock mass properties assessed for the Munmorah Conglomerate and the mining geometries proposed are summarised in **Table 12** below.

**Table 12 - Geo-mechanical Properties of the Munmorah Conglomerate Beams**

| Parameter | Units | Magnitude |
|---|---|---|
| Rock Mass Density | $t/m^3$ | 2.46 |
| Rock Mass Strength | MPa | 52 |
| Laboratory Youngs Modulus | GPa | 12.3 |
| Geological Strength Index+ | Good Sandstone | 60 |
| Rock Mass Modulus | GPa | 10.5 - 4 |
| Poissons Ratio | m/m | 0.25 |
| Abutment Angle for Beam Load Estimation | degrees | 21 |
| Abutment Angle for Beam Span & Load Estimation* | degrees | 12 |
| Horizontal/Vertical Stress Factor | K | 2 |
| Rock Mass Cohesion | MPa | 5.0 |
| Rock Mass Friction Angle | $^{o}$ | 42 |

+ - as recommended in **Marinos and Hoek, 2000**.
* - as estimated in **Seedsman, 2003**.

Average rock mass elastic moduli for the Munmorah Conglomerate units were estimated based on the laboratory data and the relationship established by **Hoek and Diederichs, 2006** below:

$$E_{rockmass} = E_{laboratory}(0.02+1/(1+e^{(60-GSI)/11})$$

The upper and lower bound Young's Modulus for each of the above have been estimated for an assessed Geological Strength Index (GSI) of 60 for ‘Good’ sandstone rock mass conditions as defined in **Marinos and Hoek, 2000** (blocky strata with good bedding parting surface quality (i.e. rough and slightly weathered).

The Factor of Safety against arch abutment crushing and mid-span deflection for all of the panels (including empirical model predictions) are summarised in **Table 13**. Effective beam spans were assessed based on two alternative abutment angles of 12$^{o}$ and 21$^{o}$ for sensitivity analysis purposes.

**Table 13 - Summary of Voussoir Beam Analysis Outcomes for the Proposed Mandalong Southern Extension Area LWs 25 to 64**

| Panel Span W (m) | Cover Depth H (m) | Abutment Angle (degrees) | Conglomerate Beam Geometry | | FoS Against Crushing | Predicted Mid-Span Deflection (m) | |
|---|---|---|---|---|---|---|---|
| | | | Thickness t (m) | Height above Workings, y (m) | | Voussoir Beam Analog* | ACARP, 2003 Single Panel (mean-U95%CL) |
| Abutment Angle = 21$^o$ | | | | | | | |
| 160 | 185-355 | 21 | 17 - 35 | 82 - 108 | 0.92 - 3.14 | 0.11 - 0.48 | 0.14 - 0.46 |
| 180 | 205-385 | | 17 - 35 | 93 - 110 | 0.82 - 2.35 | 0.19 - 1.00 | 0.25 - 1.04 |
| 200 | 198-480 | | 22 - 38 | 85 - 107 | 0.64 - 1.86 | *0.31 - 0.77* | 0.31 - 0.77 |
| Abutment Angle = 12$^o$ | | | | | | | |
| 160 | 185-355 | 12 | 17 - 35 | 82 - 108 | 0.70 - 2.43 | 0.17 - 0.58 | 0.14 - 0.46 |
| 180 | 205-385 | | 17 - 35 | 93 - 110 | 0.43 - 1.75 | 0.29 - 1.04 | 0.25 - 1.04 |
| 200 | 198-480 | | 22 - 38 | 85 - 107 | 0.45 - 1.29 | 0.31 - 0.81 | 0.31 - 0.77 |

* - Voussoir Beam Results are only valid in the pseudo-elastic to elastic range (i.e. FoS > 1). The results for yielded beams are matched to the empirical model results for a given beam thickness and location above the workings.

The results in **Table 13** are presented graphically in **Figures 18a** and **18b** for abutment angles of 21$^o$ and 12$^o$ respectively. Based on the subsidence data review for Mandalong LWs 1-12 (see **Section 10.11**), the latter case is assessed to provide a conservative outcome with > 90% of voussoir beam results greater than the empirical model predictions (and measured data).

The voussoir beam (analytical) and empirical model outcomes are presented in **Figures 18c** to **18e** for the 160, 180 and 200 m wide longwalls for good rock mass conditions (GSI = 60) and an abutment angle of 12$^o$.

It is assessed that the analytical model outcomes for good rock mass conditions and a 12$^o$ abutment angle provide a conservative fit to the **ACARP, 2003** model results in the elastic range where FoS against beam yielding is > 1. It should be noted that the accuracy of the Voussoir beam deflections for the yielded beam cases (i.e. FoS <1) are effected by non-linear beam material behaviour and are not constrained by mining height or panel geometry. It is therefore considered appropriate to assume empirical model values in the yielded beam zone.

Overall the empirical model is likely to be more reliable than the Voussoir Beam model because it includes the influence of the mining height and sub-critical to super-critical mining geometries.

The compression of the chain pillars will increase the maximum panel subsidence values after the mining of several adjacent panels. The assessment of multiple panel subsidence is presented in **Section 10.4**.

### 10.3 Predicted Maximum Single Panel Subsidence

The maximum subsidence above a single longwall panel will depend upon its width (W), cover depth (H), extraction height (T), and the SRP of the overburden.

Based on reference to the **ACARP, 2003** model, the assessed SRP categories for the massive overburden strata units are used to select the appropriate subsidence prediction lines from one of three given depth categories (i.e. H=100 m, 200 m and 300 m +/-50 m).

The depth categories were developed in the **ACARP, 2003** study to cater for the influence of scale on the spanning behaviour of the massive lithological units above panels of a given geometry. The categories derived are also consistent with the trends of the upper bound curves that were developed by the Department of Minerals Resources (now Resources and Energy) for the Newcastle and Southern Coalfields, in that measured subsidence generally increases with depth for a given panel width to cover depth ratio (W/H).

The relevant categories for the proposed Mandalong LWs 25 to 64 are the 200 m and 300 m +/- 50 m depth categories, see **Figures 19a** and **19b** respectively. The DMR empirical model curves are also shown for comparative purposes.

The maximum subsidence, $S_{max}$, for single 160 m, 180 m and 200 m wide longwall panels at 160 to 240 m depth with ‘Low’, ‘Moderate’ and ‘High’ SRP overburden is summarised in **Table 14** for XLs 1 to 13 (see **Figure 2c** for location).

### Table 14 - Predicted Maximum Single Panel Subsidence for LWs 25 to 64

| XL | LW# | Panel Width, W (m) | Cover Depth, H (m) | W/H | Extraction Height T (m) | Beam Thickness t (m) | SRP | Single $S_{max}$*(m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Mean | U95%CL |
| 1 | 25 | 180 | 290 | 0.62 | 4.1 | 29 | Mod | 0.55 | 0.68 |
| | 26 | 180 | 290 | 0.62 | 4.2 | 27 | Mod | 0.56 | 0.68 |
| | 27 | 180 | 285 | 0.63 | 4.1 | 27 | Mod | 0.56 | 0.69 |
| | 28 | 180 | 300 | 0.60 | 4.1 | 27 | Mod | 0.53 | 0.65 |
| | 29 | 180 | 340 | 0.53 | 3.9 | *27* | Low | 0.62 | 0.74 |
| 2 | 25 | 180 | 270 | 0.67 | 4.5 | 35 | High | 0.47 | 0.60 |
| | 26 | 180 | 270 | 0.67 | 4.3 | 30 | Mod | 0.60 | 0.72 |
| | 27 | 180 | 270 | 0.67 | 4.1 | 27 | Mod | 0.57 | 0.69 |
| | 28 | 180 | 270 | 0.67 | 4.0 | 27 | Mod | 0.55 | 0.67 |
| | 29 | 180 | 275 | 0.65 | 3.9 | 25 | Mod | 0.56 | 0.67 |
| | 30 | 180 | 280 | 0.64 | 3.8 | 25 | Mod | 0.53 | 0.65 |
| | 31 | 180 | 280 | 0.64 | 3.5 | 24 | Low | 0.76 | 0.87 |
| 3 | 32 | 200 | 400 | 0.50 | 3.4 | 24 | Low | 0.51 | 0.62 |
| | 33 | 200 | 420 | 0.48 | 3.5 | 24 | Low | 0.51 | 0.61 |
| | 34 | 200 | 470 | 0.43 | 3.5 | 24 | Low | 0.44 | 0.55 |
| | 35 | 200 | 420 | 0.48 | 3.5 | 24 | Low | 0.51 | 0.61 |
| | 36 | 200 | 380 | 0.53 | 3.6 | 23 | Low | 0.57 | 0.68 |
| | 37 | 200 | 410 | 0.49 | 3.5 | 23 | Low | 0.52 | 0.62 |
| 4 | 32 | 200 | 360 | 0.56 | 3.7 | 30 | Low | 0.62 | 0.73 |
| | 33 | 200 | 440 | 0.45 | 3.5 | 30 | Low | 0.48 | 0.59 |
| | 34 | 200 | 480 | 0.42 | 3.5 | 30 | Low | 0.43 | 0.54 |
| | 35 | 200 | 450 | 0.44 | 3.6 | 30 | Low | 0.48 | 0.59 |
| | 36 | 200 | 430 | 0.47 | 3.6 | 30 | Low | 0.51 | 0.62 |
| | 37 | 200 | 430 | 0.47 | 3.7 | 30 | Low | 0.52 | 0.63 |
| 5 | 55 | 160 | 205 | 0.78 | 1.8 | 20 | High | 0.10 | 0.19 |
| | 56 | 160 | 205 | 0.78 | 1.8 | 20 | High | 0.10 | 0.19 |
| | 57 | 200 | 217 | 0.92 | 1.8 | 22 | Mod | 0.51 | 0.60 |
| | 58 | 200 | 227 | 0.88 | 1.8 | 25 | High | 0.22 | 0.31 |
| | 59 | 200 | 265 | 0.75 | 1.8 | 28 | Mod | 0.39 | 0.48 |
| | 60 | 160 | 238 | 0.67 | 1.9 | 30 | High | 0.10 | 0.16 |
| | 61 | 200 | 238 | 0.84 | 2.0 | 31 | High | 0.28 | 0.38 |
| | 38 | 180 | 255 | 0.71 | 2.15 | 32 | Mod | 0.29 | 0.39 |
| | 39 | 180 | 235 | 0.77 | 2.15 | 32 | High | 0.14 | 0.25 |
| 5 | 40 | 160 | 255 | 0.63 | 2.15 | 31 | High | 0.16 | 0.22 |
| | 41 | 160 | 250 | 0.64 | 2.20 | 29 | High | 0.15 | 0.22 |
| | 42 | 160 | 245 | 0.65 | 2.25 | 27 | High | 0.14 | 0.21 |
| | 43 | 180 | 255 | 0.71 | 2.35 | 25 | Mod | 0.31 | 0.43 |
| 6 | 42 | 160 | 275 | 0.58 | 2.20 | 31 | High | 0.22 | 0.28 |
| | 43 | 180 | 310 | 0.58 | 2.30 | 28 | Mod | 0.29 | 0.36 |
| | 44 | 180 | 345 | 0.52 | 2.45 | 25 | Low | 0.39 | 0.46 |

**Table 14 (Cont…) - Predicted Maximum Single Panel Subsidence for LWs 25 to 64**

| XL | LW# | Panel Width, W (m) | Cover Depth, H (m) | W/H | Extraction Height T (m) | Beam Thickness t (m) | SRP | Single $S_{max}$*(m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Mean | U95%CL |
| 6 | 45 | 180 | 310 | 0.58 | 2.5 | 25 | Mod | 0.32 | 0.39 |
| | 46 | 180 | 295 | 0.61 | 2.55 | 26 | Mod | 0.34 | 0.41 |
| | 47 | 180 | 315 | 0.57 | 2.65 | 28 | Mod | 0.33 | 0.41 |
| | 48 | 180 | 300 | 0.60 | 2.55 | 26 | Mod | 0.33 | 0.41 |
| | 49 | 160 | 295 | 0.54 | 2.50 | 25 | Mod | 0.31 | 0.38 |
| | 50 | 160 | 288 | 0.56 | 2.35 | 24 | Mod | 0.29 | 0.36 |
| | 51 | 160 | 300 | 0.53 | 2.30 | 24 | Mod | 0.28 | 0.35 |
| 7 | 55 | 160 | 340 | 0.47 | 2.20 | 33 | Low | 0.31 | 0.38 |
| | 56 | 160 | 355 | 0.45 | 2.10 | 35 | Mod | 0.24 | 0.30 |
| | 57 | 200 | 300 | 0.67 | 1.95 | 34 | Low | 0.46 | 0.52 |
| | 58 | 200 | 285 | 0.70 | 1.95 | 30 | Mod | 0.30 | 0.40 |
| | 59 | 200 | 270 | 0.74 | 1.95 | 27 | Mod | 0.42 | 0.51 |
| | 60 | 160 | 305 | 0.52 | 1.95 | 27 | Mod | 0.24 | 0.29 |
| | 61 | 200 | 330 | 0.61 | 2.00 | 28 | Low | 0.38 | 0.44 |
| | 38 | 180 | 350 | 0.51 | 2.10 | 30 | Low | 0.33 | 0.39 |
| | 39 | 180 | 325 | 0.55 | 2.10 | 30 | Low | 0.35 | 0.41 |
| | 40 | 160 | 290 | 0.55 | 2.25 | 28 | Mod | 0.28 | 0.35 |
| | 41 | 160 | 280 | 0.57 | 2.25 | 27 | Mod | 0.28 | 0.35 |
| | 42 | 160 | 280 | 0.57 | 2.25 | 26 | Mod | 0.28 | 0.35 |
| | 43 | 180 | 255 | 0.71 | 2.25 | 25 | Mod | 0.30 | 0.41 |
| 8 | 42 | 160 | 320 | 0.50 | 2.25 | 25 | Mod | 0.27 | 0.33 |
| | 43 | 180 | 345 | 0.52 | 2.25 | 24 | Low | 0.35 | 0.42 |
| | 44 | 180 | 350 | 0.51 | 2.25 | 22 | Low | 0.35 | 0.42 |
| | 45 | 180 | 385 | 0.47 | 2.30 | 18 | Low | 0.33 | 0.40 |
| | 46 | 180 | 360 | 0.50 | 2.30 | 17 | Low | 0.35 | 0.42 |
| | 47 | 180 | 315 | 0.57 | 2.35 | 17 | Low | 0.41 | 0.48 |
| | 48 | 180 | 320 | 0.56 | 2.35 | 17 | Low | 0.40 | 0.47 |
| | 49 | 160 | 325 | 0.49 | 2.40 | 17 | Low | 0.36 | 0.43 |
| | 50 | 160 | 315 | 0.51 | 2.50 | 17 | Low | 0.38 | 0.46 |
| | 51 | 160 | 320 | 0.50 | 2.50 | 18 | Low | 0.38 | 0.45 |
| | 52 | 160 | 350 | 0.46 | 2.70 | 20 | Low | 0.37 | 0.46 |
| | 53 | 160 | 355 | 0.45 | 2.75 | 21 | Low | 0.37 | 0.46 |
| | 54 | 160 | 355 | 0.45 | 2.75 | 22 | Low | 0.37 | 0.46 |
| 9 | 62 | 200 | 275 | 0.73 | 2.50 | 34 | Mod | 0.50 | 0.63 |
| | 63 | 200 | 225 | 0.89 | 2.20 | 33 | High | 0.25 | 0.36 |
| | 64 | 200 | 198 | 1.01 | 1.90 | 32 | High | 0.46 | 0.56 |
| 10 | 62 | 200 | 305 | 0.66 | 2.20 | 34 | Mod | 0.31 | 0.38 |
| | 63 | 200 | 280 | 0.71 | 2.10 | 32 | Mod | 0.37 | 0.48 |
| | 64 | 200 | 270 | 0.74 | 2.00 | 30 | Mod | 0.43 | 0.53 |
| 11 | 55 | 160 | 230 | 0.67 | 1.80 | 30 | High | 0.08 | 0.14 |
| | 56 | 160 | 245 | 0.63 | 1.85 | 25 | High | 0.12 | 0.17 |

**Table 14 (Cont…) - Predicted Maximum Single Panel Subsidence for LWs 25 to 64**

| XL | LW# | Panel Width, W (m) | Cover Depth, H (m) | W/H | Mining Height T (m) | Beam Thickness t (m) | SRP | Single $S_{max}$*(m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Mean | U95%CL |
| 11 | 57 | 200 | 260 | 0.77 | 1.80 | 26 | Mod | 0.65 | 0.74 |
| | 58 | 200 | 240 | 0.83 | 1.80 | 27 | High | 0.26 | 0.35 |
| | 59 | 200 | 235 | 0.85 | 1.80 | 38 | High | 0.25 | 0.34 |
| | 60 | 160 | 248 | 0.65 | 1.90 | 31 | High | 0.13 | 0.18 |
| | 61 | 200 | 310 | 0.65 | 1.95 | 31 | Low | 0.43 | 0.49 |
| | 38 | 180 | 300 | 0.60 | 2.10 | 31 | Mod | 0.27 | 0.34 |
| | 39 | 180 | 330 | 0.55 | 2.20 | 31 | Low | 0.36 | 0.43 |
| | 40 | 160 | 280 | 0.57 | 2.25 | 31 | High | 0.22 | 0.29 |
| | 41 | 160 | 265 | 0.60 | 2.25 | 31 | High | 0.19 | 0.26 |
| | 42 | 160 | 280 | 0.57 | 2.25 | 31 | High | 0.22 | 0.29 |
| | 43 | 180 | 320 | 0.56 | 2.25 | 30 | Mod | 0.28 | 0.35 |
| | 42 | 160 | 275 | 0.57 | 2.30 | 31 | High | 0.23 | 0.29 |
| | 43 | 180 | 310 | 0.55 | 2.30 | 31 | Mod | 0.29 | 0.36 |
| | 44 | 180 | 350 | 0.51 | 2.30 | 30 | Low | 0.36 | 0.43 |
| 12 | 45 | 180 | 310 | 0.58 | 2.35 | 29 | Mod | 0.30 | 0.37 |
| | 46 | 180 | 295 | 0.61 | 2.35 | 27 | Mod | 0.31 | 0.38 |
| | 47 | 180 | 315 | 0.57 | 2.35 | 26 | Mod | 0.30 | 0.37 |
| | 48 | 180 | 300 | 0.60 | 2.40 | 24 | Mod | 0.45 | 0.52 |
| | 49 | 160 | 305 | 0.52 | 2.40 | 23 | Mod | 0.29 | 0.36 |
| | 50 | 160 | 287 | 0.56 | 2.40 | 22 | Mod | 0.30 | 0.37 |
| | 51 | 160 | 320 | 0.50 | 2.50 | 20 | Mod | 0.38 | 0.45 |
| | 52 | 160 | 325 | 0.49 | 2.55 | 18 | Mod | 0.38 | 0.46 |
| | 53 | 160 | 320 | 0.50 | 2.55 | 17 | Low | 0.39 | 0.46 |
| | 54 | 160 | 335 | 0.48 | 2.55 | 18 | Low | 0.37 | 0.45 |
| 13 | 55 | 160 | 185 | 0.86 | 1.80 | 25 | High | 0.18 | 0.27 |
| | 56 | 160 | 195 | 0.82 | 1.80 | 26 | High | 0.14 | 0.23 |
| | 57 | 200 | 205 | 0.98 | 1.85 | 27 | High | 0.44 | 0.53 |
| | 58 | 200 | 220 | 0.91 | 1.85 | 28 | High | 0.27 | 0.37 |
| | 59 | 200 | 205 | 0.98 | 1.85 | 29 | High | 0.44 | 0.53 |
| | 60 | 160 | 205 | 0.78 | 1.80 | 30 | High | 0.10 | 0.19 |
| | 61 | 200 | 210 | 0.95 | 1.80 | 31 | High | 0.40 | 0.49 |
| | 38 | 180 | 205 | 0.88 | 1.80 | 31 | High | 0.20 | 0.29 |
| | 39 | 180 | 210 | 0.86 | 1.80 | 31 | High | 0.18 | 0.27 |
| | 40 | 160 | 210 | 0.76 | 1.80 | 31 | High | 0.09 | 0.18 |
| | 41 | 160 | 230 | 0.70 | 1.80 | 30 | High | 0.08 | 0.14 |

SRP - Subsidence Reduction Potential; Mod = Moderate.
* - Maximum subsidence limited to 58% of mining height for the mean and U95%CL (refer to **ACARP, 2003**).

The results of the single panel spanning assessment indicate that the maximum single panel subsidence for 160 m wide panels are predicted to range between 0.08 and 0.46 m (1% to 18% of the mining height); the 180 m wide panels range between 0.14 and 0.87 m (2% to 29% of the mining height); the 200 m wide panels range between 0.22 and 0.74 m (3% to 44% of the mining height).

The single panel subsidence values predicted above will be used with the chain pillar and goaf edge subsidence to estimate the multi-panel subsidence in the following sections.

### 10.4 Maximum Predicted Subsidence Above Chain Pillars

#### 10.4.1 Chain Pillar Geometry

The predicted subsidence values above the chain pillars have been estimated based on an empirical and analytical model of the roof-pillar-floor system. The pillars have been sized in accordance with minimum tailgate serviceability requirements as required by ALTS 2009 and the CMRR of the immediate roof strata (refer to **Colwell and Frith, 2009**) as presented in **Table 15**.

**Table 15 - Proposed Chain Pillar Geometries**

| LW# | MG Pillar Width, w (m) | Development Height, h (m) | w/h | Pillar Length (m) | Extraction Height T (m) | Cover Depth H (m) | Panel Width W (m) |
|---|---|---|---|---|---|---|---|
| 25 | 46.0 | 3.2 | 14.4 | 94.8 | 4.1 - 4.5 | 270-290 | 180 |
| 26-31 | 43.4 | 3.2 | 13.6 | 94.8 | 3.5 - 4.3 | 270-340 | 180 |
| 32 | 46.0 | 3.2 | 14.4 | 94.8 | 3.4 - 3.7 | 360-400 | 200 |
| 33-34 | 48.6 | 3.2 | 15.2 | 94.8 | 3.5 | 420-480 | 200 |
| 35-37 | 45.3 | 3.2 | 14.2 | 94.8 | 3.5 - 3.7 | 380-450 | 200 |
| 38-45 | 39.7 | 2.5 | 15.9 | 94.8 | 1.8 - 2.5 | 205-385 | 160,180 |
| 46-54 | 40.7 | 2.5 | 16.3 | 94.8 | 2.2 - 2.8 | 288-355 | 160,180 |
| 55 | 39.7 | 2.5 | 15.9 | 94.8 | 1.8 - 2.2 | 185-340 | 160 |
| 56-60 | 41.8 | 2.5 | 16.7 | 94.8 | 1.8 - 2.1 | 195-355 | 160,200 |
| 61 | 144 | 2.5 | 57.6 | 94.8 | 1.8 - 2.0 | 210-330 | 200 |
| 62-64 | 37.5 | 2.5 | 15.0 | 94.8 | 1.9 - 2.5 | 198-305 | 200 |

MG = Maingate.

#### 10.4.2 Empirical Model Development

The empirical model has been developed from measured subsidence data over chain pillars ($S_p$) divided by the average of the LW face extraction (T) and the development heights (h) v. the Total Pillar Stress after longwall panel extraction has occurred along both sides, see **Figure 20a**. This approach is considered appropriate when there is a significant difference between the extraction and development heights and has been validated by measured data at a mine site.

The database indicates that when pillar stresses are < 20 MPa, chain pillar subsidence is generally between 5% - 10% T. Between 20 and 40 MPa, the chain pillars start to 'soften' or yield with subsidence increasing to around 15% - 25%T. Above 40 MPa the subsidence does not increase over 30%T, which indicates strain hardening behaviour is occurring and suggests that some of the pillar load will be re-distributed to the adjacent goaf (which also strain hardens) after yielding of the pillar starts to occur.

It is apparent from the measured data **Figure 20a** that the subsidence above the pillars is also a function of the strength and stiffness of the coal *and surrounding rock mass* (i.e. higher subsidence was measured above a pillar with a weak shale roof compared to a pillar with a strong sandstone floor (all other strata and coal properties were similar)).

Furthermore, based on reference to **ACARP, 2005**, pillars with w/h ratios > 5 are considered "squat" and would be expected to soften initially and then strain-harden if overloaded (and not collapse suddenly); see **Figures 20b** to **20d**. It is therefore reasonable to conclude that the subsidence above the chain pillars with w/h > 5 under increasing load will trend to a maximum limit that is a primarily a function of the average of the mining and development heights.

The proposed longwall extraction face and development heights for Mandalong Southern Extension Area are also generally within the limits of the empirical model's database. The empirical model database includes longwall mining heights of 2.0 m to 4.8 m with pillar development heights of 2.0 m to 3.5 m. Pillar widths range from 18 m to 40 m (and one case of 80 m) with corresponding w/h ratios of 7.4 to 25.8.

### 10.4.3 Empirical Model Stress

The estimate of the total stress acting on the chain pillars on each side of the panel under double abutment loading conditions is based on the abutment angle concept described in **ACARP, 1998a** for calibrating ALPS to Australian coal mines; see **Figure 14a**. The total stress acting on the chain pillars after mining is completed, may be estimated as follows:

$\sigma$ = pillar load/area = $(P+A_1+A_2)/wl$

where:

P = full tributary area load of column of rock above each pillar;

= $(l+ r)(w + r).\rho.g.H$;

$A_{1,2}$ = total abutment load from each side of pillar in MN/m, and

= $(l+r)\rho g(0.5W'H - W'^2/8\tan\phi)$ (for sub-critical panel widths) or

= $(l+r)(\rho g H^2 \tan\phi)/2$ (for super-critical panel widths);

w = pillar width (solid);

l = pillar length solid;

r = roadway width;

H = depth of cover;

$\phi$ = abutment angle (normally taken to be 21°) and

$\rho$ = rock mass density;

W' = effective panel width (rib to rib distance minus the roadway width).

A panel is deemed sub-critical when W'/2 <Htan$\phi$ by **ACARP, 1998a**.

### 10.4.4 Empirical Model Pillar Strength and FoS

As presented in **ACARP, 1998b** the FoS of the chain pillars were based on the strength formula for 'squat' pillars with w/h ratios > 5 as follows:

$$S = 27.63\Theta^{0.51}(0.29((w/5h)^{2.5} - 1) + 1)/(w^{0.22}h^{0.11})$$

where:

h = pillar development height;

$\Theta$ = a dimensionless 'aspect ratio' factor or w/h ratio in this case.

The FoS was then calculated by dividing the pillar strength, S, with the pillar stress, $\sigma$.

### 10.4.5 Empirical Model Results

The predicted mean and Upper 95%CL Final Subsidence values above the proposed chain pillars (under double abutment loading conditions) are summarised for cross lines XL1 to 13 in **Table 16**. The results for all cases are also plotted with the empirical model database in **Figure 20a**.

**Table 16 - Predicted Chain Pillar Subsidence based on Modified ACARP, 2003 Empirical Model**

| LW # | XL # | Panel Width W (m) | Cover Depth, H (m) | MG$^{+}$ Chain Pillar Width w (m) | Average Pillar Height* (m) | Chain Pillar Stress (MPa) | Pillar FoS under DA$^{\$}$ Loading Conditions | Chain Pillar Subsidence $S_p$ (m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Final^ (mean) | Final^ (U95 %CL) |
| 25 | 1 | 180 | 290 | 46.0 | 3.7 | 26.2 | 2.22 | 0.54 | 0.64 |
| 26 | | 180 | 290 | 43.4 | 3.7 | 27.0 | 1.95 | 0.58 | 0.68 |
| 27 | | 180 | 285 | 43.4 | 3.7 | 27.4 | 1.92 | 0.59 | 0.68 |
| 28 | | 180 | 300 | 43.4 | 3.6 | 30.8 | 1.71 | 0.69 | 0.79 |
| 25 | 2 | 180 | 270 | 46.0 | 3.9 | 23.6 | 2.47 | 0.48 | 0.59 |
| 26 | | 180 | 270 | 43.4 | 3.8 | 24.6 | 2.14 | 0.50 | 0.61 |
| 27 | | 180 | 270 | 43.4 | 3.7 | 24.6 | 2.14 | 0.49 | 0.59 |
| 28 | | 180 | 270 | 43.4 | 3.6 | 24.8 | 2.12 | 0.49 | 0.59 |
| 29 | | 180 | 275 | 43.4 | 3.6 | 25.5 | 2.06 | 0.51 | 0.60 |
| 30 | | 180 | 280 | 43.4 | 3.5 | 25.9 | 2.03 | 0.51 | 0.61 |
| 31 | | 180 | 280 | 43.4 | 3.35 | 26.2 | 2.01 | 0.50 | 0.58 |

**Table 16 (Cont…) - Predicted Chain Pillar Subsidence based on Modified ACARP, 2003 Empirical Model**

| LW # | XL # | Panel Width W (m) | Cover Depth, H (m) | MG+ Chain Pillar Width w (m) | Average Pillar Height* (m) | Chain Pillar Stress (MPa) | Pillar FoS under DA$ Loading Conditions | Chain Pillar Subsidence, $S_p$ (m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Final^ (mean) | Final^ (U95 %CL) |
| 32 | 3 | 200 | 400 | 46.0 | 3.3 | 43.4 | 1.34 | 0.86 | 1.02 |
| 33 | | 200 | 420 | 48.6 | 3.4 | 45.9 | 1.40 | 0.89 | 1.06 |
| 34 | | 200 | 470 | 48.6 | 3.4 | 47.3 | 1.35 | 0.90 | 1.07 |
| 35 | | 200 | 420 | 45.3 | 3.4 | 43.3 | 1.31 | 0.87 | 1.04 |
| 36 | | 200 | 380 | 45.3 | 3.4 | 41.6 | 1.36 | 0.86 | 1.04 |
| 32 | 4 | 200 | 360 | 46.0 | 3.1 | 41.1 | 2.51 | 0.78 | 0.86 |
| 33 | | 200 | 440 | 48.6 | 3.0 | 48.1 | 2.39 | 0.81 | 0.90 |
| 34 | | 200 | 480 | 48.6 | 3.0 | 49.8 | 2.30 | 0.82 | 0.91 |
| 35 | | 200 | 450 | 45.3 | 3.1 | 48.7 | 2.06 | 0.83 | 0.92 |
| 36 | | 200 | 430 | 45.3 | 3.1 | 47.0 | 2.13 | 0.82 | 0.91 |
| 55 | 5 | 160 | 205 | 39.7 | 2.2 | 16.8 | 4.66 | 0.15 | 0.21 |
| 56 | | 160 | 205 | 41.8 | 2.2 | 16.7 | 5.16 | 0.15 | 0.15 |
| 57 | | 200 | 217 | 41.8 | 2.2 | 18.4 | 4.69 | 0.18 | 0.24 |
| 58 | | 200 | 227 | 41.8 | 2.2 | 21.5 | 4.02 | 0.23 | 0.29 |
| 59 | | 200 | 265 | 41.8 | 2.2 | 23.2 | 3.72 | 0.26 | 0.32 |
| 60 | | 160 | 238 | 41.8 | 2.2 | 20.6 | 4.19 | 0.22 | 0.28 |
| 61 | | 200 | 238 | 144.0 | 2.3 | 10.8 | 90.89 | 0.08 | 0.08 |
| 38 | | 180 | 255 | 39.7 | 2.3 | 22.8 | 3.43 | 0.28 | 0.34 |
| 39 | | 180 | 235 | 39.7 | 2.3 | 22.0 | 3.57 | 0.26 | 0.32 |
| 40 | | 160 | 255 | 39.7 | 2.3 | 23.2 | 3.38 | 0.28 | 0.34 |
| 41 | | 160 | 250 | 39.7 | 2.4 | 22.5 | 3.48 | 0.27 | 0.33 |
| 42 | | 160 | 245 | 39.7 | 2.4 | 22.9 | 3.42 | 0.28 | 0.34 |
| 43 | | 180 | 255 | 39.7 | 2.4 | 24.6 | 3.19 | 0.33 | 0.39 |
| 42 | 6 | 160 | 275 | 39.7 | 2.4 | 28.5 | 2.75 | 0.40 | 0.46 |
| 43 | | 180 | 310 | 39.7 | 2.4 | 34.1 | 2.30 | 0.52 | 0.58 |
| 44 | | 180 | 345 | 39.7 | 2.5 | 35.1 | 2.23 | 0.55 | 0.61 |
| 45 | | 180 | 310 | 39.7 | 2.5 | 31.2 | 2.52 | 0.48 | 0.54 |
| 46 | | 180 | 295 | 40.7 | 2.5 | 30.4 | 2.70 | 0.47 | 0.53 |
| 47 | | 180 | 315 | 40.7 | 2.6 | 31.3 | 2.62 | 0.50 | 0.56 |
| 48 | | 180 | 300 | 40.7 | 2.5 | 29.2 | 2.81 | 0.45 | 0.51 |
| 49 | | 160 | 295 | 40.7 | 2.5 | 27.9 | 2.94 | 0.41 | 0.47 |
| 50 | | 160 | 288 | 40.7 | 2.4 | 27.9 | 2.94 | 0.40 | 0.46 |
| 51 | | 160 | 300 | 40.7 | 2.4 | 29.0 | 2.83 | 0.42 | 0.48 |
| 55 | 7 | 160 | 340 | 39.7 | 2.4 | 35.5 | 2.21 | 0.53 | 0.59 |
| 56 | | 160 | 355 | 41.8 | 2.3 | 33.6 | 2.57 | 0.49 | 0.55 |
| 57 | | 200 | 300 | 41.8 | 2.2 | 29.3 | 2.95 | 0.39 | 0.45 |
| 58 | | 200 | 285 | 41.8 | 2.2 | 27.0 | 3.20 | 0.35 | 0.41 |
| 59 | | 200 | 270 | 41.8 | 2.2 | 26.8 | 3.22 | 0.34 | 0.40 |
| 60 | | 160 | 305 | 41.8 | 2.2 | 31.5 | 2.74 | 0.44 | 0.50 |
| 61 | | 200 | 330 | 144.0 | 2.3 | 16.4 | 59.52 | 0.15 | 0.15 |

**Table 16 (Cont…) - Predicted Chain Pillar Subsidence based on Modified ACARP, 2003 Empirical Model**

| LW # | XL # | Panel Width W (m) | Cover Depth, H (m) | MG+ Chain Pillar Width w (m) | Average Pillar Height* (m) | Chain Pillar Stress (MPa) | Pillar FoS under DA$ Loading Conditions | Final Chain Pillar Subsidence $S_p$ (m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Final^ (mean) | Final^ (U95 %CL) |
| 38 | 7 | 180 | 350 | 39.7 | 2.3 | 36.4 | 2.15 | 0.53 | 0.59 |
| 39 | | 180 | 325 | 39.7 | 2.3 | 31.7 | 2.48 | 0.45 | 0.51 |
| 40 | | 160 | 290 | 39.7 | 2.4 | 27.6 | 2.84 | 0.39 | 0.45 |
| 41 | | 160 | 280 | 39.7 | 2.4 | 26.8 | 2.93 | 0.37 | 0.43 |
| 42 | | 160 | 280 | 39.7 | 2.4 | 25.8 | 3.04 | 0.35 | 0.41 |
| 43 | | 180 | 255 | 39.7 | 2.4 | 24.6 | 3.19 | 0.32 | 0.38 |
| 42 | 8 | 160 | 320 | 39.7 | 2.4 | 34.2 | 2.29 | 0.51 | 0.57 |
| 43 | | 180 | 345 | 39.7 | 2.4 | 37.4 | 2.10 | 0.56 | 0.62 |
| 44 | | 180 | 350 | 39.7 | 2.4 | 39.9 | 1.97 | 0.59 | 0.65 |
| 45 | | 180 | 385 | 39.7 | 2.4 | 41.5 | 1.89 | 0.61 | 0.67 |
| 46 | | 180 | 360 | 40.7 | 2.4 | 36.0 | 2.28 | 0.55 | 0.61 |
| 47 | | 180 | 315 | 40.7 | 2.4 | 32.4 | 2.53 | 0.49 | 0.55 |
| 48 | | 180 | 320 | 40.7 | 2.4 | 32.4 | 2.53 | 0.49 | 0.55 |
| 49 | | 160 | 325 | 40.7 | 2.5 | 31.7 | 2.59 | 0.48 | 0.54 |
| 50 | | 160 | 315 | 40.7 | 2.5 | 31.1 | 2.64 | 0.48 | 0.54 |
| 51 | | 160 | 320 | 40.7 | 2.5 | 33.0 | 2.49 | 0.52 | 0.58 |
| 52 | | 160 | 350 | 40.7 | 2.6 | 35.7 | 2.30 | 0.59 | 0.65 |
| 53 | | 160 | 355 | 40.7 | 2.6 | 36.1 | 2.28 | 0.60 | 0.66 |
| 62 | 9 | 200 | 275 | 37.5 | 2.5 | 25.2 | 2.80 | 0.34 | 0.40 |
| 63 | | 200 | 225 | 37.5 | 2.4 | 18.9 | 3.75 | 0.20 | 0.26 |
| 64 | | 200 | 198 | 37.5 | 2.2 | 11.2 | 6.29 | 0.09 | 0.15 |
| 62 | 10 | 200 | 305 | 37.5 | 2.4 | 31.8 | 2.22 | 0.48 | 0.54 |
| 63 | | 200 | 280 | 37.5 | 2.3 | 28.7 | 2.46 | 0.40 | 0.46 |
| 55 | 11 | 160 | 230 | 41.8 | 2.2 | 20.9 | 3.75 | 0.21 | 0.27 |
| 56 | | 160 | 245 | 41.8 | 2.2 | 22.5 | 3.84 | 0.25 | 0.31 |
| 57 | | 200 | 260 | 41.8 | 2.2 | 22.9 | 3.77 | 0.26 | 0.32 |
| 58 | | 200 | 240 | 41.8 | 2.2 | 20.8 | 4.15 | 0.22 | 0.28 |
| 59 | | 200 | 235 | 41.8 | 2.2 | 21.1 | 4.09 | 0.22 | 0.28 |
| 60 | | 160 | 248 | 41.8 | 2.2 | 25.8 | 3.34 | 0.32 | 0.38 |
| 61 | | 200 | 310 | 144.0 | 2.2 | 14.7 | 66.41 | 0.13 | 0.13 |
| 38 | | 180 | 300 | 39.7 | 2.3 | 32.3 | 2.43 | 0.46 | 0.52 |
| 39 | | 180 | 330 | 39.7 | 2.4 | 31.6 | 2.48 | 0.46 | 0.52 |
| 40 | | 160 | 280 | 39.7 | 2.4 | 26.0 | 3.02 | 0.35 | 0.41 |
| 41 | | 160 | 265 | 39.7 | 2.4 | 25.6 | 3.07 | 0.34 | 0.40 |
| 42 | | 160 | 280 | 39.7 | 2.4 | 29.5 | 2.66 | 0.43 | 0.49 |
| 43 | | 180 | 320 | 39.7 | 2.4 | 21.5 | 3.65 | 0.25 | 0.31 |
| 42 | 12 | 160 | 275 | 39.7 | 2.4 | 28.5 | 2.75 | 0.41 | 0.47 |
| 43 | | 180 | 310 | 39.7 | 2.4 | 34.3 | 2.28 | 0.52 | 0.58 |
| 44 | | 180 | 350 | 39.7 | 2.4 | 35.5 | 2.21 | 0.54 | 0.60 |
| 45 | | 180 | 310 | 39.7 | 2.4 | 31.2 | 2.52 | 0.47 | 0.53 |
| 46 | | 180 | 295 | 40.7 | 2.4 | 30.4 | 2.70 | 0.45 | 0.51 |
| 47 | | 180 | 315 | 40.7 | 2.4 | 31.3 | 2.62 | 0.47 | 0.53 |

**Table 16 (Cont…) - Predicted Chain Pillar Subsidence based on Modified ACARP, 2003 Empirical Model**

| LW # | XL # | Panel Width W (m) | Cover Depth, H (m) | MG+ Chain Pillar Width w (m) | Average Pillar Height* (m) | Chain Pillar Stress (MPa) | Pillar FoS under DA$ Loading Conditions | Final Chain Pillar Subsidence $S_p$ (m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Final^ (mean) | Final^ (U95% CL) |
| 48 | 12 | 180 | 300 | 40.7 | 2.5 | 29.7 | 2.76 | 0.44 | 0.50 |
| 49 | | 160 | 305 | 40.7 | 2.5 | 28.6 | 2.87 | 0.42 | 0.48 |
| 50 | | 160 | 287 | 40.7 | 2.5 | 28.9 | 2.84 | 0.43 | 0.49 |
| 51 | | 160 | 320 | 40.7 | 2.5 | 31.8 | 2.59 | 0.49 | 0.55 |
| 52 | | 160 | 325 | 40.7 | 2.5 | 31.9 | 2.57 | 0.50 | 0.56 |
| 53 | | 160 | 320 | 40.7 | 2.5 | 32.3 | 2.55 | 0.51 | 0.57 |
| 55 | 13 | 160 | 185 | 39.7 | 2.2 | 14.7 | 5.32 | 0.12 | 0.12 |
| 56 | | 160 | 195 | 41.8 | 2.2 | 15.2 | 5.68 | 0.13 | 0.13 |
| 57 | | 200 | 205 | 41.8 | 2.2 | 17.0 | 5.06 | 0.16 | 0.16 |
| 58 | | 200 | 220 | 41.8 | 2.2 | 17.5 | 4.94 | 0.16 | 0.22 |
| 59 | | 200 | 205 | 41.8 | 2.2 | 16.3 | 5.31 | 0.14 | 0.14 |
| 60 | | 160 | 205 | 41.8 | 2.2 | 16.3 | 5.30 | 0.14 | 0.14 |
| 61 | | 200 | 210 | 144.0 | 2.2 | 8.8 | 111.50 | 0.06 | 0.06 |
| 38 | | 180 | 205 | 39.7 | 2.2 | 17.1 | 4.59 | 0.16 | 0.22 |
| 39 | | 180 | 210 | 39.7 | 2.2 | 17.5 | 4.48 | 0.16 | 0.22 |
| 40 | | 160 | 210 | 39.7 | 2.2 | 18.5 | 4.24 | 0.18 | 0.24 |

$ - Double Abutment.
* - Average of Mining Height (T) and Development Height (h).
^ - Final Chain Pillar Subsidence = 1.2 x First Chain Pillar Subsidence.
+ - The chain pillars are on the Maingate side of the panel or leading goaf edge.

The predicted First Subsidence over the chain pillars ($S_p$) between the extracted panels 25 to 64 are estimated to range from 0.10 m to 0.94 m for the range of pillar sizes and geometries proposed (and ignoring the 144 m barrier between LWs 38 and 61). The final subsidence over the chain pillars (after mining is completed) is estimated to range from 0.12 m to 1.10 m (an overall increase of 20%).

The vertical stress acting on the pillars is estimated to range from 14.7 to 49.8 MPa with pillar FoS values of 1.16 to 5.68 estimated. The Pillar FoS is generally not used in the empirical model to estimate the subsidence, due to the higher variability in the database compared to the total stress data and other complicating factors, such as the strain hardening behaviour of squat pillars and roof and floor interaction.

### 10.4.6 Analytical Model Development

The observed behaviour of the chain pillars and roof-floor system has also been used to develop a simple analytical model that includes elastic and post-yielded pillar responses to estimate subsidence based on laboratory testing data.

The compression of the chain pillars and immediate roof and floor strata has been estimated using the superimposition of two relatively simple analytical models. The purpose of this exercise is to check that the empirical model predictions are reasonable compared to analytical predictions, based on the range of measured physical parameters of the rock mass and coal seam.

Given that the stress on the chain pillars may exceed the in-situ strength of the coal and/or roof / floor materials, the analytical models needed to consider both the elastic and post-yield stiffness moduli of the pillar-roof-floor system.

The FoS of the proposed chain pillars are expected to range between 1.31 and 6.29 under double abutment loading conditions, and are therefore likely to behave either elastically in the long-term or go into yield slowly and stop as pillars and goaf strain harden.

Reference to **Figures 20b** to **20d** and **ACARP, 2005** indicates that the proposed chain pillars with w/h ratios >12 are likely to strain-harden if they are over-loaded. Based on the equation for residual pillar modulus presented in **Zipf, 1999** (see **Figure 20d**), the post-yield stiffness of the coal pillars has been assumed to equal ~15% of the peak Young's Modulus value of 2 GPa (i.e. 300 MPa).

### 10.4.7 Bearing Capacity of Roof and Floor Strata

The bearing capacity of the roof/floor strata and chain pillar strength was firstly checked before appropriate rock mass Young's Modulii values were assigned for subsidence prediction under the assessed loading conditions.

Reference to **Pells *et al*, 1998** indicates that the bearing capacity of sedimentary rock under shallow footing type loading conditions is 3 to 5 times its UCS strength. Based on the estimated range of average UCS values of 20 MPa to 50 MPa in the immediate roof and floor strata respectively, the general bearing capacity of the strata is estimated to range between 60 and 150 MPa. The roof and floor strata are likely to behave elastically for pillar FoS values > 2.

The estimated pillar stresses of 14.7 MPa to 49.8 MPa give an FoS range of 10.2 to 1.2, and indicates that roof and floor strata with applied stresses < 30 MPa are likely to behave elastically. Pillars with stresses > 30 MPa may experience local bearing or lateral squeezing failures in the roof or floor strata and increase surface subsidence due to strain softening.

A similar outcome was assessed by applying 2-layered bearing capacity theory presented in **Brown & Meyerhof, 1969** for a strip footing on a weak layer overlying a stronger one. The theory indicates that the overall bearing capacity of the weaker layer will be increased if the stronger unit is within 0.5 times the width of the pillar as follows:

$$q_u = N_{strip} \times UCS_1/2 = [4.14 + 0.5(w/t)]\ UCS_1/2 = 57 \text{ to } 178 \text{ MPa}$$

where

$N_{strip}$ = Modified bearing capacity coefficient for a strip footing.
$w$ = 37.5 to 48 m (proposed chain pillar widths)

$UCS_1$ = weak claystone strength = 20 to 50 MPa
t = thickness of weaker layer = 8 to 12 m

Based on the bearing capacity analysis, it will be necessary to include a strata softening component in the analytical model of the roof and floor, as well as the chain pillar itself.

Another factor to also consider is the load transfer mechanism between a yielding pillar/immediate strata and the adjacent goaf. Load will be transferred from the yielding or yielded pillar when the stiffness of the goaf increases to the stiffness of the pillar (see **Section 10.6** for further details).

For chain pillars with applied loads of < 30 MPa, the compression of the pillar, roof and floor strata may be estimated using laboratory test results, provided the values are adjusted to reflect the stiffness of the overall rock mass.

Average rock mass elastic moduli for the floor and roof materials within the significant area of influence of the pillars (i.e. approximately the pillar width above and below the mine workings) are estimated below. Based on the intact laboratory data (see **Section 7.5**) and their relationship with the Geological Strength Index (GSI), refer to **Hoek and Diederichs, 2006**:

$$E_{rockmass} = E_{laboratory}(0.02+1/(1+e^{(60\text{-}GSI)/11})$$

The rock mass Young's Modulus ($E_{rockmass}$) for the roof, floor and coal materials have been estimated for an assessed GSI range of 50 to 60 for blocky to very blocky strata with fair bedding parting surface quality (i.e. smooth to rough, slightly to moderately weathered) as follows:

$E_{rockmass}$ = 0.3 $E_{laboratory}$ for Claystone/Mudstone

= 0.5 $E_{laboratory}$ for Sandstone/Siltstone/Conglomerate

The residual stiffness of the roof and floor rock mass strata that has gone into yield due to local bearing failures has been assumed to be 25% of the peak modulus for subsidence prediction purposes.

A summary of the estimated rock mass strength and stiffness properties is presented in **Table 17**.

**Table 17 - Rock Mass Strength and Stiffness Summary of Stratigraphy**

| Stratigraphy | Thickness (m) | Rock Mass UCS Range+ [Mean] (MPa) | Rock Mass Elastic Moduli Range* [Mean] (GPa) |
|---|---|---|---|
| Munmorah Conglomerate | 90 - 120 | 24 - 40<br>[30] | 8 - 14<br>[10] |
| Interbedded mudstone, sandstone and siltstone beds above the Mine Workings | 17 - 36 | 10-40<br>[*10*] | 3.5 - 14<br>[*3.5*] |
| WW and WGN Seams | 1.6 - 4.6 | 5.5 - 6.5<br>[6] | 2 - 4<br>[3] |
| Awaba Tuff | 0.5 - 12.5 | 30 - 115<br>[*30*] | 10 - <u>23</u><br>[*3.5*] |
| Laminite | 0.3 - 5 | 10-25<br>[15] | 3.5 - 8.5<br>[5] |
| Teralba Conglomerate | >10 | 30 - 40<br>[35] | 9 - 13<br>[10] |

\+ - UCS derived from Laboratory testing on bore core samples and /or correlations with sonic velocity profiles.
* - Laboratory Young's Modulus (E) derived from laboratory and sonic UCS data, E = 342 x UCS (units are in gigapascals [GPa]).
*Italics* - Design value based on lower bound values from laboratory testing.
<u>Underlined</u> - Rock Mass Young Modulus limited by laboratory testing for Mandalong.

## 10.5 Analytical Chain Pillar Subsidence Prediction Model

### 10.5.1 Model Development

The compression of the pillars in the elastic and post-yielded regimes has been calculated by assuming the pillar will behave like a spring under load and then strain-harden as follows:

$$s_{pillar} = \sigma_{net}T_s/E_c + (\sigma_{max} - S_p)T_s/E_r \qquad (1)$$

where:

$s_{pillar}$ = pillar compression;

$\sigma_{net}$ = pillar stress increase = maximum pillar stress - virgin stress;

$T_s$ = Seam thickness;

$E_c$ = Young's Modulus of Coal;

$\sigma_{max}$ = maximum stress on pillar after load redistribution to the goaf (if applicable).

$S_p$ = Pillar strength (**ACARP, 1998b**)

$E_r$ = Residual Modulus of a 'squat' coal pillar in yield (**Zipf, 1999**)
= -0.175/(w/h) + 0.437 (GPa)

The analytical model used to estimate the immediate compression of the floor and roof was taken from Boussinesq's elastic pressure bulb theory beneath strip footings of varying aspect ratio, see **Das, 1998**:

$$s_{roof} = \sigma_{net}\ w(1-v^2)I/E_{roof} \tag{2}$$

$$s_{floor} = \sigma_{net}\ w(1-v^2)I/E_{floor} \tag{3}$$

where:

$s_{roof}$ = roof compression above pillar;

$s_{floor}$ = floor compression below pillar;

$\sigma_{net}$ = net pillar stress increase (= total stress - effective virgin stress);

w = pillar width;

$E_{1,2\ roof}$= Young's Modulus of roof materials 1 and 2 within a distance w above the pillar;

$E_{1,2floor}$= Young's Modulus of floor materials 1 and 2 within a distance w below the pillar;

v = Poisson's Ratio;

I = Influence function for flexible rectangular footing shape geometries (**Das, 1998**);
= 1 for stiffness input uncertainty.

The estimate of long-term surface subsidence ($s_{total}$) above a chain pillar subject to double abutment loading condition may be estimated by summing equations (1), (2) and (3):

$$s_{total} = s_{pillar} + s_{roof} + s_{floor} \text{ (expected)}$$

Worst-case subsidence ($S_{total\text{-}WC}$) has assumed the input parameters have been underestimated by 50% or $S_{total\text{-}WC} = 1.5\ s_{total}$.

### 10.5.2 Analytical Model Results

Analytical chain pillar subsidence predictions were determined for the proposed mining layout in **Table 18** and compared to the empirical model values in **Figures 21a-j**.

Full chain pillar stability calculation details are presented in **Appendix C**.

**Table 18 - Analytical Subsidence Model Predictions Above the Proposed Chain Pillars**

| LW | XL. Case No | Cover Depth (m) | Panel Width (m) | Pillar Width w (m) | Pillar Stress (MPa) | Pillar FoS Under Final Loading | Subsidence Predictions (CWC) Based on Analytical Pillar-Strata System Compression (m) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Pillar | Roof | Floor | Total | 1.5 Total |
| 63 | 9.1 | 225 | 200 | 37.5 | 18.9 | 3.75 | 0.01 | 0.05 | 0.07 | **0.13** | **0.20** |
| 62 | 9.1 | 275 | 200 | 37.5 | 25.2 | 2.80 | 0.02 | 0.08 | 0.10 | **0.19** | **0.29** |
| 63 | 10.1 | 280 | 200 | 37.5 | 28.7 | 2.46 | 0.02 | 0.08 | 0.10 | **0.20** | **0.30** |
| 62 | 10.1 | 305 | 200 | 37.5 | 31.8 | 2.22 | 0.02 | 0.13 | 0.12 | **0.27** | **0.41** |
| 55 | 13.2 | 185 | 160 | 39.7 | 14.7 | 5.32 | 0.01 | 0.04 | 0.04 | **0.08** | **0.12** |
| 55 | 5.2 | 205 | 160 | 39.7 | 16.8 | 4.66 | 0.01 | 0.04 | 0.05 | **0.10** | **0.15** |
| 40 | 13.2 | 210 | 160 | 39.7 | 18.5 | 4.24 | 0.01 | 0.05 | 0.05 | **0.10** | **0.15** |
| 55 | 11.2 | 230 | 160 | 39.7 | 20.9 | 3.75 | 0.01 | 0.05 | 0.06 | **0.12** | **0.18** |
| 42 | 5.2 | 245 | 160 | 39.7 | 22.9 | 3.42 | 0.01 | 0.06 | 0.06 | **0.13** | **0.20** |
| 41 | 5.2 | 250 | 160 | 39.7 | 22.5 | 3.48 | 0.01 | 0.06 | 0.06 | **0.14** | **0.21** |
| 40 | 5.2 | 255 | 160 | 39.7 | 23.2 | 3.38 | 0.01 | 0.06 | 0.07 | **0.14** | **0.22** |
| 41 | 11.2 | 265 | 160 | 39.7 | 25.6 | 3.07 | 0.01 | 0.07 | 0.07 | **0.15** | **0.23** |
| 42 | 6.2 | 275 | 160 | 39.7 | 28.5 | 2.75 | 0.02 | 0.07 | 0.07 | **0.16** | **0.24** |
| 42 | 12.2 | 275 | 160 | 39.7 | 28.5 | 2.75 | 0.02 | 0.07 | 0.07 | **0.16** | **0.24** |
| 41 | 7.2 | 280 | 160 | 39.7 | 26.8 | 2.93 | 0.02 | 0.07 | 0.08 | **0.17** | **0.25** |
| 42 | 7.2 | 280 | 160 | 39.7 | 25.8 | 3.04 | 0.02 | 0.07 | 0.08 | **0.17** | **0.25** |
| 40 | 11.2 | 280 | 160 | 39.7 | 26.0 | 3.02 | 0.02 | 0.07 | 0.08 | **0.17** | **0.25** |
| 42 | 11.2 | 280 | 160 | 39.7 | 29.5 | 2.66 | 0.02 | 0.07 | 0.08 | **0.17** | **0.25** |
| 40 | 7.2 | 290 | 160 | 39.7 | 27.6 | 2.84 | 0.02 | 0.08 | 0.08 | **0.17** | **0.26** |
| 42 | 8.2 | 320 | 160 | 39.7 | 34.2 | 2.29 | 0.02 | 0.13 | 0.09 | **0.24** | **0.36** |
| 55 | 7.2 | 340 | 160 | 39.7 | 35.5 | 2.21 | 0.02 | 0.14 | 0.10 | **0.26** | **0.39** |
| 38 | 13.3 | 205 | 180 | 39.7 | 17.1 | 4.59 | 0.01 | 0.04 | 0.05 | **0.10** | **0.15** |
| 39 | 13.3 | 210 | 180 | 39.7 | 17.5 | 4.48 | 0.01 | 0.05 | 0.05 | **0.10** | **0.15** |
| 39 | 5.3 | 235 | 180 | 39.7 | 22.0 | 3.57 | 0.01 | 0.06 | 0.06 | **0.13** | **0.19** |
| 38 | 5.3 | 255 | 180 | 39.7 | 22.8 | 3.43 | 0.01 | 0.07 | 0.07 | **0.15** | **0.22** |
| 43 | 5.3 | 255 | 180 | 39.7 | 24.6 | 3.19 | 0.01 | 0.07 | 0.07 | **0.15** | **0.22** |
| 43 | 7.3 | 255 | 180 | 39.7 | 24.6 | 3.19 | 0.01 | 0.07 | 0.07 | **0.15** | **0.22** |
| 38 | 11.3 | 300 | 180 | 39.7 | 32.3 | 2.43 | 0.02 | 0.09 | 0.09 | **0.19** | **0.29** |
| 43 | 6.3 | 310 | 180 | 39.7 | 34.1 | 2.30 | 0.02 | 0.13 | 0.09 | **0.24** | **0.36** |
| 45 | 6.3 | 310 | 180 | 39.7 | 31.2 | 2.52 | 0.02 | 0.13 | 0.09 | **0.24** | **0.36** |
| 43 | 12.3 | 310 | 180 | 39.7 | 34.3 | 2.28 | 0.02 | 0.13 | 0.09 | **0.24** | **0.36** |
| 45 | 12.3 | 310 | 180 | 39.7 | 31.2 | 2.52 | 0.02 | 0.13 | 0.09 | **0.24** | **0.36** |
| 43 | 11.3 | 320 | 180 | 39.7 | 21.5 | 3.65 | 0.02 | 0.14 | 0.10 | **0.25** | **0.38** |
| 39 | 7.3 | 325 | 180 | 39.7 | 31.7 | 2.48 | 0.02 | 0.14 | 0.10 | **0.26** | **0.39** |
| 39 | 11.3 | 330 | 180 | 39.7 | 31.6 | 2.48 | 0.02 | 0.14 | 0.10 | **0.27** | **0.40** |
| 44 | 6.3 | 345 | 180 | 39.7 | 35.1 | 2.23 | 0.02 | 0.15 | 0.11 | **0.29** | **0.43** |
| 43 | 8.3 | 345 | 180 | 39.7 | 37.4 | 2.10 | 0.02 | 0.15 | 0.11 | **0.29** | **0.43** |
| 38 | 7.3 | 350 | 180 | 39.7 | 36.4 | 2.15 | 0.02 | 0.15 | 0.11 | **0.29** | **0.44** |
| 44 | 8.3 | 350 | 180 | 39.7 | 39.9 | 1.97 | 0.02 | 0.15 | 0.11 | **0.29** | **0.44** |
| 44 | 12.3 | 350 | 180 | 39.7 | 35.5 | 2.21 | 0.02 | 0.15 | 0.11 | **0.29** | **0.44** |
| 45 | 8.3 | 385 | 180 | 39.7 | 41.5 | 1.89 | 0.03 | 0.18 | 0.13 | **0.33** | **0.50** |

**Table 18 (Cont…) - Analytical Subsidence Model Predictions Above the Proposed Chain Pillars**

| LW | XL. Case No | Cover Depth (m) | Panel Width (m) | Pillar Width w (m) | Pillar Stress (MPa) | Pillar FoS Under Final Loading | Subsidence Predictions (CWC) Based on Analytical Pillar-Strata System Compression (m) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Pillar | Roof | Floor | Total | 1.5 Total |
| 50 | 12.4 | 287 | 160 | 40.7 | 28.9 | 2.84 | 0.02 | 0.08 | 0.08 | **0.17** | **0.26** |
| 50 | 6.4 | 288 | 160 | 40.7 | 27.9 | 2.94 | 0.02 | 0.08 | 0.08 | **0.17** | **0.26** |
| 49 | 6.4 | 295 | 160 | 40.7 | 27.9 | 2.94 | 0.02 | 0.08 | 0.08 | **0.18** | **0.27** |
| 51 | 6.4 | 300 | 160 | 40.7 | 29.0 | 2.83 | 0.02 | 0.08 | 0.09 | **0.18** | **0.28** |
| 52 | 6.4 | 302 | 160 | 40.7 | 30.1 | 2.73 | 0.02 | 0.08 | 0.09 | **0.19** | **0.28** |
| 49 | 12.4 | 305 | 160 | 40.7 | 28.6 | 2.87 | 0.02 | 0.08 | 0.09 | **0.19** | **0.28** |
| 50 | 8.4 | 315 | 160 | 40.7 | 31.1 | 2.64 | 0.02 | 0.09 | 0.09 | **0.20** | **0.30** |
| 53 | 6.4 | 320 | 160 | 40.7 | 32.0 | 2.57 | 0.02 | 0.13 | 0.09 | **0.24** | **0.36** |
| 51 | 8.4 | 320 | 160 | 40.7 | 33.0 | 2.49 | 0.02 | 0.13 | 0.09 | **0.24** | **0.36** |
| 51 | 12.4 | 320 | 160 | 40.7 | 31.8 | 2.59 | 0.02 | 0.13 | 0.09 | **0.24** | **0.36** |
| 53 | 12.4 | 320 | 160 | 40.7 | 32.3 | 2.55 | 0.02 | 0.13 | 0.09 | **0.24** | **0.36** |
| 49 | 8.4 | 325 | 160 | 40.7 | 31.7 | 2.59 | 0.02 | 0.13 | 0.10 | **0.24** | **0.37** |
| 52 | 12.4 | 325 | 160 | 40.7 | 31.9 | 2.57 | 0.02 | 0.13 | 0.10 | **0.24** | **0.37** |
| 54 | 6.4 | 330 | 160 | 40.7 | 21.3 | 3.85 | 0.02 | 0.13 | 0.10 | **0.25** | **0.37** |
| 52 | 8.4 | 350 | 160 | 40.7 | 35.7 | 2.30 | 0.02 | 0.14 | 0.11 | **0.27** | **0.41** |
| 53 | 8.4 | 355 | 160 | 40.7 | 36.1 | 2.28 | 0.02 | 0.15 | 0.11 | **0.28** | **0.41** |
| 54 | 8.4 | 355 | 160 | 40.7 | 23.3 | 3.52 | 0.02 | 0.15 | 0.11 | **0.28** | **0.41** |
| 46 | 6.5 | 295 | 180 | 40.7 | 30.4 | 2.70 | 0.02 | 0.08 | 0.09 | **0.19** | **0.28** |
| 46 | 12.5 | 295 | 180 | 40.7 | 30.4 | 2.70 | 0.02 | 0.08 | 0.09 | **0.19** | **0.28** |
| 48 | 6.5 | 300 | 180 | 40.7 | 29.2 | 2.81 | 0.02 | 0.09 | 0.09 | **0.19** | **0.29** |
| 48 | 12.5 | 300 | 180 | 40.7 | 29.7 | 2.76 | 0.02 | 0.09 | 0.09 | **0.19** | **0.29** |
| 47 | 6.5 | 315 | 180 | 40.7 | 31.3 | 2.62 | 0.02 | 0.13 | 0.10 | **0.25** | **0.37** |
| 47 | 8.5 | 315 | 180 | 40.7 | 32.4 | 2.53 | 0.02 | 0.13 | 0.10 | **0.25** | **0.37** |
| 47 | 12.5 | 315 | 180 | 40.7 | 31.3 | 2.62 | 0.02 | 0.13 | 0.10 | **0.25** | **0.37** |
| 48 | 8.5 | 320 | 180 | 40.7 | 32.4 | 2.53 | 0.02 | 0.13 | 0.10 | **0.25** | **0.38** |
| 46 | 8.5 | 360 | 180 | 40.7 | 36.0 | 2.28 | 0.02 | 0.16 | 0.12 | **0.30** | **0.45** |
| 56 | 13.6 | 195 | 160 | 41.8 | 15.2 | 5.68 | 0.01 | 0.04 | 0.04 | **0.09** | **0.13** |
| 56 | 5.6 | 205 | 160 | 41.8 | 16.7 | 5.16 | 0.01 | 0.04 | 0.05 | **0.10** | **0.15** |
| 60 | 13.6 | 205 | 160 | 41.8 | 16.3 | 5.30 | 0.01 | 0.04 | 0.05 | **0.10** | **0.15** |
| 60 | 5.6 | 238 | 160 | 41.8 | 20.6 | 4.19 | 0.01 | 0.06 | 0.06 | **0.13** | **0.19** |
| 56 | 11.6 | 245 | 160 | 41.8 | 22.5 | 3.84 | 0.01 | 0.06 | 0.06 | **0.13** | **0.20** |
| 60 | 11.6 | 248 | 160 | 41.8 | 25.8 | 3.34 | 0.01 | 0.06 | 0.06 | **0.14** | **0.20** |
| 60 | 7.6 | 305 | 160 | 41.8 | 31.5 | 2.74 | 0.02 | 0.08 | 0.09 | **0.19** | **0.28** |
| 56 | 7.6 | 355 | 160 | 41.8 | 33.6 | 2.57 | 0.02 | 0.15 | 0.11 | **0.27** | **0.41** |
| 57 | 13.6 | 205 | 200 | 41.8 | 17.0 | 5.06 | 0.01 | 0.04 | 0.05 | **0.10** | **0.15** |
| 59 | 13.6 | 205 | 200 | 41.8 | 16.3 | 5.31 | 0.01 | 0.04 | 0.05 | **0.10** | **0.15** |
| 57 | 5.6 | 217 | 200 | 41.8 | 18.4 | 4.69 | 0.01 | 0.05 | 0.05 | **0.11** | **0.16** |
| 58 | 13.6 | 220 | 200 | 41.8 | 17.5 | 4.94 | 0.01 | 0.05 | 0.05 | **0.11** | **0.17** |
| 58 | 5.6 | 227 | 200 | 41.8 | 21.5 | 4.02 | 0.01 | 0.05 | 0.06 | **0.12** | **0.18** |
| 59 | 11.6 | 235 | 200 | 41.8 | 21.1 | 4.09 | 0.01 | 0.06 | 0.06 | **0.13** | **0.19** |
| 58 | 11.6 | 240 | 200 | 41.8 | 20.8 | 4.15 | 0.01 | 0.06 | 0.06 | **0.13** | **0.20** |
| 57 | 11.6 | 260 | 200 | 41.8 | 22.9 | 3.77 | 0.01 | 0.07 | 0.07 | **0.15** | **0.23** |

**Table 18 (Cont…) - Analytical Subsidence Model Predictions Above the Proposed Chain Pillars**

| LW | XL. Case No | Cover Depth (m) | Panel Width (m) | Pillar Width w (m) | Pillar Stress (MPa) | Pillar FoS Under Final Loading | Subsidence Predictions (CWC) Based on Analytical Pillar-Strata System Compression (m) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Pillar | Roof | Floor | Total | 1.5 Total |
| 59 | 5.6 | 265 | 200 | 41.8 | 23.2 | 3.72 | 0.01 | 0.07 | 0.07 | **0.16** | **0.24** |
| 59 | 7.6 | 270 | 200 | 41.8 | 26.8 | 3.22 | 0.01 | 0.07 | 0.08 | **0.17** | **0.25** |
| 58 | 7.6 | 285 | 200 | 41.8 | 27.0 | 3.20 | 0.02 | 0.08 | 0.08 | **0.18** | **0.27** |
| 57 | 7.6 | 300 | 200 | 41.8 | 29.3 | 2.95 | 0.02 | 0.09 | 0.09 | **0.20** | **0.30** |
| 26 | 2.7 | 270 | 180 | 43.4 | 24.6 | 2.14 | 0.02 | 0.07 | 0.10 | **0.19** | **0.29** |
| 27 | 2.7 | 270 | 180 | 43.4 | 24.6 | 2.14 | 0.02 | 0.07 | 0.10 | **0.19** | **0.29** |
| 28 | 2.7 | 270 | 180 | 43.4 | 24.8 | 2.12 | 0.02 | 0.07 | 0.10 | **0.19** | **0.29** |
| 29 | 2.7 | 275 | 180 | 43.4 | 25.5 | 2.06 | 0.02 | 0.07 | 0.11 | **0.20** | **0.30** |
| 30 | 2.7 | 280 | 180 | 43.4 | 25.9 | 2.03 | 0.02 | 0.08 | 0.11 | **0.20** | **0.30** |
| 31 | 2.7 | 280 | 180 | 43.4 | 26.2 | 2.01 | 0.02 | 0.08 | 0.10 | **0.20** | **0.30** |
| 27 | 1.7 | 285 | 180 | 43.4 | 27.4 | 1.92 | 0.02 | 0.08 | 0.11 | **0.21** | **0.31** |
| 26 | 1.7 | 290 | 180 | 43.4 | 27.0 | 1.95 | 0.02 | 0.08 | 0.11 | **0.21** | **0.32** |
| 28 | 1.7 | 300 | 180 | 43.4 | 30.8 | 1.71 | 0.02 | 0.09 | 0.12 | **0.22** | **0.33** |
| 36 | 3.8 | 380 | 200 | 45.3 | 41.6 | 1.36 | 0.03 | 0.18 | 0.17 | **0.38** | **0.56** |
| 35 | 3.8 | 420 | 200 | 45.3 | 43.3 | 1.31 | 0.03 | 0.20 | 0.44 | **0.67** | **1.00** |
| 36 | 4.8 | 430 | 200 | 45.3 | 47.0 | 1.21 | 0.02 | 0.21 | 0.50 | **0.74** | **1.10** |
| 35 | 4.8 | 450 | 200 | 45.3 | 48.7 | 1.16 | 0.02 | 0.22 | 0.46 | **0.70** | **1.06** |
| 25 | 2.9 | 270 | 180 | 46 | 23.6 | 2.47 | 0.02 | 0.07 | 0.10 | **0.19** | **0.28** |
| 25 | 1.9 | 290 | 180 | 46 | 26.2 | 2.22 | 0.02 | 0.08 | 0.11 | **0.21** | **0.31** |
| 32 | 4.9 | 360 | 200 | 46 | 41.1 | 1.42 | 0.03 | 0.16 | 0.16 | **0.35** | **0.52** |
| 32 | 3.9 | 400 | 200 | 46 | 43.4 | 1.34 | 0.03 | 0.19 | 0.39 | **0.61** | **0.92** |
| 33 | 3.10 | 420 | 200 | 48.6 | 45.9 | 1.40 | 0.03 | 0.20 | 0.40 | **0.64** | **0.95** |
| 33 | 4.10 | 440 | 200 | 48.6 | 48.1 | 1.33 | 0.03 | 0.21 | 0.43 | **0.68** | **1.02** |
| 34 | 3.10 | 470 | 200 | 48.6 | 47.3 | 1.35 | 0.04 | 0.23 | 0.47 | **0.74** | **1.11** |
| 34 | 4.10 | 480 | 200 | 48.6 | 49.8 | 1.29 | 0.04 | 0.24 | 0.48 | **0.76** | **1.14** |

The results of the analytical subsidence prediction analysis for the mean material properties and cover depth ranges indicate that the subsidence over the proposed chain pillars will range between 0.08 m and 0.76 m after mining is completed. A 50% decrease in material stiffness will increase the predicted subsidence to 0.12 m and 1.14 m.

The analytical results also generally plot close to or below the mean and U95%CL values indicated by the empirical model (see **Figures 21a-j**). The empirical model predictions are therefore considered reasonable for impact analysis purposes.

The analytical model also indicates that in the elastic range, approximately 8% of the surface subsidence is due to the compression of the pillar with 45% from the roof and 47% from the floor strata. An assessment of goaf and pillar loading in **Section 10.6** demonstrates that no load transfer occurs to the goaf due to the elastic compression of the chain pillars under double abutment loading conditions

### 10.6 Analytical Goaf Stiffness Model

Strain-hardening response of goaf between chain pillars will occur as the overburden strata compresses it, with Young's Moduli increasing exponentially up to and beyond the pre-mining stress (**Hardy and Heasley, 2004**). The stress-strain ($\sigma$-$\varepsilon$) curve for the strain-hardening goaf model used in this study is presented below:

$\sigma_g = a[e^{b\varepsilon} - 1]$

where

$a = E_i\sigma_v/(E_f-E_i)$

$b = (E_f-E_i)/\sigma_v$

$\sigma_v$= virgin vertical stress or a maximum vertical stress for a given cover depth.

$E_i$ = initial Young's Modulus

$E_f$= final Young's Modulus

$\varepsilon$ = goaf strain at seam level = c/nT

n = ratio of goaf or rubble thickness/seam thickness or mining height

T = mining height.

c = roof convergence at seam level

There is usually a small amount of void between the top of the goaf and overburden, which must be closed before the goaf starts to load up (i.e. system 'slackness'). The author of the LaModel® program suggests a typical initial Young's Modulus ($E_i$) of 0.7 MPa for the goaf and a maximum goaf stress limit of 27 MPa to reasonably model the field conditions **Hardy and Heasley, 2004**.

The value of 'n' and Final Young's Modulus assumed are the key variables required for calibrating the goaf model to measured maximum subsidence above extracted longwall panels.

For an n = 4, the $E_f$ values for the goaf in the Mandalong South area with depths of cover from 180 m to 480 m, are estimated to range between 165 MPa and 531 MPa (see **Figure 22a**) at a maximum strain of 15%. A simulation of the chain pillar and goaf loading (stress profiles) for 200 m wide panels with 45 m wide chain pillars at a cover depth of 380 m has been completed using the Lam-2D® boundary element model; see **Figure 22b**.

The model input included strain-hardening, stress-strain characteristic curves for the pillars and goaf and is presented in **Table 19**.

**Table 19 - Lam2D Model Input Parameters**

| Parameter | Unit | Value |
|---|---|---|
| **Overburden Properties** | | |
| Elastic Rock Mass Modulus, E* | MPa | 19,000 |
| Poissons Ratio, v | m/m | 0.25 |
| Unit Weight, $\gamma$ | MPa/m$^3$ | 0.025 |
| Strata Unit Thickness Parameter* | m | 29 |
| **Pillar Geometry & Material Properties** | | |
| Panel Width, W | m | 200 |
| Cover Depth, H | m | 380 |
| W/H | m/m | 0.53 (sub-critical) |
| Pillar Width, w | m | 45.3 |
| Pillar Length, l | m | 95 |
| Mining Height, T | m | 3.6 |
| Pillar Height, h | m | 3.2 |
| Roadway width, r | m | 5.5 |
| UNSW Pillar Strength, $S_p$ | MPa | 56.7 |
| Coal Elastic Modulus, $E_c$ | MPa | 2000 |
| Pillar Poisson's Ratio | m/m | 0.25 - 0.4 |
| Pillar w/h | m/m | 14.2 |
| Residual Pillar Modulus, $S_r$ | MPa | 313 |
| **Goaf Properties** | | |
| Goaf Modulus, $E_{initial}$ | MPa | 0.7 |
| Goaf Modulus, $E_{final}$ | MPa | 403 |
| Maximum Goaf Stress | MPa | 9.5 |
| Goaf Strain at Maximum Stress | m/m | 0.15 |

* - Calibrated values to match analytical model pillar and goaf stress to within +/- 2%.

Details of the Lam-2D model is provided in **Appendix B**.

The Lam-2D goaf loading analysis does not consider the spanning capability of Munmorah Conglomerate above the panels and therefore represents a worst-case solution in regards to subsidence prediction.

The model results are summarised below:

- The proportion of the total load that will be supported by the goaf as the overburden strata deflects and the chain pillar-roof strata compresses is 0.19 for a panel width/cover depth ratio of 0.53.

- The convergence of the roof above the goaf will compress it and result in a goaf strain of 14% over 4 times the mining height, with a maximum goaf stress of 5.2 MPa and a goaf modulus of 132 MPa.

- The maximum convergence of the goaf of 1.96 m indicates a surface subsidence of 0.98 m. *Note: The authors of Lamodel apply a 50% rule to seam level convergence to estimate surface subsidence.*

- The goaf stress represents 55% of the maximum pre-mining stress of 9.5 MPa.

- The goaf stiffness will not be high enough to attract load from the chain pillars, which are likely to be loaded within the elastic range with a Youngs Modulus ranging from 1500 MPa to 3000 MPa (2000 MPa assumed in the Lam-2D modelling).

- Load transfer from chain pillars to the goaf will only occur if the pillars between sub-critical or critical panels go into yield (i.e. FoS < 1).

The results of similar analyses of the goaf loads and stiffness's for the rest of the proposed panel geometries is summarised below:

- The proportion of total panel and pillar load acting on the goaf is estimated to range from 0.14 to 0.47 for panel width/cover depth ratios of 0.42 to 0.98; see **Figure 22c**.

- The maximum goaf stress ranges from 2.5 MPa to 7.9 MPa; see **Figure 22d**.

- The goaf stiffness due to strain hardening under load ranges from 92 MPa to 308 MPa; see **Figure 22e**. It is therefore assessed that goaf hardening will have started but unlikely to exceed the stiffness of the chain pillars under double abutment loading conditions.

  The convergence of the goaf above the panels is estimated to range from 0.97 m to 2.63 m above the panels, which indicates a maximum surface subsidence range of 0.49 m to 1.32 m.

The above analysis also demonstrates the mechanism to explain the apparent strain hardening behaviour of the measured chain pillar subsidence curve, which is apparent for pillar stresses > 45 MPa in the empirical model (see **Figure 20a**).

The sharing of the total overburden load between goaf and chain pillars will also be influenced by the mining geometry (panel width and mining height) and will affect the maximum subsidence above multiple panels (see **Section 9**).

### 10.7 Goaf Edge Subsidence Prediction

Based on the modified **ACARP, 2003** model, the final mean and U95%CL goaf edge subsidence predictions for the proposed Mandalong longwall panels range from 0.03 to 0.56 m and from 0.06 to 0.79 m respectively. The results have been derived from the prediction curves shown in **Figure 23** and the maximum final panel subsidence ranges (see **Section 10.8**).

### 10.8 Multiple Panel Subsidence Prediction

Based on the predicted maximum single panel, chain pillar and goaf edge subsidence values derived from the **ACARP, 2003** model, the mean and worst-case First and Final Maximum Subsidence predictions for multi-panels (and the associated impact parameters) are summarised for cross lines (XLs 1 to 13; see **Figure 1**) in the **Table 20** for the proposed longwalls 25 to 64.

## Table 20 - Predicted Maximum Subsidence Effects for LWs 25 to 64

| LW Panel # | XL#. LW# | Panel Width W (m) | Cover Depth H (m) | W/H Ratio | Massive Strata Unit Thickness t (m) | Unit y (m) | SRP | First $S_{max}$ (m) | | Final $S_{max}$ (m) | | First Pillar $S_p$ (m) | | Final Pillar $S_p$ (m) | | Tilt $T_{max}$ (mm/m) | | Curvature ($km^{-1}$) | | Horizontal Strain (mm/m) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | hog | sag | tens | comp |
| | | | | | | | | *m* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *U95* | *U95* | *U95* | *U95* |
| 25 | 1.1 | 180 | 290 | 0.62 | 29 | 100 | Mod | 0.55 | 0.70 | 0.83 | 0.98 | 0.45 | 0.54 | 0.54 | 0.64 | 10 | 16 | 0.60 | 0.76 | 6 | 8 |
| 26 | 1.2 | 180 | 290 | 0.62 | 30 | 100 | Mod | 0.67 | 0.82 | 0.95 | 1.10 | 0.48 | 0.57 | 0.58 | 0.68 | 8 | 11 | 0.48 | 0.61 | 5 | 6 |
| 27 | 1.3 | 180 | 285 | 0.63 | 30 | 100 | Mod | 0.68 | 0.83 | 0.98 | 1.13 | 0.49 | 0.58 | 0.59 | 0.68 | 8 | 12 | 0.49 | 0.63 | 5 | 6 |
| 28 | 1.4 | 180 | 300 | 0.60 | 30 | 100 | Mod | 0.64 | 0.79 | 0.99 | 1.14 | 0.57 | 0.66 | 0.69 | 0.79 | 7 | 11 | 0.47 | 0.59 | 5 | 6 |
| 29 | 1.5 | 180 | 340 | 0.53 | 33 | 99 | Low | 0.73 | 0.88 | 0.81 | 0.96 | 0.33 | 0.42 | 0.40 | 0.49 | 9 | 13 | 0.53 | 0.67 | 5 | 7 |
| 25 | 2.1 | 180 | 270 | 0.67 | 35 | 100 | High | 0.47 | 0.63 | 0.74 | 0.90 | 0.40 | 0.49 | 0.48 | 0.59 | 9 | 13 | 0.53 | 0.68 | 5 | 7 |
| 26 | 2.2 | 180 | 270 | 0.67 | 30 | 105 | Mod | 0.69 | 0.85 | 0.95 | 1.11 | 0.42 | 0.51 | 0.50 | 0.61 | 8 | 12 | 0.50 | 0.64 | 5 | 6 |
| 27 | 2.3 | 180 | 270 | 0.67 | 25 | 105 | Mod | 0.67 | 0.83 | 0.92 | 1.07 | 0.41 | 0.50 | 0.49 | 0.59 | 8 | 12 | 0.49 | 0.62 | 5 | 6 |
| 28 | 2.4 | 180 | 270 | 0.67 | 22 | 108 | Low | 1.00 | 1.14 | 1.20 | 1.34 | 0.41 | 0.50 | 0.49 | 0.59 | 14 | 20 | 0.72 | 0.91 | 7 | 9 |
| 29 | 2.5 | 180 | 275 | 0.65 | 18 | 109 | Low | 0.96 | 1.10 | 1.17 | 1.32 | 0.42 | 0.51 | 0.51 | 0.60 | 13 | 19 | 0.69 | 0.88 | 7 | 9 |
| 30 | 2.6 | 180 | 280 | 0.64 | 15 | 110 | Low | 0.91 | 1.05 | 1.12 | 1.27 | 0.43 | 0.51 | 0.51 | 0.61 | 12 | 18 | 0.66 | 0.83 | 7 | 8 |
| 31 | 2.7 | 180 | 280 | 0.64 | 12 | 115 | Low | 0.85 | 0.98 | 1.07 | 1.20 | 0.42 | 0.50 | 0.50 | 0.58 | 11 | 16 | 0.61 | 0.78 | 6 | 8 |
| 32 | 3.1 | 200 | 400 | 0.50 | 25 | 97 | Low | 0.51 | 0.70 | 0.88 | 1.07 | 0.72 | 0.87 | 0.86 | 1.02 | 10 | 15 | 0.52 | 0.66 | 5 | 7 |
| 33 | 3.2 | 200 | 420 | 0.48 | 25 | 98 | Low | 0.64 | 0.83 | 0.97 | 1.16 | 0.75 | 0.91 | 0.89 | 1.06 | 6 | 9 | 0.37 | 0.47 | 4 | 5 |
| 34 | 3.3 | 200 | 470 | 0.43 | 26 | 100 | Low | 0.56 | 0.76 | 0.85 | 1.04 | 0.75 | 0.91 | 0.90 | 1.07 | 5 | 8 | 0.33 | 0.42 | 3 | 4 |
| 35 | 3.4 | 200 | 420 | 0.48 | 25 | 103 | Low | 0.65 | 0.84 | 0.96 | 1.15 | 0.73 | 0.89 | 0.87 | 1.04 | 6 | 9 | 0.38 | 0.48 | 4 | 5 |
| 36 | 3.5 | 200 | 380 | 0.53 | 24 | 107 | Low | 0.72 | 0.92 | 1.08 | 1.27 | 0.72 | 0.88 | 0.86 | 1.04 | 7 | 11 | 0.42 | 0.54 | 4 | 5 |
| 37 | 3.6 | 200 | 410 | 0.49 | 24 | 108 | Low | 0.66 | 0.79 | 0.81 | 0.94 | 0.47 | 0.55 | 0.56 | 0.64 | 6 | 9 | 0.38 | 0.49 | 4 | 5 |
| 32 | 4.1 | 200 | 360 | 0.56 | 30 | 90 | Low | 0.62 | 0.82 | 1.03 | 1.23 | 0.73 | 0.89 | 0.87 | 1.04 | 12 | 18 | 0.60 | 0.77 | 6 | 8 |
| 33 | 4.2 | 200 | 440 | 0.45 | 30 | 95 | Low | 0.61 | 0.80 | 0.92 | 1.12 | 0.76 | 0.92 | 0.91 | 1.08 | 6 | 8 | 0.36 | 0.45 | 4 | 5 |
| 34 | 4.3 | 200 | 480 | 0.42 | 30 | 97 | Low | 0.55 | 0.74 | 0.83 | 1.02 | 0.77 | 0.93 | 0.92 | 1.09 | 5 | 7 | 0.32 | 0.41 | 3 | 4 |
| 35 | 4.4 | 200 | 450 | 0.44 | 30 | 98 | Low | 0.61 | 0.81 | 0.92 | 1.12 | 0.77 | 0.94 | 0.93 | 1.10 | 6 | 9 | 0.36 | 0.45 | 4 | 5 |
| 36 | 4.5 | 200 | 430 | 0.47 | 30 | 102 | Low | 0.65 | 0.85 | 0.97 | 1.17 | 0.76 | 0.93 | 0.92 | 1.09 | 6 | 9 | 0.38 | 0.48 | 4 | 5 |
| 37 | 4.6 | 200 | 430 | 0.47 | 30 | 102 | Low | 0.66 | 0.80 | 0.82 | 0.96 | 0.52 | 0.61 | 0.63 | 0.72 | 6 | 10 | 0.39 | 0.49 | 4 | 5 |
| 55 | 5.1 | 160 | 205 | 0.78 | 20 | 87 | High | 0.10 | 0.21 | 0.21 | 0.31 | 0.13 | 0.18 | 0.15 | 0.21 | 2 | 3 | 0.19 | 0.24 | 2 | 2 |
| 56 | 5.2 | 160 | 205 | 0.78 | 20 | 88 | High | 0.15 | 0.25 | 0.25 | 0.35 | 0.06 | 0.12 | 0.09 | 0.15 | 2 | 3 | 0.23 | 0.29 | 2 | 3 |

**Table 20 (cont…) - Predicted Maximum Subsidence Effects for LWs 25 to 64**

| LW Panel # | XL#. LW# | Panel Width W (m) | Cover Depth H (m) | W/H Ratio | Massive Strata Unit Thickness t (m) | Unit y (m) | SRP | First $S_{max}$ (m) | | Final $S_{max}$ (m) | | First Pillar $S_p$ (m) | | Final Pillar $S_p$ (m) | | Tilt $T_{max}$ (mm/m) | | Curvature (km-1) | | Horizontal Strain (mm/m) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | hog | sag | tens | comp |
| | | | | | | | | *mean* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *U95* | *U95* | *U95* | *U95* |
| 57 | 5.3 | 200 | 217 | 0.92 | 22 | 88 | Mod | 0.54 | 0.65 | 0.64 | 0.74 | 0.15 | 0.20 | 0.18 | 0.24 | 6 | 9 | 0.37 | 0.47 | 4 | 5 |
| 58 | 5.4 | 200 | 227 | 0.88 | 25 | 88 | High | 0.26 | 0.37 | 0.42 | 0.52 | 0.19 | 0.24 | 0.23 | 0.29 | 3 | 5 | 0.24 | 0.31 | 2 | 3 |
| 59 | 5.5 | 200 | 265 | 0.75 | 28 | 92 | Mod | 0.44 | 0.54 | 0.58 | 0.68 | 0.22 | 0.27 | 0.26 | 0.32 | 5 | 8 | 0.34 | 0.43 | 3 | 4 |
| 60 | 5.6 | 160 | 238 | 0.67 | 30 | 92 | High | 0.18 | 0.25 | 0.31 | 0.39 | 0.18 | 0.23 | 0.22 | 0.28 | 3 | 4 | 0.28 | 0.36 | 3 | 4 |
| 61 | 5.7 | 200 | 238 | 0.84 | 31 | 95 | High | 0.34 | 0.45 | 0.37 | 0.49 | 0.07 | 0.13 | 0.08 | 0.14 | 3 | 4 | 0.22 | 0.28 | 2 | 3 |
| 38 | 5.8 | 180 | 255 | 0.71 | 32 | 99 | Mod | 0.29 | 0.41 | 0.45 | 0.58 | 0.23 | 0.29 | 0.28 | 0.34 | 4 | 6 | 0.33 | 0.42 | 3 | 4 |
| 39 | 5.9 | 180 | 235 | 0.77 | 32 | 99 | High | 0.22 | 0.34 | 0.39 | 0.51 | 0.21 | 0.27 | 0.26 | 0.32 | 3 | 5 | 0.28 | 0.36 | 3 | 4 |
| 40 | 5.10 | 160 | 255 | 0.63 | 31 | 98 | High | 0.22 | 0.31 | 0.39 | 0.47 | 0.24 | 0.29 | 0.28 | 0.34 | 2 | 3 | 0.20 | 0.26 | 2 | 3 |
| 41 | 5.11 | 160 | 250 | 0.64 | 29 | 98 | High | 0.22 | 0.31 | 0.38 | 0.47 | 0.23 | 0.28 | 0.27 | 0.33 | 2 | 3 | 0.20 | 0.26 | 2 | 3 |
| 42 | 5.12 | 160 | 245 | 0.65 | 27 | 98 | High | 0.21 | 0.30 | 0.39 | 0.47 | 0.24 | 0.29 | 0.28 | 0.34 | 2 | 3 | 0.19 | 0.25 | 2 | 2 |
| 43 | 5.13 | 180 | 255 | 0.71 | 25 | 98 | Mod | 0.38 | 0.51 | 0.57 | 0.70 | 0.27 | 0.33 | 0.33 | 0.39 | 6 | 9 | 0.41 | 0.52 | 4 | 5 |
| 42 | 6.1 | 160 | 275 | 0.58 | 31 | 98 | High | 0.22 | 0.30 | 0.45 | 0.54 | 0.33 | 0.39 | 0.40 | 0.46 | 2 | 3 | 0.20 | 0.25 | 2 | 3 |
| 43 | 6.2 | 180 | 310 | 0.58 | 28 | 98 | Mod | 0.38 | 0.47 | 0.65 | 0.74 | 0.43 | 0.49 | 0.52 | 0.58 | 3 | 5 | 0.27 | 0.34 | 3 | 3 |
| 44 | 6.3 | 180 | 345 | 0.52 | 25 | 98 | Low | 0.47 | 0.57 | 0.71 | 0.80 | 0.46 | 0.52 | 0.55 | 0.61 | 5 | 7 | 0.34 | 0.43 | 3 | 4 |
| 45 | 6.4 | 180 | 310 | 0.58 | 25 | 97 | Mod | 0.44 | 0.54 | 0.68 | 0.77 | 0.40 | 0.46 | 0.48 | 0.54 | 4 | 6 | 0.32 | 0.40 | 3 | 4 |
| 46 | 6.5 | 180 | 295 | 0.61 | 26 | 97 | Mod | 0.45 | 0.54 | 0.69 | 0.79 | 0.39 | 0.45 | 0.47 | 0.53 | 4 | 6 | 0.32 | 0.41 | 3 | 4 |
| 47 | 6.6 | 180 | 315 | 0.57 | 28 | 96 | Mod | 0.43 | 0.53 | 0.67 | 0.77 | 0.42 | 0.48 | 0.50 | 0.56 | 4 | 6 | 0.31 | 0.39 | 3 | 4 |
| 48 | 6.7 | 180 | 300 | 0.60 | 26 | 98 | Mod | 0.44 | 0.54 | 0.66 | 0.76 | 0.37 | 0.43 | 0.45 | 0.51 | 4 | 6 | 0.32 | 0.41 | 3 | 4 |
| 49 | 6.8 | 160 | 295 | 0.54 | 25 | 96 | Mod | 0.40 | 0.49 | 0.58 | 0.68 | 0.34 | 0.40 | 0.41 | 0.47 | 4 | 6 | 0.36 | 0.46 | 4 | 5 |
| 50 | 6.9 | 160 | 288 | 0.56 | 24 | 97 | Mod | 0.38 | 0.47 | 0.57 | 0.66 | 0.33 | 0.39 | 0.40 | 0.46 | 4 | 6 | 0.34 | 0.44 | 3 | 4 |
| 51 | 6.10 | 160 | 300 | 0.53 | 24 | 97 | Mod | 0.36 | 0.45 | 0.55 | 0.64 | 0.35 | 0.41 | 0.42 | 0.48 | 4 | 5 | 0.33 | 0.42 | 3 | 4 |
| 55 | 7.1 | 160 | 340 | 0.47 | 33 | 90 | Low | 0.31 | 0.40 | 0.55 | 0.64 | 0.44 | 0.50 | 0.53 | 0.59 | 7 | 10 | 0.50 | 0.64 | 5 | 6 |

### Table 20 (cont…) - Predicted Maximum Subsidence Effects for LWs 25 to 64

| LW Panel # | XL#. LW# | Panel Width W (m) | Cover Depth H (m) | W/H Ratio | Massive Strata Unit Thickness t (m) | Unit y (m) | SRP | First $S_{max}$ (m) | | Final $S_{max}$ (m) | | First Pillar $S_p$ (m) | | Final Pillar $S_p$ (m) | | Maximum Tilt $T_{max}$ (mm/m) | | Curvature (km$^{-1}$) hog | Curvature (km$^{-1}$) sag | Horizontal Strain (mm/m) tens | Horizontal Strain (mm/m) comp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | *mean* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *U95* | *U95* | *U95* | *U95* |
| 56 | 7.2 | 160 | 355 | 0.45 | 35 | 90 | Mod | 0.33 | 0.42 | 0.52 | 0.60 | 0.41 | 0.46 | 0.49 | 0.55 | 3 | 5 | 0.30 | 0.39 | 3 | 4 |
| 57 | 7.3 | 200 | 300 | 0.67 | 34 | 89 | Low | 0.56 | 0.64 | 0.75 | 0.83 | 0.33 | 0.38 | 0.39 | 0.45 | 8 | 12 | 0.44 | 0.56 | 4 | 6 |
| 58 | 7.4 | 200 | 285 | 0.70 | 30 | 89 | Mod | 0.40 | 0.51 | 0.59 | 0.70 | 0.29 | 0.34 | 0.35 | 0.41 | 5 | 8 | 0.34 | 0.44 | 3 | 4 |
| 59 | 7.5 | 200 | 270 | 0.74 | 24 | 91 | Low | 0.73 | 0.84 | 0.90 | 1.01 | 0.29 | 0.34 | 0.34 | 0.40 | 7 | 11 | 0.52 | 0.66 | 5 | 7 |
| 60 | 7.6 | 160 | 305 | 0.52 | 24 | 92 | Mod | 0.30 | 0.38 | 0.52 | 0.60 | 0.36 | 0.42 | 0.44 | 0.50 | 3 | 4 | 0.28 | 0.35 | 3 | 4 |
| 61 | 7.7 | 200 | 330 | 0.61 | 25 | 93 | Low | 0.47 | 0.55 | 0.49 | 0.57 | 0.13 | 0.13 | 0.15 | 0.15 | 4 | 6 | 0.27 | 0.35 | 3 | 3 |
| 38 | 7.8 | 180 | 350 | 0.51 | 30 | 94 | Low | 0.37 | 0.45 | 0.61 | 0.69 | 0.44 | 0.50 | 0.53 | 0.59 | 3 | 5 | 0.26 | 0.34 | 3 | 3 |
| 39 | 7.9 | 180 | 325 | 0.55 | 30 | 94 | Low | 0.46 | 0.54 | 0.65 | 0.74 | 0.38 | 0.43 | 0.45 | 0.51 | 4 | 7 | 0.33 | 0.42 | 3 | 4 |
| 40 | 7.10 | 160 | 290 | 0.55 | 28 | 96 | Mod | 0.38 | 0.46 | 0.55 | 0.64 | 0.32 | 0.38 | 0.39 | 0.45 | 4 | 6 | 0.34 | 0.44 | 3 | 4 |
| 41 | 7.11 | 160 | 280 | 0.57 | 27 | 98 | Mod | 0.37 | 0.45 | 0.54 | 0.63 | 0.31 | 0.36 | 0.37 | 0.43 | 4 | 6 | 0.33 | 0.42 | 3 | 4 |
| 42 | 7.12 | 160 | 280 | 0.57 | 26 | 99 | Mod | 0.36 | 0.45 | 0.52 | 0.61 | 0.29 | 0.34 | 0.35 | 0.41 | 4 | 5 | 0.33 | 0.42 | 3 | 4 |
| 43 | 7.13 | 180 | 255 | 0.71 | 25 | 100 | Mod | 0.39 | 0.52 | 0.59 | 0.71 | 0.27 | 0.32 | 0.32 | 0.38 | 6 | 9 | 0.42 | 0.54 | 4 | 5 |
| 42 | 8.1 | 160 | 320 | 0.50 | 25 | 99 | Mod | 0.27 | 0.36 | 0.53 | 0.62 | 0.43 | 0.48 | 0.51 | 0.57 | 2 | 4 | 0.24 | 0.31 | 2 | 3 |
| 43 | 8.2 | 180 | 345 | 0.52 | 24 | 100 | Low | 0.45 | 0.53 | 0.69 | 0.78 | 0.47 | 0.52 | 0.56 | 0.62 | 4 | 6 | 0.32 | 0.41 | 3 | 4 |
| 44 | 8.3 | 180 | 350 | 0.51 | 22 | 105 | Low | 0.45 | 0.54 | 0.71 | 0.80 | 0.49 | 0.55 | 0.59 | 0.65 | 4 | 6 | 0.33 | 0.41 | 3 | 4 |
| 45 | 8.4 | 180 | 385 | 0.47 | 18 | 110 | Low | 0.42 | 0.51 | 0.66 | 0.75 | 0.51 | 0.57 | 0.61 | 0.67 | 4 | 6 | 0.31 | 0.39 | 3 | 4 |
| 46 | 8.5 | 180 | 360 | 0.50 | 19 | 110 | Low | 0.46 | 0.55 | 0.67 | 0.76 | 0.46 | 0.51 | 0.55 | 0.61 | 4 | 7 | 0.33 | 0.42 | 3 | 4 |
| 47 | 8.6 | 180 | 315 | 0.57 | 20 | 110 | Low | 0.52 | 0.61 | 0.74 | 0.83 | 0.41 | 0.47 | 0.49 | 0.55 | 5 | 8 | 0.37 | 0.47 | 4 | 5 |
| 48 | 8.7 | 180 | 320 | 0.56 | 17 | 110 | Low | 0.49 | 0.58 | 0.71 | 0.80 | 0.41 | 0.47 | 0.49 | 0.55 | 5 | 7 | 0.36 | 0.45 | 4 | 5 |
| 49 | 8.8 | 160 | 325 | 0.49 | 21 | 108 | Low | 0.44 | 0.53 | 0.63 | 0.72 | 0.40 | 0.46 | 0.48 | 0.54 | 5 | 7 | 0.40 | 0.51 | 4 | 5 |
| 50 | 8.9 | 160 | 315 | 0.51 | 22 | 107 | Mod | 0.39 | 0.49 | 0.60 | 0.70 | 0.40 | 0.46 | 0.48 | 0.54 | 4 | 6 | 0.36 | 0.45 | 4 | 5 |
| 51 | 8.10 | 160 | 320 | 0.50 | 22 | 106 | Mod | 0.39 | 0.48 | 0.62 | 0.71 | 0.43 | 0.49 | 0.52 | 0.58 | 4 | 6 | 0.35 | 0.45 | 4 | 5 |
| 52 | 8.11 | 160 | 350 | 0.46 | 22 | 105 | Mod | 0.39 | 0.49 | 0.63 | 0.73 | 0.49 | 0.55 | 0.59 | 0.65 | 4 | 6 | 0.36 | 0.45 | 4 | 5 |
| 53 | 8.12 | 160 | 355 | 0.45 | 22 | 103 | Low | 0.46 | 0.57 | 0.67 | 0.78 | 0.50 | 0.56 | 0.60 | 0.66 | 5 | 8 | 0.42 | 0.53 | 4 | 5 |
| 54 | 8.13 | 160 | 355 | 0.45 | 22 | 102 | Low | 0.49 | 0.59 | 0.57 | 0.68 | 0.27 | 0.33 | 0.32 | 0.39 | 6 | 8 | 0.44 | 0.56 | 4 | 6 |

## Table 20 (cont…) - Predicted Maximum Subsidence Effects for LWs 25 to 64

| LW Panel # | XL#. LW# | Panel Width W (m) | Cover Depth H (m) | W/H Ratio | Massive Strata Unit Thickness t (m) | Unit y (m) | SRP | First $S_{max}$ (m) | | Final $S_{max}$ (m) | | First Pillar $S_p$ (m) | | Final Pillar $S_p$ (m) | | Maximum Tilt $T_{max}$ (mm/m) | | Curvature ($km^{-1}$) | | Horizontal Strain (mm/m) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | hog | sag | tens | comp |
| | | | | | | | | *mean* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *U95* | *U95* | *U95* | *U95* |
| 62 | 9.1 | 200 | 275 | 0.73 | 34 | 85 | Mod | 0.50 | 0.64 | 0.68 | 0.82 | 0.29 | 0.35 | 0.34 | 0.40 | 7 | 10 | 0.40 | 0.51 | 4 | 5 |
| 63 | 9.2 | 200 | 225 | 0.89 | 33 | 85 | High | 0.35 | 0.48 | 0.47 | 0.60 | 0.16 | 0.22 | 0.20 | 0.26 | 4 | 6 | 0.28 | 0.35 | 3 | 4 |
| 64 | 9.3 | 200 | 198 | 1.01 | 32 | 85 | High | 0.51 | 0.62 | 0.55 | 0.66 | 0.07 | 0.12 | 0.09 | 0.15 | 5 | 7 | 0.32 | 0.41 | 3 | 4 |
| 62 | 10.1 | 200 | 305 | 0.66 | 34 | 93 | Mod | 0.31 | 0.40 | 0.59 | 0.68 | 0.40 | 0.45 | 0.48 | 0.54 | 5 | 8 | 0.34 | 0.44 | 3 | 4 |
| 63 | 10.2 | 200 | 280 | 0.71 | 32 | 93 | Mod | 0.49 | 0.61 | 0.71 | 0.82 | 0.33 | 0.39 | 0.40 | 0.46 | 7 | 11 | 0.41 | 0.52 | 4 | 5 |
| 64 | 10.3 | 200 | 270 | 0.74 | 30 | 93 | Mod | 0.52 | 0.63 | 0.59 | 0.70 | 0.15 | 0.20 | 0.18 | 0.24 | 5 | 8 | 0.34 | 0.44 | 3 | 4 |
| 55 | 11.1 | 160 | 230 | 0.70 | 18 | 82 | Mod | 0.16 | 0.24 | 0.31 | 0.38 | 0.18 | 0.23 | 0.22 | 0.28 | 3 | 4 | 0.28 | 0.35 | 3 | 4 |
| 56 | 11.2 | 160 | 245 | 0.65 | 20 | 85 | High | 0.17 | 0.25 | 0.33 | 0.40 | 0.21 | 0.26 | 0.25 | 0.31 | 1 | 2 | 0.16 | 0.20 | 2 | 2 |
| 57 | 11.3 | 200 | 260 | 0.77 | 22 | 85 | Low | 0.69 | 0.80 | 0.81 | 0.91 | 0.21 | 0.26 | 0.26 | 0.32 | 9 | 13 | 0.47 | 0.60 | 5 | 6 |
| 58 | 11.4 | 200 | 240 | 0.83 | 25 | 86 | High | 0.33 | 0.43 | 0.46 | 0.56 | 0.18 | 0.23 | 0.22 | 0.28 | 4 | 6 | 0.27 | 0.34 | 3 | 3 |
| 59 | 11.5 | 200 | 235 | 0.85 | 28 | 88 | High | 0.31 | 0.41 | 0.45 | 0.55 | 0.19 | 0.24 | 0.22 | 0.28 | 4 | 5 | 0.26 | 0.33 | 3 | 3 |
| 60 | 11.6 | 160 | 248 | 0.65 | 31 | 91 | High | 0.18 | 0.26 | 0.39 | 0.46 | 0.27 | 0.32 | 0.32 | 0.38 | 1 | 2 | 0.17 | 0.21 | 2 | 2 |
| 61 | 11.7 | 200 | 310 | 0.65 | 31 | 92 | Low | 0.48 | 0.56 | 0.50 | 0.58 | 0.11 | 0.11 | 0.13 | 0.13 | 4 | 6 | 0.28 | 0.36 | 3 | 4 |
| 38 | 11.8 | 180 | 300 | 0.60 | 31 | 95 | Mod | 0.28 | 0.37 | 0.55 | 0.63 | 0.39 | 0.44 | 0.46 | 0.52 | 2 | 3 | 0.21 | 0.26 | 2 | 3 |
| 39 | 11.9 | 180 | 330 | 0.55 | 31 | 96 | Low | 0.45 | 0.53 | 0.65 | 0.73 | 0.39 | 0.44 | 0.46 | 0.52 | 4 | 6 | 0.32 | 0.41 | 3 | 4 |
| 40 | 11.10 | 160 | 280 | 0.57 | 31 | 97 | High | 0.33 | 0.42 | 0.50 | 0.59 | 0.29 | 0.35 | 0.35 | 0.41 | 3 | 5 | 0.30 | 0.38 | 3 | 4 |
| 41 | 11.11 | 160 | 265 | 0.60 | 31 | 98 | High | 0.28 | 0.37 | 0.47 | 0.56 | 0.28 | 0.34 | 0.34 | 0.40 | 3 | 4 | 0.25 | 0.32 | 3 | 3 |
| 42 | 11.12 | 160 | 280 | 0.57 | 31 | 99 | High | 0.29 | 0.38 | 0.53 | 0.62 | 0.36 | 0.41 | 0.43 | 0.49 | 3 | 4 | 0.27 | 0.34 | 3 | 3 |
| 43 | 11.13 | 180 | 320 | 0.56 | 30 | 99 | Mod | 0.37 | 0.46 | 0.46 | 0.55 | 0.21 | 0.27 | 0.25 | 0.31 | 3 | 5 | 0.27 | 0.34 | 3 | 3 |
| 42 | 12.1 | 160 | 275 | 0.58 | 31 | 99 | High | 0.23 | 0.32 | 0.47 | 0.56 | 0.34 | 0.40 | 0.41 | 0.47 | 2 | 3 | 0.21 | 0.26 | 2 | 3 |
| 43 | 12.2 | 180 | 310 | 0.58 | 31 | 99 | Mod | 0.38 | 0.47 | 0.65 | 0.74 | 0.43 | 0.49 | 0.52 | 0.58 | 3 | 5 | 0.27 | 0.35 | 3 | 3 |
| 44 | 12.3 | 180 | 350 | 0.51 | 30 | 98 | Low | 0.45 | 0.54 | 0.67 | 0.76 | 0.45 | 0.51 | 0.54 | 0.60 | 4 | 6 | 0.32 | 0.41 | 3 | 4 |
| 45 | 12.4 | 180 | 310 | 0.58 | 29 | 96 | Mod | 0.42 | 0.51 | 0.65 | 0.74 | 0.39 | 0.45 | 0.47 | 0.53 | 4 | 6 | 0.30 | 0.38 | 3 | 4 |
| 46 | 12.5 | 180 | 295 | 0.61 | 27 | 97 | Mod | 0.42 | 0.51 | 0.65 | 0.74 | 0.38 | 0.44 | 0.45 | 0.51 | 4 | 6 | 0.30 | 0.38 | 3 | 4 |
| 47 | 12.6 | 180 | 315 | 0.57 | 26 | 96 | Mod | 0.39 | 0.48 | 0.62 | 0.71 | 0.39 | 0.45 | 0.47 | 0.53 | 3 | 5 | 0.28 | 0.36 | 3 | 4 |

## Table 20 (cont…) - Predicted Maximum Subsidence Effects for LWs 25 to 64

| LW Panel # | XL#. LW# | Panel Width W (m) | Cover Depth H (m) | W/H Ratio | Massive Strata Unit Thickness t (m) | Unit y (m) | SRP | First $S_{max}$ (m) | | Final $S_{max}$ (m) | | First Pillar $S_p$ (m) | | Final Pillar $S_p$ (m) | | Maximum Tilt $T_{max}$ (mm/m) | | Curvature ($km^{-1}$) | | Horizontal Strain (mm/m) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | hog | sag | tens | comp |
| | | | | | | | | *mean* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *m* | *U95* | *U95* | *U95* | *U95* | *U95* |
| 48 | 12.7 | 180 | 300 | 0.60 | 29 | 98 | Mod | 0.42 | 0.51 | 0.64 | 0.73 | 0.37 | 0.43 | 0.44 | 0.50 | 4 | 6 | 0.30 | 0.38 | 3 | 4 |
| 49 | 12.8 | 160 | 305 | 0.52 | 28 | 98 | Mod | 0.38 | 0.47 | 0.56 | 0.66 | 0.35 | 0.41 | 0.42 | 0.48 | 4 | 6 | 0.34 | 0.44 | 3 | 4 |
| 50 | 12.9 | 160 | 287 | 0.56 | 26 | 98 | Mod | 0.39 | 0.48 | 0.59 | 0.69 | 0.35 | 0.41 | 0.43 | 0.49 | 4 | 6 | 0.35 | 0.45 | 4 | 4 |
| 51 | 12.10 | 160 | 320 | 0.50 | 24 | 98 | Mod | 0.37 | 0.47 | 0.59 | 0.69 | 0.41 | 0.47 | 0.49 | 0.55 | 4 | 6 | 0.34 | 0.43 | 3 | 4 |
| 52 | 12.11 | 160 | 325 | 0.49 | 20 | 98 | Low | 0.46 | 0.56 | 0.65 | 0.75 | 0.42 | 0.48 | 0.50 | 0.56 | 5 | 8 | 0.42 | 0.53 | 4 | 5 |
| 53 | 12.12 | 160 | 320 | 0.50 | 17 | 100 | Low | 0.47 | 0.57 | 0.67 | 0.77 | 0.42 | 0.49 | 0.51 | 0.57 | 5 | 8 | 0.43 | 0.54 | 4 | 5 |
| 54 | 12.13 | 160 | 335 | 0.48 | 18 | 100 | Low | 0.47 | 0.56 | 0.55 | 0.64 | 0.23 | 0.29 | 0.27 | 0.34 | 5 | 7 | 0.43 | 0.54 | 4 | 5 |
| 55 | 13.1 | 160 | 185 | 0.86 | 25 | 90 | High | 0.18 | 0.29 | 0.27 | 0.37 | 0.10 | 0.10 | 0.12 | 0.12 | 2 | 4 | 0.24 | 0.31 | 2 | 3 |
| 56 | 13.2 | 160 | 195 | 0.82 | 26 | 92 | High | 0.18 | 0.28 | 0.26 | 0.36 | 0.11 | 0.11 | 0.13 | 0.13 | 2 | 3 | 0.24 | 0.30 | 2 | 3 |
| 57 | 13.3 | 200 | 205 | 0.98 | 27 | 93 | High | 0.46 | 0.57 | 0.56 | 0.66 | 0.13 | 0.13 | 0.16 | 0.16 | 5 | 7 | 0.33 | 0.41 | 3 | 4 |
| 58 | 13.4 | 200 | 220 | 0.91 | 28 | 94 | High | 0.31 | 0.42 | 0.42 | 0.52 | 0.14 | 0.19 | 0.16 | 0.22 | 3 | 5 | 0.24 | 0.31 | 2 | 3 |
| 59 | 13.5 | 200 | 205 | 0.98 | 29 | 94 | High | 0.47 | 0.58 | 0.56 | 0.66 | 0.12 | 0.12 | 0.14 | 0.14 | 5 | 7 | 0.33 | 0.41 | 3 | 4 |
| 60 | 13.6 | 160 | 205 | 0.78 | 30 | 94 | High | 0.14 | 0.25 | 0.24 | 0.34 | 0.12 | 0.12 | 0.14 | 0.14 | 2 | 3 | 0.22 | 0.28 | 2 | 3 |
| 61 | 13.7 | 200 | 210 | 0.95 | 31 | 94 | High | 0.43 | 0.54 | 0.45 | 0.56 | 0.05 | 0.05 | 0.06 | 0.06 | 4 | 6 | 0.27 | 0.34 | 3 | 3 |
| 38 | 13.8 | 180 | 205 | 0.88 | 31 | 94 | High | 0.21 | 0.31 | 0.31 | 0.42 | 0.13 | 0.18 | 0.16 | 0.22 | 3 | 4 | 0.23 | 0.29 | 2 | 3 |
| 39 | 13.9 | 180 | 210 | 0.86 | 31 | 94 | High | 0.22 | 0.32 | 0.33 | 0.43 | 0.13 | 0.19 | 0.16 | 0.22 | 3 | 4 | 0.24 | 0.30 | 2 | 3 |
| 40 | 13.10 | 160 | 210 | 0.76 | 31 | 93 | High | 0.14 | 0.24 | 0.26 | 0.36 | 0.15 | 0.20 | 0.18 | 0.24 | 2 | 3 | 0.24 | 0.30 | 2 | 3 |
| 41 | 13.11 | 160 | 230 | 0.70 | 30 | 93 | High | 0.13 | 0.21 | 0.19 | 0.27 | 0.09 | 0.14 | 0.11 | 0.17 | 1 | 2 | 0.18 | 0.23 | 2 | 2 |

Unit y = distance to base of massive strata unit above the mine workings.
SRP = refers to Subsidence Reduction Potential of the assumed strata unit for the purposes of subsidence prediction (i.e. Low, Moderate, High).
* - Predicted strains are for a surface with deep soil cover and a 'smooth' profile. Near surface rock may cause strain concentrations which are 2 to 3 x 'smooth' profile strains.
mean = average or mean prediction. U*95* = Upper 95% Confidence Limit or Credible-Worst Case prediction for smooth profiles.

The predicted credible worst-case (U95%CL) subsidence effect results for LWs 25 to 64 are summarised below:

- **First maximum panel subsidence** ranges from 0.21 m to 1.14 m (average of 0.54 m).
- **Final maximum panel subsidence** ranges from 0.27 m to 1.34 m (average of 0.73 m).
- **First maximum chain pillar subsidence** ranges from 0.05 m to 0.94 m (average of 0.42 m).
- **Final maximum chain pillar subsidence** range from 0.06 m to 1.10 m (average of 0.49 m).
- **Maximum panel tilt** ranges from 2 to 20 mm/m (average of 7 mm/m).
- **Maximum panel concave curvatures** range from 0.20 to 0.91 km$^{-1}$(average of 0.44 km$^{-1}$) or radii of curvature of 5.0 km to 1.1 km (average of 2.3 km).
- **Maximum panel convex curvatures** range from 0.16 to 0.72 km$^{-1}$ (average of 0.35 km$^{-1}$) or radii of curvature 6.3 km to 1.4 km (average of 2.9 km).
- **Maximum panel compressive strains** range from 2 to 9 mm/m (average of 4 mm/m).
- **Maximum panel tensile strains** range from 2 to 7 mm/m (average of 3.5 mm/m).

*Note: Discontinuous overburden behaviour such as cracking and shearing in tensile and compressive strain zones with shallow rock exposures could exceed the maximum predicted curvatures and strains (i.e. U95%CL) by 2 times (i.e. the tensile and compressive strains could range from 14 to 18 mm/m respectively if this occurs).*

Specific predictions for the existing features within the project area are provided in the impact assessment section presented in **Section 12**.

### 10.9 Angle of Draw (AoD) Prediction

Angle of draw predictions have been derived from the mean goaf edge subsidence predictions and log-linear regression lines derived from measured data for LWs 1 to 12.

The AoD to the 20 mm subsidence contour is estimated to range from $10^o$ to $54^o$ (average of $35^o$) for the proposed longwalls 25 to 64; see **Figure 24**.

### 10.10 Subsidence Profile Predictions

Representative subsidence profiles for the proposed longwalls (LWs 25 to 64) have been derived using seven key subsidence profile points and cubic spline curve fitting techniques. The key points on the subsidence profile were derived from the modified **ACARP, 2003** model and include:

(i) maximum panel subsidence ($S_{max}$);

(ii) chain pillar subsidence ($S_p$);

(iii) inflexion point location (d);

(iv) maximum tensile strain or convex curvature locations ($d_t$);

(v) maximum compressive strain or concave curvature locations ($d_c$)

(vi) goaf edge subsidence ($S_{goe}$); and

(vii) angle of draw to the 20 mm subsidence contour (AoD).

The Newcastle Coalfield database of longwall inflexion point and tensile / compressive strain or convex / concave curvature peak locations are shown in **Figure 25**.

The database model is also consistent with the SDPS® model methodology (see **Appendix A** for further details).

The tilt and curvature profiles were then derived by taking the first and second derivatives of the predicted subsidence profiles. The tilt, curvature and strain profiles are therefore considered to represent "smooth" profile response to mining and are therefore likely to be lower in magnitude than the empirical database predictions.

Subsidence effect profile predictions for the proposed LWs 25 to 64 have been derived along cross lines XL1 to 13 after (i) each panel is extracted and (ii) on the completion of mining for SDPS model calibration purposes. Representative profiles for each panel group (Groups 1 to 5) are presented in **Figures 26a** to **26e**. The profiles are based on U95%CL Subsidence values, which represent the Credible Worst Case.

Based on the predicted subsidence profile exercise, credible worst case subsidence contours have subsequently been derived. Details of the predicted outcomes are further discussed and presented in **Section 10.12**.

## 10.11 Review of Measured Subsidence Effects at Mandalong Mine

### 10.11.1 Mining Geometry

Mandalong Mine has developed and completed 12 longwall panels (LW1-12) with similar geometries to those being proposed for the Southern Extension Project. The first four panels were 125 m wide with cover depths ranging from 150 m to 290 m (a sub-critical to critical W/H range from 0.33 to 0.81). The Panels 5 to 12 were increased to a width of 160 m, with cover depths ranging from 160 m to 370 m (with sub-critical to critical W/H range from 0.43 to 1.0); see **Figure 27a**.

The mining heights for the panels ranged from 3.5 m to 4.8 m in the WW Seam (see WW Seam thickness contours in **Figure 27b**). The chain pillars were 41 m wide for the 125 m wide panels and 46 m wide for the 160 m wide panels. The development height for the pillars was 3.3 m, giving squat or strain hardening pillar w/h ratios of 12.4 to 14.3.

Based on **Seedsman, 2003**, the lithological profiles above the panels included several massive conglomerate and sandstone units within the Munmorah Conglomerate, which ranged in thickness from 19 m to 42 m at a distance of 76 m to 120 m above the panels; see **Figures 27c** and **27d** respectively).

The panels and chain pillars are all underlain by 2.5 m to 10.5 m thick units of Awaba Tuff, which is assessed to have < 0.5 m thick layers of material with very low strengths (i.e. UCS < 3 MPa).

It is noted that some of the longwalls were mined through the following geological structure (see **Figure 27a**):

- NW-SE striking minor normal sub-vertical dolerite dykes.
- NE-SW striking reverse faults and seam rolls.

A summary of the mining geometry and massive strata units for LWs 1 - 12 are presented in **Table 21**.

**Table 21 - Mine Workings Geometry Mandalong Mine's LWs 1 - 12**

| LW # | Panel Width W (m) | Cover Depth H (m) | Panel W/H | Extraction Height T (m) | Chain Pillar Width $w_{cp}$ (m) | Pillar w/h | Massive Unit Thickness t (m) | Massive Unit Location Above Workings y (m) |
|---|---|---|---|---|---|---|---|---|
| 1 | 125 | 150 - 230 | 0.63 - 0.83 | 3.5 - 4.8 | 41 | 12.5 | 21 - 34 | 72 - 110 |
| 2 | 125 | 150 - 260 | 0.35 - 0.81 | 3.6 - 4.8 | 41 | 12.4 | 20 - 30 | 73 - 117 |
| 3 | 125 | 155 - 280 | 0.34 - 0.79 | 3.5 - 4.8 | 41 | 12.4 | 25 - 35 | 80 - 117 |
| 4 | 125 | 160 - 290 | 0.33 - 0.76 | 3.6 - 4.8 | 41 | 12.4 | 29 - 30 | 76 - 117 |
| 5 | 160 | 160 - 320 | 1.00 - 0.50 | 3.4 - 4.8 | 46 | 13.9 | 20 - 35 | 82 - 119 |
| 6 | 160 | 165 - 370 | 0.97 - 0.40 | 3.6 - 4.8 | 46 | 13.9 | 20 - 30 | 87 - 120 |
| 7 | 160 | 175 - 370 | 0.91 - 0.43 | 3.8 - 4.8 | 46 | 13.9 | 19 - 31 | 90 - 117 |
| 8 | 160 | 185 - 380 | 0.86 - 0.42 | 4.0 - 4.8 | 46 | 13.9 | 20 - 30 | 95 - 120 |
| 9 | 160 | 190 - 360 | 0.84 - 0.44 | 4.0 - 4.8 | 46 | 13.9 | 20 - 35 | 95 - 120 |
| 10 | 160 | 200 - 320 | 0.80 - 0.50 | 4.1 - 4.8 | 47 | 14.3 | 20 - 42 | 93 - 117 |
| 11 | 160 | 220 - 270 | 0.73 - 0.59 | 4.0 - 4.8 | 46 | 13.9 | 20 - 40 | 90 - 115 |
| 12 | 160 | 225 - 255 | 0.71 - 0.63 | 4.3 - 4.8 | 46 | 13.9 | 20 - 34 | 86 - 110 |

### 10.11.2 Review of Subsidence Data

The measured first and final maximum panel and chain pillar subsidence above the Mandalong panels to-date have been compared with the predictions made using the **ACARP, 2003** empirical database model in **Table 22A** and **22B**.

To-date, maximum subsidence above the 125 m wide panels has ranged from 0.26 m and 0.60 m, with 0.35 m and 1.24 m above the 160 m wide panels.

The outcome of the subsidence review indicates that in general, the measured maximum subsidence values plot below the predicted U95%CL for the given panel geometries; see **Figure 28a** (XL1), **Figure 28b** (XL2), and **Figure 28c** (XL3).

## Table 22A - Summary of Predicted v. Measured First Maximum Subsidence

| Panel No. | XL | Panel Width W (m) | Cover Depth H (m) | Panel W/H | Mining Height T (m) | SRP | First Panel $S_{max}$ (m) | | First Pillar $S_p$ (m) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Predicted U95%CL | Measured | Predicted U95%CL | Measured |
| 1 | 1 | 125 | 154 | 0.81 | 3.5 | High | 0.66 | 0.349 | 0.18 | **0.256** |
| 2 | 1 | 125 | 155 | 0.81 | 3.6 | High | 0.68 | 0.407 | 0.18 | **0.219** |
| 3 | 1 | 125 | 158 | 0.79 | 3.5 | High | 0.61 | 0.221 | 0.19 | 0.202 |
| 4 | 1 | 125 | 165 | 0.76 | 3.6 | High | 0.51 | 0.165 | 0.20 | 0.153 |
| 5 | 1 | 160 | 172 | 0.93 | 3.6 | High | 0.90 | 0.663 | 0.20 | 0.201 |
| 6 | 1 | 160 | 180 | 0.89 | 3.6 | High | 0.65 | 0.553 | 0.22 | 0.130 |
| 7 | 1 | 160 | 185 | 0.86 | 3.8 | High | 0.64 | 0.601 | 0.23 | 0.147 |
| 8 | 1 | 160 | 195 | 0.82 | 4.0 | High | 0.58 | 0.453 | 0.26 | 0.180 |
| 9 | 1 | 160 | 205 | 0.78 | 4.0 | High | 0.50 | 0.429 | 0.28 | 0.240 |
| 10 | 1 | 160 | 215 | 0.74 | 4.1 | High | 0.48 | 0.581 | 0.29 | - |
| 11 | 1 | 160 | 220 | 0.73 | 4.0 | High | 0.46 | - | 0.31 | - |
| 12 | 1 | 160 | 225 | 0.71 | 4.3 | High | 0.48 | - | 0.34 | - |
| 1 | 2 | 125 | 200 | 0.63 | 4.8 | High | 0.31 | 0.098 | 0.30 | 0.250 |
| 2 | 2 | 125 | 200 | 0.63 | 4.8 | High | 0.38 | 0.239 | 0.35 | **0.407** |
| 3 | 2 | 125 | 240 | 0.52 | 4.8 | High | 0.44 | 0.380 | 0.48 | 0.259 |
| 4 | 2 | 125 | 260 | 0.48 | 4.8 | High | 0.57 | 0.204 | 0.61 | 0.332 |
| 5 | 2 | 160 | 273 | 0.59 | 4.8 | Mod | 0.90 | 0.325 | 0.69 | 0.368 |
| 6 | 2 | 160 | 315 | 0.51 | 4.8 | Mod | 0.87 | 0.600 | 0.80 | 0.790 |
| 7 | 2 | 160 | 310 | 0.52 | 4.8 | High | 0.79 | 0.719 | 0.75 | 0.680 |
| 8 | 2 | 160 | 290 | 0.55 | 4.8 | High | 0.80 | 0.645 | 0.68 | 0.483 |
| 9 | 2 | 160 | 280 | 0.57 | 4.8 | High | 0.80 | 0.481 | 0.63 | 0.354 |
| 10 | 2 | 160 | 270 | 0.59 | 4.8 | High | 0.76 | 0.379 | 0.56 | 0.282 |
| 11 | 2 | 160 | 260 | 0.62 | 4.8 | High | 0.68 | 0.358 | 0.45 | - |
| 12 | 2 | 160 | 250 | 0.64 | 4.8 | High | 0.60 | - | 0.43 | - |
| 1 | 3 | 125 | 182 | 0.69 | 4.2 | High | 0.31 | 0.113 | 0.25 | 0.180 |
| 2 | 3 | 125 | 186 | 0.67 | 4.3 | High | 0.36 | - | 0.26 | |
| 3 | 3 | 125 | 190 | 0.66 | 4.35 | High | 0.35 | - | 0.26 | 0.140 |
| 4 | 3 | 125 | 185 | 0.68 | 4.5 | High | 0.38 | - | 0.28 | - |
| 5 | 3 | 160 | 205 | 0.78 | 4.6 | High | 0.57 | **0.852** | 0.33 | 0.154 |
| 6 | 3 | 160 | 240 | 0.67 | 4.8 | High | 0.52 | 0.427 | 0.51 | 0.266 |
| 7 | 3 | 160 | 270 | 0.59 | 4.8 | Mod | 0.85 | 0.434 | 0.55 | 0.286 |
| 8 | 3 | 160 | 250 | 0.64 | 4.8 | High | 0.64 | 0.298 | 0.51 | 0.261 |
| 9 | 3 | 160 | 260 | 0.62 | 4.8 | High | 0.67 | 0.312 | 0.51 | 0.195 |
| 10 | 3 | 160 | 247 | 0.65 | 4.8 | High | 0.61 | 0.243 | 0.47 | 0.204 |
| 11 | 3 | 160 | 245 | 0.65 | 4.8 | High | 0.58 | 0.274 | 0.42 | 0.180 |
| 12 | 3 | 160 | 252 | 0.63 | 4.8 | High | 0.60 | - | 0.45 | - |
| 6 | 4 | 160 | 300 | 0.53 | 4.8 | Mod | 0.76 | 0.299 | 0.68 | 0.345 |
| 7 | 4 | 160 | 310 | 0.52 | 4.8 | Mod | 0.87 | 0.309 | 0.77 | 0.642 |
| 8 | 4 | 160 | 370 | 0.43 | 4.8 | Mod | 0.80 | 0.621 | 0.88 | - |

**Bold** - measured data exceed predictions by >15%.

## Table 22B - Summary of Predicted v. Measured Final Maximum Subsidence

| Panel No. | XL | Panel Width W (m) | Cover Depth H (m) | Panel W/H | Mining Height T (m) | SRP | Final Panel $S_{max}$ (m) | | Final Pillar $S_p$ (m) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Predicted U95%CL | Measured | Predicted U95%CL | Measured |
| 1 | 1 | 125 | 154 | 0.81 | 3.5 | High | 0.71 | 0.516 | 0.20 | **0.309** |
| 2 | 1 | 125 | 155 | 0.81 | 3.6 | High | 0.73 | 0.493 | 0.20 | **0.232** |
| 3 | 1 | 125 | 158 | 0.79 | 3.5 | High | 0.67 | 0.372 | 0.21 | 0.231 |
| 4 | 1 | 125 | 165 | 0.76 | 3.6 | High | 0.59 | 0.263 | 0.23 | 0.216 |
| 5 | 1 | 160 | 172 | 0.93 | 3.6 | High | 0.97 | 0.757 | 0.23 | 0.224 |
| 6 | 1 | 160 | 180 | 0.89 | 3.6 | High | 0.74 | 0.696 | 0.26 | 0.187 |
| 7 | 1 | 160 | 185 | 0.86 | 3.8 | High | 0.74 | **0.933** | 0.27 | 0.204 |
| 8 | 1 | 160 | 195 | 0.82 | 4.0 | High | 0.70 | 0.564 | 0.30 | 0.180 |
| 9 | 1 | 160 | 205 | 0.78 | 4.0 | High | 0.65 | 0.555 | 0.33 | - |
| 10 | 1 | 160 | 215 | 0.74 | 4.1 | High | 0.63 | - | 0.34 | - |
| 11 | 1 | 160 | 220 | 0.73 | 4.0 | High | 0.63 | - | 0.36 | - |
| 12 | 1 | 160 | 225 | 0.71 | 4.3 | High | 0.67 | - | 0.40 | - |
| 1 | 2 | 125 | 200 | 0.63 | 4.8 | High | 0.48 | 0.410 | 0.36 | **0.450** |
| 2 | 2 | 125 | 200 | 0.63 | 4.8 | High | 0.58 | 0.595 | 0.42 | **0.580** |
| 3 | 2 | 125 | 240 | 0.52 | 4.8 | High | 0.70 | 0.596 | 0.59 | 0.460 |
| 4 | 2 | 125 | 260 | 0.48 | 4.8 | High | 0.86 | 0.501 | 0.74 | 0.543 |
| 5 | 2 | 160 | 273 | 0.59 | 4.8 | Mod | 1.24 | 0.943 | 0.84 | 0.910 |
| 6 | 2 | 160 | 315 | 0.51 | 4.8 | Mod | 1.23 | 1.238 | 0.98 | 1.056 |
| 7 | 2 | 160 | 310 | 0.52 | 4.8 | High | 1.13 | 1.125 | 0.91 | 0.871 |
| 8 | 2 | 160 | 290 | 0.55 | 4.8 | High | 1.12 | 0.928 | 0.83 | 0.641 |
| 9 | 2 | 160 | 280 | 0.57 | 4.8 | High | 1.09 | 0.720 | 0.76 | 0.425 |
| 10 | 2 | 160 | 270 | 0.59 | 4.8 | High | 1.02 | 0.530 | 0.68 | - |
| 11 | 2 | 160 | 260 | 0.62 | 4.8 | High | 0.90 | - | 0.54 | - |
| 12 | 2 | 160 | 250 | 0.64 | 4.8 | High | 0.82 | - | 0.51 | - |
| 1 | 3 | 125 | 182 | 0.69 | 4.2 | High | 0.44 | 0.445 | 0.29 | 0.370 |
| 2 | 3 | 125 | 186 | 0.67 | 4.3 | High | 0.48 | - | 0.30 | - |
| 3 | 3 | 125 | 190 | 0.66 | 4.35 | High | 0.48 | - | 0.31 | 0.150 |
| 4 | 3 | 125 | 185 | 0.68 | 4.5 | High | 0.52 | - | 0.33 | - |
| 5 | 3 | 160 | 205 | 0.78 | 4.6 | High | 0.75 | **1.065** | 0.39 | 0.156 |
| 6 | 3 | 160 | 240 | 0.67 | 4.8 | High | 0.82 | 0.629 | 0.62 | 0.310 |
| 7 | 3 | 160 | 270 | 0.59 | 4.8 | Mod | 1.10 | 0.649 | 0.68 | 0.326 |
| 8 | 3 | 160 | 250 | 0.64 | 4.8 | High | 0.92 | 0.426 | 0.62 | 0.270 |
| 9 | 3 | 160 | 260 | 0.62 | 4.8 | High | 0.93 | 0.391 | 0.62 | 0.196 |
| 10 | 3 | 160 | 247 | 0.65 | 4.8 | High | 0.86 | 0.346 | 0.57 | - |
| 11 | 3 | 160 | 245 | 0.65 | 4.8 | High | 0.80 | - | 0.51 | - |
| 12 | 3 | 160 | 252 | 0.63 | 4.8 | High | 0.84 | - | 0.54 | - |
| 6 | 4 | 160 | 300 | 0.53 | 4.8 | Mod | 1.08 | 0.633 | 0.82 | 0.525 |
| 7 | 4 | 160 | 310 | 0.52 | 4.8 | Mod | 1.22 | 0.886 | 0.93 | 0.879 |
| 8 | 4 | 160 | 370 | 0.43 | 4.8 | Mod | 1.13 | 1.080 | 1.06 | - |

**Bold** - measured data exceed predictions by >15%.

It is apparent from **Table 22B** and the data plots that there were two final subsidence prediction exceedances above two of the 160 m wide longwalls completed to date. At one location, the measured subsidence above LW7 on XL1 was 315 mm above the predicted value. At the other location, measured subsidence was 193 mm above the predicted value for LW5 on XL3. Both panels were assessed to have a 'High' SRP overburden with 28 m to 35 m thick Munmorah Conglomerate beams located 95 m above the workings indicated by the borehole data. The depth of cover was 185 m and 205 m respectively.

It is considered that the exceedances were due to either (i) a reduction in overburden strength or stiffness due to reverse faulting to the east, or (ii) reduction of the conglomerate beam thickness due to shearing and bedding parting separation. The measured profiles do not indicate any unusual increases in chain pillar subsidence due to failure of the Awaba Tuff, although some of the predicted chain pillar subsidence values were exceeded by up to 200 mm.

Whilst it is considered very difficult to identify the locations of the weaker overburden due to either of the above causes, it is possible to apply probabilistic techniques to determine the likelihood and consequences of such occurrences for a given panel geometry.

In regards to mechanism (i), it is noted that the two exceedances occurred where seam rolls have been identified beneath five measurement locations (see **Figure 27a**) and represents a probability of occurrence of 40%. This is considered a 'likely' event in accordance with the probabilistic terminology defined in **Table 29** in **Section 12.1**.

It is noted in **Doyle, 2002** that "seam rolls and steep dips can be associated with [reverse faulting]. These structures can be formed from compressional events of large magnitudes, such as basin wide tectonic events, but can also be associated with smaller localised events."

No other subsidence exceedances have occurred above the eleven panels extracted beneath 3 cross lines where the rolls are not present (i.e. no exceedances have occurred out of 25 measurement cases).

In regards to mechanism (ii), it is noted that there is no thinning of the Munmorah Conglomerate beam apparent based on the borehole data (see **Figures 27c**). If the seam rolls are not the cause of the exceedances, it would be impractical to conduct further drilling (at smaller grid spacing) to try and establish if the conglomerate was weaker. However, it was noted in **Seedsman, 2010** that the jointing at seam level effectively decreased the caving angle to $0^o$, which was considered to have subsequently increased the span of the overlying conglomerate beam.

Overall, it is not practical to identify where joint swarms or seam rolls are likely to occur until first workings development exposes these features. It will therefore be necessary to assess the exceedance occurrences in probabilistic terms. At Mandalong then, an exceedance of 2 out of 29 measurement locations represents a 7% probability of occurrence, or an 'unlikely' event.

The measured Mandalong panel and chain pillar subsidence plotted with the predicted value ranges in **Figures 29a** to **29c**. Overall, the measured final subsidence for LWs 1-12 ranged from 7% to 26% for mining heights of 3.5 m to 4.8 m, and correlates well with the predicted mean to U95%CL range of 10% to 27% T.

It is considered that the back-analysed estimates of Single Panel $S_{max}$ and chain pillar data also fit reasonably well within the databases for Moderate and High SRP overburden ranges; see **Figures 30a** to **30c**. The Single Panel $S_{max}$ values were back calculated from the measured First Smax, First Chain Pillar subsidence for the previous panel and First Goaf Edge Subsidence (see **Section 9.1** for formulae).

It is noted that the two **ACARP, 2003** prediction model outcomes that were exceeded above LWs 5 and 7 'bracket' the measured values when 'Moderate' SRP is assumed instead of 'High' SRP; see **Figures 31a** and **31b**.

It is also assessed that the **ACARP, 2003** model is likely to be conservative for sub-critical to critical longwall panels, however, there will be the potential for exceedances where 'High' SRP overburden is actually only 'Moderate' SRP due to localised conglomerate thinning or seam roll / reverse faulting effects being present. Additional subsidence of 200 mm to 300 mm may occur for mining heights ranging from 3.5 m to 4.8 m in these cases.

Based on reference to **Diedrichs and Kaiser, 1999**, Voussoir Beam Analysis (VBA) of the Munmorah Conglomerate unit thicknesses above LWs 1-12 was also completed for comparative purposes with measured and **ACARP, 2003** model outcomes. A summary of the VBA outcomes is summarised in **Table 23** in **Figures 31c** to **31f**.

**Table 23 - Predicted Voussoir Beam v. Measured Subsidence Data Summary**

| Abutment Angle (degrees) | Beam Thickness t (m) | Beam Location y (m) | Beam FoS | Predicted Voussoir Beam Deflection (m) | Predicted ACARP, 2003 Single $S_{max}$ (m) (mean - U95%CL) | Measured Single $S_{max}$ (m) |
|---|---|---|---|---|---|---|
| **Good Rock Mass Conditions (GSI = 60; UCS = 52 MPa; Erm = 6.4 GPa)** | | | | | | |
| 21 | 15-35 | 65 - 140 | 1.13 - 7.42 | 0.04 - 0.49 | 0.14 - 0.86 | **0.10 - 0.82** |
| 12 | 15-35 | 65 - 140 | 0.60 - 4.58 | 0.11 - 1.97 | 0.14 - 0.86 | **0.10 - 0.82** |

The results of the VBA analysis indicate the following inferences that can be drawn in regards to subsidence development above the Mandalong LWs 1 to 12:

- The Voussoir Beam model provides reasonably conservative values of maximum panel subsidence in the elastic zones, with <10% of prediction exceedances apparent if a Good Rock mass Condition GSI of 60 and abutment angle of $12^{o}$ is assumed.

- The Voussoir Beam model underpredicts 88% of the measured values if an abutment angle of $21^{o}$ is assumed.

- Overall, it is concluded that the Voussoir Beam analog is useful to estimate the spanning capability and deflection of the Conglomerate Beam Units, however, it is unlikely to be more reliable than the **ACARP, 2003** model if significant rock mass stiffness and beam geometry variation exists within the proposed Project Area.

### 10.11.3 Review of Tilt Data

Predicted values of maximum and final tilt for LWs 1 - 12 have been compared to the measured values in **Table 24** and **Figures 28a** (XL1), **28b** (XL2), and **28c** (XL3).

**Table 24 - Summary of Predicted v. Measured Maximum Tilts**

| Panel No. | XL | Panel Width W (m) | Cover Depth H (m) | Panel W/H | Mining Height T (m) | SRP | Maximum Tilt $T_{max}$ (mm/m) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Predicted Mean* | *Predicted U95%CL* | *Measured Side 1* | *Measured Side 2* |
| 1 | 1 | 125 | 154 | 0.81 | 3.5 | High | 9 | 13 | 7.0 | 5.4 |
| 2 | 1 | 125 | 155 | 0.81 | 3.6 | High | 9 | 14 | 5.2 | 4.7 |
| 3 | 1 | 125 | 158 | 0.79 | 3.5 | High | 8 | 12 | 3.8 | 3.1 |
| 4 | 1 | 125 | 165 | 0.76 | 3.6 | High | 6 | 9 | 2.0 | 1.1 |
| 5 | 1 | 160 | 172 | 0.93 | 3.6 | High | 11 | 17 | *15.7* | 10.4 |
| 6 | 1 | 160 | 180 | 0.89 | 3.6 | High | 7 | 10 | *10.0* | *9.3* |
| 7 | 1 | 160 | 185 | 0.86 | 3.8 | High | 6 | 10 | **16.8** | **15.7** |
| 8 | 1 | 160 | 195 | 0.82 | 4.0 | High | 6 | 8 | *8.7* | *7.1* |
| 9 | 1 | 160 | 205 | 0.78 | 4.0 | High | 5 | 7 | *6.9* | 5.1 |
| 10 | 1 | 160 | 215 | 0.74 | 4.1 | High | 4 | 7 | *6.0* | **9.9** |
| 11 | 1 | 160 | 220 | 0.73 | 4.0 | High | 4 | 7 | - | - |
| 12 | 1 | 160 | 225 | 0.71 | 4.3 | High | 5 | 7 | - | - |
| 1 | 2 | 125 | 200 | 0.63 | 4.8 | High | 4 | 6 | *6.1* | - |
| 2 | 2 | 125 | 200 | 0.63 | 4.8 | High | 2 | 3 | **5.8** | - |
| 3 | 2 | 125 | 240 | 0.52 | 4.8 | High | 3 | 5 | *4.0* | - |
| 4 | 2 | 125 | 260 | 0.48 | 4.8 | High | 6 | 9 | 2.0 | - |
| 5 | 2 | 160 | 273 | 0.59 | 4.8 | Mod | 10 | 15 | 6.1 | 3.1 |
| 6 | 2 | 160 | 315 | 0.51 | 4.8 | Mod | 9 | 14 | 4.9 | 3.8 |
| 7 | 2 | 160 | 310 | 0.52 | 4.8 | High | 8 | 11 | 7.3 | 2.2 |
| 8 | 2 | 160 | 290 | 0.55 | 4.8 | High | 8 | 12 | 7.1 | 2.1 |
| 9 | 2 | 160 | 280 | 0.57 | 4.8 | High | 8 | 12 | 5.9 | 2.8 |
| 10 | 2 | 160 | 270 | 0.59 | 4.8 | High | 7 | 11 | 4.7 | 2.4 |
| 11 | 2 | 160 | 260 | 0.62 | 4.8 | High | 6 | 9 | 4.1 | 2.2 |
| 12 | 2 | 160 | 250 | 0.64 | 4.8 | High | 5 | 7 | - | - |
| 1 | 3 | 125 | 182 | 0.69 | 4.2 | High | 4 | 5 | **8.3** | 1.5 |
| 2 | 3 | 125 | 186 | 0.67 | 4.3 | High | 5 | 7 | - | - |
| 3 | 3 | 125 | 190 | 0.66 | 4.35 | High | 2 | 3 | - | - |
| 4 | 3 | 125 | 185 | 0.68 | 4.5 | High | 5 | 8 | - | - |
| 5 | 3 | 160 | 205 | 0.78 | 4.6 | High | 6 | 9 | **25.0** | 1.5 |
| 6 | 3 | 160 | 240 | 0.67 | 4.8 | High | 8 | 13 | *11.6* | - |
| 7 | 3 | 160 | 270 | 0.59 | 4.8 | Mod | 9 | 14 | 7.8 | - |
| 8 | 3 | 160 | 250 | 0.64 | 4.8 | High | 5 | 8 | 3.4 | - |
| 9 | 3 | 160 | 260 | 0.62 | 4.8 | High | 6 | 9 | 3.5 | *16.0* |
| 10 | 3 | 160 | 247 | 0.65 | 4.8 | High | 5 | 7 | 4.0 | 6.7 |
| 11 | 3 | 160 | 245 | 0.65 | 4.8 | High | 4 | 7 | 2.7 | 4.7 |
| 12 | 3 | 160 | 252 | 0.63 | 4.8 | High | 5 | 7 | - | - |
| 6 | 4 | 160 | 300 | 0.53 | 4.8 | Mod | 14 | 21 | 5.2 | 3.9 |
| 7 | 4 | 160 | 310 | 0.52 | 4.8 | Mod | 9 | 14 | 9.2 | 2.9 |
| 8 | 4 | 160 | 370 | 0.43 | 4.8 | Mod | 8 | 12 | 3.1 | - |

U95%CL - Upper 95% Confidence Limit; Measured Side 1,2 - Measured peak value(s) above longwall panel on each side. ; *Italics* - Measured value exceeded mean prediction by > 15%; **Bold** - Measured value exceeded maximum prediction by > 15%.

The outcome of the review indicates that 70% of the measured maximum tilts plot below the mean and 90% below the U95%CL for the predicted values; see **Figure 32**. Predicted U95%CL tilt magnitudes were exceeded by 1.6 and 2.8 times by the measured values at 6 out of 57 locations (10%), and generally occurred with subsidence prediction exceedances, as discussed previously.

Overall, it is assessed that the **ACARP, 2003** model reasonably estimates the measured maximum tilts; see **Figure 33**, and may be applied to the proposed longwall panels. The predicted smooth profiles also indicate the predicted tilts are reliable, with exceedances likely to occur at <10% of the time when subsidence prediction exceedances occur.

### 10.11.4 Review of Curvature Data

Predicted values of maximum convex and concave curvature for LWs 1 - 12 have been compared to the measured values in **Table 25A** and **25B** and **Figures 28a** (XL1), **28b** (XL2), and **28c** (XL3).

The outcome of the review indicates that 67% of the measured maximum convex curvatures plot below the mean and 78% plot below the U95%CLs for the predicted values; see **Figure 34**.

Predicted U95%CL convex curvatures magnitudes were exceeded by 1.2 to 4.0 times (average of 2.2) by the measured values at 12 out of 55 locations, and were highest where the subsidence prediction exceedances also occurred, as discussed previously. It is considered that the exceedances are due to discontinuous strata behaviour, which occurs as a result of secondary curvatures due to jointing or subsidence crack interaction with bending near surface strata (eg localised humps or depressions). The **ACARP, 2003** model also provides an empirical technique to estimate the maximum convex curvatures due to discontinuous movements as follows (see **Appendix A** for details):

$$+C_{max(discontinuous)} = 1.9964.Ln(S_{max}/W^2)+8.1062 \text{ for } S/W^2 \text{ values} > 0.025$$

*Note: The model has been updated with recent Newcastle Coalfield data.*

The results for the above discontinuous curvature model are presented in **Table 25A** and reduce the number of prediction exceedance to 2 or 4% of the 55 observations at the Mandalong Mine.

Based on the above outcome, it is considered that the ‘smooth’ and ‘discontinuous’ subsidence profile models will provide reasonable estimates of convex curvature for each scenario and may be used to estimate worst-case curvatures above the proposed longwalls.

Similar outcomes were observed for concave curvatures with 58% of the measured maximum concave curvatures plotting below the predicted mean and 81% below the U95% CL values; see **Figure 35**. The predicted U95%CL concave curvature magnitudes were exceeded by 1.3 to 3.8 times (average of 2.3) by the measured values at 7 out of 33 locations, and were highest where the subsidence prediction exceedances also occurred, as discussed previously.

The **ACARP, 2003** model also provides an empirical technique to estimate the maximum concave curvatures for discontinuous movements as follows (see **Appendix A** for details):

$$-C_{max(discontinuous)} = 1.6394.Ln(S_{max}/W^2)+7.8285$$

*Note: The model has been updated with recent Newcastle Coalfield data.*

The results for the discontinuous curvature model are presented in **Table 25B** and reduce the number of prediction exceedance to 0 or 0% of the 33 observations at the Mandalong Mine.

Based on the above outcome, it is considered that the ‘smooth’ and ‘discontinuous’ subsidence profile models will provide reasonable estimates of concave curvature for each scenario and may be used to estimate worst-case curvatures above the proposed longwalls.

Overall, it is assessed that the **ACARP, 2003** model reasonably estimates the measured maximum primary and secondary curvatures; see **Figures 36** and **37**. The predicted smooth XL profiles also indicate the predicted curvatures are reasonably reliable with exceedances likely to occur once or twice/panel on average due to discontinuous strata behaviour near the points of peak curvature.

## Table 25A - Summary of Predicted v. Measured Maximum Convex Curvature

| Panel No. | XL | Panel Width W (m) | Cover Depth H (m) | Panel W/H | Mining Height T (m) | SRP | Maximum Convex (Hogging) Curvature, $C_{max}$ ($km^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Predicted | | | Measured | |
| | | | | | | | *mean* | *U95% CL* | *Discont-inuous* | *Panel Side1* | *Panel Side2* |
| 1 | 1 | 125 | 154 | 0.81 | 3.5 | High | 0.52 | 0.78 | 1.79 | 0.17 | 0.22 |
| 2 | 1 | 125 | 155 | 0.81 | 3.6 | High | 0.48 | 0.72 | 1.84 | 0.31 | 0.40 |
| 3 | 1 | 125 | 158 | 0.79 | 3.5 | High | 0.42 | 0.62 | 1.63 | 0.28 | - |
| 4 | 1 | 125 | 165 | 0.76 | 3.6 | High | 0.31 | 0.47 | 1.28 | 0.14 | - |
| 5 | 1 | 160 | 172 | 0.93 | 3.6 | High | 0.43 | 0.64 | 1.42 | *0.87* | 0.26 |
| 6 | 1 | 160 | 180 | 0.89 | 3.6 | High | 0.27 | 0.41 | 0.77 | *0.50* | 0.18 |
| 7 | 1 | 160 | 185 | 0.86 | 3.8 | High | 0.26 | 0.39 | 0.74 | *0.67* | *0.53* |
| 8 | 1 | 160 | 195 | 0.82 | 4.0 | High | 0.22 | 0.33 | 0.74 | 0.21 | 0.13 |
| 9 | 1 | 160 | 205 | 0.78 | 4.0 | High | 0.17 | 0.26 | 0.74 | 0.19 | - |
| 10 | 1 | 160 | 215 | 0.74 | 4.1 | High | 0.15 | 0.23 | 0.74 | - | - |
| 11 | 1 | 160 | 220 | 0.73 | 4.0 | High | 0.15 | 0.22 | 0.74 | - | - |
| 12 | 1 | 160 | 225 | 0.71 | 4.3 | High | 0.15 | 0.23 | 0.74 | - | - |
| 1 | 2 | 125 | 200 | 0.63 | 4.8 | High | 0.30 | 0.45 | 0.74 | *0.81* | **1.76** |
| 2 | 2 | 125 | 200 | 0.63 | 4.8 | High | 0.10 | 0.16 | 0.74 | 0.31 | *0.37* |
| 3 | 2 | 125 | 240 | 0.52 | 4.8 | High | 0.13 | 0.20 | 0.99 | 0.11 | *0.73* |
| 4 | 2 | 125 | 260 | 0.48 | 4.8 | High | 0.22 | 0.33 | 1.50 | 0.29 | 0.27 |
| 5 | 2 | 160 | 273 | 0.59 | 4.8 | Mod | 0.30 | 0.44 | 1.42 | 0.26 | - |
| 6 | 2 | 160 | 315 | 0.51 | 4.8 | Mod | 0.27 | 0.41 | 1.35 | 0.15 | 0.27 |
| 7 | 2 | 160 | 310 | 0.52 | 4.8 | High | 0.23 | 0.35 | 1.15 | 0.18 | *0.44* |
| 8 | 2 | 160 | 290 | 0.55 | 4.8 | High | 0.25 | 0.37 | 1.19 | 0.08 | 0.19 |
| 9 | 2 | 160 | 280 | 0.57 | 4.8 | High | 0.25 | 0.38 | 1.18 | 0.28 | 0.32 |
| 10 | 2 | 160 | 270 | 0.59 | 4.8 | High | 0.24 | 0.36 | 1.09 | 0.05 | 0.13 |
| 11 | 2 | 160 | 260 | 0.62 | 4.8 | High | 0.22 | 0.33 | 0.87 | 0.14 | 0.09 |
| 12 | 2 | 160 | 250 | 0.64 | 4.8 | High | 0.17 | 0.26 | 0.74 | - | - |
| 1 | 3 | 125 | 182 | 0.69 | 4.2 | High | 0.28 | 0.42 | 0.74 | 0.33 | - |
| 2 | 3 | 125 | 186 | 0.67 | 4.3 | High | 0.20 | 0.30 | 0.74 | 0.28 | - |
| 3 | 3 | 125 | 190 | 0.66 | 4.35 | High | 0.12 | 0.17 | 0.74 | - | - |
| 4 | 3 | 125 | 185 | 0.68 | 4.5 | High | 0.21 | 0.32 | 0.74 | 0.29 | - |
| 5 | 3 | 160 | 205 | 0.78 | 4.6 | High | 0.20 | 0.29 | 0.74 | **1.17** | *0.61* |
| 6 | 3 | 160 | 240 | 0.67 | 4.8 | High | 0.21 | 0.31 | 0.74 | 0.31 | 0.09 |
| 7 | 3 | 160 | 270 | 0.59 | 4.8 | Mod | 0.30 | 0.45 | 1.32 | 0.36 | 0.31 |
| 8 | 3 | 160 | 250 | 0.64 | 4.8 | High | 0.18 | 0.27 | 0.76 | 0.20 | 0.19 |
| 9 | 3 | 160 | 260 | 0.62 | 4.8 | High | 0.20 | 0.30 | 0.85 | 0.21 | - |
| 10 | 3 | 160 | 247 | 0.65 | 4.8 | High | 0.17 | 0.25 | 0.74 | 0.23 | - |
| 11 | 3 | 160 | 245 | 0.65 | 4.8 | High | 0.16 | 0.24 | 0.74 | 0.06 | - |
| 12 | 3 | 160 | 252 | 0.63 | 4.8 | High | 0.17 | 0.26 | 0.74 | - | - |
| 6 | 4 | 160 | 300 | 0.53 | 4.8 | Mod | 0.55 | 0.83 | 1.09 | 0.33 | 0.10 |
| 7 | 4 | 160 | 310 | 0.52 | 4.8 | Mod | 0.28 | 0.42 | 1.35 | *1.44* | 0.18 |
| 8 | 4 | 160 | 370 | 0.43 | 4.8 | Mod | 0.25 | 0.37 | 1.19 | 0.13 | - |

Underlined - Measured value exceeded mean predictions by >15%.

*Italics* **-** Measured value exceeded U95%CL predictions by > 15%.

**Bold** - Measured value exceeded discontinuous predictions by > 15%.

## Table 25B - Summary of Predicted v. Measured Maximum Concave Curvature

| Panel No. | XL | Panel Width W (m) | Cover Depth H (m) | Panel W/H | Mining Height T (m) | SRP | Maximum Concave (Sagging) Curvature, $C_{max}$ ($km^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Predicted | | | Measured |
| | | | | | | | *mean* | *U95% CL* | *Discont-inuous* | *Central Panel* |
| 1 | 1 | 125 | 154 | 0.81 | 3.5 | High | 0.66 | 0.98 | 2.64 | 0.34 |
| 2 | 1 | 125 | 155 | 0.81 | 3.6 | High | 0.61 | 0.91 | 2.68 | 0.30 |
| 3 | 1 | 125 | 158 | 0.79 | 3.5 | High | 0.53 | 0.79 | 2.51 | 0.21 |
| 4 | 1 | 125 | 165 | 0.76 | 3.6 | High | 0.40 | 0.60 | 2.23 | 0.25 |
| 5 | 1 | 160 | 172 | 0.93 | 3.6 | High | 0.54 | 0.81 | 2.34 | <u>0.63</u> |
| 6 | 1 | 160 | 180 | 0.89 | 3.6 | High | 0.35 | 0.52 | 1.80 | *0.63* |
| 7 | 1 | 160 | 185 | 0.86 | 3.8 | High | 0.33 | 0.50 | 1.78 | *0.58* |
| 8 | 1 | 160 | 195 | 0.82 | 4.0 | High | 0.28 | 0.42 | 1.78 | <u>0.40</u> |
| 9 | 1 | 160 | 205 | 0.78 | 4.0 | High | 0.22 | 0.33 | 1.78 | *0.43* |
| 10 | 1 | 160 | 215 | 0.74 | 4.1 | High | 0.20 | 0.29 | 1.78 | - |
| 11 | 1 | 160 | 220 | 0.73 | 4.0 | High | 0.19 | 0.28 | 1.78 | - |
| 12 | 1 | 160 | 225 | 0.71 | 4.3 | High | 0.19 | 0.29 | 1.78 | - |
| 1 | 2 | 125 | 200 | 0.63 | 4.8 | High | 0.38 | 0.58 | 1.78 | *1.24* |
| 2 | 2 | 125 | 200 | 0.63 | 4.8 | High | 0.13 | 0.20 | 1.78 | *0.85* |
| 3 | 2 | 125 | 240 | 0.52 | 4.8 | High | 0.17 | 0.25 | 1.98 | *0.52* |
| 4 | 2 | 125 | 260 | 0.48 | 4.8 | High | 0.28 | 0.42 | 2.41 | 0.19 |
| 5 | 2 | 160 | 273 | 0.59 | 4.8 | Mod | 0.38 | 0.56 | 2.34 | *1.48* |
| 6 | 2 | 160 | 315 | 0.51 | 4.8 | Mod | 0.35 | 0.52 | 2.28 | <u>0.47</u> |
| 7 | 2 | 160 | 310 | 0.52 | 4.8 | High | 0.29 | 0.44 | 2.12 | 0.25 |
| 8 | 2 | 160 | 290 | 0.55 | 4.8 | High | 0.31 | 0.47 | 2.15 | 0.20 |
| 9 | 2 | 160 | 280 | 0.57 | 4.8 | High | 0.32 | 0.48 | 2.14 | 0.22 |
| 10 | 2 | 160 | 270 | 0.59 | 4.8 | High | 0.31 | 0.46 | 2.06 | 0.20 |
| 11 | 2 | 160 | 260 | 0.62 | 4.8 | High | 0.28 | 0.42 | 1.89 | 0.24 |
| 12 | 2 | 160 | 250 | 0.64 | 4.8 | High | 0.22 | 0.33 | 1.78 | - |
| 1 | 3 | 125 | 182 | 0.69 | 4.2 | High | 0.36 | 0.54 | 1.78 | 0.33 |
| 2 | 3 | 125 | 186 | 0.67 | 4.3 | High | 0.25 | 0.38 | 1.78 | <u>0.30</u> |
| 3 | 3 | 125 | 190 | 0.66 | 4.35 | High | 0.15 | 0.22 | 1.78 | - |
| 4 | 3 | 125 | 185 | 0.68 | 4.5 | High | 0.27 | 0.40 | 1.78 | 0.29 |
| 5 | 3 | 160 | 205 | 0.78 | 4.6 | High | 0.25 | 0.37 | 1.78 | *1.40* |
| 6 | 3 | 160 | 240 | 0.67 | 4.8 | High | 0.26 | 0.39 | 1.78 | 0.26 |
| 7 | 3 | 160 | 270 | 0.59 | 4.8 | Mod | 0.38 | 0.57 | 2.25 | *0.45* |
| 8 | 3 | 160 | 250 | 0.64 | 4.8 | High | 0.23 | 0.34 | 1.79 | 0.35 |
| 9 | 3 | 160 | 260 | 0.62 | 4.8 | High | 0.25 | 0.38 | 1.87 | 0.25 |
| 10 | 3 | 160 | 247 | 0.65 | 4.8 | High | 0.21 | 0.32 | 1.78 | 0.29 |
| 11 | 3 | 160 | 245 | 0.65 | 4.8 | High | 0.20 | 0.31 | 1.78 | 0.15 |
| 12 | 3 | 160 | 252 | 0.63 | 4.8 | High | 0.22 | 0.32 | 1.78 | - |
| 6 | 4 | 160 | 300 | 0.53 | 4.8 | Mod | 0.70 | 1.05 | 2.07 | 0.20 |
| 7 | 4 | 160 | 310 | 0.52 | 4.8 | Mod | 0.35 | 0.53 | 2.28 | <u>0.53</u> |
| 8 | 4 | 160 | 370 | 0.43 | 4.8 | Mod | 0.32 | 0.47 | 2.15 | 0.18 |

<u>Underlined</u> - Measured value exceeded mean predictions by >15%.

*Italics* - Measured value exceeded U95%CL predictions by > 15%.

**Bold** - Measured value exceeded discontinuous predictions by > 15%.

### 10.11.5 Review of Horizontal Strain Data

Predicted values of maximum tensile and compressive strain for LWs 1 - 12 have been compared to the measured values in **Table 26A** and **26B** and **Figures 28a** (XL1), **28b** (XL2), and **28c** (XL3).

The outcome of the review indicates that 76% of the measured maximum tensile strains plot below the mean and 92% below the predicted U95%CL values; see **Figure 38**. Predicted tensile strain magnitudes were exceeded by 1.2 to 2.8 times (average of 1.85) by the measured values at 4 out of 51 locations, and were highest where the subsidence prediction exceedances also occurred, as discussed previously.

It is considered that the exceedances are due to discontinuous strata behaviour. The **ACARP, 2003** model also provides an empirical technique to estimate the maximum tensile strains due to discontinuous movements as follows (see **Appendix A** for details):

$$+E_{max(discontinuous)} = 10(+C_{max(discontinuous)})$$

The results for the above discontinuous curvature model are presented in **Table 24A** and reduce the number of prediction exceedance to 1 or 2% of the 51 observations.

Based on the above outcome, it is considered that the 'smooth' and 'discontinuous' subsidence profile models will provide reasonable estimates of tensile strain for each scenario and may be used to estimate worst-case strains above the proposed longwalls.

The outcomes for compressive strain indicated that 72% of the measured maximum strain plotted below the mean and 76 % below the predicted U95%CL values; see **Figure 39**. Predicted compressive strain magnitudes were exceeded by 1.3 to 2.8 times (average of 2.0) by the measured values at 7 out of 29 locations, and were highest where the subsidence prediction exceedances also occurred, as discussed previously.

The **ACARP, 2003** model also provides an empirical technique to estimate the maximum compressive strains due to discontinuous movements as follows (see **Appendix A** for details):

$$-E_{max(discontinuous)} = 10(-C_{max(discontinuous)})$$

The results for the above discontinuous strain model are presented in **Table 24B** and reduce the number of prediction exceedance to 0 or 0% of the 51 observations.

Based on the above outcome, it is considered that the 'smooth' and 'discontinuous' subsidence profile models will provide reasonable estimates of tensile strain for each scenario and may be used to estimate worst-case strains above the proposed longwalls.

## Table 26A - Summary of Predicted v. Measured Maximum Tensile Strain

| Panel No. | XL | Panel Width W (m) | Cover Depth H (m) | Panel W/H | Mining Height T (m) | SRP | Maximum Tensile Strain $E_{max}$ (mm/m) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Predicted | | | Measured | |
| | | | | | | | *mean* | *U95% CL* | *Discont-inuous* | *Panel Side1* | *Panel Side2* |
| 1 | 1 | 125 | 154 | 0.81 | 3.5 | High | 5 | 8 | 18 | 2.7 | 1.7 |
| 2 | 1 | 125 | 155 | 0.81 | 3.6 | High | 5 | 7 | 18 | 3.5 | 4.9 |
| 3 | 1 | 125 | 158 | 0.79 | 3.5 | High | 4 | 6 | 16 | 4.2 | *5.3* |
| 4 | 1 | 125 | 165 | 0.76 | 3.6 | High | 3 | 5 | 13 | 2.0 | *3.5* |
| 5 | 1 | 160 | 172 | 0.93 | 3.6 | High | 4 | 6 | 14 | *7.3* | *5.7* |
| 6 | 1 | 160 | 180 | 0.89 | 3.6 | High | 3 | 4 | 8 | 2.6 | 3.0 |
| 7 | 1 | 160 | 185 | 0.86 | 3.8 | High | 3 | 4 | 7 | *6.9* | *6.6* |
| 8 | 1 | 160 | 195 | 0.82 | 4.0 | High | 2 | 3 | 7 | 2.5 | 2.0 |
| 9 | 1 | 160 | 205 | 0.78 | 4.0 | High | 2 | 3 | 7 | *3.6* | <u>3.2</u> |
| 10 | 1 | 160 | 215 | 0.74 | 4.1 | High | 2 | 2 | 7 | - | - |
| 11 | 1 | 160 | 220 | 0.73 | 4.0 | High | 1 | 2 | 7 | - | - |
| 12 | 1 | 160 | 225 | 0.71 | 4.3 | High | 2 | 2 | 7 | - | - |
| 1 | 2 | 125 | 200 | 0.63 | 4.8 | High | 3 | 5 | 7 | 1.2 | 1.0 |
| 2 | 2 | 125 | 200 | 0.63 | 4.8 | High | 1 | 2 | 7 | 0.7 | - |
| 3 | 2 | 125 | 240 | 0.52 | 4.8 | High | 1 | 2 | 10 | 0.7 | 0.8 |
| 4 | 2 | 125 | 260 | 0.48 | 4.8 | High | 2 | 3 | 15 | 1.1 | - |
| 5 | 2 | 160 | 273 | 0.59 | 4.8 | Mod | 3 | 4 | 14 | 1.3 | - |
| 6 | 2 | 160 | 315 | 0.51 | 4.8 | Mod | 3 | 4 | 14 | 1.3 | - |
| 7 | 2 | 160 | 310 | 0.52 | 4.8 | High | 2 | 3 | 12 | *3.5* | - |
| 8 | 2 | 160 | 290 | 0.55 | 4.8 | High | 2 | 4 | 12 | <u>3.6</u> | 1.6 |
| 9 | 2 | 160 | 280 | 0.57 | 4.8 | High | 3 | 4 | 12 | 1.0 | 1.5 |
| 10 | 2 | 160 | 270 | 0.59 | 4.8 | High | 2 | 4 | 11 | 0.9 | - |
| 11 | 2 | 160 | 260 | 0.62 | 4.8 | High | 2 | 3 | 9 | 0.9 | 0.9 |
| 12 | 2 | 160 | 250 | 0.64 | 4.8 | High | 2 | 3 | 7 | - | - |
| 1 | 3 | 125 | 182 | 0.69 | 4.2 | High | 3 | 4 | 7 | - | - |
| 2 | 3 | 125 | 186 | 0.67 | 4.3 | High | 2 | 3 | 7 | - | - |
| 3 | 3 | 125 | 190 | 0.66 | 4.35 | High | 1 | 2 | 7 | - | - |
| 4 | 3 | 125 | 185 | 0.68 | 4.5 | High | 2 | 3 | 7 | 0.6 | - |
| 5 | 3 | 160 | 205 | 0.78 | 4.6 | High | 2 | 3 | 7 | **8.5** | 1.8 |
| 6 | 3 | 160 | 240 | 0.67 | 4.8 | High | 2 | 3 | 7 | <u>2.8</u> | 1.2 |
| 7 | 3 | 160 | 270 | 0.59 | 4.8 | Mod | 3 | 4 | 13 | <u>3.4</u> | - |
| 8 | 3 | 160 | 250 | 0.64 | 4.8 | High | 2 | 3 | 8 | <u>2.5</u> | 1.4 |
| 9 | 3 | 160 | 260 | 0.62 | 4.8 | High | 2 | 3 | 8 | <u>2.5</u> | 1.8 |
| 10 | 3 | 160 | 247 | 0.65 | 4.8 | High | 2 | 3 | 7 | 1.5 | 1.1 |
| 11 | 3 | 160 | 245 | 0.65 | 4.8 | High | 2 | 2 | 7 | 0.2 | 0.1 |
| 12 | 3 | 160 | 252 | 0.63 | 4.8 | High | 2 | 3 | 7 | - | - |
| 6 | 4 | 160 | 300 | 0.53 | 4.8 | Mod | 6 | 8 | 11 | 1.9 | 0.9 |
| 7 | 4 | 160 | 310 | 0.52 | 4.8 | Mod | 3 | 4 | 14 | 1.8 | 1.7 |
| 8 | 4 | 160 | 370 | 0.43 | 4.8 | Mod | 2 | 4 | 12 | 1.4 | - |

<u>Underlined</u> - Measured value exceeded mean predictions by >15%.
*Italics* **-** Measured value exceeded U95%CL predictions by > 15%.
**Bold** - Measured value exceeded discontinuous predictions by > 15%.

## Table 26B - Summary of Predicted v. Measured Maximum Compressive Strain

| Panel No. | XL | Panel Width W (m) | Cover Depth H (m) | Panel W/H | Mining Height T (m) | SRP | Maximum Compressive Strain $E_{max}$(mm/m) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Predicted | | | Measured |
| | | | | | | | *mean* | *U95% CL* | *Discont-inuous* | *Central Panel* |
| 1 | 1 | 125 | 154 | 0.81 | 3.5 | High | 7 | 10 | 26 | 6.2 |
| 2 | 1 | 125 | 155 | 0.81 | 3.6 | High | 6 | 9 | 27 | *8.3* |
| 3 | 1 | 125 | 158 | 0.79 | 3.5 | High | 5 | 8 | 25 | 3.8 |
| 4 | 1 | 125 | 165 | 0.76 | 3.6 | High | 4 | 6 | 22 | 4.2 |
| 5 | 1 | 160 | 172 | 0.93 | 3.6 | High | 5 | 8 | 23 | *10.5* |
| 6 | 1 | 160 | 180 | 0.89 | 3.6 | High | 3 | 5 | 18 | *9.1* |
| 7 | 1 | 160 | 185 | 0.86 | 3.8 | High | 3 | 5 | 18 | *9.8* |
| 8 | 1 | 160 | 195 | 0.82 | 4.0 | High | 3 | 4 | 18 | *7.9* |
| 9 | 1 | 160 | 205 | 0.78 | 4.0 | High | 2 | 3 | 18 | *7.9* |
| 10 | 1 | 160 | 215 | 0.74 | 4.1 | High | 2 | 3 | 18 | - |
| 11 | 1 | 160 | 220 | 0.73 | 4.0 | High | 2 | 3 | 18 | - |
| 12 | 1 | 160 | 225 | 0.71 | 4.3 | High | 2 | 3 | 18 | - |
| 1 | 2 | 125 | 200 | 0.63 | 4.8 | High | 4 | 6 | 18 | 2.0 |
| 2 | 2 | 125 | 200 | 0.63 | 4.8 | High | 1 | 2 | 18 | 0.8 |
| 3 | 2 | 125 | 240 | 0.52 | 4.8 | High | 2 | 2 | 20 | 1.4 |
| 4 | 2 | 125 | 260 | 0.48 | 4.8 | High | 3 | 4 | 24 | 2.5 |
| 5 | 2 | 160 | 273 | 0.59 | 4.8 | Mod | 4 | 6 | 23 | 1.0 |
| 6 | 2 | 160 | 315 | 0.51 | 4.8 | Mod | 3 | 5 | 23 | 2.3 |
| 7 | 2 | 160 | 310 | 0.52 | 4.8 | High | 3 | 4 | 21 | 2.7 |
| 8 | 2 | 160 | 290 | 0.55 | 4.8 | High | 3 | 5 | 22 | 3.2 |
| 9 | 2 | 160 | 280 | 0.57 | 4.8 | High | 3 | 5 | 21 | 2.6 |
| 10 | 2 | 160 | 270 | 0.59 | 4.8 | High | 3 | 5 | 21 | 1.2 |
| 11 | 2 | 160 | 260 | 0.62 | 4.8 | High | 3 | 4 | 19 | 2.6 |
| 12 | 2 | 160 | 250 | 0.64 | 4.8 | High | 2 | 3 | 18 | - |
| 1 | 3 | 125 | 182 | 0.69 | 4.2 | High | 4 | 5 | 18 | - |
| 2 | 3 | 125 | 186 | 0.67 | 4.3 | High | 3 | 4 | 18 | - |
| 3 | 3 | 125 | 190 | 0.66 | 4.35 | High | 1 | 2 | 18 | - |
| 4 | 3 | 125 | 185 | 0.68 | 4.5 | High | 3 | 4 | 18 | 1.2 |
| 5 | 3 | 160 | 205 | 0.78 | 4.6 | High | 2 | 4 | 18 | *11.2* |
| 6 | 3 | 160 | 240 | 0.67 | 4.8 | High | 3 | 4 | 18 | - |
| 7 | 3 | 160 | 270 | 0.59 | 4.8 | Mod | 4 | 6 | 23 | 3.7 |
| 8 | 3 | 160 | 250 | 0.64 | 4.8 | High | 2 | 3 | 18 | - |
| 9 | 3 | 160 | 260 | 0.62 | 4.8 | High | 3 | 4 | 19 | 1.4 |
| 10 | 3 | 160 | 247 | 0.65 | 4.8 | High | 2 | 3 | 18 | 2.6 |
| 11 | 3 | 160 | 245 | 0.65 | 4.8 | High | 2 | 3 | 18 | 1.9 |
| 12 | 3 | 160 | 252 | 0.63 | 4.8 | High | 2 | 3 | 18 | - |
| 6 | 4 | 160 | 300 | 0.53 | 4.8 | Mod | 7 | 10 | 21 | 1.8 |
| 7 | 4 | 160 | 310 | 0.52 | 4.8 | Mod | 4 | 5 | 23 | *9.7* |
| 8 | 4 | 160 | 370 | 0.43 | 4.8 | Mod | 3 | 5 | 22 | 2.0 |

Underlined - Measured value exceeded mean predictions by >15%.
*Italics* - Measured value exceeded U95%CL predictions by > 15%.
**Bold** - Measured value exceeded discontinuous predictions by > 15%.

Overall, it is assessed that the **ACARP, 2003** model reasonably estimates the measured maximum strains if a curvature multiplying factor of 10 is used for estimating 'smooth' or discontinuous profile strains from predicted curvatures; see **Figure 16**. It is noted however that tensile and compressive strains may increase by 2 to 3 times if discontinuous behaviour occurs due to cracking or buckling of near surface bed rock. The predicted curvatures should be multiplied by 20 to estimate maximum compressive or tensile strains from smooth profile curvatures where near surface cracking is likely to occur.

The prediction exceedance occurrences for measured curvatures and strains above longwalls are usually more frequent than tilts due to 'discontinuous' subsidence behaviour exacerbated by either surface topography and/or strain concentration effects in near surface bedrock, such as cracking or secondary curvature features (e.g. humps or depressions). However, the areas where the curvature or strain concentrations occur are usually localised and contained within 10 m to 20 m wide zone behind the retreating longwall face or parallel to the rib sides (see **Section 11.2** for further discussion on surface cracking locations).

It is also apparent that tilt, curvature and strain concentrations occur for shallower or critical panel width to cover depth ratios (W/H) are > 0.7 at Mandalong, and that the final deformations are generally lower than the maximum values predicted due to chain pillar subsidence effects; see **Figures 32**, **34**, **35**, **38** and **39**. For subsidence effect predictions above the proposed LWs 25 to 64, maximum tilt, curvatures and strains have been based on First $S_{max}$ predictions where W/H is less than or equal to 0.7 and Final $S_{max}$ predictions where W/H is > 0.7.

### 10.11.6 Review of Goaf Edge Subsidence and Angle of Draw Data

For completeness, predicted values of goaf edge subsidence and AoD for the LWs 1 to 12 have been compared to the measured values in **Table 27**.

**Table 27 - Summary of Predicted v. Measured Goaf Edge and AoD Data for LWs 1-12**

| Panel No. | XL | Panel Width W (m) | Cover Depth H (m) | Panel W/H | Mining Height T (m) | Predicted Goaf Edge Subsidence and AoD (U95%CL) | | Measured Goaf Edge Subsidence and AoD | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | First $S_{goe}$ (m) | AoD (o) | First $S_{goe}$ (m) | AoD (o) |
| 1 | 1 | 125 | 154 | 0.81 | 3.5 | 0.12 | 32 | 0.124 | 31.7 |
| 2 | 1 | 125 | 155 | 0.81 | 3.6 | 0.13 | 32 | 0.110 | 23.1 |
| 3 | 1 | 125 | 158 | 0.79 | 3.5 | 0.26 | 43 | 0.086 | 27.7 |
| 4 | 1 | 125 | 165 | 0.76 | 3.6 | 0.20 | 39 | 0.106 | 19.7 |
| 5 | 1 | 160 | 172 | 0.93 | 3.6 | 0.14 | 34 | 0.105 | 23.8 |
| 6 | 1 | 160 | 180 | 0.89 | 3.6 | 0.10 | 28 | 0.110 | 27.1 |
| 7 | 1 | 160 | 185 | 0.86 | 3.8 | 0.10 | 29 | 0.105 | 12.5 |
| 8 | 1 | 160 | 195 | 0.82 | 4.0 | 0.09 | 27 | 0.086 | 11.0 |
| 9 | 1 | 160 | 205 | 0.78 | 4.0 | 0.18 | 38 | 0.155 | **48.9** |
| 10 | 1 | 160 | 215 | 0.74 | 4.1 | 0.17 | 36 | **0.206** | 24.1 |
| 11 | 1 | 160 | 220 | 0.73 | 4.0 | 0.16 | 36 | - | - |
| 12 | 1 | 160 | 225 | 0.71 | 4.3 | 0.17 | 37 | - | - |
| 1 | 2 | 125 | 200 | 0.63 | 4.8 | 0.10 | 29 | 0.053 | 13.2 |
| 2 | 2 | 125 | 200 | 0.63 | 4.8 | 0.15 | 35 | 0.106 | 30.3 |
| 3 | 2 | 125 | 240 | 0.52 | 4.8 | 0.23 | 41 | 0.138 | 24.8 |
| 4 | 2 | 125 | 260 | 0.48 | 4.8 | 0.38 | 49 | 0.115 | 13.4 |
| 5 | 2 | 160 | 273 | 0.59 | 4.8 | 0.56 | 54 | 0.156 | 35.1 |
| 6 | 2 | 160 | 315 | 0.51 | 4.8 | 0.62 | 56 | 0.212 | 37.1 |
| 7 | 2 | 160 | 310 | 0.52 | 4.8 | 0.53 | 54 | 0.190 | 22.6 |
| 8 | 2 | 160 | 290 | 0.55 | 4.8 | 0.51 | 53 | 0.199 | 22.1 |
| 9 | 2 | 160 | 280 | 0.57 | 4.8 | 0.49 | 52 | 0.115 | 11.1 |
| 10 | 2 | 160 | 270 | 0.59 | 4.8 | 0.45 | 51 | 0.109 | 23.2 |
| 11 | 2 | 160 | 260 | 0.62 | 4.8 | 0.38 | 49 | 0.115 | 11.9 |
| 12 | 2 | 160 | 250 | 0.64 | 4.8 | 0.31 | 46 | - | - |
| 1 | 3 | 125 | 182 | 0.69 | 4.2 | 0.11 | 30 | 0.060 | 13.9 |
| 2 | 3 | 125 | 186 | 0.67 | 4.3 | 0.14 | 34 | - | - |
| 3 | 3 | 125 | 190 | 0.66 | 4.35 | 0.14 | 34 | 0.055 | 17.8 |
| 4 | 3 | 125 | 185 | 0.68 | 4.5 | 0.15 | 35 | 0.071 | 19.9 |
| 5 | 3 | 160 | 205 | 0.78 | 4.6 | 0.45 | 51 | 0.062 | 15.3 |
| 6 | 3 | 160 | 240 | 0.67 | 4.8 | 0.24 | 42 | 0.145 | 22.6 |
| 7 | 3 | 160 | 270 | 0.59 | 4.8 | 0.52 | 53 | 0.120 | 21.6 |
| 8 | 3 | 160 | 250 | 0.64 | 4.8 | 0.34 | 47 | 0.070 | 10.9 |
| 9 | 3 | 160 | 260 | 0.62 | 4.8 | 0.37 | 48 | 0.076 | 14.0 |
| 10 | 3 | 160 | 247 | 0.65 | 4.8 | 0.31 | 46 | 0.080 | 13.4 |
| 11 | 3 | 160 | 245 | 0.65 | 4.8 | 0.29 | 45 | 0.045 | - |
| 12 | 3 | 160 | 252 | 0.63 | 4.8 | 0.31 | 46 | - | - |
| 6 | 4 | 160 | 300 | 0.53 | 4.8 | 0.50 | 53 | 0.132 | - |
| 7 | 4 | 160 | 310 | 0.52 | 4.8 | 0.62 | 56 | 0.178 | - |
| 8 | 4 | 160 | 370 | 0.43 | 4.8 | 0.70 | 58 | - | - |

AoD - Angle of draw to 20 mm subsidence contour.

**Bold** - Measured value exceeded predictions by > 15%.

The measured goaf edge subsidence ranged from 45 mm to 212 mm with angles of draw to the 20 mm subsidence contour ranging between 11$^o$ and 48$^o$ (mean of 21$^o$).

The outcome of the review indicated that 14% of the measured goaf edge and 22% of the AoD (to 20 mm subsidence) values plotted above the predicted Upper 95% confidence limits using the **ACARP, 2003** model. The six AoD exceedances ranged between 27$^o$ and 48$^o$.

It was therefore considered necessary to adjust the **ACARP, 2003** model to include the measured Mandalong data; see **Figures 40** and **41**. The amended models reduced the number of prediction exceedences to one out of 33 (3%) measured goaf edge and AoD (to 20 mm subsidence) values.

### 10.11.7 Data Review Summary

The maximum subsidence predictions using the DgS Modified **ACARP, 2003** model compare favourably to the measured maximum subsidence values for LWs1-12; see **Table 28**.

The observed subsidence effect exceedences above the 125 m and 160 m wide panels at Mandalong Mine to-date are considered to be localised and infrequent events and associated with discontinuous strata behaviour during subsidence development.

Overall, it is assessed that the **ACARP, 2003** model is likely to provide reasonably conservative subsidence impact parameter predictions for the proposed Southern Extension Project Panels. It will however, be necessary to continue to review the predictions and associated impacts after each panel is completed. This is normal practise as part of the Mine's Subsidence Management Plan.

Subsidence contour predictions for the southern extension area will now be assessed in **Section 11**.

**Table 28 - Summary of Mandalong Measured Subsidence Data v. Mean & U95%CL Predictions**

| Parameter | Measured LW 1-12 | | Predicted LWs 1-12 | | Predicted LWs 25-64 | | |
|---|---|---|---|---|---|---|---|
| Panel Width W (m) | 125 | 160 | 125 | 160 | 160 | 180 | 200 |
| Cover Depth H (m) | 154 - 260 | 172 - 370 | 154 - 260 | 172 - 370 | 185 - 355 | 205 - 385 | 200 - 480 |
| Panel W/H | 0.48 - 0.81 | 0.43 - 0.93 | 0.48 - 0.81 | 0.43 - 0.93 | 0.45 - 0.86 | 0.47 - 0.98 | 0.42 - 1.01 |
| Mining Height T (m) | 3.5 - 4.8 | 3.6 - 4.8 | 3.5 - 4.8 | 3.6 - 4.8 | 1.8 - 2.8 | 1.8 - 4.5 | 1.8 - 3.7 |
| Beam Thickness t (m) | 25 - 30 | 15 - 35 | 20 - 36 | 23 - 38 | 17 - 35 | 17 - 35 | 22 - 38 |
| Beam Location y (m) | 65 - 80 | 85 - 140 | 72 - 117 | 82 - 123 | 82 - 108 | 93 - 110 | 85 - 107 |
| Maximum First Panel Subsidence First $S_{max}$ | 0.10 - 0.41 | 0.24 - 0.85 | 0.31 - 0.68 | 0.46 - 0.96 | 0.16 - 0.59 | 0.31 - 0.98 | 0.37 - 0.92 |
| Maximum Final Panel Subsidence Final $S_{max}$ (m) | 0.26 - 0.60 | 0.35 - 1.24 | 0.44 - 0.86 | 0.63 - 1.24 | 0.27- 0.78 | 0.42 - 1.20 | 0.49 - 1.27 |
| Final $S_{max}$/T | 0.07 - 0.14 | 0.07 - 0.26 | 0.13 - 0.26 | 0.19 - 0.37 | 0.15 - 0.31 | 0.20 - 0.35 | 0.24 - 0.51 |
| Chain Pillar Width, w (m) | 41 - 41.2 | 45.8 - 47.1 | 41 - 41.2 | 45.8 - 47.1 | 39.7 - 41.8 | 39.1 - 41.8 | 37.5 - 48.6 |
| Chain pillar w/h | 12.1 - 12.4 | 13.5 - 14.3 | 12.4 - 12.5 | 13.9 - 14.3 | 12.1 - 16.7 | 12.1 - 16.3 | 12.1 - 16.7 |
| Maximum Chain Pillar Stress (MPa) | 10 - 23 | 11.9 - 33.8 | 10.4 - 23 | 11.9 - 33.8 | 14.8 - 36.1 | 17.1 - 41.5 | 16.3 - 49.8 |
| Chain Pillar Subsidence Final $S_p$ (m) | 0.15 - 0.58 | 0.16 - 1.06 | 0.2 - 0.74 | 0.23 - 1.06 | 0.66 - 0.12 | 0.22 - 0.79 | 0.06 - 1.10 |
| Maximum Tilt (mm/m) | 2 - 8 | 3 - 25 | 3 - 14 | 7 - 21 | 2 - 10 | 3 - 19 | 4 - 18 |
| Final Tilt (mm/m) | 2 - 7 | 3 - 12 | 2 - 9 | 4 - 14 | 1.5 - 7 | 2 - 13 | 3 - 12 |
| Maximum Convex (Hog) Curvature ($km^{-1}$) | 0.11 - 0.73 | 0.05 - 1.44 | 0.16 - 0.78 | 0.22 - 0.83 | 0.16 - 0.50 | 0.21 - 0.69 | 0.22 - 0.60 |
| Maximum Concave (Sag) Curvature ($km^{-1}$) | 0.10 - 0.85 | 0.15 - 1.48 | 0.2 - 0.98 | 0.28 - 1.05 | 0.20 - 0.64 | 0.26 - 0.87 | 0.28 - 0.77 |
| Maximum Tensile Strain $+E_{max}$ (mm/m) | 0.6 - 5.3 | 0.2 - 8.5 | 1.5 - 8 | 2 - 8 | 1.5 - 5 | 2-7 | 2-6 |
| Maximum Compressive Strain $-E_{max}$ (mm/m) | 0.8 - 8.3 | 0.1 - 6.6 | 2 - 9 | 3 - 11 | 2 - 6 | 2.5-9 | 3-8 |

# 11.0 Prediction of Subsidence Impact Parameter Contours

## 11.1 Calibration of the SDPS® Model

Credible worst-case subsidence contours for the proposed longwall panels have been generated using SDPS® influence function-based subsidence prediction software.

The SDPS® model was calibrated to the credible worst-case (U95%CL) profiles predicted by the **ACARP, 2003** empirical model. Based on the results of the subsidence data review for Mandalong Mine, the re-calibration of the SDPS® model is considered unlikely to be required once data for Mandalong South becomes available.

The outcome of the model calibration exercise is summarised in **Table 29**.

**Table 29 - SDPS® Model Calibration Summary for the Proposed LWs 25 - 64**

| **Input Parameters from Modified ACARP, 2003** | **Value** |
|---|---|
| Panel Nos. below XL s 1 - 13 shown in **Figure 1** | 25 - 64 |
| Panel Void Widths, W (m) | 160, 180, 200 |
| Cover Depth, H (m) | 185 - 480 |
| Seam Thickness (m) | 1.6 - 4.6 |
| Mining Height, T (m) | 1.8 - 4.5 |
| Roadway Development Height, h (m) | 2.5 - 3.4 |
| W/H range | 0.42 - 1.01 |
| SRP for Mining Area | Low, Mod, High |
| Maximum Final Panel Subsidence*, $S_{max}$ (m) | 0.27 - 1.35 |
| Effective $S_{max}$/T Range | 0.15 - 0.51 |
| Chain Pillar Width, $w_{cp}$ (m) | 37.5 - 48.6 |
| Roadway width (m) | 5.2 |
| Pillar width to height ratio, w/h | 12 - 17 |
| Chain Pillar Subsidence* $S_p$ (m) | 0.06 - 1.1 |
| $S_p$/T Range | 0.03 - 0.32 |
| Distance to Influence Inflexion Point from Rib-Side (m) (d/H) | 0.10 - 0.31 |
| **SDPS Calibration Results for 'Best Fit' Solution to the Modified ACARP, 2003 Model Predictions^** | **Optimum Values** |
| Influence Angle (Tan(beta)) | 1.8 (internal)<br>2.0 (external) |
| Influence Angle (beta) | 61 - 63 |
| Supercritical Subsidence Factors ($S_{max}$/T) | 0.6 |
| Distance to Influence Inflexion Point from Rib-Side (m) (d/H) | 0.10 - 0.31 |

Notes:
* - Upper 95% Confidence Limits predicted from modified version of **ACARP, 2003**
^ - See SDPS manual extract in **Appendix B** for explanation of methodology and terms used.

The predicted **ACARP, 2003** and **SDPS®** model subsidence impact parameter profiles for the five Panel Groups have been compared in **Figures 42a** to **45d**.

The predicted **SDPS®** subsidence and tilt profiles were generally located within +/- 10 to 20% of the predicted modified **ACARP, 2003** models U95%CL. This outcome is considered a reasonable fit considering that the **ACARP, 2003** profiles represent measured tilt profiles that are invariably affected by 'skewed' or kinked subsidence profiles.

The results of the analysis indicate that the majority of the predicted convex curvature (and tensile strain) and concave curvature (and compressive strains) predicted by the **SDPS®** model would fall within +/- 50% of the modified **ACARP, 2003** model predictions. This result is also considered reasonable in the context that the **ACARP, 2003** model represents measured profile data that includes strain concentration effects such as cracking and shearing. As mentioned earlier, this 'discontinuous' type of overburden behaviour can increase 'smooth' profile strains by 2 times 'occasionally'.

### 11.2 Predicted Subsidence Contours

Based on the calibrated SDPS® model, predictions of final worst-case subsidence effect contours (subsidence, tilt, curvature and horizontal strain) for the proposed longwall panel layout, are presented in **Figures 46a** to **46d**.

Pre-mining and post-mining surface levels for the proposed mining layout are shown in **Figure 47**.

# 12.0 Subsidence Impacts and Management Strategies

## 12.1 General

Based on the predicted maximum panel subsidence, tilt and strain values for the longwall panel layouts, the potential for the following subsidence related impacts and their likely effect on natural and man-made features have been assessed:

- surface cracking;
- height of sub-surface fracturing above the panels (direct and in-direct hydraulic connection zones);
- surface gradient changes;
- ponding;
- general slope stability and erosion;
- valley uplift and closure, and
- far-field horizontal displacements and strains.

Based on the observation that a finite range of subsidence effect values can occur at a given location above an extracted longwall panel of known mining geometry and geology, it is possible to provide a range of predictions that are likely to occur within a nominal confidence limit (i.e. usually 95%). This approach will allow specialist consultants and stakeholders to apply risk management principles in a practical way.

Discussions of likelihood of impact occurrence in the following sections generally refer to the qualitative measures of likelihood described in **Table 29**, and are based on terms used in **AGS, 2007** and **Vick, 2002**.

As explained in **Appendix A**, the terms ‘mean' and ‘Upper 95% Confidence Limit’ (U95%CL) infer that the predicted maximum subsidence effect values may be exceeded on a small number of occasions, due to the presence of adverse geological or topographical conditions.

**Table 29 - Qualitative Measures of Likelihood**

| Likelihood of Occurrence | Event implication | Indicative relative probability of a single event |
|---|---|---|
| Almost Certain | The event is expected to occur. | 90-99% |
| Very Likely | The event is expected to occur, although not completely certain. | 75-90% |
| Likely+ | The event will probably occur under normal conditions. | 25-75% |
| Possible | The event may occur under normal conditions. | 10-25% |
| Unlikely* | The event is conceivable, but only if adverse conditions are present. | 5-10% |
| Very Unlikely | The event probably will not occur, even if adverse conditions are present. | 1-5% |
| Not Credible | The event is inconceivable or practically impossible, regardless of the conditions. | <1% |

Notes:
\+ - Equivalent to the mean or line-of-best fit regression lines for a given impact parameter presented in **ACARP, 2003**.
* - Equivalent to the credible worst-case or U95%CL subsidence impact parameter in **ACARP, 2003**.

The predicted impacts and suggested management strategies for the natural and man-made features in the proposed mining area are presented in the following sections.

## 12.2 Surface Cracking

### 12.2.1 Predicted Impacts

The development of surface subsidence above longwall extraction panels is caused by the bending of the overburden strata as it sags down into the newly created void in the workings. The sagging strata are supported in turn by the collapsed immediate roof, which then slowly compresses to a maximum subsidence limit.

Based on previous experience at Mandalong, the predicted Project Area's final maximum panel subsidence magnitudes of 0.27 m to 1.34 m may result in the occasional surface crack developing within the limits of the extracted panels in relatively flat terrain. Cracks may also occur outside the high sides of longwall panels beneath the steep slopes (> $18^o$) in the south-west of the proposed mining area. It is 'Not Credible' that surface cracks will develop above first workings pillars, where subsidence magnitudes of < 20 mm are expected.

For the longwalls beneath gently undulating terrain in the east of the Project Area, cracks (if they occur) are likely to develop in the tensile strain zones defined by an area that extends in from the rib-sides of each panel some 44 m to 64 m (i.e. the distance to the inflexion points or maximum tilt locations).

Based on predicted maximum tensile strains of 1 mm/m to 7 mm/m, crack widths are estimated to range from 10 mm to 70 mm wide where shallow rock exists within 5 m of the surface. If alluvium or deep soil profiles exist, the strain will probably be more uniformly distributed and consist of several smaller width cracks (rather than just one single crack) or not occur at all. The cracks are also likely to be tapered to depths ranging from 5 to 15 m, and possibly deeper if near surface bedrock exposures and steep slopes are present.

Where steep slopes exist, the crack widths due to the predicted subsidence of 0.72 m to 1.27 m, could range from 150 mm to 320 mm due to rigid body rotation movements that can occur if the toe of a slope is undermined.

Compressive strains > 2 to 3 mm/m can also cause cracking and upward ‘buckling’ of near surface rock beds due to low-angle shear failures. The compressive strains generally peak at one or two locations in the middle third area of the panels.

It should be understood, that occasionally, the measured crack widths would be expected to exceed the U95%CL indicated by the subsidence prediction model. These are generally found to be related to the presence of adverse or anomalous geological or topographical conditions.

The predicted range of maximum transverse compressive strains (i.e. 2 to 9 mm/m) may result in shear displacements or 'shoving' of between 20 mm and 90 mm within the central limits of proposed panels. Uplift or buckling of near surface rock beds of < 50 mm could also occur due to these ‘closure’ type movements. Compressive strain peaks and resultant shoving / shearing is also likely to occur on the down-slope side of panels beneath steep slopes.

In addition, tensile cracks of similar magnitudes to those mentioned above will probably develop up to 50 m behind the advancing goaf edge of the longwall panels. The majority of these cracks are transient however, and some may partially close in the central areas of the panels where permanent compressive strains develop after mining is completed.

### 12.2.2 Impact Management Strategies

Surface crack repair works may need to be implemented around the affected areas of the site, and in particular, if public roads, watercourses and steep slopes are impacted.

The decision on whether crack repairs need to be undertaken will depend upon the perceived risk to public safety, the potential for natural infilling, long-term degradation potential, site accessibility to effect repairs and the requirements of the stakeholder agreement.

General crack repairs in the flatter areas may involve ripping, backfilling and top dressing works or the pouring of cement-based grout or crushed rock into wider, deeper cracks. Crack repairs should not be attempted until the majority of active mine subsidence has occurred.

For the creeks, the following are proposed:

- Undertake pre-mining and post-mining inspections along the creeks, with the results of these inspections communicated to the stakeholders through Extraction Plans, End of Panel Reports and the Annual Environmental Management Reports..

- Trigger Action Response Plans and remediation strategies would be developed and outlined in Extraction Plans.

- Consultation with relevant government agencies at other mine sites has suggested that natural regeneration may be the favoured management strategy in most scenarios, due to the likely level of disturbance caused by other remediation strategies, such as back filling with imported, free-draining materials from haulage trucks.

Surface cracking is considered unlikely to occur along the water courses where depth of cover is > 180 m. Notwithstanding, Extraction Plans will include Trigger Action Response Plans and remediation strategies for the occasions when cracking does occur.

In regards to the 3$^{rd}$ Order streams, surface cracking will be limited by the panel geometries, and it is considered 'very unlikely' that surface cracks will develop along the creek beds. Extraction Plans will need to include Trigger Action Response Plans to monitor and respond appropriately to affected sections of creek.

## 12.3 Sub-Surface Cracking

### 12.3.1 Sub-Surface Fracturing Zones

The caving and subsidence development processes above a longwall panel usually results in sub-surface fracturing and shearing of sedimentary strata in the overburden according to **Kendorski, 1993**; see **Figure 48a**. The extent of fracturing and shearing up through the strata is dependent on the mining geometry and overburden geology.

International and Australian research on longwall mining interaction with groundwater systems indicates that the overburden may be divided into essentially four or five zones of surface and subsurface fracturing and strata dilation; see **Figures 48b** and **48c**. The zones are based on the **Forster, 1995** and **ACARP, 2007** models and are defined (in descending order) in **Table 30a**.

**Table 30a - Sub-Surface Fracture Zone Summary**

| Zone Type | Zone | Fracture and Groundwater Response Description | Typical Vertical Strain (mm/m) |
|---|---|---|---|
| Surface (un-constrained) | D | Vertical cracking due to horizontal strains extending to 10 - 15 m depth. Surface waters may be diverted below affected area and resurface downstream. | <3 |
| Elastic (constrained) | C | Generally unaffected by strains with some bedding parting dilation. Horizontal strains constrained by overlying/underlying strata.<br>Groundwater levels may be lowered temporarily due to new storage volume in voids between beds, but likely to recover at a rate dependant on climate.<br>Elastic Zone may not be present if B or A Zones extend up to Surface Zone. | <3 |
| Discontinuous Fractures (constrained) | B | Minor vertical cracking due to bending that do not extend through strata units. Increased bedding parting dilation and similar groundwater response to Zone C. Some groundwater leakage may occur to B Zone, however, losses likely to be recharged by surface hydro-geological system. | <8 |
| Continuous Fractures (unconstrained) | A | Major vertical cracking due to bending that pass through strata units and allow a direct hydraulic connection to workings below. Full depressurisation of groundwater occurs in the Zone that may recover in the long term once mining is completed. | >20 |
| Caved (included in the A-Zone) | A | Caved strata up to 3 to 5 x Mining Height above the workings. Collapsed roof bulks in volume to provide some support to overlying strata. | >80 |

Details of the above fracture zones are provided in **Appendix A**.

In summary, the A-Zone represents the area above the workings with connective cracking that will probably drain all groundwater present within the zone to the workings. The B and C-Zones are constrained with strata dilations and discontinuous cracks present in the strata units. The fractures are only discontinuous because the bending of the strata is not great enough to cause them to penetrate right through the individual units. This is why spanning strata units usually limit the height of continuous or A-Zone fracturing above the longwall goaf.

The differences between the B and C Zones are subtle and have the same characteristics of bedding parting separations and shearing with low levels of vertical strain (< 8 mm/m). The two zones may essentially be assumed to act as one Constrained Zone for prediction purposes.

Ground water flow to the A-Zone is likely to be restricted by the overlying Constrained Zone, which limits vertical flow into the workings to very low levels. The Constrained Zone therefore acts as a ‘barrier’ to drainage of overlying water bodies and its thickness is a very important element in surface to seam connection control. At Mandalong, the Munmorah Conglomerate defines the upper limit of the A-Zone, and acts as a barrier to significant water flow from overlying strata into the workings.

The D-Zone is usually affected by vertical fracturing due to unconfined strata bending at the surface. Surface waters or shallow groundwater aquifers may re-route or drain down to dilated strata in the C and/or B zones if cracking in the D-Zone intersect with bedding parting dilations in these zones. The Surface Zone extends to depths ranging from 5 m to 15 m in the Newcastle Coalfield, and is dependent on near-surface geology.

Two empirically-based models (**Forster, 1995** and modified **ACARP, 2003**) have been used in this study to predict the A and B-Zone heights above the workings within the study area. In some cases, the mine workings may not be deep enough for a C-Zone to develop.

**Forster, 1995** and **Wardell, 1975** suggest that the minimum Constrained Zone thickness above the Fractured Zone to rock head (i.e. including the surface zone) should be the greater of 12T + 10 m or 17T - the surface zone thickness beneath water bodies such as lakes.

Based on a proposed mining height of 1.8 m to 4.5 m, a minimum Constrained Zone thickness of 32 m to 64 m (i.e. 12T+10) has been adopted for the proposed mining layouts beneath watercourses in the Mandalong South Area.

The **Forster, 1995** model was developed from deep multi-piezometer data from subsided overburden above supercritical-width pillar extraction panels in the Central-Coast area of the Newcastle Coalfield and indirectly defines the A-Zone as a function of the mining height. In this model of the overburden, the A Zone occurs at the top of the Fractured Zone and the B-Zone is considered to exist within the Constrained Zone (see **Figure 48b**).

The **Forster, 1995** model predicts that the height of the Fractured or A-Zone will generally range between 21 and 33 times the mining height (T) for super-critical panel geometries with 30 to 40 m thick Munmorah Conglomerate beds. The predicted extent or height of the Constrained Zone thickness may be estimated as the difference between the cover depth and height of A-Zone fracturing at Mandalong.

The original **ACARP, 2003** model included the key parameters of the Mining Height and Cover Depth as defined by **Forster, 1995** and **Whittaker and Reddish, 1989** with additional parameters such as the panel width, cover depth, first maximum panel subsidence and geological conditions (i.e. the Subsidence Reduction Potential of massive units within the strata). The mining height was applied indirectly through the subsidence prediction (further model development details may be found in **Appendix A**).

The measured height of fracturing and subsidence data were plotted in **ACARP, 2003** as the height of A or B-Zone fracturing/cover depth v. $S_{max}$/Effective Panel Width$^2$. Log-normal regression lines were derived to give predictions of mean and U95%CL values for both A and B-Fracture Zones and are presented in **Figure 49a**.

Based on a recent review of the Mandalong height of fracturing data for LW5 presented in **Section 12.3.7**, it is apparent that the **ACARP, 2003** model could be significantly under predicting the A-Zone Horizon for sub-critical panel to critical panel geometries and over-predicting the B-Zone Horizon (because the model does not distinguish between the B and C- Zones).

Due to the currently held belief in the mining industry that the sub-surface fracture heights are strongly influenced by panel width and mining height, an alternative model has been developed for this study based on a different approach to analysing the UK model data presented in **ACARP, 2003**.

Predictions of the heights of continuous and discontinuous fracturing (the A and B-Zone horizons) have been re-analysed using the panel width, the mining height and simple parabolic profile formulae as follows:

- Continuous Fracture Zone Height, A = W'/(4tan($theta_A$))

- Discontinuous Fracture Zone Height, B = W'/(4tan($theta_B$))

When the UK model's fracture height data is plotted as an effective caving angle (estimated from an assumed parabolic fracturing profile between rib abutments), a strong correlation is apparent with the mining height for a given panel width and cover depth (W/H = 1.34); see **Figures 49b** and **49c** for A and B-Zone Horizons respectively.

The regression analysis indicates the following effective caving angles (in degrees) apply for estimating A and B Zone fracture heights:

$theta_A = 25.083T^{-0.401}$ (lower bound) and $41.174T^{-0.444}$ (mean)

$theta_B = 17.795T^{-0.243}$ (lower bound) and $21.806T^{-0.233}$ (mean)

For real-world mining heights in the model data base of 1.9 m to 6.0 m (median of 3.0 m) the calibrated caving angles range from $18^o$ to $34^o$ for the A-Zone, and from $13^o$ to $22^o$ for the B-Zone. One A-Zone case had a caving angle of $58^o$ due to the 'truncating' effect of a spanning strata unit.

The alternative caving angle method (see **Appendix A** for details) is considered to provide a more robust approach to estimate height of continuous and discontinuous fracturing and constrained zone thicknesses above sub-critical to supercritical longwall panels.

### 12.3.3 Sub-Surface Fracture Height Predictions

The predicted values for continuous (A-Zone) and discontinuous (B-Zone) sub-surface fracturing heights and Constrained Zone thickness above the proposed 160 m, 180 m and 200 m wide longwall panels are summarised in **Table 30** for the Effective Caving Angle (i.e. modified **ACARP, 2003**). Predicted A-Zone Horizons for Critical to Supercritical panel width geometries from **Forster, 1995** are also provided for comparison with the proposed sub-critical panel width outcomes.

The *continuous* sub-surface fracture heights (A-Horizon) have been plotted against depth of cover in **Figure 49d** for the range of proposed longwall widths.

The *discontinuous* sub-surface fracture heights (B-Horizon) have also been plotted against depth of cover in **Figure 49e** for the range of proposed longwall widths.

Minimum Constrained Zone (B/C Zone) thicknesses are also indicated on the above figures.

**Table 30b - Summary of Predicted Sub-Surface Fracturing Heights above LWs 25 - 64**

| XL. No LW | LW Panel No. | T (m) | Panel Width W (m) | Cover Depth H (m) | First Panel $S_{max}$ (U95% CL) (m) | A-Zone Horizon (m) | | | B-Zone Horizon (m) | Constrained Zone Thickness | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Caving Angle Model^ | Forster 1995 | | Caving Angle Model^ | B+C (m) | (B+C)/ T |
| | | | | | | | 21T | 33T | | | |
| 1.1 | 25 | 4.1 | 180 | 290 | 0.70 | 177 | 86 | 135 | 205 | 98 | 24 |
| 1.2 | 26 | 4.2 | 180 | 290 | 0.82 | 178 | 87 | 137 | 206 | 97 | 23 |
| 1.3 | 27 | 4.1 | 180 | 285 | 0.83 | 177 | 86 | 135 | 205 | 93 | 23 |
| 1.4 | 28 | 4.1 | 180 | 300 | 0.79 | 176 | 85 | 134 | 205 | 109 | 27 |
| 1.5 | 29 | 3.9 | 180 | 340 | 0.88 | 174 | 82 | 129 | 203 | 151 | 39 |
| 2.1 | 25 | 4.5 | 180 | 270 | 0.63 | 184 | 95 | 149 | 210 | 71 | 16 |
| 2.2 | 26 | 4.3 | 180 | 270 | 0.85 | 181 | 90 | 142 | 208 | 74 | 17 |
| 2.3 | 27 | 4.1 | 180 | 270 | 0.83 | 177 | 86 | 135 | 205 | 78 | 19 |
| 2.4 | 28 | 4.0 | 180 | 270 | 1.14 | 175 | 84 | 132 | 204 | 80 | 20 |
| 2.5 | 29 | 3.9 | 180 | 275 | 1.10 | 174 | 82 | 129 | 203 | 86 | 22 |
| 2.6 | 30 | 3.8 | 180 | 280 | 1.05 | 172 | 80 | 125 | 202 | 93 | 25 |
| 2.7 | 31 | 3.5 | 180 | 280 | 0.98 | 166 | 74 | 116 | 198 | 99 | 28 |
| 3.1 | 32 | 3.4 | 200 | 400 | 0.70 | 182 | 71 | 112 | 218 | 203 | 60 |
| 3.2 | 33 | 3.5 | 200 | 420 | 0.83 | 184 | 74 | 116 | 220 | 221 | 63 |
| 3.3 | 34 | 3.5 | 200 | 470 | 0.76 | 184 | 74 | 116 | 220 | 271 | 77 |
| 3.4 | 35 | 3.5 | 200 | 420 | 0.84 | 184 | 74 | 116 | 220 | 221 | 63 |
| 3.5 | 36 | 3.6 | 200 | 380 | 0.92 | 187 | 76 | 119 | 221 | 178 | 50 |
| 3.6 | 37 | 3.5 | 200 | 410 | 0.79 | 184 | 74 | 116 | 220 | 211 | 60 |
| 4.1 | 32 | 3.7 | 200 | 360 | 0.82 | 189 | 78 | 122 | 223 | 156 | 42 |
| 4.2 | 33 | 3.5 | 200 | 440 | 0.80 | 184 | 74 | 116 | 220 | 241 | 69 |
| 4.3 | 34 | 3.5 | 200 | 480 | 0.74 | 184 | 74 | 116 | 220 | 281 | 80 |
| 4.4 | 35 | 3.6 | 200 | 450 | 0.81 | 187 | 76 | 119 | 221 | 248 | 69 |
| 4.5 | 36 | 3.6 | 200 | 430 | 0.85 | 187 | 76 | 119 | 221 | 228 | 63 |

**Table 30b (Cont…) - Summary of Predicted Sub-Surface Fracturing Heights above LWs 25 - 64**

| XL. No LW | LW Panel No. | T (m) | Panel Width W (m) | Cover Depth H (m) | First Panel $S_{max}$ (U95% CL) (m) | A-Zone Horizon (m) | | | B-Zone Horizon (m) | Constrained Zone Thickness | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Caving Angle Model^ | Forster, 1995 | | Caving Angle Model^ | B+C (m) | (B+C)/T |
| | | | | | | | 21T | 33T | | | |
| 4.6 | 37 | 3.70 | 200 | 430 | 0.80 | 189 | 78 | 122 | 223 | 226 | 61 |
| 5.1 | 55 | 1.80 | 160 | 205 | 0.21 | 111 | 38 | 59 | 149 | 79 | 44 |
| 5.2 | 56 | 1.80 | 160 | 205 | 0.25 | 111 | 38 | 59 | 149 | 79 | 44 |
| 5.3 | 57 | 1.80 | 200 | 217 | 0.65 | 139 | 38 | 59 | 186 | 63 | 35 |
| 5.4 | 58 | 1.80 | 200 | 227 | 0.37 | 139 | 38 | 59 | 186 | 73 | 41 |
| 5.5 | 59 | 1.80 | 200 | 265 | 0.54 | 139 | 38 | 59 | 186 | 111 | 62 |
| 5.6 | 60 | 1.90 | 160 | 238 | 0.25 | 114 | 40 | 63 | 151 | 109 | 58 |
| 5.7 | 61 | 2.00 | 200 | 238 | 0.45 | 145 | 42 | 66 | 191 | 78 | 39 |
| 5.8 | 38 | 2.15 | 180 | 255 | 0.41 | 135 | 45 | 71 | 175 | 105 | 49 |
| 5.9 | 39 | 2.15 | 180 | 235 | 0.34 | 135 | 45 | 71 | 175 | 85 | 40 |
| 5.1 | 40 | 2.15 | 160 | 255 | 0.31 | 120 | 45 | 71 | 156 | 120 | 56 |
| 5.11 | 41 | 2.20 | 160 | 250 | 0.31 | 121 | 46 | 73 | 157 | 114 | 52 |
| 5.12 | 42 | 2.25 | 160 | 245 | 0.30 | 122 | 47 | 74 | 157 | 108 | 48 |
| 5.13 | 43 | 2.35 | 180 | 255 | 0.51 | 140 | 49 | 78 | 179 | 100 | 43 |
| 6.1 | 42 | 2.20 | 160 | 275 | 0.30 | 121 | 46 | 73 | 157 | 139 | 63 |
| 6.2 | 43 | 2.30 | 180 | 310 | 0.47 | 139 | 48 | 76 | 178 | 156 | 68 |
| 6.3 | 44 | 2.45 | 180 | 345 | 0.57 | 143 | 51 | 81 | 181 | 187 | 76 |
| 6.4 | 45 | 2.50 | 180 | 310 | 0.54 | 144 | 53 | 83 | 182 | 151 | 60 |
| 6.5 | 46 | 2.55 | 180 | 295 | 0.54 | 145 | 54 | 84 | 183 | 135 | 53 |
| 6.6 | 47 | 2.65 | 180 | 315 | 0.53 | 147 | 56 | 87 | 184 | 153 | 58 |
| 6.7 | 48 | 2.55 | 180 | 300 | 0.54 | 145 | 54 | 84 | 183 | 140 | 55 |
| 6.8 | 49 | 2.50 | 160 | 295 | 0.49 | 128 | 53 | 83 | 162 | 152 | 61 |
| 6.9 | 50 | 2.35 | 160 | 288 | 0.47 | 125 | 49 | 78 | 159 | 148 | 63 |
| 6.1 | 51 | 2.30 | 160 | 300 | 0.45 | 123 | 48 | 76 | 158 | 162 | 70 |
| 7.1 | 55 | 2.20 | 160 | 340 | 0.40 | 121 | 46 | 73 | 157 | 204 | 93 |
| 7.2 | 56 | 2.10 | 160 | 355 | 0.42 | 119 | 44 | 69 | 155 | 221 | 105 |
| 7.3 | 57 | 1.95 | 200 | 300 | 0.64 | 144 | 41 | 64 | 190 | 141 | 72 |
| 7.4 | 58 | 1.95 | 200 | 285 | 0.51 | 144 | 41 | 64 | 190 | 126 | 65 |
| 7.5 | 59 | 1.95 | 200 | 270 | 0.84 | 144 | 41 | 64 | 190 | 111 | 57 |
| 7.6 | 60 | 1.95 | 160 | 305 | 0.38 | 115 | 41 | 64 | 152 | 175 | 90 |
| 7.7 | 61 | 2.00 | 200 | 330 | 0.55 | 145 | 42 | 66 | 191 | 170 | 85 |
| 7.8 | 38 | 2.10 | 180 | 350 | 0.45 | 133 | 44 | 69 | 174 | 202 | 96 |
| 7.9 | 39 | 2.10 | 180 | 325 | 0.54 | 133 | 44 | 69 | 174 | 177 | 84 |
| 7.1 | 40 | 2.25 | 160 | 290 | 0.46 | 122 | 47 | 74 | 157 | 153 | 68 |
| 7.11 | 41 | 2.25 | 160 | 280 | 0.45 | 122 | 47 | 74 | 157 | 143 | 63 |
| 7.12 | 42 | 2.25 | 160 | 280 | 0.45 | 122 | 47 | 74 | 157 | 143 | 63 |

**Table 30b (Cont…) - Summary of Predicted Sub-Surface Fracturing Heights above LWs 25 - 64**

| XL. No LW | LW Panel No. | T (m) | Panel Width W (m) | Cover Depth H (m) | First Panel $S_{max}$ (U95% CL) (m) | A-Zone Horizon (m) | | | B-Zone Horizon (m) | Constrained Zone Thickness | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Caving Angle Model^ | Forster, 1995 21T | Forster, 1995 33T | Caving Angle Model^ | B+C (m) | (B+C)/T |
| 7.13 | 43 | 2.25 | 180 | 255 | 0.52 | 138 | 47 | 74 | 177 | 102 | 46 |
| 8.1 | 42 | 2.25 | 160 | 320 | 0.36 | 122 | 47 | 74 | 157 | 183 | 81 |
| 8.2 | 43 | 2.25 | 180 | 345 | 0.53 | 138 | 47 | 74 | 177 | 192 | 86 |
| 8.3 | 44 | 2.25 | 180 | 350 | 0.54 | 138 | 47 | 74 | 177 | 197 | 88 |
| 8.4 | 45 | 2.30 | 180 | 385 | 0.51 | 139 | 48 | 76 | 178 | 231 | 101 |
| 8.5 | 46 | 2.30 | 180 | 360 | 0.55 | 139 | 48 | 76 | 178 | 206 | 90 |
| 8.6 | 47 | 2.35 | 180 | 315 | 0.61 | 140 | 49 | 78 | 179 | 160 | 68 |
| 8.7 | 48 | 2.35 | 180 | 320 | 0.58 | 140 | 49 | 78 | 179 | 165 | 70 |
| 8.8 | 49 | 2.40 | 160 | 325 | 0.53 | 126 | 50 | 79 | 160 | 184 | 77 |
| 8.9 | 50 | 2.50 | 160 | 315 | 0.49 | 128 | 53 | 83 | 162 | 172 | 69 |
| 8.1 | 51 | 2.50 | 160 | 320 | 0.48 | 128 | 53 | 83 | 162 | 177 | 71 |
| 8.11 | 52 | 2.70 | 160 | 350 | 0.49 | 132 | 57 | 89 | 165 | 203 | 75 |
| 8.12 | 53 | 2.75 | 160 | 355 | 0.57 | 133 | 58 | 91 | 165 | 207 | 75 |
| 8.13 | 54 | 2.75 | 160 | 355 | 0.59 | 133 | 58 | 91 | 165 | 207 | 75 |
| 9.1 | 62 | 2.50 | 200 | 275 | 0.64 | 160 | 53 | 83 | 202 | 100 | 40 |
| 9.2 | 63 | 2.20 | 200 | 225 | 0.48 | 151 | 46 | 73 | 196 | 59 | 27 |
| *9.3* | *64* | *1.90* | *200* | *200* | *0.62* | *142* | *40* | *63* | *189* | *43* | *23* |
| 10.1 | 62 | 2.20 | 200 | 305 | 0.40 | 151 | 46 | 73 | 196 | 139 | 63 |
| 10.2 | 63 | 2.10 | 200 | 280 | 0.61 | 148 | 44 | 69 | 193 | 117 | 56 |
| 10.3 | 64 | 2.00 | 200 | 270 | 0.63 | 145 | 42 | 66 | 191 | 110 | 55 |
| 11.1 | 55 | 1.80 | 160 | 230 | 0.24 | 111 | 38 | 59 | 149 | 104 | 58 |
| 11.2 | 56 | 1.85 | 160 | 245 | 0.25 | 112 | 39 | 61 | 150 | 118 | 64 |
| 11.3 | 57 | 1.80 | 200 | 260 | 0.80 | 139 | 38 | 59 | 186 | 106 | 59 |
| 11.4 | 58 | 1.80 | 200 | 240 | 0.43 | 139 | 38 | 59 | 186 | 86 | 48 |
| 11.5 | 59 | 1.80 | 200 | 235 | 0.41 | 139 | 38 | 59 | 186 | 81 | 45 |
| 11.6 | 60 | 1.90 | 160 | 248 | 0.26 | 114 | 40 | 63 | 151 | 119 | 63 |
| 11.7 | 61 | 1.95 | 200 | 310 | 0.56 | 144 | 41 | 64 | 190 | 151 | 78 |
| 11.8 | 38 | 2.10 | 180 | 300 | 0.37 | 133 | 44 | 69 | 174 | 152 | 72 |
| 11.9 | 39 | 2.20 | 180 | 330 | 0.53 | 136 | 46 | 73 | 176 | 179 | 81 |
| 11.10 | 40 | 2.25 | 160 | 280 | 0.42 | 122 | 47 | 74 | 157 | 143 | 63 |
| 11.11 | 41 | 2.25 | 160 | 265 | 0.37 | 122 | 47 | 74 | 157 | 128 | 57 |
| 11.12 | 42 | 2.25 | 160 | 280 | 0.38 | 122 | 47 | 74 | 157 | 143 | 63 |
| 11.13 | 43 | 2.25 | 180 | 320 | 0.46 | 138 | 47 | 74 | 177 | 167 | 74 |
| 12.1 | 42 | 2.30 | 160 | 275 | 0.32 | 123 | 48 | 76 | 158 | 137 | 59 |
| 12.2 | 43 | 2.30 | 180 | 310 | 0.47 | 139 | 48 | 76 | 178 | 156 | 68 |
| 12.3 | 44 | 2.30 | 180 | 350 | 0.54 | 139 | 48 | 76 | 178 | 196 | 85 |
| 12.4 | 45 | 2.35 | 180 | 310 | 0.51 | 140 | 49 | 78 | 179 | 155 | 66 |
| 12.5 | 46 | 2.35 | 180 | 295 | 0.51 | 140 | 49 | 78 | 179 | 140 | 60 |

**Table 30b (Cont…) - Summary of Predicted Sub-Surface Fracturing Heights above LWs 25 - 64**

| XL. No LW | LW Panel No. | T (m) | Panel Width W (m) | Cover Depth H (m) | First Panel $S_{max}$ (U95% CL) | A-Zone Horizon (m) Caving Angle Model^ | A-Zone Horizon (m) Forster, 1995 21T | A-Zone Horizon (m) Forster, 1995 33T | B-Zone Horizon (m) Caving Angle Model^ | Constrained Zone Thickness B+C (m) | Constrained Zone Thickness (B+C)/T |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12.6 | 47 | 2.35 | 180 | 315 | 0.48 | 140 | 49 | 78 | 179 | 160 | 68 |
| 12.7 | 48 | 2.40 | 180 | 300 | 0.51 | 141 | 50 | 79 | 180 | 144 | 60 |
| 12.8 | 49 | 2.40 | 160 | 305 | 0.47 | 126 | 50 | 79 | 160 | 164 | 68 |
| 12.9 | 50 | 2.40 | 160 | 287 | 0.48 | 126 | 50 | 79 | 160 | 146 | 61 |
| 12.10 | 51 | 2.50 | 160 | 320 | 0.47 | 128 | 53 | 83 | 162 | 177 | 71 |
| 12.11 | 52 | 2.55 | 160 | 325 | 0.56 | 129 | 54 | 84 | 162 | 181 | 71 |
| 12.12 | 53 | 2.55 | 160 | 320 | 0.57 | 129 | 54 | 84 | 162 | 176 | 69 |
| 12.13 | 54 | 2.55 | 160 | 335 | 0.56 | 129 | 54 | 84 | 162 | 191 | 75 |
| 13.1 | 55 | 1.80 | 160 | 185 | 0.29 | 111 | 38 | 59 | 149 | 59 | 33 |
| 13.2 | 56 | 1.80 | 160 | 195 | 0.28 | 111 | 38 | 59 | 149 | 69 | 38 |
| 13.3 | 57 | 1.85 | 200 | 205 | 0.57 | 140 | 39 | 61 | 187 | 50 | 27 |
| 13.4 | 58 | 1.85 | 200 | 220 | 0.42 | 140 | 39 | 61 | 187 | 65 | 35 |
| 13.5 | 59 | 1.85 | 200 | 205 | 0.58 | 140 | 39 | 61 | 187 | 50 | 27 |
| 13.6 | 60 | 1.80 | 160 | 205 | 0.25 | 111 | 38 | 59 | 149 | 79 | 44 |
| 13.7 | 61 | 1.80 | 200 | 210 | 0.54 | 139 | 38 | 59 | 186 | 56 | 31 |
| 13.8 | 38 | 1.80 | 180 | 205 | 0.31 | 125 | 38 | 59 | 168 | 65 | 36 |
| 13.9 | 39 | 1.80 | 180 | 210 | 0.32 | 125 | 38 | 59 | 168 | 70 | 39 |
| 13.10 | 40 | 1.80 | 160 | 210 | 0.24 | 111 | 38 | 59 | 149 | 84 | 47 |
| 13.11 | 41 | 1.80 | 160 | 230 | 0.21 | 111 | 38 | 59 | 149 | 104 | 58 |

W' = Effective Panel Width = lesser of actual width and 1.4H (i.e. the super-critical width).
**Bold** - Mean or U95%CL A-Horizon prediction is within 15 m of the surface.
***Italics*** - Mean or U95%CL B-Horizon prediction is within 15 m of surface.

### 12.3.4 Discussion of A-Zone Horizon Model Predictions

The Modified **ACARP, 2003** model's predictions for the U95%CL A-Zone horizon above the proposed longwall panels (see **Figure 49d**) range from 111 m to 189 m for cover depths of 185 m to 480 m respectively (41T to 77T). The lower bound caving angles for the A-Zone Fracture Heights are estimated to range from 14$^o$ to 20$^o$ based on the empirical model and mining heights of 1.8 m to 4.5 m.

The upper limit of the **Forster, 1995** model (i.e. 33T) indicates a range of connective cracking heights from 59 m to 149 m above the workings, and below the predicted range of the **DgS, 2012** model results. It is considered the super-critical panel data is not a conservative scenario for sub-critical panels, as the height of fracturing in the supercritical panel geometries is actually limited by the cover depth and the critical panel width for a given mining height.

The corollary to the above assessment is the depth to the height of A-Zone fracturing from the surface ranges from 58 m to 296 m, and 'very unlikely' to interact with surface cracking within 15 m of the surface, regardless of any adverse conditions (such as a fault) being present.

In regards to subsurface aquifers, any aquifers below the predicted A-Zone fracture heights for a given mining geometry are likely to drain into the workings after longwall mining is completed.

### 12.3.5 Discussion of B-Zone Horizon Model Predictions

The modified **ACARP, 2003** model predicts that the U95%CL B-Zone horizon above the proposed longwall panels (see **Figure 49e**) ranges from 149 m and 223 m for cover depths of 185 m to 480 m (47T - 103T). The effective caving angles for the B-Zone fracture heights are estimated to range from $12^o$ to $15^o$ based on the empirical model and mining heights of 1.8 m to 4.5 m.

The corollary to the above assessment is the predicted depth to the worst-case depth to B-Zone fracturing from the surface ranges from 11 m to 260 m, it is likely that the B-Zone horizon will be limited by the presence of spanning Munmorah Conglomerate, which exists between 83 m to 115 m below the surface. It is therefore considered that the B-Zone is very unlikely to reach the surface zone above the proposed longwalls.

### 12.3.6 Discussion of C-Zone Horizon and Thickness Predictions

The C-Zone horizon models for the proposed panels estimate that bedding dilation could interact with the surface zone, due to small bedding parting dilations up to the rock head across the site. The dilation of the strata up to rock head is unlikely to cause significant groundwater or surface water system losses provided the Constrained Zone has a minimum recommended thickness of 12T + 10 m (i.e. 32 m to 64 m) as recommended by **Wardell, 1975** and **Forster, 1995**.

The thickness of the Constrained Zone is estimated to range from 43 m to 281 m or 16T to 105T above the A-Horizon to the base of the Surface Zone. The predicted Constrained Zone thicknesses above the proposed panel widths are therefore consistent with the minimum thickness required in similar geological conditions above supercritical panels.

### 12.3.7 Impact on Rock Mass Permeability

In regards to changes to rock mass permeability, **Forster, 1995** indicates that horizontal permeability in the fractured A-Zone above longwall mines (see **Figure 48b**) could increase by 2 to 4 orders of magnitude (e.g. pre-mining $k_h = 10^{-9}$ to $10^{-10}$ m/s; post-mining $k_h = 10^{-7}$ to $10^{-6}$ m/s).

Vertical permeability could not be measured directly from the boreholes discussed in the **Forster, 1995** model, but could be inferred by assuming complete pressure loss in the 'A-Zone', where direct hydraulic connection to the workings occurs. Only a slight increase in the 'B-Zone' or indirect / discontinuous fracturing develops (mainly due to increase in storage capacity) from bedding parting separation. It is possible however, that vertical flows (i.e. leakage) could occur from B-Zone into the A-Zone (and workings) as well, but at a significantly lower rate than in the A-Zone itself.

Overall, bedding parting separation would be expected to increase rock mass storage capacity and horizontal permeability without direct hydraulic connection to the workings in the B-Zone.

Rock mass hydraulic conductivity is unlikely to increase significantly outside the angle of draw from the extraction limits.

### 12.3.8 Discussion of Prediction Model Uncertainties and Spanning Strata

In regards to prediction model uncertainty, both models are consistent in that they indicate surface-to-seam hydraulic connection is 'unlikely' to 'very unlikely' to occur for proposed mining cover depths >180 m, which is the entire Project Area.

However, it is clear from the database on which the models were derived, that there is a high degree of variability in the data. This is probably due to the truncating effects of massive, spanning strata or shallow cover depth limiting potential fracture heights. *Note: It is apparent from the database that higher fracture heights have occurred in the deeper coalfields of NSW with similar mining geometries - see **Appendix A**.*

This means that there will always be uncertainty in predicting the A and B-Zone horizons using any of the available models. The measurement of sub-surface fracturing and their impact on groundwater should therefore be undertaken in non-sensitive areas or cognisance made of all available local information. An adaptive management approach should be adopted to avoid continuous fracturing occurring beneath streams.

Heights of A and B-Zone fracturing and groundwater response to Mandalong Mine's longwall panels LW1-12 have been assessed in **GHD, 2012** and also measured directly over LW5, and have been referred to herein for the purpose of further validating the prediction models applied in this study.

### 12.3.9 Measured v. Predicted Heights of Fracturing above Mandalong Mine

The measured heights of fracturing of the A, B and C- Zones above Mandalong Mine's LW5 were based on deep borehole extensometer anchor displacements (provided by the mine) and screened (slotted pipe) piezometers presented in **GHD, 2012**.

It is considered that the geological conditions and proposed mining geometries for the Project Area are also very similar to the current Mandalong Mine, with groundwater impacts affected by the response of the spanning capability of the Munmorah Conglomerate beds.

Extensometer measurements above LW5 are summarised in **Table 31**. Plots of the data are presented in **Figures 49f** and **49g**.

**Table 31 - Summary of Measured Deep Borehole Extensometer Anchor Displacements and Vertical Strain Profiles above LW5**

| Anchor No. (BH No. CM72) | Anchor Depth below Ground (m) | Anchor Location above Workings y^ (m) | Maximum Anchor Displacement or Strata Dilation* (mm) | Vertical Strain between Overlying Anchor & Anchor No. (mm/m) | Anchor Location/ Mining Height $y/T^{\#}$ | Fracture Zone |
|---|---|---|---|---|---|---|
| 20 | 8.4 | 170.6 | 14 | | 46 | Surface (C) |
| 19 | 16.8 | 162.2 | 21 | 0.8 | 44 | Surface/Dilated (C/B) |
| 18 | 25.2 | 153.8 | 47 | 3.1 | 42 | Dilated (B) |
| 17 | 33.6 | 145.4 | 75 | 3.4 | 39 | Dilated (B) |
| 16 | 42 | 137 | 70 | -0.7 | 37 | Dilated (B) |
| 15 | 50.4 | 128.6 | 75 | 0.6 | 35 | Dilated (B) |
| 14 | 58.8 | 120.2 | 93 | 2.2 | 32 | Dilated/ Fractured (A/B) |
| 13 | 67.2 | 111.8 | 166 | 8.7 | 30 | |
| 12 | 75.6 | 103.4 | 356 | 22.6 | 28 | |
| 11 | 84 | 95 | 767 | 48.9 | 26 | |
| 10 | 92.4 | 86.6 | 1243 | 56.7 | 23 | |
| 9 | 100.8 | 78.2 | 1915 | 80.0 | 21 | Fractured (A) |
| 8 | 109.2 | 69.8 | 1985 | 8.3 | 19 | Fractured (A) |
| 7 | 117.6 | 61.4 | 1975 | -1.1 | 17 | Fractured (A) |
| 6 | 126 | 53 | 2006 | 3.7 | 14 | Fractured (A) |
| 5 | 134.4 | 44.6 | 2010 | 0.5 | 12 | Fractured (A) |
| 4 | 142.8 | 36.2 | 2010 | 0.0 | 10 | Fractured (A) |
| 3 | 151.2 | 27.8 | 2008 | -0.2 | 8 | Fractured (A) |
| 2 | 159.6 | 19.4 | 1992 | -1.9 | 5 | Caved (A) |
| 1 | 168 | 11 | 1334 | -78.3 | 3 | Caved (A) |

^ - Cover depth to WW Seam was 179 m and panel width W= 160 m (W/H=0.89).
\# - Mining height was 3.7 m. Final maximum panel subsidence was 0.76 m or 0.21T (see **Figure 30a**).
*- Movement recorded on 1/2/2009 after LW5 had retreated 379 m past the extensometer location.
Shaded - Munmorah Conglomerate Unit is present between 61 and 86 m below the surface.

The maximum anchor displacements in **Table 31** are relative displacements and indicate strata dilation or separation of sagging rock beds over extracted areas; see **Figures 49f** and **49g**.

The extensometer data indicates that the boundary between the A and B Zones ranges somewhere within the Munmorah Conglomerate beam, which is located 86 m to 118 m above the workings. The highest tensile strain or dilation of 80 mm/m was measured at the base of the unit, with strains decreasing to 8.7 mm/m at 118 m. Although the Munmorah Conglomerate unit appears to have broken down into separate units (with strains ranging from 23 to 59 mm/m measured within the conglomerate itself), the measured subsidence of 0.76 m suggests the dilated units were continuing to span, with Moderate SRP being assessed at this location. The exto data therefore demonstrates a feasible mechanism of conglomerate beam breakdown for the two subsidence prediction exceedances measured above LWs 5 and 7.

The exto data concurs with the findings of **GHD, 2012**, which indicates groundwater impacts have been greatest across the Mandalong mine up to 120 m above the workings, with groundwater impacts assessed to have been limited to short term lowering in dilated strata above the Munmorah Conglomerate. No losses in groundwater level and quality have been detected in surface alluvium along creeks after the extraction of LWs 1-12.

Comparison between predicted v. measured heights of sub-surface fracturing zones above LW5 have been assessed for model validation purposes and presented in **Tables 32A**.

**Table 32A - Summary of Predicted Sub-Surface Fracturing Heights above LW5**

| Cover Depth H (m) | Panel Width W (m) | Mining Height T (m) | First Panel $S_{max}$ (mean - U95%) (m) | Panel $S_{max}/W'^2$ (mean) (mm/m$^2$ or km$^{-1}$) | Predicted Fracture Heights (m) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Continuous Fracture Zone (A Horizon) | | | | Discontinuous Fracture Zone (B Horizon) | |
| | | | | | ACARP Models (U95%CL) | | Forster, 1995) | | ACARP Models (U95%CL) | |
| | | | | | 2003 | DgS, 2012 | 21T | 33T | 2003 | DgS, 2012 |
| 179 | 160 | 3.7 | 0.49-0.69 | 0.019 - 0.027 | 88 - 102 | 96 - 147 | 78 | 122 | 159 - 169 | 131 - 164 |

**Table 32B - Summary of Predicted v Measured Sub-Surface Fracturing Heights above LW5 at Mandalong Mine**

| Panel No. | Panel Width W (m) | Cover Depth H (m) | Mining Height T (m) | First Panel $S_{max}$ (m) | | Continuous Fracture Zone (A Horizon) | | Discontinuous Fracture Zone (B Horizon) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | P | M | P | M | P | M |
| 5 | 160 | 179 | 3.7 | 0.49-0.69 | 0.66 | 88 - 147 | 82-120 | 159 - 169 | 162 |

P - Predicted; M - Measured.

The height of continuous fracturing (A Horizon) is probably located within the dilated Munmorah Conglomerate beam unit and between 59 m and 97 m below the surface. The dilated or discontinuous fracture zone is estimated to extend to within 15 m of the surface for both ACARP models.

The results of the analysis demonstrates that the measured A-Zone above LW5 was up to 18 m higher than the **ACARP, 2003** model results and within the **Forster, 1995** model upper limit of 33T, see **Figure 49a**.

Overall, it is considered that the measured and predicted fracture zones above LW5 are in best agreement with the **Forster, 1995** and **DgS, 2012** models, and it is recommended that the maximum limit for the A and B Zones between the two models should therefore be adopted as the worst-case fracture height estimates for the proposed longwalls.

#### 12.3.10 Impact Management Strategies

It is understood that the surface alluvium and sub-surface aquifers are not considered to be a groundwater resource of significance due to their brackish water quality (**GHD, 2012**). The surface alluvium along the creeks is estimated to range from 5 m to approximately 20 m below the surface. The overburden stratum has low permeability generally with both higher and lower conductivities in the vicinity of persistent geological structure (i.e. faults, dykes and joints).

Based on **Table 29**, the prediction model outcomes have been assessed in accordance with the Likelihood of Occurrence that continuous fracturing will intersect with surface alluvium or cracks that extend 15 m depth below the surface. The results are summarised in **Table 30** and **Figures 49d** and **49e**. It is 'Not Credible' that A-Zone cracking will affect the surface alluvium beneath any of the creeks. It is also considered 'Unlikely' that surface watercourses will be subject to sub-surface flow re-routing due to interaction with sub-surface bed separation or discontinuous fracturing in the B or C-Zones.

Based on discussions with the specialist groundwater consultants for the Project Area, the absence of significant surface alluvium and ephemeral nature of the creeks/gullies is unlikely to result in significant degradation of the creeks if sub-surface fracturing / bedding separations or discontinuous cracking intersects with the bases of the alluvium along the creeks within the Project area.

The presence of geological structure should be viewed with caution in regards to potential interaction with surface water courses and management strategies prepared to deal with disproportionate water inflows into the workings if aquifers become 'perched' behind adjacent faults. Undermining significant faults may also result in higher continuous fracture connectivity and water makes and should be avoided if possible.

Recommendations for monitoring sub-surface fracture heights at the Southern Area Extension Project are provided in **Section 13**.

### 12.4 Ponding

#### 12.4.1 Potential Impacts

Ponding refers to pre and post mining depressions on the surface. Pre-mining ponds are usually located in-channel along watercourses and may be altered in size and location after mine subsidence effects. Changes to existing pond locations along a watercourse could affect drainage patterns, flora, fauna and Groundwater Dependent Ecosystems (GDEs). Flat, low lying land may be susceptible to out-of channel ponds or depressions forming after mine subsidence. The actual ponding depths will also depend upon several other factors, such as rain duration, surface cracking and permeability of the site soils.

The pre-mining and predicted post-mining ponding depths for the proposed mining layout have been estimated from the surface level contours shown in **Figures 50a** and **50b** respectively and summarised in **Tables 33A-B**. The ponded areas and volumes before and after mining have been assessed in **Umwelt, 2013**.

**Table 33A - Pre-Mining Ponding Assessment for LWs 25 to 64**

| Creek | Location | LW | Max Pond Level (AHD) | Min Pond Level (AHD) | Max. Pond Depth d (m) |
|---|---|---|---|---|---|
| Wyee | 1.1 | 40 | 50.0 | 46.7 | 3.3 |
| | 1.2 | 40/41 | 42.6 | 42.3 | 0.30 |
| | 1.3 | 40/41 | 41.6 | 41.2 | 0.40 |
| | 1.4 | 41 | 39.2 | 38.9 | 0.65 |
| | 1.5 | 41/42 | 38.1 | 37.7 | 0.40 |
| | 1.6 | 42/43 | 34.0 | 33.8 | 0.20 |
| | 1.7 | 42 | 33.6 | 33.5 | 0.10 |
| | 1.8 | 40 | 28.8 | 28.3 | 0.50 |
| | 1.9 | 38/39 | 26.7 | 26.15 | 0.55 |
| | 1.10 | 38 | 27.65 | 27.25 | 0.40 |
| Wyee North Trib | 2.1 | 59 | 37.3 | 36.6 | 0.7 |
| Mannering | 3.1 | 47 | 67.4 | 66.9 | 0.5 |
| | 3.2 | 48 | 64.0 | 62.7 | 1.3 |
| | 3.3 | 49 | 62.7 | 61.3 | 1.4 |
| | 3.4 | 50/51 | 51.3 | 51.0 | 0.25 |
| | 3.5 | 51 | - | - | 0 |
| Morans | 4.1 | 32 | 44.5 | 43.5 | 1.0 |
| | 4.2 | 31 | 39.9 | 39.4 | 0.5 |
| | 4.3 | 29 | 33.95 | 33.8 | 0.15 |
| | 4.4 | 28 | 33.6 | 33.0 | 0.6 |
| | 4.5 | 27 | 31.85 | 31.7 | 0.15 |
| | 4.6 | 26 | 31.10 | 31.0 | 0.10 |
| | 4.7 | 25 | - | - | 0 |
| Stockton West Trib | 5.1 | 26 | 32.25 | 31.70 | 0.45 |
| | 5.2 | 25 | 31.4 | 31.33 | 0.07 |

**Table 33B - Post-Mining Ponding Predictions for LWs 25 to 64**

| Creek | Location | LW | Max Pond Level (AHD) | Min Pond Level (AHD) | Max. Pond Depth h (m) |
|---|---|---|---|---|---|
| Wyee | 1.1 | 40 | 49.2 | 46.4 | 2.80 |
| | 1.2 | 40/41 | 42.2 | 41.85 | 0.35 |
| | 1.3 | 40/41 | 41.1 | 40.80 | 0.30 |
| | 1.4 | 41 | 38.7 | 38.35 | 0.35 |
| | 1.5 | 41/42 | 37.75 | 37.35 | 0.40 |
| | 1.6 | 42/43 | 35.8 | 35.5 | 0.30 |
| | 1.7 | 42 | 32.5 | 31.95 | 0.55 |
| | 1.8 | 40 | 28.75 | 28.15 | 0.60 |
| | 1.9 | 38/39 | 26.6 | 26.05 | 0.55 |
| | 1.10 | 38 | Pond combined with 1.9 | | |
| Wyee North Trib | 2.1 | 59 | 37.3 | 36.2 | 1.1 |
| Mannering | 3.1 | 47 | 66.6 | 66.1 | 0.50 |
| | 3.2 | 48 | 63.6 | 61.7 | 1.90 |
| | 3.3 | 49 | 60.6 | 59.8 | 0.85 |
| | 3.4 | 50/51 | 50.8 | 50.5 | 0.30 |
| | 3.5 | 51 | 39.6 | 39.3 | 0.30 |
| Morans | 4.1 | 32 | 43.4 | 42.75 | 0.65 |
| | 4.2 | 31 | 39.0 | 38.5 | 0.50 |
| | 4.3 | 29 | 32.95 | 32.5 | 0.45 |
| | 4.4 | 28 | 32.85 | 31.75 | 1.10 |
| | 4.5 | 27 | 31.1 | 30.7 | 0.40 |
| | 4.6 | 26 | 29.65 | 29.25 | 0.40 |
| | 4.7 | 25 | 29.05 | 28.9 | 0.15 |
| Morans West Trib | 5.1 | 26 | 31.60 | 31.1 | 0.50 |
| | 5.2 | 25 | 29.65 | 29.45 | 0.20 |

The pre-and post-mining surface level profiles with ponding locations along Wyee, Wyee North Tributary, Mannering and Morans Creeks are shown in **Figures 51a** to **51d** respectively. The net changes to the ponding depths along the creeks after mining is completed are summarised in **Table 33C**.

**Table 33C - Post-Mining Ponding Depth Increase Estimates for LWs 25 to 64**

| Creek | Location | LW | Pre-Mining Pond Depth (m) | Post-Mining Pond Depth (m) | Estimated Pond Depth Increase dh (m) |
|---|---|---|---|---|---|
| Wyee | 1.1 | 40 | 3.30 | 2.80 | **-0.50** |
| | 1.2 | 40/41 | 0.30 | 0.35 | **0.05** |
| | 1.3 | 40/41 | 0.40 | 0.30 | **-0.10** |
| | 1.4 | 41 | 0.65 | 0.35 | **-0.30** |
| | 1.5 | 41/42 | 0.40 | 0.40 | **0.00** |
| | 1.6 | 42/43 | 0.20 | 0.30 | **0.10** |
| | 1.7 | 42 | 0.10 | 0.55 | **0.45** |
| | 1.8 | 40 | 0.50 | 0.60 | **0.10** |
| | 1.9 | 38/39 | 0.55 | 0.55 | **0.00** |
| | 1.10 | 38 | 0.40 | 0.55 | **0.15** |
| Wyee North Trib | 2.1 | 59 | 0.70 | 1.10 | **0.40** |
| Mannering | 3.1 | 47 | 0.50 | 0.50 | **0.00** |
| | 3.2 | 48 | 1.30 | 1.90 | **0.60** |
| | 3.3 | 49 | 1.40 | 0.85 | **-0.55** |
| | 3.4 | 50/51 | 0.25 | 0.30 | **0.05** |
| | 3.5 | 51 | 0.00 | 0.30 | **0.30** |
| Morans | 4.1 | 32 | 1.00 | 0.65 | **-0.35** |
| | 4.2 | 31 | 0.50 | 0.50 | **0.00** |
| | 4.3 | 29 | 0.15 | 0.45 | **0.30** |
| | 4.4 | 28 | 0.60 | 1.10 | **0.50** |
| | 4.5 | 27 | 0.15 | 0.40 | **0.25** |
| | 4.6 | 26 | 0.10 | 0.40 | **0.30** |
| | 4.7 | 25 | 0.00 | 0.15 | **0.15** |
| Morans West Trib | 5.1 | 26 | 0.45 | 0.50 | **0.05** |
| | 5.2 | 25 | 0.07 | 0.20 | **0.13** |

Analysis of the pre- and post-mining surface levels suggests that ponding is likely to remain in-channel and along existing watercourses. Pre-mining ponding depths are assessed to range from 0.0 m to 3.3 m with post-mining ponding depths ranging from 0.15 m to 2.8 m.

Based on **Table 33C**, it is estimated that there will be ponding depth **increases** of up to 0.6 m and ponding depth **decreases** of up to 0.55 m after the proposed longwall panels are completed.

The ponding analysis completed in **Umwelt, 2013** indicates an increase in 1 in 100 year flood levels of 0.1 m to 0.4 m after mining is complete, with an increase in ponded area of 3.6 ha.

Overall, it is concluded that the above assessment outcomes are consistent. Details of ponding and scouring effects and impact management strategies are provided in **Umwelt, 2013**. General management strategies are provided in **Section 12.4.2**.

### 12.4.2 Impact Management Strategies

An appropriate ponding management strategy may include:

(i) The development of a suitable monitoring and mitigation response plan as a component of the Extraction Plan process, based on consultation with the regulatory government authorities to ensure ponding impacts on existing vegetation do not result in long-term environmental degradation.

(ii) The review and appraisal of changes to drainage paths and surface vegetation in areas of ponding development (if they occur), after each panel is extracted.

(iii) Engineered channel earth works may be necessary to re-establish surface flows between sections of creek that become 'disjointed'. Local experience to-date suggests that if increased in-channel ponding occurs it can either remain as an 'additional' pond along the creek or be remediated in consultation with the relevant government agency.

(iv) The impact of the predicted ponding changes along the creeks should be assessed by specialist ecological consultants.

## 12.5 Slope Instability and Erosion

### 12.5.1 Potential Impacts

Based on a preliminary reconnaissance of the site, the following potential impacts (due to mine subsidence) could occur in logistical order above the Group 2 and 3 longwalls:

- Cracking and tilting of public access roads and steep slopes;
- Collapse of rock face overhangs;
- Rock fall movements (falling and rolling boulders) from rock faces and steep slopes towards public access areas (i.e. access roads) and private properties, and
- General instability of steep slopes (including the access roads) due to deep or shallow translational sliding along mudstone / claystone bedding planes.

The potential impacts of the proposed mining layout in regards to the above impacts have been assessed in the following sections. Strategies to manage the impacts appropriately have also been provided. The assessments are considered preliminary at this stage and further detailed studies may be necessary in areas identified as having 'moderate' and 'high' risk in terms of (i) damage to sensitive surface features, such as existing or proposed residences, (ii) loss of life and/or injury and (iii) significant landform impact (i.e. deep seated landslide).

Discussions of likelihood of impact occurrence in the following sections generally refer to the qualitative measures of likelihood are described in **Table 29**, and are based on terms used in **AGS, 2007** and **Vick, 2002**.

The potential for instability of the steep slopes and rock falls due to mine subsidence will be strongly influenced by the geology and geomorphic characteristics of the near surface strata and is discussed further in **Section 12.5.2**.

### 12.5.2 Geology and Geomorphic Features

**Erskine and Fityus, 1998** note that the Narrabeen Group geology of the region is dominated by resistant sandstones with occasional claystones and shales. Much of the sandstone is quartzose, relatively thickly bedded and often it erodes at a faster rate than it can weather and accumulate to form soils. Where beds of quartz sandstone become thicker, they form cliff lines and structural benches. These often contain thin mudstone units that lie at the base of the cliffs, or coincide with the benches.

A landform evolution model, similar to that for the conglomerate landforms in the coal measures has been postulated for Narrabeen Group sandstones, however, rather than the sandstone blocks sliding on the underlying mudstone (as occurs in the Newcastle Coal Measures), the mudstone is exposed to erosion and eroded preferentially, thus under-cutting the sandstone cliffs and causing blocks to topple (rotate) away from the receding cliff lines.

As the mudstone in the Triassic-aged rocks are typically less expansive and dispersive than the siltstones and tuffs of the Permian coal measures, they are more resistant to weathering. This means that the rate of undercutting of sandstone exposures along the Narrabeen Group ridges is relatively slower. The major difference therefore, between the Triassic and Permian Group cliff forming processes, is that the former is related to small scale block instability and not large scale mass sliding along weak tuffaceous claystone and coal seams, which has generally been the case for cliffs in the Upper Permian Group (e.g. Teralba Conglomerate).

The indicative surface geology on steep slope areas of the Project Area is presented in **Figure 4a** and shows the upper slopes are situated within interbedded sandstone / conglomerate and mudstone of the Terrigal Formation. The lower slopes are located within the interbedded mudstone and sandstone beds of the Patonga Claystone. The borehole logs in the area indicate the bedding dips towards the south-west at $1^o$ to $2^o$. Rock faces < 5 m high exist within the Terrigal Formation sandstone and conglomerate units only. The talus slopes below the cliff lines are approximately 90 m to 100 m long (down slope) and have gradients ranging from $15^o$ to $35^o$.

The rock faces are generally considered to be discontinuous, with sections ranging between 5 and 15 m in length along the slopes. Extremely weathered sections of the rock faces have left wide gaps between the sections, and it is assessed that they will act independently of each other if subject to bending and tilting from subsidence.

The rock faces are joint controlled by persistent, sub-vertical and orthogonal joint sets spaced between 1 m and 5 m. The joints strike sub-parallel and normal (perpendicular) to the faces

(NW/SE, NE/SW and E/W), with many open joints and detached blocks observed along the rock faces.

Weathering of mudstone and weaker sandstone beds has resulted in the development of 3 m to 10 m deep overhangs with 3 m to 5 m wide spans and 1 m to 2 m thick sandstone beds forming the roof.

Well-developed talus slopes with sandstone and conglomerate boulders from 0.5 m to 5 m diameter exist beneath the rock faces. The talus slopes range in height (i.e. vertical elevation between toe and crest) from 50 m to 60 m and have gradients ranging from $15^o$ to $35^o$ (typically $30^o$). The lithology of the slopes comprises interbedded sandstone and mudstone or shale of the Narrabeen Group. There are several concave and convex breaks in slope due to transitioning of sandstone dominant to claystone dominant lithologies.

Naturally incised, radial drainage gullies and ephemeral watercourses have developed along the ridges at approximately 200 m to 300 m spacing. Sandy sediments have accumulated at breaks in slope along exposed rocky, ephemeral creek beds. Open joints along the rock faces are being infilled by slopewash sediments or provide pathways for surface runoff to drain further down slope. The watercourses typically run perpendicular to the surface contours with no evidence of drainage along the contours (that is indicative of slope instability) observed.

Overall, there is no evidence of previous deep seated landslip or translational shallow sliding of the steep slopes at this stage except for the cliff fall debris (i.e. talus) already mentioned. Based on the surface observations, it is considered that the groundwater table is probably located below the rock faces and slopes. Groundwater seepages tend to concentrate along claystone beds below permeable sandstone units or form perched water tables or piezometric heads in open, clay infilled joints (on a temporary basis) after prolonged rainfall events.

### 12.5.3 Subsidence Effect Predictions

The proposed longwalls will cause subsidence, tilting and bending of the surface supporting the rock faces and steep slopes. Worst case subsidence predictions range from 0.6 m to 1.2 m above the Group 2 and 3 longwalls beneath the elevated ridges.

The predicted post mining surface slope gradient changes for the proposed mining layout are presented in **Figure 52** and indicate bedding dips may be increased or decreased by up to **+/-** $1^o$ by mine subsidence ranging from 0.6 m to 1.2 m (refer to **Figure 46a**). The predictions of maximum tilt and strain are shown in **Figures 46b** and **46d**, and indicate the slopes may be subject to tilts of 5 to 15 mm/m and tensile strains of 2 to 5 mm/m (based on a smooth subsidence profile). Strains up to 15 mm/m may occur locally due to discontinuous movements associated with steep slopes.

Based on the predictions, surface cracks ranging from 50 mm to 200 mm width may occur on the slopes. The crack depths are likely to range between 5 m and 10 m but could reach 15 m to 20 m at some locations.

It is understood that cracking has not been detected on the ridges above the Mandalong Mine's longwalls 1 to 12, with subsidence of up to 1.2 m occurring. However, the occurrence of cracking is strongly influenced by near surface lithology and differential subsidence effects and should not be ruled out above the southern Project Area.

#### 12.5.4 Overhang Collapse and Rock Falls

The predicted subsidence and associated tilt and strains could result in cracking from bending occurring in the existing cliff faces, with the release of sandstone boulders down slope. Some existing pre-mining sandstone boulders of between 0.5 m and 5 m diameter have rolled for distances of up to 100 m downhill of the cliff line crests. The boulders appear to have been stopped by tree impacts on the densely timbered slopes or at breaks in slope.

Based on reference to **ACARP, 2002**, it is possible that the release of sandstone blocks from natural weathering processes or mine induced processes could roll down slope and across public or private access roads. The proximity of existing houses to the toe of a steep slope with the potential for rock rollout events creating a hazard to buildings and persons are summarised in **Table 34**.

**Table 34 - Rock Rollout Hazard Assessment Summary**

| House No. | House Location Relative to Steep Slopes | Potential Hazard | LW |
|---|---|---|---|
| 35 | Crest of Ridge above Chain Pillar | Tensile cracking, slope instability | 33/34 |
| 34 | 400 m from toe of steep slopes | Rock roll out | 34 |
| 55 | 50 m below toe of steep slope | Rock roll out | 37 |
| 54 | Crest of steep slope | Tensile cracking, Slope instability | 43 |
| 33 | 503 m from toe of steep slope | Rock roll out | 41 |
| 109 | 314 m from toe of steep slope | Rock roll out | 31 |

The likelihood that the houses and access roads will be impacted by rock fall roll out is beyond the scope of this report. It will therefore be necessary to conduct a detailed risk assessment prior to commencement of mining in order to ascertain if rock roll out control measures will be required.

### 12.5.5 Deep-seated Land Sliding

A preliminary assessment of the likelihood of *en-masse* sliding (i.e. a deep landslip) on the ridges or hills over basal mudstone beds cracked and tilted by subsidence, have been assessed based on the Landslide Risk Assessment Guideline presented in **AGS, 2007**.

The stability of the slopes below the cliff lines in the study area should be assessed by a slope stability specialist for large-scale block sliding potential on mudstone or claystone beds in wet (saturated) and dry conditions before and after the effects of longwall mining; see **Figure 53a**.

For the purposes of a preliminary assessment, the factor of safety (FoS) against translational sliding of a sandstone rock face on mudstone beds may also be calculated using a simple force balance model defined in **Das, 1998**. The FoS for a dry and wet, cracked slope with perched water present (in the cracks) has been calculated as follows:

Before mining:

$FoS_{dry}$ = $(u_b/u_r)$ tan(Ø')/tan(theta) = 1.0 tan (10°)/tan(2°) = 5.0.

$FoS_{wet}$ = $(u_b/u_r)$ tan(Ø')/tan(theta) = 0.6 tan (10°)/tan(2°) = 3.0.

After mining:

$FoS_{dry}$ = $(u_b/u_r)$ tan(Ø')/tan(theta) = 1.0 tan (10°)/tan(3°) = 3.3.

$FoS_{wet}$ = $(u_b/u_r)$ tan(Ø')/tan(theta) = 0.6 tan (10°)/tan(3°) = 2.0.

where:

$u_b$ = buoyant unit weight of sandstone above the mudstone = 14 kN/m3

$u_r$ = dry unit weight of sandstone above the mudstone = 24 kN/$m^3$

The above theory indicates that the stability of the steep slopes will be most sensitive to (i) the shear strength properties of mudstone beds, (ii) bedding or failure plane slope (iii) surface slope and (iv) water filled cracks.

Based on reference to **Fell, 1995**, conservative drained Mohr-Coulomb residual shear strength parameters of cohesion, c=0 and friction angle, phi=$10^o$ were assumed for a softened mudstone or claystone bed in the Narrabeen Group that had been exposed to a water filled crack caused by mine subsidence or previously active slide plain material.

*Note: Residual strength implies lower bound shear strength has developed on a claystone bedding plane due to initial softening caused by water ingress, and the magnitude of bedding plane shear / horizontal strain and tilt (associated with subsidence) was sufficient to develop residual strength properties.*

*This is a conservative assumption because residual shear strength needs to develop along the bedding planes over a significant area to induce large-scale instability (eg Teralba Conglomerate block-sliding over tuffaceous claystone beds in the Lake Macquarie area). The subsidence induced residual shear strength parameters that could develop along claystone* *beds are more likely to be stepped up through the profile, rather than forming laterally extensive residual strength zones along individual bedding planes.*

*This could explain why there are no known cases of deep-seated landslips that have been attributed to mine subsidence. It is however, considered prudent to conduct laboratory testing on available core samples to estimate the residual shear strength properties of the claystone units below the steep slopes.*

The potential or likelihood of slope failure may then be considered based on reference to **Luo and Peng, 1999**, which provides the following assessment of 'sliding potential' categories for the predicted FoS values:

FoS > 1.5 'Low Potential' for slope failure

1.2 < FoS < 1.5 'Medium Potential' for slope failure

FoS < 1.2 'High Potential' for slope failure

The above values are consistent to values often used to design cuttings and fill embankments in civil works, with long and short-term stability criteria set at 1.5 and 1.2 to 1.3 for average and lower bound peak material strengths respectively (refer to **Leventhal and Stone, 1995**).

A minimum FoS of 1.2 may be adopted for a softened mudstone or claystone unit with residual strength properties that may develop after being exposed to a water filled crack for several weeks. An FoS as low as 1.0 may also be acceptable for short-term adverse loading conditions due to water filled cracks and earthquakes occurring simultaneously (which is a very unlikely scenario).

The steep slopes in their current, pre-mining condition are assessed to have a 'Low' sliding potential over an extreme range of climatic conditions (i.e. Dry to Saturated) with an FoS ranging from 3.0 to 5.0. This is confirmed by the absence of slope features that are indicative of existing or past deep seated slope instability.

The subsided slopes for the same climatic conditions and range of expected tilts and strains are also assessed to have 'Low' sliding potential (FoS ranges from 2.0 to 3.3) during worst-case conditions with unrepaired, water filled cracks.

Another important factor is the alignment of the tensile cracking in relation to the slope crests. Cracks that are sub-parallel to the slope crests will have a greater potential impact on slope instability than cracks which are perpendicular to the slope crests. The stability analysis has assumed that the cracks are longitudinal and continuous along the length of the northern and south facing slopes.

Based on the proposed east-west layout, it has been assumed that the transient cracking that occurs behind the longwall face will be perpendicular or at a high angle to the east and west facing slopes.

The potential for slope instability to develop will be minimised if significant longitudinal cracks can be sealed in a timely manner to prevent water ingress and pore-pressure build up in deep cracks.

### 12.5.6 Shallow Translational Slides

The stability of shallow clayey sands/sandy clay scree or slope wash on the $20^o$ to $35^o$ degree slopes in the Project Area should also been assessed for wet (saturated) and dry conditions before and after the effects of longwall mining.

The factor of safety (FoS) for translational sliding of the sandy clay soils over the sandstone and mudstone strata units may be calculated using a simple force balance model defined in **Das, 1998** and shown in **Figure 53c**.

The stability of the slopes will be most sensitive to (i) soil cover thickness and (ii) water filled cracks with full depth seepage along the slope. The cracking due to subsidence will also reduce the stability of the soils by removing down-side toe support to the section of slope affected by persistent cracking through the soil profile.

Based on reference to **Fell, 1995**, peak soil strength parameters of c' of 0 kPa and p' of $15^o$ to $25^o$ may be assumed for the stiff clayey sands/sandy clays in the Narrabeen Group.

The presence of water filled cracks (due to subsidence) may reduce the FoS of the slope until marginally stable conditions develop at locations where tensile cracking has occurred and prolonged rainfall events have saturated the soil and filled the cracks to the surface.

However, it is considered that the high density of tree and vegetation coverage on the slopes will mitigate against widespread translational slide failures and therefore considered acceptable in risk management terms, provided the cracks are repaired (eg. backfilled with gravel or grout) as soon as practicable.

In summary, it is considered that the potential for steep soil slope failure after mining would be 'Medium' to 'High' for the predicted tilts, strains and cracks, but may be reduced to 'Low' to 'Medium' sliding potential overall, due to the high density of trees and vegetation and with crack repairs / grouting completed.

The consequence of a shallow translational slope failure is likely to be localised and unlikely to impact on slope aesthetics. Public safety however, is a significant issue that will require further consideration (see **Section 12.5.8**).

### 12.5.7 Erosion of Slopes and Creek Beds

The potential for terrain adjustment due to erosion and deposition of soils after subsidence has also been broadly assessed.

The rate of soil erosion is expected to increase in areas with exposed dispersive/reactive soils and slopes > 18°, where these slopes are subjected to the estimated tilt increases of $1^o$. Areas with slopes < 18° are expected to have low erosion rate increases, except for the creek channels, which would be expected to re-adjust to any changes in gradient; see **Figures 52** and **Figures 54a** to **54d** for predicted gradient changes over the site.

In general, head-cuts in creek channels would be expected to develop above chain pillars between the panels and on the side where gradients increase. Sediment would be expected to accumulate where gradients decrease.

### 12.5.8 Impact Management Strategies

To minimise the likelihood of slope instability and increased erosion potential along creeks due to cracking or changes to drainage patterns after mining, the following management strategies may be implemented:

(i) Surface slope monitoring (combined with general subsidence monitoring along panel cross lines and centre lines).

(ii) Placement of signs along public access ways warning of mine subsidence impacts.

(iii) Slopes that are significantly affected by erosion after mining may need to be repaired and protected with mitigation works such as re-grading, infilling and re-vegetation of exposed areas, based on consultation with the relevant government agencies and stakeholders.

(iv) On-going review and appraisal of any significant changes to surface slopes such as cracking, increased erosion, seepages and drainage path adjustments observed after each panel is extracted.

(v) Engage specialist geotechnical consultants to conduct detailed slope stability risk management assessments for vulnerable features (i.e. Residences and public access roads located on slopes likely to be affected by mine subsidence).

(vi) Remedial works such as backfilling of surface cracks with durable material should not be attempted until after the majority of active subsidence has occurred. The active subsidence zone is likely to develop with angle of draw ahead of the retreating longwall face and approximately 1 times the cover depth behind the face.

## 12.6 Valley Uplift and Closure

### 12.6.1 Potential Impacts

Valley uplift and closure movements may occur along the drainage gullies present above the proposed mining area, based on reference to **ACARP, 2002** and local experience.

However, due to the observed low horizontal stress regime in the Mandalong Mine workings, it is considered unlikely that similar magnitude movements will occur in the gullies and broad crested valleys above the proposed longwall panels.

Uplift movements of between 100 mm and 200 mm have occurred in compressive strain zones above Mandalong Mine panels to-date at depths of cover of 180 m to 370 m. These movements are not due to the valley closure mechanism, but related to systematic subsidence development of compressive strains and cantilevering of the bending rock mass.

The lack of thick, massive beds of conglomerate and sandstone units along the creeks / valleys at the surface will also mean the development of these phenomena are likely to be limited to < 200 mm above the Project Area. Minor cracking in creek beds may cause some shallow sub-surface re-routing of surface flows due to the valley closure mechanism if it does occur.

### 12.6.2 Impact Management Strategies

The impact of valley uplift closure effects due to mine subsidence may be managed as follows:

(i) Review predictions of upsidence and valley crest movements after each panel is extracted.

(ii) Assess whether repairs to cracking, as a result of upsidence or gully slope stabilisation works are required to minimise the likelihood of long-term degradation to the environment or risk to personnel and the general public.

### 12.7 Practical Angle of Draw

The design of mining layouts that have been approved by the Department of Minerals and Resources (now Department of Industry and Investment) have applied what are known as "practical angles of draw" (referred to as Design AoD). These are conservative angles of draw that recognise the potential variability in actual draw angles, but will probably result in negligible surface impacts outside their limits. Practical angles of draw therefore provide limits to the differential movements such as tilt, curvature and strain to tolerable magnitudes, rather than attempt to limit subsidence to 20 mm.

In the NSW Coalfield's, the practical or design angle of draw applied to sensitive features is typically $26.5^{o}$ and has been applied successfully to cliff lines, waterways and sensitive archaeological sites. In some instances an additional buffer zone has been added to the design angle of draw to allow for uncertainties in final mining limits and geological and/or topographical factors.

The effectiveness of the design angle of draw of $26.5^{o}$ at Mandalong can be demonstrated by reviewing the angles of draw to the key impact parameters of tilt, curvature and strain that have been measured to-date.

Reference to **NERDDP, 1993** and **ACARP, 2002** indicate the following subsidence profile limits are appropriate for minimising impact to TransGrid Tension Towers and other sensitive environmental or Aboriginal Heritage features:

- Subsidence: 50 - 100 mm
- Tilt: 1.5 - 2 mm/m
- Curvature: 0.06 - 0.1 $km^{-1}$ (radius of curvature > 10 km)
- Tensile Strain: 0.5 - 1.0 mm/m
- Compressive Strain: 1.5 - 2 mm/m

The limits above also take into account the survey accuracy limits for the available data.

The measured impact parameters at a $26.5^{o}$ angle of draw to the above parameters at Mandalong Mine are summarised in **Table 37**. Histograms of the measured subsidence, tilt and tensile strain values measured at or outside a distance equivalent to the $26.5^{o}$ angle of draw is presented in **Figures 55a** to **55c**.

It is apparent from the results in **Table 37** and experience at Mandalong that a design angle of draw of $26.5^{o}$ from the sides and ends of longwall panels to sensitive surface features is unlikely to impact a given feature. The measured subsidence and tilts were within the tolerable limits defined above, however the curvatures and strains exceed the limits on occasion and may be due to survey accuracy limits for the method of measurement.

**Table 37 - Summary of Practical Angle of Draw Limits**

| Impact Parameter Limit | Measured Impact Parameters at or outside a 26.5$^o$ Angle of Draw | | | |
|---|---|---|---|---|
| | XL1 | XL2 | XL3 | Mean |
| Subsidence (mm) | 2 - 41 | 6 - 45 | 3 - 22 | 16 |
| Tilt (mm/m) | 0.3 - 1.0 | 0.3 - 1.8 | 0.3 - 1.9 | 0.9 |
| Curvature (km$^{-1}$) | 0.02 - 0.12 | 0.02 - 0.14 | 0.03 - 0.19 | 0.08 |
| *Horizontal Tensile or Compressive Strain (mm/m)* | *0.2 - 1.4* | *0.3 - 1.5* | *0.4 - 1.6* | *0.85* |

*Italics* - Total Station strains likely to be affected by survey accuracy limits of +/- 1 mm/m.

Reference to measured strains using standard steel tape at other Newcastle Coalfield mines indicate that the horizontal strains are likely to be < 1 mm/m at a 26.5$^o$ angle of draw for the panel extraction limits proposed (see **Section 12.8**).

It will therefore be necessary to conduct further curvature and strain measurement programs using a more accurate technique to define appropriate set-back distances from the tension towers.

## 12.8 Far-Field Horizontal Displacements and Strains

### 12.8.1 Background to Prediction Model Development

Far-field displacements (FFDs) generally only have the potential to damage long, linear features such as pipelines, bridges and dam walls. TransGrid tension towers may also be vulnerable to far-field movements and strains. It is understood from preliminary discussions with TransGrid Engineers that the tension towers will be able to tolerate up to 1 mm/m of horizontal strain. Horizontal tower displacements are usually accommodated by installing flexible ‘stringers’ on the towers before subsidence occurs.

Horizontal movements due to longwall mining have been recorded at distances well outside of the angle of draw in the Newcastle, Southern and Western Coalfields (**Reid, 1998, Seedsman and Watson, 2001**). Horizontal movements recorded beyond the angle of draw are referred to as far-field horizontal displacements.

For example, at Cataract Dam in the Southern NSW Coalfield, **Reid, 1998** reported horizontal movements of up to 25 mm when underground coal mining was about 1.5 km away. **Seedsman and Watson, 2001** reported movements in the Newcastle Coalfield of around 20 mm at distances of approximately 220 m, for a cover depth ranging from 70 to 100 m and a panel width of 193 m.

Based on a review of the above information, it is apparent that this phenomenon is dependent on (i) cover depth, (ii) distance from the goaf edges, (iii) maximum subsidence over the extracted area, (iv) topographic relief and (v) horizontal stress field characteristics.

An empirical model for predicting FFDs in the Newcastle Coalfield is presented in **Figure 56a**. The model indicates that measurable FFD movements (i.e. 20 mm) generally occur in relatively flat terrain for distances up to 3 to 4 times the cover depth.

An empirical model for predicting far-field strains (FFSs) in the Newcastle Coalfield is presented in **Figure 56b**. The model indicates that measureable (but diminishing) strains can also occur outside the limits of longwall extraction for distances up to one cover depth (based on the Upper 99% Confidence limit curve). It is assessed that strains will be <1 mm/m at a distance equal to 0.5 x cover depth in the Newcastle Coalfield, and therefore unlikely to cause damage beyond this distance.

It should be noted that the model was based on steel tape measurements which did not extend further than a distance equal to the 1.5 times the cover depth from the extraction limits. Any FFS predictions that are >1.5 times the cover depth from the panels in this report are therefore an extrapolation of the regression lines for the database and have no empirical justification.

### 12.8.2 Far-Field Strain Predictions at TransGrid Tension Towers

The existing TransGrid Tension Towers that are not proposed to be re-located will be protected from excessive horizontal strains by the 26.5$^o$ Angle of Draw Buffer zone from proposed longwall extraction limits. For predicted maximum panel subsidence of 0.5 m and 1.2 m, the far-field strains are predicted to range between 0.4 mm/m and 1 mm/m from the ends of the longwall panels; see **Figure 56a**.

Available total station survey data at Mandalong indicates a horizontal tensile strain range of 0.2 mm/m to 1.6 mm/m (mean of 0.85 mm/m) has occurred along XLs 1 to 3 at an angle of draw of 26.5$^o$ outside the limits of the workings. It is apparent that the total station data is affected by survey accuracy limitations, with some tensile and compressive strains of up to 4 mm/m reported. These strain values are unprecedented in the Newcastle Coalfield and therefore considered to be data “errors” or associated with disturbed survey pegs (which can be identified by pairs of high tensile and compressive strain readings).

It is considered that the method of measuring strain using total station techniques has an accuracy range of +/- 1 to 1.5 mm/m at best. It is therefore likely that measured strains in excess of 1 mm/m beyond a 26.5$^o$ AoD at Mandalong are not ‘real’ and more likely to be related to survey technique accuracy rather than actual ground strain exceedances. It will therefore be necessary to improve on strain measurement accuracy above future longwalls at non-sensitive locations to demonstrate that this is the case.

### 12.8.3 Far- Field Displacement and Strains at F3 Freeway and Infrastructure

The F3 Freeway and associated infrastructure is 1200m from LW51 and five times the cover depth of 240 m from the eastern longwall panels and assessed to be well outside the limits of measureable absolute horizontal displacement and strain (i.e. +/-10 mm and +/- 0.3 mm/m). It is considered that it will not be necessary to prepare a subsidence management plan for these.

### 12.8.4 Impact Management Strategies

The proposed 0.5H set-back distances of longwall mining to the TransGrid Towers are considered adequate at this stage to minimise the potential for damage occurring to them to very low likelihoods (i.e. < 1% probability of occurrence). Monitoring of absolute and relative ground and tower structure movement as subsidence develops will still be necessary for all of the tension towers within the Project Area.

Centennial is in consultation with TransGrid to undertake a feasibility study on the treatment of tension towers. This may require the relocation of a section of TL24.

Further research, in consultation with TransGrid and DRE, into the performance of the various buffer zone set back distances should therefore be established with simulated tower monitoring programs in non-sensitive locations. Isolation of tension towers from ground strains may also be able to be achieved by constructing trenches backfilled with compressible material between the towers and the limits of longwall extraction.

Further discussion of impact management strategies for existing suspension towers are presented in **Section 12.10**.

## 12.9 Aboriginal Heritage Sites

### 12.9.1 Predicted Subsidence Effects

The predicted final subsidence, tilt and horizontal strain for each listed site after the proposed LWs 25 to 64 are presented in **Table 38**.

**Table 38 - Predicted Subsidence Effects at Aboriginal Heritage Sites**

| Site No | Site Type | Easting (MGA) (m) | Northing (MGA) (m) | Final Subsidence (m) | Tilt (mm/m) | Horizontal Strain (mm/m)^ |
|---|---|---|---|---|---|---|
| RPS TBM11 | Artefact | See notes below | | -0.61 | 1.6 | -2.0 |
| RPS PS25 | Artefact Scatter | | | -0.98 | 1.1 | -0.2 |
| RPS TBM03 | Artefact Scatter | | | -0.40 | 2.4 | -0.1 |
| RPS TBM29 | Artefact Scatter | | | -0.63 | 7.5 | 4.6 |
| RPS TBM30a | Artefact Scatter | | | 0.00 | 0.0 | 0.0 |
| RPS TBM30b | Artefact Scatter | | | 0.00 | 0.0 | 0.0 |
| RPS TBM37 | Artefact Scatter | | | -0.59 | 1.3 | -1.5 |
| RPS AH06 | Stone Artefacts | | | 0.00 | 0.0 | 0.0 |
| RPS AH18 | Isolated Find | | | 0.00 | 0.0 | 0.0 |
| RPS TBM04 | Isolated Find | | | -0.47 | 4.6 | -0.4 |
| RPS TBM60 | Isolated Find | | | 0.00 | 0.0 | 0.0 |
| RPS AH05 | Scarred Tree | | | 0.00 | 0.0 | 0.0 |
| RPS AH12 | Scarred Tree | | | 0.00 | 0.0 | 0.0 |
| RPS AH13 | Scarred Tree | | | 0.00 | 0.0 | 0.0 |
| RPS AH17 | Scarred Tree | | | 0.00 | 0.0 | 0.0 |
| RPS CYL03 | Scarred Tree | | | 0.00 | 0.0 | 0.0 |
| RPS PS33 | Scarred Tree | | | 0.00 | 0.0 | 0.0 |
| RPS TBM17 | Scarred Tree | | | -0.24 | 3.7 | 0.3 |
| RPS TBM20 | Scarred Tree | | | -0.49 | 1.7 | -0.4 |
| RPS TBM22 | Scarred Tree | | | -0.47 | 2.0 | 0.6 |
| RPS TBM33 | Scarred Tree | | | -0.95 | 1.5 | -3.1 |
| RPS TBM52 | Scarred Tree | | | -0.44 | 2.3 | 3.7 |
| 45-3-1223 | Open Camp Site | | | -0.96 | 2.8 | -4.1 |
| 45-3-1224 | Grinding Groove | | | -0.28 | 4.7 | 4.6 |
| 45-3-1225 | Grinding Groove | | | -0.66 | 7.7 | -1.0 |
| 45-3-1226 | Grinding Groove | | | -1.03 | 1.4 | 0.4 |
| 45-3-1227 | Grinding Groove | | | 0.00 | 0.0 | 0.0 |
| 45-3-1234 | Grinding Groove | | | 0.00 | 0.0 | 0.0 |
| 45-3-1235 | Grinding Groove | | | 0.00 | 0.0 | 0.0 |
| 45-3-2970 | Grinding Groove | | | -0.58 | 2.0 | 2.1 |
| RPS AH01 | Grinding Groove | | | -0.40 | 1.3 | 2.3 |
| RPS AH02 | Grinding Groove | | | -0.12 | 3.8 | 1.9 |
| RPS AH03 | Grinding Groove | | | -0.01 | 0.4 | 0.4 |
| RPS AH04 | Grinding Groove | | | 0.00 | 0.2 | 0.2 |
| RPS AH07 | Grinding Groove | | | -0.01 | 1.1 | 0.4 |
| RPS AH08 | Grinding Groove | | | -0.01 | 1.2 | 0.4 |

## Table 38 (Cont…) - Predicted Subsidence Effects at Aboriginal Heritage Sites

| Site No | Site Type | Easting (MGA) (m) | Northing (MGA) (m) | Final Subsidence (m) | Tilt (mm/m) | Horizontal Strain (mm/m)^ |
|---|---|---|---|---|---|---|
| RPS AH09 | Grinding Groove | See notes below | | 0.00 | 0.0 | 0.0 |
| RPS CYL01 | Grinding Groove | | | -0.54 | 4.8 | -3.3 |
| RPS CYL02 | Grinding Groove | | | -0.18 | 5.2 | 2.0 |
| RPS CYL04a | Grinding Groove | | | -0.41 | 1.3 | 3.6 |
| RPS CYL04b | Grinding Groove | | | -0.41 | 1.0 | 3.8 |
| RPS CYL04c | Grinding Groove | | | -0.45 | 3.8 | 3.0 |
| RPS CYL05 | Grinding Groove | | | -1.01 | 3.4 | -1.6 |
| RPS CYL06 | Grinding Groove | | | -0.61 | 2.2 | -0.5 |
| RPS CYL07 | Grinding Groove | | | -0.03 | 1.4 | 1.3 |
| RPS DF01 | Grinding Groove | | | 0.00 | 0.0 | 0.0 |
| RPS DF02 | Grinding Groove | | | 0.00 | 0.0 | 0.0 |
| RPS DF03 | Grinding Groove | | | -0.82 | 8.3 | -3.0 |
| RPS DF04 | Grinding Groove | | | -0.77 | 8.5 | -2.4 |
| RPS PS11 | Grinding Groove | | | -0.95 | 4.1 | -4.1 |
| RPS PS12A | Grinding Groove | | | -0.74 | 4.6 | -2.1 |
| RPS PS12B | Grinding Groove | | | -0.62 | 5.6 | 0.4 |
| RPS PS26 | Grinding Groove | | | -0.80 | 2.5 | -0.5 |
| RPS TBM01 | Grinding Groove | | | 0.00 | 0.1 | 0.0 |
| RPS TBM02 | Grinding Groove | | | -0.50 | 2.6 | 0.5 |
| RPS TBM05 | Grinding Groove | | | -0.57 | 2.7 | -0.6 |
| RPS TBM06 | Grinding Groove | | | -0.64 | 0.9 | -1.2 |
| RPS TBM07 | Grinding Groove | | | -0.54 | 1.5 | 0.9 |
| RPS TBM08 | Grinding Groove | | | -0.52 | 2.4 | -0.8 |
| RPS TBM10 | Grinding Groove | | | -0.54 | 2.8 | 2.0 |
| RPS TBM12 | Grinding Groove | | | 0.00 | 0.9 | 0.0 |
| RPS TBM13 | Grinding Groove | | | 0.00 | 0.7 | 0.2 |
| RPS TBM14 | Grinding Groove | | | 0.00 | 0.3 | 0.2 |
| RPS TBM26 | Grinding Groove | | | -0.02 | 0.8 | 0.6 |
| RPS TBM27 | Grinding Groove | | | 0.00 | 0.1 | 0.1 |
| RPS TBM28 | Grinding Groove | | | 0.00 | 0.2 | 0.2 |
| RPS TBM31 | Grinding Groove | | | -0.91 | 5.9 | -3.2 |
| RPS TBM34 | Grinding Groove | | | -0.74 | 9.4 | 1.9 |
| RPS TBM38 | Grinding Groove | | | -0.69 | 3.7 | -0.2 |
| RPS TBM40 | Grinding Groove | | | -1.03 | 9.0 | 0.1 |
| RPS TBM43 | Grinding Groove | | | -0.54 | 5.9 | 2.1 |
| RPS TBM44 | Grinding Groove | | | -0.47 | 2.7 | 3.8 |
| RPS TBM45 | Grinding Groove | | | -0.54 | 5.8 | 2.9 |
| RPS TBM46 | Grinding Groove | | | -0.69 | 7.3 | -0.4 |
| RPS TBM47 | Grinding Groove | | | -0.84 | 2.5 | -4.1 |
| RPS TBM49 | Grinding Groove | | | -0.44 | 2.5 | 3.1 |
| RPS TBM50 | Grinding Groove | | | -0.43 | 0.7 | 3.5 |
| RPS TBM51 | Grinding Groove | | | -0.47 | 4.1 | 3.4 |
| RPS TBM54 | Grinding Groove | | | -0.46 | 1.1 | 3.1 |

## Table 38 (Cont…) - Predicted Subsidence Effects at Aboriginal Heritage Sites

| Site No | Site Type | Easting (MGA) (m) | Northing (MGA) (m) | Final Subsidence (m) | Tilt (mm/m) | Horizontal Strain (mm/m)^ |
|---|---|---|---|---|---|---|
| RPS TBM63 | Grinding Groove | See notes below | | 0.00 | 0.0 | 0.0 |
| RPS TBM64 | Grinding Groove | | | 0.00 | 0.0 | 0.0 |
| 45-3-1228 | Rock Shelter + Art | | | -0.11 | 3.4 | 1.6 |
| 45-3-1229 | Rock Shelter + Art | | | -0.01 | 0.9 | 0.1 |
| 45-3-1230 | Rock Shelter + Art | | | 0.00 | 0.0 | 0.0 |
| 45-3-1233 | Rock Shelter + Art | | | -1.04 | 0.2 | 0.7 |
| 45-3-2880 | Rock Shelter + Art | | | -0.01 | 0.2 | 0.2 |
| 45-3-2881 | Rock Shelter + Art | | | -0.01 | 0.3 | 0.2 |
| 45-3-2889 | Rock Shelter + Art | | | -0.01 | 0.2 | 0.1 |
| RPS PS06 | Rock Shelter + Art + Deposit | | | -0.40 | 4.0 | -0.1 |
| 45-3-1232 | Rock Shelter + Art | | | -0.39 | 4.3 | -0.1 |
| 45-3-1231 | Rock Shelter + Deposit | | | -0.72 | 0.6 | -0.7 |
| RPS AH10 | Rock Shelter + PAD | | | 0.00 | 0.0 | 0.0 |
| RPS AH11 | Rock Shelter + PAD | | | 0.00 | 0.0 | 0.0 |
| RPS AH16 | Rock Shelter + PAD | | | 0.00 | 0.0 | 0.0 |
| RPS PS08 | Rock Shelter + PAD | | | -0.52 | 3.1 | -0.4 |
| RPS PS09 | Rock Shelter + PAD | | | -0.47 | 3.5 | -0.3 |
| RPS PS20 | Rock Shelter + PAD | | | -0.72 | 0.8 | -0.7 |
| RPS PS22 | Rock Shelter + PAD | | | -0.69 | 1.4 | -0.4 |
| RPS PS28 | Rock Shelter + PAD | | | -1.02 | 1.4 | -0.6 |
| RPS PS32 | Rock Shelter + PAD | | | -0.92 | 3.6 | -1.3 |
| RPS TBM19 | Rock Shelter + PAD | | | -0.46 | 2.2 | -0.6 |
| RPS TBM35 | Rock Shelter + PAD | | | -0.56 | 1.9 | -0.3 |
| RPS TBM41 | Rock Shelter + PAD | | | -1.12 | 3.4 | -1.2 |
| RPS TBM42 | Rock Shelter + PAD | | | -1.16 | 3.5 | 0.0 |
| RPS TBM53 | Rock Shelter + PAD | | | -0.46 | 2.2 | 3.1 |
| RPS TBM58 | Rock Shelter + PAD | | | 0.00 | 0.0 | 0.0 |
| 45-3-3436 | Rock Shelter | | | -0.53 | 2.6 | -0.1 |
| 45-3-3437 | Rock Shelter | | | -0.42 | 0.6 | 0.9 |
| 45-3-3438 | Rock Shelter | | | -0.30 | 3.1 | -0.2 |
| RPS AH14 | Stone Arrangement | | | 0.00 | 0.0 | 0.0 |
| RPS AH15 | Stone Arrangement | | | 0.00 | 0.0 | 0.0 |
| RPS TBM32 | Stone Arrangement | | | -0.93 | 3.1 | -2.5 |

^ - Tensile strain is positive.
The site coordinates have been removed as requested by one of the Aboriginal groups.

### 12.9.2 Potential Impacts

The likelihood of damage occurring at the sites has been assessed based on the following impact parameter criteria (see **Table 39**). The criteria consider the theoretical cracking limits of rock of 0.3 to 0.5 mm/m and the 'system' slackness or strain 'absorbing' properties of a jointed and weathered rock mass during subsidence deformation. The lack of measured observed impact (i.e. surface cracking) due to measured strains of up to 2 to 3 mm/m above the Mandalong Mine is an example of the difference between theoretical and in-situ rock mass cracking behaviour.

If necessary, the span or dimensions of rock shelters or grinding groove sites and the orientation of natural jointing and mining panels proposed, may also be factored into the assessment of the criteria for individual sites (refer to **Shepherd and Sefton, 2001**). At this stage, the specific geotechnical characteristics of each site have not been included, but may be necessary for Extraction Plan development.

**Table 39 – Impact Potential Criteria for Aboriginal Heritage Sites**

| **Cracking Damage Potential - Indicative Probabilities of Occurrence** | **Predicted 'smooth profile' Horizontal Strain (mm/m)** | |
|---|---|---|
| | **Tensile** | **Compressive** |
| Very Unlikely (<5%) | <0.5 | <2 |
| Unlikely (5 - 10%) | 0.5 - 1.5 | 2 - 3 |
| Possible (10 - 25%) | 1.5 - 2.5 | 3 - 5 |
| Likely (>25%) | >2.5 | >5 |
| **Erosion Damage Potential - Indicative Probabilities of Occurrence** | **Predicted Surface Gradient Change or Tilt Increase** | |
| Very Unlikely (<5%) | <0.3% (<3 mm/m) | |
| Unlikely (5 - 10%) | 0.3-1% (3 - 10 mm/m) | |
| Possible (10 - 25%) | 1-3% (10 - 30 mm/m) | |
| Likely (>25%) | >3% (>30 mm/m) | |

The 'Cracking Damage Potential' is considered the primary damage potential indicator and the 'Erosion Damage Potential' is an additional, secondary criterion that is relevant to features exposed to concentrated water flows along creeks or sites that have been damaged by cracking. Therefore, for the cases where cracking is deemed 'possible' or 'likely' at a site, the potential for erosion damage will also be considered 'possible' or 'likely'.

The results of the impact assessment are presented in **Table 40**.

**Table 40 - Predicted Subsidence Impacts at Aboriginal Heritage Sites**

| Site No | Site Type | Subsidence (m) | Horizontal Strain (mm/m)^ | Cracking Damage Potential* | Tilt (mm/m) | Erosion Damage Potential* |
|---|---|---|---|---|---|---|
| RPS TBM11 | Artefact | -0.61 | -2.0 | V. Unlikely | 1.6 | V. Unlikely |
| RPS PS25 | Artefact Scatter | -0.98 | -0.2 | V. Unlikely | 1.1 | V. Unlikely |
| RPS TBM03 | Artefact Scatter | -0.40 | -0.1 | V. Unlikely | 2.4 | V. Unlikely |
| **RPS TBM29** | **Artefact Scatter** | **-0.63** | **4.6** | **Likely** | **7.5** | **Likely** |
| RPS TBM30a | Artefact Scatter | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS TBM30b | Artefact Scatter | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS TBM37 | Artefact Scatter | -0.59 | -1.5 | V. Unlikely | 1.3 | V. Unlikely |
| RPS AH06 | Stone Artefacts | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS AH18 | Isolated Find | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS TBM04 | Isolated Find | -0.47 | -0.4 | V. Unlikely | 4.6 | Unlikely |
| RPS TBM60 | Isolated Find | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS AH05 | Scarred Tree | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS AH12 | Scarred Tree | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS AH13 | Scarred Tree | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS AH17 | Scarred Tree | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS CYL03 | Scarred Tree | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS PS33 | Scarred Tree | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS TBM17 | Scarred Tree | -0.24 | 0.3 | V. Unlikely | 3.7 | Unlikely |
| RPS TBM20 | Scarred Tree | -0.49 | -0.4 | V. Unlikely | 1.7 | V. Unlikely |
| RPS TBM22 | Scarred Tree | -0.47 | 0.6 | Unlikely | 2.0 | V. Unlikely |
| RPS TBM33 | Scarred Tree | -0.95 | -3.1 | *Possible* | 1.5 | V. Unlikely |
| **RPS TBM52** | **Scarred Tree** | **-0.44** | **3.7** | **Likely** | **2.3** | **Likely** |
| 45-3-1223 | Open Camp Site | -0.96 | -4.1 | *Possible* | 2.8 | V. Unlikely |
| **45-3-1224** | **Grinding Groove** | **-0.28** | **4.6** | **Likely** | **4.7** | **Likely** |
| 45-3-1225 | Grinding Groove | -0.66 | -1.0 | V. Unlikely | 7.7 | Unlikely |
| 45-3-1226 | Grinding Groove | -1.03 | 0.4 | V. Unlikely | 1.4 | V. Unlikely |
| 45-3-1227 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| 45-3-1234 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| 45-3-1235 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| 45-3-2970 | Grinding Groove | -0.58 | 2.1 | *Possible* | 2.0 | V. Unlikely |
| RPS AH01 | Grinding Groove | -0.40 | 2.3 | *Possible* | 1.3 | V. Unlikely |
| RPS AH02 | Grinding Groove | -0.12 | 1.9 | *Possible* | 3.8 | Unlikely |
| RPS AH03 | Grinding Groove | -0.01 | 0.4 | V. Unlikely | 0.4 | V. Unlikely |
| RPS AH04 | Grinding Groove | 0.00 | 0.2 | V. Unlikely | 0.2 | V. Unlikely |
| RPS AH07 | Grinding Groove | -0.01 | 0.4 | V. Unlikely | 1.1 | V. Unlikely |
| RPS AH08 | Grinding Groove | -0.01 | 0.4 | V. Unlikely | 1.2 | V. Unlikely |
| RPS AH09 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS CYL01 | Grinding Groove | -0.54 | -3.3 | *Possible* | 4.8 | Unlikely |
| RPS CYL02 | Grinding Groove | -0.18 | 2.0 | *Possible* | 5.2 | Unlikely |
| **RPS CYL04a** | **Grinding Groove** | **-0.41** | **3.6** | **Likely** | **1.3** | **Likely** |
| **RPS CYL04b** | **Grinding Groove** | **-0.41** | **3.8** | **Likely** | **1.0** | **Likely** |
| **RPS CYL04c** | **Grinding Groove** | **-0.45** | **3.0** | **Likely** | **3.8** | **Likely** |
| RPS CYL05 | Grinding Groove | -1.01 | -1.6 | V. Unlikely | 3.4 | Unlikely |

**Table 40 (Cont…) - Predicted Subsidence Impacts at Aboriginal Heritage Sites**

| Site No | Site Type | Subsidence (m) | Horizontal Strain (mm/m)^ | Cracking Damage Potential* | Tilt (mm/ m) | Erosion Damage Potential* |
|---|---|---|---|---|---|---|
| RPS CYL06 | Grinding Groove | -0.61 | -0.5 | V. Unlikely | 2.2 | V. Unlikely |
| RPS CYL07 | Grinding Groove | -0.03 | 1.3 | Unlikely | 1.4 | V. Unlikely |
| RPS DF01 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS DF02 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS DF03 | Grinding Groove | -0.82 | -3.0 | *Possible* | 8.3 | Unlikely |
| RPS DF04 | Grinding Groove | -0.77 | -2.4 | Unlikely | 8.5 | Unlikely |
| RPS PS11 | Grinding Groove | -0.95 | -4.1 | *Possible* | 4.1 | Unlikely |
| RPS PS12A | Grinding Groove | -0.74 | -2.1 | Unlikely | 4.6 | Unlikely |
| RPS PS12B | Grinding Groove | -0.62 | 0.4 | V. Unlikely | 5.6 | Unlikely |
| RPS PS26 | Grinding Groove | -0.80 | -0.5 | V. Unlikely | 2.5 | V. Unlikely |
| RPS TBM01 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.1 | V. Unlikely |
| RPS TBM02 | Grinding Groove | -0.50 | 0.5 | Unlikely | 2.6 | V. Unlikely |
| RPS TBM05 | Grinding Groove | -0.57 | -0.6 | V. Unlikely | 2.7 | V. Unlikely |
| RPS TBM06 | Grinding Groove | -0.64 | -1.2 | V. Unlikely | 0.9 | V. Unlikely |
| RPS TBM07 | Grinding Groove | -0.54 | 0.9 | Unlikely | 1.5 | V. Unlikely |
| RPS TBM08 | Grinding Groove | -0.52 | -0.8 | V. Unlikely | 2.4 | V. Unlikely |
| RPS TBM10 | Grinding Groove | -0.54 | 2.0 | *Possible* | 2.8 | V. Unlikely |
| RPS TBM12 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.9 | V. Unlikely |
| RPS TBM13 | Grinding Groove | 0.00 | 0.2 | V. Unlikely | 0.7 | V. Unlikely |
| RPS TBM14 | Grinding Groove | 0.00 | 0.2 | V. Unlikely | 0.3 | V. Unlikely |
| RPS TBM26 | Grinding Groove | -0.02 | 0.6 | Unlikely | 0.8 | V. Unlikely |
| RPS TBM27 | Grinding Groove | 0.00 | 0.1 | V. Unlikely | 0.1 | V. Unlikely |
| RPS TBM28 | Grinding Groove | 0.00 | 0.2 | V. Unlikely | 0.2 | V. Unlikely |
| RPS TBM31 | Grinding Groove | -0.91 | -3.2 | *Possible* | 5.9 | Unlikely |
| RPS TBM34 | Grinding Groove | -0.74 | 1.9 | *Possible* | 9.4 | Unlikely |
| RPS TBM38 | Grinding Groove | -0.69 | -0.2 | V. Unlikely | 3.7 | Unlikely |
| RPS TBM40 | Grinding Groove | -1.03 | 0.1 | V. Unlikely | 9.0 | Unlikely |
| RPS TBM43 | Grinding Groove | -0.54 | 2.1 | *Possible* | 5.9 | Unlikely |
| **RPS TBM44** | **Grinding Groove** | **-0.47** | **3.8** | **Likely** | **2.7** | **Likely** |
| **RPS TBM45** | **Grinding Groove** | **-0.54** | **2.9** | **Likely** | **5.8** | **Likely** |
| RPS TBM46 | Grinding Groove | -0.69 | -0.4 | V. Unlikely | 7.3 | Unlikely |
| RPS TBM47 | Grinding Groove | -0.84 | -4.1 | *Possible* | 2.5 | V. Unlikely |
| **RPS TBM49** | **Grinding Groove** | **-0.44** | **3.1** | **Likely** | **2.5** | **Likely** |
| **RPS TBM50** | **Grinding Groove** | **-0.43** | **3.5** | **Likely** | **0.7** | **Likely** |
| **RPS TBM51** | **Grinding Groove** | **-0.47** | **3.4** | **Likely** | **4.1** | **Likely** |
| **RPS TBM54** | **Grinding Groove** | **-0.46** | **3.1** | **Likely** | **1.1** | **Likely** |
| RPS TBM63 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS TBM64 | Grinding Groove | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| 45-3-1228 | Rock Shelter + Art | -0.11 | 1.6 | *Possible* | 3.4 | Unlikely |
| 45-3-1229 | Rock Shelter + Art | -0.01 | 0.1 | V. Unlikely | 0.9 | V. Unlikely |
| 45-3-1230 | Rock Shelter + Art | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| 45-3-1233 | Rock Shelter + Art | -1.04 | 0.7 | Unlikely | 0.2 | V. Unlikely |
| 45-3-2880 | Rock Shelter + Art | -0.01 | 0.2 | V. Unlikely | 0.2 | V. Unlikely |

**Table 40 (Cont…) - Predicted Subsidence Impacts at Aboriginal Heritage Sites**

| Site No | Site Type | Subsidence (m) | Horizontal Strain (mm/m)^ | Cracking Damage Potential* | Tilt (mm /m) | Erosion Damage Potential* |
|---|---|---|---|---|---|---|
| 45-3-2881 | Rock Shelter + Art | -0.01 | 0.2 | V. Unlikely | 0.3 | V. Unlikely |
| 45-3-2889 | Rock Shelter + Art | -0.01 | 0.1 | V. Unlikely | 0.2 | V. Unlikely |
| RPS PS06 | Rock Shelter + Art + Deposit | -0.40 | -0.1 | V. Unlikely | 4.0 | Unlikely |
| 45-3-1232 | Rock Shelter + Art | -0.39 | -0.1 | V. Unlikely | 4.3 | Unlikely |
| 45-3-1231 | Rock Shelter + Deposit | -0.72 | -0.7 | V. Unlikely | 0.6 | V. Unlikely |
| RPS AH10 | Rock Shelter + PAD | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS AH11 | Rock Shelter + PAD | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS AH16 | Rock Shelter + PAD | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS PS08 | Rock Shelter + PAD | -0.52 | -0.4 | V. Unlikely | 3.1 | Unlikely |
| RPS PS09 | Rock Shelter + PAD | -0.47 | -0.3 | V. Unlikely | 3.5 | Unlikely |
| RPS PS20 | Rock Shelter + PAD | -0.72 | -0.7 | V. Unlikely | 0.8 | V. Unlikely |
| RPS PS22 | Rock Shelter + PAD | -0.69 | -0.4 | V. Unlikely | 1.4 | V. Unlikely |
| RPS PS28 | Rock Shelter + PAD | -1.02 | -0.6 | V. Unlikely | 1.4 | V. Unlikely |
| RPS PS32 | Rock Shelter + PAD | -0.92 | -1.3 | V. Unlikely | 3.6 | Unlikely |
| RPS TBM19 | Rock Shelter + PAD | -0.46 | -0.6 | V. Unlikely | 2.2 | V. Unlikely |
| RPS TBM35 | Rock Shelter + PAD | -0.56 | -0.3 | V. Unlikely | 1.9 | V. Unlikely |
| RPS TBM41 | Rock Shelter + PAD | -1.12 | -1.2 | V. Unlikely | 3.4 | Unlikely |
| RPS TBM42 | Rock Shelter + PAD | -1.16 | 0.0 | V. Unlikely | 3.5 | Unlikely |
| **RPS TBM53** | **Rock Shelter + PAD** | **-0.46** | **3.1** | **Likely** | **2.2** | **Likely** |
| RPS TBM58 | Rock Shelter + PAD | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| 45-3-3436 | Rock Shelter | -0.53 | -0.1 | V. Unlikely | 2.6 | V. Unlikely |
| 45-3-3437 | Rock Shelter | -0.42 | 0.9 | Unlikely | 0.6 | V. Unlikely |
| 45-3-3438 | Rock Shelter | -0.30 | -0.2 | V. Unlikely | 3.1 | Unlikely |
| RPS AH14 | Stone Arrangement | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS AH15 | Stone Arrangement | 0.00 | 0.0 | V. Unlikely | 0.0 | V. Unlikely |
| RPS TBM32 | Stone Arrangement | -0.93 | -2.5 | Unlikely | 3.1 | Unlikely |
| RPS TBM09 | Water Source | -0.68 | 0.3 | V. Unlikely | 2.5 | V. Unlikely |

^ - Tensile strain is positive; V. Unlikely - Very Unlikely; * - see **Table 39** for Impact Potential definitions.

The results in **Table 40** indicate the following potential impacts to the Aboriginal Heritage Sites due to the proposed longwalls:

- One Artefact Scatter site is 'likely' to be impacted or lost into surface cracking by erosional processes.

- One Scared tree site is 'likely' to be impacted by surface cracking and one site may 'possibly' be impacted.

- Ten grinding groove sites are 'likely' to be impacted by cracking and 12 may 'possibly' be impacted.

- One Rock Shelter with PADs is ‘likely’ to be impacted by cracking and erosion damage.

- One Rock Shelter with Art may ‘possibly’ be impacted by cracking and erosion damage.

- All other sites are ‘unlikely’ or very unlikely’ to be affected by cracking.

Overall, it is assessed that 13 sites (12% of known sites) are ‘likely’ to be impacted by cracking and erosion damage and 15 (13%) may possibly be impacted by the proposed longwalls.

#### 12.9.3 Impact Management Strategies

Impact management strategies for Aboriginal sites are presented in the Aboriginal Cultural Heritage Assessment for the Mandalong Southern Extension Project and have been developed in consultation with Aboriginal stakeholders and their consultants.

### 12.10 TransGrid Towers

#### 12.10.1 Predicted Subsidence and Potential Impacts

Predictions of worst-case transient and final subsidence, tilt and strain at each of the TransGrid Towers have been made based on the proposed longwalls 25 to 64.

A summary of the subsidence prediction results for each mining scenario is presented in **Tables 41**. The results are derived from the subsidence contour predictions and do not include discontinuous strata behaviour effects.

## Table 41 - Final and Transient* Subsidence Effects at the TransGrid Towers

| Tower # | Line # | Final Tower Subsidence $S_{max}$ (m) | Maximum Tilt $T_{max}$ (mm/m) | | Maximum Horizontal Displacement $HD_{max}$ (mm) | | Tower Movement Directions | Maximum Horizontal Strain^ $E_{max}$ (mm/m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Trans | Final | Trans | Final | | Trans | Final |
| 27 | TL25.26 | 0.00 | 0.0 | 0.0 | 0 | 7 | SW | 0.0 | 0.0 |
| 28 | TL25.26 | 0.00 | 0.0 | 0.0 | 0 | 9 | S | 0.1 | 0.1 |
| 29 | TL25.26 | 0.00 | 0.0 | 0.0 | 0 | 10 | S | 0.2 | 0.2 |
| 30 | TL25.26 | 0.00 | 0.2 | 0.2 | 2 | 8 | S | 0.2 | 0.2 |
| 31 | TL25.26 | 0.00 | 0.3 | 0.3 | 3 | 8 | S | 0.3 | 0.3 |
| **32** | **TL25.26** | **-0.01** | **0.3** | **0.3** | **3** | **9** | **S** | **0.3** | **0.3** |
| 33 | TL25.26 | -0.02 | 0.5 | 0.5 | 5 | 19 | S | 0.2 | 0.2 |
| **34** | **TL25.26** | **-0.04** | **0.7** | **0.7** | **7** | **61** | **S/N** | **0.1** | **0.7** |
| 35 | TL25.26 | -0.59 | 6.0 | 4.6 | 60 | 46 | E/S | 2.0 | -2.1 |
| 36 | TL25.26 | -0.55 | 0.5 | 0.5 | 5 | 5 | SE/S | 2.0 | 0.3 |
| 37 | TL25.26 | -0.49 | 2.9 | 2.9 | 29 | 29 | E/S | 2.0 | -0.7 |
| **38** | **TL25.26** | **0.00** | **0.1** | **0.1** | **1** | **78** | **E/W** | **0.1** | **0.8** |
| 39 | TL25.26 | -0.15 | 3.9 | 3.9 | 39 | 96 | NW | 1.5 | 2.4 |
| 40 | TL25.26 | -0.88 | 6.1 | 6.1 | 61 | 61 | W/SE | 1.5 | -0.3 |
| 41 | TL25.26 | -0.96 | 7.0 | 7.0 | 70 | 70 | SW/S | 2.0 | 1.6 |
| 42 | TL25.26 | -1.28 | 8.0 | 1.5 | 80 | 15 | W/S | 2.0 | -5.0 |
| **43** | **TL25.26** | **-0.05** | **0.1** | **0.1** | **1** | **35** | **N/E/S** | **0.6** | **1.1** |
| 44 | TL25.26 | -1.06 | 5.0 | 3.5 | 50 | 35 | SW/S | 2.0 | -1.0 |
| 45 | TL25.26 | -1.06 | 5.0 | 0.1 | 50 | 1 | W/S | 1.5 | -0.3 |
| **46** | **TL25.26** | **-1.17** | **7.0** | **1.7** | **70** | **17** | **W/N** | **1.5** | **1.5** |
| 47 | TL25.26 | -0.02 | 0.7 | 0.7 | 7 | 57 | NE | 0.4 | 1.3 |

**Table 41 - Final and Transient* Subsidence Effects at the TransGrid Towers**

| Tower # | Line # | Final Tower Subsidence $S_{max}$ (m) | Maximum Tilt $T_{max}$ (mm/m) | | Maximum Horizontal Displacement $HD_{max}$ (mm) | | Tower Movement Directions | Maximum Horizontal Strain^ $E_{max}$ (mm/m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Trans | Final | Trans | Final | | Trans | Final |
| 23 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 6 | W | 0.0 | 0.0 |
| 24 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 31 | SW/NW | 0.1 | 0.2 |
| 25 | TL24 | -0.01 | 0.2 | 0.2 | 2 | 72 | S/N | 0.5 | 0.6 |
| 26 | TL24 | -0.02 | 0.2 | 0.2 | 2 | 95 | S/N | 1.0 | 1.0 |
| **27** | **TL24** | **-0.06** | **0.9** | **0.9** | **9** | **115** | **S/N** | **1.4** | **1.4** |
| **28** | **TL24** | **-0.07** | **1.3** | **1.3** | **13** | **119** | **S/N** | **1.6** | **1.6** |
| 29 | TL24 | -0.13 | 0.4 | 0.4 | 4 | 113 | S/N | 1.6 | 1.6 |
| 30 | TL24 | -0.13 | 1.0 | 1.0 | 10 | 118 | S/N | 1.5 | 1.5 |
| 31 | TL24 | -0.13 | 1.4 | 1.4 | 14 | 129 | S/N | 1.6 | 1.6 |
| 32 | TL24 | -0.12 | 1.2 | 1.2 | 12 | 135 | S/N | 2.1 | 2.1 |
| 33 | TL24 | -0.09 | 2.2 | 2.2 | 22 | 110 | S/N | 1.2 | 1.2 |
| 34 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 37 | W/E | 0.0 | 0.8 |
| **35** | **TL24** | **-0.96** | **17.0** | **17.0** | **170** | **170** | **SW/S** | **3.0** | **-0.5** |
| 36 | TL24 | -0.66 | 2.5 | 2.5 | 25 | 25 | SW/S | 4.0 | 3.6 |
| **37** | **TL24** | **-1.14** | **10.2** | **10.2** | **102** | **102** | **W/S** | **2.0** | **-1.9** |
| **38** | **TL24** | **-1.11** | **10.4** | **10.4** | **104** | **104** | **W/N** | **2.0** | **-1.4** |
| 39 | TL24 | -1.36 | 12.0 | 5.5 | 120 | 55 | W/S | 2.0 | -6.4 |
| **40** | **TL24** | **-0.66** | **5.2** | **5.2** | **52** | **52** | **NW/S** | **2.0** | **3.7** |
| 41 | TL24 | -0.61 | 10.0 | 10.0 | 100 | 100 | NW/S | 2.0 | 3.1 |
| 42 | TL24 | -0.11 | 3.4 | 3.4 | 34 | 106 | SW/S | 2.6 | 2.6 |
| **43** | **TL24** | **0.00** | **0.0** | **0.0** | **0** | **26** | **S** | **0.0** | **0.2** |
| 44 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 10 | S | 0.0 | 0.1 |
| 45 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 3 | SW | 0.0 | 0.0 |
| 46 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 0 | SE | 0.0 | 0.0 |
| 47 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 1 | SE | 0.0 | 0.0 |
| 48 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 1 | SE | 0.0 | 0.0 |
| 49 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 2 | SE | 0.0 | 0.0 |
| 50 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 4 | SE | 0.0 | 0.0 |
| 51 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 10 | SE | 0.0 | 0.1 |
| 52 | TL24 | 0.00 | 0.1 | 0.1 | 1 | 23 | SE | 0.1 | 0.2 |
| 53 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 15 | SE | 0.0 | 0.2 |
| 54 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 20 | SE | 0.0 | 0.1 |
| 55 | TL24 | 0.00 | 0.0 | 0.0 | 0 | 5 | SE | 0.0 | 0.0 |
| 29 | TL22 | 0.00 | 0.0 | 0.0 | 0 | 7 | W | 0.0 | 0.1 |
| 30 | TL22 | -0.01 | 0.3 | 0.3 | 3 | 99 | NW | 0.1 | 1.0 |
| 31 | TL22 | -0.22 | 3.9 | 3.9 | 39 | 51 | N | 1.1 | 1.1 |
| **32** | **TL22** | **-0.42** | **5.0** | **4.2** | **50** | **42** | **W/S** | **-0.9** | **-0.9** |
| 33 | TL22 | -0.55 | 5.0 | 1.2 | 50 | 12 | W/S | -0.9 | -0.9 |
| 34 | TL22 | -0.49 | 4.0 | 1.8 | 40 | 18 | W/N | 0.7 | 0.7 |
| 35 | TL22 | -0.14 | 2.0 | 2.0 | 20 | 68 | NW/N | 0.6 | 0.6 |

**Table 41 - Final and Transient* Subsidence Effects at the TransGrid Towers**

| Tower # | Line # | Final Tower Subsidence $S_{max}$ (m) | Maximum Tilt $T_{max}$ (mm/m) | | Maximum Horizontal Displacement $HD_{max}$ (mm) | | Tower Movement Directions | Maximum Horizontal Strain^ $E_{max}$ (mm/m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Trans | Final | Trans | Final | | Trans | Final |
| 36 | TL22 | -0.18 | 5.3 | 5.3 | 53 | 53 | NE | 1.8 | 1.8 |
| 37 | TL22 | 0.00 | 0.0 | 0.0 | 0 | 5 | NE | 0.0 | 0.0 |
| 29 | TL2M | 0.00 | 0.0 | 0.0 | 0 | 3 | NE | 0.0 | 0.0 |
| 30 | TL2M | 0.00 | 0.0 | 0.0 | 0 | 3 | NE | 0.0 | 0.0 |
| 31 | TL2M | 0.00 | 0.0 | 0.0 | 0 | 0 | NE | 0.0 | 0.0 |
| 32 | TL2M | 0.00 | 0.0 | 0.0 | 0 | 0 | NE | 0.0 | 0.0 |
| 33 | TL2M | 0.00 | 0.0 | 0.0 | 0 | 0 | NE | 0.0 | 0.0 |

**Bold** - Tension Tower.
* - Refers to subsidence movements directly associated with the retreating extraction face.
^ - Maximum Tensile strain is positive and includes far-field affects. Maximum strain refers to major principal strain for U95%CL Subsidence Contours. Minor principle strain = 0.25 x major principle strain.

The assessment of subsidence effect predictions for all of the TransGrid towers within the project area is summarised below:

- Five tension towers along TL 24 are currently within the proposed limits of the longwall extraction with two towers inside a 26.5$^o$ angle of draw from the panel limits (No.s 27 and 28). These towers are likely to be subjected to cumulative tensile or compressive strains in excess of 1 mm/m. It is understood that these towers will be re-located prior to mining impacts.

- Four of the five tension towers along TL25.26 are located outside a 26.5$^o$ angle of draw and assessed as unlikely to have strains > 1 mm/m. Tensile strains of 1.5 mm/m are estimated for the tension tower (No. 46) located above LW35. This tower is in line and likely to be able to withstand the strains predicted, based on earlier discussions with TransGrid engineers. However, this will need to be confirmed by TransGrid during their detailed assessment of the towers.

- The tension tower No. 32 along TL22 is likely to experience strains of +/- 1 mm/m above LW54.

- Thirteen of the fifty-one suspension towers are estimated to have strains ranging from +/- 2 to 5 mm/m above the proposed longwalls, with the remainder estimated to have strains < 2 mm/m.

- Final tower tilt predictions range between 0 mm/m and 17 mm/m with horizontal displacements ranging from 0 mm to 170 mm.

- Surface cracking may increase the estimated 'smooth' profile values by 2 to 3 times if shallow bedrock exists beneath the towers. Local tilts may exceed the smooth profile tilts by 1.5 times due to secondary surface 'hump' development as the goaf edge retreats along the panel.

### 12.10.2 Impact Management Strategies

Some of the tension towers that exist at changes in easement angle have been assessed with $26.5^{o}$ angle of draw buffer zones assumed. There are several tension towers that are not located at high conductor angle changes and will be further considered by TransGrid Engineers on whether buffer zones will be necessary or not .

It is understood that impact mitigation measures will include the re-location of the unprotected tension towers above areas with tolerable subsidence magnitudes or the use of appropriate buffer zones. Suspension towers that may be subject to strains > 2 mm/m are likely to require engineer designed cruciform footing and conductor adjustment before subsidence starts to develop at each of the towers.

Once the tower footings assessment and any necessary mitigation works have been completed, the following monitoring program may be implemented in accordance with a revised Public Safety Management Plan that will be prepared in consultation with TransGrid as a component of the Extraction Plan process:

- Install a minimum of four stable survey pegs or stations in the ground adjacent to each tower leg and on the structure itself. The 8 towers should be monitored.

- Determine levels and in-line strains between the pegs (perimeter distances only) with a base-line survey prior to mining. Survey accuracy should be within the limits discussed below.

- Conduct visual inspections and measurement of subsidence, total horizontal displacements and in-line distances between ground and tower stations during mine subsidence development. Record and photograph details of any changes to the towers and adjacent ground (i.e. cracking).

- Measure the vertical distance from the ground to the conductor catenaries at minimum clearance points between each tower before, during and after subsidence development.

- Prepare and distribute results of each survey to relevant stakeholders.

- Review and implement any Trigger Action Response Plans.

Subsidence should be determined using precise levelling and terrestrial total station traverse techniques to determine 3-D coordinates (see **Section 13** for survey accuracy requirements).

### 12.11 Ausgrid Power Line Easements

There are timber power poles spaced at approximately 200 m centres along the Ausgrid 132 kV Feeder 957 easement above longwalls 38 to 61 (see **Figure 2a**). The poles in each pair are approximately 15 m high and spaced 5 m apart with a galvanised steel brace between the tops of the poles. The conductors are supported by relatively flexible vertical 'stringers' that will be able to tolerate some adjustment due to pole movements.

Worst-case predictions of final subsidence, tilt, strain, final tilt direction at each pole and conductor clearance loss between the pole pairs are not possible at this stage, so a general range of values have been provided along the easement in **Table 42.**

**Table 42 - Worst Case Final Subsidence Predictions for Ausgrid 132 kV Power Poles**

| LW No. | Final $S_{max}$ (m) | Final $S_p$ (m) | Final Tilt $T_{max}$ (mm/m) | Final Tilt Direction | Final Ground Strain$^+$ (mm/m) | Final Horizontal Displacement^ (mm) | | Conductor Clearance Loss Between Pole pairs (m) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Base* | Top | |
| 55 | 0.31 | 0.21 | 2 - 3 | N or S | 2-3 | 20 - 30 | 50 - 75 | 0.25-0.31 |
| 56 | 0.35 | 0.15 | 2 - 3 | N or S | 2-3 | 20 - 30 | 50 - 75 | 0.18-0.24 |
| 57 | 0.74 | 0.24 | 4 - 5 | N or S | 4-5 | 60 - 90 | 150 - 225 | 0.39-0.45 |
| 58 | 0.52 | 0.29 | 2 - 3 | N or S | 2-3 | 30 - 50 | 75 - 125 | 0.31-0.37 |
| 59 | 0.68 | 0.32 | 3 - 4 | N or S | 3-4 | 50 - 50 | 125 - 200 | 0.28-0.34 |
| 60 | 0.39 | 0.28 | 3 - 4 | N or S | 3-4 | 30 - 40 | 75 - 100 | 0.26-0.32 |
| 61 | 0.49 | 0.14 | 2 - 3 | N or S | 2-3 | 30 - 40 | 75 - 100 | 0.16-0.22 |
| 38 | 0.58 | 0.34 | 3 - 4 | N or S | 3-4 | 40 - 60 | 100 - 150 | 0.46-0.52 |
| 39 | 0.51 | 0.32 | 3 - 4 | N or S | 3-4 | 30 - 40 | 75 - 100 | 0.21-0.27 |
| 40 | 0.47 | 0.34 | 2 - 3 | N or S | 2-3 | 20 - 30 | 50 - 75 | 0.17-0.23 |
| 41 | 0.47 | 0.33 | 2 - 3 | N or S | 2-3 | 20 - 30 | 50 - 75 | 0.13-0.19 |
| 42 | 0.56 | 0.47 | 2 - 3 | N or S | 2-3 | 20 - 30 | 50 - 75 | 0.21-0.27 |
| 43 | 0.74 | 0.58 | 3 - 3 | N or S | 3-3 | 30 - 50 | 75 - 125 | 0.18-0.24 |
| 44 | 0.76 | 0.60 | 3 - 4 | N or S | 3-4 | 40 - 60 | 100 - 150 | 0.17-0.23 |
| 45 | 0.74 | 0.53 | 3 - 4 | N or S | 3-4 | 40 - 60 | 100 - 150 | 0.21-0.27 |
| 46 | 0.74 | 0.51 | 3 - 4 | N or S | 3-4 | 40 - 60 | 100 - 150 | 0.22-0.28 |
| 47 | 0.71 | 0.53 | 3 - 4 | N or S | 3-4 | 30 - 50 | 75 - 125 | 0.20-0.26 |
| 48 | 0.73 | 0.50 | 3 - 4 | N or S | 3-4 | 40 - 60 | 100 - 150 | 0.19-0.25 |
| 49 | 0.66 | 0.48 | 3 - 4 | N or S | 3-4 | 40 - 60 | 100 - 150 | 0.20-0.26 |
| 50 | 0.69 | 0.49 | 4 - 4 | N or S | 4-4 | 40 - 60 | 100 - 150 | 0.24-0.30 |
| 51 | 0.69 | 0.55 | 3 - 4 | N or S | 3-4 | 40 - 60 | 100 - 150 | 0.20-0.26 |
| 52 | 0.75 | 0.56 | 4 - 5 | N or S | 4-5 | 50 - 80 | 125 - 200 | 0.17-0.23 |
| 53 | 0.77 | 0.57 | 4 - 5 | N or S | 4-5 | 50 - 80 | 125 - 200 | 0.20-0.26 |
| 54 | 0.64 | 0.34 | 4 - 5 | N or S | 4-5 | 50 - 70 | 125 - 145 | 0.14-0.20 |

+ - Tensile and compressive phases may occur during subsidence development.
* - HD Base = Absolute horizontal displacement of pole at ground level.
^ - HD top = Absolute horizontal displacement of pole at conductor level (assumed to be 15 m above the ground)

The predicted U95%CL subsidence for the easement ranges between 0.31 m and 0.77 m above the completed longwalls and between 0.15 m and 0.6 m above the chain pillars.

Each of the power pole pairs will be subject to transient tilts and displacements towards the retreating extraction face and then 'swing' around (up to 90 degrees in bearing) to their final positions after subsidence is fully developed. Maximum final tilts are estimated to range from 2 mm/m to 8 mm/m with total pole base displacements of 20 mm to 80 mm. Pole top displacements are estimated to range from 50 mm to 200 mm.

The poles and conductors above the panels are likely to be subject to tensile and compressive strains ranging from 2 mm/m to 5 mm/m associated with the subsidence 'wave' as it passes underneath the poles. The transient tilts and strains are expected to range from 50% to 100% of the final values, depending on panel geometry and face retreat rates.

Conductor clearances are estimated to be decreased by between 0.13 m and 0.45 m along the easement after completion of LWs 38 to 61.

#### 12.11.1 Impact Management Strategies

Appropriate impact management strategies for the 132kV power line easement may include:

(i) Update of the Mandalong Public Safety Management Plan based on consultation with Ausgrid as a component of the Extraction Plan process to ensure the predicted subsidence effects on the poles and power lines do not result in unsafe conditions or loss of serviceability during and after mining.

(ii) Replacement of any damaged poles and/or mitigation works to conductors as mine subsidence develops.

Suitable responses to predicted subsidence impacts may be to provide flexible/roller-type conductor sheathing on the poles to control the tension during/after mining impacts. It is noted that shortening of several conductors (to reduce catenary sag) and adjustment to sheathing has been required above the Mandalong Mine panels.

(iii) Damage from subsidence (i.e. cracking and tilting) can manifest quickly after mining (i.e. within hours). The appropriate management plan will therefore need to consider the time required to respond to an impact exceedance if it occurs. The erection of temporary fencing in critical areas before subsidence develops may also need to be considered.

## 12.12 Public Roads and Drainage Infrastructure

### 12.12.1 Details and Potential Impacts

A summary of the predicted subsidence effects acting on the roads and culverts due to the proposed panels are presented in **Table 43**.

**Table 43 - Summary of Worst-Case Subsidence Predictions for Roads**

| Road | Final Maximum Subsidence $S_{max}$ (m) | Final Maximum Tilt $T_{max}$ (mm/m) | Final Maximum Tensile Strain* (mm/m) | Final Maximum Compressive Strain* (mm/m) | LW # |
|---|---|---|---|---|---|
| Mandalong | 0.74 - 1.14 | 7 - 13 | 5 | 6 - 7 | 25 - 29 |
| Binalong Way | 0.83 - 1.16 | 5 - 15 | 3 - 5 | 4 - 7 | 32 - 35 |
| Kiar Ridge | 0.82 - 1.17 | 6 - 10 | 4 - 4 | 5 | 35 - 37 |
| Toepfers | 0.58 - 0.80 | 4 - 6 | 3 - 4 | 4 - 5 | 44 - 49 |
| Hue Hue | 0.55 - 0.68 | 4 - 6 | 3 - 4 | 4 - 5 | 49 - 52 |
| Woods | 0.55 - 0.71 | 4 - 6 | 3 - 4 | 4 - 5 | 51 - 52 |
| Wyee Farm | 0.39 - 0.56 | 2 - 4 | 2 - 3 | 3 - 3 | 40 - 41 |
| Man Hire | 0.24 - 0.58 | 2 - 6 | 2 - 3 | 3 - 4 | 60 - 61 |
| Dyce | 0.21 - 0.66 | 2 - 7 | 2 - 3 | 2 - 4 | 57 - 55 |
| Crooks | 0.47 - 0.82 | 4 - 10 | 3 - 4 | 4 - 5 | 62 - 64 |
| Kiar Ridge | 0.60 - 0.80 | 4 - 7 | 4 | 5 | 48 - 50 |

* - Tensile and compressive strains may increase 2 to 3 times occasionally due to crack development.

The impacts due to the predicted subsidence effects may include:

- Tensile crack widths of between 20 mm and 50 mm.
- Compressive shearing or shoving between 20 mm and 70 mm.
- Increase of super-elevation in the road of 0.2% to 1.5%.
- Cracking of culverts and fill embankments.
- Erosion and slope instability of fill embankments.

### 12.12.2 Impact Management Strategies

A Public Safety Management Plan already exists for the Mine and would be updated for the roads in consultation with Lake Macquarie and Wyong Councils as a component of the Extraction Plan process and may include impact management strategies in place for roads such as:

(i) Pre-mining condition survey of road and drainage infrastructure prior to commencement of second workings.

(ii) Installation of subsidence monitoring lines along one side of sealed roads to review measured impacts and predictions.

(iii) Remediation of pavement and drainage impacts using normal road maintenance techniques.

(iv) On-going consultation with the Councils during and following mining, including notification of mine subsidence results.

(v) An emergency response plan for unanticipated mining related impacts.

## 12.13 Private Residences

### 12.13.1 Potential Impacts

There are 114 residences located above the proposed longwall panels 25 to 64. Twenty-four houses are single or double storey brick structures on slabs and ninety are timber framed clad structures on strip and pad footings.

As has been done above previous Mandalong Longwalls 1 to 12 to-date, it is intended to limit the potential subsidence impacts to safe, serviceable and repairable (SSR). The definition of SSR used by the MSB is understood to mean the following:

- Houses after mining are left on a residual tilt of < 7 mm/m.
- Houses are not subject to tensile or compressive ground strains > 4 mm/m.
- The impacts to the buildings due to mine subsidence is not greater than Category 2 or Slight Damage as defined in **AS2870, 2011**.

Category 2 Damage is defined in **AS2870, 2011** as follows for walls and concrete floors:

- Cracks in walls are < 5 mm wide and can be easily filled or repaired.
- Doors and windows stick slightly.

- Cracks in concrete floors are < 2 mm wide and slab is noticeably curved or changed in level (<15 mm offset from a 3 m straight edge).

**ACARP, 2009** also considers the following impacts should be added to the **AS2870, 2011**criteria for 'Slight' impact as follows:

- Internal and external cracking < 5 mm may cause loss of weather tightness.
- Shear slippage along damp proof courses < 5 mm.
- Small areas of tiling or wall may need to be replaced.
- Roof gutters and wet area floor levels might need adjustment.

It is noted however, that the **ACARP, 2009** impact criteria includes some of the impacts defined in **AS2870, 2011** as Category 3 or 'Moderate' Damage in regards to loss of weather tightness and replacement of small areas of walls. It is therefore unclear at this stage, as to whether the **ACARP, 2009** criteria has been adopted by regulatory authorities. It is recommended that the **AS2870, 2001** definitions of impact be adopted in this study until further notice to the contrary.

In regards to the acceptable tilt limit of 7 mm/m, this value refers to the point where re-levelling the structure after mine subsidence may need to be considered to maintain serviceability of the building. The risk of structural collapse is 'not credible' for tilts of this magnitude, and would need to be an order of magnitude higher before this would become a concern. In some cases, buildings may require roof guttering to be adjusted to re-establish cross falls within this tilt limit. Tilts of up to 10 mm/m may also be tolerable.

In regards to the strain limits of 4 mm/m, based on field and laboratory research in Australia (and overseas), it is also recognized by subsidence practitioners that it is unlikely that 100% of ground strain will be transferred into the structure due to soil slippage along the base and sides of footings. Full transfer would only be considered for structures founded to rock on bored piers.

Field estimates of visible 'cracking' strains by **Holla *et al*, 1991** for brick walls on conventional footings has been found to be in the order of 1.5 to 2 mm/m for tensile strain and 3 mm/m for compressive strain. A similar outcome was assessed in **Willey *et al*, 1993**, which assessed impacts of longwall mine subsidence on conventional brick structures at several locations in the Newcastle Coalfield.

Buildings are more susceptible to damage from tensile strains due to the lower tensile strength of mortar and brick compared to their compressive strength. The length and level of articulation (i.e. in-built flexibility) of the walls will also affect the amount of damage sustained. Overall, the strain limits defined by the MSB are based on the knowledge base of observed impact to a range of house types and geometries in mine subsidence districts and the cost of repairs.

Ground curvatures due to mine subsidence are usually the main cause of damage to buildings as footings are rarely stiff enough to span the ‘hogging’ or convex curvatures and ‘sagging’ or concave curvatures. The curvatures cause the footings to deflect into a circular profile along their entire length, which is significantly greater than localised curvatures within 1 m to 2 m of the footing edges due to reactive clay soil movements allowed for in **AS2870-2011**.

The key parameter in regards to curvature impacts to houses is usually defined by an allowable span/deflection ratio. The ratio allows the maximum differential offset from a straight edge or span to be defined for a given building type and its length. The most recent assessment of acceptable curvatures for building type and length is provided in **ACARP, 2009** with examples of structure type, length and acceptable curvatures (for slight impact) as shown in **Table 44.**

**Table 44 - Allowable Curvatures for Building Structures**

| Type of Residential Building* | Allowable Deflection Ratio | Maximum Wall Dimension (m) | | | |
|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 |
| | | Maximum Curvature $km^{-1}$ (or 1/Radius) | | | |
| Full Masonry, rendered | 1:4000 | 0.20 | 0.10 | 0.07 | 0.05 |
| Full Masonry, non-rendered | 1:3000 | 0.27 | 0.13 | 0.09 | 0.07 |
| Articulated Full Masonry, rendered | 1:800 | 1.00 | 0.50 | 0.33 | 0.25 |
| Masonry Veneer, non-rendered | 1:600 | 1.33 | 0.67 | 0.44 | 0.33 |
| Articulated Masonry Veneer, rendered | 1:600 | 1.33 | 0.67 | 0.44 | 0.33 |
| Timber or steel frame clad in weatherboard | 1:300 | 2.63 | 1.33 | 0.89 | 0.67 |

* - Articulation refers to structures with full wall height construction joints with minimum spacing as recommended in **AS2870, 2011**.

Cracking of concrete driveways, pools and tennis courts may be considered based on the allowable deflection ratio and curvature limits provided for Articulated Full Masonry and rendered buildings.

**Li et al, 2009** also identifies 3-D effects such horizontal shear strain distortion effects caused by subsidence trough development beneath structures. Torsion (twisting) of structures may also occur. It is suggested that these movements are not considered in risk assessments based on tilt and curvature alone and may result in a non-conservative outcome.

It is therefore recommended that in-plane ground displacements should be measured along survey lines to establish the horizontal *Shear Index* (determined by the difference in horizontal displacement perpendicular to survey cross lines divided by the distance between peg measurements) to establish the magnitude of impact that these movements may cause (or contribute) to undermined structures. At this stage, however, it is considered the assessment of the Shear Index should be included in the proposed monitoring and management plans as on-going research at Mandalong.

As sensitive surface features (i.e. residences) are typically medium dense to sparsely distributed across the Project Area, and located in areas with relatively deep soil cover, it is assessed that it is appropriate to adopt the ‘smooth profile’ values derived from the U95%CL subsidence contours to assess the potential impacts to residences.

The impact register for the houses above the LWs 1 to 12 indicates that SSR impacts have occurred at the structures subsided by the magnitudes of subsidence predicted for the proposed LWs 25 to 64.

The predicted transient and final subsidence effect results for each house (subsidence, tilt, curvature and horizontal strain) have been estimated from the U95%CL contours presented in **Figures 46a** to **46d**. The results are summarised in **Table 45** and presented graphically in **Figures 57a** to **57d**.

**Table 45 - Predicted Subsidence Effects at Existing Residences above LWs 25 to 64**

| House No. | Road | LW# | Final Subsidence $S_{max}$ | Final Max Tilt $T_{max}$ (mm/m) | Final Max Curvature $C_{max}$ ($km^{-1}$) | Final Max Strain $E_{max}$ (mm/m) | Transient Max Curvature & Strain (mm/m) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | $C_{max}$ | $E_{max}$ |
| 1 | Mandalong | 25/26 | -0.42 | 1.4 | 0.29 | 2.9 | 0.29 | 2.9 |
| 2 | Dyce | 55 | -0.13 | 2.6 | 0.06 | 1.1 | 0.06 | 1.1 |
| 3 | Dyce | 55 | -0.22 | 3.2 | -0.05 | -1.0 | 0.05 | 1.0 |
| 4 | Dyce | 55 | -0.10 | 1.4 | 0.07 | 1.4 | 0.05 | 1.0 |
| 5 | Dyce | 55 | -0.14 | 3.4 | 0.07 | 1.4 | 0.05 | 1.0 |
| 6 | Dyce | 55 | -0.10 | 1.4 | 0.08 | 1.6 | 0.05 | 1.0 |
| 7 | Dyce | 55 | -0.23 | 3.6 | -0.06 | -1.2 | 0.05 | 1.0 |
| 8 | Dyce | 55 | -0.18 | 3.7 | 0.01 | 0.3 | 0.05 | 1.0 |
| 9 | Dyce | 56 | -0.21 | 3.7 | -0.03 | -0.5 | 0.05 | 1.0 |
| 10 | Dyce | 56 | -0.30 | 0.7 | -0.13 | -2.6 | 0.05 | 1.0 |
| 11 | Mandalong | 28 | -1.21 | 9.3 | -0.17 | -3.4 | 0.17 | 1.0 |
| 12 | Mandalong | 26/27 | -0.67 | 0.5 | 0.17 | 3.5 | 0.17 | 1.0 |
| 13 | Dyce | 58 | -0.44 | 2.9 | -0.12 | -2.4 | 0.05 | 1.0 |
| 14 | Wyee Farms | - | 0.00 | 0.0 | 0.00 | 0.1 | 0.00 | 0.0 |
| 15 | Wyee Farms | - | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| 16 | Wyee Farms | 38 | -0.59 | 1.9 | -0.04 | -0.9 | 0.05 | 1.0 |
| 17 | Wyee Farms | 38 | -0.56 | 2.8 | 0.00 | 0.0 | 0.05 | 1.0 |
| 19 | Wyee Farms | 38 | -0.45 | 4.1 | -0.04 | -0.8 | 0.05 | 1.0 |
| 21 | Wyee Farms | 39 | -0.29 | 5.1 | -0.04 | -0.8 | 0.05 | 1.0 |
| 22 | Wyee Farms | 39 | -0.40 | 1.5 | -0.17 | -3.4 | 0.05 | 1.0 |

**Table 45 (Cont…) - Predicted Subsidence Effects at Existing Residences above LWs 25 to 64**

| House No. | Road | LW# | Final Subsidence $S_{max}$ (m) | Final Max Tilt $T_{max}$ (mm/m) | Final Max Curvature $C_{max}$ ($km^{-1}$) | Final Max Strain $E_{max}$ (mm/m) | Transient Max Curvature & Strain (mm/m) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | $C_{max}$ | $E_{max}$ |
| 28 | Wyee Farms | 40 | -0.44 | 3.6 | -0.08 | -1.7 | 0.05 | 1.0 |
| 29 | Wyee Farms | 40 | -0.66 | 3.0 | -0.10 | -2.0 | 0.05 | 1.0 |
| 30 | Wyee Farms | 40 | -0.69 | 1.0 | -0.14 | -2.8 | 0.05 | 1.0 |
| 31 | Wyee Farms | 41 | -0.47 | 2.8 | 0.11 | 2.2 | 0.05 | 1.0 |
| 33 | Wyee Farms | 41 | -0.61 | 0.3 | -0.05 | -1.0 | 0.05 | 1.0 |
| 34 | Wyee Farms | 34 | -0.21 | 4.8 | 0.08 | 1.6 | 0.05 | 1.0 |
| 35 | Wyee Farms | 33/34 | -1.02 | 1.3 | 0.02 | 0.4 | 0.05 | 1.0 |
| 36 | Wyee Farms | 41 | 0.00 | 0.1 | 0.00 | 0.1 | 0.05 | 1.0 |
| 37 | Wyee Farms | 41 | 0.00 | 0.1 | 0.01 | 0.1 | 0.05 | 1.0 |
| 40 | Wyee Farms | 41/42 | -0.16 | 1.7 | 0.13 | 2.7 | 0.05 | 1.0 |
| 41 | Wyee Farms | - | 0.00 | 0.0 | 0.00 | 0.0 | 0.05 | 1.0 |
| 42 | Wyee Farms | 40/41 | -0.26 | 0.8 | 0.15 | 3.1 | 0.05 | 1.0 |
| 43 | Wyee Farms | 41 | -0.45 | 3.5 | -0.08 | -1.7 | 0.05 | 1.0 |
| 46 | Wyee Farms | 41 | -0.51 | 1.7 | -0.05 | -0.9 | 0.05 | 1.0 |
| 48 | Wyee Farms | 41 | -0.53 | 4.4 | 0.01 | 0.2 | 0.05 | 1.0 |
| 49 | Wyee Farms | 42 | -0.42 | 2.6 | 0.05 | 1.0 | 0.05 | 1.0 |
| 50 | Wyee Farms | 41 | -0.47 | 3.9 | 0.08 | 1.5 | 0.05 | 1.0 |
| 52 | Wyee Farms | 41 | -0.63 | 2.0 | -0.15 | -3.0 | 0.05 | 1.0 |
| 53 | Wyee Farms | 41 | -0.41 | 0.5 | 0.14 | 2.8 | 0.05 | 1.0 |
| 54 | Toepfer | 41/42 | -0.56 | 2.9 | -0.02 | -0.3 | 0.05 | 1.0 |
| 55 | Kiar ridge | 43 | -0.39 | 5.2 | 0.02 | 0.4 | 0.05 | 1.0 |
| 56 | Toepfers | 37 | -0.55 | 3.7 | 0.14 | 2.9 | 0.05 | 1.0 |
| 60 | Toepfers | 46 | -0.59 | 2.7 | 0.07 | 1.4 | 0.05 | 1.0 |
| 61 | Hue Hue | 45 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.00 |
| 62 | Hue Hue | - | -0.08 | 2.4 | 0.05 | 1.0 | 0.05 | 1.0 |
| 63 | Toepfers | 48 | -0.72 | 5.0 | -0.11 | -2.2 | 0.05 | 1.0 |
| 65 | Toepfers | 47 | -0.69 | 5.4 | -0.11 | -2.1 | 0.05 | 1.0 |
| 68 | Toepfers | 48 | -0.45 | 2.2 | 0.15 | 3.0 | 0.05 | 1.0 |
| 69 | Toepfers | 48 | -0.51 | 4.3 | 0.06 | 1.2 | 0.05 | 1.0 |
| 70 | Toepfers | 49 | -0.66 | 2.6 | -0.13 | -2.6 | 0.05 | 1.0 |
| 71 | Toepfers | 49 | -0.47 | 3.5 | 0.10 | 2.0 | 0.05 | 1.0 |
| 72 | Toepfers | 47/48 | -0.57 | 0.7 | 0.10 | 1.9 | 0.05 | 1.0 |
| 73 | Toepfers | 48 | -0.74 | 1.9 | -0.11 | -2.3 | 0.05 | 1.0 |
| 74 | Toepfers | 49 | -0.54 | 5.3 | 0.02 | 0.4 | 0.05 | 1.0 |
| 75 | Hue Hue | 49 | -0.55 | 5.0 | 0.03 | 0.5 | 0.05 | 1.0 |
| 76 | Hue Hue | 54 | -0.44 | 3.4 | -0.05 | -1.0 | 0.05 | 1.0 |
| 77 | Woods | 52 | -0.76 | 2.0 | -0.05 | -1.0 | 0.05 | 1.0 |
| 78 | Woods | 53 | -0.86 | 3.3 | -0.16 | -3.1 | 0.05 | 1.0 |
| 79 | Woods | 52 | -0.72 | 1.3 | 0.01 | 0.2 | 0.05 | 1.0 |
| 80 | Woods | 52/53 | -0.64 | 1.0 | 0.11 | 2.1 | 0.05 | 1.0 |
| 81 | Woods | 52/53 | -0.48 | 2.3 | 0.21 | 4.2 | 0.05 | 1.0 |
| 82 | Woods | 52/53 | -0.47 | 1.6 | 0.21 | 4.2 | 0.05 | 1.0 |

**Table 45 (Cont…) - Predicted Subsidence Effects at Existing Residences above LWs 25 to 64**

| House No. | Road | LW # | Final Subsidence $S_{max}$ (m) | Final Max Tilt $T_{max}$ (mm/m) | Final Max Curvature $C_{max}$ ($km^{-1}$) | Final Max Strain $E_{max}$ (mm/m) | Transient Max Curvature & Strain (mm/m) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | $C_{max}$ | $E_{max}$ |
| 36 | Wyee Farms | 41 | 0.00 | 0.1 | 0.00 | 0.1 | 0.05 | 1.0 |
| 37 | Wyee Farms | 41 | 0.00 | 0.1 | 0.01 | 0.1 | 0.05 | 1.0 |
| 40 | Wyee Farms | 41/42 | -0.16 | 1.7 | 0.13 | 2.7 | 0.05 | 1.0 |
| 41 | Wyee Farms | - | 0.00 | 0.0 | 0.00 | 0.0 | 0.05 | 1.0 |
| 83 | Hue Hue | 51 | -0.67 | 3.2 | -0.17 | -3.4 | 0.05 | 1.0 |
| 84 | Hue Hue | 51/52 | -0.35 | 4.3 | 0.10 | 2.0 | 0.05 | 1.0 |
| 87 | Woods | 51 | -0.67 | 2.1 | 0.01 | 0.2 | 0.05 | 1.0 |
| 88 | Woods | 51 | -0.54 | 4.8 | -0.07 | -1.3 | 0.05 | 1.0 |
| 89 | Woods | 51 | -0.50 | 4.4 | 0.13 | 2.7 | 0.05 | 1.0 |
| 90 | Woods | 50 | -0.54 | 5.2 | 0.01 | 0.1 | 0.05 | 1.0 |
| 91 | Toepfers | 49 | -0.67 | 1.8 | -0.16 | -3.1 | 0.05 | 1.0 |
| 92 | Hue Hue | 49/50 | -0.46 | 1.9 | 0.13 | 2.6 | 0.05 | 1.0 |
| 93 | Hue Hue | 49 | -0.52 | 5.4 | -0.05 | -0.9 | 0.05 | 1.0 |
| 95 | Hue Hue | - | 0.00 | 0.0 | 0.00 | 0.0 | 0.05 | 1.0 |
| 96 | Woods | 50 | -0.60 | 5.7 | -0.04 | -0.8 | 0.05 | 1.0 |
| 97 | Woodville | 49 | -0.58 | 4.4 | 0.06 | 1.1 | 0.05 | 1.0 |
| 98 | Mandalong | 25 | -0.01 | 0.2 | 0.01 | 0.1 | 0.05 | 1.0 |
| 99 | Chapmans | 62 | -0.07 | 1.4 | 0.08 | 1.5 | 0.10 | 2.0 |
| 100 | Crooks | - | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| 101 | Manhire | 60 | -0.29 | 2.7 | -0.12 | -2.3 | 0.05 | 1.0 |
| 102 | Toepfers | 46/47 | -0.50 | 0.4 | 0.15 | 3.0 | 0.05 | 1.0 |
| 103 | Woods | 51 | -0.79 | 2.8 | -0.15 | -3.1 | 0.05 | 1.0 |
| 104 | Crooks | 64 | -0.05 | 0.6 | 0.04 | 0.8 | 0.10 | 2.0 |
| 105 | Crooks | 64 | -0.04 | 0.3 | 0.00 | 0.0 | 0.10 | 2.0 |
| 106 | Crooks | - | 0.00 | 0.0 | 0.00 | 0.0 | 0.10 | 2.0 |
| 107 | Crooks | 63 | -0.04 | 1.9 | 0.07 | 1.4 | 0.10 | 2.0 |
| 108 | Crooks | 64 | 0.00 | 0.1 | 0.01 | 0.1 | 0.10 | 2.0 |
| 109 | Mandalong | 31 | -0.47 | 5.8 | 0.01 | 0.1 | 0.05 | 1.0 |
| 110 | Bushells | - | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.00 |
| 111 | Dyce | 55 | -0.16 | 3.4 | 0.04 | 0.9 | 0.05 | 1.0 |
| 112 | Manhire | 60 | -0.21 | 3.5 | -0.03 | -0.6 | 0.05 | 1.0 |
| 114 | Woods | 53 | -0.79 | 1.0 | -0.18 | -3.6 | 0.05 | 1.0 |
| 18 | Wyee Farms | 38/39 | -0.48 | 1.2 | 0.06 | 1.2 | 0.05 | 1.0 |
| 20 | Wyee Farms | 39 | -0.01 | 0.5 | 0.03 | 0.6 | 0.05 | 1.0 |
| 23 | Wyee Farms | 39/40 | -0.13 | 0.7 | 0.13 | 2.5 | 0.05 | 1.0 |
| 23 | Wyee Farms | 39/40 | -0.13 | 0.7 | 0.13 | 2.5 | 0.05 | 1.0 |
| 24 | Wyee Farms | 40 | -0.42 | 2.3 | -0.06 | -1.2 | 0.05 | 1.0 |
| 25 | Wyee Farms | 39 | -0.25 | 3.8 | 0.05 | 0.9 | 0.05 | 1.0 |
| 26 | Wyee Farms | 40 | -0.52 | 1.4 | -0.18 | -3.6 | 0.05 | 1.0 |
| 27 | Wyee Farms | 40 | -0.46 | 4.0 | -0.10 | -2.0 | 0.05 | 1.0 |
| 32 | Wyee Farms | 40 | -0.58 | 3.8 | -0.04 | -0.9 | 0.05 | 1.0 |
| 38 | Wyee Farms | 40 | -0.07 | 2.2 | 0.04 | 0.8 | 0.05 | 1.0 |

**Table 45 (Cont…) - Predicted Subsidence Effects at Existing Residences above LWs 25 to 64**

| House No. | Road | LW # | Final Subsidence $S_{max}$ (m) | Final Max Tilt $T_{max}$ (mm/m) | Final Max Curvature $C_{max}$ ($km^{-1}$) | Final Max Strain $E_{max}$ (mm/m) | Transient Max Curvature & Strain (mm/m) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | $C_{max}$ | $E_{max}$ |
| 39 | Wyee Farms | 40 | -0.31 | 2.8 | -0.10 | -2.1 | 0.05 | 1.0 |
| 44 | Wyee Farms | 42 | -0.38 | 4.6 | 0.06 | 1.2 | 0.05 | 1.0 |
| 45 | Wyee Farms | 42 | -0.48 | 4.1 | -0.07 | -1.5 | 0.05 | 1.0 |
| 47 | Wyee Farms | 41/42 | -0.35 | 0.5 | 0.16 | 3.2 | 0.05 | 1.0 |
| 51 | Wyee Farms | 41 | -0.52 | 4.6 | 0.00 | -0.1 | 0.05 | 1.0 |
| 57 | Toepfers | 47 | -0.79 | 2.2 | -0.18 | -3.6 | 0.05 | 1.0 |
| 58 | Toepfers | 47 | -0.52 | 4.2 | 0.15 | 3.0 | 0.05 | 1.0 |
| 59 | Toepfers | 47 | -0.52 | 4.2 | 0.15 | 3.0 | 0.05 | 1.0 |
| 64 | Toepfers | 47 | -0.50 | 4.9 | 0.13 | 2.6 | 0.05 | 1.0 |
| 66 | Toepfers | 48/49 | -0.45 | 4.1 | 0.15 | 3.0 | 0.05 | 1.0 |
| 67 | Toepfers | 47 | -0.57 | 6.2 | 0.05 | 1.0 | 0.05 | 1.0 |
| 85 | Woods | 51/52 | -0.49 | 1.9 | 0.18 | 3.6 | 0.05 | 1.0 |
| 86 | Woods | 52 | -0.73 | 1.7 | -0.03 | -0.6 | 0.05 | 1.0 |
| 94 | Hue Hue | 49 | -0.11 | 3.6 | 0.07 | 1.5 | 0.05 | 1.0 |
| 113 | Woods | 52/53 | -0.64 | 1.3 | 0.11 | 2.3 | 0.05 | 1.0 |

Curvature and span/deflection ratio limits have not been specified at this stage due to the damage potentials dependence on other pertinent factors such as structure type, building geometry and footing stiffness. For example, *Table 6.4.8* in **ACARP, 2009** indicates that a 20 m long Articulated Masonry structure can tolerate curvatures of up to 0.44 $km^{-1}$ with timber or weatherboard buildings able to tolerate 1.33 $km^{-1}$. Brick veneer buildings of similar length are likely to tolerate curvatures of up to 0.20 $km^{-1}$ whilst solid masonry buildings would probably exceed 'slight' or Category 2 damage if it were subject to curvatures > 0.1 $km^{-1}$.

The results presented in **Table 45** and **Figures 57a-d** indicate that the maximum subsidence at the residences are likely to range between 0.02 m to 1.21 m (average of 0.46 m), with tilts from 0 to 9 mm/m, hogging and sagging curvatures of < 0.29 $km^{-1}$, and tensile and compressive strains < 4.2 mm/m (including transient strains that develop when a longwall passes below a given point on the surface.

The plots indicate the impact limits defined in **ACARP, 2009** for likely repairs for full masonry structures up to 40 m in length with predictions for the existing brick and non-brick houses. Further detailed assessment of existing condition of and likely impacts to houses should be completed prior to undermining by the Mine and MSB representatives. It is understood that if SSR limits are unlikely to be achieved, the mine will be obligated to compensate the owner of the residence before any impact occurs.

It is concluded that the impacts to the majority of structures (i.e. >95%) will remain within SSR impact limits due to mine subsidence, however, it is also likely that approximately 5% of houses and structures may experience 'Moderate' Category 3 impact from mine subsidence that could require the following repairs according to **AS2870, 2011**:

- Cracks in walls between 5 mm to 15 mm that can be repaired and walls possibly need to be replaced.
- Doors and windows stick and service pipes can fracture.
- Loss of weather tightness often occurs.
- Concrete floor cracks are 2 mm to 4 mm wide with 15 mm to 25 mm curvature offset along a 3 m long straight edge.

The overall proportion of expected impact and measured impact to the buildings will need to be reviewed after detailed property inspection and on a panel by panel basis as mining progresses.

#### 12.13.2 Impact Management Strategies

As previously discussed, it is likely that all residences, associated machinery sheds, in-ground tanks, pools, tennis courts etc within the proposed mining area will need to be monitored during and remediated after mining.

Any damage to residences should not be greater than Category 2 Damage Classification categories ("Slight") in accordance with **AS2870, 2011**. Building impact will depend upon the tolerance limits to movement of the structure(s).

The proposed impact management strategies required for new or existing residences due to subsidence are:

- Review of assessed impacts, based on pre-mining inspections of the properties by representatives of Mandalong Mine and the Mine Subsidence Board (MSB) before and after second workings.
- Installation of monitoring pins or pegs around each structure and conduct base line subsidence, peg location and strain measurements prior to undermining if considered necessary.
- Structure surveys and visual inspections should be completed within the timeframe nominated in the Property Subsidence Management Plan.
- Any minor repair works to internal/externals cracking or re-levelling of Stakeholder-agreed structures should be implemented as soon as mining related movements have ceased.
- If > 95% of houses impacted by mining within the project area exceed a Category 2 or "Moderate" damage classification in accordance with **AS2870, 2011**, then is it will be necessary to review the mining layout and proposed panel geometries.

- A Damage impact register has been established and will be updated after mining impacts and repair costs are established by the MSB.

Appropriate management strategies for the other structures or property developments that may be impacted by mine subsidence, should include and address the following issues in consultation between the stakeholders and the MSB.

A Property Subsidence Management Plan shall be prepared and implemented for the mitigation and remediation of any damage in conjunction with the Mine Subsidence Board to include:

- A pre- and post-mining condition survey and/or inspection of all structures within the mining lease should be made by the MSB.

- Development of a monitoring plan for the property during mine subsidence and post mine subsidence periods and safety/hazard management plan.

- An inspection of mine subsidence damaged properties should be made by the MSB and any repair / mitigation / remediation works to be undertaken will be related to the extent of damage experienced.

Mine subsidence is expected to develop soon after the face retreats beneath a property and would be expected to continue until the face is 1 to 2 times the cover depth past the property (see **Section 13** for more details). Secondary subsidence movements would also be expected soon after the passing of subsequent longwall panels, albeit at decreasing rates and magnitudes. It is considered likely that subsidence movements will affect undermined properties for periods of at least 6 to 8 weeks after each longwall panel is extracted.

## 12.14 House Flooding Potential

### 12.14.1 Potential Impacts

The potential for house flooding is deemed acceptable by the MSB if post-mining floor levels of houses are at least 0.5 m above the 1 in 100 year flood level adjacent to creeks and water courses. A flood study has been completed to establish the pre-mining flood limits and maximum allowable flood levels at affected residences are presented on **Figure 47**.

Preliminary estimates of post-mining floor level free board surplus above the post 1 in 100 year flood levels is presented in **Table 46**, with floor level surpluses shown graphically in **Figure 58**.

**Table 46 - Predicted Floor Level Free Board Surplus at Houses after Proposed Mining**

| House No. | Road | Proposed LW | 100yr Flood RL (AHD) | Pre-Mining Ground Level (AHD) | Pre-Mining Floor RL^ (AHD) | Predicted U95%CL Subsidence (m) | Post-Mining Freeboard Surplus to Floor RL* (m) |
|---|---|---|---|---|---|---|---|
| 6 | Dyce | 55 | 29.2 | 29.7 | 30.2 | 0.10 | 0.40 |
| 7 | Dyce | 55 | 29.2 | 29.4 | 29.9 | 0.23 | **-0.03** |
| 8 | Dyce | 55 | 29 | 29.2 | 29.7 | 0.18 | 0.02 |
| 22 | Wyee Farms | 39 | 27.5 | 28 | 28.5 | 0.40 | 0.10 |
| 23 | Wyee Farms | 39/40 | 29.3 | 29.8 | 30.3 | 0.13 | 0.37 |
| 24 | Wyee Farms | 40 | 30.8 | 31.3 | 31.8 | 0.42 | 0.08 |
| 29 | Wyee Farms | 40 | 43 | 45 | 45.5 | 0.66 | 1.34 |
| 30 | Wyee Farms | 40 | 43 | 44 | 44.5 | 0.69 | 0.31 |
| 31 | Wyee Farms | 41 | 44 | 45 | 45.5 | 0.47 | 0.53 |
| 39 | Wyee Farms | 40 | 30 | 31 | 31.5 | 0.31 | 0.69 |
| 45 | Wyee Farms | 44/45 | 35 | 36.5 | 37 | 0.48 | 1.02 |
| 47 | Wyee Farms | 41/42 | 47.5 | 48.5 | 49 | 0.35 | 0.65 |
| 51 | Wyee Farms | 41 | 39.8 | 40.5 | 41 | 0.52 | 0.18 |
| 52 | Wyee Farms | 41 | 40.5 | 41 | 41.5 | 0.63 | **-0.13** |
| 53 | Wyee Farms | 41/42 | 45 | 47 | 47.5 | 0.41 | 1.59 |
| 96 | Woods | 50 | 47.8 | 47.8 | 48.3 | 0.60 | **-0.60** |
| 101 | Manhire | 60 | 27 | 29 | 29.5 | 0.29 | 1.71 |
| 111 | Dyce | 41 | 29.2 | 29.9 | 30.4 | 0.16 | 0.54 |

^ - Estimated to be 0.5 m above ground level.
* - Estimated to be Floor Level - Predicted Subsidence - Flood Level - 0.5.
**Bold** - Predicted Floor level free board < 0.5 m above 1 in 100 Year Flood Level after mining.

It is apparent from this preliminary assessment that three houses out of 114 (2.6%) may have their floor levels subsided below the minimum free board of 0.5 m above the 1 in 100 year flood level after mining is completed. However, the subsiding of a property does not necessarily increase the flood potential. The upstream and downstream areas may also be subsided allowing water to flow laterally resulting in an overall reduction in flood hazard. This is investigated further in the modelling undertaken by Umwelt in their surface water assessment (**Umwelt, 2013**). Further discussion on this issue is presented in **Section 12.14.2**.

### 12.14.2 Impact Management Strategies

It will be necessary to confirm existing floor levels with the MSB prior to mine subsidence occurring at the aforementioned properties. Further discussions with Stakeholders and regulatory authorities will also be necessary if detailed assessment of house floor levels confirm the above assessment in regards to flooding potential due to the proposed mining layouts.

The current Impact Management strategies for Mandalong Mine seem appropriate which include mitigation works, or landholder compensation or compulsory property purchase.

## 12.15 Telstra Copper and Optical Fibre Cables

### 12.15.1 Potential Impacts

Telstra infrastructure in the Project Area includes buried and aerial copper cables and buried optical fibre. The cables are likely to be subject to subsidence between 0.02 m to 1.0 m and in-line ground strains between 2 and 10 mm/m compressive strain and tensile strain. An initial investigation of the infrastructure has been completed and a detailed report provided to Telstra.

### 12.15.2 Impact Management Strategies

Mandalong currently has an effective Telstra Management Plan which is revised for each Subsidence Management Plan. This plan outlines the expected impacts, inspection regimes and potential or proposed mitigation measures. This plan is agreed to by Centennial Mandalong and Telstra.

## 12.16 Nextgen Optical Fibre Cable

### 12.16.1 Potential Impacts

Nextgen infrastructure in the Project Area includes a buried optical fibre cable that runs along Hue Hue Rd. Part of this cable runs over the inbye end of proposed LWs 48-54. The cables are likely to be subject to subsidence between 0.02 m to 0.77 m and in-line ground strains of +/- 5 mm/m.

An initial investigation of the infrastructure has been completed and a detailed report provided to Nextgen.

### 12.16.2 Impact Management Strategies

Mandalong currently has an effective Telstra Management Plan which is revised for each Subsidence Management Plan. This plan outlines the expected impacts, inspection regimes and potential or proposed mitigation measures. It is expected that a similar Management Plan would be prepared for the Nextgen infrastructure and be agreed to by Centennial Mandalong and Nextgen.

## 12.17 Farm Dams

### 12.17.1 Potential Impacts

There are several farm dams within the Project Area that may be subsided by up to 1 m.

Non-engineered farm dams and water storages will be susceptible to surface cracking and tilting (i.e. storage level changes) due to mine subsidence. The tolerable tilt and strain values for the dams would depend upon the materials used, construction techniques, foundation type and likely repair costs to re-establish the dam’s function and pre-mining storage capacity.

The expected phases of tensile and compressive strain development may result in breaching of the dam walls or water losses through the floor of the dam storage area. Loss or increase of storage areas may also occur due to the predicted tilting. Damage to fences around the dams may also occur and require repairing.

It should be noted that farm dams have been subsided by underground coal mines elsewhere in NSW and any damage has been effectively managed. The dams were reinstated in a timely manner and an alternative supply of water was provided by the Mine during the interim period.

### 12.17.2 Impact Management Strategies

The Property Subsidence Management Plan (PSMP) will include any farm dams located on the property.

(i) Inspections of each dam are usually conducted by the MSB for:

- current water storage level;
- wall orientation relative to the potential cracking;
- construction method and soil / fill materials;
- dam condition (presence of rilling / piping / erosion / vegetation cover);
- potential for safety risk to people or animals;
- downstream receptors, such as minor or major streams, roads, tracks or other farm infrastructure; and
- potential outwash effects.

(ii) Photographs of each dam will be taken prior to and after undermining, when the majority of predicted subsidence has occurred.

(iii) Dam water levels will be monitored prior to and after undermining to assess the baseline and post-mining dam water level in order to determine whether rehabilitation is required.

(iv) In the event that subsidence / crack development monitoring indicates a significant potential for dam wall failure, dam water will be managed in one of the following manners:

- pumped to an adjacent dam to lower the water level to a manageable height that reduces the risk of dam wall failure,

- discharged to a lower dam via existing channels if the water cannot be transferred, or not transferred if the dam water level is sufficiently low to pose a minor risk.

- An alternate water supply will be provided to the dam owner until the dam can be reinstated.

(v) In the event of subsidence damage to any dams, the Mine shall remediate the damage and reinstate the dam in conjunction with the MSB.

## 12.18 Property Fences

### 12.18.1 Potential Impacts

The impact of 0.2 m to 1.3 m of subsidence on fencing could include loss of tension or failure of wire strands and the possible failure of strainer posts. Swing gates could also be affected and not function properly after mine subsidence.

Failure of fencing could allow livestock to get out of paddocks and properties until remediation works are completed.

### 12.18.2 Impact Management Strategies

The above impacts may be managed with the rapid repair of damaged fences and gates. Relocation of livestock / animals before mining impacts occur may also be undertaken in anticipation of fence failure. A Property Subsidence Management Plan would be prepared in consultation with the landowner to address these potential issues.

## 12.19 Unsealed Tracks and Fire Trails

### 12.19.1 Potential Impacts

There are a number of unsealed tracks and fire trails above the proposed longwalls, including The Olney State Forest and easement access roads and forestry access roads.

The impacts due to the predicted subsidence effects may include:

- Tensile crack widths of between 20 mm and 50 mm.
- Compressive shearing or shoving between 20 mm and 70 mm.
- Increase of super-elevation in the road of 0.2% to 1.5%.
- Cracking of culverts and fill embankments.

### 12.19.2 Impact Management Strategies

The management measures in the Public Safety Management Plan and remediation strategies would be developed for unsealed track and fire trails and outlined in Extraction Plans. This would include:

(i) Pre-mining condition survey of tracks prior to commencement of longwall extraction.

(ii) Visual monitoring during mining and maintenance of appropriate warning signs.

(iii) Remediation of surface cracks by Mandalong Mine using approved fill and grading works.

(iv) On-going consultation with relevant stakeholder (Forests NSW, Rural Fire Service) during and following mining, including notification of mine subsidence results.

## 12.20 Buttonderry Waste Management Facility

### 12.20.1 Potential Impacts

The Buttonderry Waste Management Facility will be located well outside a 26.5$^{o}$ angle of draw to the proposed longwalls and is very unlikely to be impacted by vertical subsidence.

Far-field horizontal displacements can extend further out than the vertical subsidence, however, horizontal strains are likely to be negligible (< 0.3 mm/m) beyond 45$^{o}$ or 1 x the cover depth of 320 m from the longwall extraction limits.

### 12.20.2 Impact Management Strategies

Impact management strategies are therefore unlikely to require more than the following:

- Pre-mining condition survey of existing structures and infrastructure associated with the facility.
- Review of measured subsidence effects after mining is completed within 600 m of the facility to confirm angle of draw and far-field movement predictions.
- Provide monitoring data to Wyong Shire Council and advise them of any significant increases to the predicted movements in the vicinity of the facility.

## 12.21 F3 Freeway

### 12.21.1 Potential Impacts

The F3 Freeway will be located well outside a 26.5$^{o}$ angle of draw to the proposed longwalls and very unlikely to be impacted by vertical subsidence.

Far-field horizontal displacements can extend further out than the vertical subsidence, however, horizontal strains are likely to be negligible (< 0.3 mm/m) beyond 45$^{o}$ or 1 x the cover depth of 180 m to 240 m from the extraction limits.

### 12.21.2 Impact Management Strategies

Impact management strategies are therefore unlikely to require more than the following:

- Pre-mining condition survey of existing infrastructure associated with the section of Freeway due east of the proposed mining area.

- Review of measured subsidence effects after mining is completed to confirm angle of draw and far-field movement predictions.

- Provide monitoring data to the Stakeholder and advise them of any significant increases to the predicted movements in the vicinity of the infrastructure.

## 12.22 Yambo Survey Trig Station

The Yambo Survey Trigonometry Station is located within the Project Area and is likely to be affected by mine subsidence.

The new location of the station will be surveyed after the completion of mine subsidence in consultation with Land and Property Information (Department of Finance & Services NSW).

# 13.0 Monitoring Requirements

## 13.1 Subsidence Development

The development of subsidence above longwall panels generally consist of three phases that are defined as 'primary', ‘secondary’ and 'residual' subsidence.

Primary subsidence is referred to the subsidence that is directly related to the retreating longwall extraction face.

Reference to **ACARP, 2003** and local data for the Mandalong Mine LWs 1-12 indicate that primary subsidence is likely to commence at a given location above the panel centreline when the longwall extraction face is a distance of about 0.5 times the cover depth ahead of the point. The subsidence will then start to accelerate up to rates from 50 to 100 mm/day when the face is 0.5 to 1 times the cover depth past of the point, and then decrease to < 2 mm/day when the face is > 2 times the cover depth past it; see **Figure 59**.

Maximum subsidence above a panel generally does not start to occur until the retreating extraction face has moved at least a distance equal to the width of the panel, and is referred to as the 'square' position.

Secondary subsidence is directly related to subsequent adjacent longwalls and caused by compression of chain pillars and goaf movements as they retreat past the site. Based on Mandalong subsidence data, secondary subsidence may continue to occur at an exponentially decreasing rate for at least four or five longwall passes; see **Figure 60**.

Approximately 90% to 95% of mine subsidence development will occur within 4 to 6 weeks after undermining occurs. On-going residual settlements due to goaf reconsolidation may continue for a period of up to 2 years, however, these movements are likely to be small and unlikely to result in significant impact occurring to the surface.

## 13.2 Surface Monitoring Plans

Based on the surface topography and surface infrastructure present above the proposed longwall panels 25 to 64, the following subsidence and strain-monitoring program is suggested to provide adequate information to monitor and implement appropriate subsidence impact management plans and provide prediction model performance data.

The following general monitoring program activities are suggested:

- Subject to landholder approval for access, a minimum of one transverse subsidence line across the proposed longwall panels. The lines should be installed to at least the middle of the next adjacent panel before undermining occurs. The final transverse surveys for each panel should include the previous panels to capture chain pillar subsidence as it develops.

- A longitudinal line will be installed as directed by the Principal Subsidence Engineer.

- A survey line along and across the banks of the main creeks to the satisfaction of the NSW Office of Water and the Department of Resources and Energy (refer to Surface Water Assessment).

- Horizontal strain angle of draw measurements from the sides and ends of the first longwall panel using standardized steel tape techniques for the purpose of assessing tensile strain predictions and the adequacy of proposed TransGrid Tension Tower buffer zones.

- A minimum of 4 pegs spaced 10 m apart adjacent to or around any feature of interest to measure subsidence, tilt and strain at the feature in consultation with the Principal Subsidence Engineer.

- The panel survey pegs should be spaced at a minimum of 10 m and a maximum of 20 m apart (i.e. cover depth / 20). For the first two or three panels it is recommended that pegs be installed along full cross lines and within the panel square end centrelines.

- As more survey data is obtained it is envisaged that the peg spacing may be widened at non-critical locations (eg the central sections of the panel centrelines) or deleted altogether.

- Survey frequency will be dependent upon mine management requirements for subsidence development data in order to implement subsidence and mine operation management plans.

- Visual inspections and mapping of damage to be conducted before, during, and after mining.

- The location of the extraction face should be recorded with each survey.

Further site or stakeholder specific monitoring may also be required which will be detailed in the Property Subsidence Management Plan for that property.

### 13.3 Survey Method and Accuracy

The surveys shall be conducted in accordance with the standards set out in the *Survey and Drafting Directions for Mining Surveyors 2007 (NSW-Coal)* in agreement with the Principal Subsidence Engineer.

### 13.4 Sub-Surface Monitoring

Monitoring of sub-surface fracture heights above longwall panels may be necessary within the mining area to confirm the predictions of potential areas of connective surface cracking.

One deep borehole extensometer has been installed in the middle of Mandalong Mine's LW5 to monitor heights of sub-surface fracturing due to the caving or goafing process during mining.

The details and results of the monitoring have been successfully collated and indicate that the height of continuous fracturing is within the predicted ranges. Sub-surface fracture height measurements (through installation of deep borehole extensometers and pairs of shallow stand pipe piezometers along creeks to depths ranging from 5 m to 15 m) above the proposed longwalls should be considered during the Project at representative locations as part of the Extraction Plan TARP requirements.

Consideration of further deep borehole extensometers in the low lying eastern areas of the Project Area would allow a more comprehensive review of groundwater interaction with the extracted longwall panels.

Inspections and monitoring of underground workings stability, groundwater makes and goaf air entry should continue to be recorded and included with subsidence monitoring data. In particular, the presence of faults between panels has the potential to create perched water tables and delayed/increased inflow responses into extracted panels.

## 14.0 Conclusions and Recommendations

Overall, it is concluded that the assessed range of potential subsidence and far-field displacement impacts after the mining of the proposed longwall panels will be manageable for the majority of the site features, based on the analysis outcomes and discussions with the Stakeholders to-date.

Centennial Mandalong will implement an adaptive management approach to ensure Project Approval performance measures are achieved. Adaptive management will involve the monitoring, remediation and periodic evaluation of the consequences of mining, with possible adjustment of the mining layout through the Extraction Plan process to achieve the required measure of performance.

The prediction methods applied in this report will allow specialist consultants to assess the potential range of impacts to a given feature in a probabilistic manner.

Impact Management Plans and strategies can then be developed that allows appropriate Trigger Action Responses and mine planning adjustments or mitigation measures necessary to deliver satisfactory outcomes to the feature and the stakeholders.

The subsidence effect and impact assessment predictions have also been validated against surface and subsurface monitoring programs at Mandalong Mine with similar geological conditions and mining methods.

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