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Donaldson Coal Pty Ltd

Subsidence Predictions and Impact Assessment for the Proposed Pillar Extraction Panels at Abel Mine, Black Hill

DGS Report No. ABL-001/1

Date: 6 December 2009

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6th December, 2009

Mr Tony Sutherland
Technical Services Manager - Underground Operations
Donaldson Coal
Abel Mine
1132 John Renshaw Drive,
Black Hill NSW 2322

DGS Report No. ABL-001/1

Dear Tony,

Subject: Subsidence Predictions and Impact Assessment for the Proposed Pillar Extraction Panels at Abel Mine, Black Hill

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 report presents predictions of worst-case mine subsidence magnitudes and management strategies to minimise impacts on natural and man-made features at the Abel Mine, John Renshaw Drive, Blackhill. The report will be used for the purpose of preparing a Subsidence Management Plan (SMP) submission to the NSW Department of Industry and Investment.

The report has assessed the proposed mining layout of thirteen, 160.5 m wide pillar extraction panels (Panels 1 - 13) in the 2.0 m to 3.2 m thick Upper Donaldson Seam. It is also proposed to extract the pillars in the 125 m to 131 m wide East Mains Headings on retreat after completion of the production panels.

The proposed mining area is bounded by John Renshaw drive to the north, the F3 Freeway to the east and Blackhill Road to the west and south. The SMP area land is semi-cleared, dry-sclerophyll forest with generally flat to gently undulated terrain.

The entire surface of the SMP application area is contained within land owned by Black Hill Land Pty Limited, Catholic Diocese of Maitland-Newcastle and a narrow strip traversing the area owned by Hunter Water Corporation.

Land use in the area is a combination of the following:

- Native bushland;
- Grazing, and
- Industrial (Boral asphalt plant in north eastern corner).

Infrastructure above the mining area consists of:

- Boral asphalt plant and associated infrastructure;
- Transgrid 330kV transmission line;
- Energy Australia 132kV transmission line;
- Energy Australia 11 kV rural supply lines;
- Hunter District Water Board pipeline;
- Optus fibre optic cable;
- Redundant Telstra copper cables;
- Disused, unoccupied residences;

- Stock water supply line;
- Access roads and tracks.
- Various fences; and
- One small disused dam.

The SMP Area was classified as a subsidence district until 1995. The Mine Subsidence Board is in the process of re-classifying the area as a Mine subsidence district before mine subsidence impacts occurs.

The Catholic Diocese land is presently used to graze cattle (and previous to that was the Steggles Poultry Farm). Disruption of the existing stock watering system is a significant business risk and will need to be managed carefully during mining.

The Black Hill Land Pty Ltd land is currently partially developed with a Boral Asphalt plant and the remediated Iron Bark Colliery pit top area. The Black Hill Land Pty Ltd land is likely to be re-developed into industrial lots with sealed access roads. No development proposals have been indicated for the Catholic Diocese land at this stage.

The estimate of post-mining 1 in 100 Year ARI flood levels along the creeks in the SMP area will require a hydrological assessment. Based only on the predicted post-mining subsidence contour predictions prepared in this study, it is estimated that the areal extent of flooding due to the 1 in 100 year ARI event may increase by up to 5% after mining is completed.

The surface slopes range from 1^o to 10^o and steepen locally to 15^o along Viney Creek (a NSW Department of Environment, Climate Change and Water listed Schedule 2 Creek), which drains the site towards the north-east. Topographic relief ranges from 10 m AHD to 56 m AHD across the panels.

Aboriginal Artefact scatters (silcrete stone axe flakes) have been identified at three locations within the mining area, but all are outside the limits of proposed secondary extraction. It has also been assessed that there are likely to be further archaeological sites with 'moderate cultural significance' along the Viney Creek corridor to the south of the proposed SMP area.

A 330 kV power line corridor traverses the site with a total of eight transmission towers (No.s 29B to 36B), including a tension tower (No. 33B). The towers were constructed with cruciform footings in the early 1980's in anticipation of mine subsidence from the Iron Bark Colliery (which did not proceed).

Based on consultation with stakeholders to-date, Subsidence Control Zones (SCZ) will be required for Viney Creek (DECCW), the Transgrid tension tower (No. 33B) and the Boral Asphalt Plant Pty Ltd.

The pillar extraction panels will have cover depths ranging from 50 m to 135m and mining heights ranging from 2.0 to 3.2 m (i.e. almost equal to the seam thickness). The East Mains headings will also be extracted on retreat after the production panels are completed and will have panel void widths of 125 m to 131 m. The mining height in the East Mains panels will range from 2.0 m to 3.2 m.

Panel development headings will be 5.5 m wide and range from 2.2 m to 3.0 m high (depending on seam thickness).

Barrier pillars between production panels and the East Mains headings will generally have widths of 19.5 m and 14.5 m respectively and are expected to behave elastically in the long term (i.e. strain hardening characteristics are likely to develop if the pillars are overloaded). It is expected that some of the 13 m wide x 19.5 m long row of remnant pillars that are to be left after secondary extraction of Panel 1 and the East Mains Headings will yield after mining.

The overburden comprises thinly bedded sandstone, siltstone and mudstones (shale) of the Dempsey Formation, which is part of the Permian Aged Tomago Coal Measures. A persistent geological structure (reverse fault) with an 8 m throw intersects the eastern SMP area on a north westerly strike.

The panel width to cover depth (W/H) ratios for the proposed 160.5 m wide pillar extraction panels will range from 1.23 to 2.92, indicating 'critical' to 'supercritical' subsidence behaviour, which are assumed to occur when panel W/H ratios are > 0.6 and >1.4 respectively.

The panel width to cover depth (W/H) ratios for the East Mains 125 m to 131 m wide panels will range from 1.32 to 1.75, indicating supercritical subsidence behaviour.

The following subsidence impact parameters for all proposed pillar extraction panels are predicted:

- First and Final maximum panel subsidence ranging from 0.87 m to 1.76 m (40% to 55% of the mining height).

- First and Final barrier pillar subsidence ranges from 0.03 m to 0.26 m due to total pillar stresses after mining of 1.7 MPa to 12.9 MPa.

- Final maximum panel tilt ranges from 15 mm/m to 76 mm/m.

- Final maximum panel hogging curvature ranges from 0.61 km^{-1} to 3.61 km^{-1}.

- Final maximum panel sagging curvature will range from 0.77 km^{-1} to 4.58 km^{-1}.

- Final tensile strains associated with the hogging curvatures will range from 4 mm/m to 26 mm/m.

- Compressive strains associated with the sagging curvatures will range from 6 mm/m to 33 mm/m.

- Final maximum panel horizontal displacement from 110 mm to 555 mm.

The key outcomes from the impact assessment are as follows:

- Based on the predicted range of maximum transverse tensile strains (i.e. 4 to 26 mm/m), maximum surface cracking widths of between 40 mm and 260 mm could occur within the limits of extraction (i.e. goaf), and soon after mining is completed beneath the area. The larger cracks (i.e. >150 mm) are predicted in the shallow areas where cover depths are < 80m.

- Crack widths in the deeper areas > 80m are likely to be in the order of 40 to 150 mm above the pillar extraction. The tensile cracks will probably be tapered and extend to depths ranging from 5 to 10 m, and possibly deeper in near surface sandstone exposures, if present.

- The predicted range of maximum transverse compressive strains (i.e. 6 to 33 mm/m) above the pillar extraction panels may result in shear displacements of between 60 mm and 330 mm within the central limits of extraction.

- The **ACARP, 2003** model predicts that mean heights of continuous sub-surface fracturing are likely occur within 10 m of the surface for cover depths <50 m and possible up to cover depths of 80 m. Connective cracking to the surface will be unlikely to occur where cover depth exceeds 80 m.

- The **Forster, 1995** model indicates a similar range of connective cracking heights from 46 m to 106 m for the pillar extraction panels with a mining height of 2.2 to 3.2 m.

- Discontinuous fracturing is likely to interact with surface fractures and open joints in the rock mass for cover depths <100m. It is possible that the interaction could continue for cover depths up to 140 m for the given mining geometries.

- In regards to changes to rock mass permeability, **Forster, 1995** indicates that horizontal permeabilities in the fractured zones above longwall mines (see **Figure 30**) 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).

- Discontinuous fracturing would be expected to increase rock mass storage capacity and horizontal permeability without direct hydraulic connection to the workings. Rock mass permeability is unlikely to increase significantly outside the limits of extraction.

- Scarp development or surface steps up to 300 mm could develop above total extraction panels with a depth of cover < 80 m and a panel width/cover depth ratio > 2. The deep soil profile across the site may mitigate against the potential for scarp development however.

- The potential ponding depths (i.e. closed form depressions) are very unlikely to develop along the lower reaches of Viney Creek, based on the post-surface topography and the proposed SCZ beneath the creek.

- A potential pond area of 5,000 m^2 and 1 m depth has been identified from predicted post-mining surface levels above Panel 8. The area is also located along the western boundary of the Black Hill Land Pty Ltd re-development scheme. Re-grading of this area may therefore be necessary unless an SCZ is established in the panel beneath this area.

- It is considered unlikely that valley closure movements will occur in the gullies / broad crested valleys above the proposed panels. 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 is likely to be limited to < 100 mm. Minor cracking in creek beds may cause some shallow sub-surface re-routing of surface flows due to the valley closure mechanism.

- To-date, local longwall mining experiences in undulating terrain with ground slopes up to 25^o has not resulted in any large scale, *en-masse* sliding instability due to mine subsidence (or other natural weathering processes etc.). In general, it is possible that localised instability could occur where ground slopes are > 15°, if the slopes are also affected by mining-induced cracking and increased erosion rates.

- The rate of erosion is expected to increase significantly in areas with exposed dispersive / reactive alluvial or residual soils or tuffaceous claystone and slope gradients are increased by more than 2% (>20 mm/m). It is estimated that the gradients above the site will increase or decrease by 1% to 4%.

- An empirical model for predicting far-field displacement (FFDs) in the Newcastle Coalfield 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. Predicted lateral curvature radii for each road after mining are > 200 km for horizontal displacements of < 15 mm.

  An empirical model for predicting far-field strains (FFSs) in the Newcastle Coalfield 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 95% Confidence limit curve). It is assessed, however, that strains will be <0.5 mm/m at a distance equal to 0.5 x cover depth from the pillar extraction panels at Abel.

  Based on the above, no impacts due to the proposed mining layout are likely to develop along John Renshaw Drive and the F3 Freeway.

- Mitigation, repair or replacement works may be required after mining impacts for the other features, which include a buried 200 mm diameter UPVC Hunter Water Pipeline, the stock watering system on Catholic Diocese Land, the buried PVC sheathed Optus Fibre Optic cable, eight pairs of timber poles, which suspend the

Energy Australia 132 kV power lines, twenty three timber poles, which suspend the Energy Australia 11 kV domestic power lines, and buried Telstra copper telecommunications cabling.

- The likely impacts of 1.2 m to 1.6 m of mine subsidence on the Optus Fibre Optic Cable and Hunter Water pipeline are unknown at this stage. Further analysis of the predicted deflected shapes provided in this report and likely stress / strain transfer into each feature will need to be undertaken by the stakeholders.

  Draft impact management strategies have been developed to allow for sections of each of these features to be uncovered and relocated or replaced either before, during or after mining.

- No mining related impacts are predicted for the Aboriginal artefact scatters sites identified outside the limits of secondary extraction and angle of draw.

The interpretation and use of the predictions from this report for subsequent impact assessment may need further review, once the magnitudes of tolerable or acceptable impacts are defined by the stakeholders during SMP development.

It is considered that whilst the proposed SMP layout is not orientated the same way as the layout presented in the Environmental Assessment (EA) Report for the Abel Mining Lease Application, the mining geometry and resulting impacts to the natural and man-made features will be similar in magnitude and location to the EA study outcomes.

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Glossary of Terms

1.0 Introduction

This report presents a mine subsidence impact assessment for the proposed pillar extraction panels in the Upper Donaldson Seam at Abel Underground Coal Mine, Black Hill.

The report will be used for the purpose of preparing a Subsidence Management Plan (SMP) submission to the NSW Department of Industry and Investment.

The report has assessed the proposed mining layout of thirteen pillar extraction panels (Panels 1 - 13), as shown in **Figure 1**.

The scope of work for the report includes predictions of the following:

(i) Maximum surface subsidence impact parameters;

(ii) Surface subsidence impact parameter profiles and contours;

(iii) Pre and post mining topography;

(iv) Sub-surface heights of continuous and discontinuous fracturing above the panels.

(v) Potential cracking width locations;

(vi) Potential ponding depth locations and impacts on 1 in 100 Year Average Recurrence Interval (ARI) flood levels along creeks within the site;

(vii) Potential surface gradient changes;

(viii) Far-field horizontal displacements and strains

(ix) Predicted impacts on man-made developments and Aboriginal heritage sites

(x) Design of Subsidence Control Zones (SCZ) beneath sensitive surface features.

Mean and Credible Worst-case subsidence impact parameter predictions with or without impact management controls have been estimated in this study to assist specialist consultants assess the potential range of impact to a given feature. The necessary mine planning adjustments or mitigation measures will then be implemented to deliver satisfactory outcomes to the affected stakeholders.

Reference has been made to relevant information provided in the Abel Mine's Environmental Impact Assessment submission to the NSW Department of Planning in October, 2006.

The predictions in this study have been based on three empirical models developed for the Newcastle and US Coalfields (refer to **ACARP, 2003**, **Holla, 1987** and **SDPS, 2007**).

2.0 Available Information

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

- The proposed mining layout.
- Cover depth contours to the Upper Donaldson Seam and seam thickness isopachs.
- Borehole log and core testing data from the SMP Area.
- Geological structure (fault and dyke) locations.
- Surface topographic levels and existing drainage regime locations.
- Locations of surface developments and infrastructure in the study area.
- Locations of Aboriginal Artefact Scatter sites.

Plans of the proposed mining layout with cover depth contours, seam thickness isopachs and pre-mining surface topography are presented in **Figures 1** to **3**.

Bore core log and testing data was applied from the boreholes shown in **Table 1**.

Table 1 - Borehole Log Data

BH#	Easting	N	Collar RL	Date
C153	369525	6366791	40.21	10/03/09
C155	370012	6367148	30.85	19/03/09
C156	369569	6366357	49.28	23/03/09
C158	370111	6366526	41.12	30/03/09
C159R	370444	6367172	30.68	08/04/09
C161	370656	6367523	36.24	23/04/09

3.0 Mining Geometry

3.1 Pillar Extraction Panels

The following mine workings details have been assumed in this assessment for the pillar extraction panels beneath non-sensitive features:

(i) The pillar extraction panels (P1 to P13) will be located at depths ranging from 50 m to 135 m and will be 160.5 m rib to rib width.

(ii) The pillar extraction panels will be developed to the north and south from the East Main headings generally on a four heading layout. The first workings will consist of three 25 m wide pillars formed on 45 m and 65 m length centres. Based on a nominal roadway width of 5.5 m, the solid pillar geometries will be 19.5 m wide x 39.5 m and 59.5 m in length.

(iii) The barriers between the extracted pillar panels will be 19.5 m wide and 0.3 km to 0.8 km long. The pillar height will range from 2.2 m to 3.0 m, depending on the seam thickness. The inter-panel barrier will have w/h ratios ranging from 7.5 to 8.5. These pillars are expected to yield gradually and strain-harden if the unlikely scenario of overloading occurs.

(iv) It has been assumed that approximately 85% to 90% of the pillars (high extraction mining) will be extracted during second workings using a continuous miner and Mobile Breaker Line Supports (MBLS) to provide temporary roof control.

(v) The pillars and adjacent solid ribs in the will then be extracted (i.e. lifted) on retreat. The rib-stripping will be 9.75 m deep. The solid barrier between the finishing ends of the panels and the adjacent East Mains will be 14.5 m wide (after allowing for a similar 9.75 m wide rib strip during retreat along the East Mains).

(vi) The seam thickness ranges from 2.0 m to 2.4 m along the northern limits of the mining area and from 2.2 to 3.2 m along the southern limits of the proposed mining area. The full seam thickness will be mined during secondary extraction.

(vii) The East Mains will be developed as a 5 heading layout with pillars formed on 25 m wide x 45 m long centre spacing. The pillars will be lifted to a depth of 9.75 m on retreat after completion of mining in the production panels. The final rib-rib width of the Mains panels will be 125 m and 131.25 m, with solid pillar barrier widths of 14.5 m left between the adjacent pillar extraction panels. These pillars will have w/h ratios ranging from 5.6 to 6.0 and are also expected to yield gradually and strain-harden if the unlikely scenario of overloading occurs.

(ix) The panel width to cover depth ratio (W/H) for the proposed pillar extraction panels will range from 1.19 to 2.92, indicating critical to supercritical subsidence behaviour is likely to occur. Similar behaviour is also expected after the secondary extraction of the East Mains headings, which will have W/H ratios ranging from 1.31 to 1.75.

Note: Critical subsidence refers to the point where sub-critical or natural overburden 'arching' behaviour stops (i.e. when W/H > 0.6) and the development of maximum subsidence or super-critical overburden behaviour starts (i.e. maximum possible subsidence occurs when W/H > 1.4 but will be limited by the mining height also).

3.2 Subsidence Control Zones

For mine workings below sensitive surface features or a designated Subsidence Control Zone (SCZ), the following design assumptions have been applied:

(i) The panels will have only first workings pillars.

(ii) The pillars will be designed to behave elastically under long-term abutment loading conditions from adjacent total extraction ratio panels.

4.0 Site Conditions

4.1 Land Use and Surface Features

The proposed mining area is predominately zoned as rural residential or commercial property with several public utility easements and Council roads.

The land is semi-cleared, dry-sclerophyll forest and the terrain is generally flat to gently undulated. The surface slopes range from 1^o to 10^o and steepen locally to 15^o along Viney Creek (a NSW Department of Environment, Climate Change and Water listed Schedule 2 Creek), which drains the site towards the north-east. Topographic relief ranges from 12 m AHD to 50 m AHD across the panels.

The natural and archaeological features of significance within the study area include:

- Gently undulating terrain and mild slopes.
- Headwaters of Viney Creek (A DECCW Schedule 2 Creek) and an unnamed drainage gully (A DECCW listed Schedule 1 watercourse).
- Sandy alluvial deposits (up to 3 m deep) exist along the lower reaches of the creek with no rock exposures evident.
- Silty sand and sandy clay surface soils present on the site are likely to be mildly to highly erosive / dispersive if exposed to concentrated runoff during storm flow events.
- The 1 in 100 Year ARI flood levels along the creeks within the site (see **Figure 3**)
- Vegetation on the site consists of dense stands of dry schlerophyll forest with shrubs, ferns and grasses. The riparian zones along creeks have sparse to dense stands of melaleucas, vines and grasses.
- Common flora/fauna habitats within the study area and groundwater dependent ecosystems along the watercourses.
- Reference to three separate studies of the area (**Parsons Brinkerfhoff, 2003**, **South Eastern, 2006** and **ERM, 2008)** have identified three scattered Aboriginal artefact sites in the SMP area that are located outside the limits of proposed secondary extraction (see **Figure 3**). The artefacts are listed as silcrete stone axe flakes and were identified by the Mindaribba Local Aboriginal Land Council, Awabakal Traditional Owners and Kukuyal Burritjapa.

Existing developments within the SMP area include the following:

- Eight 330kV Transgrid Transmission towers (29B to 36B) including one tension tower, 33B.

- A buried optic fibre cable in the Transgrid easement (Optus).

- One buried 200 mm diameter UPVC water supply pipeline (pressurised) with rubber ring joints and a disused 500 mm diameter welded steel pipeline (Hunter Water).

- A 132 kV transmission line suspended on nine pairs (EA1 to EA9) of un-guyed, timber poles with bolted steel cross bracing (Energy Australia).

- Redundant Domestic buried copper telephone lines (Telstra). This local cable reticulation was used when the property was functioning as a chicken farm and the cable provided services to the individual properties located on the land. It has not been used since for some time and the cable has fallen into disrepair due to lack of maintenance. As the only future Principal Residence listed on the Catholic Land at the time of approval is the proposed school, the impact on the redundant copper cables within the SMP Area 1 will not be considered. There is live local copper cable feed to the residents along BlackHill Road which will not be affected from the mining within SMP Area 1.

- One domestic 11 kV suspended power lines suspended on twenty-three timber poles (Energy Australia).

- Demolished chicken battery farm shed rubble and disused houses/buildings (Catholic Diocese Land). *Note: It is understood through stakeholder discussions that potentially hazardous waste may be placed in a controlled (lined) landfill somewhere on the site.*

- Unsealed access roads and fences (on land owned by the Catholic Diocese and Black Hill Land Pty Ltd).

- Buried water reticulation pipelines and above ground troughs for livestock watering (Catholic Diocese Land).

- An abandoned earth embankment dam with < 1ML capacity (Black Hill Land Pty Ltd). The dam is dry and covered in reeds. There are no plans at this stage to monitor or re-instate the dam after mining.

- The abandoned (and cleared) pit top area of Iron Bark Colliery (Black Hill Land Pty Ltd)

- Concrete box culverts for unsealed access road across Viney Creek to Iron Bark Colliery pit top (Black Hill Land Pty Ltd)

- The Boral Asphalt Plant (Black Hill Land Pty Ltd)

- Semi-cleared and undeveloped land (Catholic Diocese and Black Hill Land Pty Ltd)

At this stage, the Black Hill Land Pty Ltd land is likely to be re-developed into industrial lots with sealed access roads and drainage works. No development proposals have been indicated for the Catholic Diocese land at this stage.

Based on consultation with stakeholders to-date, Subsidence Control Zones (SCZ) will be required for Viney Creek, the Transgrid tension tower (No. 33B) and the Boral Asphalt Plant.

The locations of the above features (and surface gradients) are shown in **Figure 1** to **3**.

4.2 Sub-Surface Conditions

Reference to the 1:100,000 Geological Sheet for the Newcastle Coalfield (**DMR, 1995**), indicates the proposed SMP layouts are located within the Dempsey Formation of the Permian Tomago Coal Measures.

The overburden for the area will consist of gently, south-west dipping (i.e. 2 to 5 degrees) sedimentary strata of the Tomago Coal Measures, which generally comprise interbedded sandstone, shale, carbonaceous mudstone, tuffaceous claystone and coal. The coal seams present in the overburden (in descending order) include the Sandgate, Buttai, Beresfield, Upper and Lower Donaldson, Big Ben and Ashtonfield Seams.

Based on reference to the DMR Geological Sheet, there are several significant NW:SE striking geological structure zones (i.e. faults and dykes) which occur along Buttai Creek and Long Gully Creek to the west of the site, and also an 8 m throw reverse fault in the north-east corner of the SMP area (see **Figure 1**). The south-eastern bedding dip across the site is associated with the southern arm of the Four Mile Creek Anticline, which is located to the west of the site.

Surface joint patterns measured on the sandstone cliff lines and outcrops to the south of the SMP area consist of a sub-vertical, widely spaced, planar to wavy, persistent joint sets striking between 025° and 035° (NNE to NE). A sub-vertical joint set striking at approximately 135° (NW:SE) is also present. The trends of the cliff faces are similar to the above joint sets.

The Upper Donaldson Seam has low strength with sonic derived unconfined compressive strength (UCS) values ranging from 7 to 15 MPa. Some medium to high strength stone bands up to 0.5 m thick are present within the coal seam, with UCS values ranging between 30 and 90 MPa.

The immediate roof and floor of the proposed mining horizon will typically consist of 5 to 10 m or more of thin to medium interbedded shale and sandstone with low to medium strength (10 to 50 MPa). The weaker materials, such as carbonaceous mudstone, mudstone and claystone are very thin (< 0.1 m thick) and exist in both the roof and floor.

Low strength immediate roof and floor materials were also generally noted in several boreholes in the north, where the cover depths are less than 40 m. This is also considered to be the depth of weathering on the Donaldson open cut mine to the north of the underground mining area. The sonic UCS results indicated thinly bedded strata with strengths ranging between 10 and 50 MPa and generally from 30 to 50 MPa for the overburden materials at depths > 40 m.

The UCS and stiffness properties of the immediate roof and floor materials have been derived from laboratory and point load strength test results from core taken from six boreholes and in-situ geophysical testing data. Good correlation was apparent between the laboratory derived and *in situ* sonic UCS results presented in the Environmental Assessment.

Estimates of the range of material strength and stiffness properties present in the roof and floor of the Upper Donaldson Seam are summarised in **Table 2**.

Table 2 - Strength Property Estimates for Upper Donaldson Seam, Roof and Floor Lithology

Lithology	Strata Thickness (m)	UCS Range+ [Average] (MPa)	Elastic Moduli Range* (GPa)	Average Moisture Sensitivity^
Interbedded sandstone/ shale beds above the UD Seam	<10	10.5 - 93 [18 - 51]	3 - 15	Non-Sensitive to Moderately Sensitive
Interbedded sandstone/ shale beds below the UD Seam	<10	11.5 - 130 [31 - 72]	3 - 15	Non-Sensitive to Slightly Sensitive
Upper Donaldson Seam	2.0 - 3.2	5 - 15	2 - 4	Non- Sensitive to slightly sensitive stone bands

Note:
+ - Unconfined Compressive Strength derived from point load testing to **ISRM, 1985** on bore core samples taken from SMP area.
* - Laboratory Young's Modulus (E) derived from laboratory and sonic UCS data, E = 300 x UCS (units are in MPa).
^ - Moisture sensitivity testing determined from the Immersion Test procedure presented in **Mark & Molinda, 1996**.

5.0 Subsidence Prediction Methodology

5.1 General

The study included the following activities and the application of several industry established empirical models to predict the 'mean' and 'credible worst-case' subsidence for a given mining layout:

(i) Development of a geotechnical model for the study area (i.e. mining geometry, geology, material properties etc).

(ii) Calculation of maximum subsidence impact parameter predictions and representative parameter profiles using the **ACARP, 2003** and **Holla, 1987** empirical subsidence models and the mining geometries proposed.

(iii) Assessment of barrier and chain pillar stability, based on **ACARP, 1998a** and **ACARP, 1998b**.

(iv) Development and calibration of **SDPS®** models (using the subsidence, tilt and strain profiles from (ii)) to generate subsidence and associated impact parameter contours above the proposed mining layouts.

(v) Generation of subsidence, tilt, strain, horizontal displacement, post mining topography, potential cracking width, ponding location and surface slope gradient change contours for the proposed mining layouts using **Surfer8®** contouring software.

(vi) Estimation of sub-surface fracturing heights above the panels using empirically based models in **ACARP, 2003**, **Forster, 1995** and **Mark, 2007**.

(vii) Estimation of the extent and magnitude of far-field displacements (FFD) and strains (FFE), based on empirically based models developed from Newcastle Coalfield data by **DgS, 2008**.

5.2 Subsidence Prediction Model Details

The two subsidence predictions models used in this study are summarised 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 includes 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 or barrier pillar subsidence, inflexion point distance from panel edges, inflexion point subsidence, goaf edge subsidence and angle of draw prediction models. These models allow subsidence profiles to be generated for any number of panels within a range of appropriate statistical confidence limits. The mean and Upper 95% Confidence Limit (U95%CL) values have been adopted in this study for predictions of the average and Credible Worst-Case values expected, due to the proposed mining activities.

The **ACARP, 2003** model may also be used for predicting maximum subsidence above pillar extraction panels by applying the ‘effective’ mining height principal (i.e. extraction ratio x mining height) defined in **Van de Merwe and Madden, 2002**. The principal allows for subsidence reducing effect of crushed out remnant coal that will be left behind in the workings.

Based on a comparison between high extraction panel and longwall panel subsidence databases in **ACARP, 2003** and **Holla, 1987**, a conservative extraction ratio of 95% and a maximum longwall panel subsidence of 58% of the mining height, give a maximum pillar extraction panel subsidence of 55% of the mining height.

A summary of the **ACARP, 2003** model, which defines the parameters and terms used, is presented in **Appendix A**.

- **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. An extract from the **SDPS®** user manual defining the parameters and terms used is presented in **Appendix B**.

Overall, the SDPS® model should preferably be calibrated to measured subsidence profiles above pillar extraction workings with similar conditions as Abel. However, due to the lack of similar mining data, the calibration procedure applied in this study is considered best practice for a ‘green fields’ study. A re-calibration of the model may be necessary, however, if the predicted outcomes of this study are significantly different to measured ones.

The modifications to the **ACARP, 2003** model by DgS included adjustments to the following key parameters, which were made to improve compatibility between the two models used in this study:

- Chain (and barrier) pillar subsidence prediction is now based on pillar subsidence over extraction height (S_p/T) v. pillar stress (under double abutment loading conditions).

- 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).

- The horizontal strain coefficient (β_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 NSW coalfield data, a value of $d_n = 7.3$ m or a $\beta_s = 0.136$ m^{-1} has been applied to predict 'smooth' profile strains using the calibrated **SDPS®** model.

Multiple-panel effects are determined by the **ACARP, 2003** model by adding a proportion of the chain (or barrier) pillar subsidence to the predicted single panel subsidence. Estimates of first and final subsidence above a given set of pillar extraction panels use this general approach. The definition of First and Final S_{max} is as follows:

First S_{max} = the total subsidence after the extraction of a panel, including the effects of previously extracted panels adjacent to the subject panel;

Final S_{max} = the total subsidence over an extracted panel, after at least three more panels have been extracted, or when mining is completed.

First and Final S_{max} for a panel are predicted by adding 50% and 100% of the predicted subsidence over the respective barrier pillars (i.e. between the previous and current panel), less the goaf edge subsidence (which occurs before the barrier pillar is loaded from both sides). The maximum subsidence is limited to 58% of the effective mining height for the panels.

The subsidence above chain and barrier pillars has been defined in this study as follows:

First S_p = subsidence over a pillar after panels have been extracted on both sides of the pillar;

Final S_p = the total subsidence over a pillar after at least another three more panels have been extracted, or when mining is completed.

A conceptual model of the multiple panel subsidence mechanism is given in **Figure 4a**.

Residual subsidence above chain (and barrier) pillars and extracted panels tend to occur after mining of adjacent panels due to (i) increased overburden loading on the pillars, and (ii) on-going goaf consolidation or creep of the collapsed roof or goaf in the panel. The residual movements can increase subsidence by a further 10 to 30% above chain (and barrier) pillars after the first pillar subsidence occurs. Residual subsidence is likely to decrease exponentially as mining moves further away from a given panel.

A subsidence increase of 20% after double abutment loading occurs (i.e. First S_p) has been assumed in this study to allow for long-term loading effects (i.e. Final S_p).

Unless otherwise stated the predicted values presented in the following sections of this report are given as a range from the mean to the U95%CL values. The measured subsidence will be expected to be somewhere between these values.

Tilts and curvatures 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.

Predictions of strain and horizontal displacement were made based on the relationship between the measured curvatures and tilt respectively as discussed in **ACARP, 1993** and **ACARP, 2003**.

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, or in other words, half the beam thickness. **ACARP, 1993** studies returned strain over curvature ratios 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.

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 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 lead to the median value of 7.3 being adopted as a more appropriate value for impact prediction purposes.

A d_n value of 7.3 m has therefore been applied to the predicted 'smooth' curvature and tilt profiles to estimate strain and horizontal displacement respectively above the proposed Abel panels. These values may then be compared to the empirical model outcomes to estimate localised, concentrated strain effects due to cracking. Cracking is expected to occur in zones of peak tensile (or compressive) strains when tensile and compressive strains exceed 1 to 2 mm/m respectively and where surface rock exposures are present.

For the Abel mining lease, the presence of deep alluvial soils are likely to reduce the potential for strain concentration, resulting in strain profiles close to the predicted 'smooth' subsidence profile strains presented herein.

Surface crack widths (in mm) may be estimated by multiplying the predicted strains by 10 which is an empirical relationship based on the distance between the pegs in the **ACARP, 2003** model database and the measured strains and crack widths above extracted panels.

5.3 Design of Subsidence Control Zones

5.3.1 General

The design of a reliable Subsidence Protection Zone (SPZ) will require consideration of the following issues:

- The minimum set-back distance from total pillar extraction panels (i.e. panels with > 85% of coal extracted) to control subsidence deformation to below tolerable design limits for the feature.
- The long-term stability of the pillars in the SPZ under abutment loading conditions from adjacent high extraction areas.
- The use of narrower total extraction panels that are sub-critical (i.e. W/H < 0.6) or partial extraction panels with long term stable remnant pillars left beneath sensitive surface features to control subsidence impacts to within tolerable limits.
- Whether the performance of the SPZ needs to be trialled in non-sensitive panels.

5.3.2 Minimum Design Set-Back Distances for SPZs

Minimum set back distances required for SPZs will depend upon the type of feature and the consequences of excessive damage if it occurs.

The minimum set-back distance from Viney Creek to high extraction mining has been defined in the EA document as a 26.5^o Angle of Draw (AoD) + 40 m, to limit subsidence of the creek bed and banks to < 20 mm.

Based on consultation with the surface water consultant for the project, it is understood that Viney Creek will tolerate higher magnitudes of subsidence if no hydraulic connection or change in drainage patterns and watercourse ecology occur.

For the Abel mining lease and reference to nearby mine sites, it is assessed that the development of significant surface cracking (i.e. > 20 mm wide) may be defined as the point where tensile strains exceed 3 mm/m in areas with relatively deep soil cover. Provided the proposed mining method does not result in widespread exceedences of 3 mm/m tensile (or compressive) strains, then it is assessed that the creek may be subsided by up to 0.35 m without impact.

Based on the above, it is also considered the following techniques may be adopted to control subsidence impacts to within tolerable limits for Viney Creek:

(i) Extract sub-critical total extraction panels (i.e. with W/H < 0.6) beneath the creek with squat chain pillars (i.e. with pillar w/h ratios > 5) between the panels.

(ii) Alternatively it will be possible to conduct partial pillar extraction beneath the creek, which results in similar minimal subsidence magnitudes and impacts as defined above.

(iii) Adopt an angle of draw of 26.5^o or 0.5 x cover depth from the creek centreline to define a 'low' impact set-back distance from total extraction mining limits, pending confirmation from earlier panel monitoring data (see **Section 12**).

Other features such as the Transgrid tension tower and Boral Asphalt plant may require adequate set-back distances from total extraction mining to control subsidence, tilt and strains to tolerable levels to protect the structures from differential displacements (pending confirmation of tolerable limits from Transgrid). The following set-back distances from these features have been adopted at this stage:

- Transgrid Tension Tower - will require a minimum set-back distance of 45^o or the cover depth. *Note: a set-back distance of 2 x cover depth or 63^o has been applied to the total pillar extraction panels at Abe at this stage*.

- Boral Asphalt Plant - will require a minimum set-back distance of 26.5^o or 0.5 x the cover depth.

Further justification for the above design set-back distances are provided in **Section 7** of this report.

5.3.3 Pillar Stability

The stability of the SCZ will be controlled by mine design. The total stress acting on the first and subsequent row of pillars in the SPZ has been estimated using the abutment load concept defined in **ACARP, 1998a** for estimating single abutment loads on barrier pillars with an adjacent goaf. The load model is shown schematically in **Figure 4b**.

The total stress acting on the pillars after mining may be estimated as follows:

σ_{pillar} = pillar load/area = (P+RA)/wl

where:

P/wl = Full tributary area load of column of rock above each pillar;

= (w+ r)(l+r).ρ.g.H;

RA/wl = Single Abutment load due to cantilever action of overburden over goaf

$= 0.5\ u\ H^2 \tan(\theta)(l+r)/(wl)$ (where u = unit weight of overburden 0.025 MPa/m
θ = abutment angle (normally taken as 21^o))

R = Proportion of abutment load acting on first row of SPZ pillars;

$= 1 - [(D-w-r)/D]^3$ (where D = distance (m) that load distribution will extend from goaf edge according to **Peng & Chiang, 1986**: $D = 5.13\sqrt{H}$

$= 1$ (assumed for Abel SCZs)

w = pillar width (solid);
l = pillar length (solid);
r = roadway width;

H = depth of cover;

The FoS of the SPZ pillars were based on the strength formula presented in **ACARP, 1998b** (i.e. UNSW Power Rule) 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 height;
Θ = a dimensionless 'aspect ratio' factor or w/h ratio.

The FoS is then calculated by dividing the pillar strength, S, with the pillar stress, σ_{pillar}:

$$FoS = S/\sigma_{pillar}.$$

The next row of pillars inside the SPZ will be subject to significantly lower stress (<20% A).

For long-term stability it is recommended that a minimum Design FoS of 2.11 under worst-case service load conditions be adopted for sensitive surface features. Based on **ACARP 1998b**, the probability of failure of the SCZ pillars will be < 1 in 1 million.

The pillar width/height ratio is also a very important factor that indicates the post-yield behaviour of the pillars if they are overloaded.

Pillars with w/h ratios < 3 are considered most likely to 'strain-soften' if overloaded and result in rapid failure and pillar runs, whereas w/h ratios > 5 are more likely to 'strain-harden' and yield slowly or 'squeeze'. These types of post-yield behaviour have been discussed in **ACARP, 2005** and demonstrated in **Figure 6c** for various in-situ observations and laboratory experiments.

The proposed pillars in the SPZs will have width/height ratios that are between 5 and 10 for the nominal mining height ranges. The pillars are therefore likely to remain stable as a group and strain harden if local overloading occurs. A summary of design calculations for the currently proposed SCZs at the Abel mine are presented in **Table 3**.

The above formulae have also been applied in the subsidence assessment that follows for the proposed Abel mining layout.

Table 3 - Design Calculation Summary for Proposed Subsidence Protection Zones

Location	Cover Depth (m)	Pillar Area w x l (m)	Pillar Height h	Pillar Strength (MPa)	FTA Stress (MPa)	Service Load Stress* (MPa)	Pillar FoS	Pillar w/h
Viney Creek Buffer Zone	80	19.5 x 39.5	2.4	25.55	2.92	4.72	5.42	8.1
	85		2.4	25.55	3.10	5.13	4.98	8.1
	90		2.4	25.55	3.29	5.56	4.60	8.1
	95		2.4	25.55	3.47	6.00	4.26	8.1
	100		2.4	25.55	3.65	6.45	3.96	8.1
	120		2.6	22.66	4.38	8.42	2.69	7.5
	125		2.6	22.66	4.56	8.94	2.53	7.5
	130		2.6	22.66	4.75	9.48	2.39	7.5
Boral Asphalt Plant Buffer Zone	90	19.5 x 39.5	2.4	25.55	3.29	5.56	4.60	8.1

* - Service load for Viney Creek and Boral Asphalt Plant assumed to be equal to full single abutment load from an adjacent total extraction area goaf.

6.0 Results of Subsidence Assessment

6.1 Subsidence Reduction Potential

The Subsidence Reduction Potential (SRP) refers to the subsidence reducing effect that massive conglomerate / sandstone units above longwall or pillar extraction panels of a given width. The typical stratigraphy over the SMP area is shown in **Figure 5a** and indicates the strata units are < 10 m thick.

The thickness (t) of the sandstone units above the proposed Abel Mine panels were plotted against panel width (W) and distance (y) of the unit above the panels (and normalised to cover depth, H) as shown in **Figure 5b**.

Based on the database, the sandstone units within the overburden are likely to have 'Low' SRP for unit thicknesses < 10 m. This outcome generally applies to all of the 125 m to 160.5 m wide panels with cover depths ranging from 50 to 135 m.

It is also considered prudent at this stage to assume 'Low' SRP exists for all panels until sufficient local subsidence data becomes available to change this report's assessment of the strata properties.

6.2 Single Panel Subsidence Prediction

Based on the SRP assessment, the range of subsidence for the ‘Low’ SRP limit lines was determined from the subsidence prediction curves for the 100 m +/- 50 m panel depth category, as shown in **Figure 6**.

The predictions of maximum single panel subsidence for the pillar extraction panels, P1 to P13, range between 0.95 m and 1.66 m for W/H ratios of 1.28 to 2.92 and mining height range of 2.2 m to 3.2 m.

The secondary extraction of the East Mains headings will have critical and supercritical panel W/H ratios of 1.32 to 1.75, with predictions of maximum single panel subsidence ranging from 0.87 m to 1.34 m for a mining height range of 2.1 m to 3.2 m.

Subsequent mining of adjacent panels will result in further subsidence increases due to barrier pillar compression.

6.3 Barrier Pillar Subsidence Predictions

6.3.1 Empirical Model Development

The predicted subsidence values above the barrier pillars have been estimated based on an empirical model and an analytical model of the roof-pillar-floor system.

The empirical model has been developed from measured NSW Coalfields subsidence data over chain pillars (S_p) divided by the mining height (T) v. the total pillar stress after longwall panel extraction on both sides.

Reference to the longwall chain pillar database indicates that the subsidence measured above chain pillars may increase significantly when total average pillar stresses exceed 25 MPa (see **Figure 7a**) or when the pillar stress exceeds 0.625 times the pillar strength (see **Figure 7b**). This is also equivalent to a FoS of <1.67.

The estimate of the stress acting on a barrier pillar under double abutment loading conditions (due to mining of total pillar extraction panels on both sides of it) is based on the abutment angle concept described in **ACARP, 1998a** as follows:

σ = 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

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

w = pillar width (solid);

l = pillar length;

r = roadway width;

H = depth of cover;

ϕ = abutment angle (normally 21° adopted for cover depths < 350 m in the NSW Coalfields);

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

A panel is deemed sub-critical when $W'/2 < H\tan\phi$.

As presented in **ACARP, 1998b** the FoS of the barrier and 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 height;

Θ = a dimensionless 'aspect ratio' factor or w/h ratio in this case.

The FoS was calculated by dividing the pillar strength, S, with the pillar stress, σ.

6.3.2 Inter-Panel Pillars

Predictions of the maximum first and final barrier pillar subsidence for Panels P1 to P13 have been based on the mean and U95%CL curves shown in **Figure 7a** and the total stress acting on the pillars under double abutment loading conditions.

The predictions of first and final subsidence above the 19.5 m wide barriers between Panels 2 to 13 range from 0.03 m to 0.16 m for a mining height range of 2.2 m to 3.2 m. Pillar stresses are estimated to range from 1.7 MPa to 11.8 MPa for cover depths of 55 m to 125 m.

The post-mining factors of safety for the barrier pillars are estimated to range from 2.52 to 10.77 and likely to behave elastically in the long-term. The pillar w/h ratio range of 6.5 to 8.7 also indicates that the barrier pillars are likely to strain-harden if overloaded, and limit maximum subsidence to < 10% of the pillar development heights (see **Figure 7c**).

The predictions of first and final pillar subsidence for the 13 m wide x 19.5 m long pillars between the northern edge of Panel 1 and the East Mains range from 0.06 m to 0.30 m. The pillar stresss are estimated to range from 9.5 MPa to 12.9 MPa for cover depths of 75 m to 95 m.

The post-mining factors of safety for the 13 m wide pillars are estimated to range from 1.02 to 2.02 and may behave elastically with some localised yielding in the long term. However, the pillar w/h ratio range of 4.3 to 6.2 indicates that the barrier pillars are likely to strain-harden if overloaded and limit maximum subsidence to < 10% of the pillar development heights.

6.3.3 Barrier Pillars at Finishing Ends of Pillar Extraction Panels

The predictions of first and final pillar subsidence for the 14.5 m wide x 58.5 m long barrier pillars between the ends of the production panels and the East Mains range from 0.04 m to 0.26 m. The total pillar stresses are 6.5 MPa and 10.1 MPa for cover depths of 75 m to 95 m.

The post-mining factors of safety for the 14.5 m wide barrier pillars are estimated to range from 1.53 to 3.5 and may behave elastically with some localised yielding in the long term.

However, the pillar w/h ratio range of 4.8 to 6.6 also indicates that the barrier pillars are likely to strain-harden if overloaded, and limit maximum subsidence to < 10% of the pillar development heights.

6.4 Bearing Capacity of Roof and Floor Strata

The bearing capacity of the roof and floor strata should be considered when designing the barrier pillars for long-term subsidence control.

Reference to **Pells *et al* , 1998** indicates that the bearing capacity of sedimentary rock under shallow footing type loading conditions is 3 to 4 times its UCS strength. Based on the estimated average UCS values in the immediate floor and roof strata of 18 to 72 MPa, the general bearing capacity of the strata is estimated to range between 54 and 288 MPa.

Based on the predicted average pillar stress range of 1.7 to 11.8 MPa after the mining of the total pillar extraction panels, an overall FoS against roof and floor bearing failure of > 4.60 is assessed. The roof and floor strata are therefore likely to behave elastically in the long term.

Some local shear failure may occur in the wetter areas of the mine with weaker floor units however, resulting in minor floor heave and rib instability.

The observed behaviour of longwall chain pillars and roof / floor system has also been used to develop a simple analytical model in **Section 6.5**.

6.5 Analytical Pillar Subsidence

6.5.1 Model Development

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

Given that the stress on the barrier or 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 as defined in **ACARP, 2005**.

Reference to **Figure 7b** indicates that the proposed barrier pillars (that will generally have w/h ratios > 5) would be expected to strain-harden if they are over-loaded and go into yield. The post-yield stiffness of the coal pillars has been assumed to equal 15% of the peak Young's Modulus value of 3 GPa (i.e. 450 MPa) and limit subsidence to within the observed range of subsidence values for Australian longwall mines; as shown in **Figure 7a**.

The roof and floor strata FoS values estimated in the previous sections of this report indicate that the compression of these materials may be estimated using laboratory test results that have been 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 or 20 to 25 m above and below the pillars) 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) range of 50 to 60 (very blocky or jointed strata with fair to good bedding party surface quality (i.e. rough and slightly to moderately weathered) as follows:

$E_{rockmass}$ = 0.3 - 0.5$E_{laboratory}$

E_{roof} = 5 - 10 GPa (for an estimated laboratory stiffness range 15 to 20 GPa)

E_{floor} = 2.5 - 5 GPa (for an estimated laboratory stiffness range of 7.5 to 10 GPa)

E_{coal} = 2 - 4 GPa (back analysis from field measurements as laboratory stiffness is not possible to measure)

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:

$$s_{pillar} = \sigma_{net}T_s/E_c + (\sigma_{max} - S_p)T_s/0.15E_c \qquad (1)$$

where:

s_{pillar} = pillar compression;

σ_{net} = pillar stress increase = total pillar stress - virgin stress;

T_s = seam thickness;

E_c = Young's Modulus of Coal;

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

S_p = pillar strength (**ACARP, 1998b**)

The analytical model adopted 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**:

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

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

where:

s_{roof} = roof compression above pillar;

s_{floor} = floor compression below pillar;

σ_{net} = net pillar stress increase (= total stress - pre-mining stress);

w = pillar width;

E_{roof} = average Young's Modulus of roof material for a distance w above the pillar;

E_{floor} = average Young's Modulus of floor material for a distance w below the pillar;

v = Poisson's Ratio (0.25 assumed for all materials);

I = Influence Function for various footing shape geometries (1.5 in this case).

Lower and upper bound estimates of long-term surface subsidence (s_{total}) above a pillar subject to the assumed loading may be estimated by summing equations (1), (2) and (3):

$$s_{total} = s_{pillar} + s_{roof} + s_{floor}$$

where the lower bound solution assumes the upper limit estimate of *insitu* rock mass stiffness properties and the upper bound solution assumes the lower limit estimate of the *insitu* rock mass stiffness properties.

6.5.2 Analytical Model Outcomes

Lower and upper bound barrier pillar subsidence predictions are presented in **Table 5** for the pillars left between the total pillar extraction panels No. 2 to 13. The calculations were based on a pillar heights ranging from 2.2 to 3.0 m. Calculation details are presented in **Appendix C**.

The results of the analytical subsidence prediction analysis for the lower bound material properties and cover depth ranges indicate that the worst-case subsidence over the proposed barrier pillars between Panels 2 to 13 will range between 0.03 and 0.22 m after mining is completed. The pillar FoS values are all > 2.12 and are therefore expected to behave elastically in the long term.

The predictions for the 19.5 m wide barriers are compared to the empirical model values in **Figure 7d**. Overall, the results generally plot between the mean and U95%CL values predicted by the empirical model, and are therefore considered reasonable for impact analysis purposes.

Similar exercises were completed for the 14.5 m wide x 58.5 m long end of panel barriers proposed to be left between Panel No.s 2 to 13 and the East Mains and the 13 m wide (average width) x 19.5 m long remnant pillars to be left between the East Mains and Panel No. 1. A summary of the results is also presented in **Table 4**.

The worst case subsidence for the 13 m x 19.5 m pillars left between the East Mains and Panel No. 1 are estimated to range between 0.05 and 0.28 m after mining is completed. Some yielding of pillars after mining may develop at this location, with pillar FoS ranging from 1.87 to 1.02.

The worst case subsidence for the 14.5 m x 58.5 m pillars left between the East Mains and Panel No.s 2 and 13 are estimated to range between 0.05 and 0.26 m after mining is completed. Pillar FoS is estimated range from 3.09 to 1.57 with some localised pillar yielding occurring in the long-term also.

Table 4 - Analytical Model Subsidence Predictions Above the Proposed Barrier Pillars for the Pillar Extraction Panels

Cover Depth (m)	Pillar Height h (m)	Pre-Mining Stress (MPa)	Applied Pillar Stress (MPa)	Pillar FoS Under Final Loading	Subsidence Predictions Based on Non-Linear Pillar and Strata System Compression (m)				
					Pillar	Roof	Floor	Total (Lower & Upper Bounds)*	
Panels 1 to 13 Inter-panel Barrier Pillar width = 19.5 m									
60	2.2	1.50	4.04	7.71	0.00	0.02	0.01	**0.03**	**0.06**
60	2.3	1.50	4.04	7.17	0.00	0.02	0.01	**0.03**	**0.06**
60	2.4	1.50	4.04	6.70	0.00	0.02	0.01	**0.03**	**0.06**
60	2.6	1.50	4.04	5.94	0.00	0.02	0.01	**0.03**	**0.06**
65	2.4	1.63	4.55	5.94	0.00	0.02	0.01	**0.03**	**0.07**
75	2.3	1.88	5.66	5.12	0.00	0.02	0.02	**0.04**	**0.09**
80	2.2	2.00	6.25	4.99	0.00	0.03	0.02	**0.05**	**0.10**
85	2.6	2.13	6.87	3.50	0.00	0.03	0.02	**0.05**	**0.11**
85	2.7	2.13	6.87	3.31	0.00	0.03	0.02	**0.06**	**0.11**
85	2.8	2.13	6.87	3.16	0.00	0.03	0.02	**0.06**	**0.11**
85	3.0	2.13	6.87	2.89	0.00	0.03	0.02	**0.06**	**0.11**
90	2.8	2.25	7.52	2.88	0.00	0.03	0.02	**0.06**	**0.12**
100	2.4	2.50	8.89	3.04	0.00	0.04	0.03	**0.07**	**0.15**
110	2.4	2.75	10.37	2.61	0.00	0.05	0.03	**0.09**	**0.18**
125	2.4	3.13	12.80	2.12	0.01	0.06	0.04	**0.11**	**0.22**
Panels 1 to 13 End-panel Barrier Pillar width = 14.5 m									
80	2.2	2.00	7.65	3.01	0.00	0.03	0.02	**0.05**	**0.11**
85	2.4	2.13	8.44	2.47	0.00	0.03	0.02	**0.06**	**0.12**
90	2.8	2.25	9.26	1.67	0.01	0.04	0.03	**0.07**	**0.14**
90	2.9	2.25	9.26	1.73	0.01	0.04	0.03	**0.07**	**0.14**
90	3.0	2.25	9.26	1.81	0.00	0.04	0.03	**0.07**	**0.14**
90	3.0	2.38	10.12	1.53	*0.06*	0.04	0.03	**0.13**	**0.26**
95	2.2	2.38	10.12	2.28	0.00	0.04	0.03	**0.07**	**0.15**
100	2.2	2.50	11.01	2.09	0.00	0.05	0.03	**0.08**	**0.16**
Panel 1 & East Mains Inter-panel Remnant Pillar width = 13.0 m x 19.5 m									
80	2.2	2.00	9.71	1.87	0.00	0.03	0.02	**0.05**	**0.09**
85	2.4	2.13	10.71	1.53	*0.05*	0.03	0.02	**0.10**	**0.20**
90	2.6	2.25	11.77	1.28	*0.06*	0.03	0.02	**0.11**	**0.23**
95	3.0	2.38	12.87	1.02	*0.09*	0.03	0.02	**0.14**	**0.28**

Notes:
* - the Upper Bound Total value = 2 x Lower Bound Total value.
Italics - Coal pillar stiffness modulus reduced to 10% of peak or elastic value if pillar FoS < 1.67 under design loading conditions.

6.6 Goaf Edge Subsidence Prediction

The predictions of goaf edge subsidence have been derived from the modified **ACARP, 2003** model's curves shown in **Figure 8**.

The goaf edge subsidence predictions for Panels 1 to 13 and the extracted mains panels range from 0.030 m to 0.15 m for cover depths from 50 m to 135 m.

6.7 Angle of Draw Prediction

The angle of draw values have been estimated from the prediction curves shown in **Figure 9** and range from 6^o to 18^o for cover depths of 50 to 135 m.

The Angle of Draw predictions have been derived from the goaf edge subsidence predictions for Panels 1 to 13 and the extracted East Mains panels in **Section 6.6**.

6.8 Multiple Panel Subsidence Predictions

Maximum subsidence predictions for multiple panels may be estimated by adding 50% to 100% of the chain or barrier pillar subsidence predictions to the mean single panel S_{max}. The predicted goaf edge subsidence is subtracted from the chain pillar subsidence (as it is included in the single panel predictions).

The maximum subsidence impact parameter predictions (i.e. tilt, curvature and strain etc) for multiple panels may then be derived using the empirical relationships defined in **ACARP, 2003** (see the following sections).

6.8.1 Maximum Subsidence above Pillar Extraction Panels

The maximum first and final subsidence predictions for the proposed 160.5 m wide extraction Panels 1 to 13 are summarised in **Table 5** for the range of cover depths of 55 m to 130 m and average panel mining heights of 2.2 to 3.2 m.

Predicted first and final maximum subsidence for the production panels range from 0.97 m to 1.76 m respectively (i.e. 40% to 55% of the mining height).

Predictions of maximum first and final subsidence for the 125 m to 131.25 m wide East Mains panels range from 0.89 m to 1.68 m (i.e. 50% to 55% of the mining height).

General maximum subsidence prediction curves for the pillar extraction panels and range of mining geometries in the SMP area is presented in **Figure 11**. Representative first and final subsidence profiles have been prepared along cross lines XL 1 in **Figure 12a** (the location of the cross line is shown in **Figure 1**).

Reference to the Holla curves for total pillar extraction mining suggests maximum subsidence above the production panels will range between 1.05 m and 1.76 m (50% and 55% the mining heights) for the given mining geometries and similar to the **ACARP, 2003** model predictions.

Table 5 - Predicted Maximum Subsidence for Multiple Pillar Extraction Panels

Panel #	Cover Depth H (m)	Panel Width W (m)	Seam Thickness T (m)	Mean Single Panel S_{max} (m)	Mean Final Barrier Pillar Subsidence S_p (m)	Mean First Panel S_{max} (m)	Mean Final Panel S_{max} (m)	U95%CL Final Panel S_{max} (m)
Pillar Extraction Panels 1 to 13								
1	85	160.5	2.4	1.24	0.03	1.25	1.26	*1.32*
1	95	160.5	2.4	1.15	0.03	1.18	1.18	*1.32*
1	95	160.5	3.2	1.54	0.05	1.58	1.58	*1.76*
2	55	160.5	2.3	1.27	0.04	1.27	1.27	*1.27*
2	65	160.5	2.6	1.43	0.04	1.43	1.43	*1.43*
2	75	160.5	2.9	1.60	0.06	1.60	1.60	*1.60*
2	85	160.5	3.2	1.66	0.07	1.66	1.68	*1.76*
3	55	160.5	2.7	1.49	0.04	1.49	1.49	*1.49*
3	65	160.5	2.8	1.54	0.05	1.54	1.54	*1.54*
3	75	160.5	2.8	1.54	0.05	1.54	1.54	*1.54*
3	85	160.5	3.0	1.56	0.07	1.56	1.58	*1.65*
4	55	160.5	2.5	1.38	0.04	1.38	1.38	*1.38*
4	65	160.5	2.6	1.43	0.04	1.43	1.43	*1.43*
4	75	160.5	2.8	1.54	0.05	1.54	1.54	*1.54*
4	85	160.5	2.8	1.45	0.06	1.46	1.48	*1.54*
5	55	160.5	2.3	1.27	0.04	1.27	1.27	*1.27*
5	65	160.5	2.4	1.32	0.04	1.32	1.32	*1.32*
5	75	160.5	2.6	1.43	0.05	1.43	1.43	*1.43*
5	85	160.5	2.7	1.40	0.06	1.40	1.42	*1.49*
6	55	160.5	2.2	1.21	0.03	1.21	1.21	*1.21*
6	65	160.5	2.3	1.27	0.04	1.27	1.27	*1.27*
6	75	160.5	2.4	1.32	0.05	1.32	1.32	*1.32*
6	85	160.5	2.7	1.40	0.06	1.40	1.42	*1.49*
7	55	160.5	2.3	1.27	0.04	1.27	1.27	*1.27*
7	65	160.5	2.3	1.27	0.04	1.27	1.27	*1.27*
7	75	160.5	2.4	1.32	0.05	1.32	1.32	*1.32*
7	85	160.5	2.6	1.35	0.06	1.35	1.37	*1.43*
8	55	160.5	2.4	1.32	0.03	1.32	1.32	*1.32*
8/9/10	65	160.5	2.4	1.32	0.03	1.32	1.32	*1.32*
8/9/10	75	160.5	2.4	1.32	0.03	1.32	1.32	*1.32*
8	85	160.5	2.4	1.24	0.03	1.25	1.26	*1.32*
11	105	160.5	2.4	1.08	0.07	1.09	1.13	1.30
12	105	160.5	2.5	1.12	0.08	1.14	1.18	1.35
13	110	160.5	2.3	1.00	0.04	1.02	1.02	1.19
13	125	160.5	2.4	0.95	0.10	0.97	1.03	1.16
13	125	160.5	2.4	0.95	0.06	0.98	1.00	1.13

Table 5 (cont...) - Predicted Maximum Subsidence for Multiple Pillar Extraction Panels

Panel #	Cover Depth H (m)	Panel Width W (m)	Seam Thickness T (m)	Mean Single Panel S_{max} (m)	Mean Final Barrier Pillar Subsidence S_p (m)	Mean First Panel S_{max} (m)	Mean Final Panel S_{max} (m)	U95%CL Final Panel S_{max} (m)
East Mains Adjacent to Panel 1								
EM1	75	131.25	2.1	1.03	0.07	1.03	1.07	1.16
EM2	85	131.25	2.5	1.13	0.10	1.14	1.21	1.38
EM3	95	131.25	3.2	1.34	0.15	1.36	1.47	1.68
East Mains Adjacent to Finishing Ends of Panels 2 and 13								
EM4	95	125	3.2	1.29	0.11	1.31	1.38	1.59
EM5	85	125	2.9	1.27	0.08	1.29	1.34	1.54
EM6	87	125	2.4	1.03	0.07	1.05	1.10	1.26
EM7	92	125	2.1	0.87	0.05	0.89	0.91	1.06

Notes:
Mean Final S_{max} = Mean First S_{max}+ Final S_p - First S_{goe}
U95%CL Final S_{max} = Mean Final S_{max} + U95%CL error
Italics - Super-critical subsidence limited to 0.58 x effective mining height.

6.8.2 Maximum Panel Tilts and Horizontal Displacements

The maximum first and final tilt predictions for the proposed 160.5 m wide pillar extraction Panels 1 to 13 are summarised in **Table 6** for the range of cover depths and average panel mining heights of 2.1 to 3.2 m.

Predictions of final maximum tilt values for the pillar extraction panels range from 15 mm/m to 76 mm/m. Maximum horizontal displacements are estimated to range from 110 to 555 mm for the above tilts.

Predictions of final maximum tilt for the 125 m to 131.25 m wide mains panels range from 19 mm/m to 60 mm/m. Maximum horizontal displacements are estimated to range from 139 to 438 mm for the above tilts.

General maximum tilt prediction curves for the range of pillar panel geometries in the SMP area are presented in **Figure 13**. Representative first and final tilt and horizontal displacement profiles have been prepared along cross lines XL 1 and XL3 in **Figure 14** (the location of the cross lines are shown in **Figure 1**).

Reference to the **Holla, 1987** curves suggests maximum tilt above the proposed pillar extraction panels will range between 15 mm/m and 49 mm/m, which are all similar to the **ACARP, 2003** model predictions.

Table 6 - Predicted Maximum Tilt and Horizontal Displacement for Multiple Pillar Extraction Panels

Panel #	Cover Depth H (m)	Panel Width W (m)	Seam Thickness T (m)	Mean Final Panel S_{max} (m)	Mean Final Panel T_{max} (mm/m)	U95%CL Final Panel T_{max} (mm/m)	Mean Final Panel HD_{max} (mm)	U95%CL Final Panel HD_{max} (mm)
Pillar Extraction Panels 1 to 13								
1	85	160.5	2.4	1.26	32	45	234	328
1	95	160.5	2.4	1.18	25	35	184	257
1	95	160.5	3.2	1.58	38	53	276	386
2	55	160.5	2.3	1.27	41	58	301	422
2	65	160.5	2.6	1.43	49	69	357	500
2	75	160.5	2.9	1.60	53	75	389	544
2	85	160.5	3.2	1.68	48	67	350	490
3	55	160.5	2.7	1.49	52	72	377	527
3	65	160.5	2.8	1.54	54	76	396	555
3	75	160.5	2.8	1.54	51	71	370	518
3	85	160.5	3	1.58	44	62	322	450
4	55	160.5	2.5	1.38	46	65	338	474
4	65	160.5	2.6	1.43	49	69	357	500
4	75	160.5	2.8	1.54	51	71	370	518
4	85	160.5	2.8	1.48	40	56	292	409
5	55	160.5	2.3	1.27	41	58	301	422
5	65	160.5	2.4	1.32	44	61	320	447
5	75	160.5	2.6	1.43	46	64	334	467
5	85	160.5	2.7	1.42	38	53	277	388
6	55	160.5	2.2	1.21	39	54	283	396
6	65	160.5	2.3	1.27	41	58	301	422
6	75	160.5	2.4	1.32	41	57	299	418
6	85	160.5	2.7	1.42	38	53	277	388
7	55	160.5	2.3	1.27	41	58	301	422
7	65	160.5	2.3	1.27	41	58	301	422
7	75	160.5	2.4	1.32	41	57	299	418
8	55	160.5	2.4	1.32	44	61	320	447
8/9/10	65	160.5	2.4	1.32	44	61	320	447
8/9/10	75	160.5	2.4	1.32	41	57	299	418
8	85	160.5	2.4	1.26	32	45	233	326
11	105	160.5	2.4	1.13	21	29	150	210
12	105	160.5	2.5	1.18	22	30	159	223
13	110	160.5	2.3	1.02	17	23	123	172
13	125	160.5	2.4	1.03	16	22	117	163
13	125	160.5	2.4	1.00	15	22	112	157

Table 6 (Cont..) - Predicted Maximum Tilt and Horizontal Displacement for Multiple Pillar Extraction Panels

Panel #	Cover Depth H (m)	Panel Width W (m)	Seam Thickness T (m)	Mean Final Panel S_{max} (m)	Mean Final Panel T_{max} (mm/m)	U95%CL Final Panel T_{max} (mm/m)	Mean Final Panel HD_{max} (mm)	U95%CL Final Panel HD_{max} (mm)
East Mains Adjacent to Panel 1								
EM1	75	131.25	2.1	1.07	30	43	222	311
EM2	85	131.25	2.5	1.21	30	42	222	310
EM3	95	131.25	3.2	1.47	35	48	252	353
East Mains Adjacent to Finishing Ends of Panels 2 and 13								
EM4	95	125	3.2	1.38	34	47	248	347
EM5	85	125	2.9	1.34	35	49	255	356
EM6	87	125	2.4	1.10	26	36	187	261
EM7	92	125	2.1	0.91	19	27	138	194

Notes:
Mean First T_{max} = 1.1925[(Mean First S_{max})/(Effective Panel Width)]$^{1.3955}$
Mean Final T_{max} =1.1925[(Mean Final S_{max})/(Effective Panel Width)]$^{1.3955}$
U95%CL Final T_{max} = Mean Final T_{max} + U95%CL error (= 0.4*mean value)
Italics - Super-critical subsidence limited to 0.55 x mining height.
HD_{max} = 7.3 T_{max}

6.8.3 Maximum Panel Curvature and Strains

The maximum first and final curvature and strain predictions for the proposed 160.5 m wide total extraction Panels 1 to 13 are summarised in **Tables 7A** and **7B** for the range of cover depths and average panel mining heights of 2.1 to 3.2 m.

Predictions of final maximum hogging curvature values for the pillar extraction panels range from 0.61 km^{-1} to 3.61 km^{-1}. Maximum tensile strains are estimated to range from 4 to 26 mm/m for the above curvatures.

Predictions of final maximum sagging curvatures for the pillar extraction panels range from 0.77 km^{-1} to 4.58 km^{-1}. Maximum compressive strains are estimated to range from 6 to 33 mm/m for the above curvatures.

Predictions of final maximum hogging curvatures for the 125 m to 131.25 m wide mains panels range from 0.91 km^{-1} to 2.19 km^{-1}. Maximum tensile strains are estimated to range from 7 to 17 mm/m for the above curvatures.

Predictions of final maximum sagging curvatures for the 125 m to 131.25 m wide mains panels range from 1.15 km^{-1} to 2.88 km^{-1}. Maximum compressive strains are estimated to range from 8 to 21 mm/m for the above curvatures.

General maximum curvature and strain prediction curves for the range of mining geometries in the SMP area are presented in **Figures 15a** and **15b** and **Figures 16a** and **16b** respectively.

Representative first and final curvature and strain profiles have been prepared along cross lines XL 1 and XL 3 in **Figure 17** (the location of the cross lines are shown in **Figure 1**).

Reference to the Holla curves for high extraction pillar mining suggests maximum tensile strain above the pillar extraction panels will range between 4 mm/m and 11 mm/m with compressive strains ranging between 5 and 16 mm/m for the given mining geometries, which are generally 50 to 60 % of the **ACARP, 2003** model predictions, based on the effective mining heights.

As discussed previously, discontinuous displacements can result in secondary curvatures and strains, which exceed predicted ‘smooth’ profile values by 2 to 4 times. The discrepancy between the two models is therefore not surprising, as the data base will be strongly dependent on surface topography and near surface lithologies.

Table 7A - Predicted Maximum Hogging Curvature and Tensile Strains for Multiple Pillar Extraction Panels

Panel #	Cover Depth H (m)	Panel Width W (m)	Seam Thickness T (m)	Mean Final Panel S_{max} (m)	Mean Final Panel Hogging Curvature C_{max} (km^{-1})	U95%CL Final Panel Hogging Curvature C_{max} (km^{-1})	Mean Final Panel Tensile Strain $+E_{max}$ (mm/m)	U95%CL Final Panel Tensile Strain $+E_{max}$ (mm/m)
Pillar Extraction Panels 1 to 13								
1	85	160.5	2.4	1.26	1.39	2.06	10	15
1	95	160.5	2.4	1.18	1.04	1.52	8	11
1	95	160.5	3.2	1.58	1.40	2.03	10	15
2	55	160.5	2.3	1.27	1.98	2.97	14	22
2	65	160.5	2.6	1.43	2.23	3.35	16	24
2	75	160.5	2.9	1.60	2.26	3.39	17	25
2	85	160.5	3.2	1.68	1.85	2.74	14	20
3	55	160.5	2.7	1.49	2.32	3.48	17	25
3	65	160.5	2.8	1.54	2.41	3.61	18	26
3	75	160.5	2.8	1.54	2.18	3.27	16	24
3	85	160.5	3	1.58	1.74	2.57	13	19
4	55	160.5	2.5	1.38	2.15	3.22	16	24
4	65	160.5	2.6	1.43	2.23	3.35	16	24
4	75	160.5	2.8	1.54	2.18	3.27	16	24
4	85	160.5	2.8	1.48	1.63	2.40	12	18
5	55	160.5	2.3	1.27	1.98	2.97	14	22
5	65	160.5	2.4	1.32	2.06	3.09	15	23
5	75	160.5	2.6	1.43	2.03	3.04	15	22
5	85	160.5	2.7	1.42	1.57	2.31	11	17
6	55	160.5	2.2	1.21	1.89	2.84	14	21
6	65	160.5	2.3	1.27	1.98	2.97	14	22
6	75	160.5	2.4	1.32	1.87	2.81	14	20
6	85	160.5	2.7	1.42	1.57	2.31	11	17
7	55	160.5	2.3	1.27	1.98	2.97	14	22
7	65	160.5	2.3	1.27	1.98	2.97	14	22
7	75	160.5	2.4	1.32	1.87	2.81	14	20
7	85	160.5	2.6	1.37	1.51	2.23	11	17
8	55	160.5	2.4	1.32	2.06	3.09	15	23
8/9/10	65	160.5	2.4	1.32	2.06	3.09	15	23
8/9/10	75	160.5	2.4	1.32	1.87	2.81	14	20
8	85	160.5	2.4	1.26	1.38	2.06	10	15
11	105	160.5	2.4	1.13	0.82	1.17	6	9
12	105	160.5	2.5	1.18	0.85	1.22	6	9
13	110	160.5	2.3	1.02	0.67	0.99	5	7
13	125	160.5	2.4	1.03	0.62	0.87	5	7
13	125	160.5	2.4	1.00	0.61	0.87	4	7

Table 7A (Cont...) - Predicted Maximum Hogging Curvature and Tensile Strains for Multiple Pillar Extraction Panels

Panel #	Cover Depth H (m)	Panel Width W (m)	Seam Thickness T (m)	Mean Final Panel S_{max} (m)	Mean Final Panel Hogging Curvature $+C_{max}$ (km^{-1})	U95%CL Final Panel Hogging Curvature $+C_{max}$ (km^{-1})	Mean Final Panel Tensile Strain $+E_{max}$ (mm/m)	U95%CL Final Panel Tensile Strain $+E_{max}$ (mm/m)
East Mains Adjacent to Panel 1								
EM1	75	131.25	2.1	1.07	1.51	2.19	11	17
EM2	85	131.25	2.5	1.21	1.33	1.87	10	15
EM3	95	131.25	3.2	1.47	1.33	1.83	10	15
East Mains Adjacent to Finishing Ends of Panels 2 and 13								
EM4	95	125	3.2	1.38	1.37	1.94	10	15
EM5	85	125	2.9	1.34	1.47	2.10	11	16
EM6	87	125	2.4	1.10	1.15	1.63	8	13
EM7	92	125	2.1	0.91	0.91	1.30	7	10

Notes:
Mean Final Hogging C_{max} = 15.603(Mean Final S_{max})/(Effective Panel Width)^2]
U95%CL Final C_{max} = Mean Final C_{max} + U95%CL error (= 0.5*mean value)
Italics - Super-critical subsidence limited to 0.55 x mining height.
$+E_{max}$ = Maximum Tensile Strain = 7.3 C_{max} (applies to mean and U95%CL values).

Table 7B - Predicted Maximum Sagging Curvature and Compressive Strains for Multiple Pillar Extraction Panels

Panel #	Cover Depth H (m)	Panel Width W (m)	Seam Thickness T (m)	Mean Final Panel S_{max} (m)	Mean Final Panel Sagging Curvature $-C_{max}$ (km^{-1})	U95%CL Final Panel Sagging Curvature $-C_{max}$ (km^{-1})	Mean Final Panel Compressive Strain $-E_{max}$ (mm/m)	U95%CL Final Panel Compressive Strain $-E_{max}$ (mm/m)
Pillar Extraction Panels 1 to 13								
1	85	160.5	2.4	1.26	1.76	2.64	13	19
1	95	160.5	2.4	1.18	1.32	1.98	10	14
1	95	160.5	3.2	1.58	1.77	2.66	13	19
2	55	160.5	2.3	1.27	2.51	3.76	18	27
2	65	160.5	2.6	1.43	2.84	4.25	21	31
2	75	160.5	2.9	1.60	2.87	4.30	21	31
2	85	160.5	3.2	1.68	2.35	3.52	17	26
3	55	160.5	2.7	1.49	2.94	4.42	21	32
3	65	160.5	2.8	1.54	3.05	4.58	22	33
3	75	160.5	2.8	1.54	2.77	4.15	20	30
3	85	160.5	3	1.58	2.21	3.31	16	24
4	55	160.5	2.5	1.38	2.73	4.09	20	30
4	65	160.5	2.6	1.43	2.84	4.25	21	31
4	75	160.5	2.8	1.54	2.77	4.15	20	30
4	85	160.5	2.8	1.48	2.06	3.09	15	23
5	55	160.5	2.3	1.27	2.51	3.76	18	27
5	65	160.5	2.4	1.32	2.62	3.93	19	29
5	75	160.5	2.6	1.43	2.57	3.86	19	28
5	85	160.5	2.7	1.42	1.99	2.98	15	22
6	55	160.5	2.2	1.21	2.40	3.69	18	27
6	65	160.5	2.3	1.27	2.37	3.56	18	26
6	75	160.5	2.4	1.32	2.37	3.56	17	26
6	85	160.5	2.7	1.42	1.99	2.98	14	22
7	55	160.5	2.3	1.27	2.51	3.76	18	27
7	65	160.5	2.3	1.27	2.51	3.76	18	27
7	75	160.5	2.4	1.32	2.37	3.56	17	26
7	85	160.5	2.6	1.37	1.91	2.87	14	21
8	55	160.5	2.4	1.32	2.62	3.93	19	29
8/9/10	65	160.5	2.4	1.32	2.62	3.93	19	29
8/9/10	75	160.5	2.4	1.32	2.37	3.56	17	26
8	85	160.5	2.4	1.26	1.75	2.63	13	19
11	105	160.5	2.4	1.13	1.04	1.55	8	11
12	105	160.5	2.5	1.18	1.08	1.62	8	12
13	110	160.5	2.3	1.02	0.85	1.28	6	9
13	125	160.5	2.4	1.03	0.79	1.19	6	9
13	125	160.5	2.4	1.00	0.77	1.16	6	8

Table 7B (Cont...) - Predicted Maximum Sagging Curvature and Compressive Strains for Multiple Pillar Extraction Panels

Panel #	Cover Depth H (m)	Panel Width W (m)	Seam Thickness T (m)	Mean Final Panel S_{max} (m)	Mean Final Panel Sagging Curvature $-C_{max}$ (km^{-1})	U95%CL Final Panel Sagging Curvature $-C_{max}$ (km^{-1})	Mean Final Panel Compressive Strain $-E_{max}$ (mm/m)	U95%CL Final Panel Compressive Strain $-E_{max}$ (mm/m)
East Mains Adjacent to Panel 1								
EM1	75	131.25	2.1	1.92	2.88	2.877	14	21
EM2	85	131.25	2.5	1.69	2.54	2.537	12	19
EM3	95	131.25	3.2	1.68	2.53	2.525	12	18
East Mains Adjacent to Finishing Ends of Panels 2 and 13								
EM4	95	125	3.2	1.74	2.62	2.616	13	19
EM5	85	125	2.9	1.87	2.80	2.802	14	20
EM6	87	125	2.4	1.46	2.19	2.191	11	16
EM7	92	125	2.1	1.15	1.72	1.725	8	13

Notes:
Mean Final Sagging C_{max} = 19.79(Mean Final S_{max})/(Effective Panel Width)^2]
U95%CL Final C_{max} = Mean Final C_{max} + U95%CL error (= 0.5*mean value)
Italics - Super-critical subsidence limited to 0.55 x mining height.
$-E_{max}$ = Maximum Compressive Strain = 7.3 C_{max} (applies to mean and U95%CL values).

6.9 Prediction of Subsidence Impact Parameter Contours

6.9.1 Calibration of the SDPS® Model

Credible worst-case Subsidence contours for the proposed pillar extraction and miniwall panels have been generated using SDPS® influence function-based subsidence prediction software.

As there is no readily available subsidence data yet available for Abel, the SDPS® model was calibrated to the credible worst-case (U95%CL) profiles predicted by the **ACARP, 2003** empirical model.

The outcome of the model calibration exercise is summarised in **Table 8**.

Table 8 - SDPS® Model Calibration Summary for the Proposed Pillar Extraction Panels

Input Parameters	**Value**
Panel No.s below XL s 1- 4 shown in **Figure 1**	P2 - P13, EM - P1
Panel Void Width, W (m)	160.5, 125, 131.25
Cover Depth, H (m)	55 - 130
Maximum Panel Extraction Ratio Assumed (%)	95
Actual Mining Height, T (m)	2.1 - 3.2
Effective Mining Height, h (m)	2.09 -3.04
W/H range	1.23 - 2.92
SRP for Mining Area	Low
Maximum Final Panel Subsidence*, S_{max} (m)	1.04 - 1.76
S_{max}/T Range	0.49 - 0.55
Barrier Pillar Width, w_{cp} (m)	19.5, 13.0
Roadway width (m)	5.5
Pillar Height (m)	2.2 - 3.2
Barrier Pillar Subsidence* Sp (m)	0.04 - 0.27
S_p/T Range	0.02 - 0.09
Distance to Influence Inflexion Point from Rib-Side (m) (d/H)	22 - 58 (0.38 - 0.45)
Calibration Results for 'Best Fit' Solution to the Modified ACARP, 2003 Model Predictions^	**Optimum Values**
Influence Angle (Tan(beta))	1.36 - 1.97
Influence Angle (beta)	54° - 63°
Best-Fit Supercritical Subsidence Factors (S_{max}/T)	*0.56 - 0.72*
Distance to Influence Inflexion Point from Rib-Side (m) (d/H)	22 - 58 (0.38 - 0.45)

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 along XL 1 have been compared in **Figures 18a** to **21a**. The profiles for XL 2 are presented in **Figures 18b** to **21b**.

The predicted **SDPS®** subsidence and tilt profiles were generally located within +/- 10 to 20% of the predicted modified **ACARP, 2003** models Upper 95% Confidence Limits. 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 to 4 times locally.

6.9.2 Predicted Subsidence Contours

Based on the calibrated SDPS® model, predictions of worst-case subsidence contours for the Pillar Extraction panels are presented in **Figure 22**.

Associated subsidence impact parameter contours of principle tilt, curvature, strain and horizontal displacements have been subsequently derived and are presented in **Figures 23** to **26** respectively. Pre and post mining surface levels are shown in **Figure 27**.

7.0 Subsidence Impacts and Management Strategies

7.1 General

Based on the predicted maximum panel subsidence, tilt and strain values for the total extraction panel layouts, the following general subsidence impact parameters have been estimated in the following sections for the purpose of impact assessment on natural and man-made features:

- surface crack widths;
- height of sub-surface fracturing above the panels (direct and in-direct hydraulic connection zones);
- surface gradient changes;
- ponding potential;
- general slope stability and erosion;
- valley uplift and closure;
- scarp or surface step development potential
- far-field horizontal displacements and strains;

Due to the range of subsidence impact parameters at a given location that have been observed for a given mining geometry and geology etc, it is considered a prudent impact management technique to provide a range of values that are linked to design methodologies to assist 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 10**, and are based on terms used in **AGS, 2007** and **Vick, 2002**.

Table 10 - 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.	50-75%
Possible	The event may occur under normal conditions.	10-50%
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**.

It should be also be understood that the terms ‘mean' and ‘Upper 95% Confidence Limit’ used in this study generally infer that the predictions will be exceeded by 50% and 5% respectively of panels mined with similar geometry and geology etc. Using lower probability of exceedence values (i.e. <5%) may be justified for particularly sensitive features.

The selection of an appropriate ‘credible worst-case’ is normally inferred by the U95%CL values but should also consider the reliability of current survey technology, available mitigation techniques, likely response action times and the potential for uneconomic or marginal mining layouts.

The predicted impacts and suggested management strategies for the natural and manmade features in the SMP area are presented in the following sections.

7.2 Surface Cracking

7.2.1 Predicted Impacts

The development of surface subsidence above a total pillar 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.

The predicted panel subsidence magnitudes of 0.89 m to 1.74 m are likely to result in surface cracks developing within the limits of the extracted panels. It is very unlikely that surface cracks will develop above first workings pillars, where subsidence magnitudes of < 20 mm are expected.

Cracks are likely to develop in the tensile strain zones that will occur between 15 to 25 m in from the rib-sides of each total extraction panel. Crack widths of up to 10 mm may start to develop at the surface where tensile strains exceed 1 mm/m over a distance of 10 m. The maximum crack widths generally develop where maximum tensile strains occur.

Compressive strains 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.

Based on the predicted range of maximum transverse tensile strains (i.e. 4 to 26 mm/m), maximum surface cracking widths of between 40 mm and 260 mm could occur within the limits of extraction (i.e. goaf), and soon after mining is completed beneath the area. The larger cracks are predicted in the shallow areas where cover depths are < 80 m.

Crack widths in the areas deeper than 80 m are likely to be in the order of 30 to 150 mm above pillar extraction panels. The tensile cracks will probably be tapered and extend to depths ranging from 5 to 10 m, and possibly deeper if near surface bedrock exposures are present.

For the case of the total pillar extraction panels, the predicted range of maximum transverse compressive strains (i.e. 5 to 33 mm/m) may result in shear displacements or 'shoving' of between 50 mm and 330 mm within the central limits of proposed panels.

Based on the strain contour figures, the location of the tensile cracking and total shear displacements for the proposed mining layout are shown in **Figure 28**.

In addition, tensile cracks will probably develop up to 30 m behind the advancing goaf edge of the total pillar extraction panels. The majority of these cracks are transient however, and likely to be 10 mm to 50 mm wide. They also generally close in the central areas of the panels where permanent compressive strains develop after mining is completed.

7.2.2 Impact Management Strategies

Surface crack repair works (such as the pouring of cement-based grout or crushed, high strength rock into the larger, deep cracks) may need to be implemented around the affected low depth of cover areas of the site (i.e. < 80 m cover depth), and in particular, where public roads and ephemeral watercourses are present.

In regards to Viney Creek, surface cracking will be limited by the panel geometries and proposed first working buffer zones. It is considered unlikely that surface cracks will develop along the creek bed, however, if they do occur, the following remediation strategy may be adopted:

- Undertake pre-mining and post-mining inspections along the creek, with the results of these inspections communicated to the respective stakeholders. Should a significant impact be identified during these inspections, an appropriate remediation strategy will be developed.

- Consultation with DECCW 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 materials from haulage trucks.

7.3 Sub-Surface Cracking

7.3.1 Sub-Surface Fracturing Zones

The caving and subsidence development processes above a longwall or pillar extraction panel usually results in sub-surface fracturing and shearing of sedimentary strata in the overburden, see **Figure 29**. The extent of fracturing and shearing is dependent on 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 three or four zones of surface and subsurface fracturing. The zones are generally defined (in descending order) as:

- Surface Zone
- Continuous or Constrained Zone
- Fractured Zone
- Caved Zone

Starting from the seam level, the Caved Zone refers to the immediate mine workings roof above the extracted panel, which has collapsed into the void left after the coal seam has been extracted. The Caved Zone usually extends for 3 to 5 times the mining height above the roof of the mine workings.

The Fractured Zone has been affected by a high degree of bending deformation, resulting in significant fracturing and bedding parting separation and shearing. The Fractured Zone is supported by the collapsed material in The Caved Zone, which usually has a bulked volume equal to 1.2 to 1.5 times its undisturbed volume.

The Continuous or Constrained Zones refer to the section of overburden which has also been deformed by bending action, but to a lesser degree than the Fractured Zone below it.

The Surface Zone includes the tensile and compressive surface cracking caused by mine subsidence and is assumed to extend to depths of 5 to 10 m in the Newcastle Coalfield.

Based on reference to **Whittaker and Reddish, 1990** and **ACARP, 2003**, the impact of mining on the sub-surface aquifers and surface waters, requires an estimate of the '*Continuous*' and '*Discontinuous*' heights of fracturing or the A and B Zones - shown schematically in **Figure 29**.

Continuous sub-surface fracturing (A-Zone) refers to the zone of cracking above a longwall panel that is likely to result in a direct flow-path or hydraulic connection to the workings, if a sub-surface (or shallow surface) aquifer was intersected.

Discontinuous sub-surface fracturing (B-Zone) refers to the zone above the A-Zone where there could be a general increase in horizontal and vertical rock mass permeability, due to bending or curvature deformation of the overburden. This type of fracturing does not usually provide a direct flow path or connection to the mine workings like the A-Zone; however, it is possible that B-Zone fracturing may interact with surface cracks, joints, or faults. This type of fracturing can therefore result in an adjustment to surface and sub-surface flow paths, but may not result in a significant change to the groundwater or surface water resource in the long-term.

In regards to the general zones of fracturing mentioned earlier, the A-Zone may be assumed to include the Caved and Fractured Zones, and the B-Zone will develop in the Constrained Zone. Both A and B-Zones can extend to the Surface Zone and will depend on the mining height, cover depth, geology and panel width.

Two empirically-based models (**Forster, 1995** and **ACARP, 2003**) and have been used in this study to predict the A and B-Zone heights of sub-surface fracturing within the study area.

The **Forster, 1995** model was developed from deep multi-piezometer data from subsided overburden in the Central-Coast area of the Newcastle Coalfield and in-directly defines the A and B-Zones as a function of the mining height (the model refers to the A and B-Zones as the tops of the Fractured and Confined Zones respectively - see **Figure 30** for the model fracture zone definitions).

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). The predicted extent or height of the Confined or B-Zone and its thickness will be dependent on the cover depth and height of A-Zone fracturing.

The **ACARP, 2003** model was derived from the **Forster, 1995** Model data, and supplemented with drilling fluid loss records from surface to seam drilling logs in subsided, fractured overburden from the NSW Southern Coalfield and Oaky Creek Mine in the Bowen Basin.

The **ACARP, 2003** model includes several of the key parameters defined by **Whittaker and Reddish, 1989** and referred to in **Mark, 2007**. The additional parameters include the panel width, cover depth, maximum single panel subsidence and geological conditions (i.e. Subsidence Reduction Potential). The mining height is not applied directly, but indirectly through the subsidence prediction (further model development details may be found in **Appendix A**).

The measured data in **ACARP, 2003** has been plotted as the height of A or B-Zone fracturing /cover depth v. S_{max}/Effective Panel Width^2. A log-normal regression line has subsequently been derived to give predictions of mean and U95%CL values for both fracture zones.

7.3.2 Sub-Surface Fracture Height Predictions

The predicted values for the **ACARP, 2003** model's continuous and discontinuous sub-surface fracturing heights above the proposed pillar extraction panels are summarised in **Table 11** and presented in **Figure 31**.

Table 11 - Summary of Predicted Sub-Surface Fracturing Heights above the Proposed SMP Pillar Extraction Panels

Panel No.	Cover Depth, H (m)	Panel Width, W (m)	Average Mining Height, T (m)	Single Panel S_{max} (mean) (m)	Single Panel S_{max}/W'^2 (mean) (mm/m^2 or km^{-1})	Predicted Fracture Heights (m)					
						Continuous (A Horizon)				Discontinuous (B Horizon)	
						ACARP, 2003 Model (mean - U95%CL)		**Forster, 1995**) (21-33T')		**ACARP, 2003** Model (mean - U95%CL)	
Pillar Extraction Panels P1 to P13											
1	85	160.5	2.5	1.30	0.088	49	72	48	**75**	82	*97*
1	95	160.5	3.2	1.54	0.065	48	74	48	**75**	87	*104*
1	95	160.5	2.4	1.08	0.087	54	80	64	**100**	92	*108*
2	55	160.5	2.3	1.27	0.214	36	**51**	46	**72**	57	*66*
2	65	160.5	2.6	1.43	0.173	45	**62**	52	**82**	68	*80*
2	75	160.5	2.9	1.60	0.145	52	**72**	58	**91**	79	*92*
2	85	160.5	3.2	1.66	0.117	54	**77**	64	**100**	87	*101*
3	55	160.5	2.7	1.49	0.251	38	**53**	54	**85**	58	*68*
3	65	160.5	2.8	1.54	0.186	46	**63**	56	**88**	69	*81*
3	75	160.5	2.8	1.54	0.140	51	**71**	56	**88**	79	*92*
3	85	160.5	3	1.56	0.110	53	**76**	60	**94**	86	*100*
4	55	160.5	2.5	1.38	0.232	37	**52**	50	**78**	57	*67*
4	65	160.5	2.6	1.43	0.173	45	**62**	52	**82**	68	*80*
4	75	160.5	2.8	1.54	0.140	51	**71**	56	**88**	79	*92*
4	85	160.5	2.8	1.45	0.103	52	75	56	**88**	85	*99*
5	55	160.5	2.3	1.27	0.214	36	**51**	46	**72**	57	*66*
5	65	160.5	2.4	1.32	0.160	43	**61**	48	**75**	67	*79*
5	75	160.5	2.6	1.43	0.130	50	**70**	52	**82**	78	*91*
5	85	160.5	2.7	1.40	0.099	51	74	54	**85**	84	*99*
6	55	160.5	2.2	1.21	0.204	36	**50**	44	**69**	56	*66*
6	65	160.5	2.3	1.27	0.153	43	**60**	46	**72**	67	*78*
6	75	160.5	2.4	1.32	0.120	48	**69**	48	**75**	77	*90*
6	85	160.5	2.7	1.40	0.099	51	74	54	**85**	84	*99*
7	55	160.5	2.3	1.27	0.214	36	51	46	**72**	57	*66*
7	65	160.5	2.3	1.27	0.153	43	**60**	46	**72**	67	*78*
7	75	160.5	2.4	1.32	0.120	48	**69**	48	**75**	77	*90*
7	85	160.5	2.6	1.35	0.095	50	73	52	**82**	84	*98*
8	55	160.5	2.4	1.32	0.223	37	**51**	48	**75**	57	*67*
8/9/10	65	160.5	2.4	1.32	0.160	43	**61**	48	**75**	67	*79*
8/9/10	75	160.5	2.4	1.32	0.120	48	**69**	48	**75**	77	*90*
8	85	160.5	2.4	1.24	0.088	49	72	48	75	82	97

Table 11 (Cont...) - Summary of Predicted Sub-Surface Fracturing Heights above the Proposed SMP Pillar Extraction Panels

Panel No.	Cover Depth, H (m)	Panel Width, W (m)	Average Mining Height, T (m)	Single Panel S_{max} (mean) (m)	Single Panel S_{max}/W'^2 (mean) (mm/m^2 or km^{-1})	Predicted Fracture Heights (m)					
						Continuous (A Horizon)				Discontinuous (B Horizon)	
						ACARP, 2003 Model (mean - U95%CL)		Forster, 1995) (21-33T')		ACARP, 2003 Model (mean - U95%CL)	
Pillar Extraction Panels P1 to P13											
11	105	160.5	2.4	1.08	0.050	47	75	48	75	92	*110*
12	105	160.5	2.5	1.12	0.052	48	76	50	78	92	*111*
13	110	160.5	2.3	1.00	0.042	45	74	46	72	93	*112*
13	125	160.5	2.4	0.95	0.031	47	80	48	75	103	*125*
13	125	160.5	2.4	0.95	0.031	47	80	48	75	103	*125*
East Mains Adjacent to Panel 1											
EM1	75	131	2.1	1.03	0.094	44	64	42	66	73	*87*
EM2	85	131	2.5	1.13	0.080	47	70	50	78	81	*96*
EM3	95	131	3.2	1.34	0.076	52	77	64	100	90	*107*
East Mains Adjacent to Finishing Ends of Panels 2 and 13											
EM4	95	125	3.2	1.29	0.073	53	79	64	100	91	*108*
EM5	85	125	2.9	1.27	0.090	49	72	58	91	83	*98*
EM6	87	125	2.4	1.03	0.070	45	69	48	75	81	*96*
EM7	92	125	2.1	0.87	0.052	43	68	42	66	82	*98*

Notes:
Single panel S_{max} = f(effective mining height, W/H, H, W/t, y/H) (**ACARP, 2003**).
Heights of fracturing based on effective mining heights T'= 0.95T.
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 10 m of the surface.
Italics - Mean or U95%CL B-Horizon prediction is within 10 m of surface.

7.3.3 Discussion of A-Zone Horizon Model Predictions Above Pillar Extraction Panels

The **ACARP, 2003** model's predictions for the mean A-Zone horizon above the proposed pillar extraction panels would be within 10 m of the surface if mining occurred at cover depths of < 50 m. It is considered that the potential for connective cracking to the surface is 'likely' for these scenarios, regardless of any adverse conditions (such as a fault) being present.

The predicted U95%CL A-Zone horizon values are within 10 m of the surface for panel cover depths of between 50 m and 80 m. It is considered that the potential for connective cracking to the surface is 'possible' for these scenarios.

Connective cracking to the surface is considered 'unlikely' for depths of cover between 80 m and 100 m, as the A-Zone Horizon is predicted to be between 10 m and 20 m from the surface.

Connective cracking is considered 'very unlikely' for depths of cover > 100 m, as the A-Zone Horizon is predicted to be > 20 m below the surface.

The results for the **Forster, 1995** model are also included and predict heights of fracturing above pillar extraction panels will generally range between 21 and 33 times the mining height (T), based on Newcastle - Central Coast Coalfield measurements. It is assumed that the fracture height in the **Forster, 1995** model is similar to the Height of Continuous Fracturing (A Zone Horizon) in the **ACARP, 2003** model. The **Forster, 1995** model indicates a similar range of connective cracking heights (46 m to 106 m).

A similar US version of the **Forster, 1995** model indicates that the height of continuous fracturing could range between 10T and 24T (26 m and 62 m) with discontinuous fracturing from 24 T to 60T (62 m to 156 m). A comment is made in a paper by **Mark, 2007**, that the "variation is also probably due to differences in geology and panel geometry".

7.3.4 Discussion of B-Zone Horizon Model Predictions Above Pillar Extraction Panels

The **ACARP, 2003** model predicts that the mean B-Zone Horizon values will occur within 10 m of the surface for cover depths < 100 m above the pillar extraction panels for the given mining geometries. *Discontinuous sub-surface fracturing* for these panels is considered 'likely' to interact with surface cracks.

In areas of shallow or exposed surface rock, creek flows may be re-routed to below-surface pathways and re-surfacing down-stream of the mining extraction limits in these areas.

The predicted U95%CL B-Horizon values are all within 10 m of the surface for cover depths < 130 m. It is therefore assessed that surface water impacts from *Discontinuous sub-surface fracturing* interaction will be 'possible' where cover depths range between 100 m and 140 m.

Mark, 2007 indicates that the height of *Discontinuous fracturing* could range between 24T and 60T (112 m to 282 m).

7.3.5 Discussion of Prediction Model Uncertainties

Due to the complexity of the problem, it is difficult to ascertain which of the two Newcastle Coalfield based models is likely to be the most accurate. It has therefore been considered necessary to review the assumptions made in each model.

Both models indicate that the height of continuous fracturing is fairly insensitive to depth of cover (see **Figure 32** and **33**). However, it is apparent that the **Forster, 1995** model predicts a higher A-Zone horizon than the **ACARP, 2003** model and predicts surface connection could occur for cover depths up to 100 m.

The height of continuous (and discontinuous) fracturing is also probably influenced by the panel width and overburden spanning capability to some degree. Other subsidence workers in the Southern Coalfield claim that fracture heights could extend as high as 1.4 x Panel Width, which would indicate a fracture height of 224 m is possible for the 160 m wide pillar extraction panels. This particular model however, does not distinguish between continuous and discontinuous fracturing, and is therefore considered to be a 'Discontinuous Fracture Height' model only.

The height of fracturing data presented in **Forster, 1995** and **ACARP, 2003** infers that the fracture height is not significantly influenced by the panel width alone (see **Figure 34**). This seems to contradict arching theory, where the height of the 'arch' or fractured zone would be expected to increase as the panel width increases. However, as the effective width of the panel decreases with increasing height above the workings, the spanning capability of the rock 'beams' will also increase and limit the height of continuous fracturing to the base of the spanning units, effectively.

Overall, based on experience at a nearby mine where cover depths ranged from 130 to 250 m above 178 m wide longwall panels with mining heights of 4.5 to 4.7 m, continuous or discontinuous fracturing has not affected the surface watercourses.

What is clear from the above exercise is that there a high degree of uncertainty in predicting the A and B-Zone horizons using any of the available models. The impact management strategies will therefore need to carefully consider the consequences of the predictions if they are exceeded (see **Section 7.3.9**).

7.3.6 Impact on Rock Mass Permeability

In regards to changes to rock mass permeability, **Forster, 1995** indicates that horizontal permeabilities in the fractured zones above longwall mines (see **Figure 30**) 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's could not be measured directly from the boreholes 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 minor vertical flows will occur from B-Zone into the A-Zone (and workings) as well.

Discontinuous fracturing would be expected to increase rock mass storage capacity and horizontal permeability without direct hydraulic connection to the workings. Rock mass permeability is unlikely to increase significantly outside the limits of extraction.

7.3.7 Impact Management Strategies

It is understood that there are no subsurface aquifers of potential resource significance within the overburden that could be affected by *continuous and/or discontinuous fracturing* above the extracted pillar panels. Subsequent groundwater and surface aquifer impact studies have considered the high level of uncertainty in regards to predicting the height of each zone of sub-surface fracturing.

Based on **Table 11**, the **ACARP, 2003** model outcomes have been assessed in accordance with the Likelihood of Occurrence that continuous fracturing will intersect with surface cracks that extend to 10 m depth below the surface. The results are summarised in **Table 12** and **Figures 32a** and **32b** for **ACARP, 2003** and **Figure 33** for the **Forster, 1995** model.

Table 12 - Likelihood Assessment for Continuous Fracturing Extending from Mine Workings to Within 10 m of the Surface Above the Proposed Pillar Extraction and

Likelihood of Occurrence*	Mining Height Range	Cover Depth Range (m)	Probability of a Single Hazardous Event
Likely	2.2 - 3.0	< 40	50 - 75%
Possible	2.2 - 3.0	40 - 80	5 - 50%
Unlikely	2.2 - 3.0	80 - 100	5 - 10%
Very Unlikely	2.2 - 3.0	>100	<5%

* - refer to **Table 10** for definitions of likelihood of occurrence.

Based on the above, SCZ options may be required in areas of the mining lease where cover depths are < 80 m below creeks or if connective cracking to the surface is an issue for the underground operations. Measurement of the A-Zone horizon may be attempted above panels with cover depths > 80 m and non-sensitive surface features exist (see **Section 8** for further monitoring suggestions).

Based on discussions with the specialist groundwater consultant for the project, the absence of significant surface alluvium and ephemeral nature of the creeks/gullies is unlikely to result in significant degradation of the creeks or inrush event into the underground workings should connective cracking to the surface occur. It is considered more likely that any re-directed surface flows will be manageable underground and cracks able to be repaired at the surface.

The above assessment is dependent on our limited understanding of the continuous fracture heights in this area of the mine until monitoring/measurement data becomes available.

7.4 Scarp Development

7.4.1 Potential Impacts

It is possible that scarp development or surface steps up to 300 mm could develop above total extraction panels with a depth of cover < 80 m and a panel width/cover depth ratio > 2.

Similar sized steps have been observed above the old Great Northern Seam workings at Tasman Mine, ~10 km to the south-east of the proposed panels, however, the scarps occurred where massive conglomerate units were present in the overburden.

It is anticipated however, that the deeper soil conditions above the Abel panels will not be conducive for scarp development, due to the more 'flexible' overburden that is present near the surface.

7.4.2 Impact Management Strategies

Scarps will be remediated by the mine if and when they occur, based on consultation with relevant stakeholders. Remediation work would include the regrading and revegetation of affected areas with locally sourced materials to the appropriate standards required by the stakeholders.

7.5 Ponding

7.5.1 Potential Impacts

Ponding refers to the potential for closed-form depressions to develop at the surface after mining of total extraction panels beneath gentle slopes and relatively flat terrain. Ponding could affect drainage patterns, flora, fauna and groundwater dependent ecosystems.

The actual ponding depths will depend upon several other factors, such as rain duration, surface cracking and effective percolation and evapo-transpiration rates.

The potential ponding depths and volumes for the proposed mining layout has been estimated from the 1 m post-mining topographic contours shown in **Figure 35a**. Based on this figure, it appears that a closed form depression could occur along the unnamed gully above the central area of Panel 8, with a maximum potential pond depth of 1.0 m. An area of approximately 5,000 m^2 may be affected, with the volume of the depression estimated to be 2,545 m^3. The depression will be located on the western edge of the Black Hill Land Pty Ltd land.

The 1 m pre-mining topographic contours are shown in **Figure 35b** for comparison.

The potential for ponding along Viney Creek is likely to be minimised where subsidence is limited to < 0.35 m. The pre-and post-mining surface profile along Viney Creek (with subsidence controls implemented) is shown in **Figure 36a**. The worst-case subsided profile predicted for the creek is shown in **Figure 36b**.

Overall, the impact of the increased ponding along the creek beds is likely to be 'in-channel' and therefore the potential effects on existing flora and fauna is likely to be minimal. Further discussion on the ponding impacts are provided in the specialist consultant's reports.

7.5.2 Impact Management Strategies

The minimisation of potential ponding areas may be achieved by adopting one of the SCZ options (such as partial pillar extraction panels) as defined in **Section 5.3** or managing any ponding impacts as described below.

An appropriate ponding management strategy would include:

(i) The development of a suitable monitoring and mitigation response plan, based on consultation with the DECCW and regulatory 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.

7.6 Flood Levels on Black Hill Land Pty Ltd Land

7.6.1 Potential Impacts

The pre-mining 1 in 100 Year ARI flood levels for the Black Hill Pty Ltd were provided by the stakeholder (see **Figure 35b**) to assess potential flooding impacts due to the proposed mining layout.

The post-mining 1 in 100 Year ARI flood levels will require a hydrological assessment based on the predicted surface levels prepared in this study. For indicative purposes, the worst-case flood levels have been estimated from the predicted post-mining contours, as shown in **Figure 35a**.

It is estimated that the areal extent of flooding due to the 1 in 100 year may increase by up to 5% for the subsided reaches of the un-named creek above Panel 8.

7.6.2 Impact Mitigation Strategies

As mentioned above, a post-mining hydrological assessment of the Black Hill Land Pty Ltd site should be completed by the stakeholder for both the current site and re-developed site conditions. The assessment should determine if any additional drainage system measures may be required as a result of mine subsidence.

7.7 Slope Instability and Erosion

7.7.1 Potential Impacts

To-date, local longwall mining experiences in undulating terrain with ground slopes up to 25^{o} has not resulted in any large scale, *en-masse* sliding instability due to mine subsidence (or other natural weathering processes etc). In general, it is possible that localised instability could occur where ground slopes are > 15°, if the slopes are also affected by mining-induced cracking and increased erosion rates.

The rate of erosion is expected to increase significantly in areas with exposed dispersive / reactive alluvial or residual soils or tuffaceous claystone and slope gradients are increased by more than 2% (>20 mm/m).

Based on the difference between the post and pre-mining surfaces presented earlier, the predicted increase or decrease in surface slope gradients after mining are presented in **Figures 37a** and **37b**.

The above figures indicate that the maximum gradient changes will be located above Panels 1 to 13 and likely to range between 1% and 4%. It is assessed that some erosion / sedimentation adjustments may develop at these locations where exposed soils are present.

The predicted changes in surface gradients along Viney Creek are unlikely to exceed 0.5% and therefore unlikely to cause any degradation to the creek.

7.7.2 Impact Management Strategies

To minimise the likelihood of slope instability and increased erosion potential 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 cross lines and centre lines);

(ii) Placement of signs along public access ways warning of mine subsidence impacts.

(iii) Infilling of surface cracking to prevent excessive ingress of run-off into the slopes as soon as practicable and preferably after each panel is completed.

(iv) Slopes that are significantly affected by erosion after mining may need to be repaired and protected with mitigation works such as re-grading and re-vegetation of exposed areas, based on consultation with the relevant government agencies.

(v) 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.

7.8 Valley Uplift and Closure

7.8.1 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 Southern Coalfield experience.

High horizontal stresses have been measured and uplift movements of about 230 mm have occurred along the F3 Freeway cuttings in ridges about 10 km to the south-east of the mine, where massive conglomerate strata existed at the surface.

However, due to the suspected (and observed) low horizontal stress regime in the Abel mine workings roof to-date (i.e. the Upper Donaldson Seam at this location is in relatively flat area with shallow cover), it is considered unlikely that similar magnitude movements will occur in the gullies / broad crested valleys above the proposed panels.

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 < 100 mm. Minor cracking in creek beds may cause some shallow sub-surface re-routing of surface flows due to the valley closure mechanism.

7.8.2 Impact Management Strategy

The impact of valley uplift closure effects due to mine subsidence may be managed as follows:

(i) Install and monitor survey lines along representative drainage gullies where considered appropriate and along gully crests during and after undermining. Combine with visual inspections to locate damage (cracking, uplift).

(ii) Review predictions of upsidence and valley crest movements after each panel is extracted.

(iii) 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.

7.9 Far-Field Horizontal Displacements and Strains

7.9.1 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.

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 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. However, the results may have been affected by GPS baseline accuracy limitations.

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) the maximum subsidence over the extracted area, (iv) topographic relief and (v) the horizontal stress field characteristics.

An empirical model for predicting far-field displacement (FFDs) in the Newcastle Coalfield is presented in **Figure 38**. 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.

The direction of the FFD movement is generally towards the extracted area, but can vary due to the degree of regional horizontal stress adjustment around extracted area and the surface topography. The movements also appear to decrease around the corners of longwall panels. An empirical model for predicting far-field strains (FFSs) in the Newcastle Coalfield is presented in **Figure 39a** and **39b**. 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 95% Confidence limit curve). It is assessed that strains will be <0.5 mm/m at a distance equal to 0.5 x cover depth.

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 FFE 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 likely to be conservative.

7.9.2 Potential Impacts

The surface features that have been assessed in this study for potential FFD and FFS impacts due to mining of the proposed pillar extraction panels include:

- Transgrid tension tower (No. 33B) and suspension towers 29B and 36B.
- F3 Freeway
- John Renshaw Drive and Hunter Water Pipeline (above ground)

As previously discussed, an SCZ setback distance has been applied to the above items that will minimise the potential for significant FFD or FFS impact. The SCZ setbacks are not the same for each feature and have been determined based on conservative tolerance strain limit estimates (shown in brackets)

The design SCZ setback distances adopted in this study are summarised below in terms of 'angle of draw' from the pillar extraction limits to the surface feature:

Transgrid Tower No. 33B (tensile strain < 0.3 mm/m) - 2 x cover depth (63.4^o angle of draw), which gives a minimum set-back distance of 108 m for a cover depth of 54 m at the centre of the tower. The proposed panels P8 and P9 are 105 m and 165 m to the south east and south west of the tower respectively or 1.94 and 3.06 times the cover depth from the tower centre (i.e. 62.7^o and 72^o angle of draw).

F3 Freeway (tensile strain < 0.5 mm/m and lateral curvature radii > 200 km) - 1 x cover depth (45^o angle of draw), which gives a minimum set-back distance of 110 m to 130 m from the freeway. The proposed panels P11 to P13 are approximately 150 m west of the freeway or 1.15 to 1.36 times the cover depth (i.e. 48^o to 53^o angle of draw).

John Renshaw Drive and Hunter Water Pipeline (tensile strain < 0.5 mm/m and lateral curvature radii > 200 km) - 1 x cover depth (45^o angle of draw), which gives a minimum set-back distance of 50 m to 80 m from the road. The proposed Panels 7 to 10 are located approximately 85 m to 155 m south of the road or 1.55 to 3.1 times the cover depth (i.e. 59^o to 72^o angle of draw).

The suspension towers within the SMP area all have cruciform footings installed and will therefore tolerate significantly higher ground strains (e.g. > 10 mm/m).

Predictions of worst-case FFDs and FFSs are summarised in **Table 13**.

Table 13 - Summary of Far-Field Displacement and Strain Predictions for the Proposed Pillar Extraction Panels

Panel #	Feature	z (m)	H (m)	z/H	AoD (o)	Final S_{max} (m)	FFD (mm)	FFS (mm/m)	Principal Movement Direction
8	Transgrid Tower B33	165	54	3.06	72	1.32	1	0.0	SW
9		105	54	1.94	63	1.32	5	0.1	SE
7	John Renshaw Drive/Hunter Pipeline	150	50	3.00	72	1.27	1	0.0	SE
8		90	55	1.64	59	1.32	8	0.1	SE
9		150	60	2.50	68	1.32	2	0.0	SE
10		130	65	2.00	63	1.27	5	0.1	SE
11	F3 Freeway Pavement	150	110	1.36	54	1.29	11	0.2	W
12		150	125	1.20	50	1.30	14	0.3	W
13		150	130	1.15	49	1.23	14	0.3	W
East Mains	Tower B36	54	100	0.54	28	1.05	28	0.8	W
	Tower B29	170	112	1.52	57	1.53	11	0.2	NW

Notes:
z = normal distance to feature from panel centreline.
H = Cover depth at panel end.
AoD = effective angle of draw.
Final Smax = Final maximum panel subsidence (mean values).
FFD = Predicted far-field displacement (mean value).
FFS = Predicted far-field strain (U99%CL value).

The results of the analysis indicate that the Transgrid tension tower (B33) displacements are unlikely to exceed 5 mm towards the mining area (SE and SW). Tensile strains are estimated to be < 0.1 mm/m. Towers B36 and B29 may be displaced west and north-west by 28 mm and 11 mm respectively, with tensile strains of 0.8 and 0.2 mm/m.

John Renshaw Drive and Hunter Water Pipeline may be displaced by up to 8 mm over 160.5 m towards the south-east, with tensile ground strains of < 0.2 mm/m across the features. It is estimated that approximately 1 km of the road and pipeline may be affected, with a minimum lateral curvature radius estimated to be in the order of 400 km.

The F3 Freeway may be displaced by up to 14 mm towards the west over a distance along the freeway of approximately 160.5 m, with tensile ground strains of < 0.3 mm/m. It is estimated that approximately 0.6 km of the freeway may be affected, with a minimum lateral curvature radius estimated to be in the order of 230 km.

It is considered that the impact of the predicted FFD and FFS values are within the tolerable limits of the features assessed. The set-back distances of the proposed mining layout are therefore considered reasonable at this stage.

7.9.3 Impact Management Strategies

The proposed set-back distances of total extraction mining to the sensitive features will reduce the potential for damage occurring to very low likelihoods (ie < 1% probability of occurrence). Monitoring of ground and feature movements as subsidence develops above the extracted panels may still be necessary however.

It should also be understood that the predicted displacements and strains are likely to be < currently available survey accuracy limits and will therefore be practically immeasurable. The monitoring may therefore be limited to visual inspections during mining only.

Some monitoring of ground displacements may still be required at several mutually agreeable locations until the actual extent and magnitude of far-displacements described above can be confirmed. An 'early-warning' type monitoring program around panels in non-sensitive locations is suggested as a reasonable approach.

7.10 Transgrid Towers

7.10.1 Potential Impacts

Detailed descriptions and predictions of the worst-case transient and final subsidence related movements at eight Transgrid Towers (29B to 36B) are provided in a separate report (**DgS Report No. ABL-001/2** (dated 25/09/09)).

A summary of the subsidence prediction results for each tower are re-presented in **Tables 14** to **16**.

Table 14 - Tower Locations and Mining Geometry

Tower #	Panel #	Panel Width W (m)	Cover Depth Above Panel H (m)	Mining Height (m)	Panel S_{max} (m)	Panel Length L (m)	Inflexion Point Distance from Panel Side d (m)	Tower Distance From Start y^+ (m)	Tower Distance from Panel Side x* (m)
31B	7	160.5	85	2.6	1.32	600	45	533	65
32B	8	160.5	74	2.4	1.32	600	46	355	65
33B	8 9	160.5 160.5	70 (54) 70 (54)	2.4 2.4	1.32 1.32	600 400	22 25	70 -105	-165 60
34B	10	160.5	67	2.4	1.27	440	29	31	27
35B	East Mains	125	91	2.1	1.05	2000	35	18	-9
36B	East Mains	125	100	2.1	1.05	2000	35	-82	-54
30B	East Mains	125	99	2.8	1.53	2000	33	1244	16
29 B	East Mains	125	112	2.9	1.53	2000	33	1444	-170

+ - positive distance measured from starting end of panel and within panel limits.
* - positive distance measured from nearest side of panel and within panel limits.
Negative values indicate tower is located outside of panel limits.
(54) - cover depth at Tower 33B

The location of the towers and graphical representation of the analysis results for each tower are given in the abovementioned report for the predicted subsidence, tilt, strain and horizontal displacement respectively. The results are associated with 'smooth' subsidence profile development and do not include discontinuous strata behaviour effects.

Table 15 - Transient* Subsidence Impact Parameter Development at the Transgrid Towers

Tower #	Final Tower Subsidence S_{max} (m)	Maximum Tilt T_{max} (mm/m)		Maximum Horizontal Displacement HD_{max} (mm)		Initial Tower Movement Direction (grid bearing(°)	Maximum Tensile Strain^ $+E_{max}$ (mm/m)		Maximum Compressive Strain^ $-E_{max}$ (mm/m)	
Face Retreat Rate:		25 m/wk	<10 m/wk	25 m/wk	<10 m/wk		25 m/wk	<10 m/wk	25 m/wk	<10 m/wk
31B	0.82	17	33	120	240	324	1.5	5	4	5
32B	1.09	14.5	29.5	106	215	324	1.5	5.5	4	5.5
33B	0.00	0	0	0	0	234	0	0	0	0
34B	0.57	13	26	80	190	144	4	4	0	0
35B	0.02	1.5	4.5	11	33	144	1	1	0	0
36B	0.00	0	0	0	0	268	0	0	0	0
30B	0.57	4	23	29	168	054	1	2	0	0
29B	0.00	0	0	0	0	324	0	0	0	0

* - Refers to subsidence movements directly associated with the retreating extraction face.
^ - Maximum strains refer to major principal strains. Minor principle strains = 0.25 x major principle strains.

Table 16 - Final* Subsidence Impact Parameter Development at the Transgrid Towers

Tower #	Final Tower Subsidence S_{max} (m)	Tilt T_{max} (mm/m)	Horizontal Displacem't HD_{max} (mm)	Final Tower Movement Direction grid bearing (°)	Total Tower Rotation# (°)	Major Principle Strain E_{max} (mm/m)	Minor^ Principle Strain e_{max} (mm/m)
31B	0.82	16	119	017	53	-4.9	-1.2
32B	1.09	7	53	048	90	-4.2	-1.0
33B	0.00	0	*5*	144	0	*0.1*	*0.0*
34B	0.57	25	181	144	0	-1.7	1.4
35B	0.02	2	18	192	48	1.4	0.2
36B	0.00	0	*28*	268	0	*0.8*	*0.2*
30B	0.57	24	173	324	-90	3.4	0.9
29B	0.00	0	*11*	324	0	0.2	0.0

* - Refers to subsidence movements after mining of panel has stopped.
\# - Clockwise rotation is positive.
^ - minor principle strains = 0.25 x major principle strains.
Italics - Far-field displacements and strains are Upper 99%CL values (refer to **DgS, 2009**).

7.10.2 Towers above the Proposed Pillar Extraction Panels

In summary, the five towers within the proposed limits of the pillar extraction panels are likely to be subjected to subsidence ranging from 0.02 m to 1.1 m at the tower centres.

Transient tilts above the pillar extraction panels are estimated to range from 4 to 33 mm/m for the possible range of retreat rates. Transient tensile and compressive strains are expected to range from 4 to 5.5 mm/m, depending on face retreat rates.

Final tower tilts will range between 2 mm/m and 25 mm/m. Horizontal displacements are estimated to range between 18 mm and 181 mm. Three of the tower locations will have residual compressive strains ranging from 4 mm/m to 5 mm/m, with the other two towers likely to have residual tensile strains ranging from 1.5 to 3.5 mm/m.

Surface cracking may increase the estimated 'smooth' profile values by 2 to 4 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' or scarp development.

Predicted subsidence impact parameter development profiles for the first two towers likely to be effected (Towers 31 and 32) by Panels 7 and 8 are taken from **DgS, 2009** and presented in **Figures 40a-d** and **Figures 41a-d** respectively.

7.10.3 Towers outside of the Proposed Mining Limits

The tension tower 33B is very unlikely directly by subsidence or tilt, but may experience minor far-field movements, which are unlikely to exceed 5 mm horizontal displacement and 0.1 mm/m tensile strain.

The predicted FFDs at Towers 29B and 36B are very unlikely to be > 28 mm, with FFSs not > 0.8 mm/m.

7.10.4 Impact Management Strategies

Based on the predicted subsidence profiles for the eight transmission towers, it is assessed that cruciform footings or subsidence protection pillars would have been necessary above the proposed mining areas to mitigate subsidence impacts on the towers to tolerable limits.

While the towers already have cruciform footings installed, the design limits for the footings (and towers) to resist the predicted movements are unknown and should be checked by a structural engineer before mine subsidence occurs.

Once the tower footings have been assessed and any necessary mitigation works have been completed, the following monitoring program may be implemented in accordance with a Tower SMP that will need to be prepared in consultation with Transgrid:

(i) Install a minimum of four stable survey pegs or stations in the ground adjacent to each tower leg and on the structure itself (including Tower 33B).

(ii) Determine 3-D coordinates (E, N, RL), levels and in-line strains between the pegs (perimeter distances only) with a minimum of two base-line surveys prior to mining. Survey accuracy should be within the limits discussed below.

(iii) 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).

(iv) Measure the vertical distance from the ground to the conductor catenaries between each tower before, during and after subsidence development.

(v) Prepare and distribute results of each survey to relevant stakeholders.

(vi) 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 8** for survey accuracy requirements).

7.11 Boral Asphalt Plant on Black Hill Land Pty Ltd Land

7.11.1 Site Details and Potential Impacts

The Boral Asphalt plant produces 40,000 tonnes/annum of hot asphalt and 5 Million litres/annum of sprayed bitumen seal for the Australian road construction industry. The site has the following sensitive items of infrastructure that will have very low differential settlement tolerances and represent a business, safety and environmental hazard:

- rotating drum burner to dry aggregate (340^{o}C operating temperature)
- 22 m high x 0.75 m stainless steel exhaust stack with guywires
- elevated diesel and bitumen storage tanks
- elevated conveyors and pipe network for materials transfer
- lime storage tank
- hot asphalt and spray-seal bitumen storage tanks (46,000 litres @ 170^{o}C operating temperature)
- diesel and CRS Emulsion tanks (27,000 and 15,000 litres)
- in-ground concrete oil separator pits
- weigh-bridge / loading bay
- kerosene and Elgas storage tanks with underground pipe lines
- workshops with concrete slab footings
- masonry block retaining walls
- Gravel hardstand equipment and transport vehicle storage areas
- Buried 100 mm Victaulic water supply pipeline

Other features on the site include staff offices, amenities buildings and car parking. Based on discussions with the site manager, the plant may be partially decommissioned in two to three years (2011 to 2012), however, until notice is given by Boral, it will be necessary to restrict subsidence to very low levels beneath the site by adopting an appropriate subsidence control zone.

The SCZ at this stage has been defined as a 26.5^o angle of draw from the site boundary to the limits of secondary pillar extraction (see **Figure 1**). The buffer zone is only required within the East Mains when pillars are to be taken.

7.11.2 Impact Management Strategies

Impact management strategies for the Boral Asphalt plant will require the following:

(i) Dilapidation survey of site infrastructure prior to second workings in the East Mains.

(ii) Installation of subsidence monitoring lines and stations at key site features to confirm performance of SCZ.

(iii) Monitoring of draw angle and surface impacts around Abel mine workings in non-sensitive areas prior to second workings in the East Mains, and to confirm or adjust minimum set-back distances from the site features of interest.

(iv) On-going consultation with stakeholder in regards to preparation of a subsidence management plan for minimising mine subsidence impacts within the site boundary.

The stakeholder should be notified of mine subsidence survey results and mining activities in advance of subsidence development adjacent to the mine. The SMP should also include an emergency response plan to unanticipated mining related impacts.

7.12 Energy Australia Power Line Easements

7.12.1 Potential Impacts to 132 kV Line

There are eight pairs of timber power poles (EA1 to EA8) which will be within or just outside the zone of mine subsidence. The pole pairs are approximately 15 m high and 5 m apart. The pole pairs are connected by a galvanised steel brace between the tops of the poles. The pole pairs are spaced from 161 m to 269 m along the easement, as shown in **Figure 1**.

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 and final tilt direction at each pole are presented in **Table 17**. The predictions have been determined from the contour predictions presented in **Figures 22** to **25**. The clearances of the conductors have been assessed from the easement subsidence profiles presented in **Figure 42**.

Table 17 - Worst Case Subsidence Predictions for Energy Australia 132 kV Power Poles

Pole Pair and Pole No.	Panel No.	Final Subs S_{max} (m)	Final Tilt T_{max} (mm/m)	Final Tilt Direction (grid bearing) (o)	Final Ground Strain (mm/m)	Final HD* Base (mm)	Final HD^ Top (mm)	Final Pole Pair Closure (mm)	Conductor Clearance Loss (m)
1.1	*8*	*0.00*	*0*	*234*	*0.1*	0	0	*0*	0.52
1.2	*8*	*0.00*	*0*	*234*	*0.1*	0	0		0.51
2.1	8	-0.99	16	054	-6.4	118	360	62	1.06
2.2	8	-1.03	14	054	-6.2	101	308		1.02
3.1	7	-1.13	16	054	-6.2	117	358	63	1.16
3.2	7	-1.16	14	054	-6.2	103	313		1.13
4.1	6	-1.25	2	052	-3.0	17	52	15	1.17
4.2	6	-1.25	2	097	-3.0	15	44		**1.18**
5.1	5	-1.26	15	235	-5.0	113	345	**70**	0.64
5.2	5	-1.19	**18**	235	-4.6	**131**	**400**		0.67
6.1	4	-0.35	16	252	**3.6**	120	367	5	0.73
6.2	4	-0.29	15	254	3.8	106	324		0.73
7.1	EM	**-1.56**	6	256	**-10.7**	45	137	66	0.81
7.2	EM	-1.54	8	304	-10.2	61	186		0.79
8.1	EM	-0.05	4	320	1.8	28	84	17	0.02
8.2	EM	-0.03	3	320	1.5	20	62		0.02
9.1	1/EM	*0.00*	*0*	300	*1.3*	*47*	*47*		*0*
9.2	1/EM	*0.00*	*0*	300	*1.0*	*45*	*45*	-2	*0*

Notes:
* - 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)
Italics - Far-field displacements and strains.
Bold - Maximum value.

Each of the power pole pairs will be subject to transient movements towards the retreating pillar extraction face. The poles will generally start moving towards the north and then 'swing' around (up to 90 degrees in bearing) to their final positions after subsidence is fully developed. The poles will also be subject to tensile and compressive strains 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, and will be dependent on face retreat rates.

During subsidence development the distance between the pole pairs will tend to close by between 5 and 70 mm (see **Table 17**). These movements are primarily due to the differential tilt between the poles that may be exacerbated or reduced by the ground strains.

Conductor clearances are estimated to be decreased by between 0.02 m and 1.17 m along the easement as shown in **Table 17**.

The impacts of the predicted movement and management strategies will require assessment by Energy Australia engineers.

7.12.2 Potential Impacts to 11 kV Line

There are twenty-three timber power poles (1 to 23) which will be within or just outside the zone of mine subsidence. The poles are approximately 15 m high and 90 m apart (distances vary from 31 m to 132 m) as shown in **Figure 1**.

The conductors are supported by relatively inflexible ceramic insulators that will probably not be able to tolerate the predicted pole movements.

Worst-case predictions of final subsidence, tilt, strain and final tilt direction at each pole are presented in **Table 18**. The predictions have been determined from the contour predictions presented in **Figures 22** to **25**. The clearances of the conductors have been assessed from the easement subsidence profiles presented in **Figure 43**.

Table 18 - Worst-Case Final Subsidence Predictions for Energy Australia 11 kV Power Poles

Pole No.	Easting	Northing	Maximum Subsidence S_{max} (m)	Final Tilt+ T_{max} (mm/m)	Final Tilt Direction (grid bearing) (o)	Final Ground Strain& (mm/m)	Final HD* Base (mm)	HD^ Top (mm)	Conductor Clearance Loss (m)
1	370798	6368197	0.0	0	0	0	0	0	0.13
2	370820	6368126	-0.3	22	149	**7**	158	482	0.16
3	370777	6368016	-0.1	11	234	7	83	253	0.48
4	370753	6367997	-0.9	**29**	234	-5	**211**	**643**	0.99
5	370724	6367918	-1.1	18	54	**-8**	131	400	0.88
6	370674	6367809	-0.7	**29**	234	-1	209	639	0.57
7	370631	6367696	-0.5	26	54	3	188	573	0.83
8	370584	6367577	-1.3	6	238	-4	44	135	0.98
9	370553	6367510	-0.8	25	53	-3	182	555	0.53
10	370526	6367446	-0.2	15	234	6	109	334	0.73
11	370495	6367377	**-1.5**	5	218	-3	33	101	**1.21**
12	370479	6367313	-1.0	25	54	-2	181	552	0.57
13	370445	6367229	-0.5	23	236	4	165	503	0.54
14	370405	6367131	-0.6	21	343	3	156	478	0.49
15	370348	6367019	-0.6	27	145	4	198	604	0.47
16	370295	6366898	-0.3	17	343	4	122	374	0.55

Notes:
+ - Transient tilts due to travelling subsidence wave may be assumed to equal the final tilt magnitudes at a given location. Further analysis may be required if marginal conditions indicated.
& - Transient strains may be assumed to range from +/- Final Values.
* - 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)
Bold - Maximum value.

The power poles will be subject to transient movements towards the retreating pillar extraction face. The poles will generally start moving towards the north and then 'swing' around (up to 90 degrees in bearing) to their final positions after subsidence is fully developed. The poles will also be subject to tensile and compressive strains 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, and will be dependent on face retreat rates.

Conductor clearances are estimated to be decreased by between 0.13 m and 1.21 m along the easement as shown in **Table 18**.

The impacts of the predicted movement and management strategies will require assessment by Energy Australia engineers.

7.12.3 Impact Management Strategies

Appropriate impact management strategies for the Energy Australia powerline easements include:

(i) The development of a suitable monitoring and response plan based on consultation with the owners of the power line to ensure the impacts on the poles and powerlines do not result in unsafe conditions, bush fires or loss of serviceability during and after mining.

(ii) Management of impacts would include replacement of damaged poles and preventing potential damage to conductors and surrounding bush land (e.g. in the event of a conductor break sparking a bush fire) and/or providing an alternate supply of power (if possible) until subsidence has fully developed. It is understood that poles may be sourced and replaced at short notice from the Thornton pole yard.

(iii) Suitable responses to predicted subsidence impacts to the power poles and conductors would be to provide appropriate sheathing on the poles to control the tension in the conductors during/after mining impacts.

(iv) 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 exceedence if it occurs. The erection of temporary fencing in critical areas before subsidence develops may also need to be considered.

The impact management plan should include the following activities:

(i) Measurement of the vertical distance from the ground to the conductor catenaries between each pole pair before, during and after subsidence development.

(ii) Prepare and distribute results of each survey to relevant stakeholders.

(iii) Review and implement Trigger Action Response Plan.

7.13 Optus Fibre Optic Cable

7.13.1 Potential Impacts

The Optus Fibre Optic cable is buried within a shallow trench that is located within the Transgrid Powerline easement (see **Figure 1**).

The worst-case subsidence predictions along the easement after mining are presented in **Table 19**.

Table 19 - Worst-Case Subsidence Predictions for the Optus Fibre Optic Cable Easement

Panel	Chain Start (m)	Chain End (m)	Final Subsidence S_{max} (m)	Final Tilt T_{max} (mm/m)	Final In-Line Ground Strain (mm/m)		Final Principal Ground Strain (mm/m)	
EM	1455	1632	1.53	21	2.5	-5.1	5.6	-10.1
P7	1665	1880	0.93	12	2.0	-5.2	4.2	-5.2
P8	1908	2135	1.14	17	3.8	-2.3	5.8	-5.3
P10	2600	2767	0.92	16	2.7	-4.2	6.1	-5.5
East Mains	3093	3241	0.11	3	0.74	-0.93	1.5	-1.1

Graphical representation of the final subsidence, tilt and strain profiles along the Optus FOC easement are presented in **Figures 44a** to **44c**.

7.13.2 Impact Management Strategies

Based on discussions with Optus engineers, the following strategies are available to mitigate against cable impacts:

- Uncover and relocate the cable prior to mine subsidence impacts
- Re-route and replace the FOC after mine subsidence impact occurs
- Limit subsidence impacts to within tolerable limits (details have been requested and yet to be supplied)

The tolerable limits of the FOC are likely to be dependent on the sheath reinforcement limits and/or strain transfer properties of the sheath and trench backfill.

It may therefore be necessary to re-route or replace the section of cable above the proposed pillar extraction panels. Further consultation with Optus will be necessary to prepare a suitable management strategy for the FOC.

7.14 Hunter Water Pipeline

7.14.1 Potential Impacts

The Hunter Water pipeline is buried within a trench that traverses the site above the proposed East Mains and Panel 2 pillar extraction panels (see **Figure 1**).

The worst-case subsidence predictions along the pipeline easement after mining is complete are presented in **Table 20**.

Table 20 - Worst-Case Subsidence Predictions for the Hunter Water Pipeline Easement

Panel	Chain Start (m)	Chain End (m)	Final Subsidence S_{max} (m)	Final Tilt T_{max} (mm/m)	Final Curvature C_{max} (km^{-1})		Final Horiz. Displacement (mm)		Final Ground Strain (mm/m)	
					In-line	Lateral	In-Line	Lateral	In-Line	Lateral
East Mains	886	1021	1.50	28	0.88/ -1.75	0.074/ -0.074	201	86	6/ -13	0.7/-0.6
P1	1063	1223	1.07	18	1.28/ -0.70	0.052/ -0.20	122	160	9/ -5	0.4/-1.7

Graphical representation of the final subsidence, tilt, curvature, horizontal displacement and strain profiles along the Hunter Water pipeline easement are presented in **Figures 45a** to **45e**.

Based on reference to **Ho and Dominish, 2004**, the impact of the predicted subsidence movements will be dependent on the tolerable limits of the UPVC pipeline walls and rubberised ring joints to the induced bi-lateral curvatures and tensile/compressive strains acting along the pipeline. Both parameters are likely to increase or decrease the normal and shear stresses in the pipeline wall.

The generation of stress in the pipeline walls due to curvature in both the vertical and horizontal planes will be function of the pipe wall thickness, pipe diameter and Young's Modulus of the pipe material and internal operating pressures.

The transfer of strain (and stress) into the pipe wall will also be dependent on the depth of backfill over the pipe and the coefficient of friction between the trench backfill and the pipe wall.

The deformed shape of the pipeline after mining should therefore be assessed by Hunter Water Engineers in order to determine whether mitigation works will be required during subsidence development.

7.14.2 Impact Management Strategies

The proposed management strategies required to minimise impact on the pipeline due to subsidence are:

- Determine tolerable in-line and lateral pipeline deformation limits to be used for trigger action responses based on consultation with Hunter Water engineers.

- Install survey pegs and monitor the deformation of the ground surface along and across representative sections of the pipeline.

- Uncover the pipeline sections where deformations and strains have exceeded the tolerable or agreed trigger action response limits.

- Reduce subsidence above the East Mains and No. 2 Panel by mine design.

- Re-align the pipeline, replace damaged sections and backfill prior to re-commissioning.

7.15 Stock Watering System on the Catholic Diocese Land

7.15.1 Potential Impacts

The cattle grazing on the Catholic Diocese land are watered by a series of buried pipelines which supply several watering troughs. The system was devised during the time when the chicken battery was operating and open water bodies such as farm dams were deemed a disease risk to the chickens.

There are three 75 mm diameter PVC pipelines (Lines 1 to 3) that provide stock water to 8 troughs around the Catholic Diocese Land, see **Figure 1**. One of the lines (Line 3) provides water to two residences to the south of the SMP area.

The pipelines are connected to the 200 mm diameter Hunter Water pipeline at different locations above the East Mains Panels and Panel 1. It will be necessary to ensure that the water supply will not be disrupted by mine subsidence effects.

The worst-case subsidence parameter predictions along the pipeline easements and Hunter Water mains connections after mining is complete are presented in **Table 21** and have been derived from the subsidence contours in **Figure 22**.

Table 21 - Worst-Case Subsidence Predictions for the Stock Watering System on the Catholic Diocese Land

Line	Panel	Location	Final Subsidence S_{max} (m)	Final Tilt T_{max} (mm/m)	Final Ground Strain E_{max} (mm/m)	Final Curvature C_{max} (km^{-1})	Final Horiz. Displacement (mm)
1	1	HW	0	0	0.0	0.00	0
	4	T1.3	0.29	12	2.0	0.27	88
	5	T1.2	1.38	7	-3.0	0.41	51
	7	T1.1	0.04	3	0.0	0.00	22
2	2	Kink	1.69	3	-1.5	-0.21	22
	2	T2.2	0.68	20	1.0	0.14	146
	2/3	T2.1	0.08-0.63	32	4.0	0.55	234
	EM	HW	0.040	4	-4.0	-0.55	29
	EM	T2.3	0.15	5	0.2	0.03	37
3	1	T3.1	0.29	7	4.5	0.62	51
	EM	HW	1.45	17	-14.0	-1.92	124

Notes:
EM = East Mains.
HW = Hunter water pipeline.
T1.3 = Trough #3 on Line # 1.
Kink = High angle change in pipeline direction.

Graphical representation of the final subsidence, tilt, and strain profiles along the three stock watering lines are presented in **Figures 46a** to **46c** (Line 1), **Figures 47a** to **47c** (Line 2) and Figures 48a to **48c** (Line 3).

Based on reference to the comments on the Hunter Water pipeline in **Section 7.14.1**, it is estimated that the smaller diameter pipeline in shallower trenches will have higher tolerable ground movement impact limits than the Hunter Water Pipeline. However, it is assessed that damage to joints/couplings along the pipelines and at connections between troughs and the mains should be anticipated during mining.

7.15.2 Impact Management Strategies

The proposed management strategies required to minimise impact on the stock watering system due to subsidence are:

- Review the existing Land Management Plan for the Catholic Diocese Land and assess the daily water supply requirements for the stock and residences and range of impact management options.

- Determine whether it is possible to isolate sections of line that may be actively subsided in the future through existing valves or installation of additional ones.

- Install flexible couplings at the troughs and Water Mains prior to subsidence development.

- Prepare a property management plan that either duplicates the line to allow a temporary by-pass system to operate during mining or isolate and repair damage to the line at short notice.

  Transporting water to ensure supply could also provide an effective back-up supply provided daily requirements can be delivered in a timely manner. This option may also avoid the need to move livestock from an effected area as water may be delivered to the affected troughs as needed.

7.16 Property Fences and Livestock Grazing on Catholic Diocese Land

7.16.1 Potential Impacts

The impact of 1.21 m to 1.76 m of subsidence on the grazing of livestock and fencing could include the disruption of the buried water supply pipelines (see **Section 7.15**), the development of surface cracks and erosion, breakage of wire fencing strands and the possible failure of strainer posts.

Failure of fencing could allow livestock to get out of paddocks within the Catholic Land, but not from the site itself. Ponding is not expected to affect grazing or pasture areas.

7.16.2 Impact Management Strategies

The above impacts may be managed with the rapid repair of surface cracking, damaged water supply pipes and fences. Relocation of livestock before mining impacts occur may also be undertaken in anticipation of fence failure or loss of water supply. A property management plan (PMP) will be developed in consultation with the landowner to address these potential issues.

7.17 Disused Buildings on Catholic Diocese Land

7.17.1 Potential Impacts

The previous land user buildings on the Catholic Diocese Land are either in various stages of disrepair or have been demolished. It is understood that areas of site contamination exists where the buildings once stood.

Mine subsidence is likely to impact existing disused residences and structures above the proposed pillar extraction panels significantly (based on damage criteria presented in **AS2870, 1996**).

It is understood that the Catholic Diocese Land Management group are preparing a proposal to bury hazardous waste associated with the previous land users in a lined 'control' fill in-situ.

The site of the landfill is unknown at this stage but could have significant impact on the mining layout.

7.17.2 Impact Management Strategies

Appropriate impact management strategies for the existing disused structures that may be impacted by mine subsidence may include and address the following issues in consultation between the stakeholders:

- a dilapidation survey and inspection of all structures within the mining lease before and after mine subsidence should be made by a qualified building consultant.

- Determine when mining impacts will occur to the buildings and install temporary fencing to prevent site personal or general public access to potentially unstable structures. Alternatively, the buildings may be demolished prior to mining impacts.

- The monitoring plan for the property during mining and safety/hazard management plan.

- The timing of disconnection of power and water supply etc.

- The post-mining inspection and reporting of property damage and repair or demolition works options.

  Any repair works to internal/external cracking or re-levelling of damaged structures should be implemented to ensure the properties are safe before allowing access.

- These items will also be addressed in the property management plan (PMP) to be developed in consultation with the landowner.

The potential also exists for the mine to trial minimum proposed set-back distances from pillar extraction areas to existing structures. This information may prove to be invaluable in regards to gaining stakeholder confidence when mining approval is being sought in areas to the south of Black Hill Drive.

7.18 Proposed Re-Development of Black Hill Land Pty Ltd Land

7.18.1 Predicted Impacts

It is understood that there is to be no residual subsidence risk remaining beneath the site after mining has ceased.

The impacts to the Black Hill Land Pty Ltd land after the mining of pillar extraction panels P7 to P13 may include the following:

- Maximum surface subsidence ranging from 1.0 m to 1.3 m.
- Surface cracking from 40 mm to 230 mm wide.
- Surface ponding potential of up to 1 m along the western area above Panel 8.
- Changes to surface gradients of +/- 4% above pillar extraction panels.

Approximately 90% to 95% of mine subsidence development will occur within 6 to 10 weeks after undermining occurs. On-going residual settlements due to goaf reconsolidation may continue for a period of up to 1 year, however, these movements are unlikely to result in further damage occurring to the surface.

7.18.2 Impact Management Strategies

The predicted impact management strategies for the Black Hill Land Pty Ltd are likely to be adequately addressed by the proposed strategies presented in earlier sections of this report for the management of surface cracking, scarps, ponding and slope instability if they occur.

The barrier pillars that will be left between the extracted panels do not represent a future subsidence potential risk to future land re-development and ultimately the users for the following reasons:

- The factor of safety of the barrier pillars after mining of Panels 7 to 13 will be > 2.23 under double abutment loading conditions. Reference to **ACARP, 2005** suggests that the pillars will have a probably of failure of < 1 in 10 million.
- The proposed barrier pillars left between the panels will be strain-hardening and very unlikely to cause further increases in subsidence after the initial subsidence development period. It is unlikely that future pillar rib instability will result in any significant decrease in pillar strength or stiffness. The height of the pillars are also unlikely to increase above 2.4 m in this area of the mine due to seam thickness constraints.
- The goaf adjacent to the pillars will provide support to overburden between the barrier pillars.

Based on the above, it is not considered necessary to remove or extract the pillars to minimise future subsidence potential or demonstrate long-term stability criteria have been satisfied for subsequent re-development. It is an option that may be discussed with the DPI, however there are ventilation and underground safety risks involved with removing the pillars during mining.

A property management plan (PMP) will be developed in consultation with the landowner to address these potential issues.

7.19 Aboriginal Heritage Sites

7.19.1 Potential Impacts

The three scattered artefact sites exist within the Abel mine lease but outside the zone of subsidence due to the proposed mining layout (see **Figure 3**). It is therefore very unlikely that the sites above the pillar extraction panels will be affected or damaged by surface cracking and increased erosion rates.

Further artefact sites may be present along Viney Creek which have yet to be identified (**ERM, 2008**).

7.19.2 Impact Management Strategies

The Department of Environment, Climate Change and Water (DECCW) require that an archaeological record of the artefact scatters be developed before recommending that mining activities be approved. The record for the SMP Area is understood to have now been completed.

As the archaeological surveys to-date have not identified any sites that are likely to be affected by mine subsidence, formal management plans will need to be established prior to mining of Panels 1 to 13.

7.20 F3 Freeway and John Renshaw Drive

7.20.1 Potential Impacts

John Renshaw Drive and the F3 Freeway are located well outside the angle of draw around the proposed mining areas. Far-field horizontal displacements of < 13 mm towards the mining area may occur along some sections of both roads adjacent to extracted panels P7 to P13.

Strains associated with the predicted FFDs, are likely to be < 0.3 mm/m and very unlikely to cause cracking or impact to the roads.

7.20.2 Impact Management Strategies

It is not considered necessary to monitor far-field movements along these roads as any movements that occur will probably be less than survey accuracy limits for horizontal displacement (i.e. <10 to 20 mm).

It is however, considered reasonable to conduct visual inspections along the roads during subsidence development and prepare an impact management response strategy with the Newcastle City Council (NCC) and the RTA to deal with mining impacts if they do occur.

A series of far-field monitoring stations which monitor total horizontal displacement and strain may be established at strategic points around the mining lease to further understand this phenomenon for defining appropriate set-back distances from other sensitive items of infrastructure that may exist elsewhere within the mining lease.

7.21 Comparison of Subsidence Profile Predictions to the Environmental Assessment

For completeness the proposed SMP mining layout and impact predictions have been compared to the Environmental Assessment.

It is considered that whilst the proposed SMP layout is not similar to the layout presented in the Environmental Assessment (EA) Report for the Abel Mining Lease Application (see **Figure 49a**), the predicted subsidence and associated impacts to the natural and man-made features will be similar in magnitude and location to the EA study outcomes.

A representative predicted subsidence profile across EA Panels (UD 15 to UD 6) with similar geometry to the SMP Panels P1 to P13 are presented **Figure 49b**, and has been compared to the predicted profiles for XL 1 (see **Figure 12)** in **Figure 49c**. The differences between the profiles are primarily due to the seam thickness differences along each crossline.

8.0 Monitoring Requirements

8.1 Subsidence Development

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.

Reference to **ACARP, 2003** indicates that primary subsidence at a given location above the panel centreline is likely to commence at a distance of about 0.5 times the cover depth ahead of the retreating longwall face; accelerate up to rates from 50 to 300 mm/day when the face is 0.2 to 1 times the cover depth past the point; and decrease to < 0.020 m/week when the face is > 1.5 times the cover depth past the point (see **Figures 50a** and **50b**). Primary subsidence is generally referred to the subsidence that is directly related to the retreating pillar extraction face.

Residual subsidence, due to re-consolidation of goaf, represents approximately 5 to 10% of maximum final subsidence and will be on-going for several months after primary subsidence ceases. It is recommended that complete subsidence development is monitored at several locations above the first pillar extraction panel to confirm the above estimates.

Further subsidence is also expected to develop when adjacent panels are subsequently extracted and will be due to the compression of barrier pillars when subject to increasing abutment loads. The development and magnitude of these movements will be similar to the residual subsidence movements.

8.2 Surface Monitoring Plans

Based on the surface topography and surface infrastructure present above the proposed pillar extraction, the following subsidence and strain-monitoring program is suggested to provide adequate information to monitor and implement appropriate subsidence impact management plans and provide pillar stability and performance data.

The following general monitoring program activities are suggested:

(i) A minimum of one transverse subsidence line across the pillar extraction panels. The lines should be installed to at least the middle of the next adjacent panel before undermining occurs.

(ii) A longitudinal line extending in-bye and out-bye from each panels starting and finishing points, for a minimum distance equal to the cover depth (i.e. to an AoD of 45^{o}).

(iii) A survey line along and across the banks of Viney Creek (refer to surface water consultants).

(iv) A minimum of 4 pegs spaced 10 m apart adjacent to or around any feature of interest (i.e. transgrid tower, archaeological sites) to measure subsidence, tilt and strain.

(v) The panel survey pegs should be spaced at a minimum of 10 m and a maximum of 20 m apart. For the first two or three panels it is recommended that the pegs are spaced 10 m apart along full crosslines and 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.

(vi) A minimum of two baseline surveys of subsidence and strain is recommended before mine subsidence occurs to establish survey accuracy.

(vii) Survey frequency will be dependent upon mine management requirements for subsidence development data in order to implement subsidence and mine operation management plans.

(viii) Visual inspections and mapping of damage to be conducted before, during, and after mining.

(ix) The location of the extraction face should be recorded with each survey.

Further site or stakeholder specific monitoring may also be required.

8.3 Survey Accuracy

Subsidence and strains may be determined using total station or spirit levelling and steel tape techniques, depending on the survey accuracy requirements.

The accuracy of total station traverse techniques from a terrestrial base line is normally expected to be within +/- 10 mm for level and +/- 10 to 20 mm for horizontal displacement (i.e. a strain measurement accuracy of +/- 1 to 2 mm/m over a 10 m bay-length).

The accuracy of level measurements using spirit level should give subsidence to within +/- 3 mm. Strain measurements using the steel tape techniques would be expected to have an accuracy of +/- 2 mm (or 0.2 mm/m strain over 10 m).

It is recommended that total station techniques are used only for locating and monitoring of absolute X and Y displacements were possible and spirit levelling be used to measure all vertical movements. Steel tape measurements would be the preferred method for measuring strain.

8.4 Sub-Surface Monitoring

Monitoring of sub-surface fracture heights above pillar extraction panels may be necessary within the mining lease to confirm the predictions of potential areas of connective surface cracking.

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

8.5 Alternative Monitoring Techniques

Aerial Laser Scanning (ALS) techniques may also be undertaken over the mining lease and will allow comprehensive ground movement monitoring over entire panels. The ALS may be linked into terrestrial baseline monument surveys and provide subsidence data to within +/- 0.15 m, based on published information. The ALS scans also provide a more thorough picture of the subsidence development along creeks and surface terrain generally and without the need for intrusive surveys or monitoring pegs (which can be a hazard to livestock and be lost by future re-development activities).

9.0 Conclusions

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

It is considered that whilst the proposed SMP layout is not similar to the layout presented in the Environmental Assessment (EA) Report for the Abel Mining Lease Application, the impacts to the natural and man-made features will be similar in magnitude and location to the EA study outcomes.

No practically measureable mine subsidence or far-field displacement movements or impacts are expected along John Renshaw Drive or the F3 Freeway due to the proposed mining layout.

Subsidence Control Zones (SCZ) have been proposed to limit impacts to within tolerable levels from the proposed mining layout at Abel for Viney Creek, the Transgrid tension tower No. B33 and the Boral Asphalt Plant. The proposed setback distances are considered conservative, however, they will still need to be confirmed as adequate through subsidence monitoring in less sensitive areas during mining.

The above subsidence impact limit criteria will be achieved in the SCZ with first workings only proposed at this stage. The potential exists however to implement a partial pillar extraction layout provided the long-term stability of remnant pillars and tolerable impacts to surface features can be demonstrated.

Provided the proposed impact management strategies are acceptable to the relevant stakeholders, the proposed mining layout is considered satisfactory at this stage.

If the estimated worst-case impacts cannot be reasonably managed in the event that exceedences occur (however unlikely), through mitigation or amelioration strategies, then it will be necessary to adjust to the mining layout further to provide a more acceptable risk to the stakeholders.

The extent of mining layout adjustment will also require further discussions (and review of monitoring data) after the completion of a given panel with stakeholder and government agencies.

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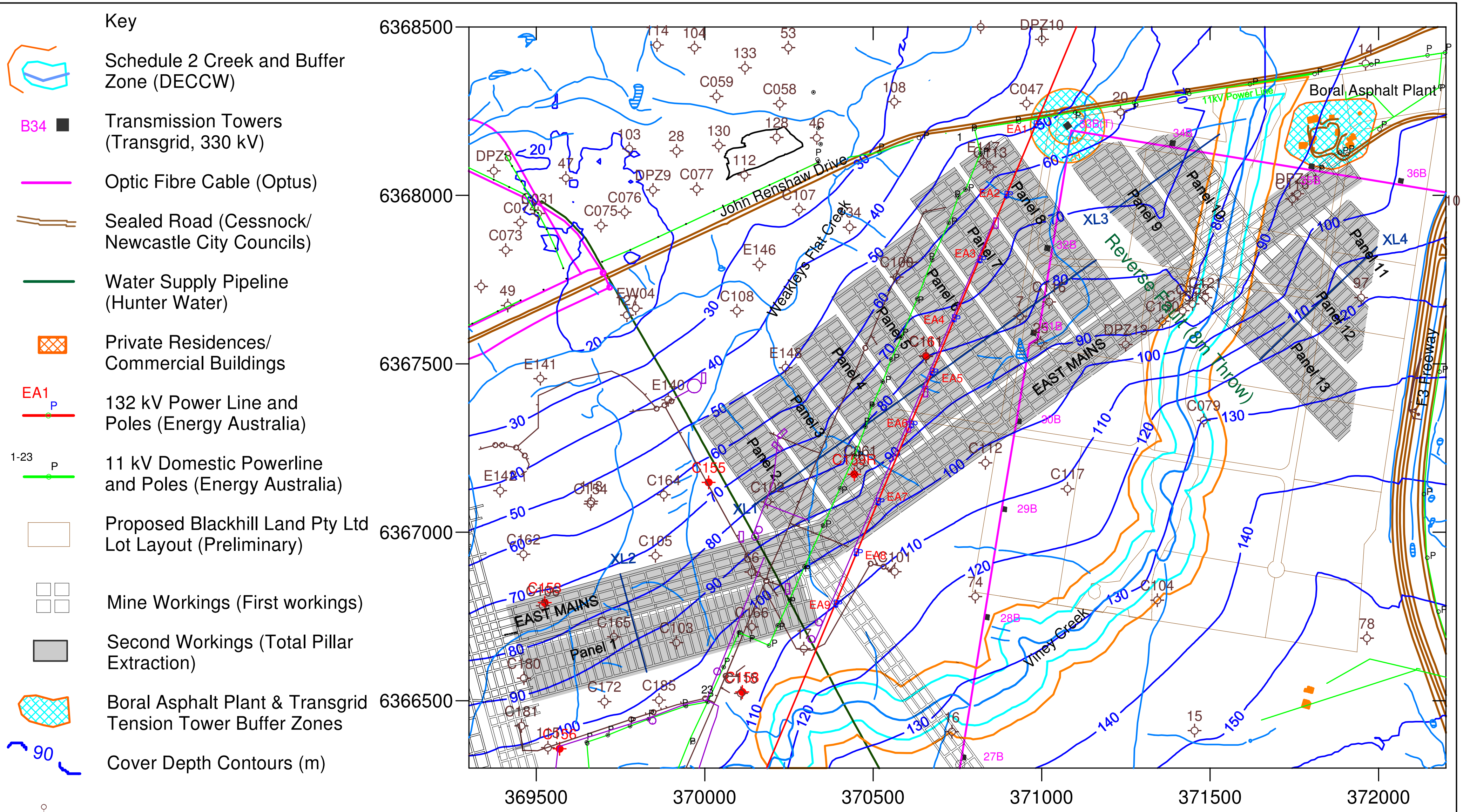
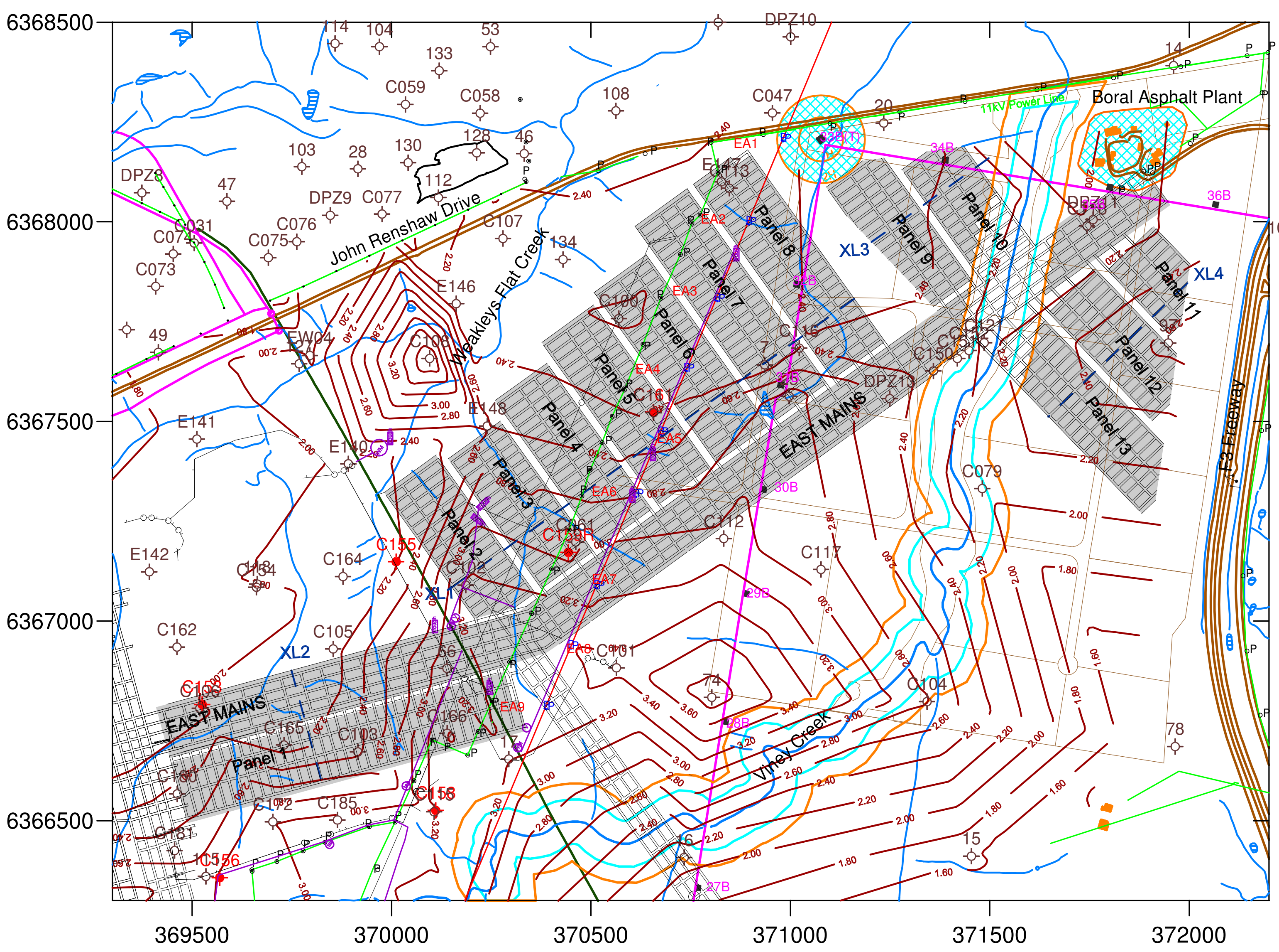


DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn:	S.Ditton		
	Date:	23.11.09	Title:	Cover Depth Contours above the Proposed Abel SMP Mine Layout
Ditton Geotechnical Services Pty Ltd			Scale:	1:20,000
			Figure No:	1

Key

- Schedule 2 Creek and Buffer Zone (DECCW)
- B34 — Transmission Towers (Transgrid, 330 kV)
- Optic Fibre Cable (Optus)
- Sealed Road (Cessnock/ Newcastle City Councils)
- Water Supply Pipeline (Hunter Water)
- Private Residences/ Commercial Buildings
- EA1 P — 132 kV Power Line and Poles (Energy Australia)
- P — 11 kV Domestic Powerline and Poles (Energy Australia)
- Proposed Blackhill Land Pty Ltd Lot Layout (Preliminary)
- Mine Workings (First workings)
- Second Workings (Total Pillar Extraction)
- Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones
- 3.20 — Seam Thickness Isopachs (m)
- Telstra Copper Cabling (buried)
- Schedule 1 creeks/ gullies
- 47, C155 — Borehole Locations
- Stock Watering System



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn:	S.Ditton		
	Date:	23.11.09	Title:	Seam Thickness Isopachs in the Proposed Abel SMP Mine Layout
Ditton Geotechnical Services Pty Ltd			Scale:	1:20,000 — Figure No: 2

Key

Schedule 2 Creek and Buffer Zone (DECCW)

B34 Transmission Towers (Transgrid, 330 kV)

Optic Fibre Cable (Optus)

Sealed Road (Cessnock/ Newcastle City Councils)

Water Supply Pipeline (Hunter Water)

Private Residences/ Commercial Buildings

EA1 P 132 kV Power Line and Poles (Energy Australia)

P 11 kV Domestic Powerline and Poles (Energy Australia)

Proposed Blackhill Land Pty Ltd Lot Layout (Preliminary)

Mine Workings (First workings)

Second Workings (Total Pillar Extraction)

Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones

25 Surface Level Contours (m)

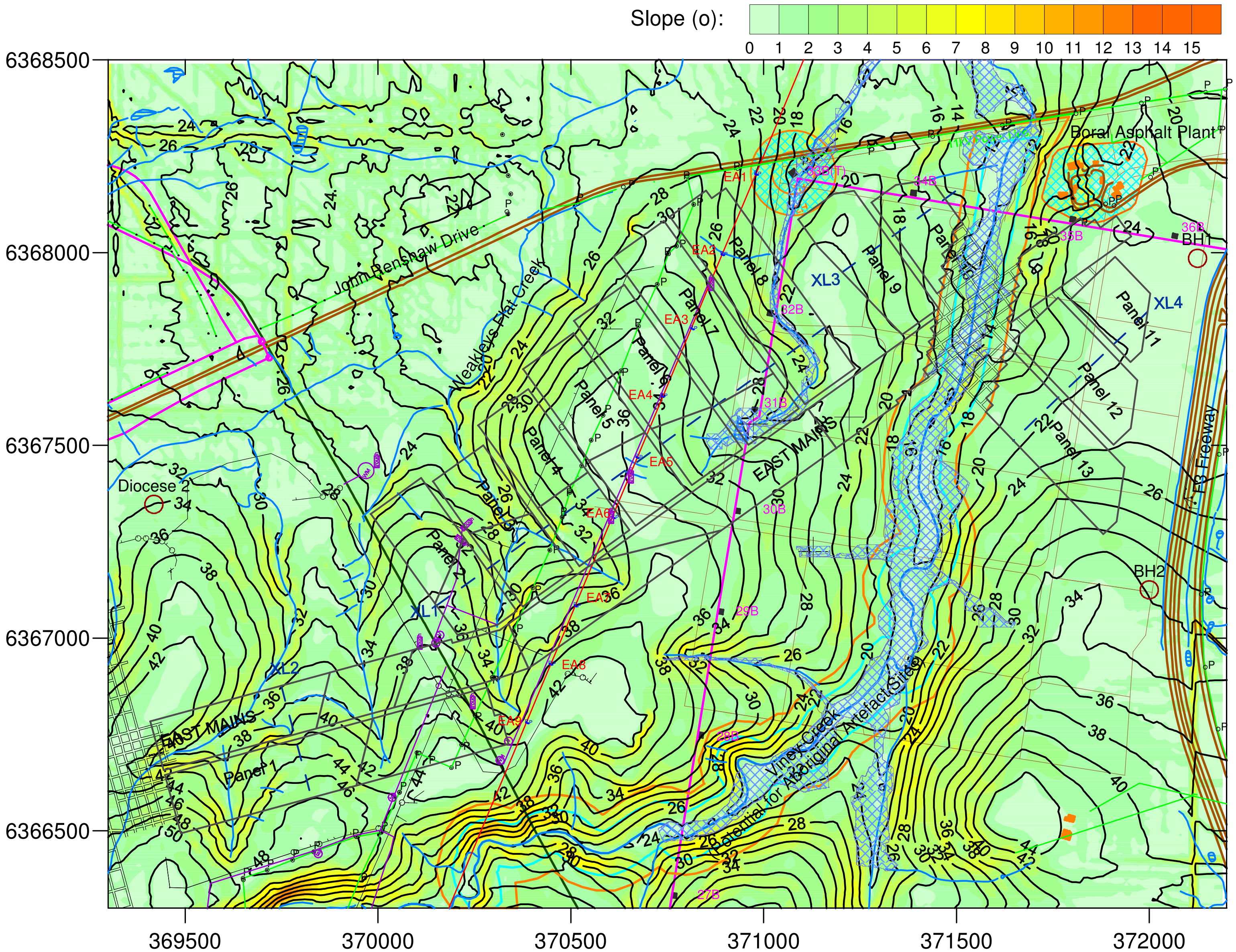
Telstra Copper Cabling (buried)

Schedule 1 creeks/ gullies

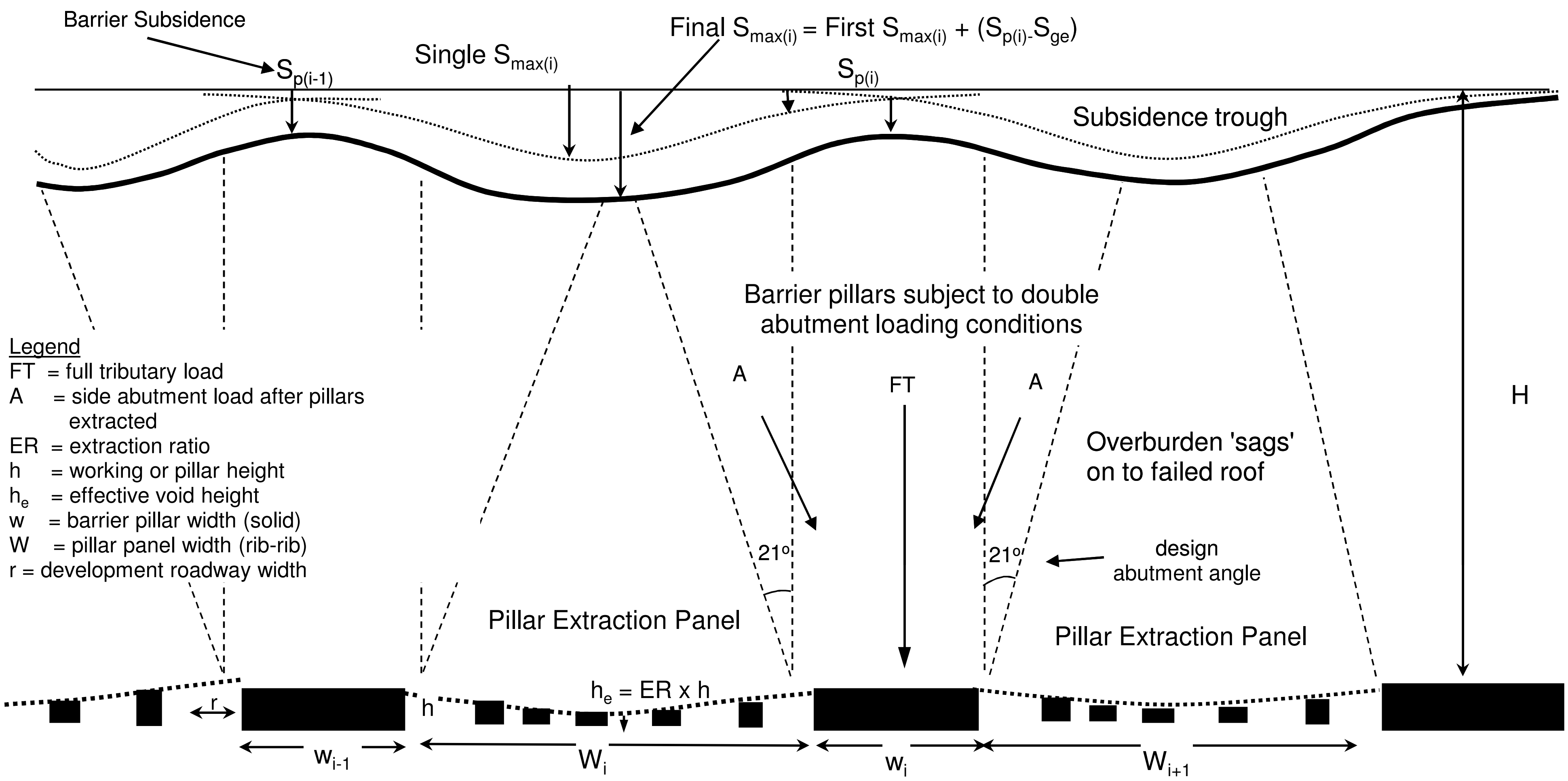
BH1 Aboriginal Artefact Scatters

Stock Watering System

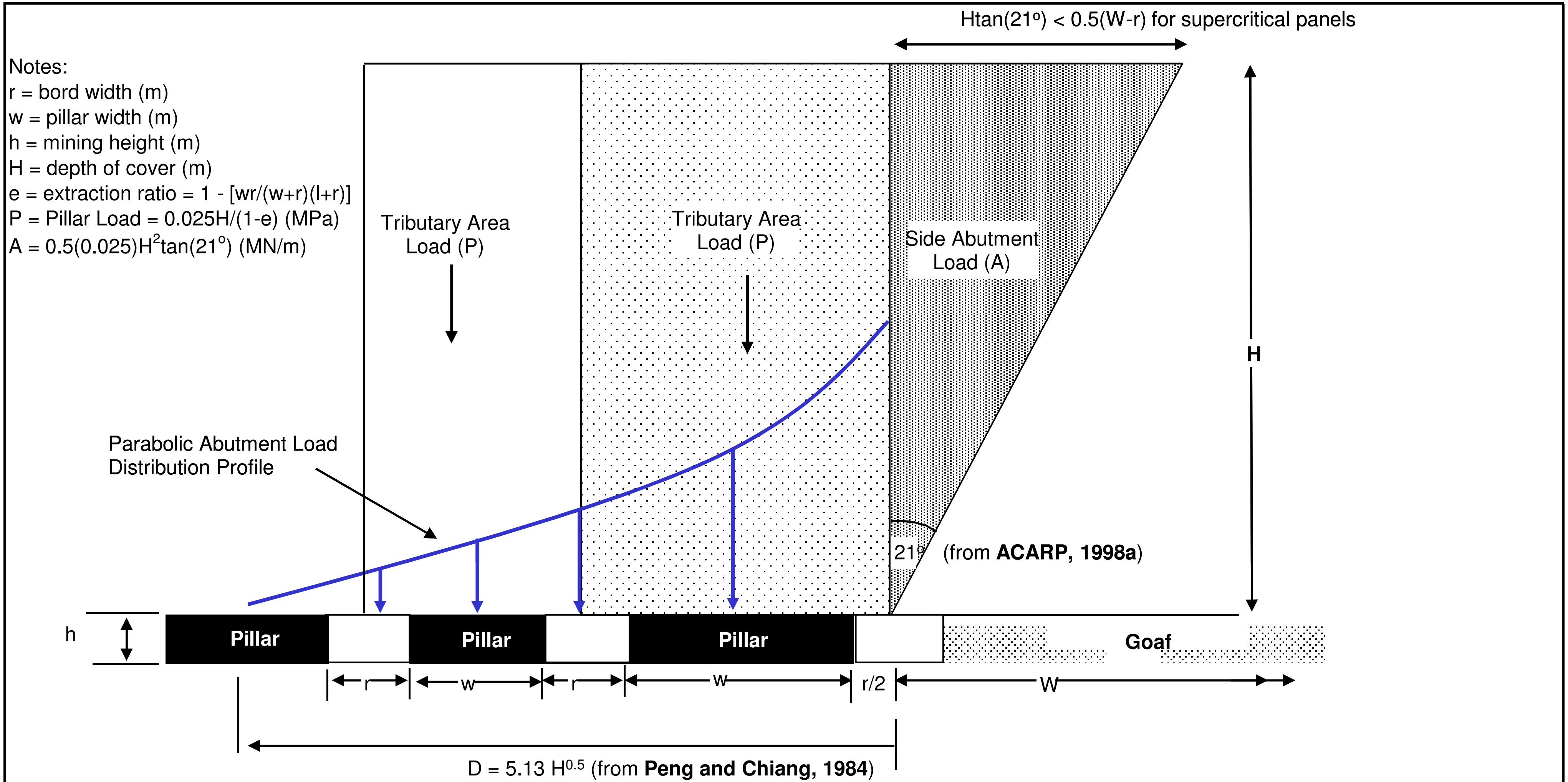
1 in 100 Year ARI Flood Levels



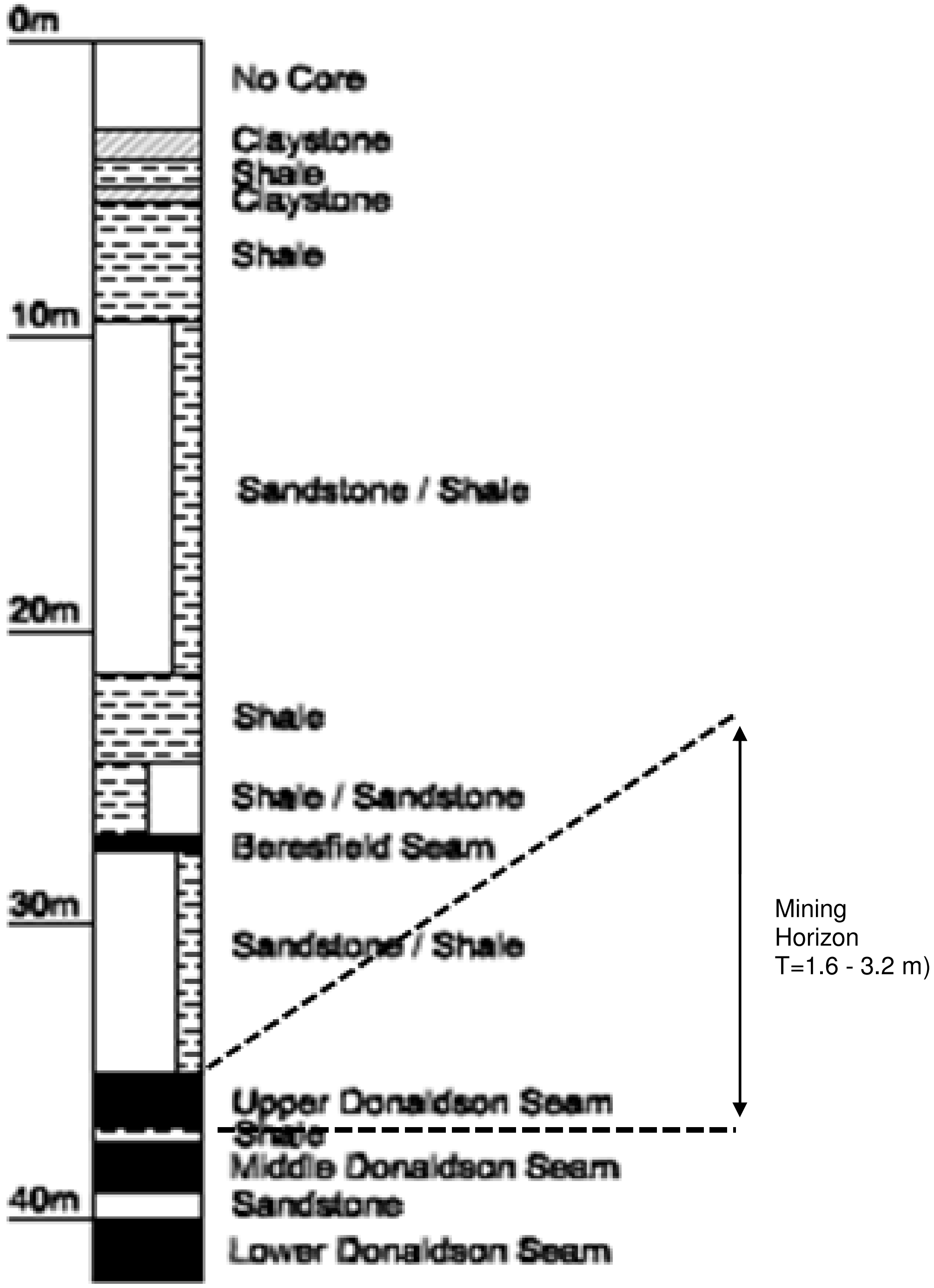
DgS Ditton Geotechnical Services Pty Ltd	Engineer: S.Ditton Drawn: S.Ditton Date: 23.11.09	Client:	Donaldson Coal Pty Limited ABL-001/1
		Title:	Pre-Mining Topography Isopachs (2 m contours) and Slopes above the Proposed Abel SMP Mine Layout
		Scale:	1:20,000 — Figure No: 3



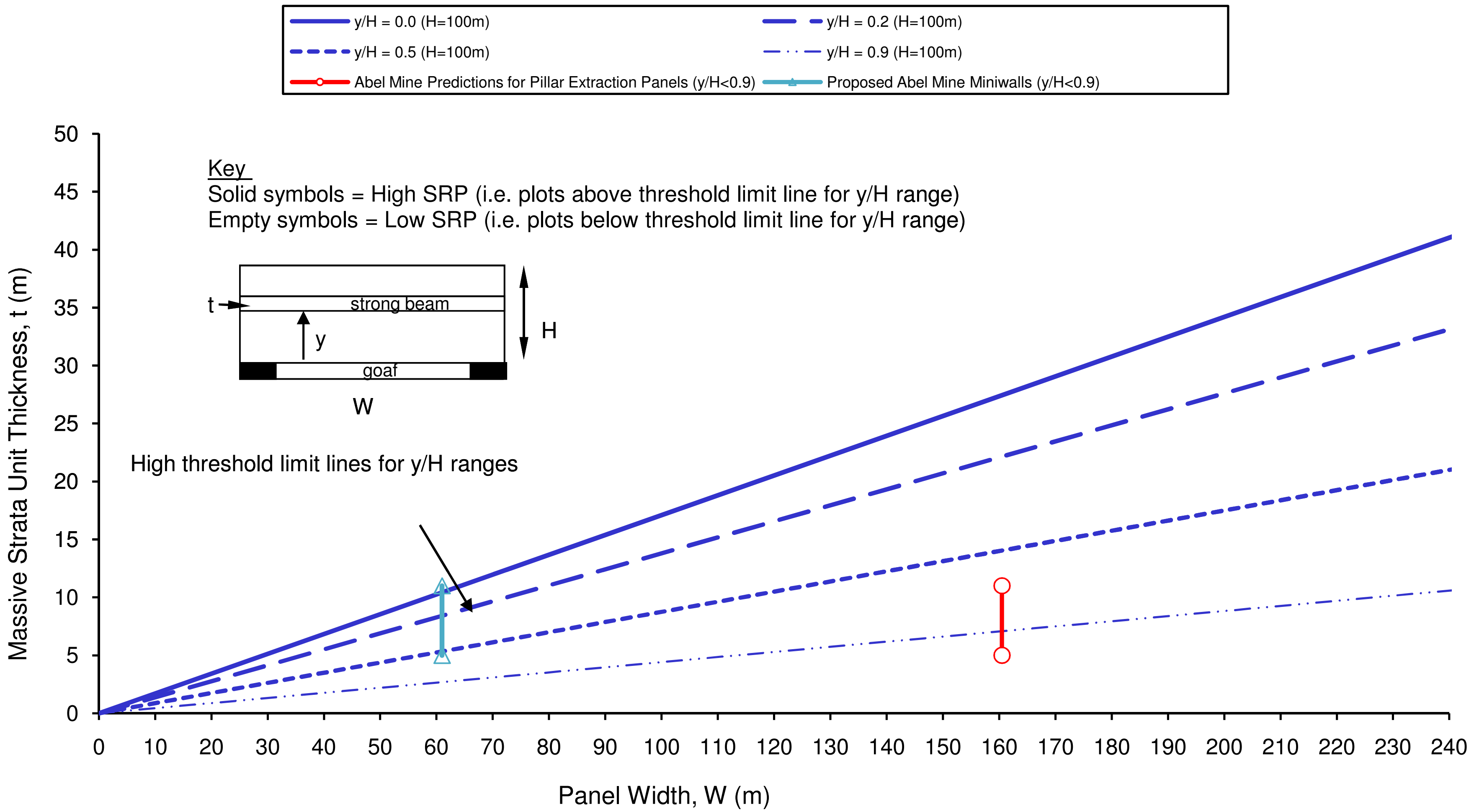
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited
	Drawn:	S.Ditton		ABL-001/1
	Date:	08.09.09	Title:	Conceptual Model of Multiple Pillar Extraction Panels and Barrier Pillar System Interaction at the Proposed Abel Mine
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	4a



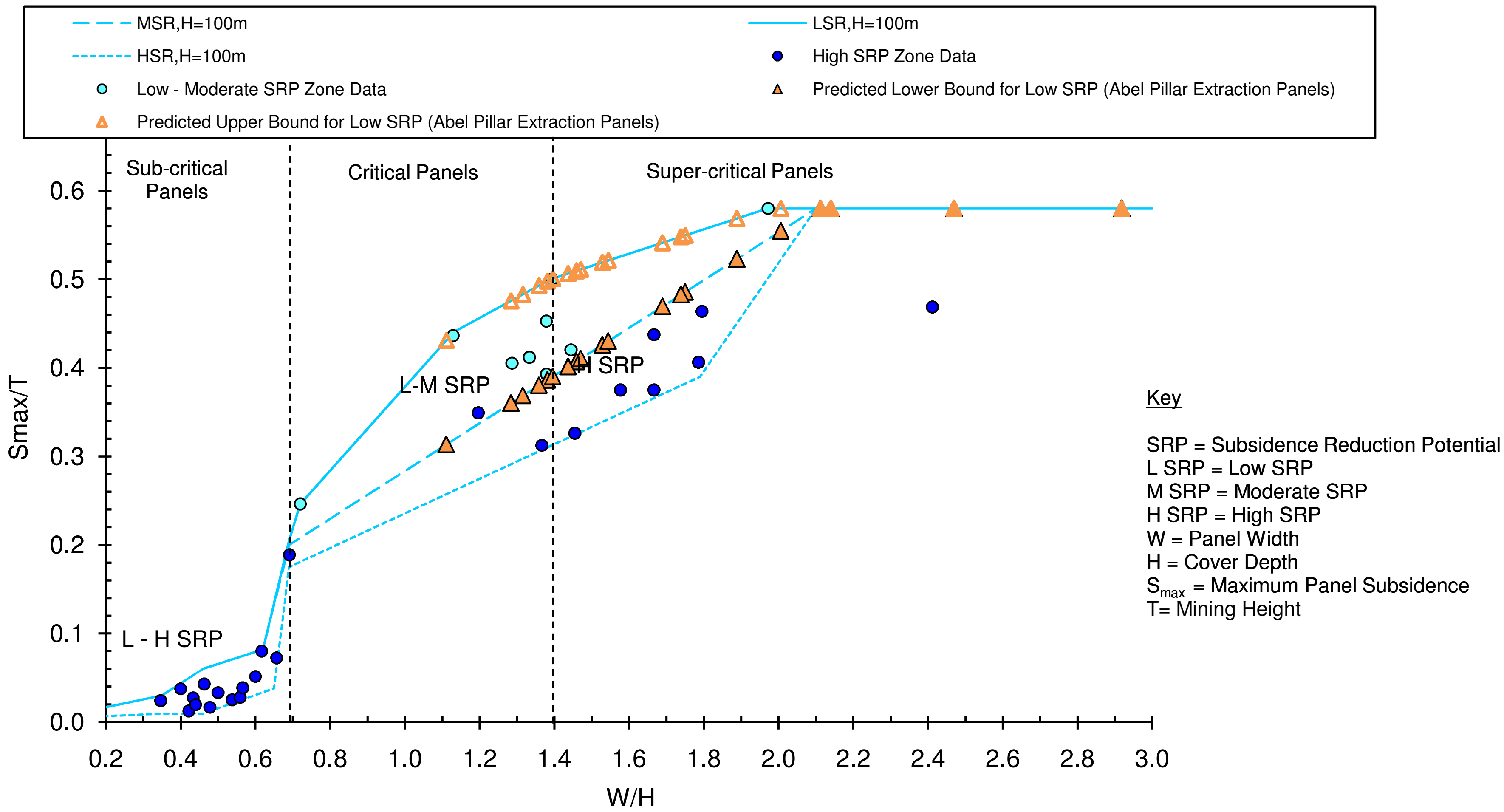
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited
	Drawn:	S.Ditton		ABL-001/1
	Date:	28.09.08	Title:	Analytical Model for Calculating Abutment Load Acting on SPZ Pillars after 2nd Workings
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	4b



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn:	S.Ditton		ABL-001/1		
	Date:	08.09.09	Title:	Typical Overburden Stratigraphy above the Abel Mine's SMP Area		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	5a

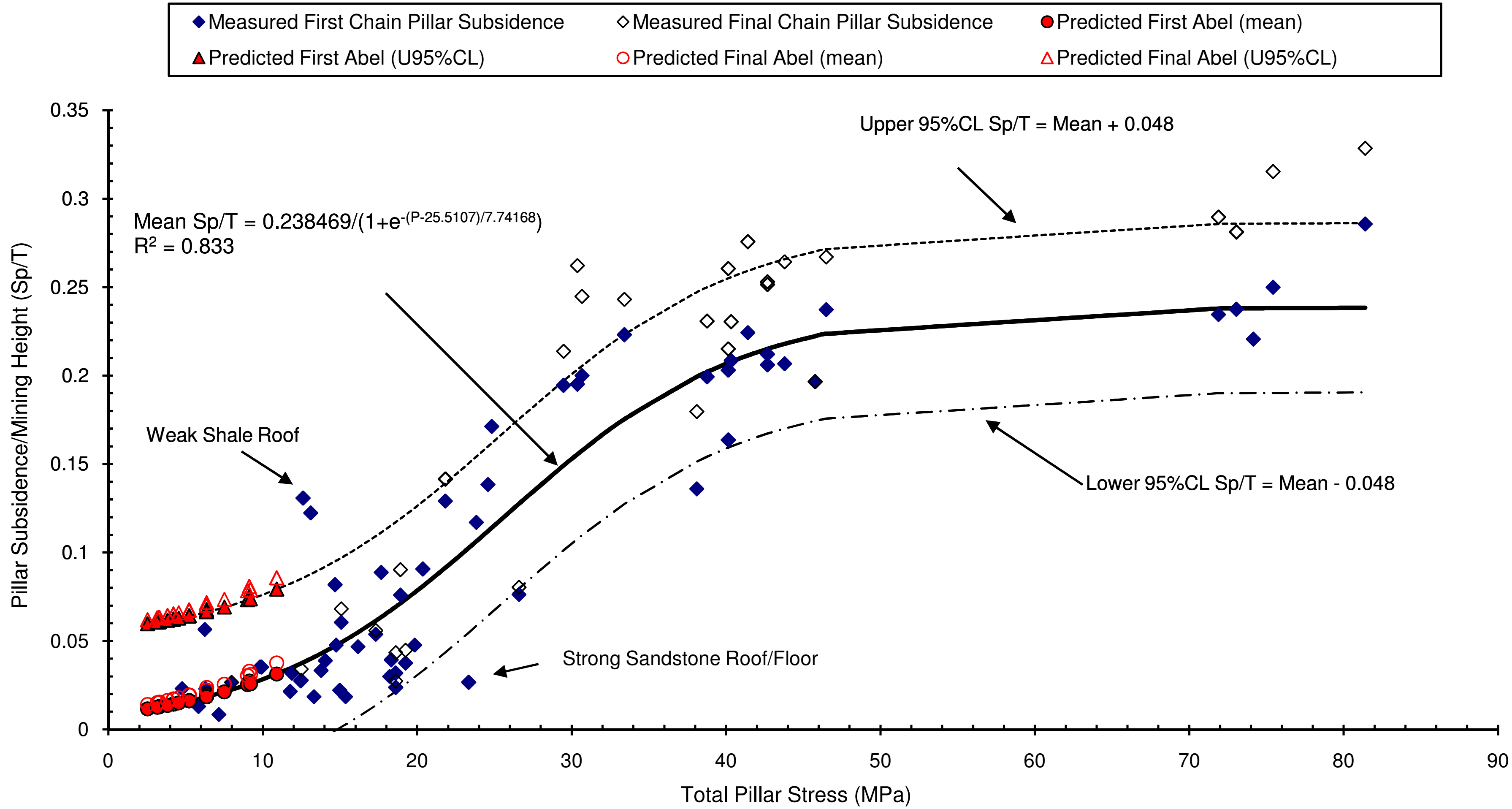


DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	30.04.09	Title:	Predicted Subsidence Reduction Potential of Sandstone Units Above Proposed Abel SMP Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	5b

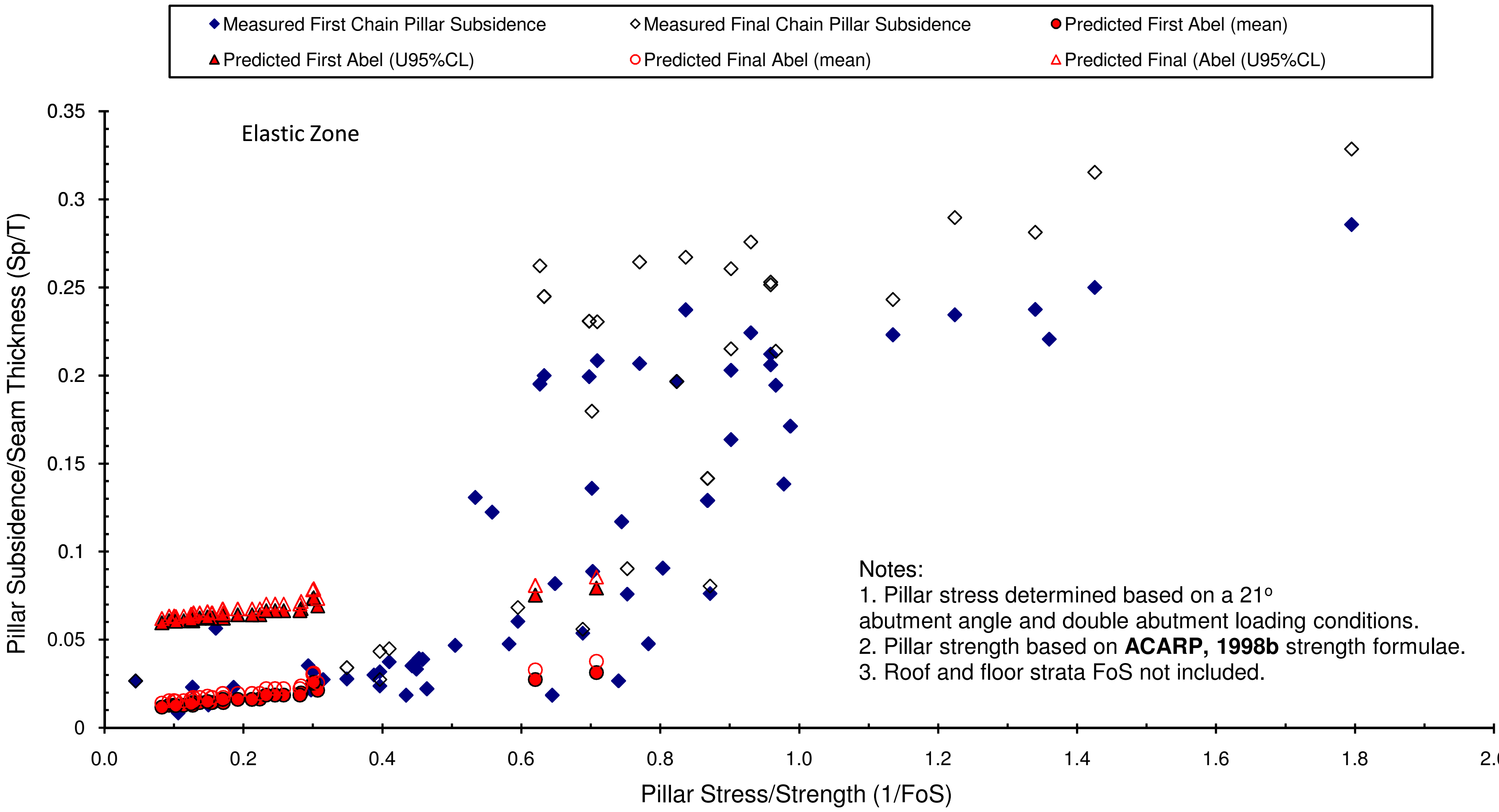


Note: No SRP distinguishment for panels with W/H<0.65

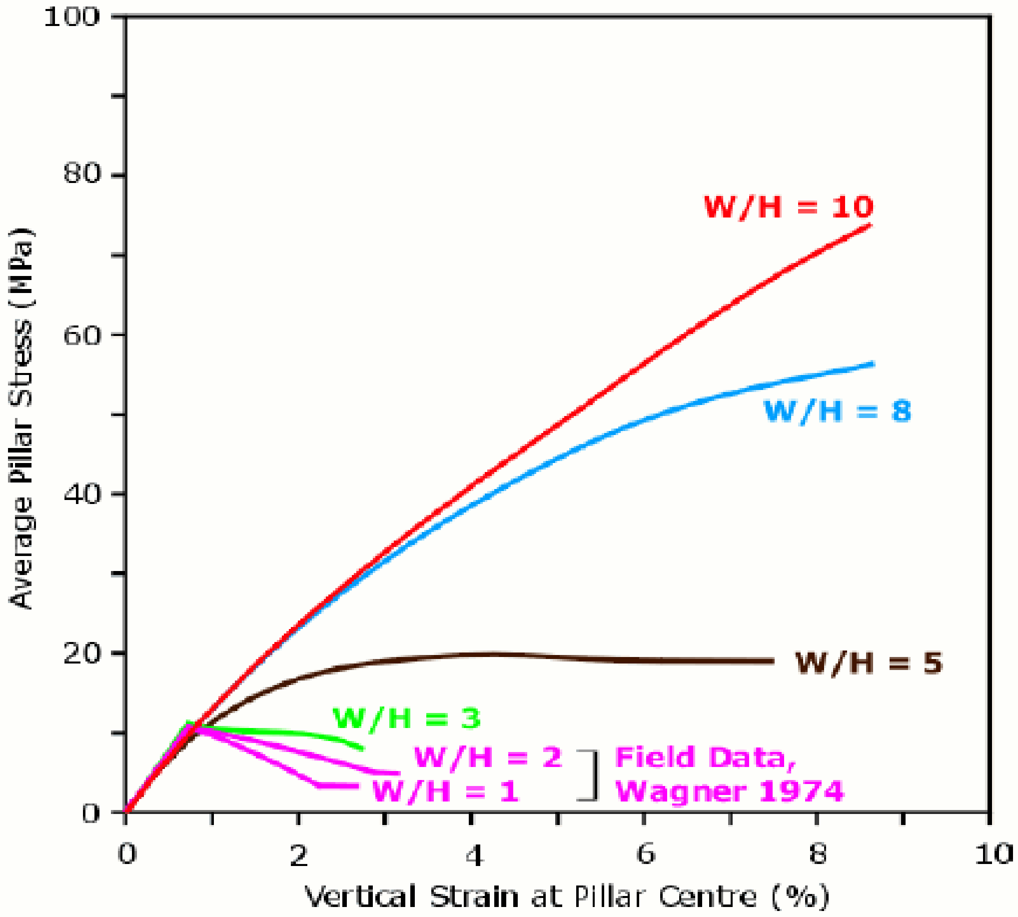
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal - Abel Mine
	Drawn:	S.Ditton		ABL-001/1
	Date:	08.09.09	Title:	Empirical Model for Predicting Subsidence Above Pillar Extraction Panels with Cover Depths Between 50 and 150 m and Low to High SRP Zones
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	6



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn:	S.Ditton		ABL-001/1		
	Date:	08.08.09	Title:	Barrier Pillar Subsidence Prediction Model based on the ACARP, 2003 and the Predicted Outcomes for the Proposed Abel SMP Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	7a

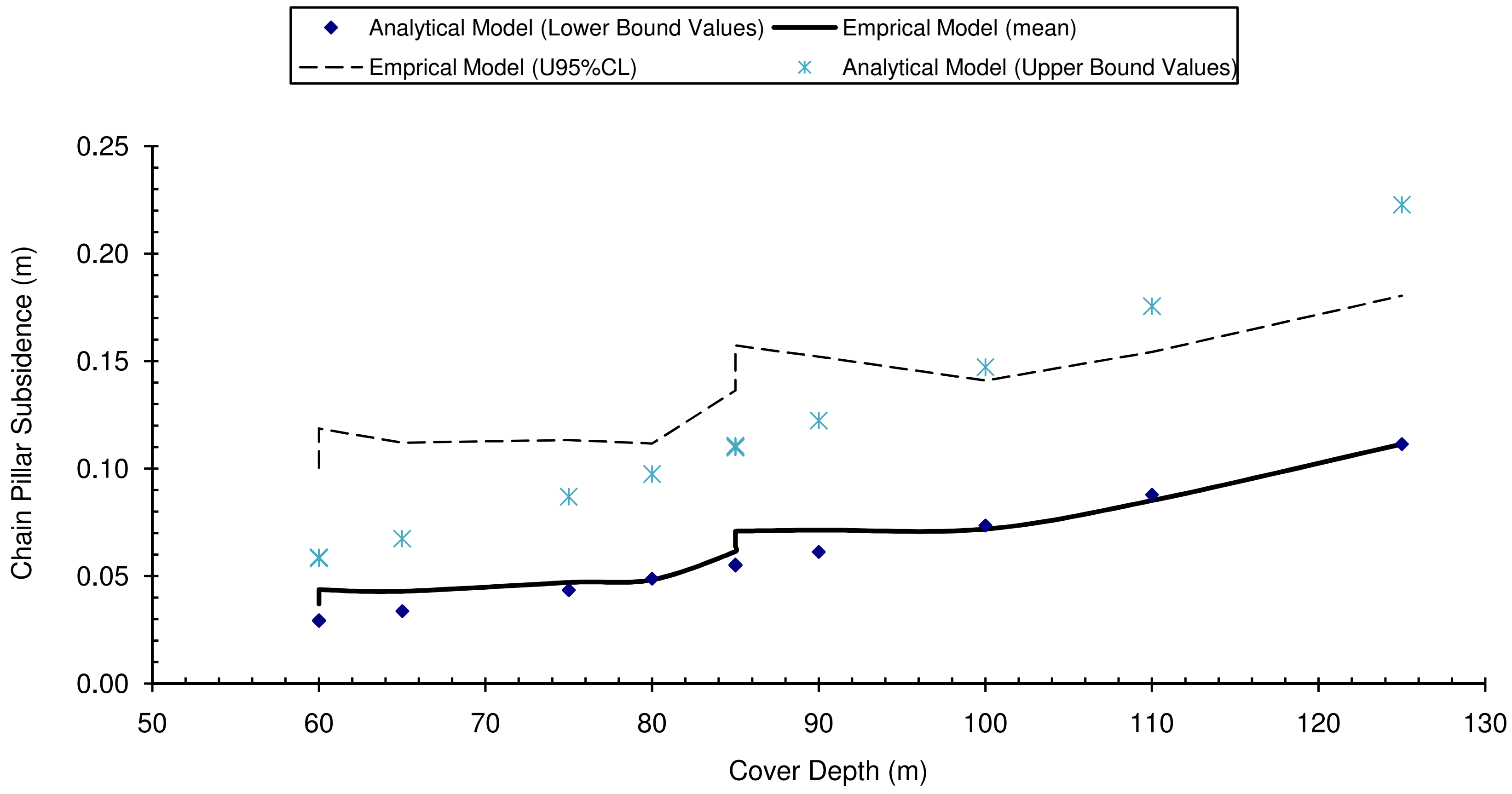


DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1	
	Drawn:	S.Ditton			
	Date:	08.05.09	Title:	Barrier Pillar Subsidence/Seam Thickness v. Pillar Stress over Strength Model (derived from the Modified ACARP, 2003) Outcomes for Abel SMP Mine Layout	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 7b

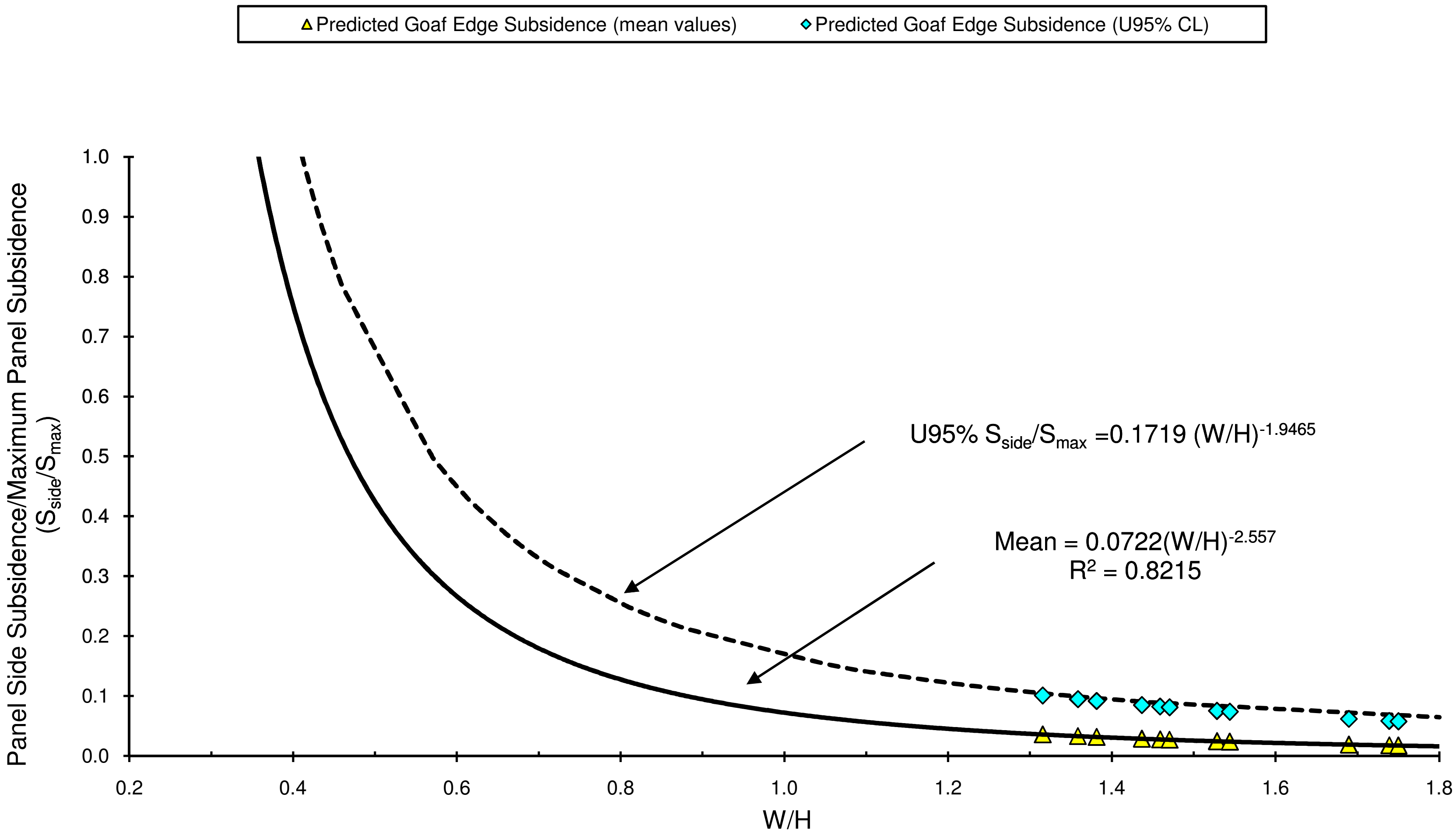


Source: **ACARP, 2005** (refer to text)

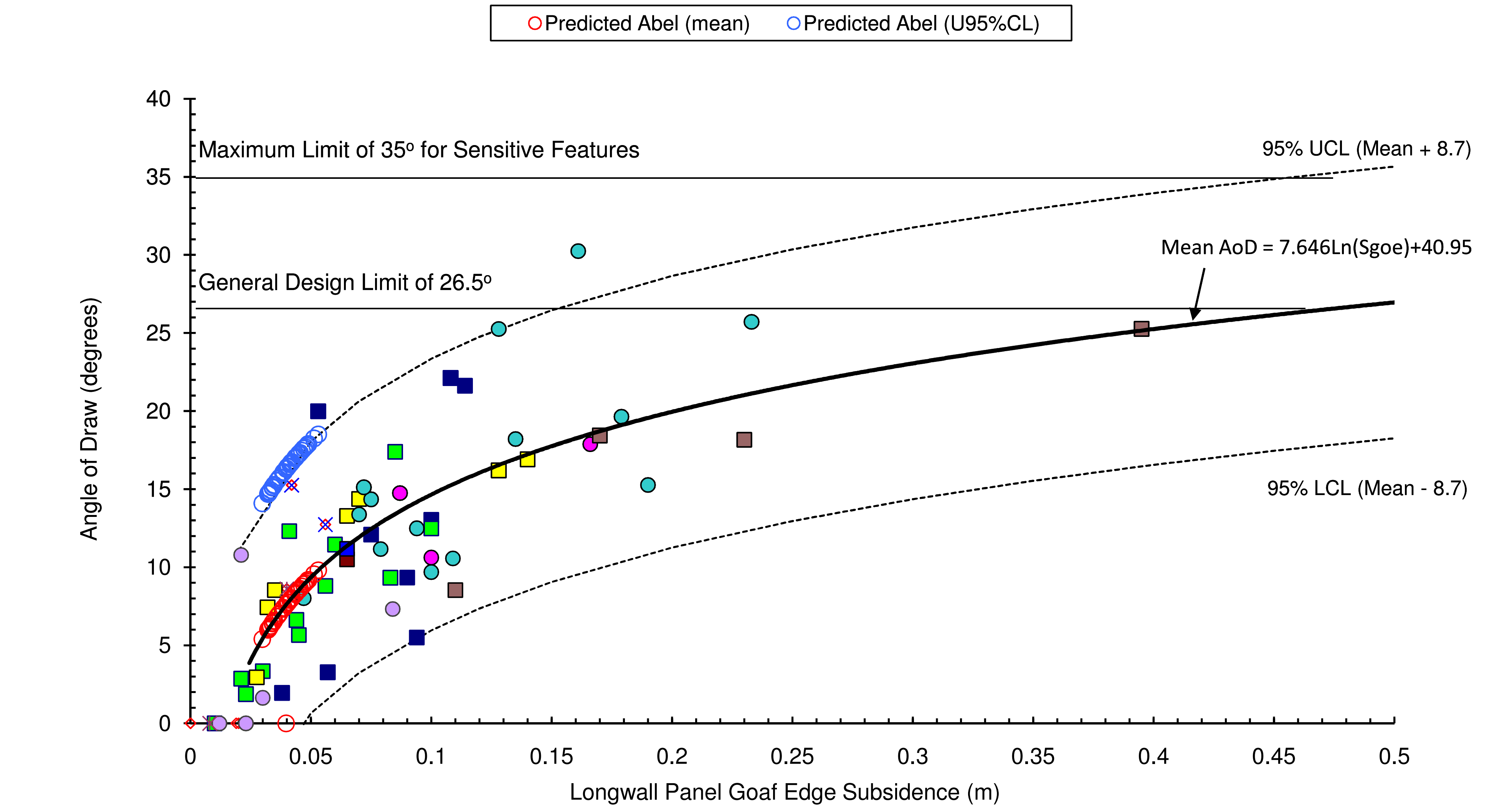
DgS	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited	
	Drawn: S.Ditton		ABL-001/1	
	Date: 21.09.09	Title:	In-situ Pillar Stress v. Strain Response for a Range of Pillar Width/Height Ratios	
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No: 7c



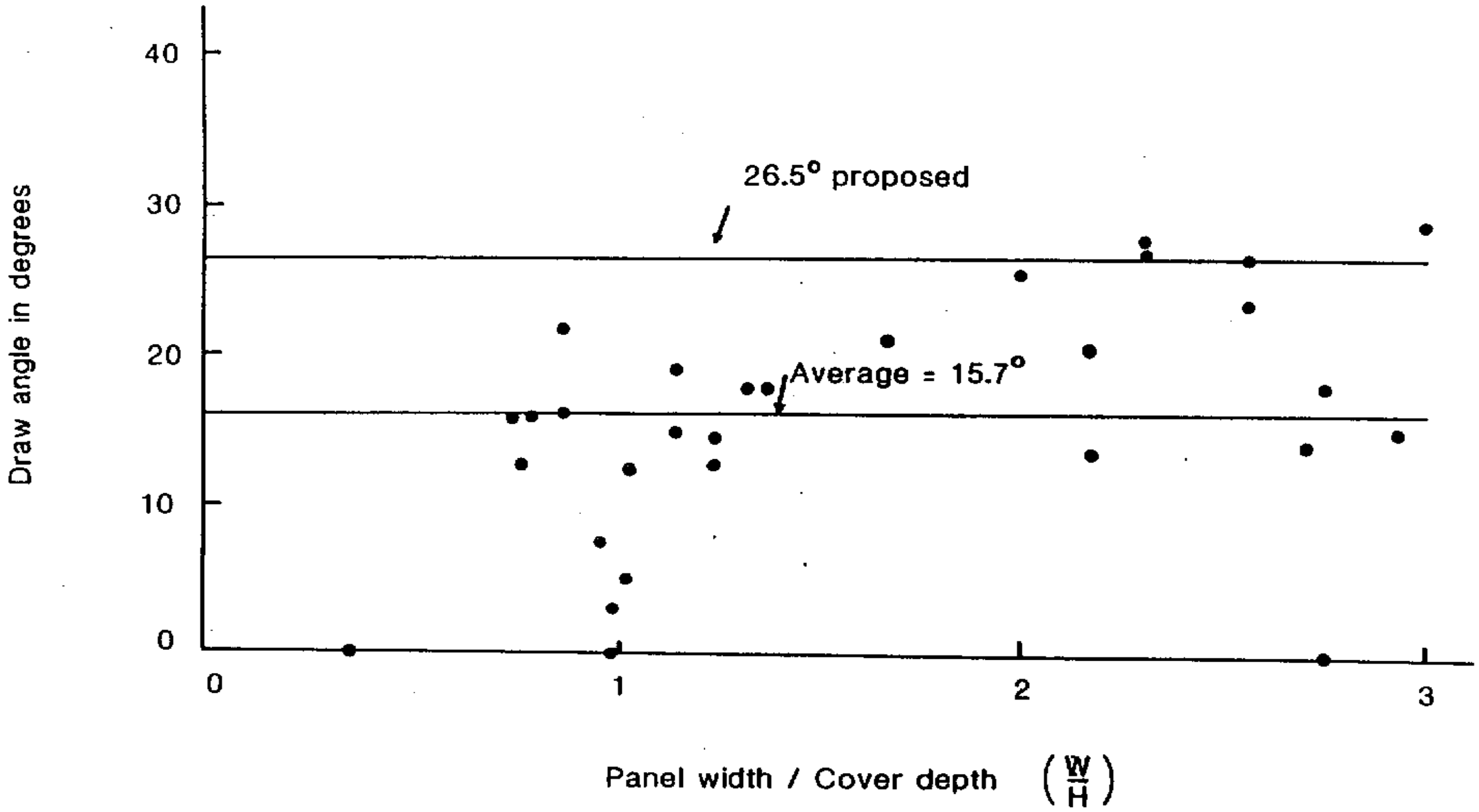
DgS	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn: S.Ditton				
	Date: 10.03.09	Title:	Empirical v. Analytical Barrier Pillar Subsidence Prediction Model Outcomes for Pillar Extraction Panels 1 to 14		
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No:	7d



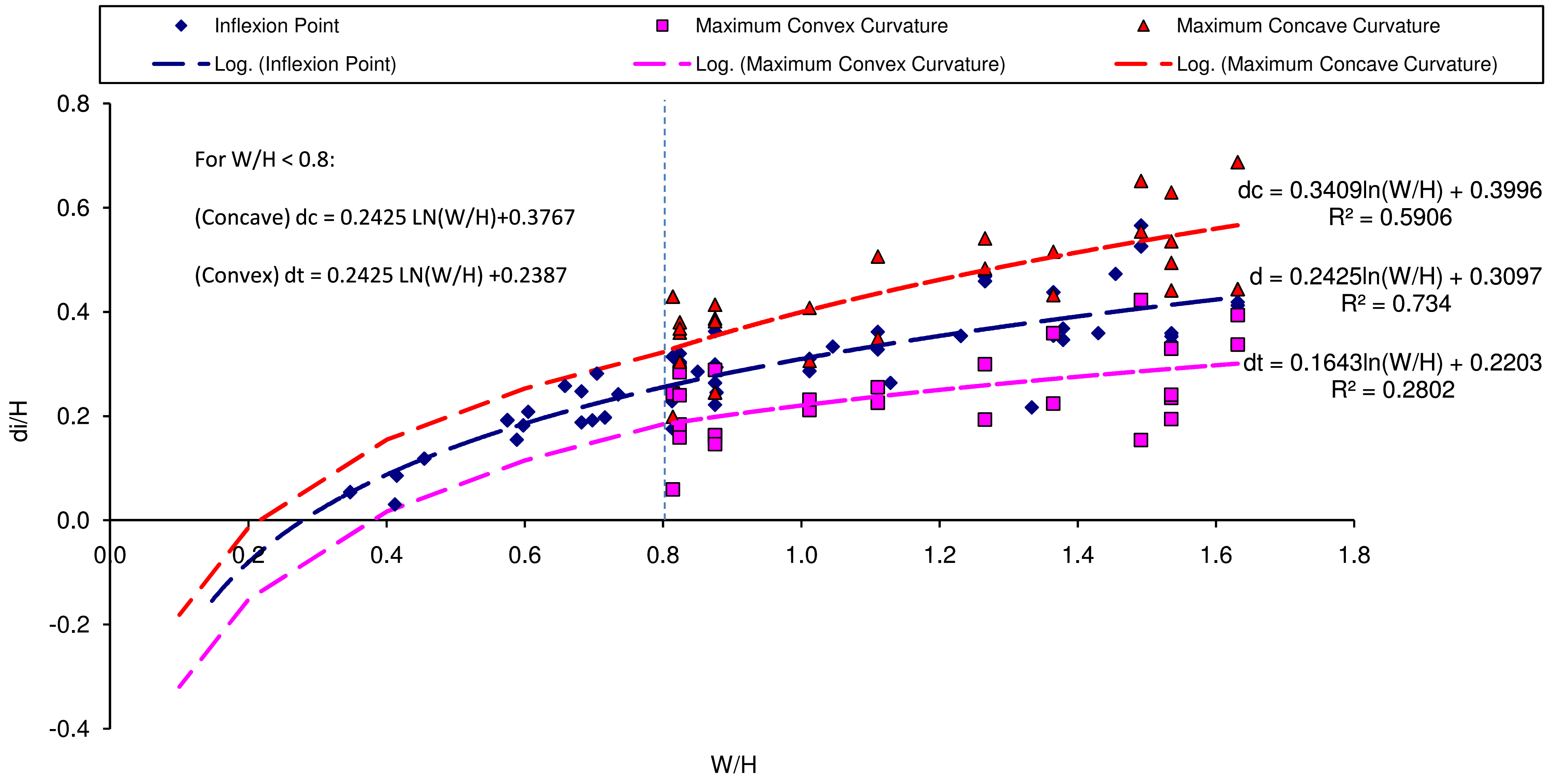
DgS	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn: S.Ditton		ABL-001/1		
	Date: 08.09.09	Title:	Empirical Model for Goaf Edge Subsidence Prediction Above Longwall Panels in the Newcastle Coalfield with Predicted Outcomes for the Proposed Abel SMP Mine Layout		
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No:	8



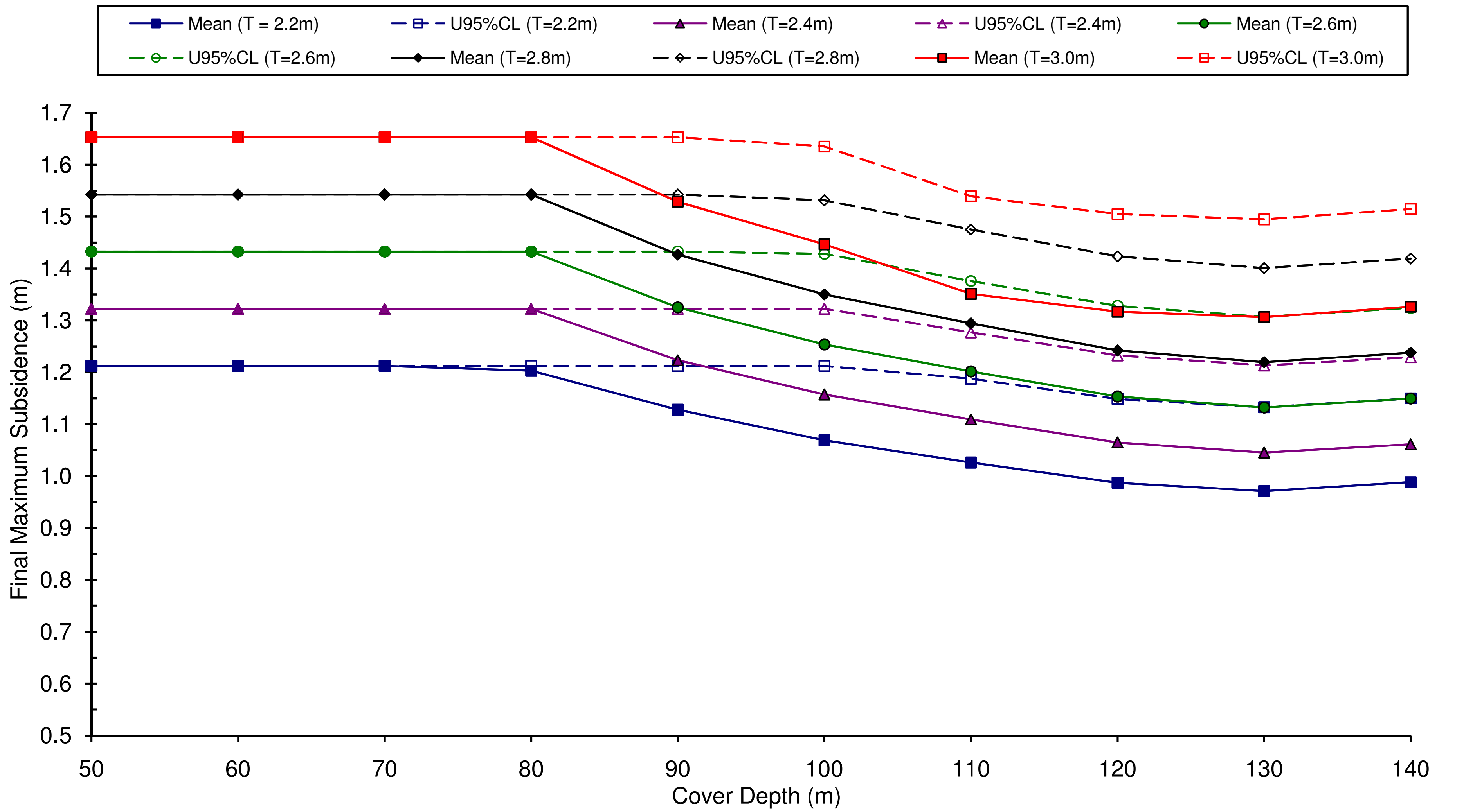
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn:	S.Ditton		ABL-001/1		
	Date:	08.09.09	Title:	Empirical Model for Predicting the Angle of Draw from Longwall Panel Limits in the Newcastle Coalfield (ACARP, 2003) and Proposed Abel SMP Mine Outcomes		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	9a



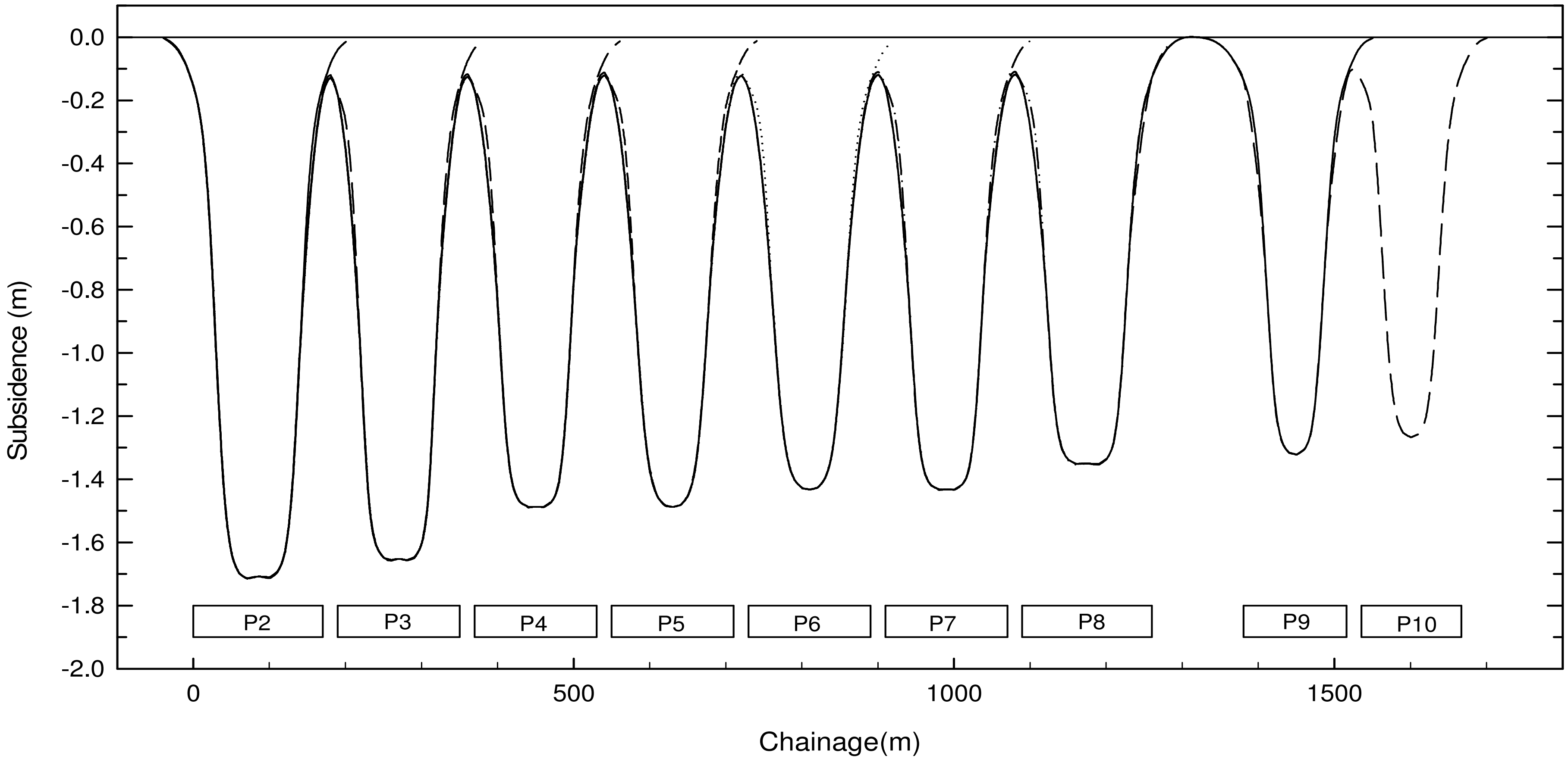
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn:	S.Ditton		ABL-001/1		
	Date:	16.03.09	Title:	Empirical Model for Predicting the Angle of Draw from High Pillar Extraction Panel Limits in the Newcastle Coalfield (Holla, 1987)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	9b



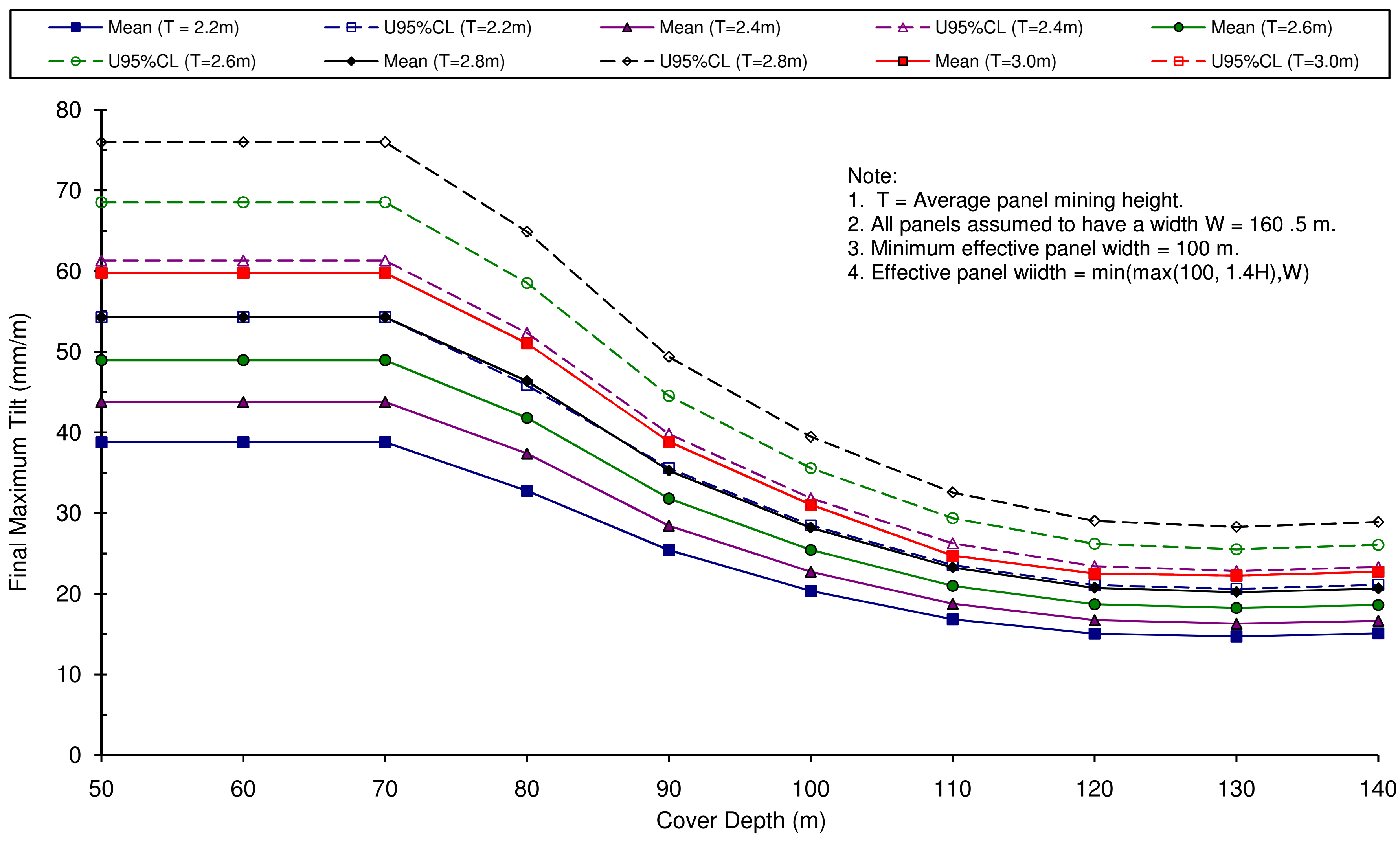
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn:	S.Ditton		
	Date:	08.05.09	Title:	Empirical Model for Predicting the Location of Inflexion Point, Maximum Tensile and Compressive Strain Peaks due to Longwall Panel Subsidence in the Newcastle Coalfield
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	10



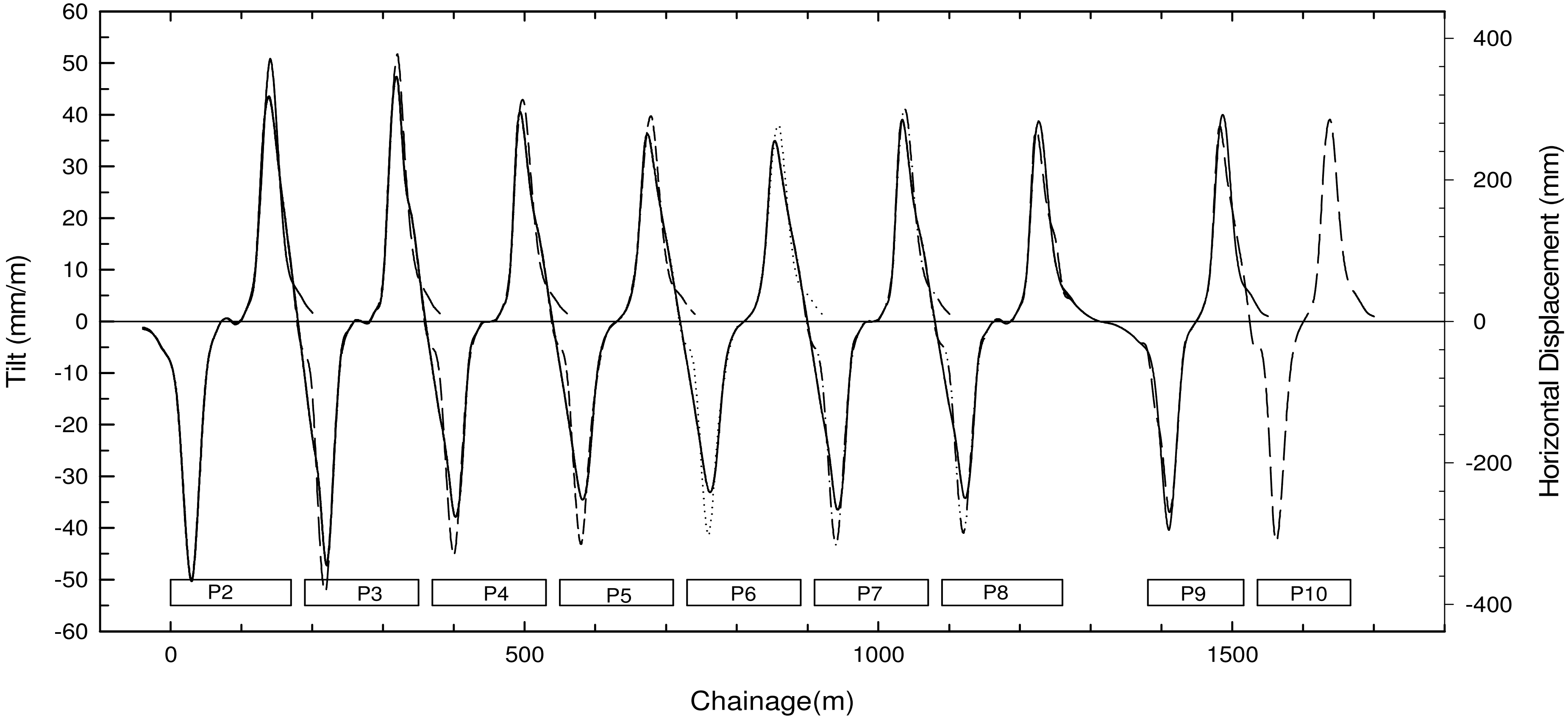
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn:	S.Ditton		
	Date:	31.07.09	Title:	Empirical Model Prediction Curves of Mean and U95%CL Final Smax for the Proposed Abel Mine SMP Full Pillar Extraction Panels
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	11



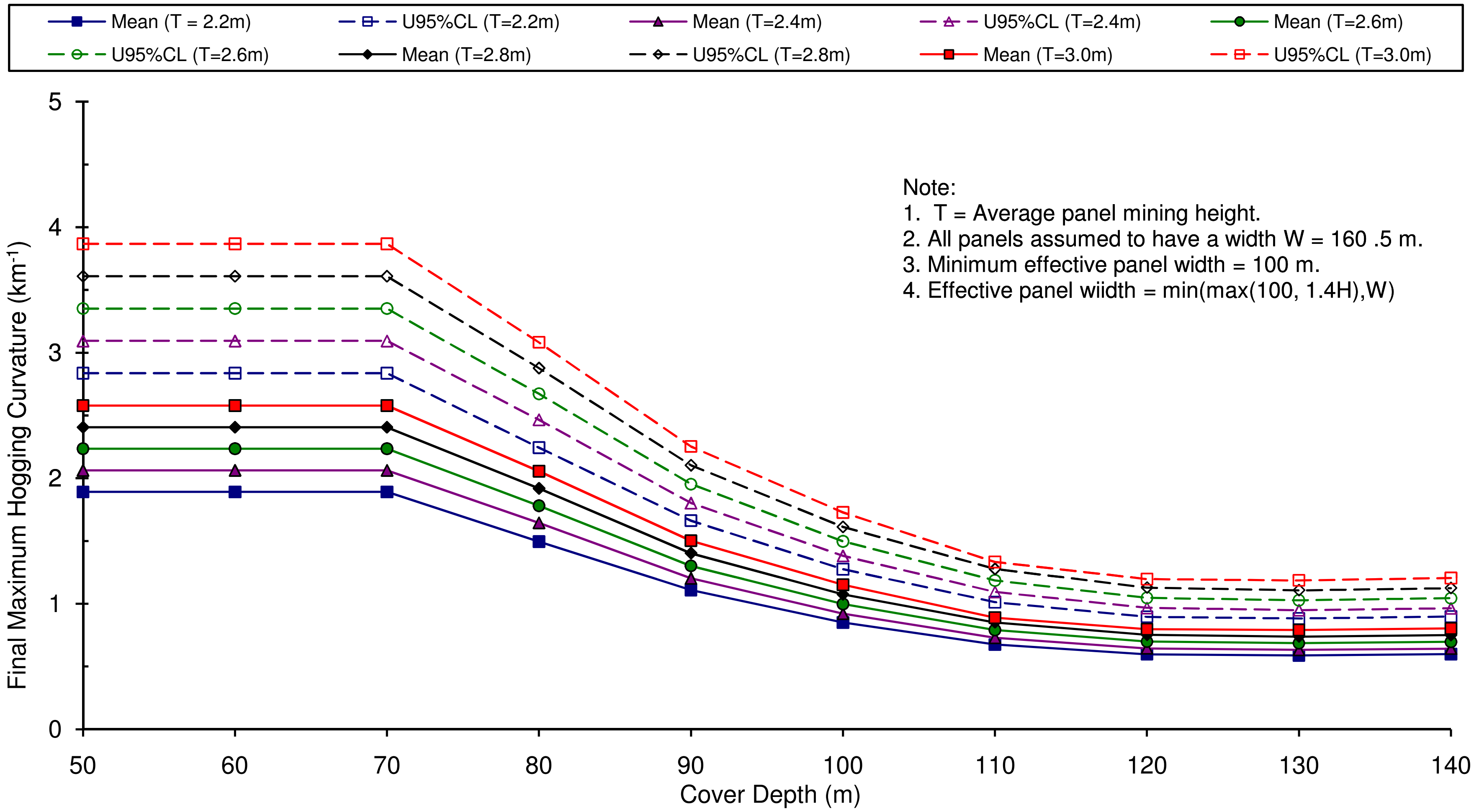
DgS	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited
	Drawn: S.Ditton		ABL-001/1
	Date: 20.11.09	Title:	Predicted U95%CL Subsidence Profiles Along XL 1 and 3 for the Proposed Abel Mine Pillar Extraction Panels - see Figure 1 for Location
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS
		Figure No:	12



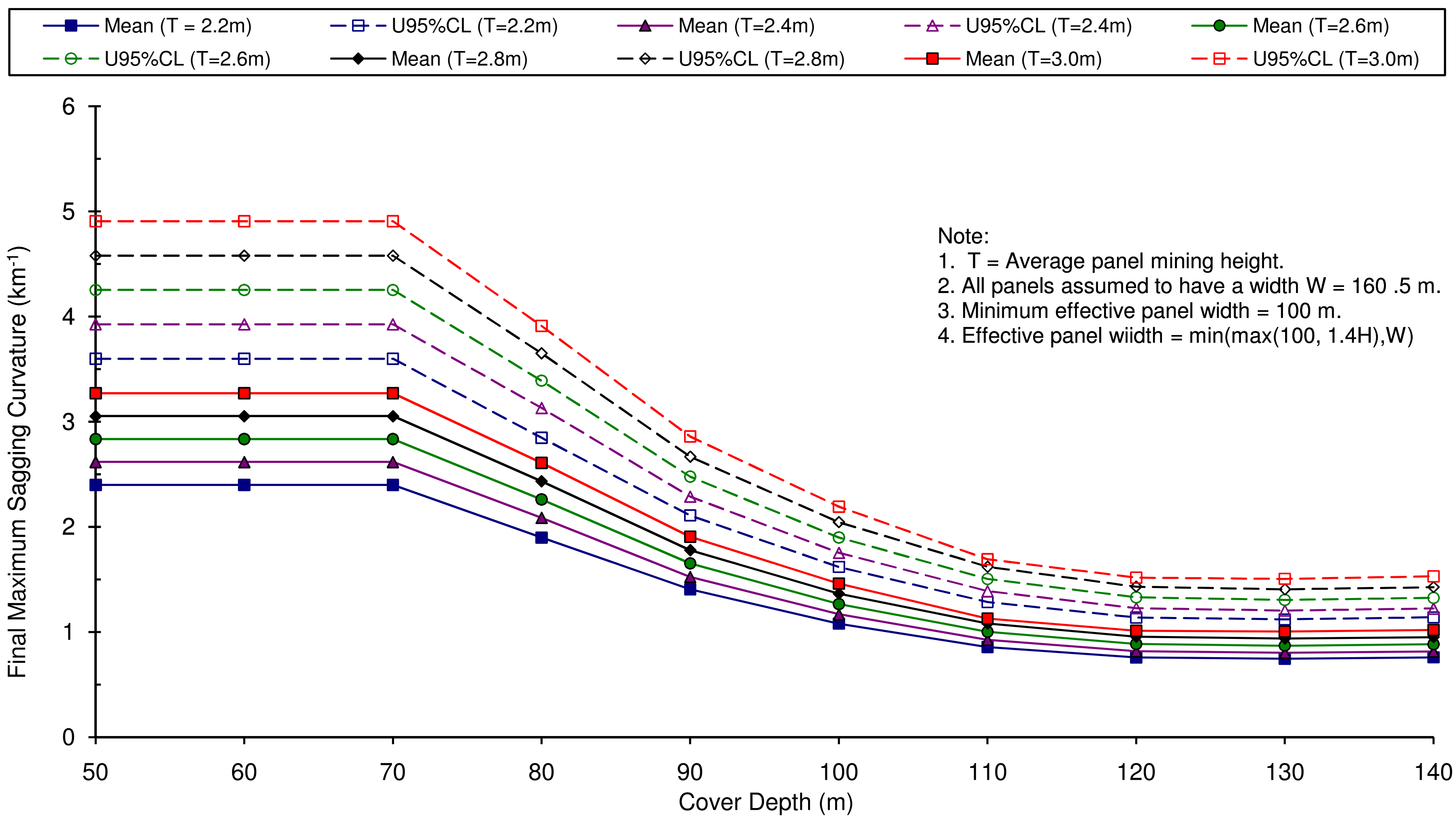
DgS	Engineer: S.Ditton		Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn: S.Ditton			
	Date: 31.07.09		Title:	Empirical Model Prediction Curves of Mean and U95%CL Final Maximum Tilt for the Proposed Abel Mine SMP Pillar Extraction Panels
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 13



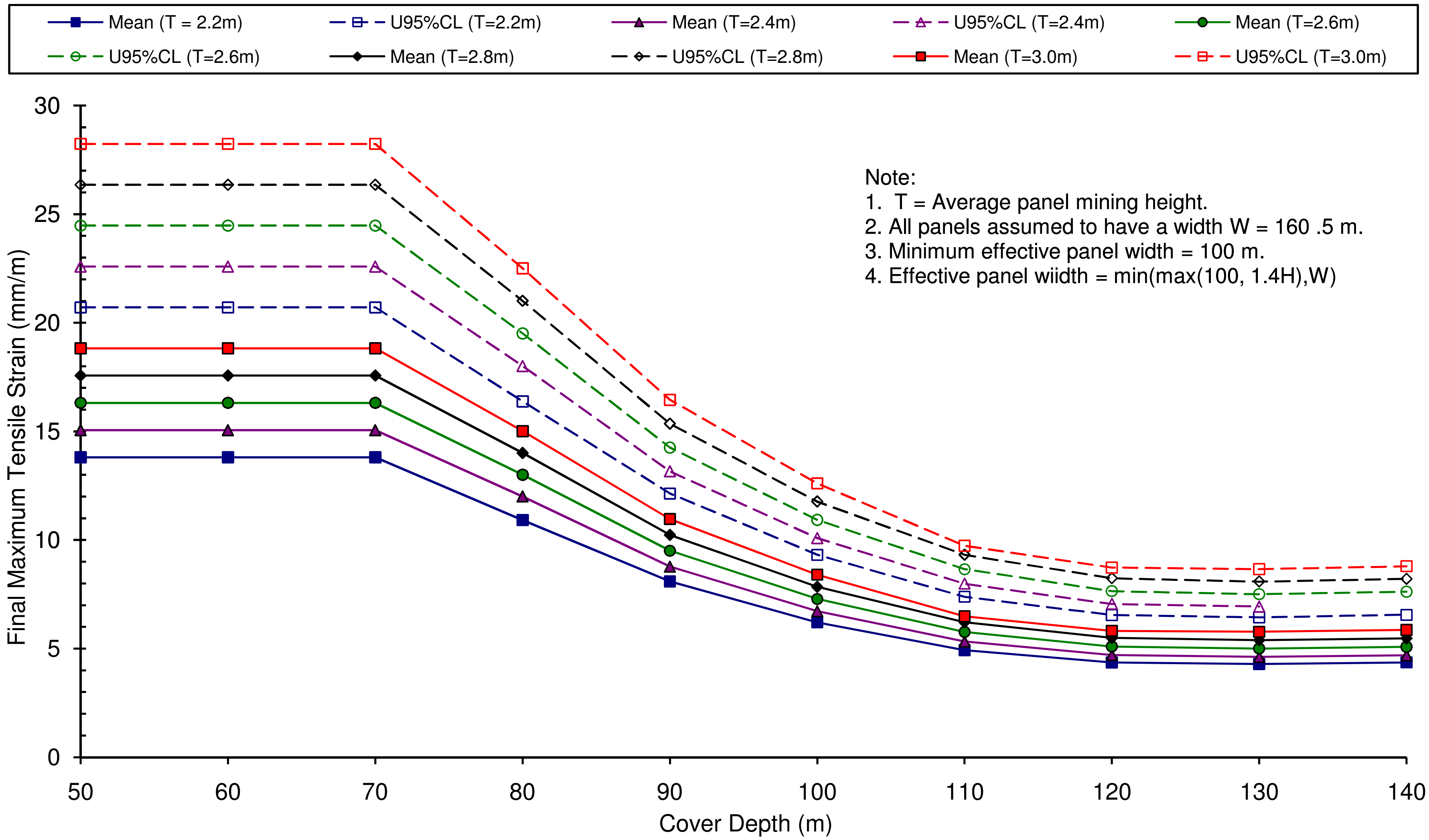
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn:	S.Ditton		ABL-001/1		
	Date:	20.11.09	Title:	Predicted U95%CL Tilt Profiles Along XL 1 and 3 Above the Proposed Abel Mine Pillar Extraction Panels - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	14



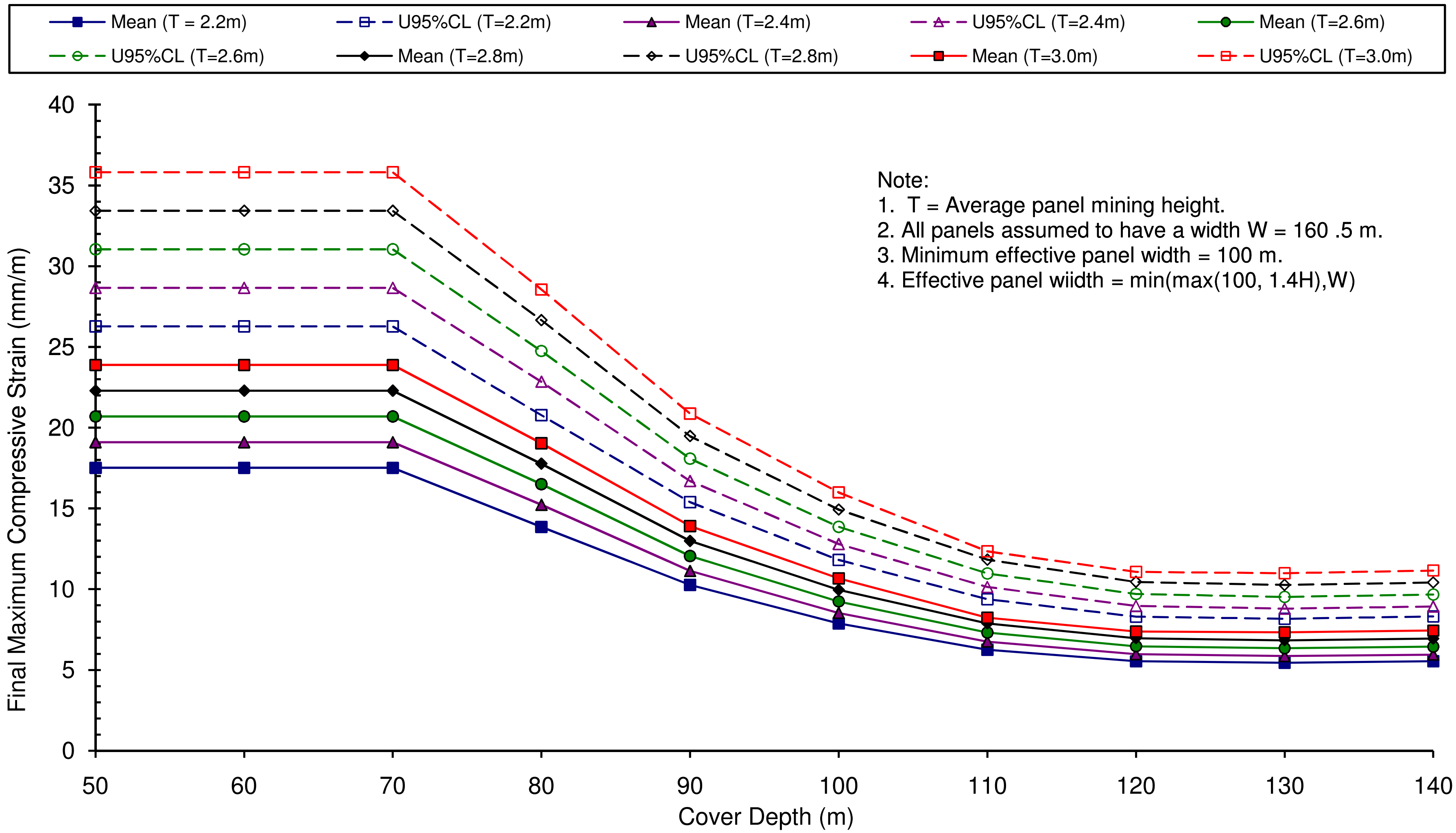
DgS	Engineer: S.Ditton		Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn: S.Ditton			
	Date: 31.07.09		Title:	Empirical Model Prediction Curves of Mean and U95%CL Final Maximum Hogging Curvature for the Proposed Abel Mine SMP Pillar Extraction Panels
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	15a



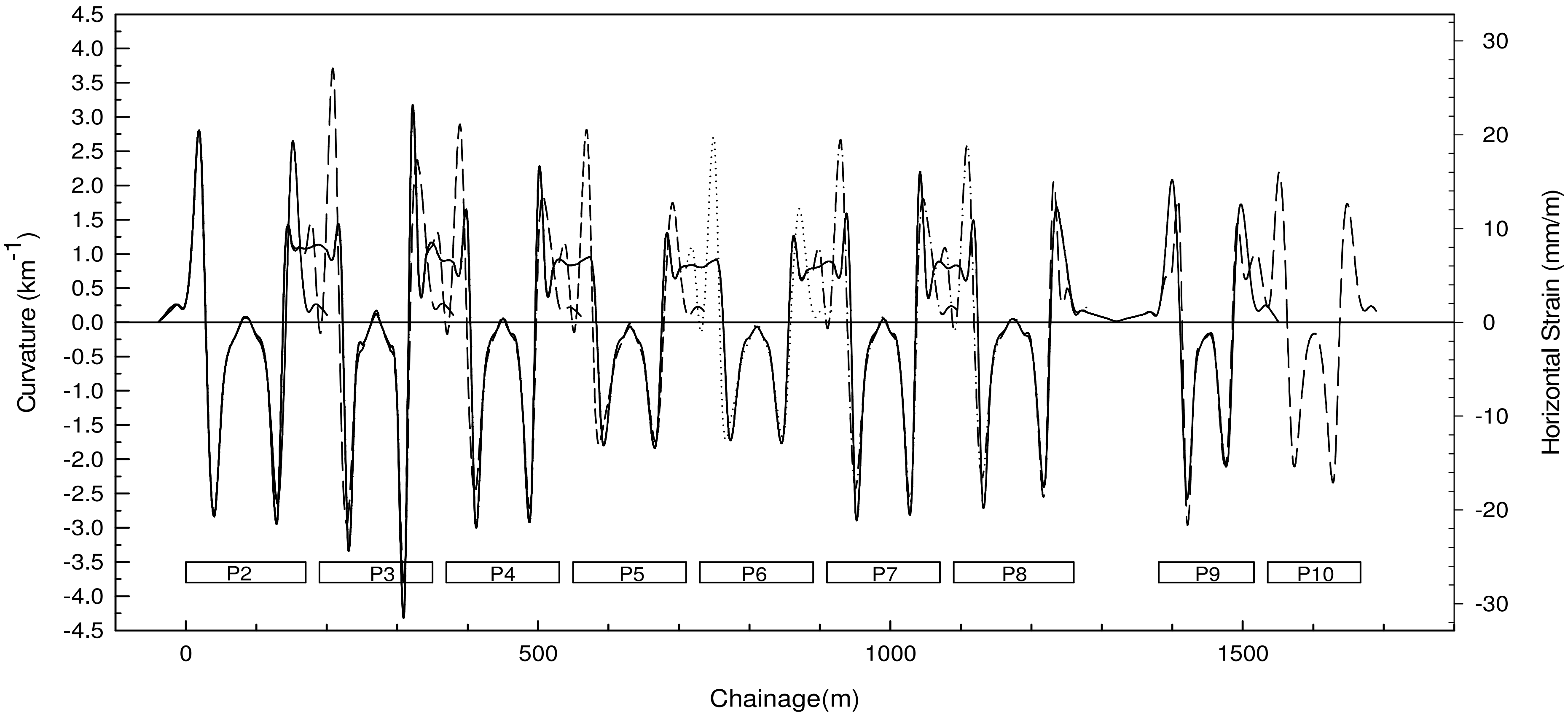
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn:	S.Ditton		ABL-001/1		
	Date:	31.07.09	Title:	Empirical Model Prediction Curves of Mean and U95%CL Final Maximum Sagging Curvature for the Proposed Abel Mine SMP Pillar Extraction Panels		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	15b



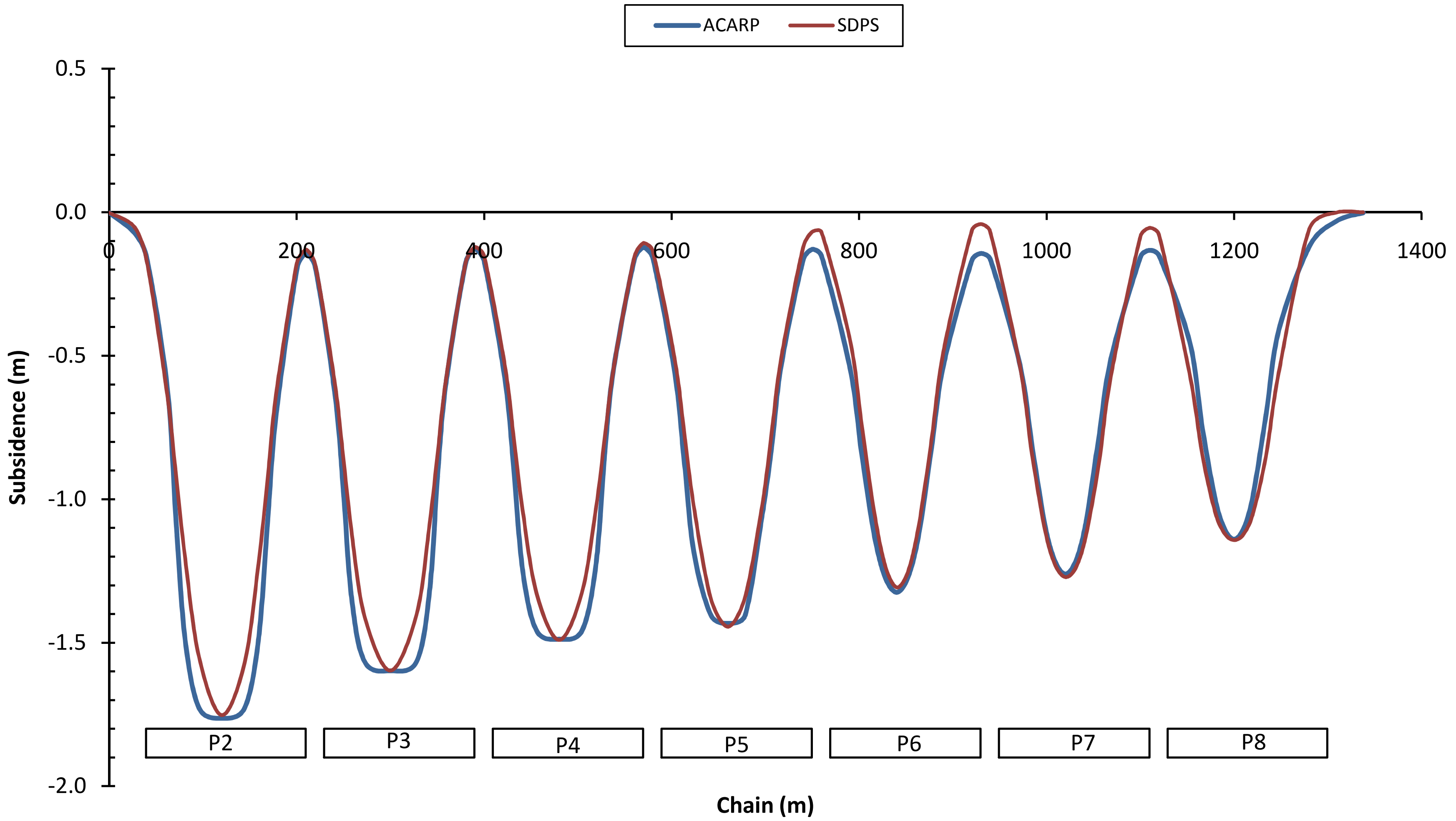
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited
	Drawn:	S.Ditton		ABL-001/1
	Date:	31.07.09	Title:	Empirical Model Prediction Curves of Mean and U95%CL Final Maximum Tensile Strain for the Proposed Abel Mine SMP Pillar Extraction Panels
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 16a



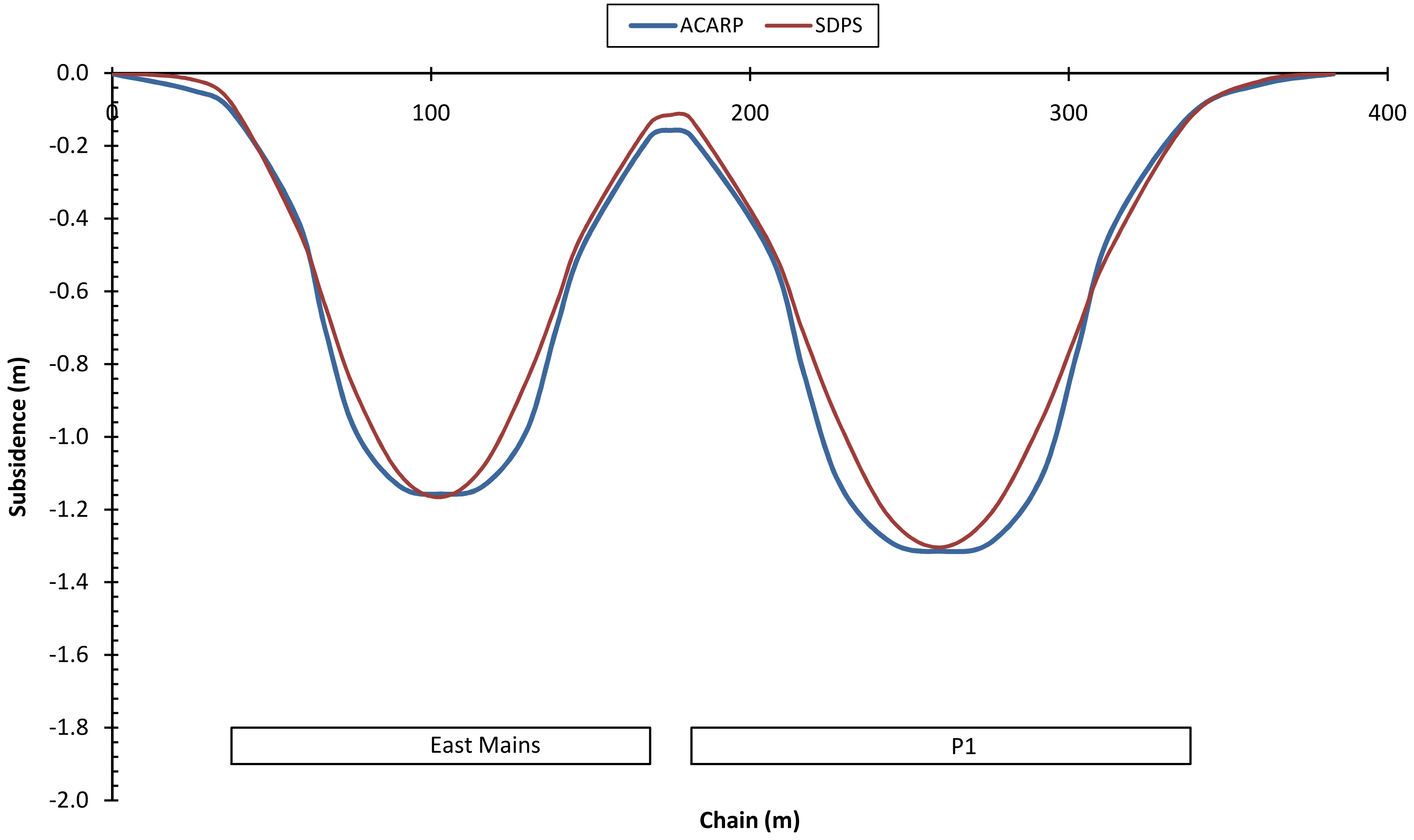
DgS	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited	
	Drawn: S.Ditton		ABL-001/1	
	Date: 31.07.09	Title:	Empirical Model Prediction Curves of Mean and U95%CL Final Maximum Compressive Strain for the Proposed Abel Mine SMP Pillar Extraction Panels	
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No: 16b



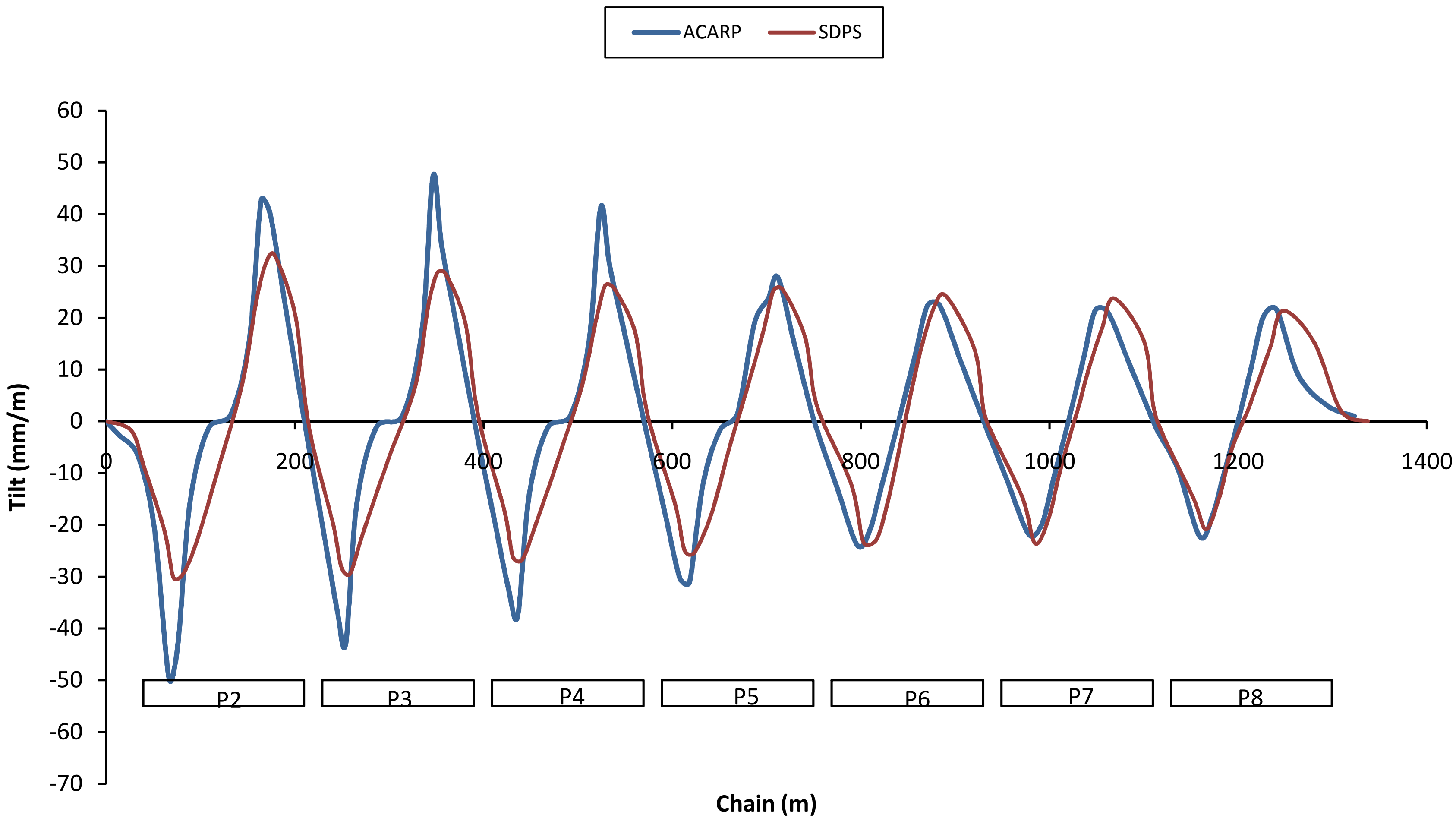
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Predicted U95% Confidence Limit Curvature Profiles for XL 1 and 3 Above the Proposed Abel Mine Pillar Extraction Panels - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	17



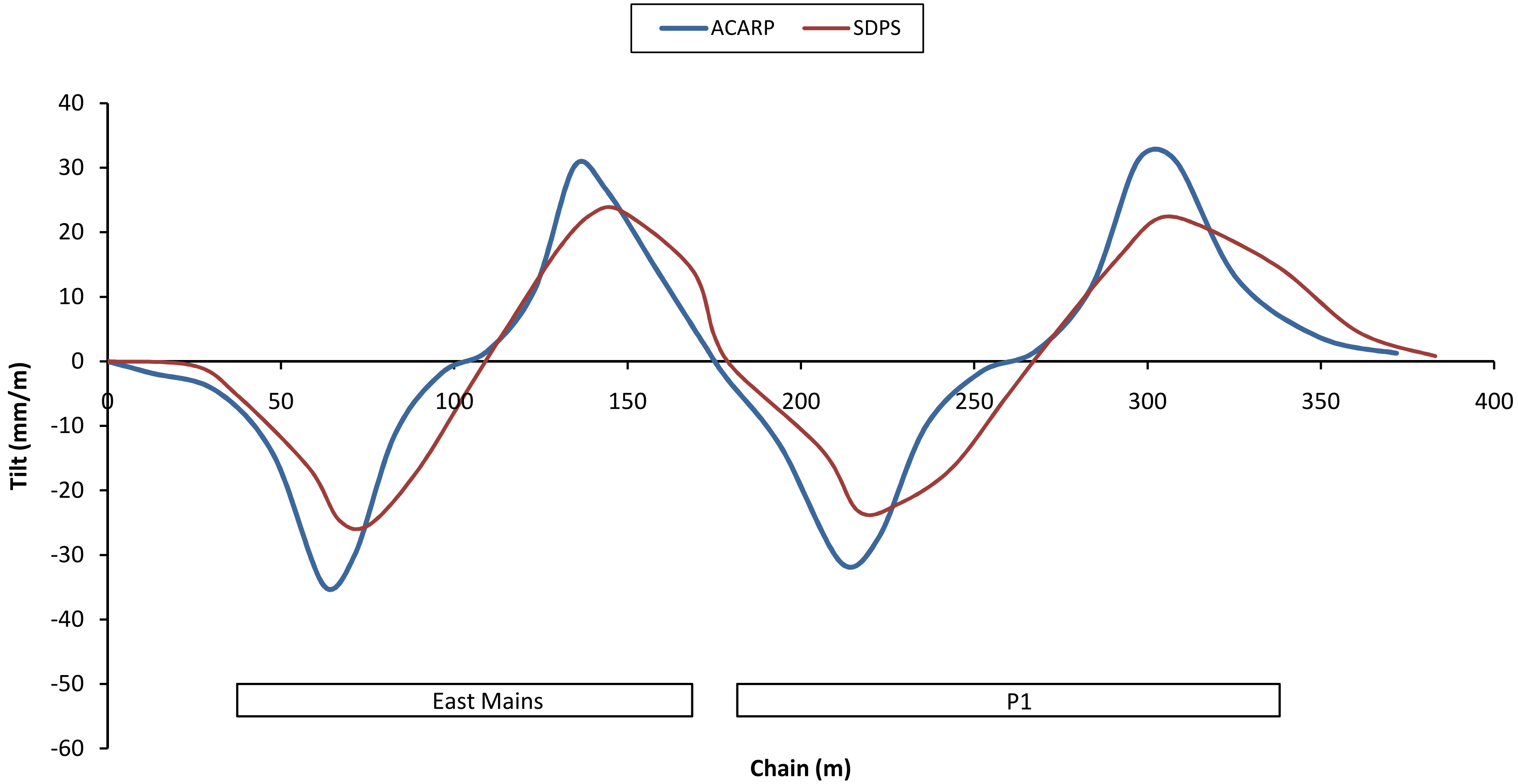
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	08.09.09	Title:	SDPS Model Calibration Results v. ACARP, 2003 Subsidence Profile (U95%CL) along XL 1 above the Proposed Abel Mine Pillar Extraction Panels - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	18a



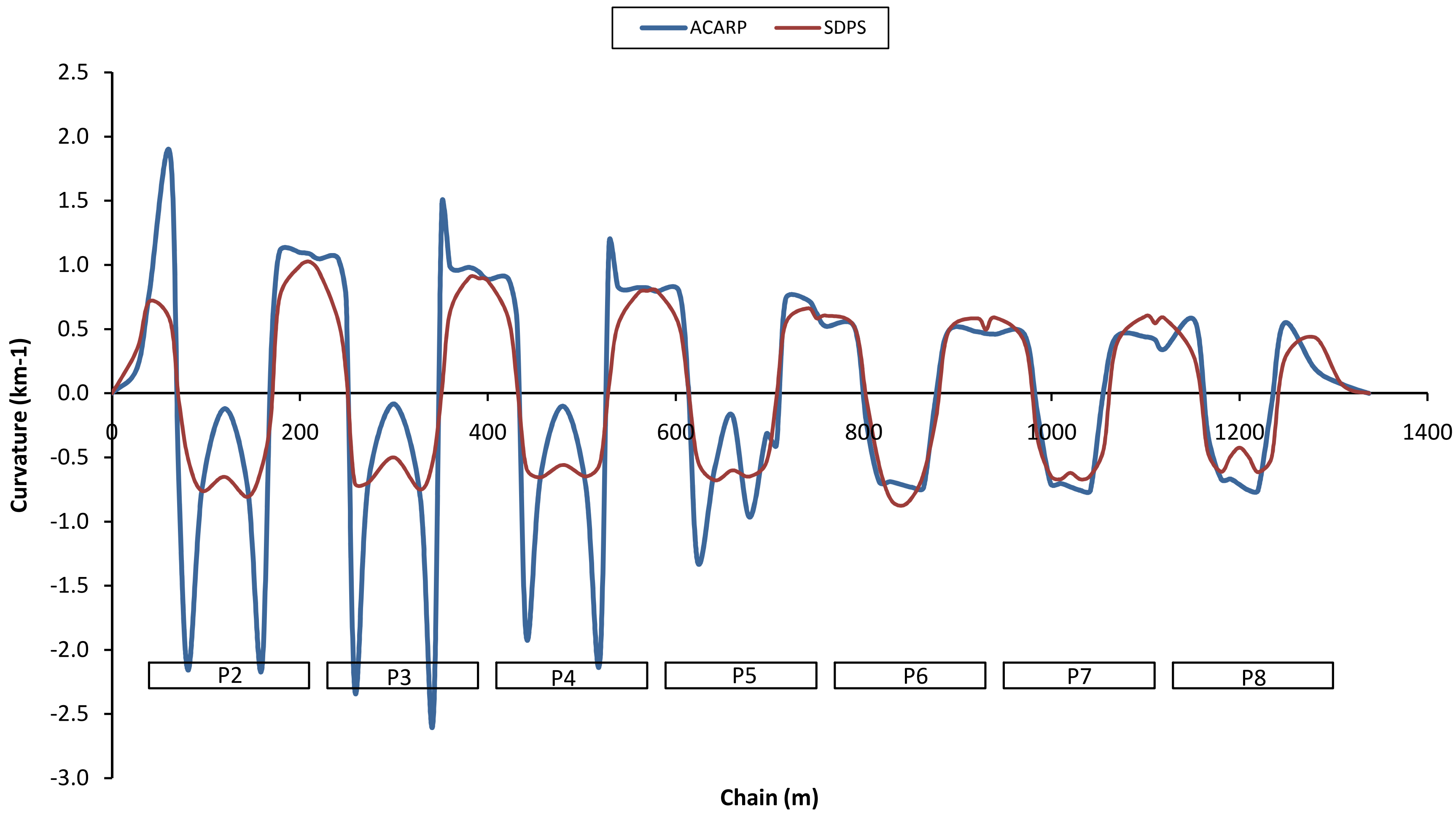
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	08.09.09	Title:	SDPS Model Calibration Results v. ACARP, 2003 Subsidence Profile (U95%CL) along XL2 above the Proposed Abel Mine Miniwall Panels - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	18b



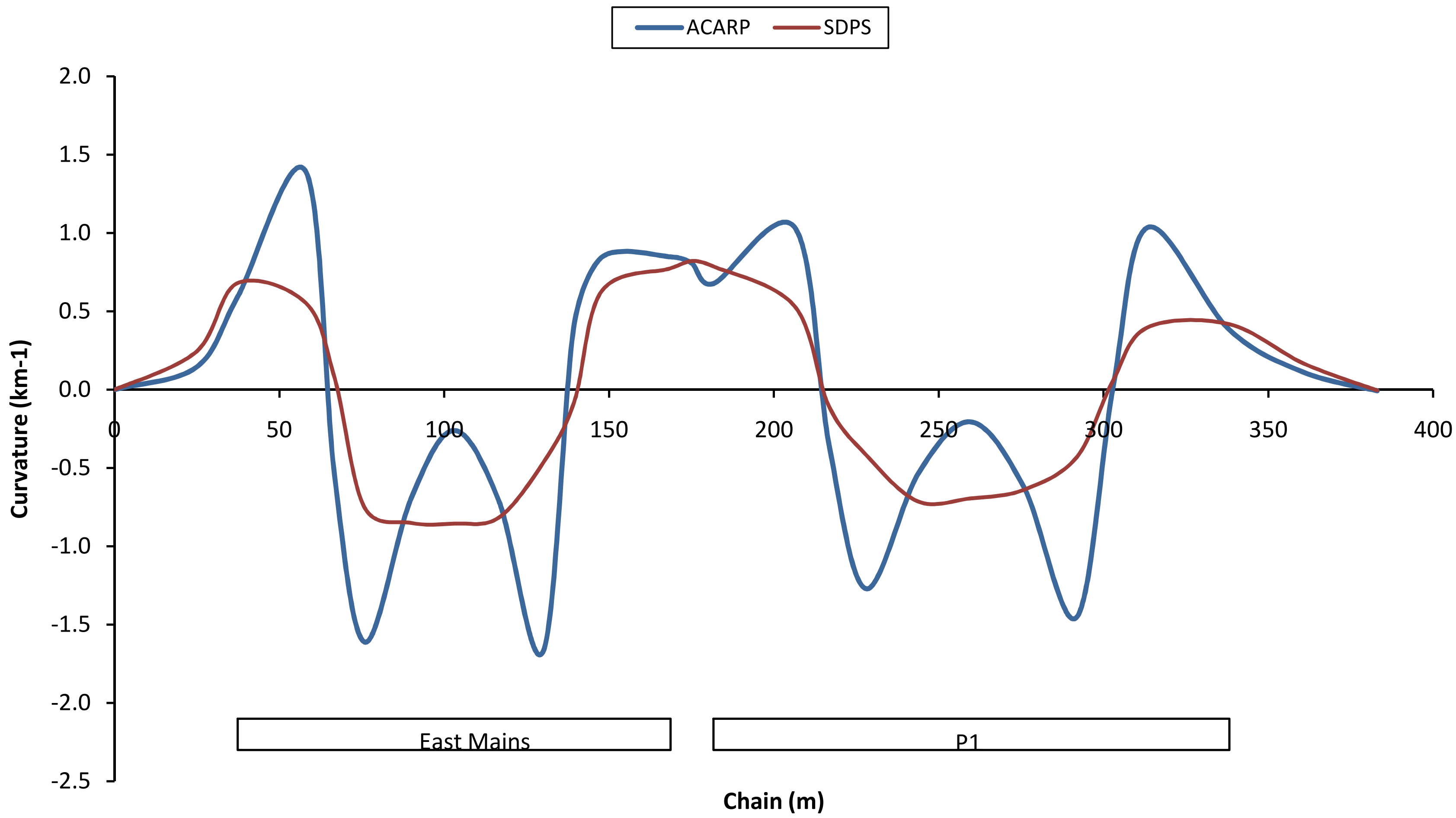
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	08.09.09	Title:	SDPS Model Calibration Results v. ACARP, 2003 Tilt Profile (U95%CL) along XL1 above the Proposed Abel Mine Pillar Extraction Panels - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	19a



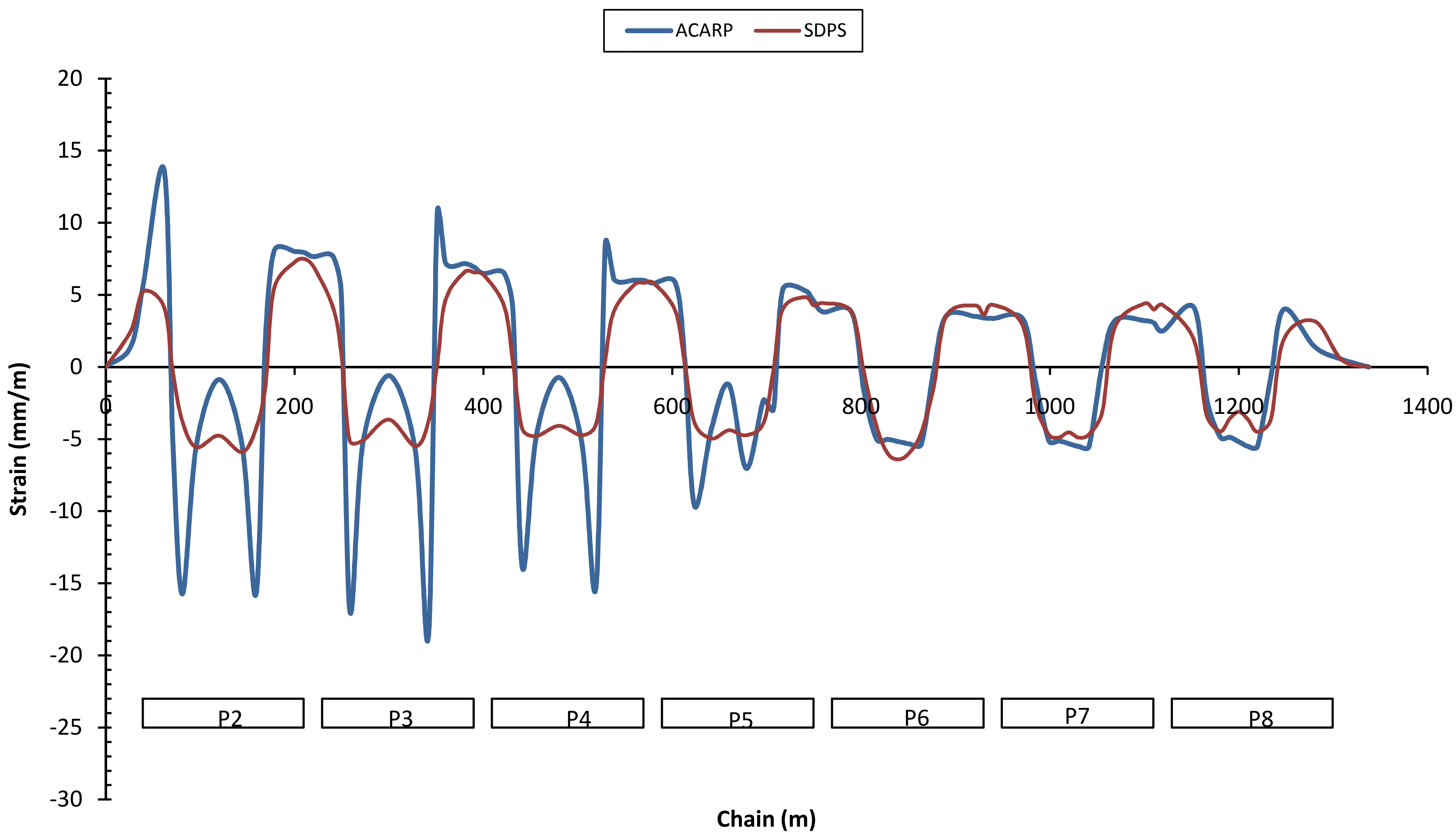
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	08.09.09	Title:	SDPS Model Calibration Results v. ACARP, 2003 Tilt Profile (U95%CL) along XL2 above the Proposed Abel Mine Miniwall Panels - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	19b



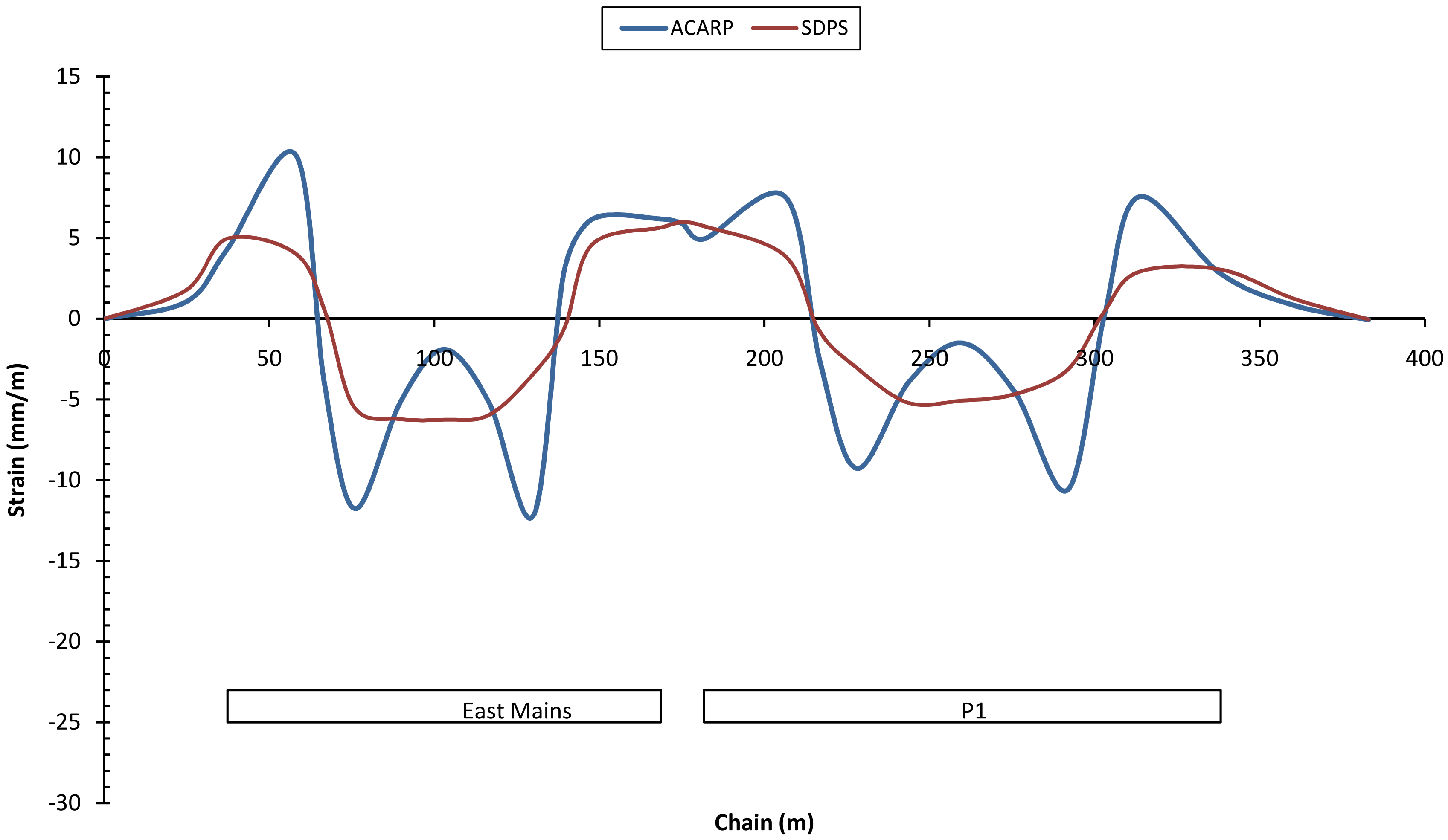
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	08.09.09	Title:	SDPS Model Calibration Results v. ACARP, 2003 Curvature Profile (U95%CL) along XL1 above the Proposed Abel Mine Pillar Extraction Panels - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	20a



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	08.09.09	Title:	SDPS Model Calibration Results v. ACARP, 2003 Curvature Profile (U95%CL) along XL3 above the Proposed Abel Mine Miniwall Panels - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	20b



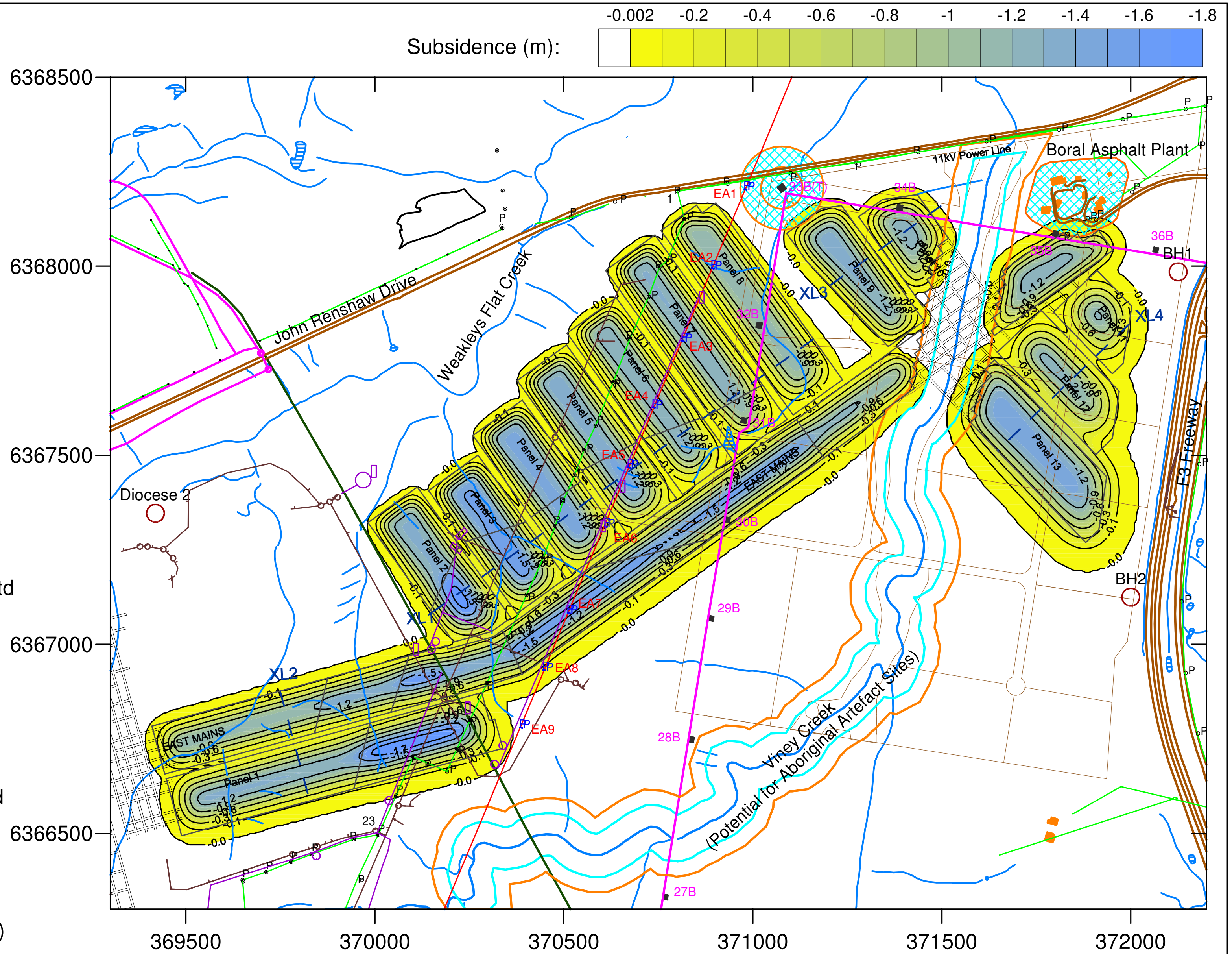
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	08.09.09	Title:	SDPS Model Calibration Results v. ACARP, 2003 Strain Profile (U95%CL) along XL1 Above the Proposed Abel Mine Pillar Extraction Panels - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	21a



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited			
	Drawn:	S.Ditton		ABL-001/1			
	Date:	08.09.09	Title:	SDPS Model Calibration Results v. ACARP, 2003 Strain Profile (U95%CL) along XL2 Above the Proposed Abel Mine Miniwall Panels - see Figure 1 for Location			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	21b	

Key

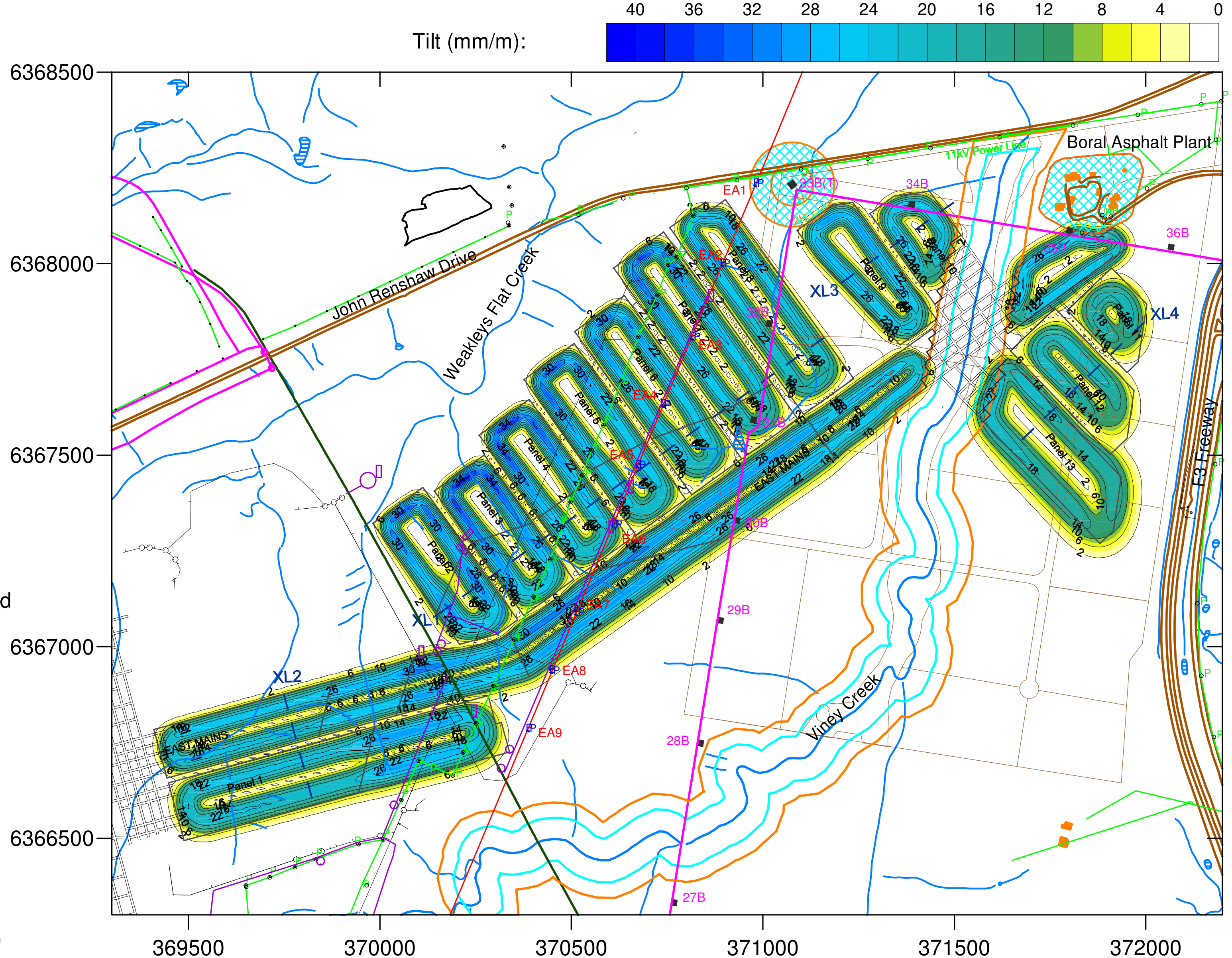
- Schedule 2 Creek and Buffer Zone (DECCW)
- B34 — Transmission Towers (Transgrid, 330 kV)
- Optic Fibre Cable (Optus)
- Sealed Road (Cessnock/ Newcastle City Councils)
- Water Supply Pipeline (Hunter Water)
- Private Residences/ Commercial Buildings
- EA1 P — 132 kV Power Line and Poles (Energy Australia)
- 1-23 P — 11 kV Domestic Powerline and Poles (Energy Australia)
- Proposed Black Hill Land Pty Ltd Lot Layout (Preliminary)
- Mine Workings (First workings)
- Second Workings (Total Pillar Extraction)
- Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones
- 0.6 — Subsidence Contours (0.1 m)
- Telstra Copper Cabling (buried)
- Schedule 1 creeks/ gullies
- BH1 — Aboriginal Artefact Scatters
- Stock Watering System



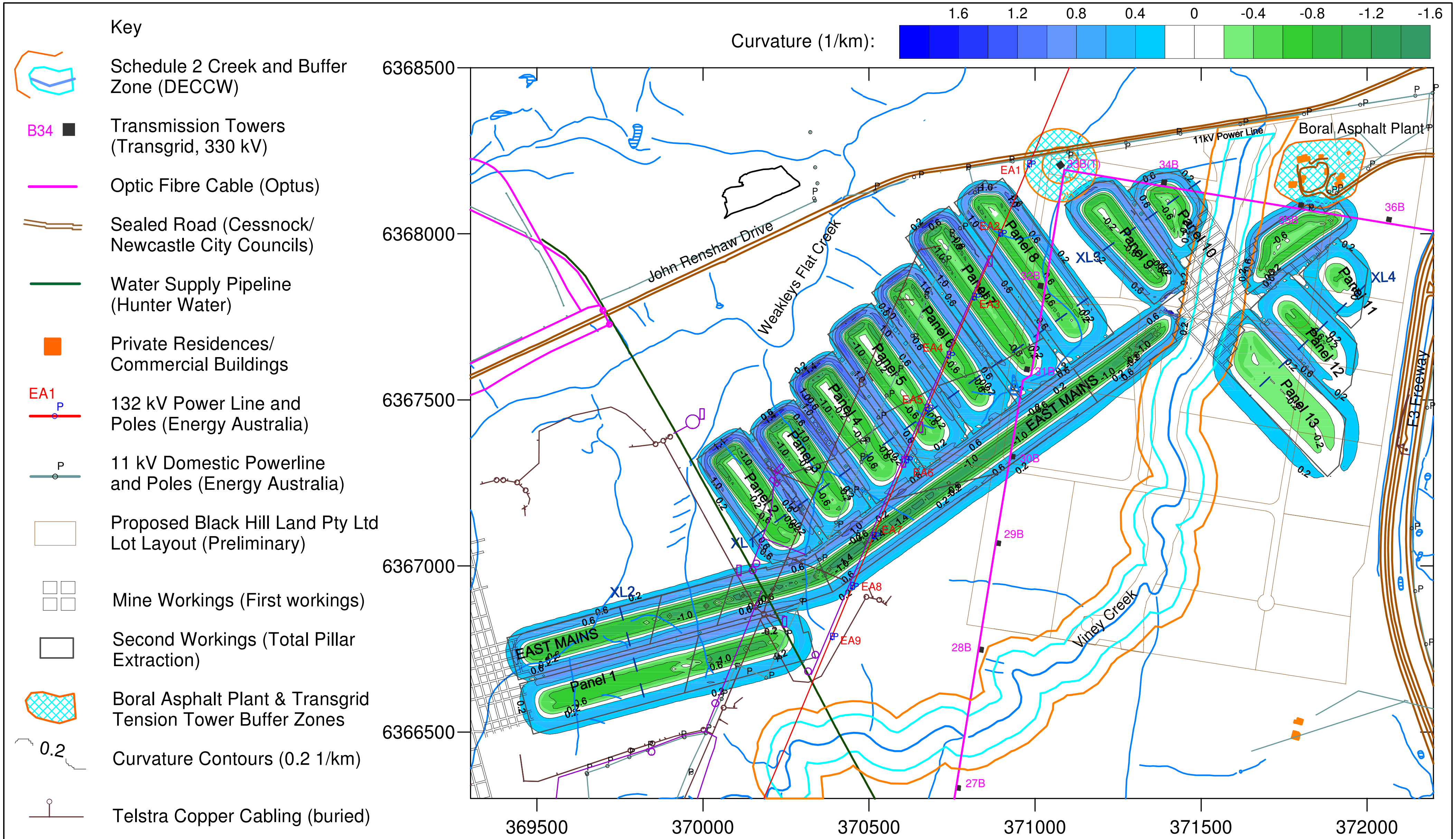
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton	Title:	Subsidence Contours above the Proposed Abel SMP Mine Layout		
	Date:	23.11.09				
	Ditton Geotechnical Services Pty Ltd		Scale:	1:20,000	Figure No:	22

Key

- Schedule 2 Creek and Buffer Zone (DECCW)
- B34 ■ Transmission Towers (Transgrid, 330 kV)
- Optic Fibre Cable (Optus)
- Sealed Road (Cessnock/ Newcastle City Councils)
- Water Supply Pipeline (Hunter Water)
- Private Residences/ Commercial Buildings
- EA1 P 132 kV Power Line and Poles (Energy Australia)
- P 11 kV Domestic Powerline and Poles (Energy Australia)
- Proposed Black Hill Land Pty Ltd Lot Layout (Preliminary)
- Mine Workings (First workings)
- Second Workings (Total Pillar Extraction)
- Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones
- 2 Tilt Contours (2 mm/m)
- Telstra Copper Cabling (buried)
- Schedule 1 creeks/ gullies
- Stock Watering System



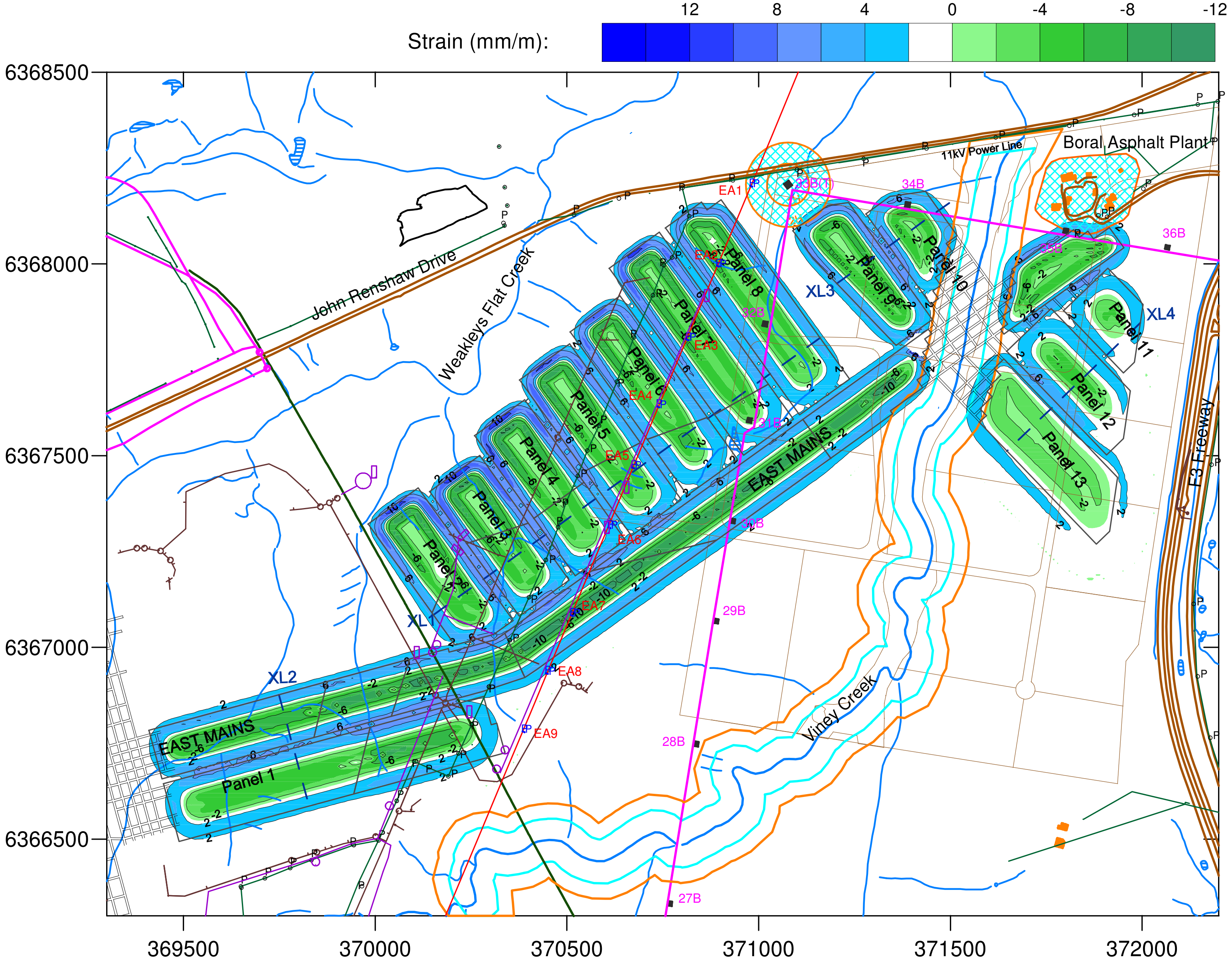
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	23.11.09	Title:	Principle Tilt Contours above the Proposed Abel SMP Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	1:20,000	Figure No:	23



DgS Ditton Geotechnical Services Pty Ltd	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1	
	Drawn: S.Ditton	Title:	Principle Curvature Contours above the Proposed Abel SMP Mine Layout	
	Date: 23.11.09	Scale:	1:20,000	Figure No: 24

Key

- Schedule 2 Creek and Buffer Zone (DECCW)
- B34 Transmission Towers (Transgrid, 330 kV)
- Optic Fibre Cable (Optus)
- Sealed Road (Cessnock/ Newcastle City Councils)
- Water Supply Pipeline (Hunter Water)
- Private Residences/ Commercial Buildings
- EA1 P 132 kV Power Line and Poles (Energy Australia)
- P 11 kV Domestic Powerline and Poles (Energy Australia)
- Proposed Black Hill Land Pty Ltd Lot Layout (Preliminary)
- Mine Workings (First workings)
- Second Workings (Total Pillar Extraction)
- Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones
- 4 Strain Contours (2 mm/m)
- Telstra Copper Cabling (buried)
- Schedule 1 creeks/ gullies
- Stock Watering System



DgS	Engineer:	S.Ditton	Client: Donaldson Coal Pty Limited ABL-001/1
	Drawn:	S.Ditton	
	Date:	23.11.09	Title: Principle Horizontal Strain Contours above the Proposed Abel SMP Mine Layout
Ditton Geotechnical Services Pty Ltd			Scale: 1:20,000 — Figure No: 25

Key

Schedule 2 Creek and Buffer Zone (DECCW)

B34 Transmission Towers (Transgrid, 330 kV)

Optic Fibre Cable (Optus)

Sealed Road (Cessnock/ Newcastle City Councils)

Water Supply Pipeline (Hunter Water)

Private Residences/ Commercial Buildings

EA1 P 132 kV Power Line and Poles (Energy Australia)

P 11 kV Domestic Powerline and Poles (Energy Australia)

Proposed Black Hill Land Pty Ltd Lot Layout (Preliminary)

Mine Workings (First workings)

Second Workings (Total Pillar Extraction)

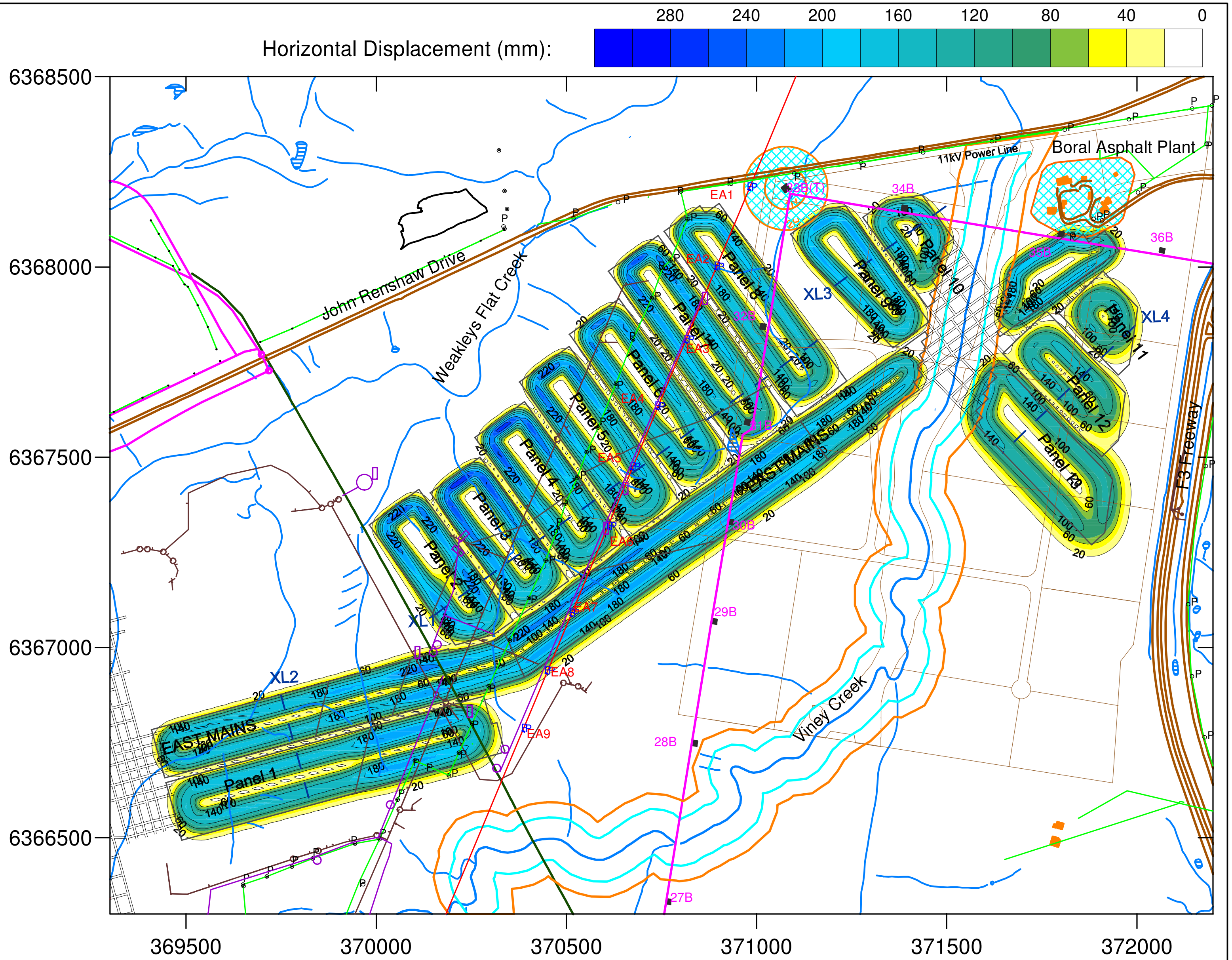
Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones

20 Horizontal Displacement Contours (20 mm)

Telstra Copper Cabling (buried)

Schedule 1 creeks/ gullies

Stock Watering System



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn:	S.Ditton		
	Date:	23.11.09	Title:	Principle Horizontal Displacement Contours above the Proposed Abel SMP Mine Layout
	Ditton Geotechnical Services Pty Ltd		Scale:	1:20,000

Figure No: 26

Key

Schedule 2 Creek and Buffer Zone (DECCW)

B34 Transmission Towers (Transgrid, 330 kV)

Optic Fibre Cable (Optus)

Sealed Road (Cessnock/ Newcastle City Councils)

Water Supply Pipeline (Hunter Water)

Private Residences/ Commercial Buildings

EA1 P 132 kV Power Line and Poles (Energy Australia)

P 11 kV Domestic Powerline and Poles (Energy Australia)

Proposed Black Hill Pty Ltd Lot Layout (Preliminary)

Mine Workings (First workings)

Second Workings (Total Pillar Extraction)

Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones

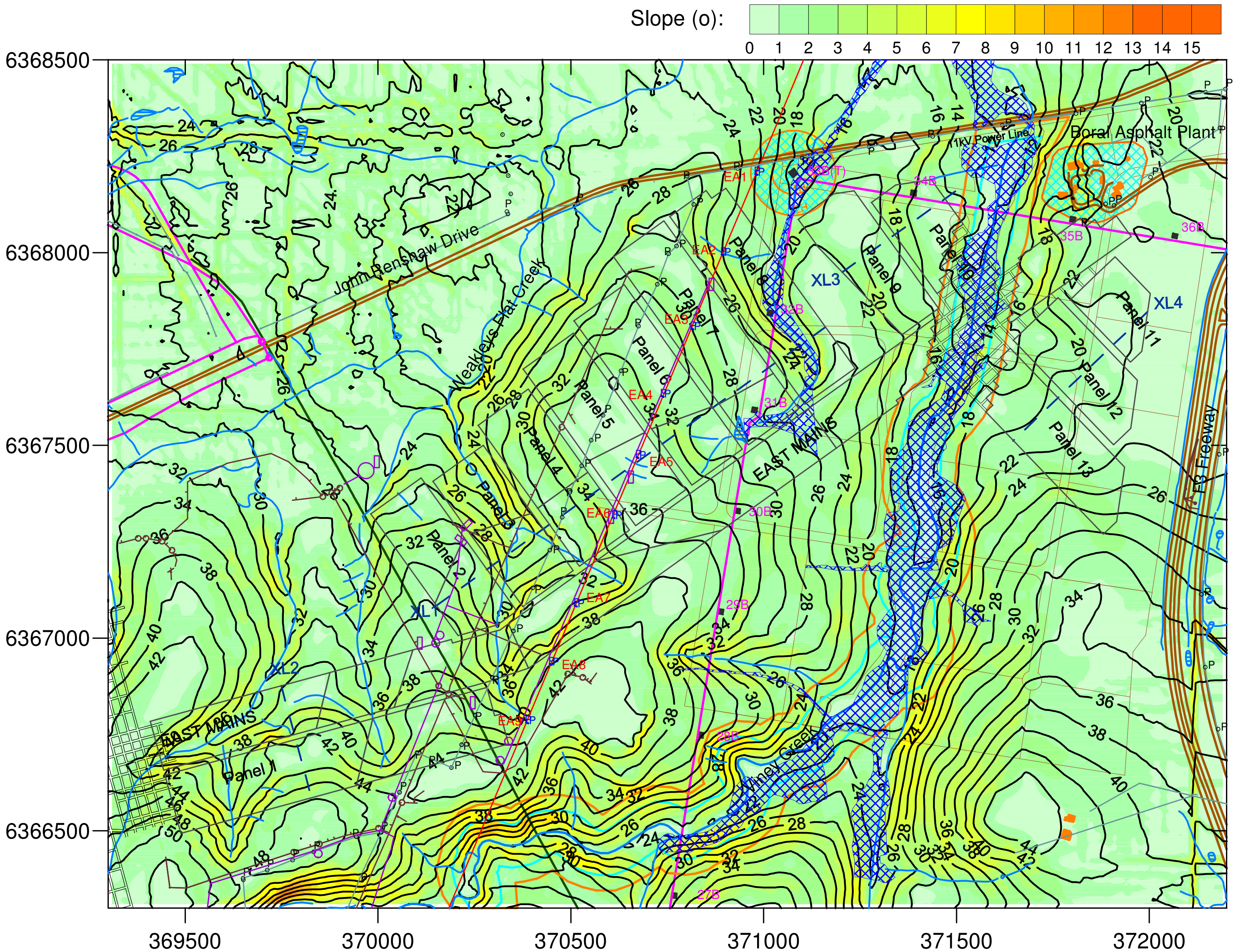
25 Surface Level Contours (m)

Telstra Copper Cabling (buried)

Schedule 1 creeks/ gullies

Stock Watering System

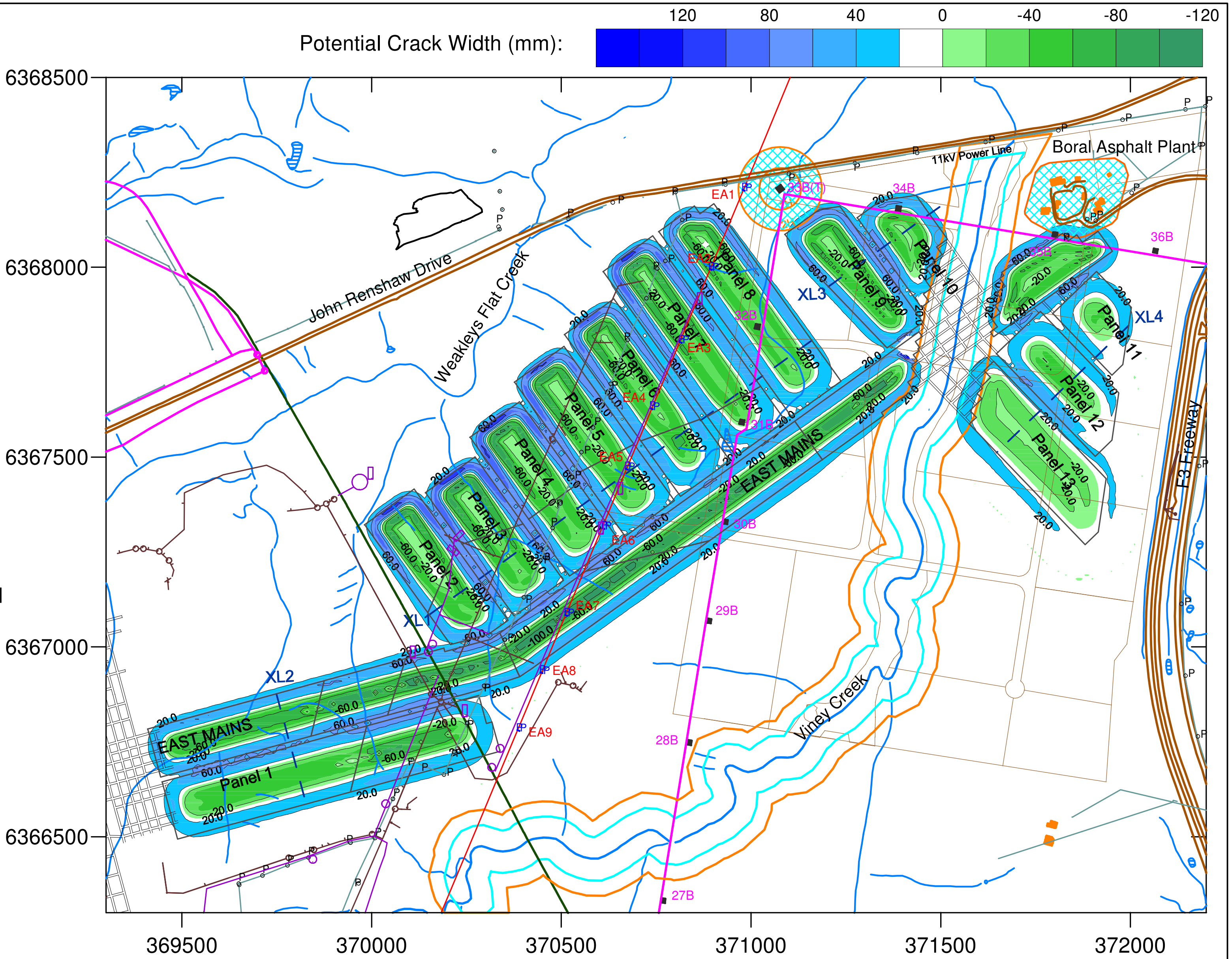
1 in 100 ARI Flood Levels (post-mining)



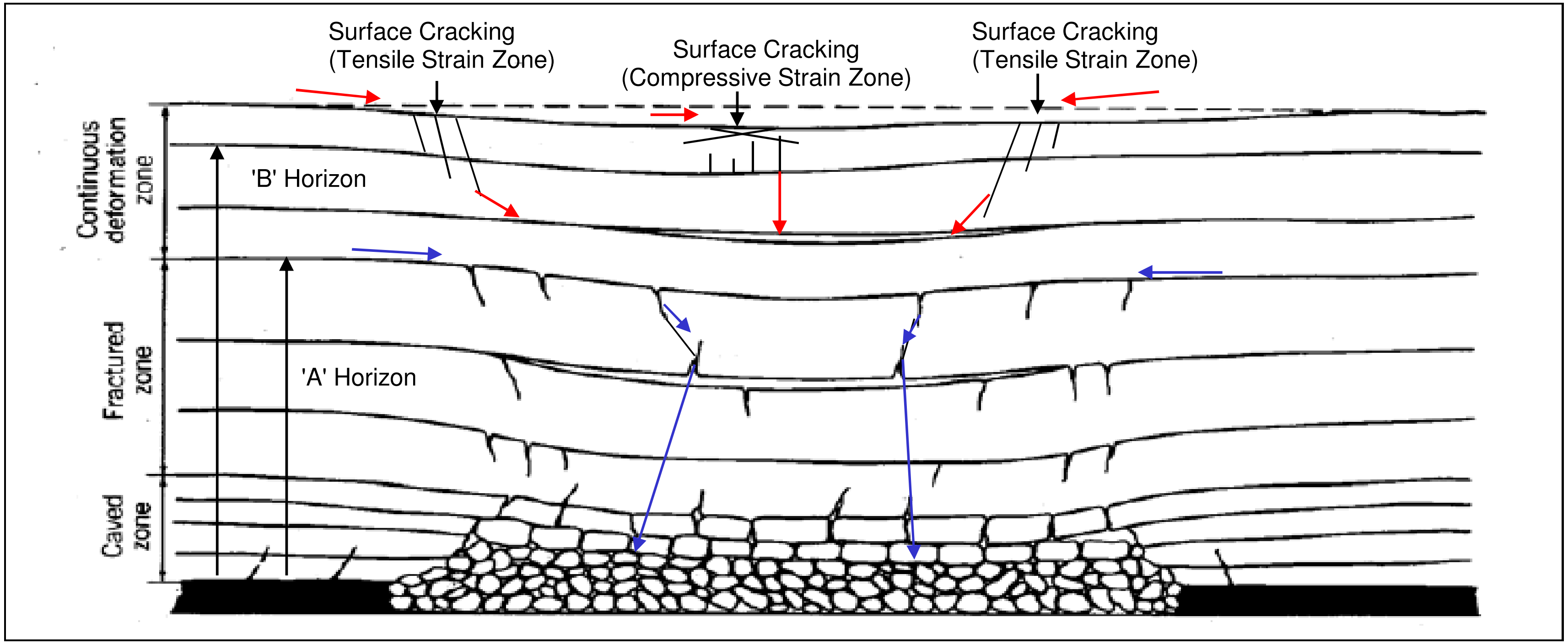
DgS Ditton Geotechnical Services Pty Ltd	Engineer: S.Ditton Drawn: S.Ditton Date: 23.11.09	Client:	Donaldson Coal Pty Limited ABL-001/1
		Title:	Post-Mining Topography Isopachs (2 m contours) and Slopes above the Proposed Abel SMP Mine Layout
		Scale:	1:20,000 — Figure No: 27

Key

- Schedule 2 Creek and Buffer Zone (DECCW)
- B34 — Transmission Towers (Transgrid, 330 kV)
- Optic Fibre Cable (Optus)
- Sealed Road (Cessnock/ Newcastle City Councils)
- Water Supply Pipeline (Hunter Water)
- Private Residences/ Commercial Buildings
- EA1 P — 132 kV Power Line and Poles (Energy Australia)
- P — 11 kV Domestic Powerline and Poles (Energy Australia)
- Proposed Black Hill Land Pty Ltd Lot Layout (Preliminary)
- Mine Workings (First workings)
- Second Workings (Total Pillar Extraction)
- Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones
- 20 — Crack Width Contours (20 mm)
- Telstra Copper Cabling (buried)
- Schedule 1 creeks/ gullies
- Stock Watering System



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn:	S.Ditton		
	Date:	23.11.09	Title:	Predicted Maximum Potential Crack Width Contours above the Proposed Abel SMP Mine Layout
	Ditton Geotechnical Services Pty Ltd		Scale:	1:20,000 — Figure No: 28



Zones in the Overburden According to Peng and Chiang (1984)

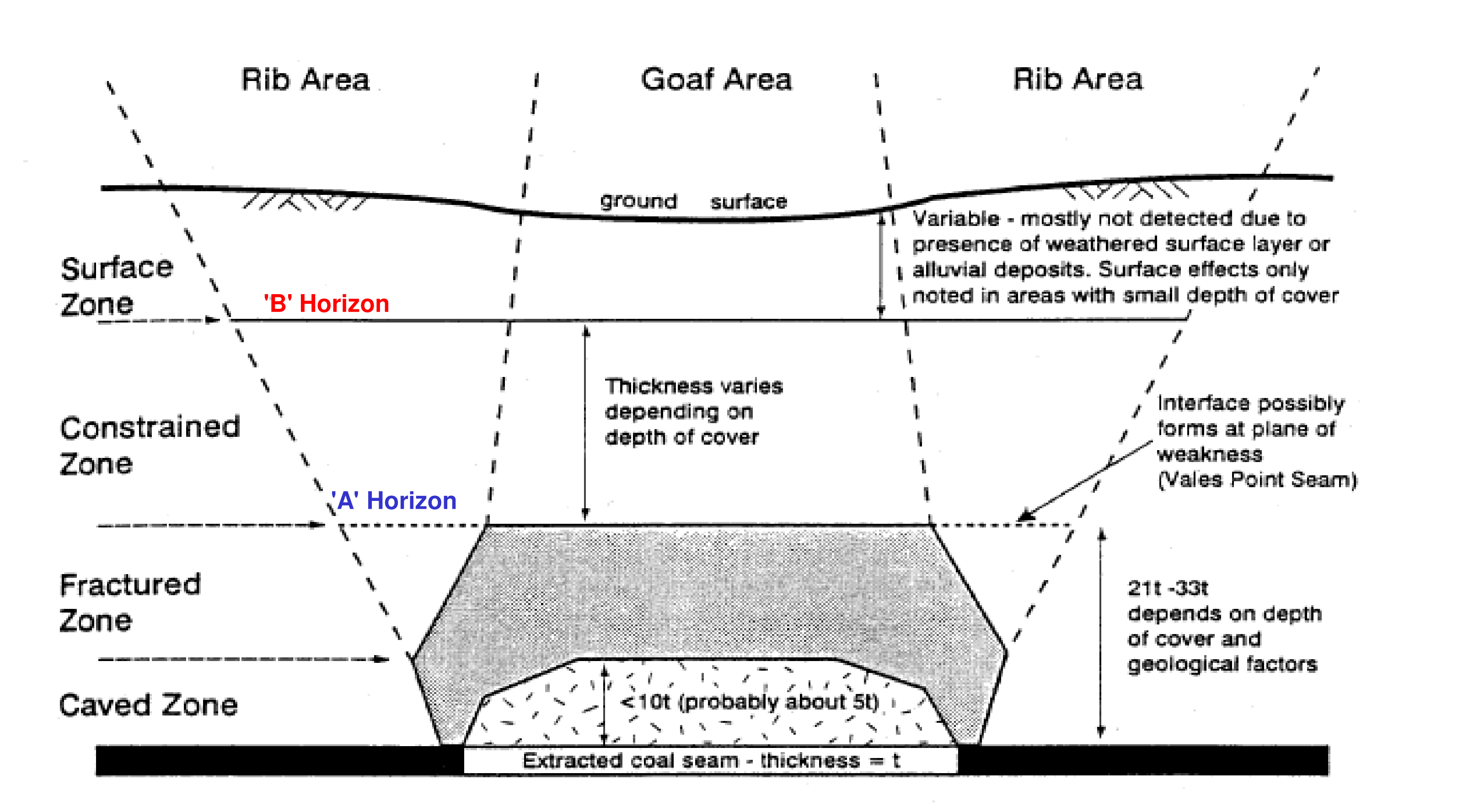
Key

'A' Horizon - Zone of Continuous Crack Connection to Workings (**Whittaker and Reddish,1989**)

'B" Horizon - Zone Of Discontinuous Crack Connection to Workings (**Whittaker and Reddish, 1989**)

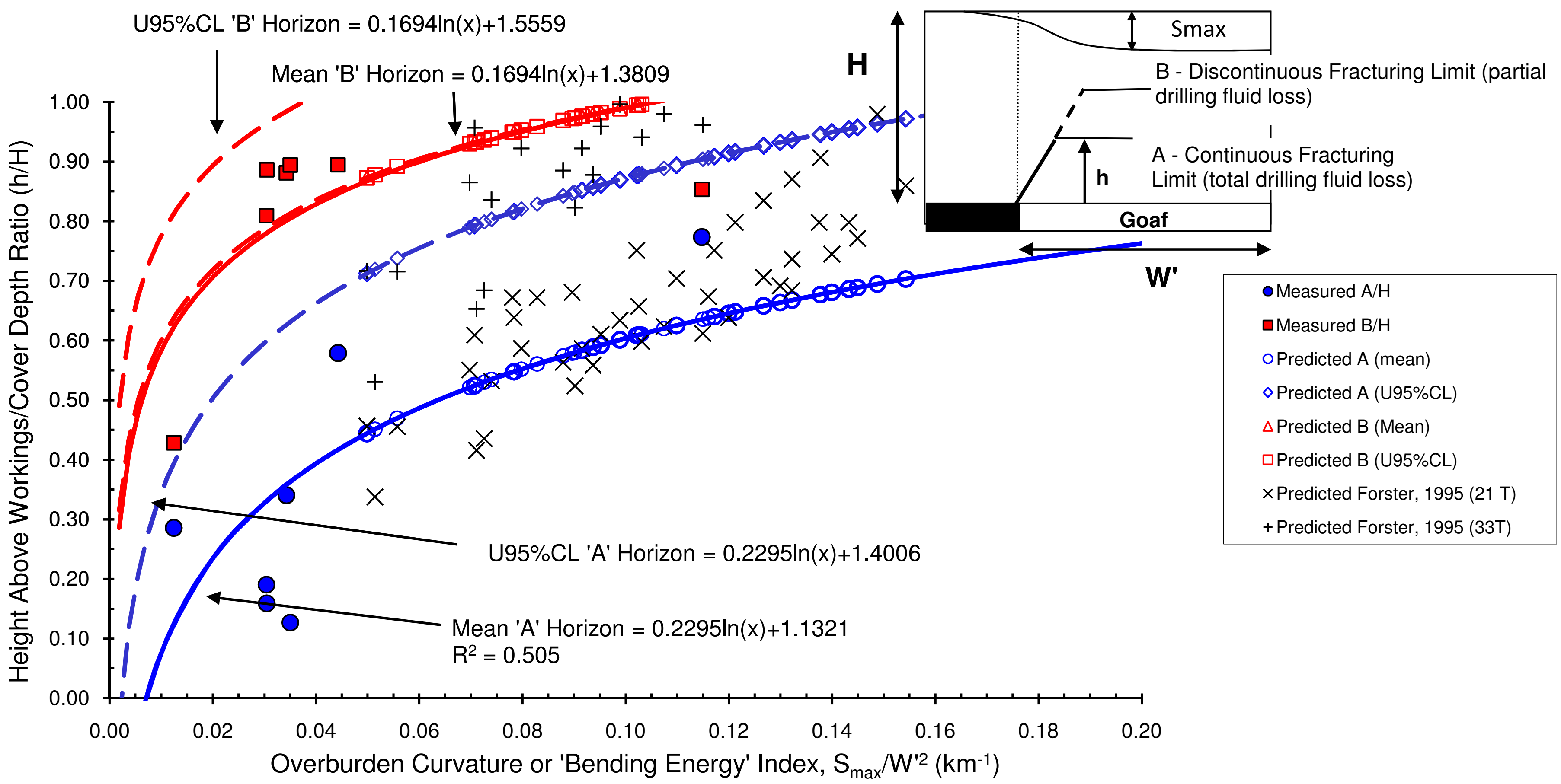
→ Surface water flow path → Sub-surface water flow path

DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	12.05.09	Title:	Schematic Model of Overburden Fracture Zones Above Longwall Panels		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	29

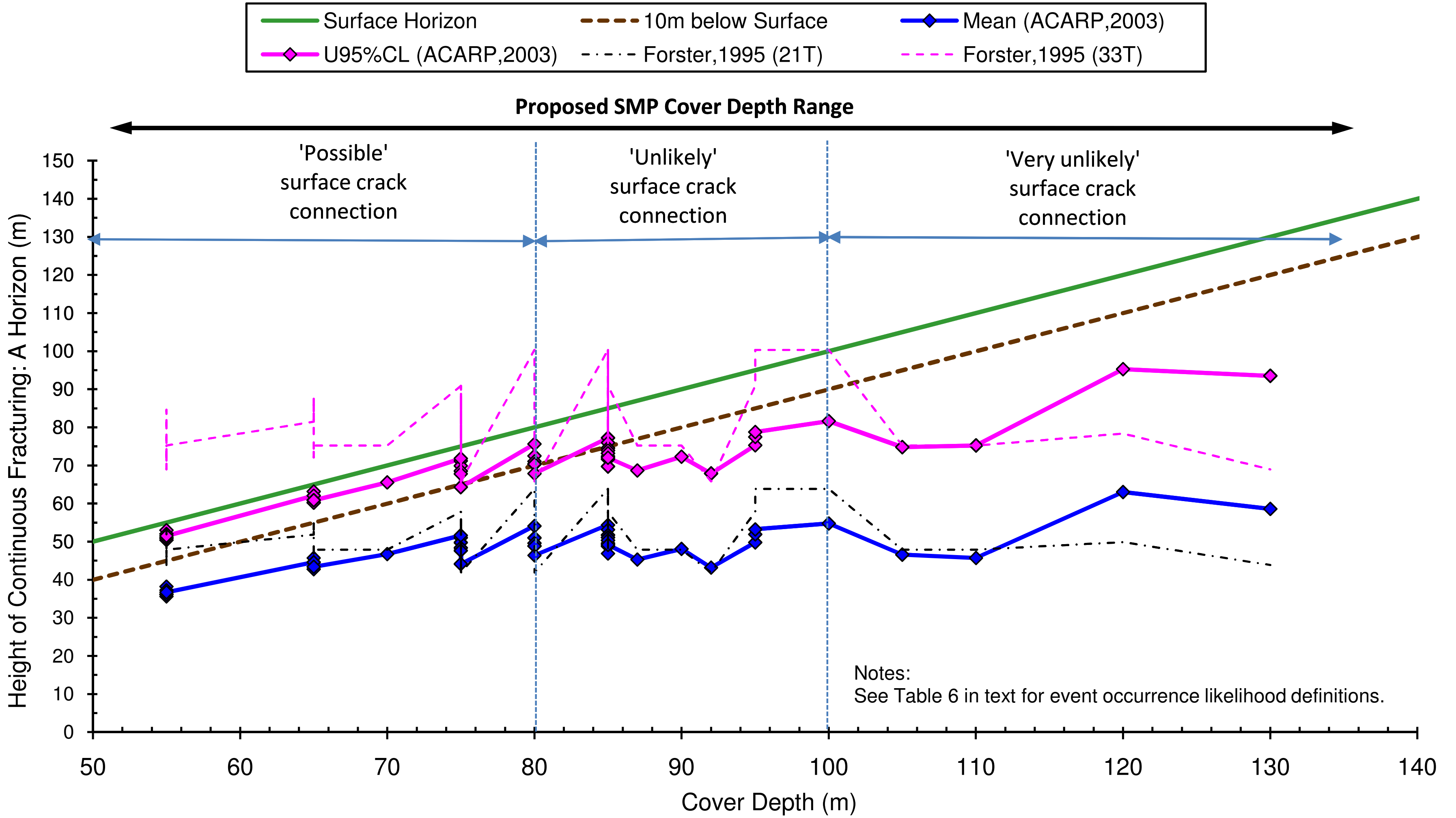


Zones in the Overburden according to Forster (1995)

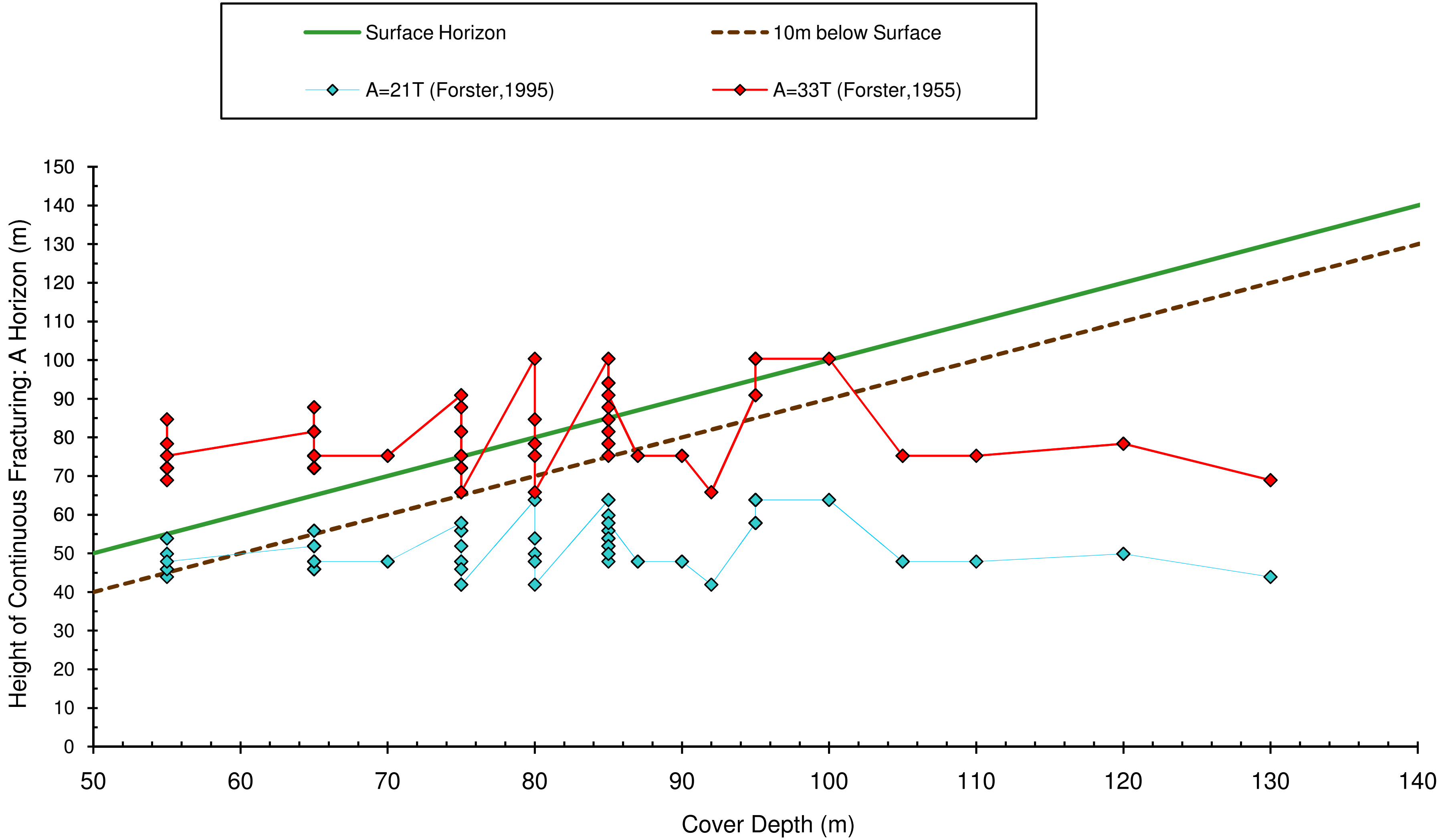
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited			
	Drawn:	S.Ditton		ABL-001/1			
	Date:	12.05.09	Title:	Schematic Model of Overburden Fracture Zones in **Forster, 1995** Model (based on Piezometric Data Above Total Extraction Panels in the Newcastle Coalfield)			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS		Figure No:	30



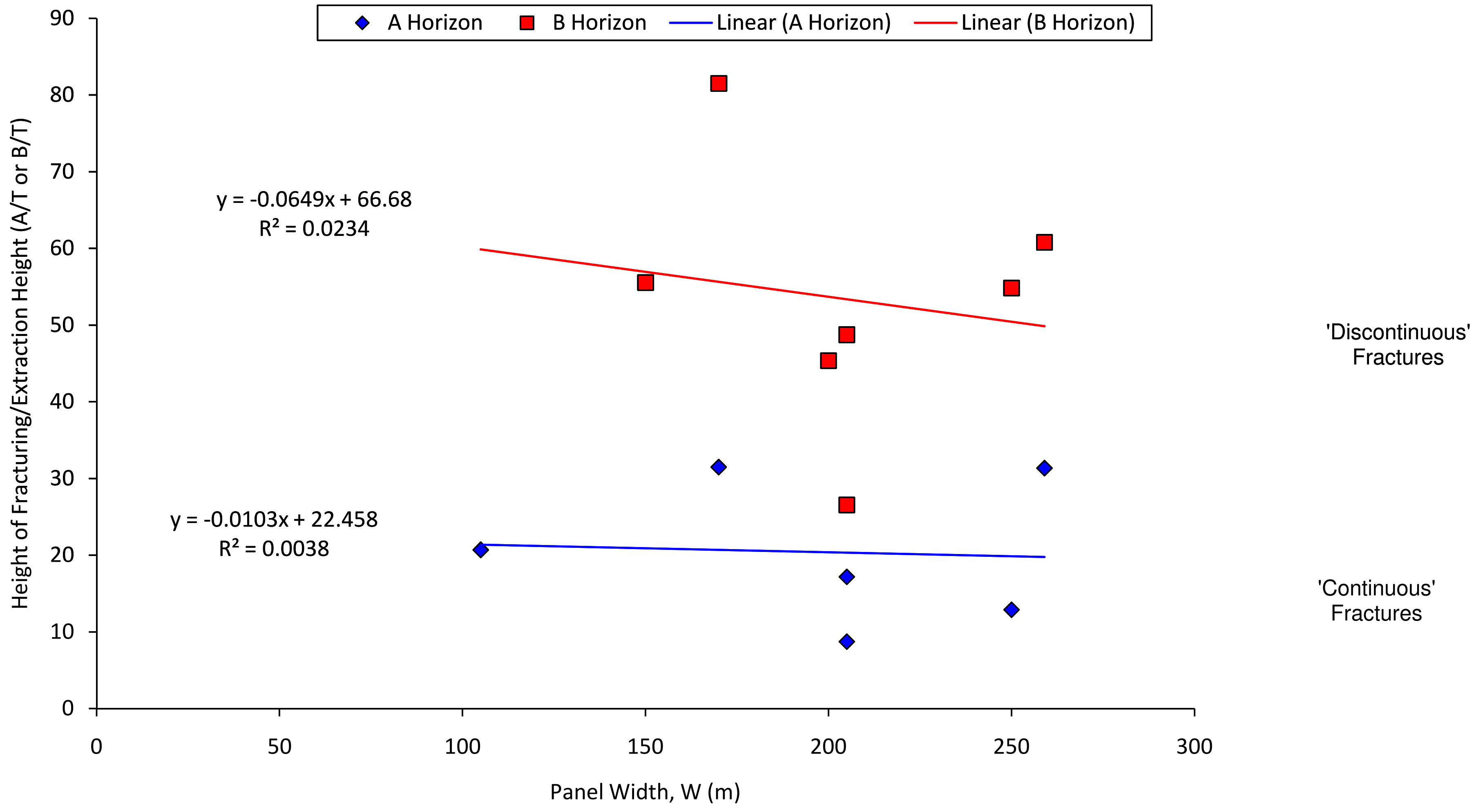
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn:	S.Ditton		ABL-001/1		
	Date:	08.09.09	Title:	Continuous and Discontinuous Sub-Surface Fracture Heights above the Proposed Abel Mine Pillar Extraction Panels (based on ACARP, 2003 and Forster,1995)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	31



DgS						
Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited			
Drawn:	S.Ditton		ABL-001/1			
Date:	23.10.09	Title:	Predicted Sub-surface Fracture Height v. Cover Depth for the Proposed Abel Mine Pillar Extraction Panels (based on ACARP, 2003 Model)			
Ditton Geotechnical Services Pty Ltd		Scale:	NTS		Figure No:	32



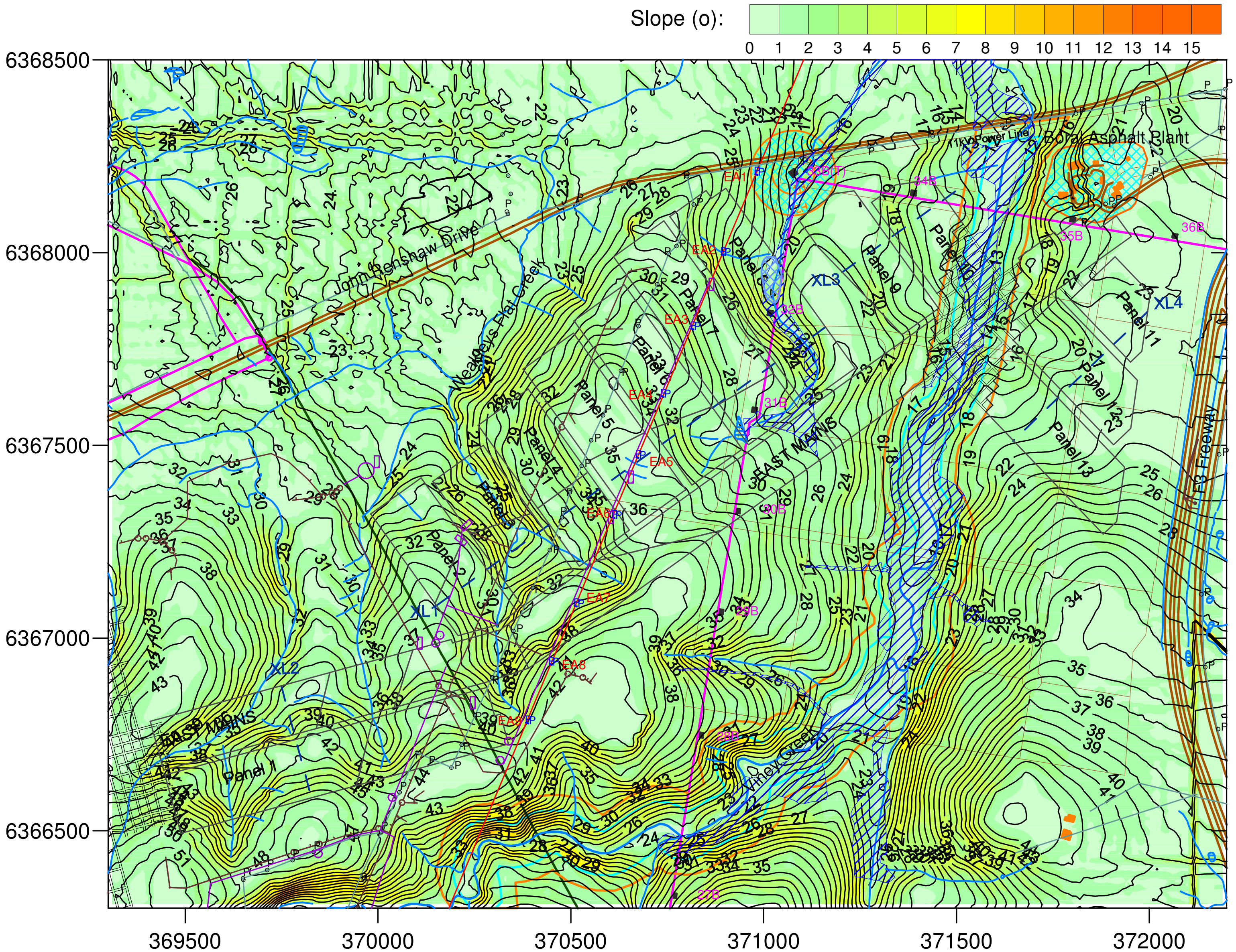
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal - Abel Mine
	Drawn:	S.Ditton		ABL-001/1
	Date:	12.05.09	Title:	Predicted Sub-surface Fracture Height v. Cover Depth for the Proposed Pillar Extraction Panels (based on Forster,1995 Model)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS Figure No: 33



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn:	S.Ditton		ABL-001/1		
	Date:	17.04.09	Title:	Measured Sub-surface Fracture Heights above Longwall Panels v. Panel Width (based on ACARP, 2003 data)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	34

Key

- Schedule 2 Creek and Buffer Zone (DECCW)
- B34 Transmission Towers (Transgrid, 330 kV)
- Optic Fibre Cable (Optus)
- Sealed Road (Cessnock/ Newcastle City Councils)
- Water Supply Pipeline (Hunter Water)
- Private Residences/ Commercial Buildings
- EA1 P 132 kV Power Line and Poles (Energy Australia)
- P 11 kV Domestic Powerline and Poles (Energy Australia)
- Proposed Black Hill Land Pty Ltd Lot Layout (Preliminary)
- Mine Workings (First workings)
- Second Workings (Total Pillar Extraction)
- Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones
- 25 Surface Level Contours (m)
- Telstra Copper Cabling (buried)
- Schedule 1 creeks/ gullies
- Potential Ponding Area
- Stock Watering System
- 1 in 100 Year ARI (post-mining)



Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1
Drawn:	S.Ditton	Title:	Post-Mining 1 m Topography Isopachs and Slopes above the Proposed Abel SMP Mine Layout for Ponding Potential Assessment
Date:	23.11.09	Scale:	1:20,000
		Figure No:	35a

DgS

Ditton Geotechnical Services Pty Ltd

Key

Schedule 2 Creek and Buffer Zone (DECCW)

B34 Transmission Towers (Transgrid, 330 kV)

Optic Fibre Cable (Optus)

Sealed Road (Cessnock/ Newcastle City Councils)

Water Supply Pipeline (Hunter Water)

Private Residences/ Commercial Buildings

EA1 P 132 kV Power Line and Poles (Energy Australia)

P 11 kV Domestic Powerline and Poles (Energy Australia)

Proposed Blackhill Land Pty Ltd Lot Layout (Preliminary)

Mine Workings (First workings)

Second Workings (Total Pillar Extraction)

Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones

25 Surface Level Contours (m)

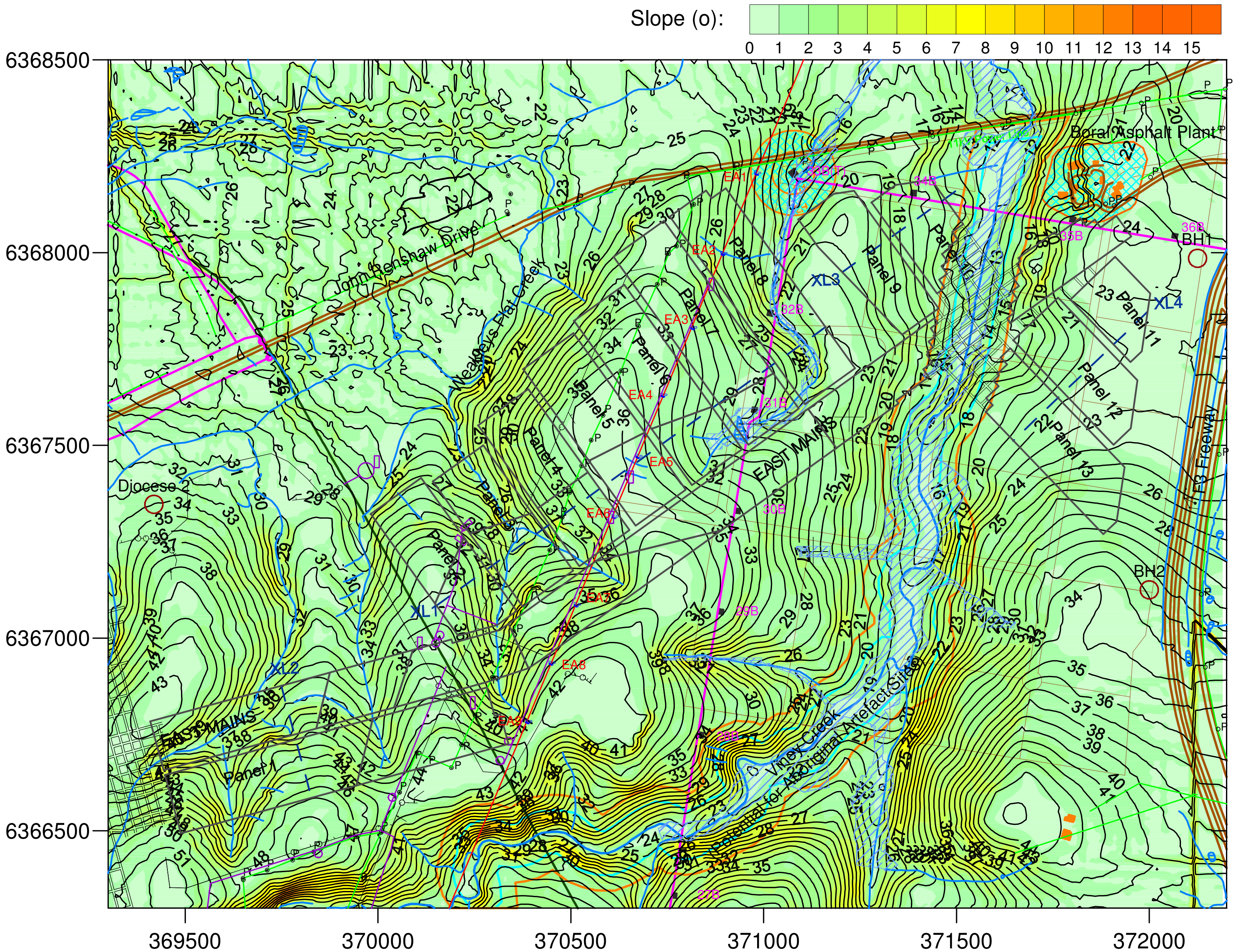
Telstra Copper Cabling (buried)

Schedule 1 creeks/ gullies

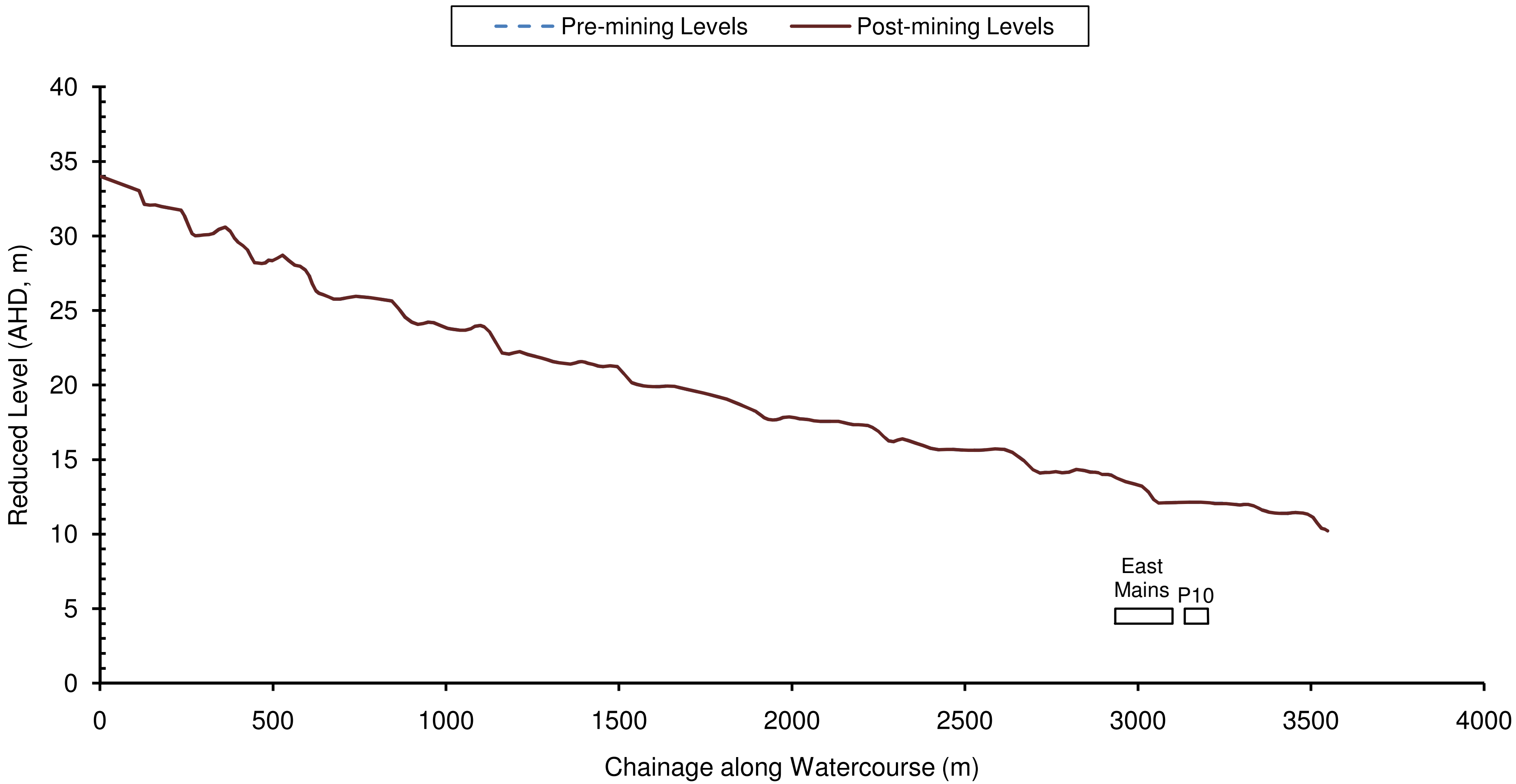
BH1 Aboriginal Artefact Scatters

Stock Watering System

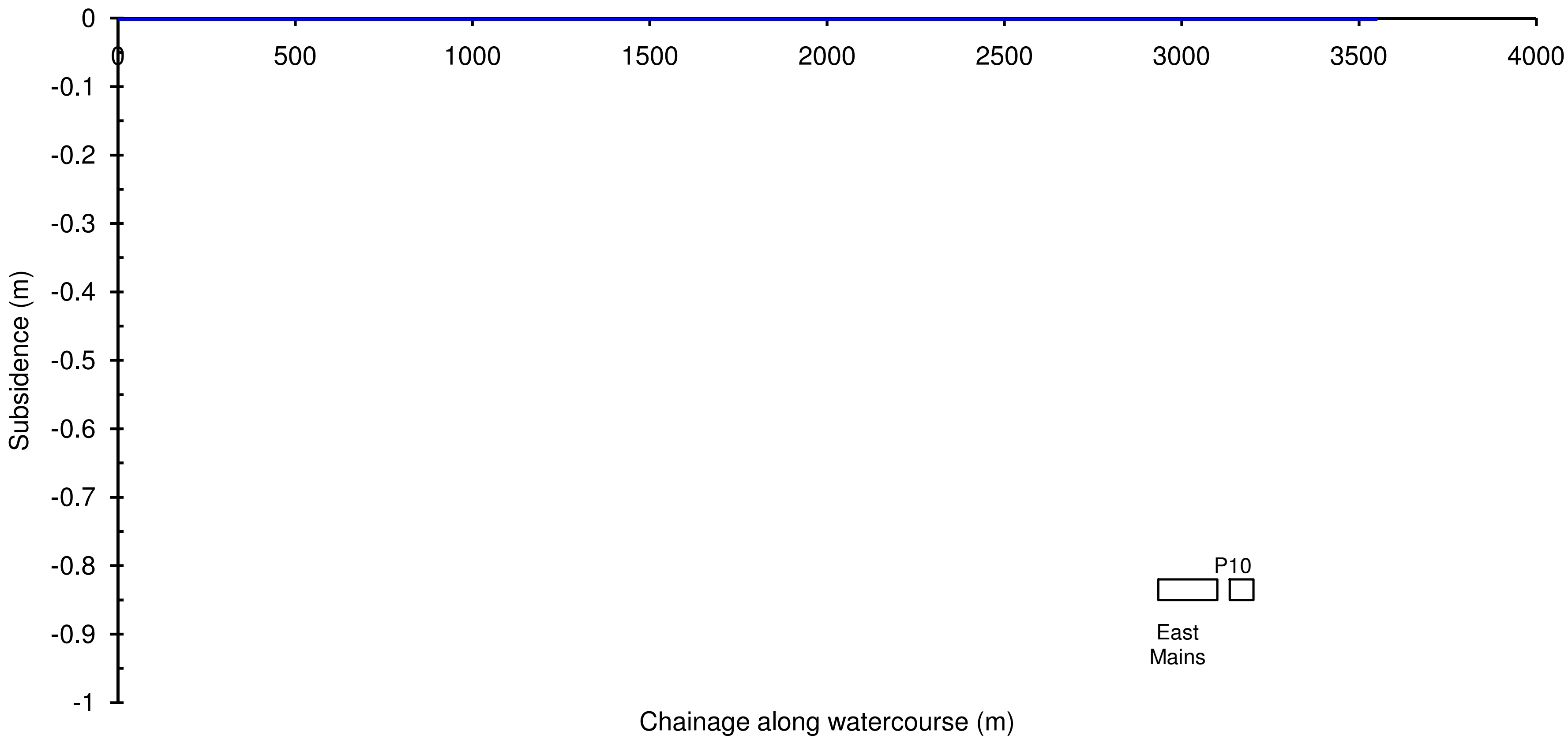
1 in 100 Year ARI Flood Levels



DgS	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn: S.Ditton	Title:	Pre-Mining Topography Isopachs (1 m contours) and Slopes above the Proposed Abel SMP Mine Layout
	Date: 23.11.09		
Ditton Geotechnical Services Pty Ltd		Scale:	1:20,000
		Figure No:	35b



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Pre and Post Mining Surface Profile along Viney Creek due the the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	36a



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited	
	Drawn:	S.Ditton		ABL-001/1	
	Date:	20.11.09	Title:	Predicted Worst-case Subsidence Profile along Viney Creek due the the Proposed Abel Mine Layout	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 36b

Key

Schedule 2 Creek and Buffer Zone (DECCW)

B34 Transmission Towers (Transgrid, 330 kV)

Optic Fibre Cable (Optus)

Sealed Road (Cessnock/ Newcastle City Councils)

Water Supply Pipeline (Hunter Water)

Private Residences/ Commercial Buildings

EA1 P 132 kV Power Line and Poles (Energy Australia)

P 11 kV Domestic Powerline and Poles (Energy Australia)

Proposed Black Hill Land Lot Layout (Preliminary)

Mine Workings (First workings)

Second Workings (Total Pillar Extraction)

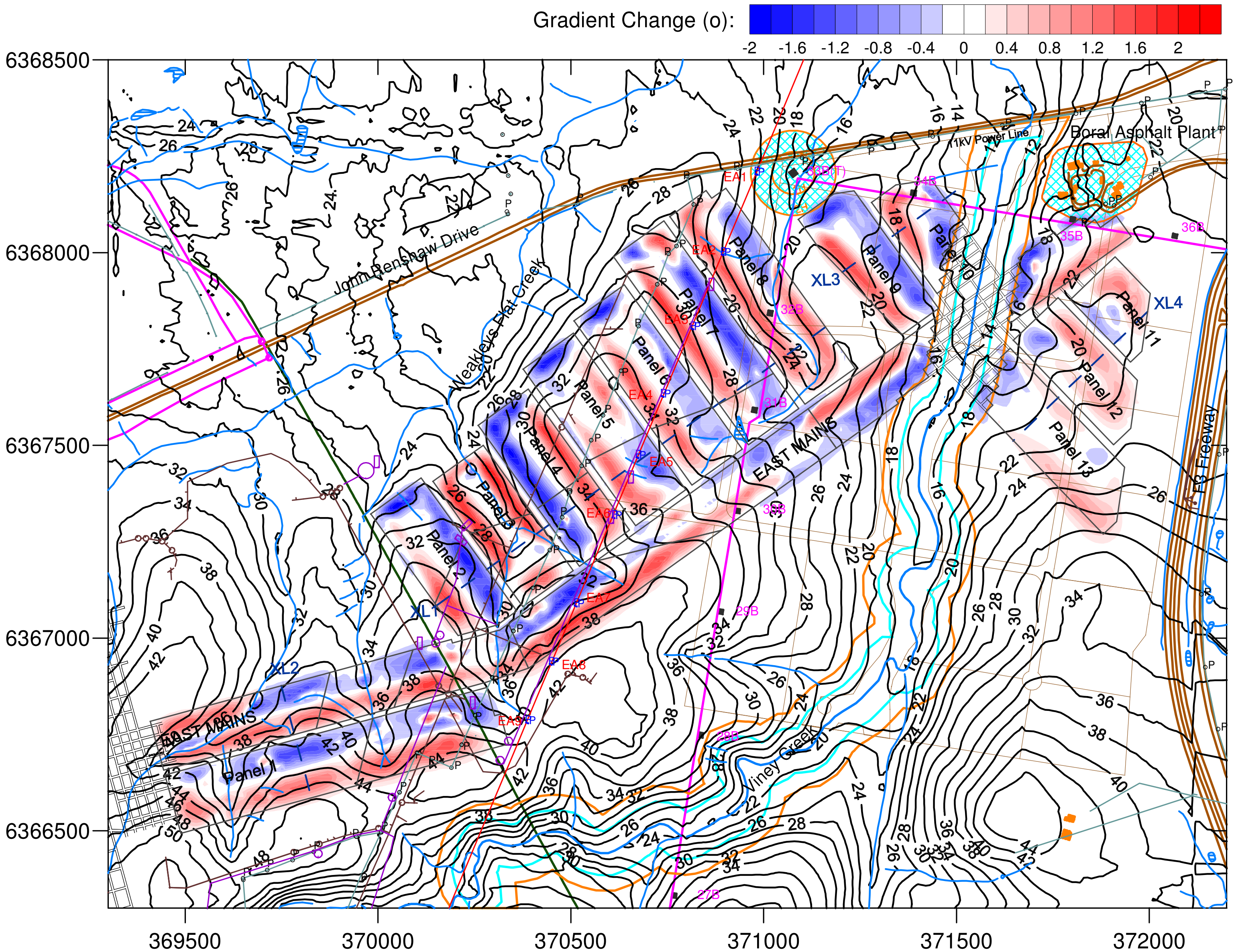
Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones

25 Surface Level Contours (m)

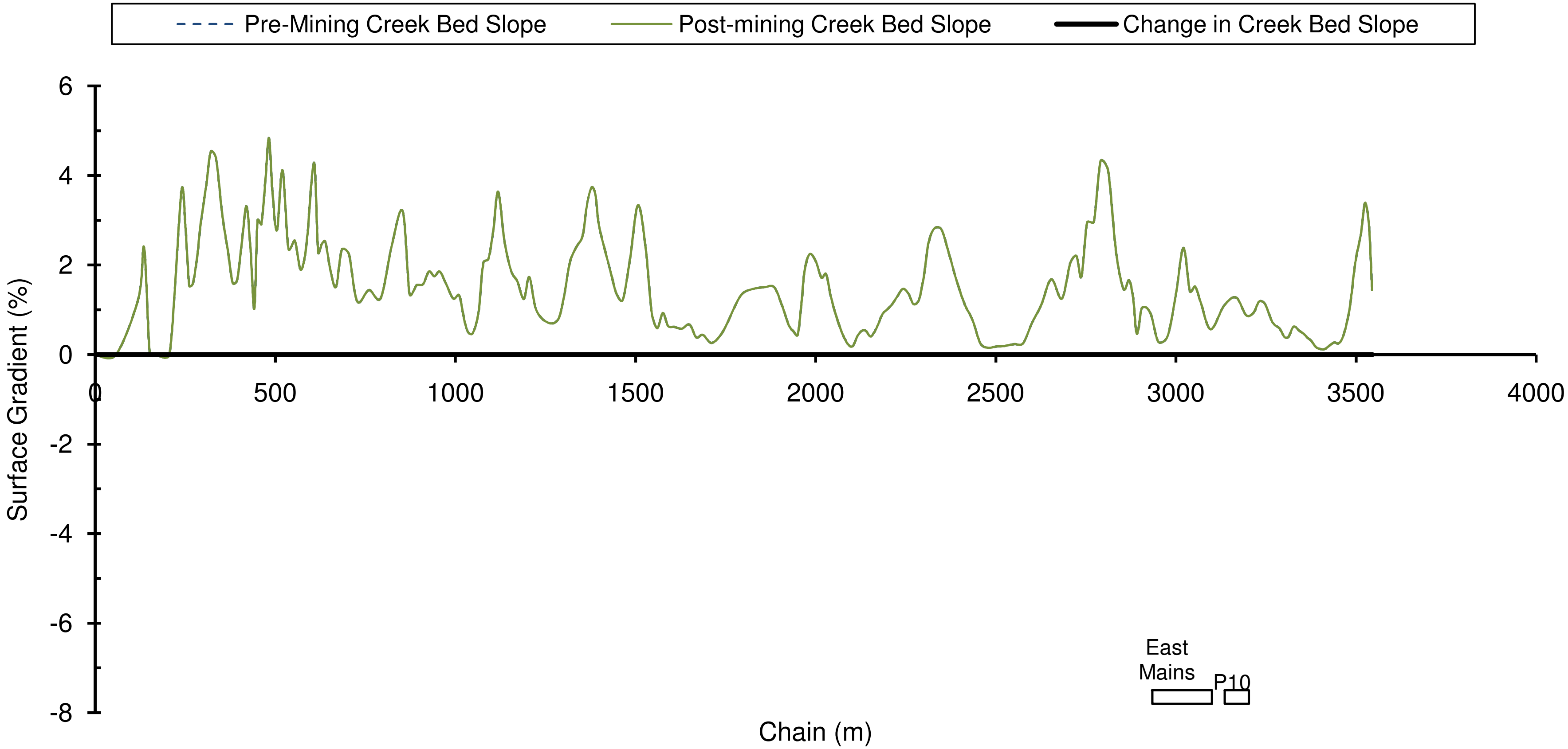
Telstra copper cabling (buried)

Schedule 1 creeks/ gullies

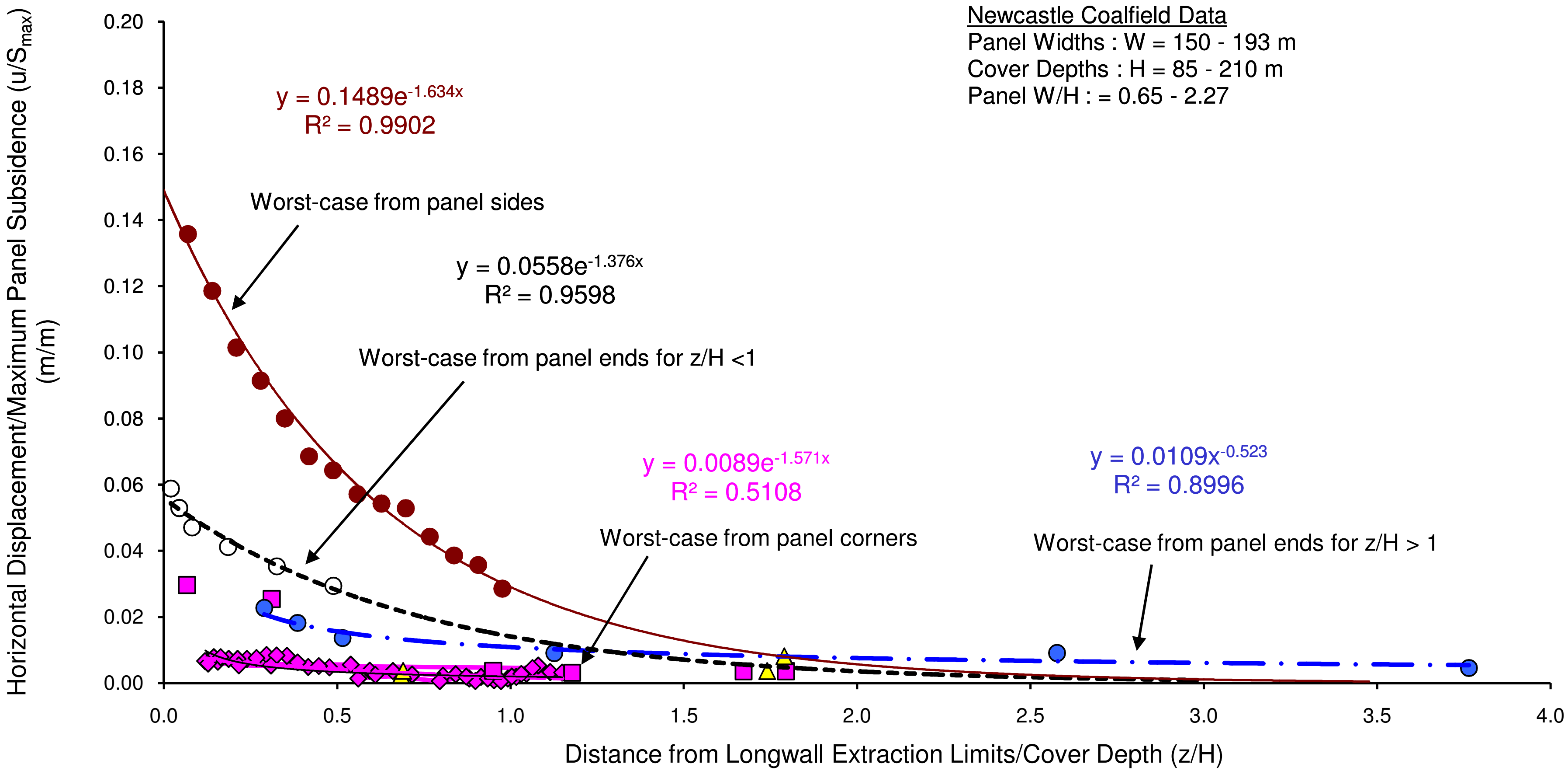
Stock Watering System



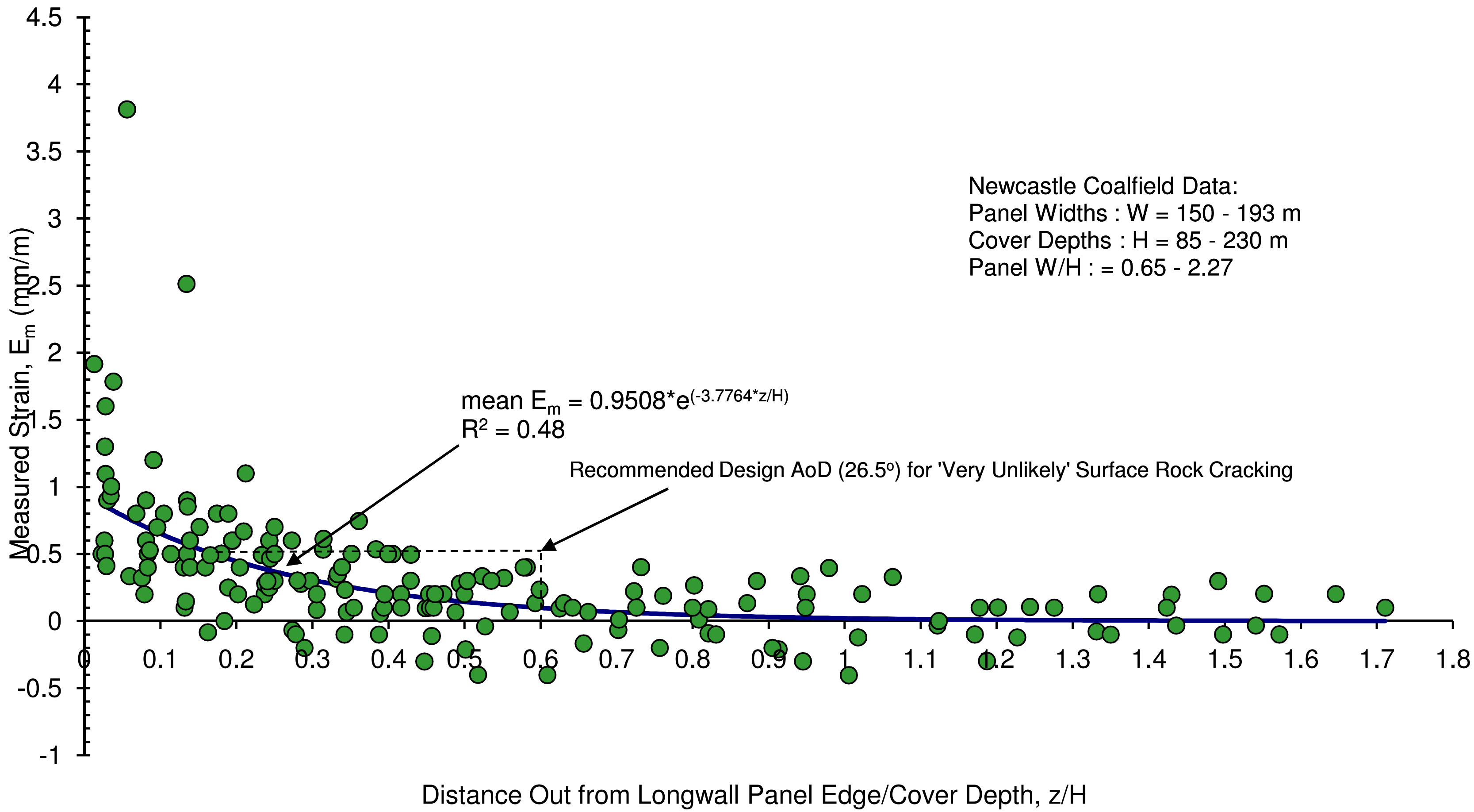
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1
	Drawn:	S.Ditton	Title:	Predicted Worst-Case Slope Gradient Change Contours above the Proposed Abel SMP Mine Layout
	Date:	23.11.09		
Ditton Geotechnical Services Pty Ltd			Scale:	1:20,000
			Figure No:	37a



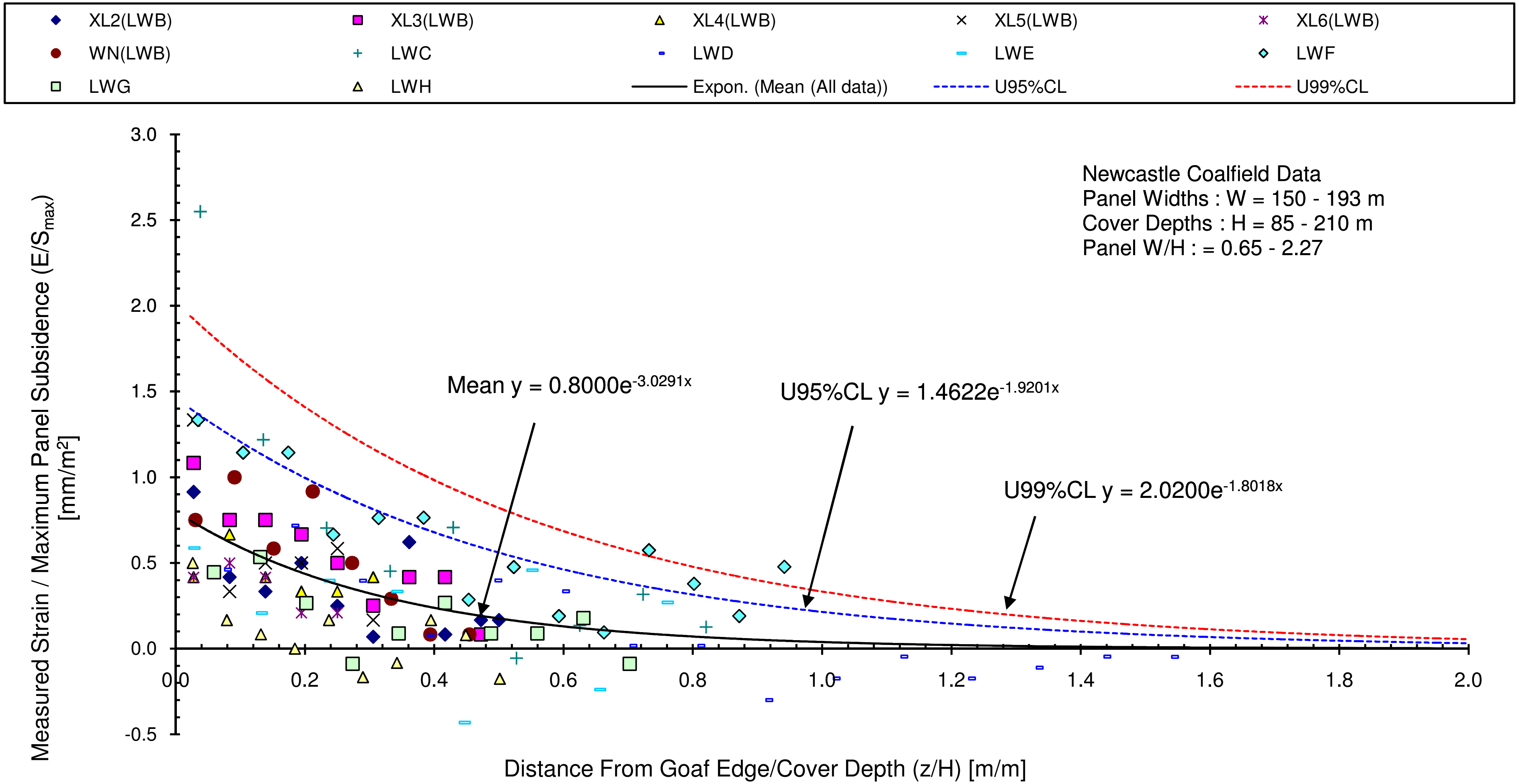
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Predicted Gradient Changes along Viney Creek due the the proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	37b



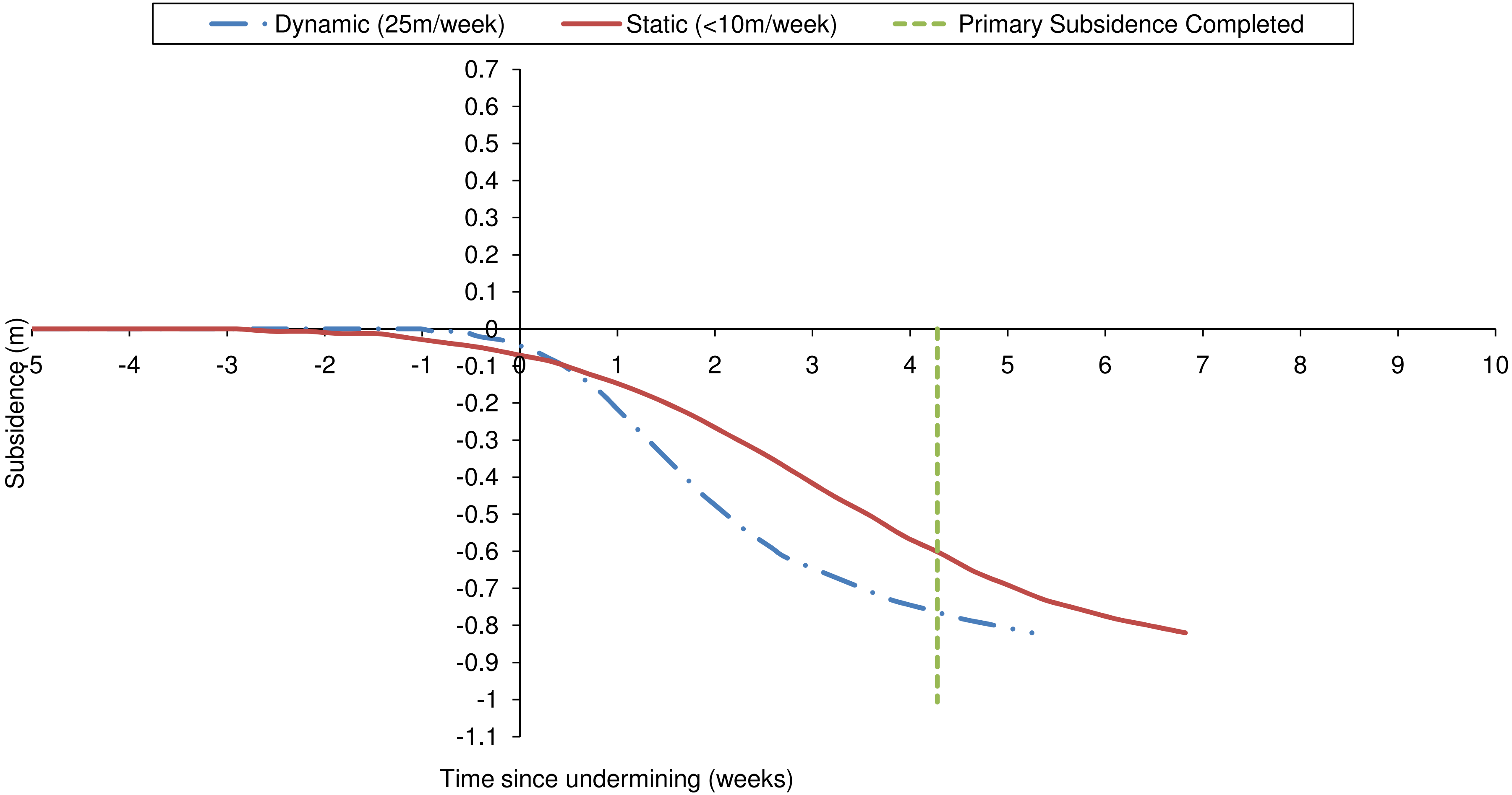
DgS	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1	
	Drawn: S.Ditton	Title:	Combined Empirical Far-Field Displacement Prediction Models for Longwall Panel Sides, Ends and Corners.	
	Date: 02.04.09			
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No: 38



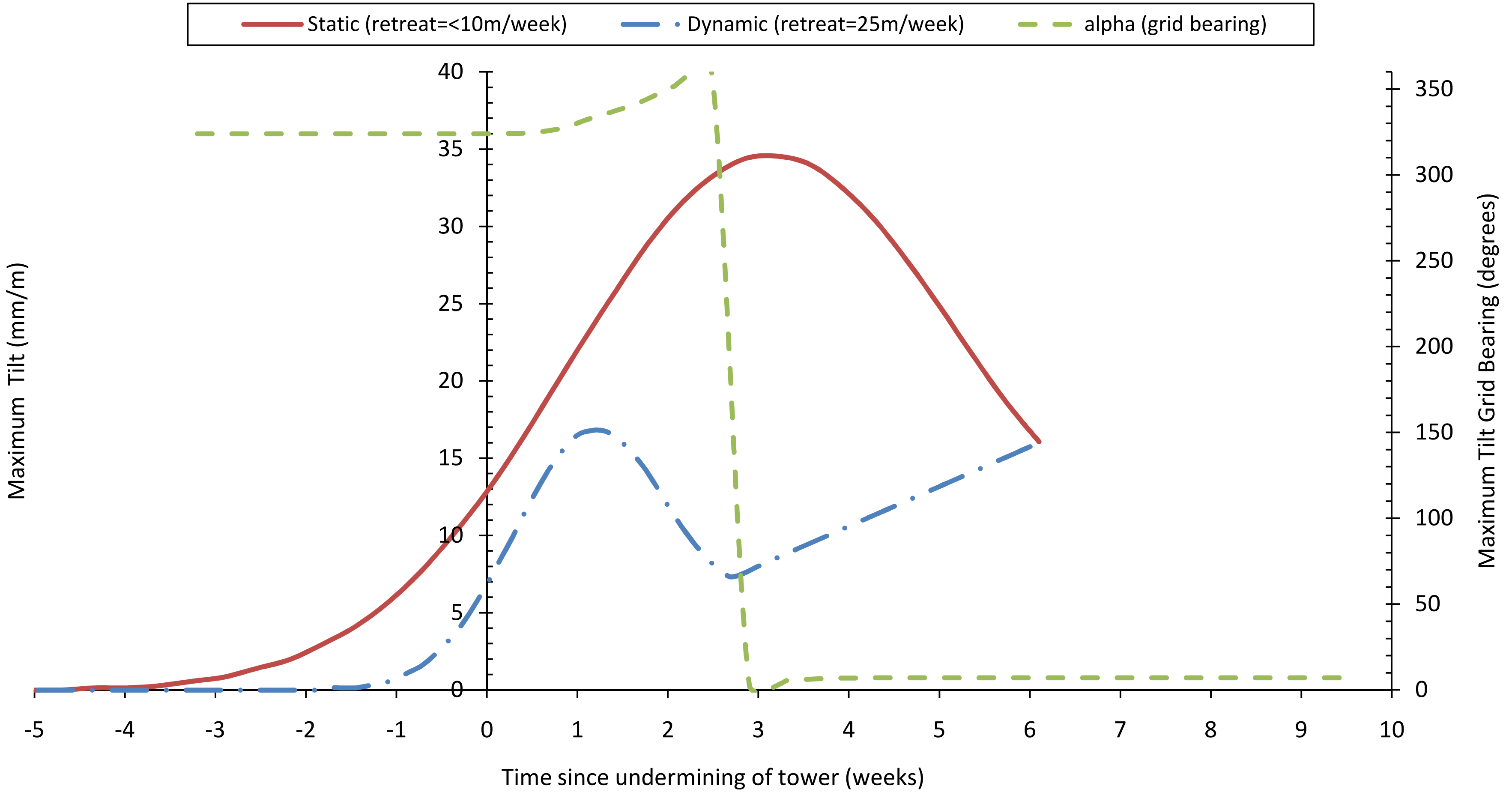
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited
	Drawn:	S.Ditton		ABL-001/1
	Date:	02.04.09	Title:	Measured Far-Field Strain Database Using Cummulative Steel Tape from Longwall Sides in the Newcastle Coalfield
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	39a



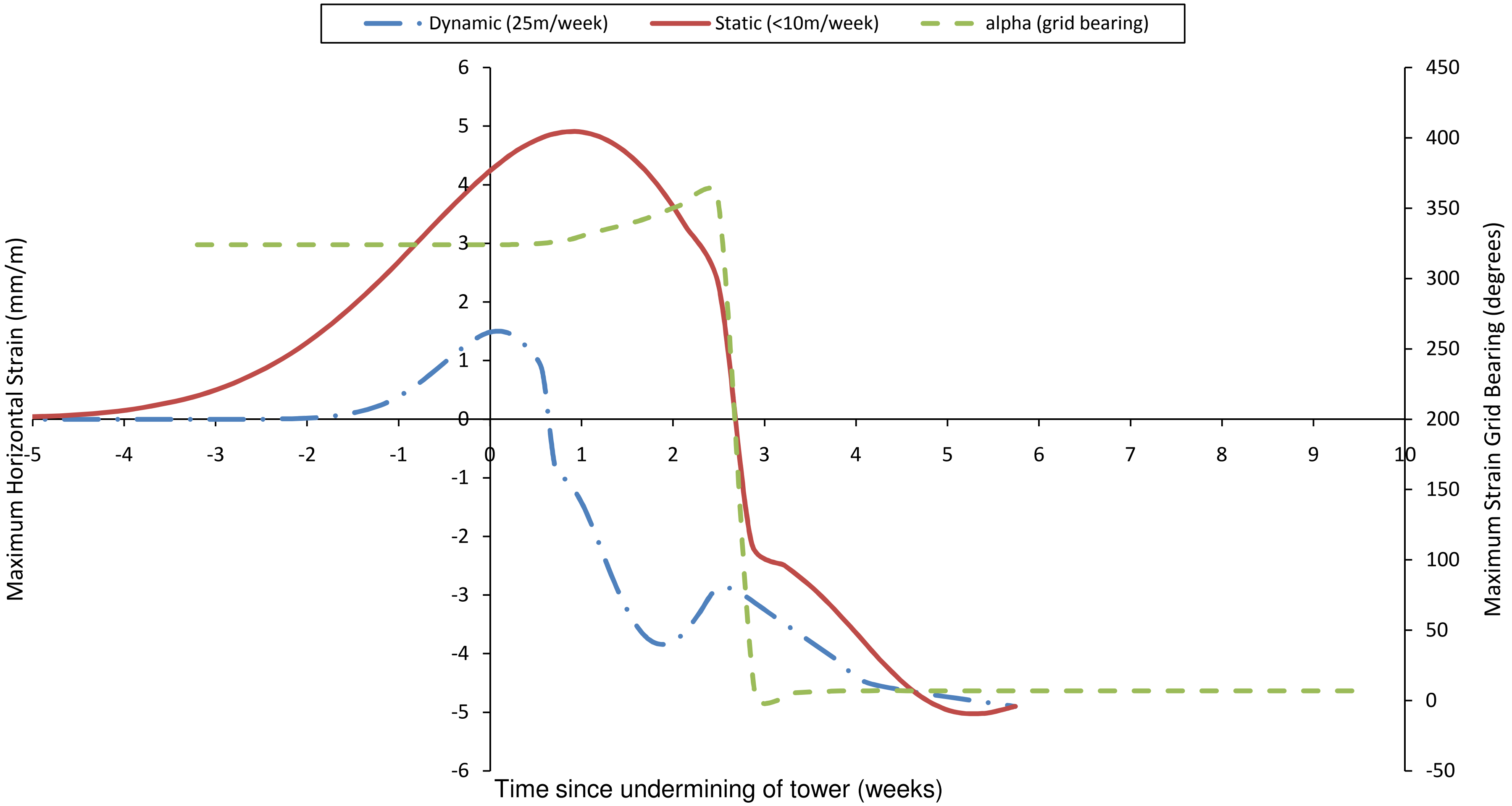
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	02.05.09	Title:	Empirical Far-Field Strain Prediction Model Using Cummulative Steel Tape Measurements from Longwall Sides in the Newcastle Coalfield		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	39b



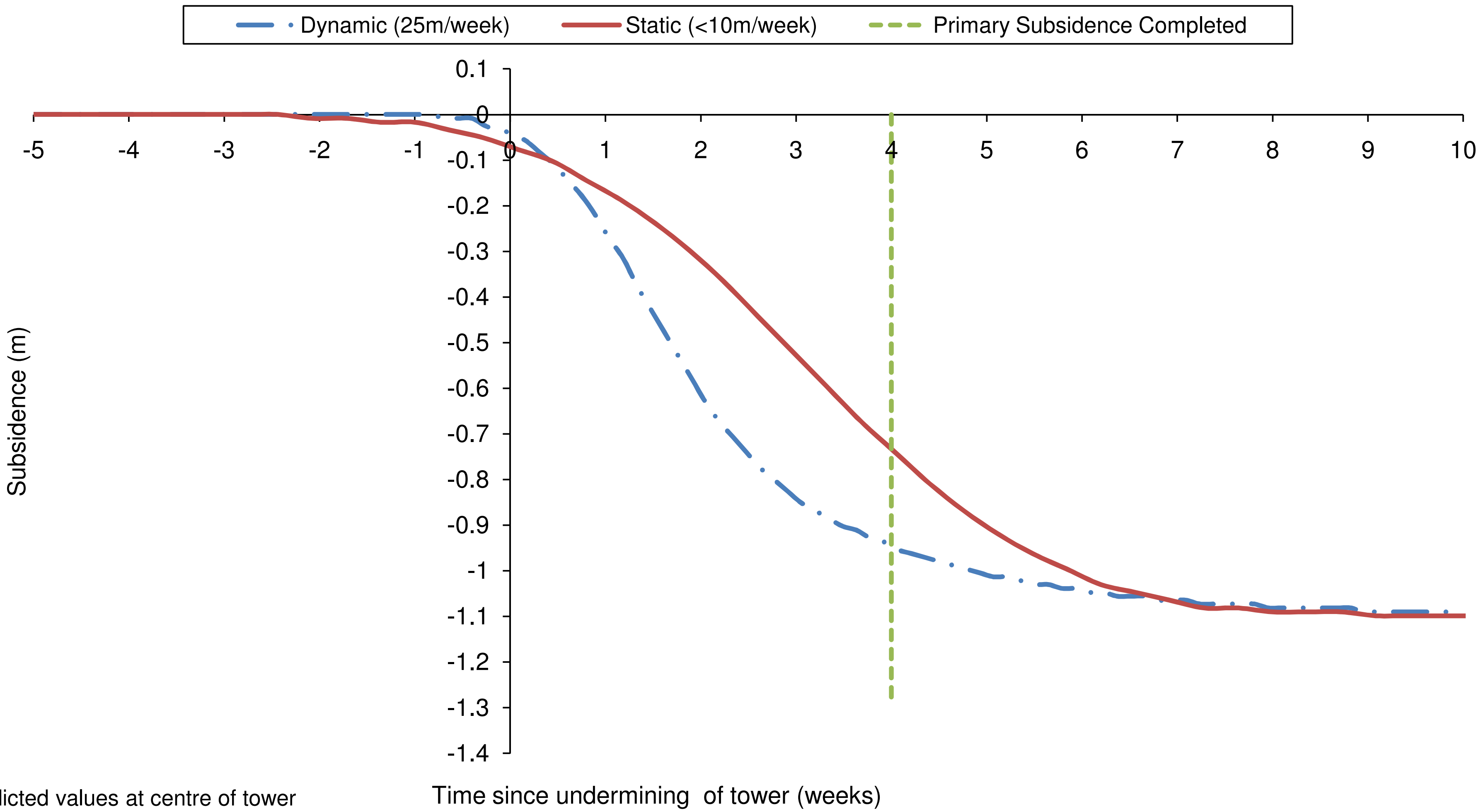
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Ltd ABL-001/1			
	Drawn:	S.Ditton					
	Date:	20.11.09	Title:	Subsidence Development at Tower 31B Above the Proposed SMP Mining Layout - see Figure 1 for Location			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	40a	



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Ltd ABL-001/1	
	Drawn:	S.Ditton			
	Date:	20.11.09	Title:	Tilt Development at Tower 31B Above the Proposed SMP Mining Layout - see Figure 1 for Location	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 40b

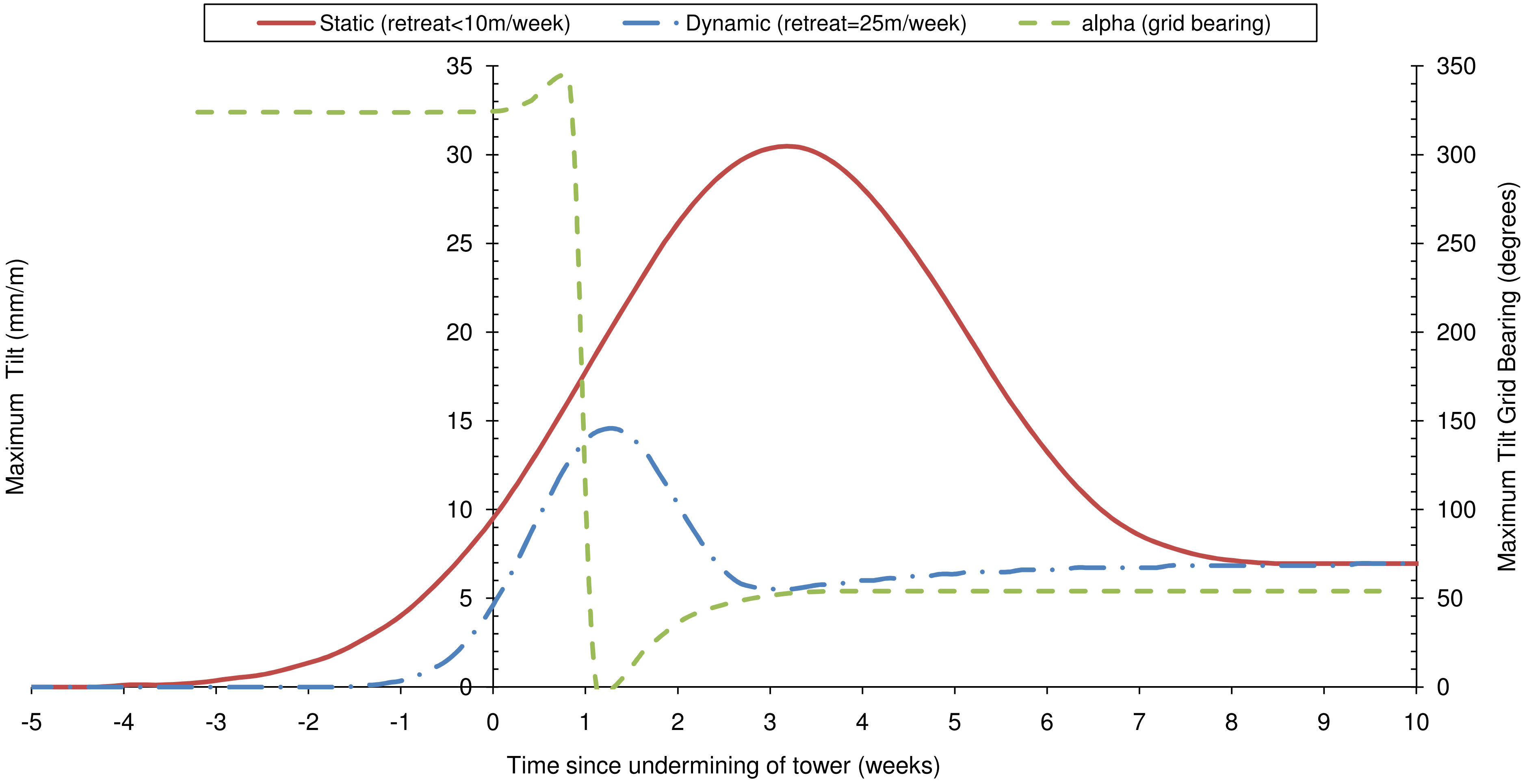


DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Ltd ABL-001/1
	Drawn:	S.Ditton		
	Date:	20.11.09	Title:	Strain Development at Tower 31B Above the Proposed SMP Mining Layout - see Figure 1 for Location
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	40c

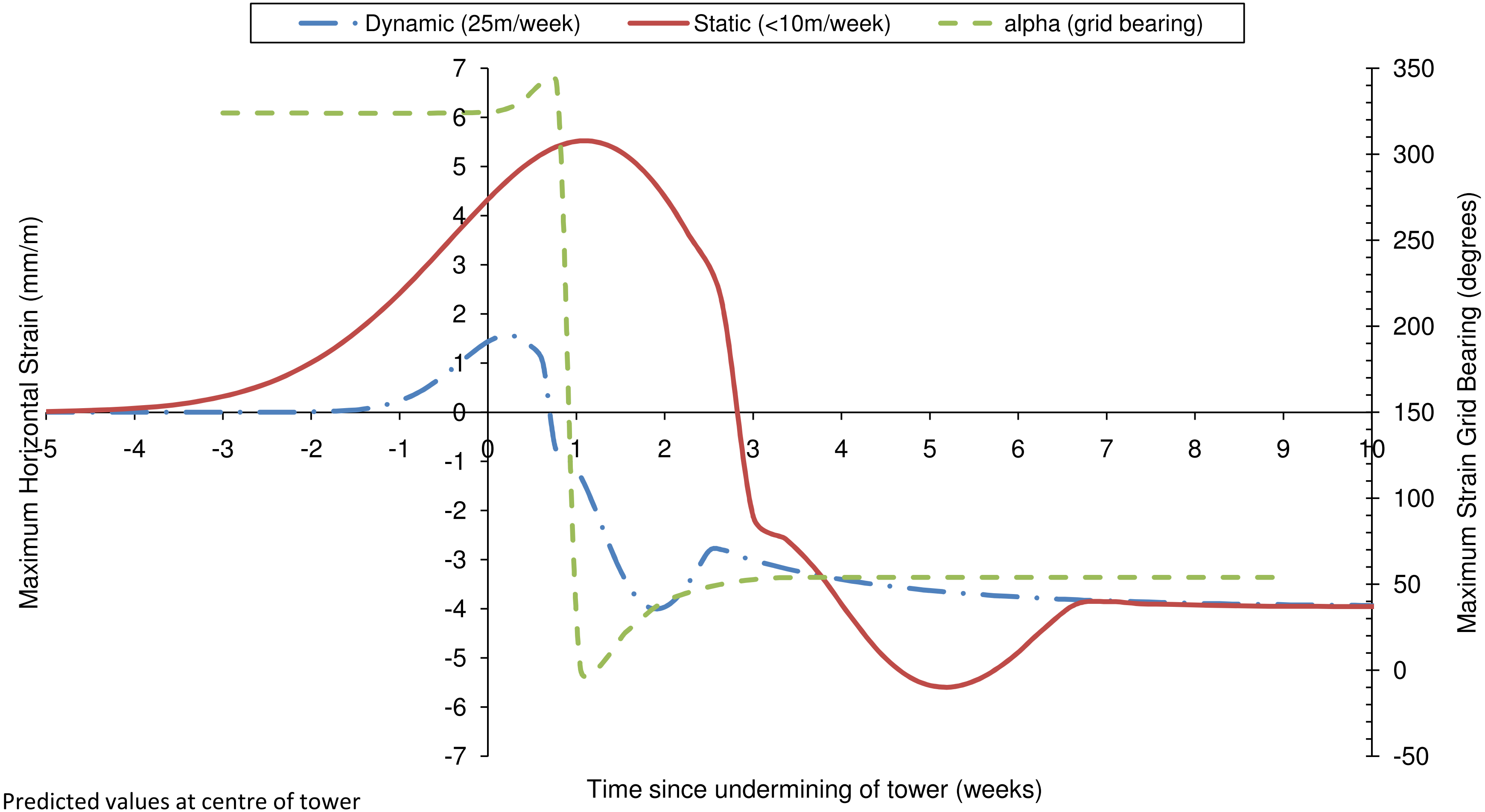


Note: Predicted values at centre of tower

DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Ltd ABL-001/1
	Drawn:	S.Ditton		
	Date:	20.11.09	Title:	Subsidence Development at Tower 32B Above the Proposed SMP Mining Layout - see Figure 1 for Location
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 41a

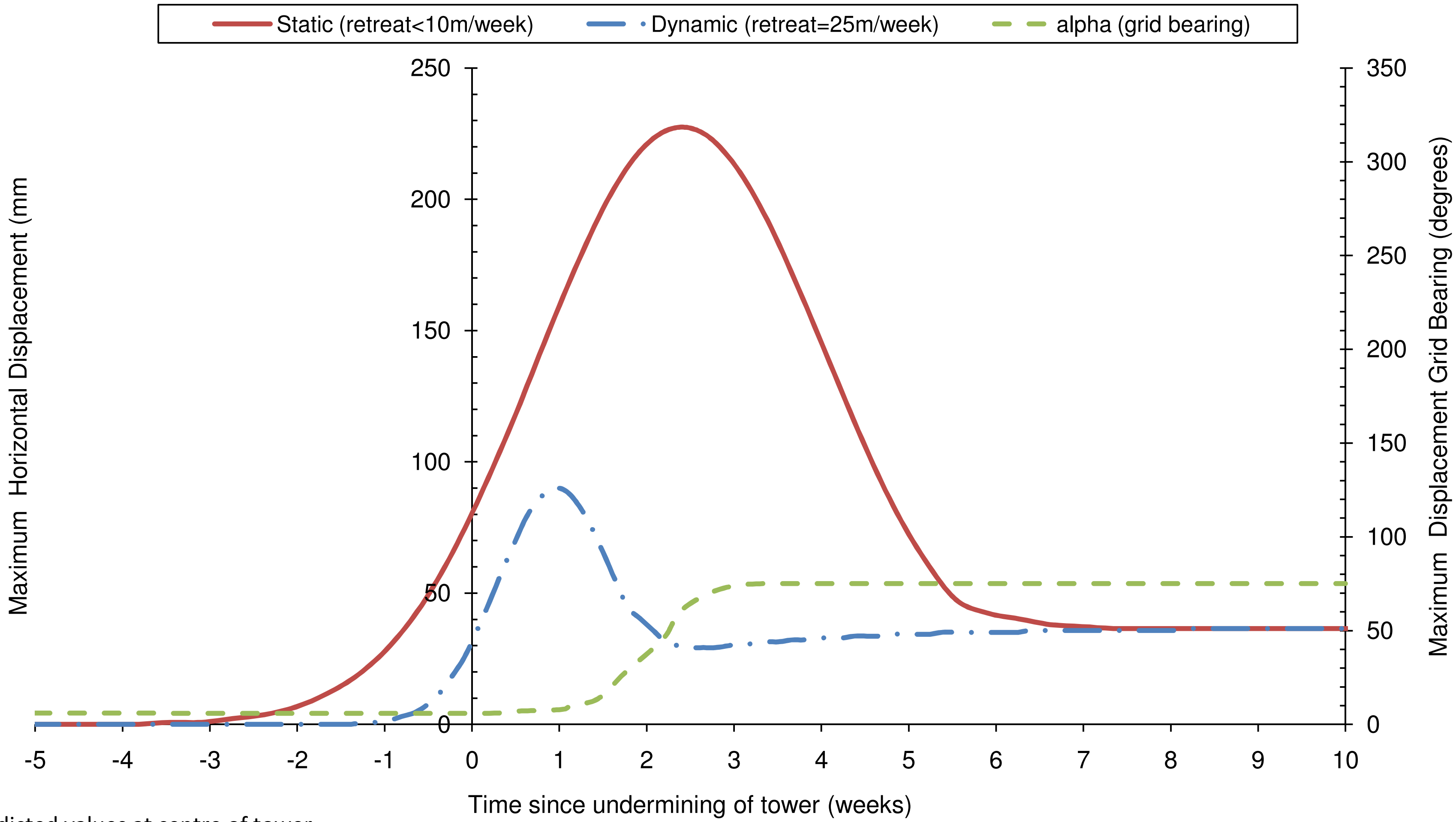


DgS						
	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Ltd ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Tilt Development at Tower 32B Above the Proposed SMP Mining Layout - see Figure 1 for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	41b



Note: Predicted values at centre of tower

DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Ltd
	Drawn:	S.Ditton		ABL-001/1
	Date:	20.11.09	Title:	Strain Development at Tower 32B Above the Proposed SMP Mining Layout - see Figure 1 for Location
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	41c



Note: Predicted values at centre of tower

DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Ltd ABL-001/1
	Drawn:	S.Ditton		
	Date:	20.11.09	Title:	Horizontal Displacement Development at Tower 32B Above the Proposed SMP Mining Layout - see Figure 1 for Location
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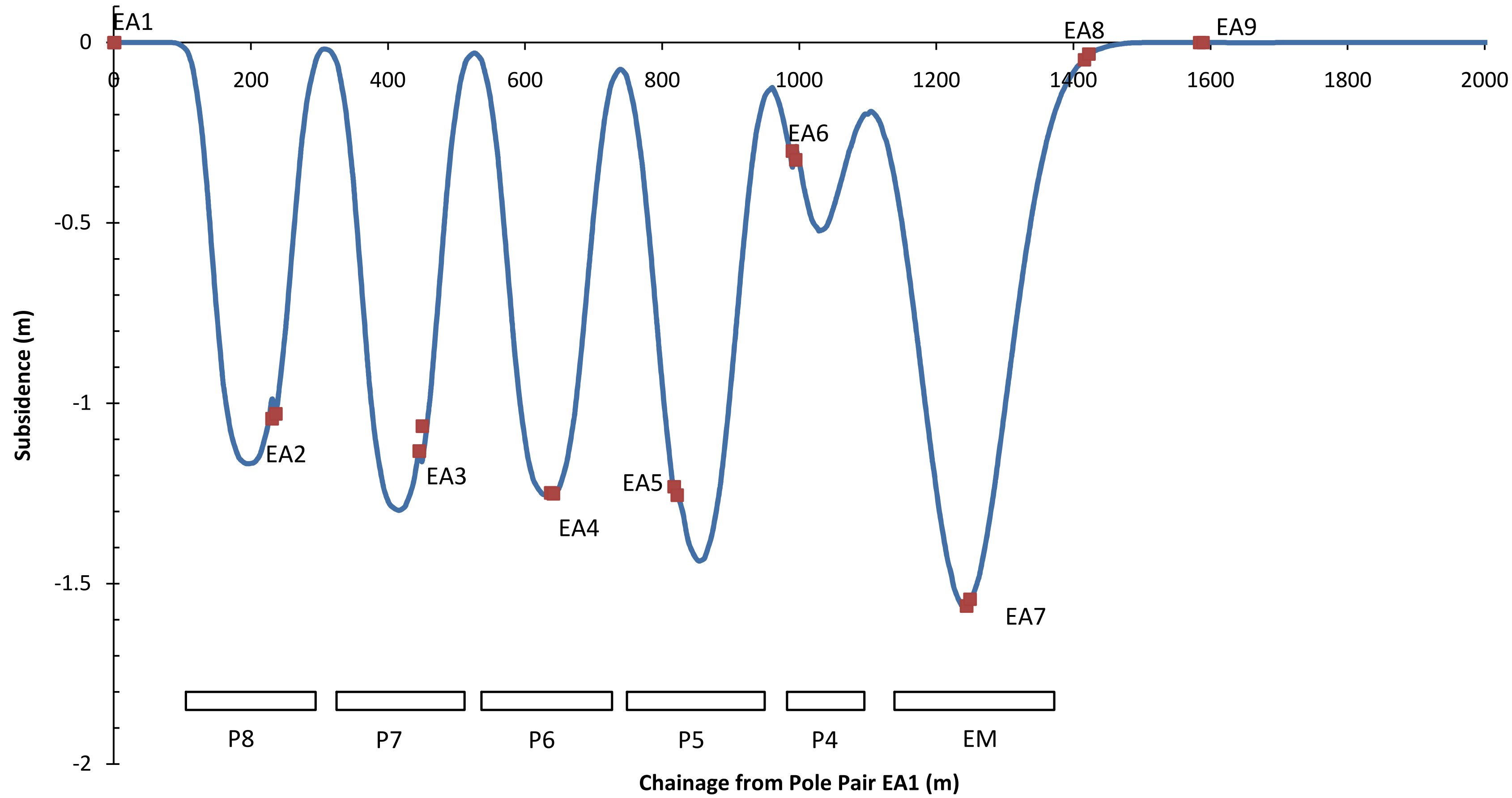
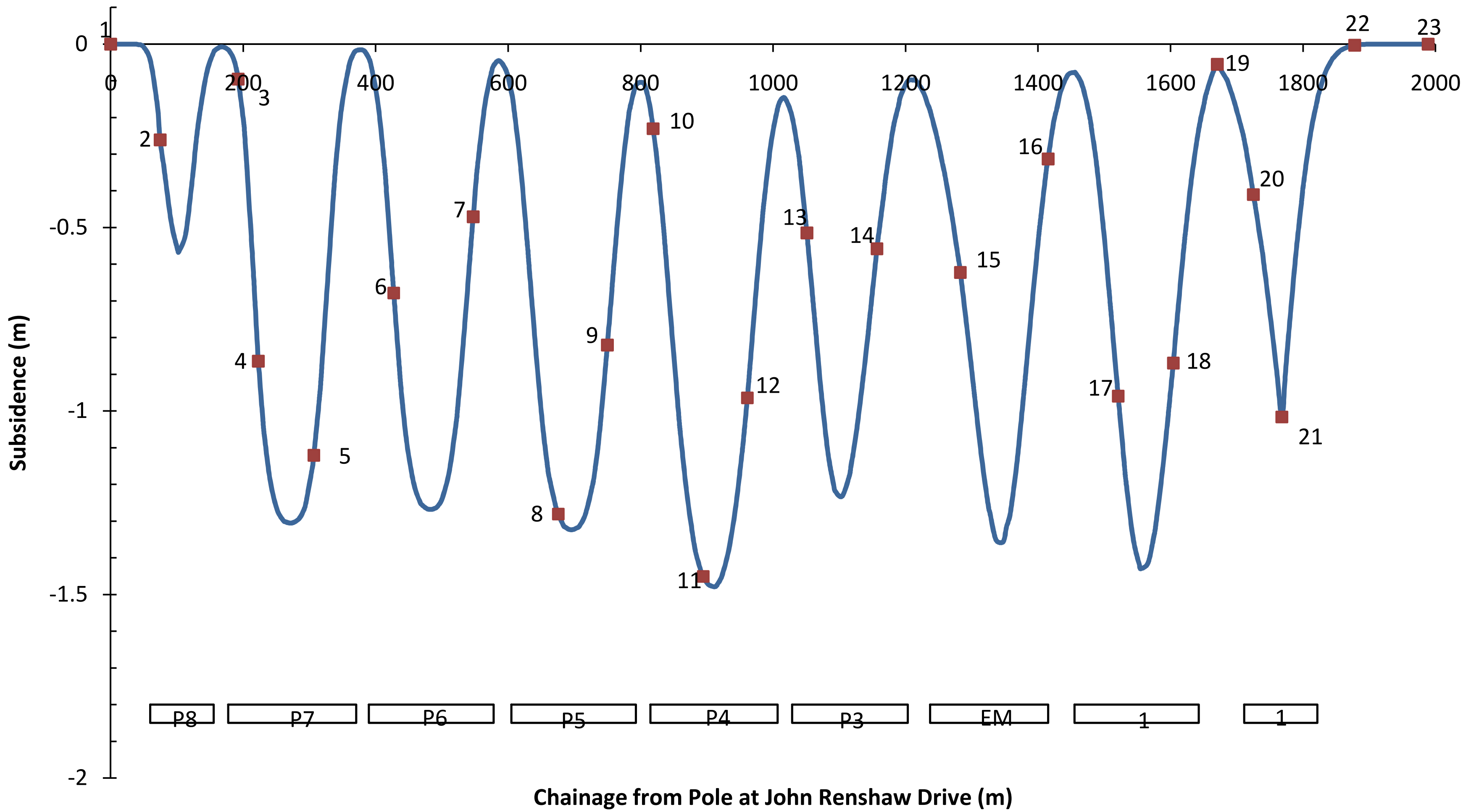
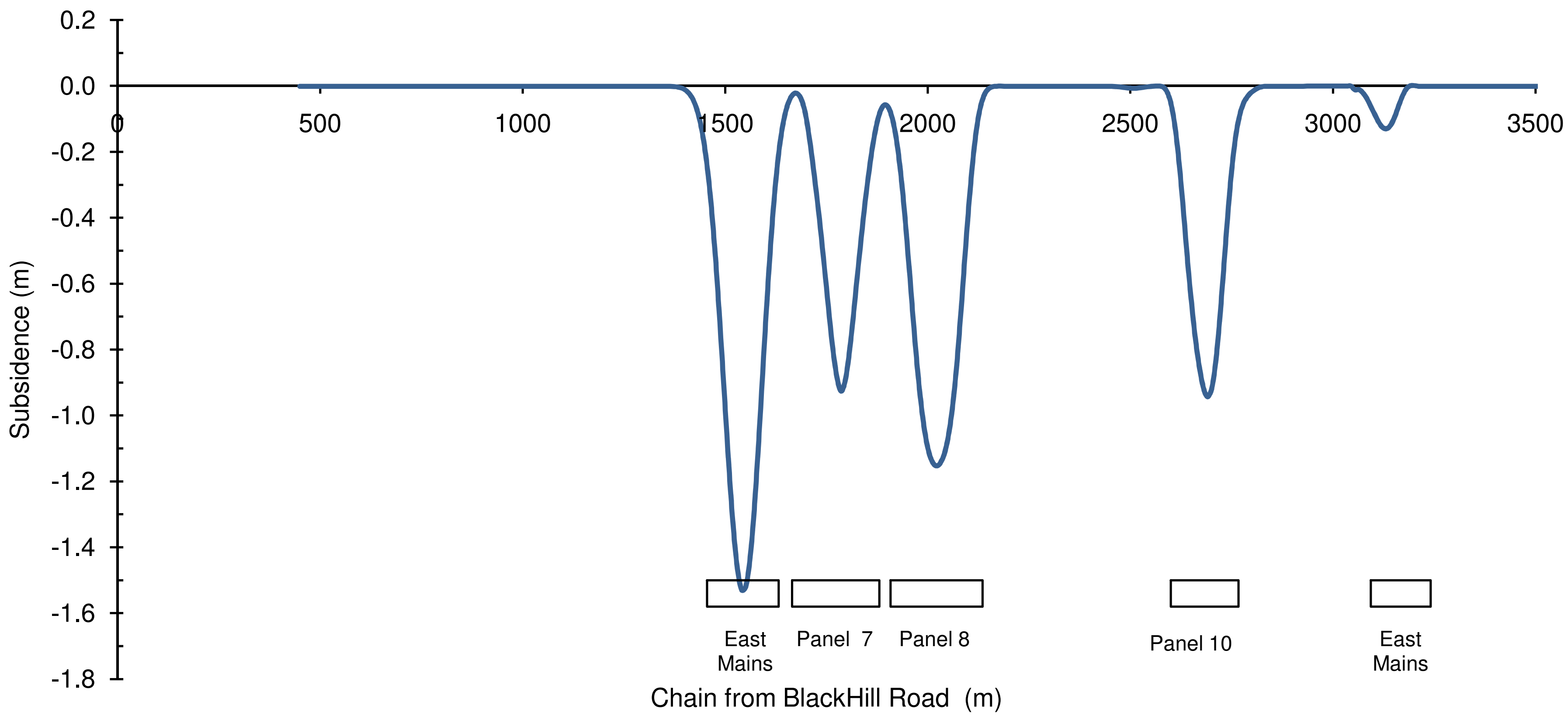


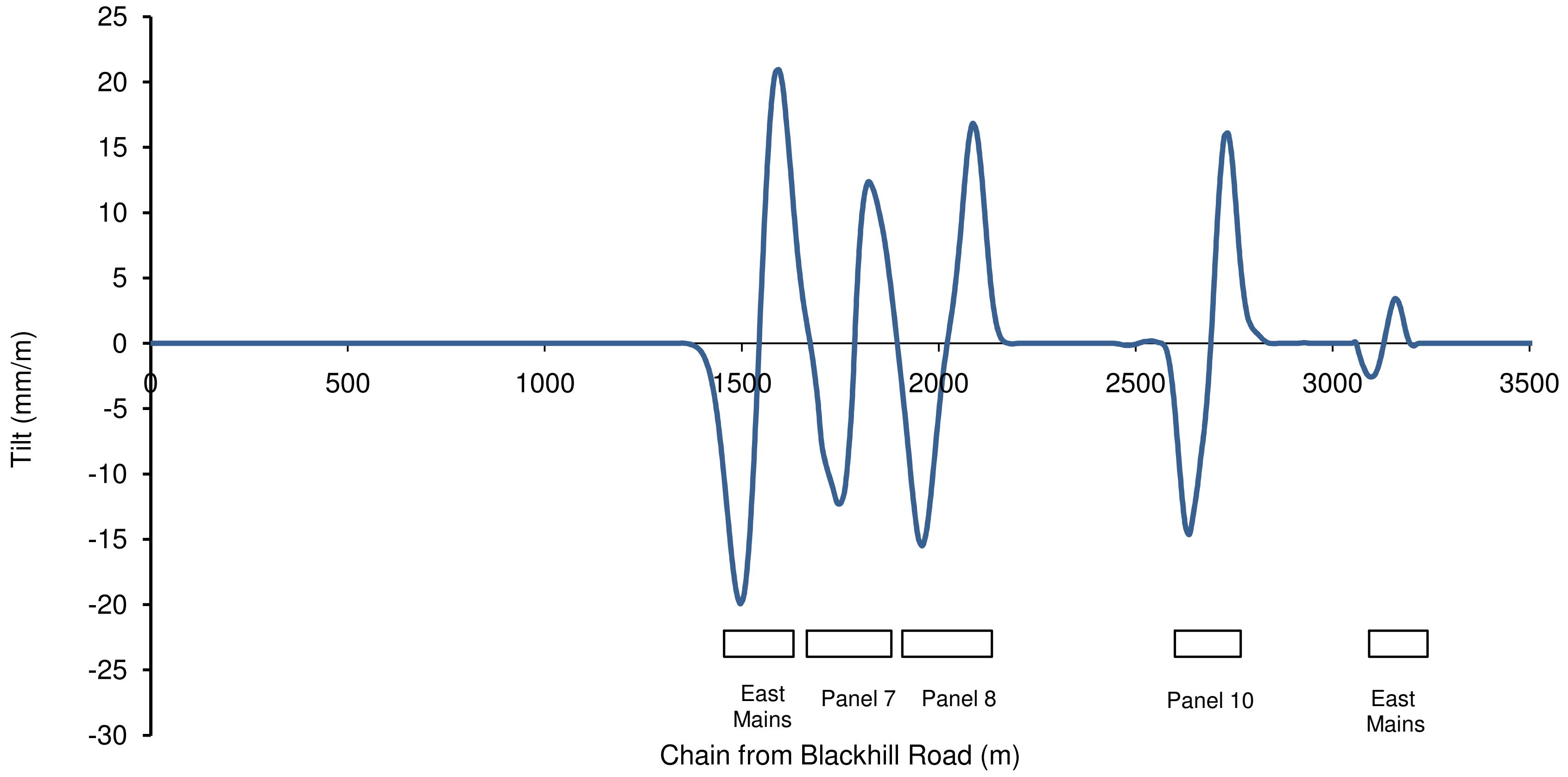
DgS	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn: S.Ditton		ABL-001/1		
	Date: 20.11.09	Title:	Worst-case Final Subsidence Profile Predictions Along the 132 kV Energy Australia Easement and Stock Watering System due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No:	42



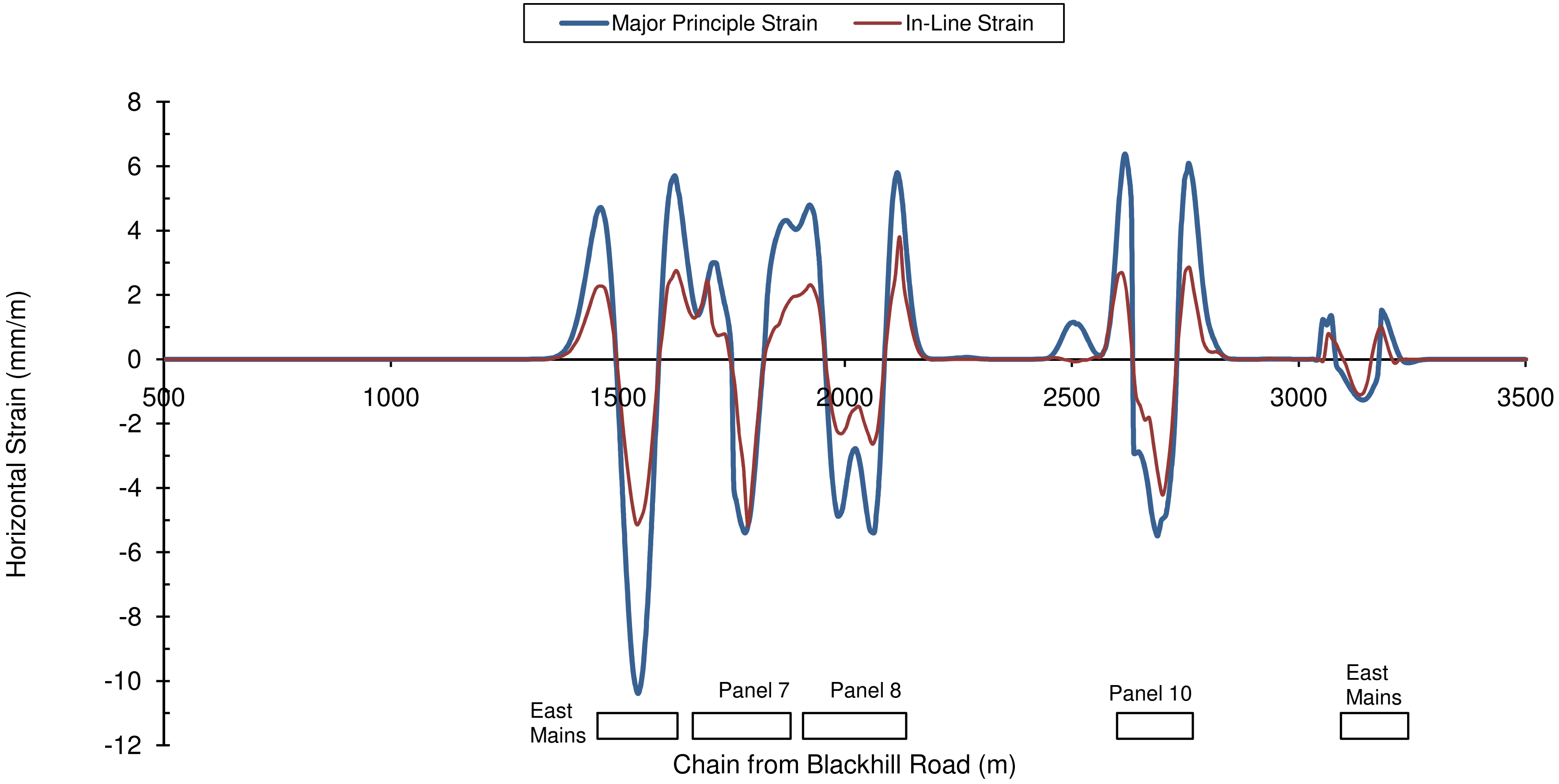
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1	
	Drawn:	S.Ditton			
	Date:	20.11.09	Title:	Worst-case Final Subsidence Profile Predictions Along the 11 kV Energy Australia Easement Poles (1 - 23) due to the Proposed Abel Mine Layout	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 43



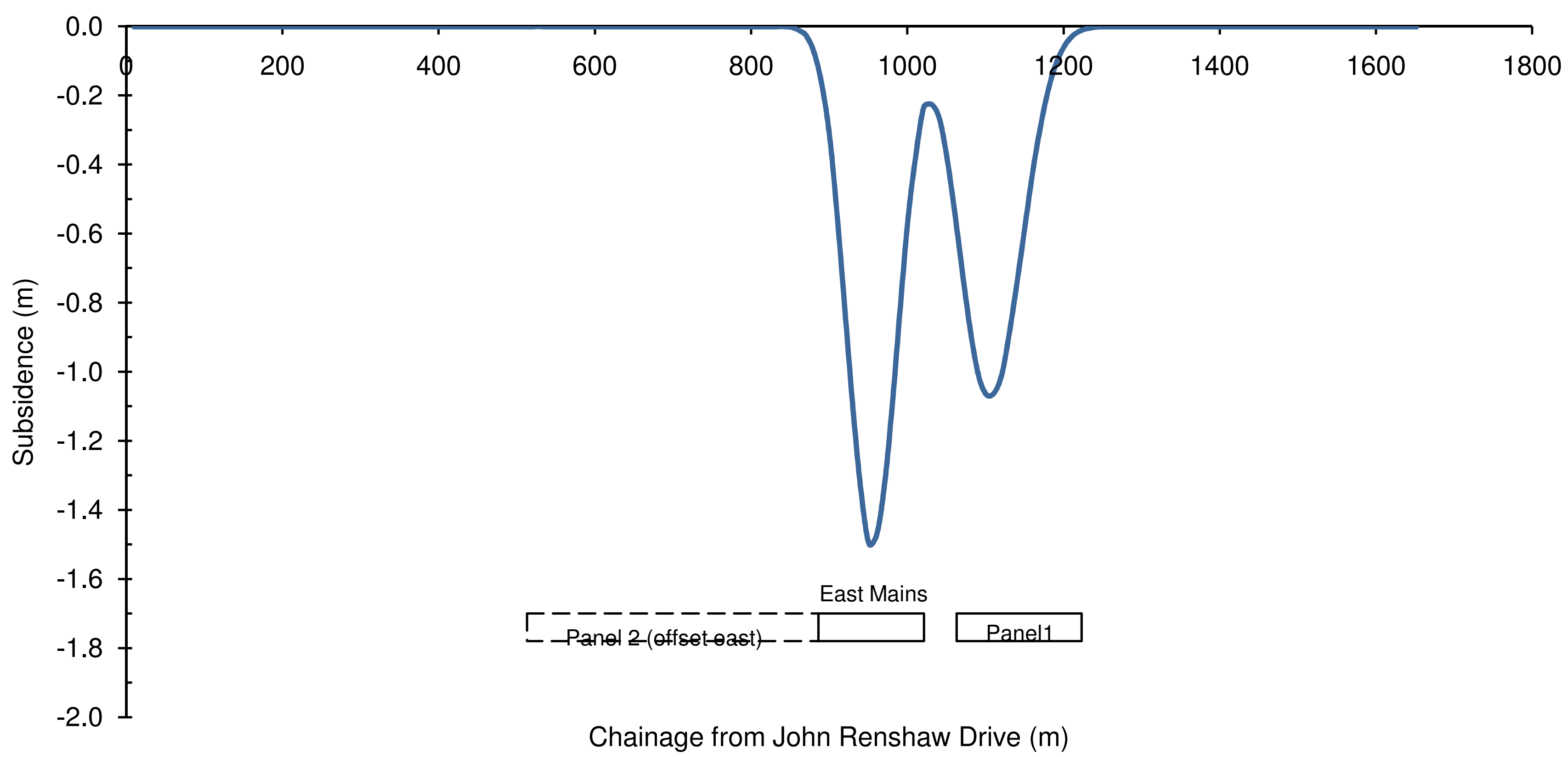
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Subsidence Profile Predictions Along the Optus Fibre Optic Cable Easement due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	44a



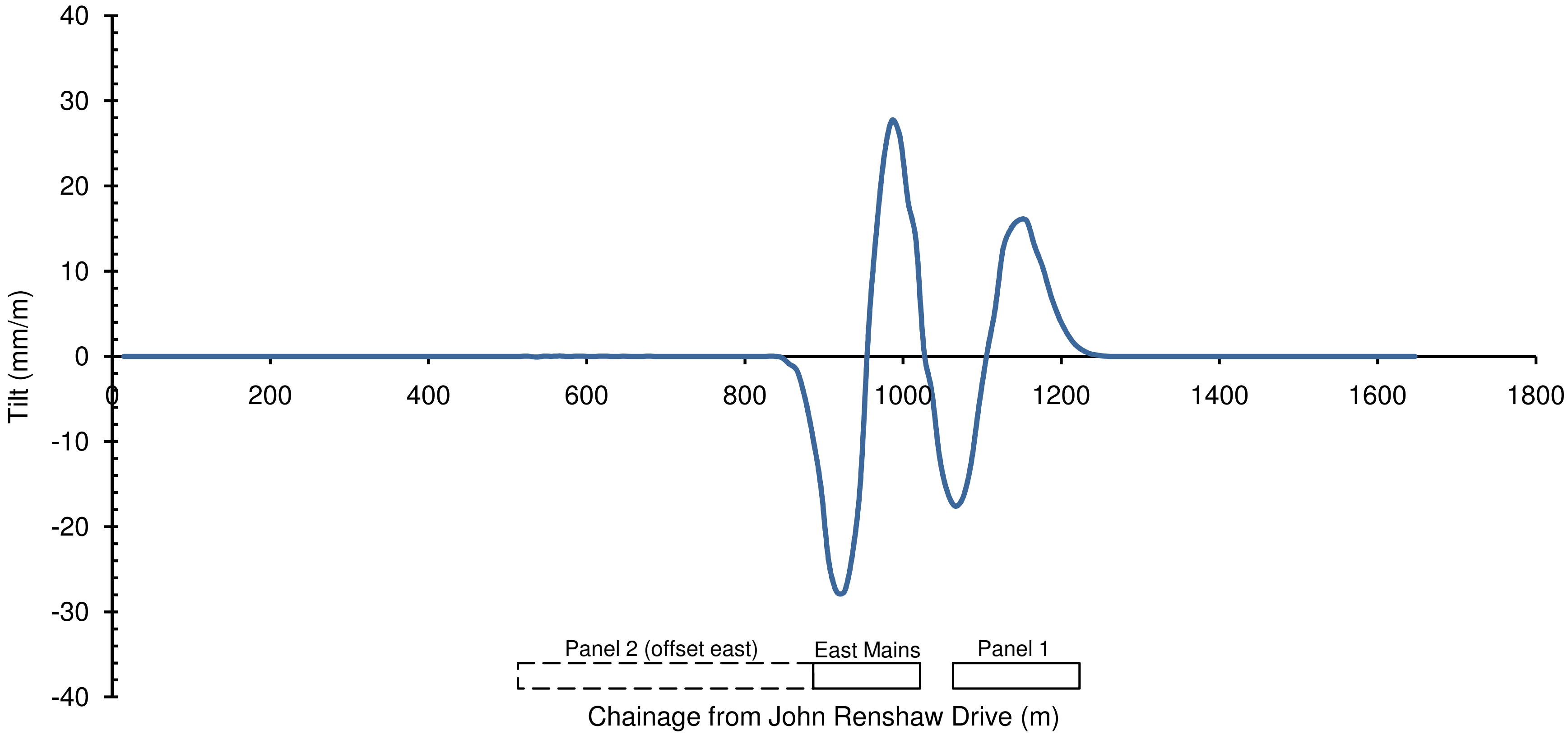
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final In-Line Tilt Profile Predictions Along the Optus Fibre Optic Cable Easement due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	45b



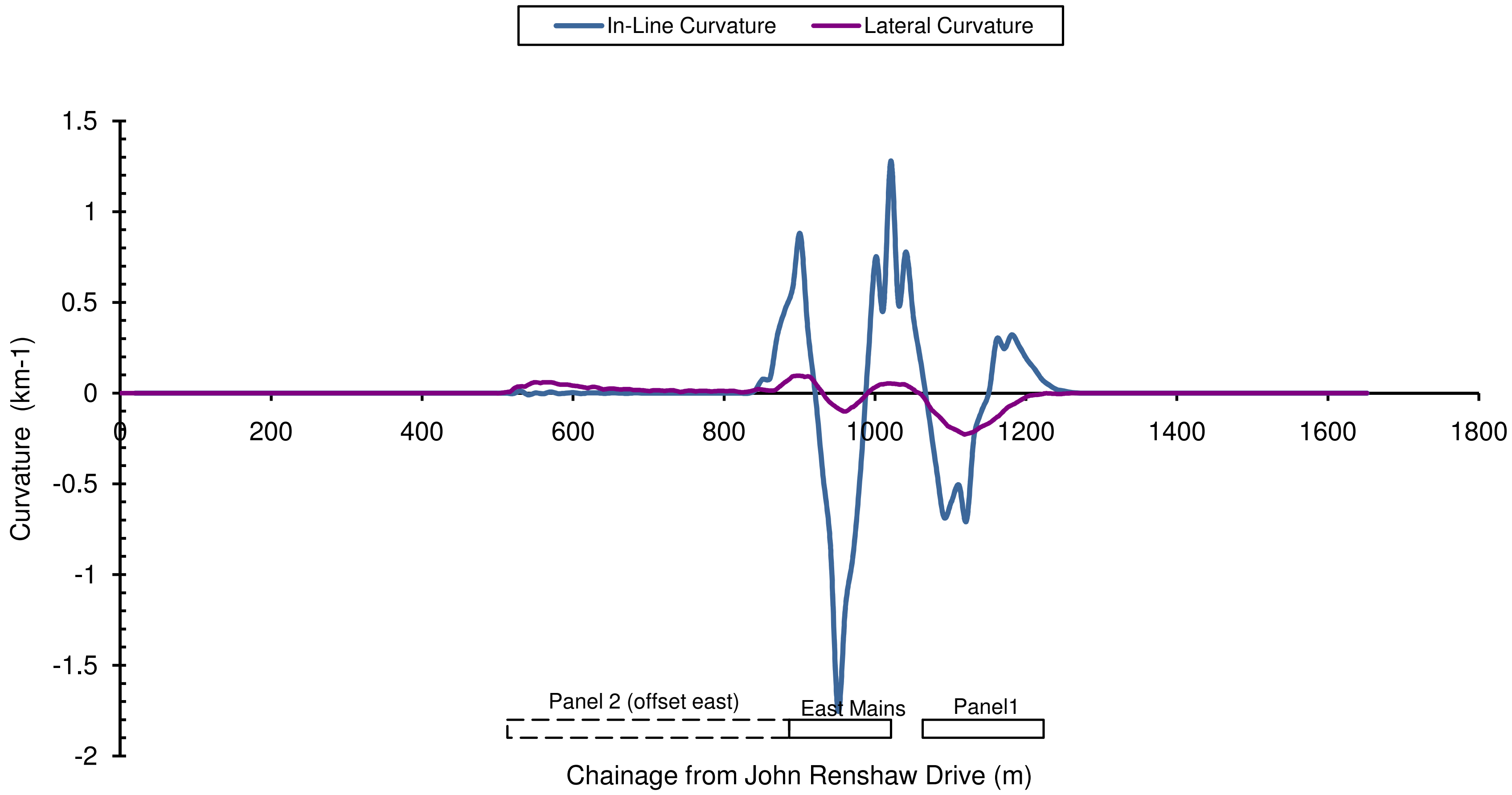
DgS	Engineer: S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1	
	Drawn: S.Ditton			
	Date: 20.11.09	Title:	Worst-case Final Strain Profile Predictions Along the Optus Fibre Optic Cable Easement due to the Proposed Abel Mine Layout	
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No: 44c



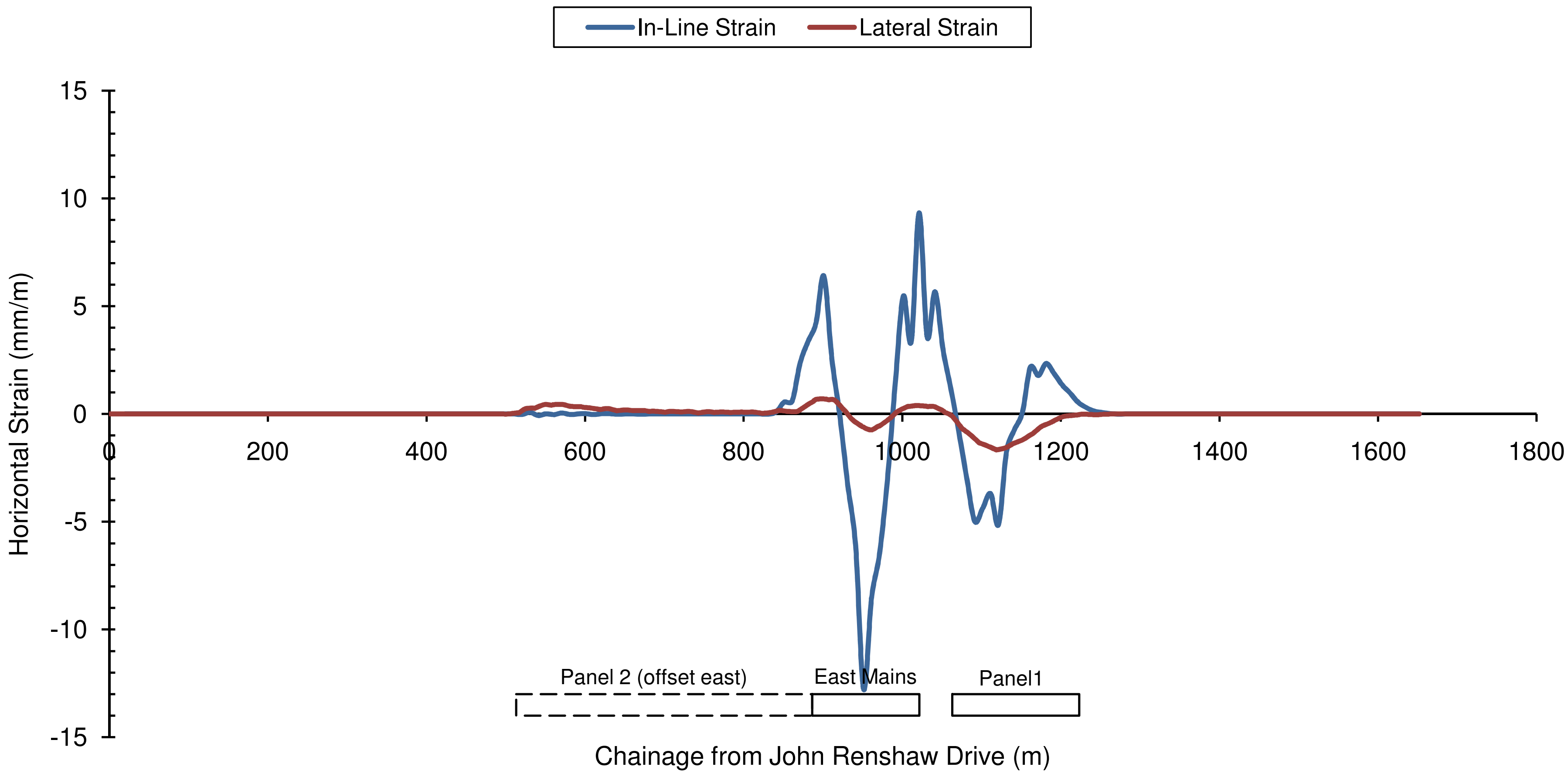
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Subsidence Profile Predictions Along the Hunter Water Pipeline Easement due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	45a



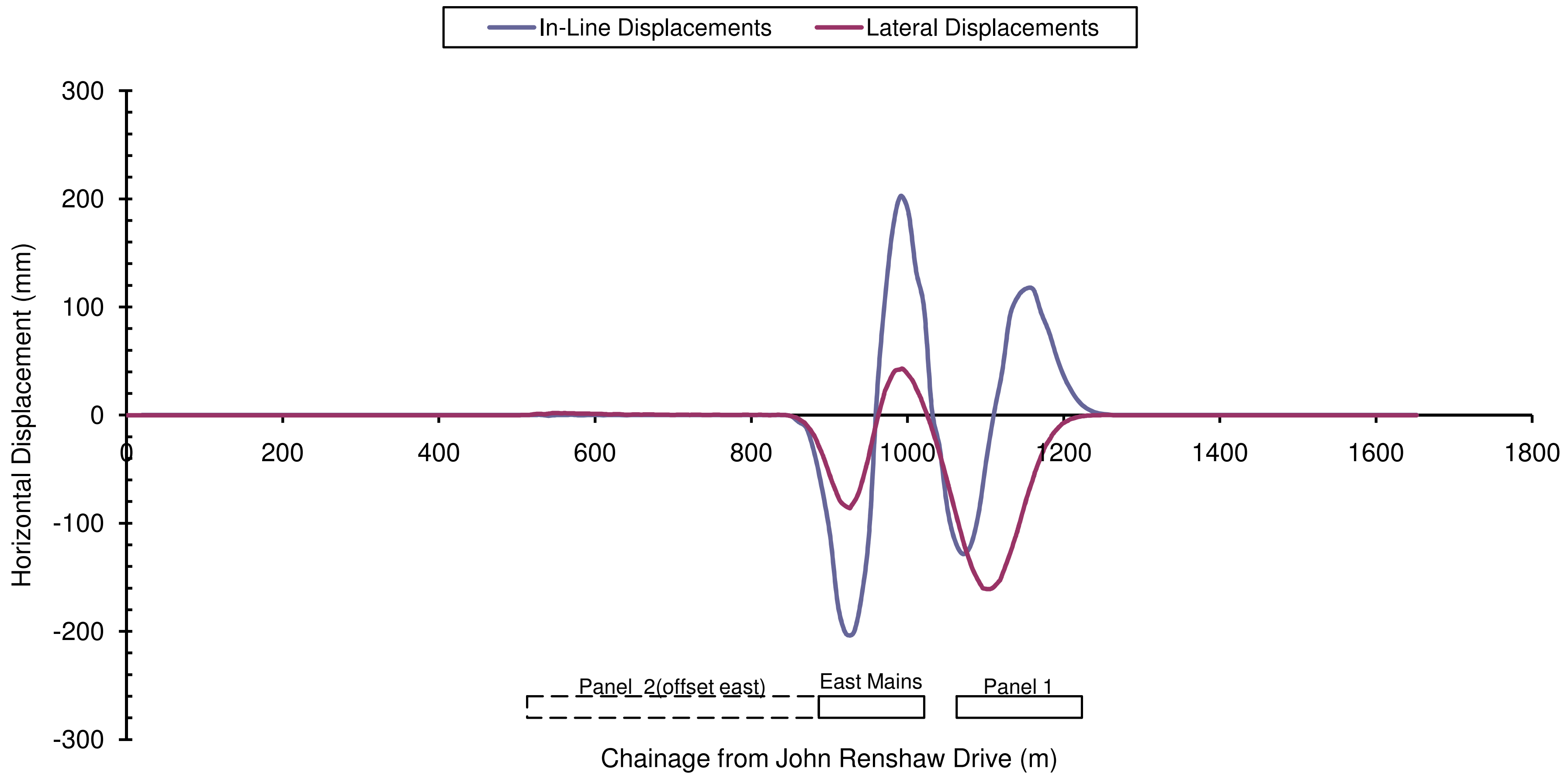
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final In-Line Tilt Profile Predictions Along the Hunter Water Pipeline Easement due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	45b



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Curvature Profile Predictions Along the Hunter Water Pipeline Easement due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	45c



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited		
	Drawn:	S.Ditton		ABL-001/1		
	Date:	20.11.09	Title:	Worst-case Final Strain Profile Predictions Along the Hunter Water Pipeline Easement due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	45d



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited	
	Drawn:	S.Ditton		ABL-001/1	
	Date:	20.11.09	Title:	Worst-case Final Horizontal Displacement Profile Predictions Along the Hunter Water Pipeline Easement due to the Proposed Abel Mine Layout	
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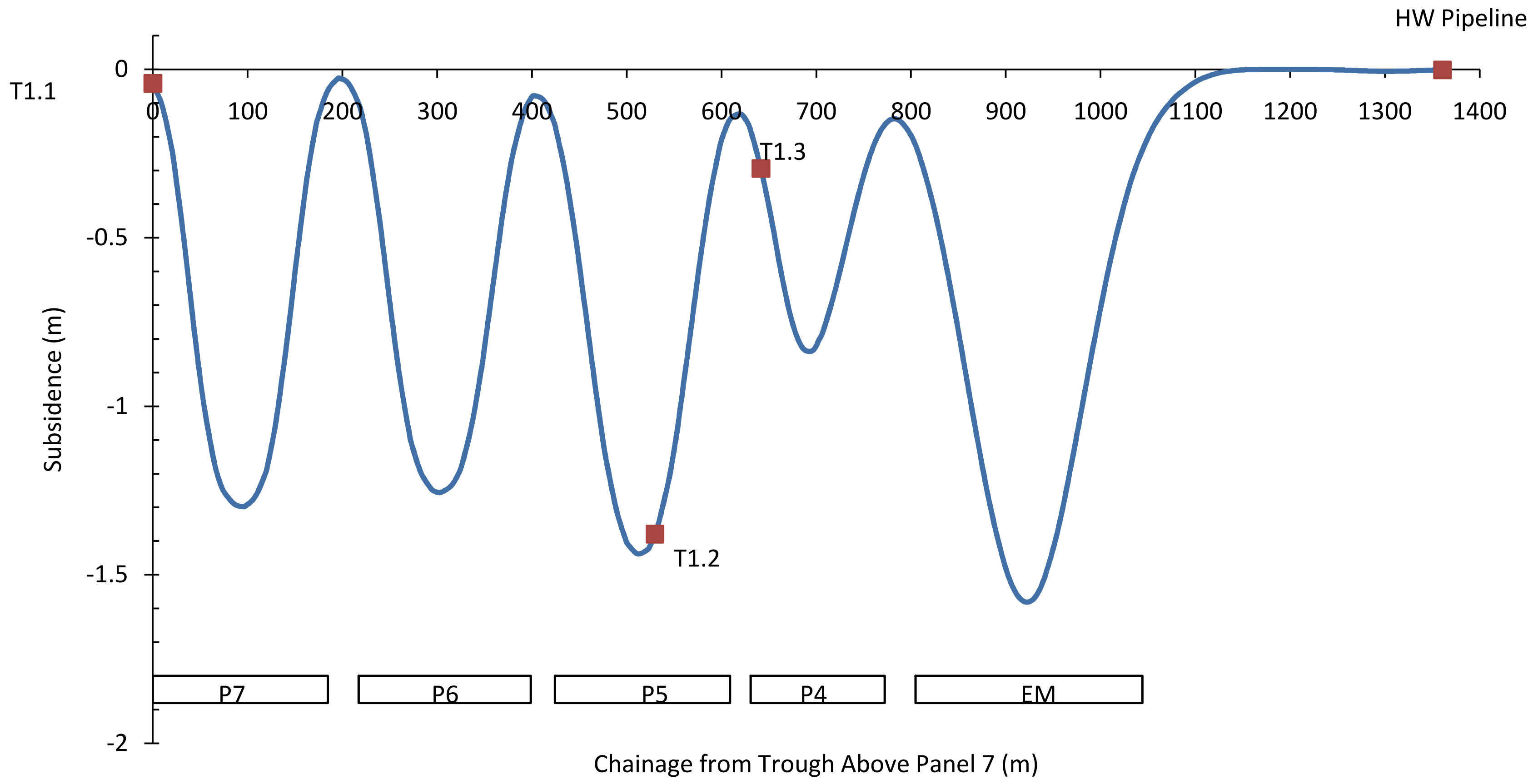
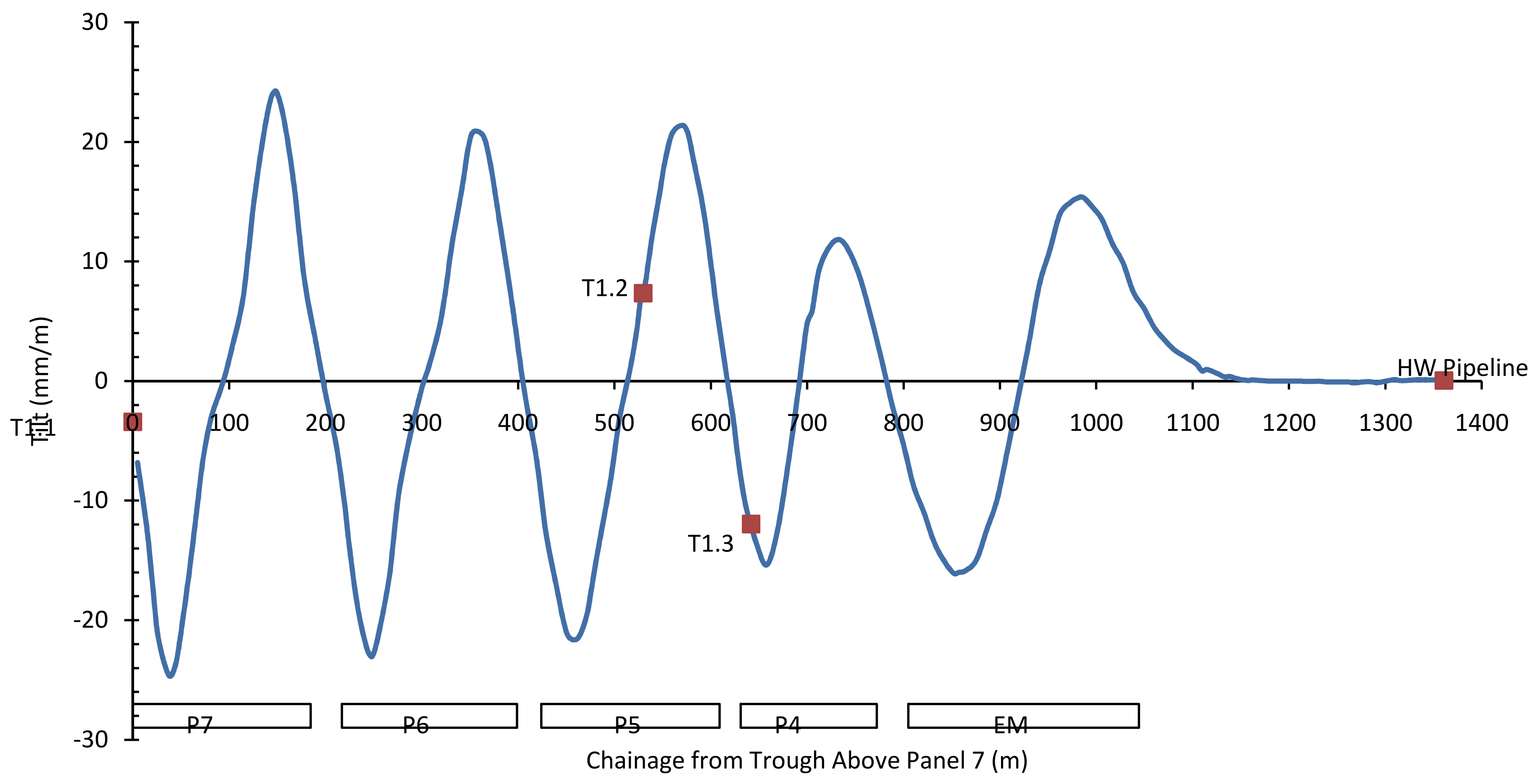
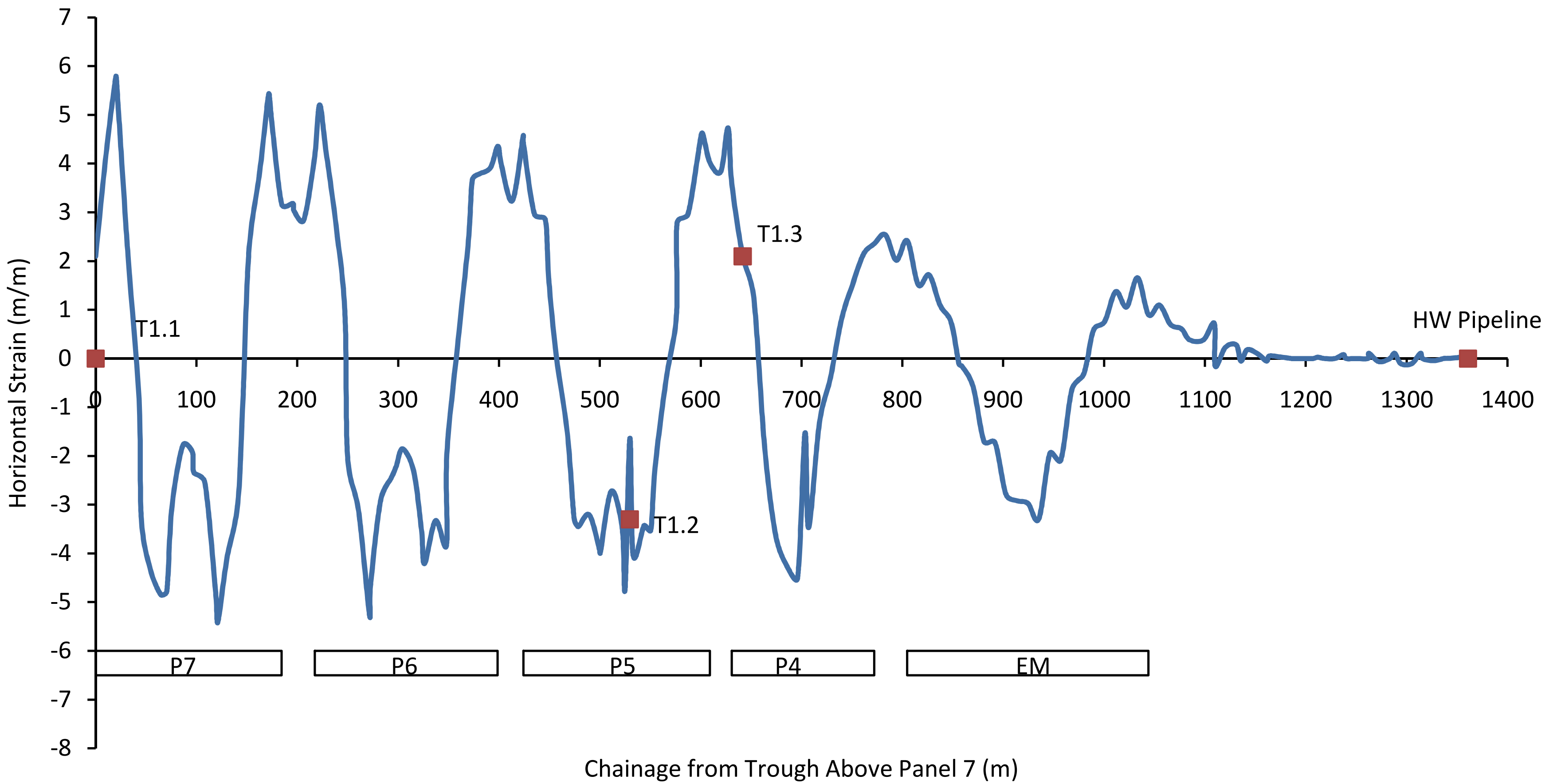


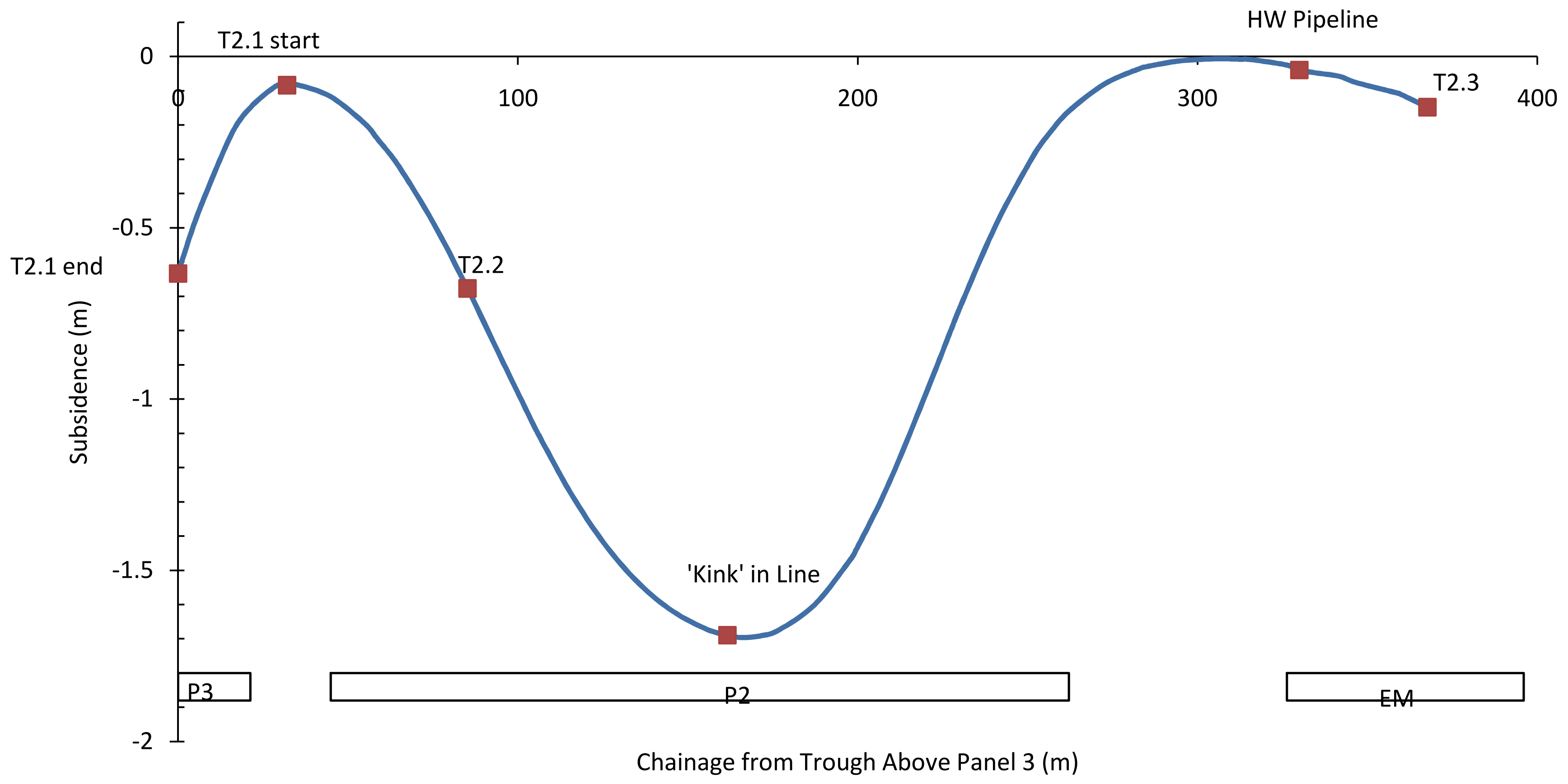
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Subsidence Profile Predictions Along the Stock Watering System Line 1 due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	46a



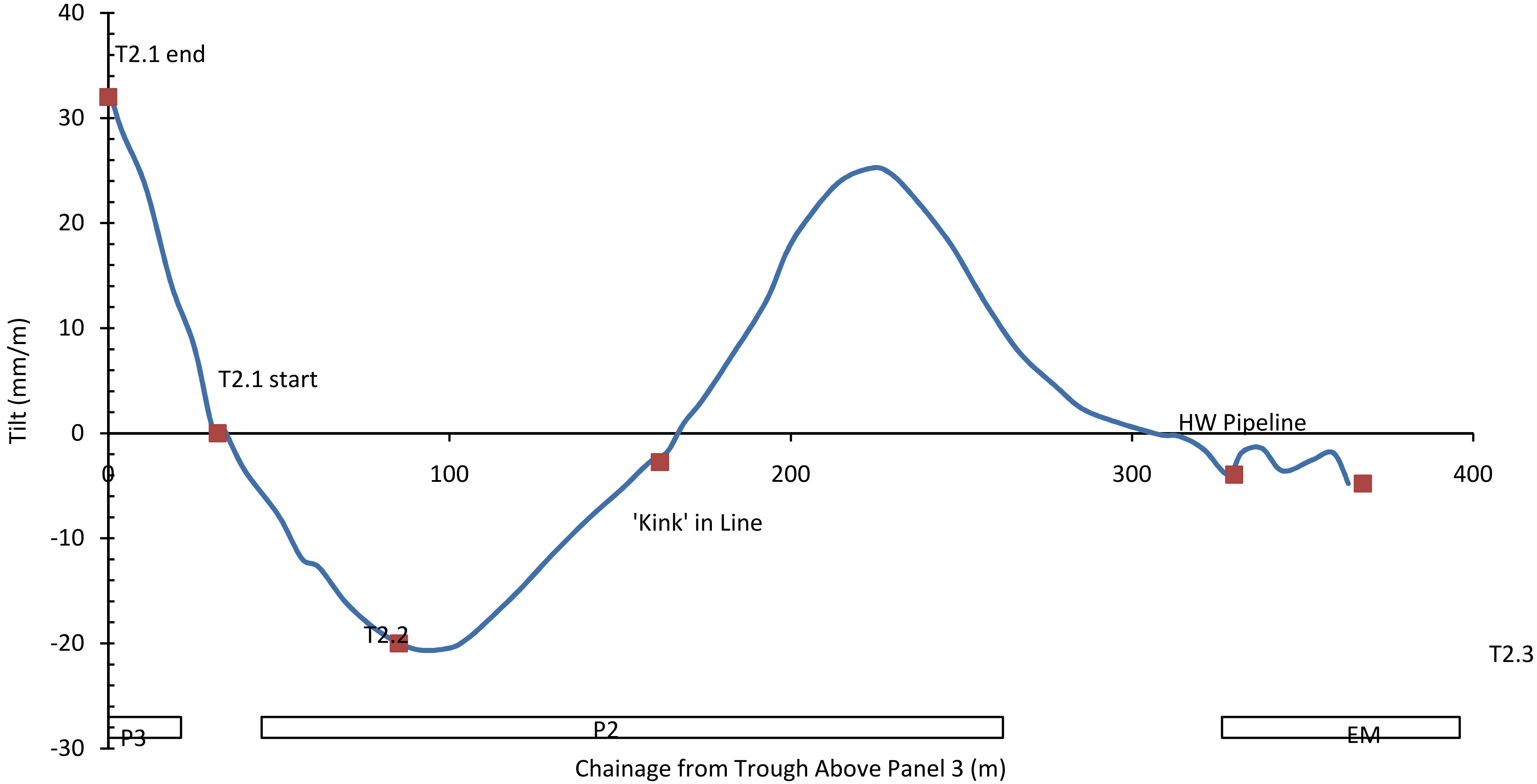
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Tilt Profile Predictions Along the Stock Watering System Line 1 due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	46b



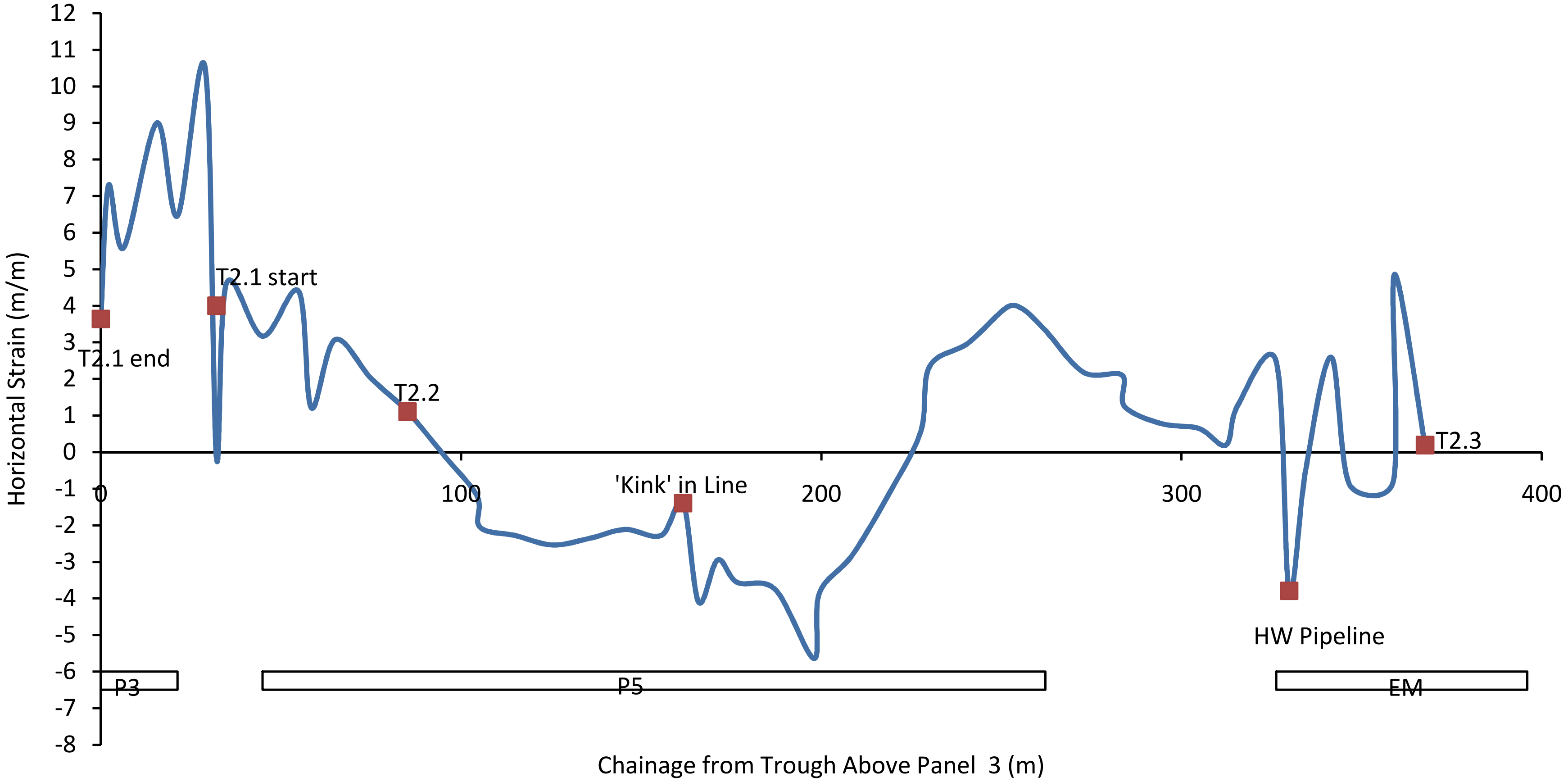
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Strain Profile Predictions Along the Stock Watering System Line 1 due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	46c



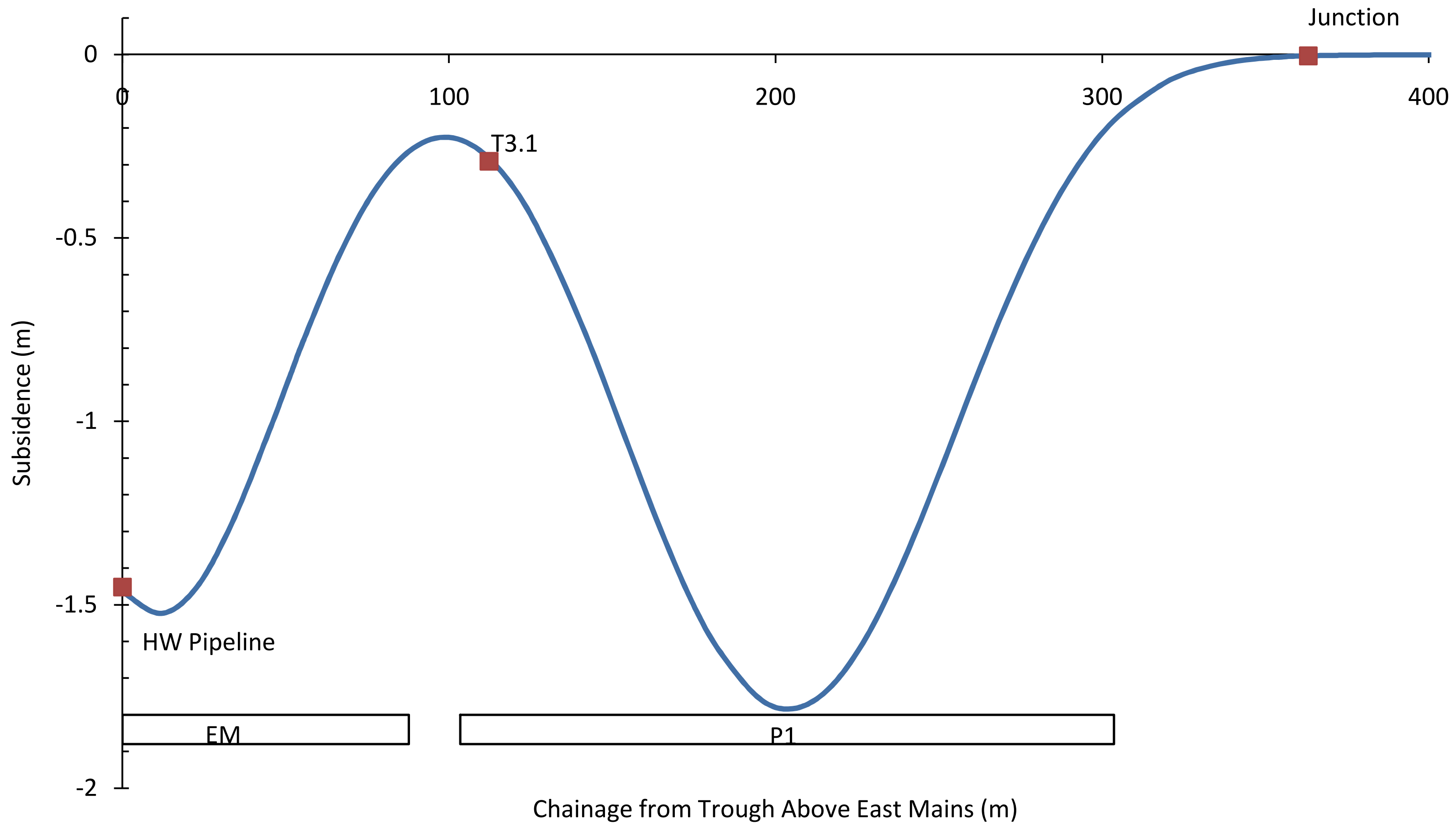
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Subsidence Profile Predictions Along the Stock Watering System Line 2 due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	47a



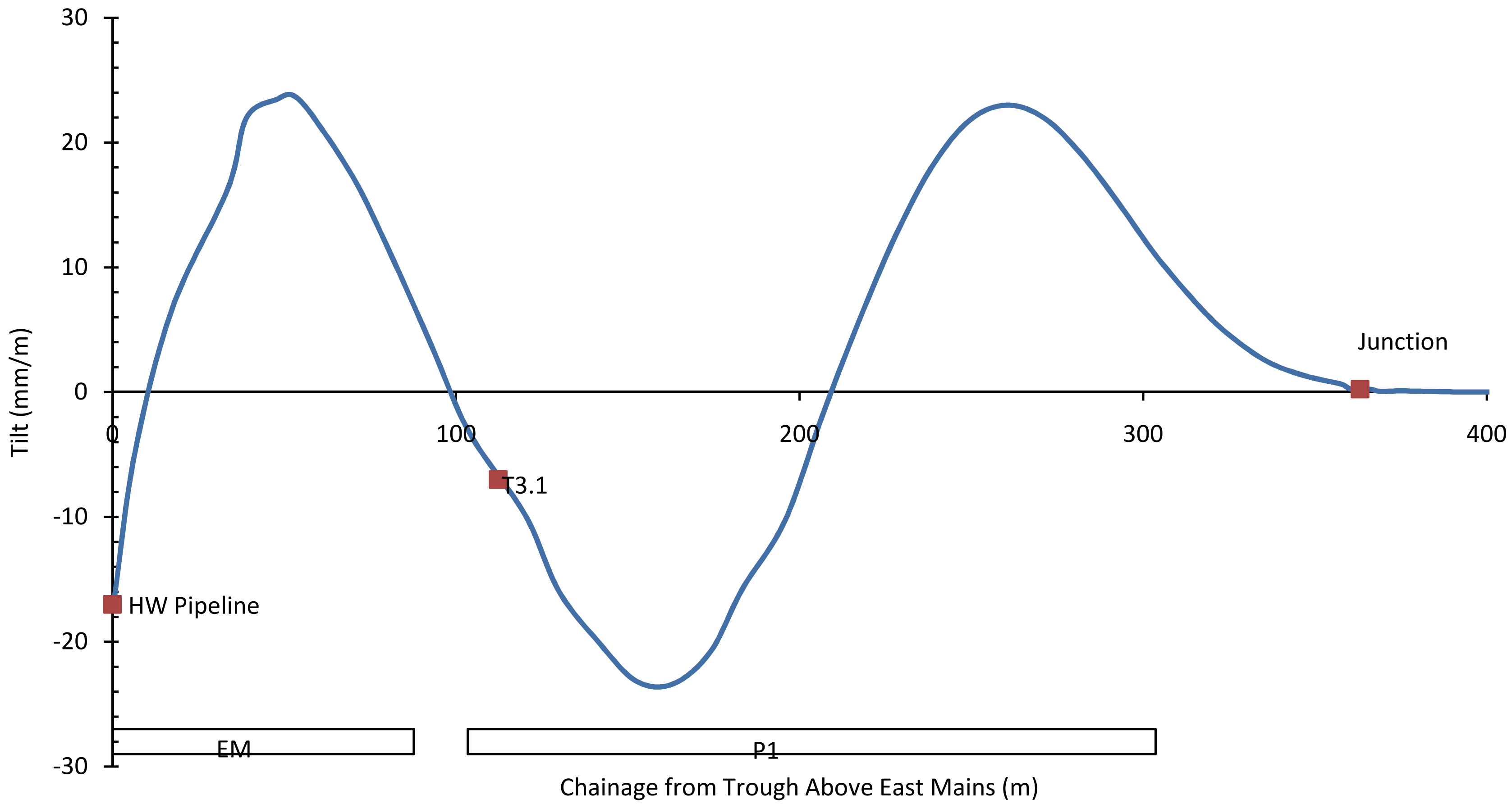
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1	
	Drawn:	S.Ditton			
	Date:	20.11.09	Title:	Worst-case Final Tilt Profile Predictions Along the Stock Watering System Line 2 due to the Proposed Abel Mine Layout	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 47b



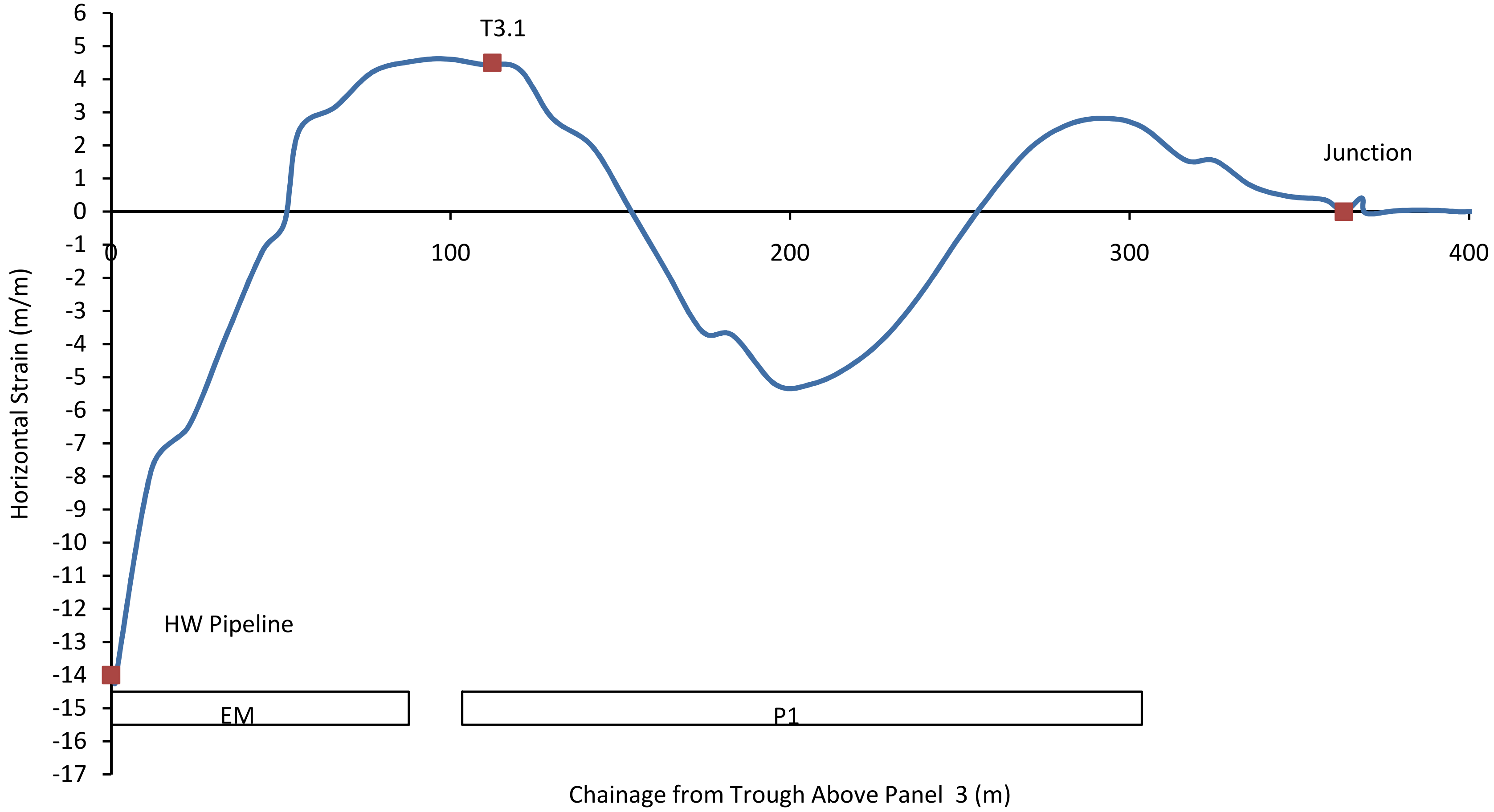
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1	
	Drawn:	S.Ditton			
	Date:	20.11.09	Title:	Worst-case Final Strain Profile Predictions Along the Stock Watering System Line 2 due to the Proposed Abel Mine Layout	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 47c



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Subsidence Profile Predictions Along the Stock Watering System Line 3 due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	48a



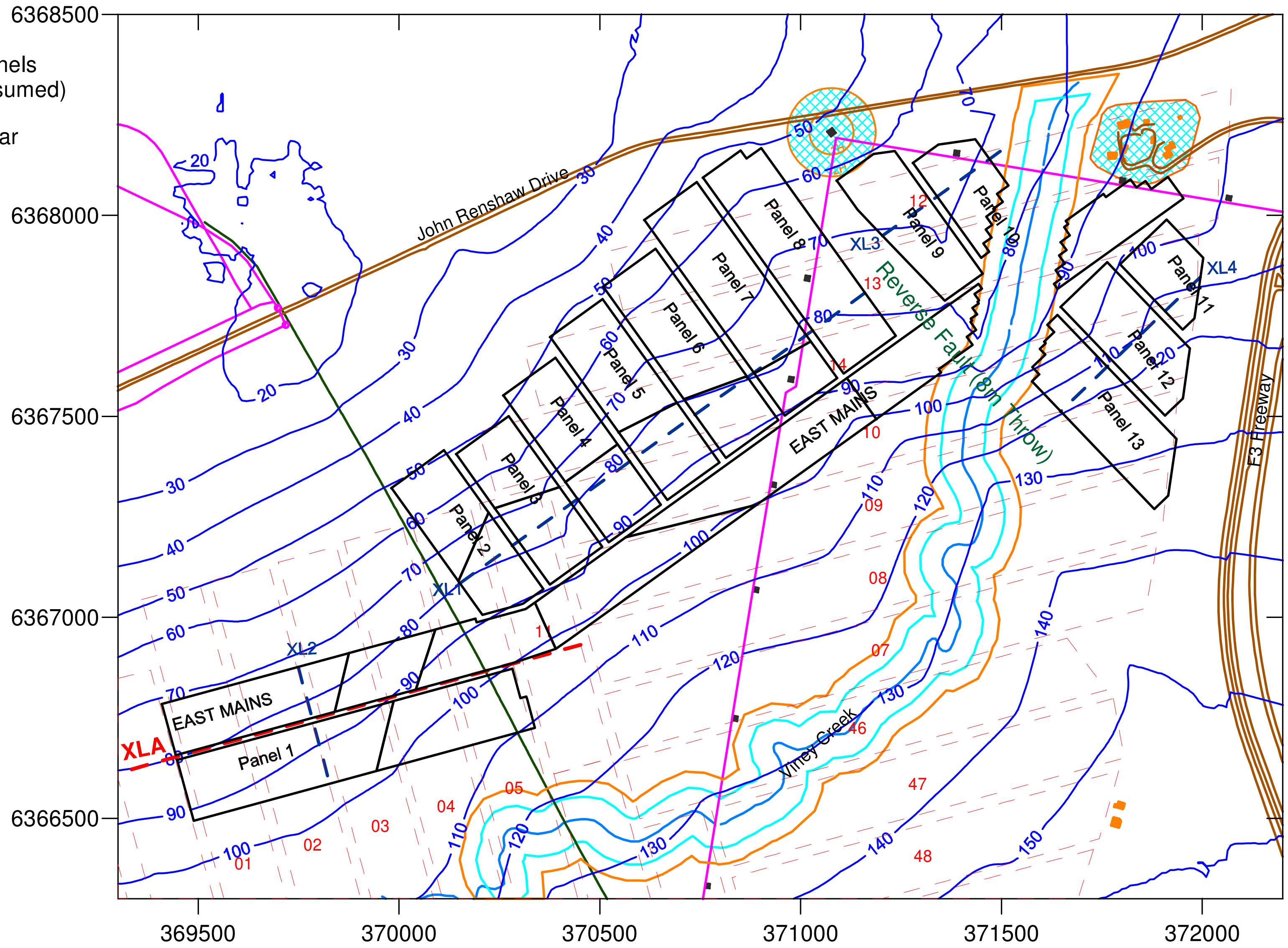
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Tilt Profile Predictions Along the Stock Watering System Line 3 due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	48b



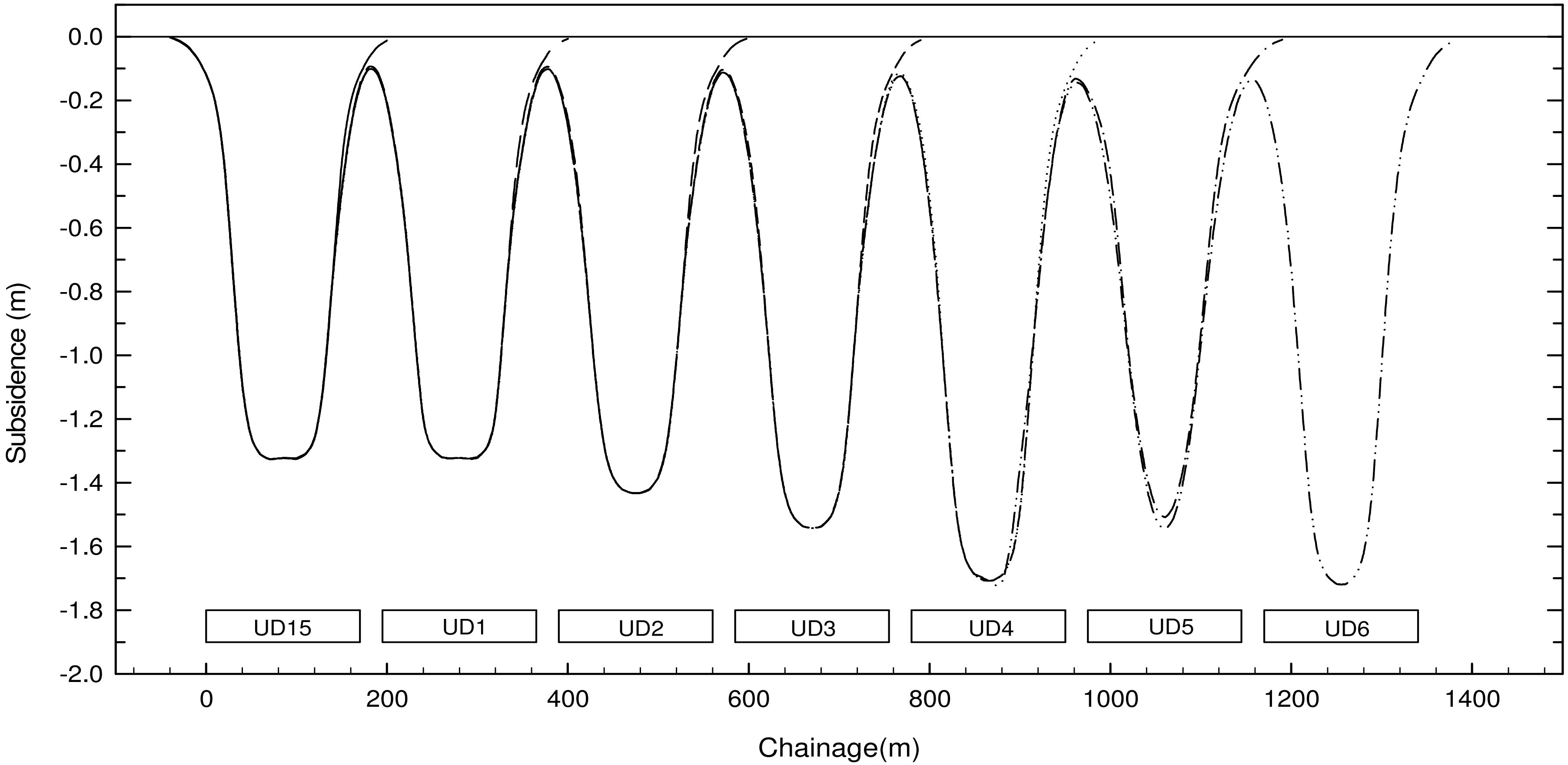
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Worst-case Final Strain Profile Predictions Along the Stock Watering System Line 3 due to the Proposed Abel Mine Layout		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	48c

Key

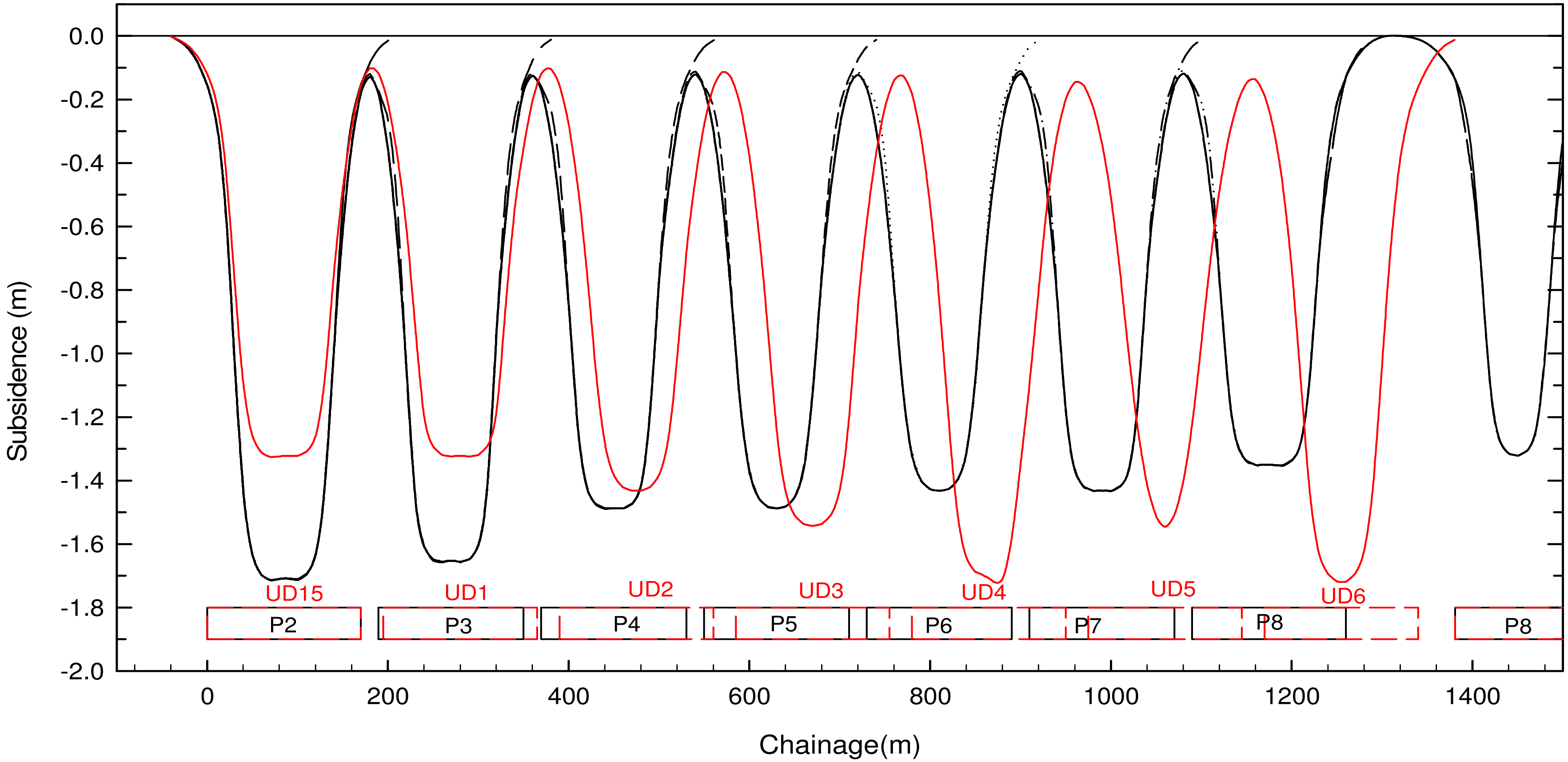
- Proposed EA Total Extraction Panels (with Viney Creek buffer zone assumed)
- Second Workings (SMP Total Pillar Extraction)
- Boral Asphalt Plant & Transgrid Tension Tower Buffer Zones
- 90 Cover Depth Contours (m)
- Schedule 2 Creek and Buffer Zone (DECCW)
- Transmission Towers (Transgrid, 330 kV)
- Optic Fibre Cable (Optus)
- Sealed Road (Cessnock/ Newcastle City Councils)
- Water Supply Pipeline (Hunter Water)
- Private Residences/ Commercial Buildings



DgS Ditton Geotechnical Services Pty Ltd	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1	
	Drawn:	S.Ditton	Title:	Cover Depth Contours above the Proposed Abel EA Mine Layout v. SMP Layout	
	Date:	01.12.09			
			Scale:	1:20,000	Figure No: 49a



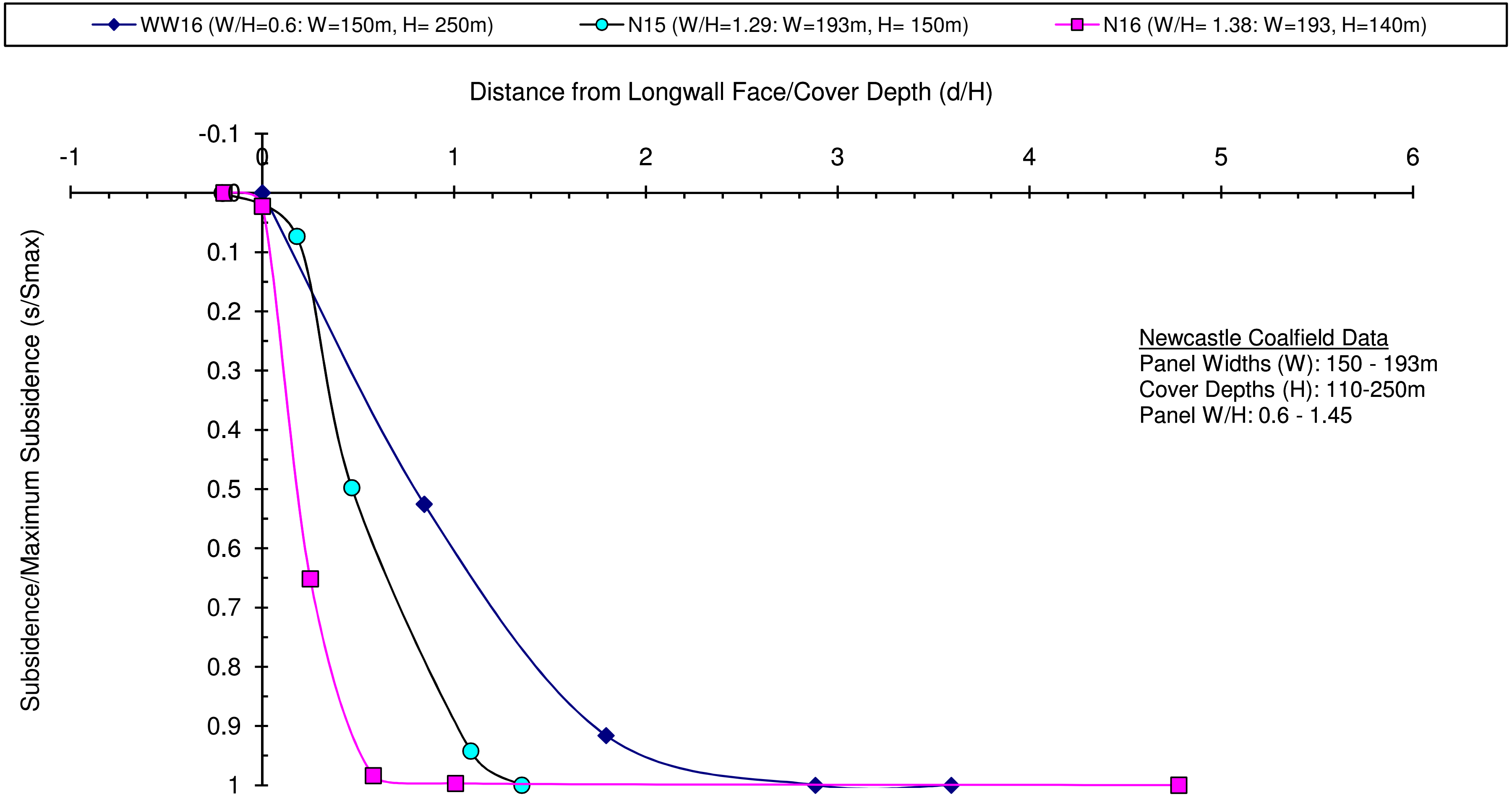
DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited
	Drawn:	S.Ditton		ABL-001/1
	Date:	01.12.09	Title:	Predicted U95%CL Subsidence Profiles Along XL A for the Proposed Abel Mine EA Pillar Extraction Panels - see **Figure 49a** for Location
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	49b



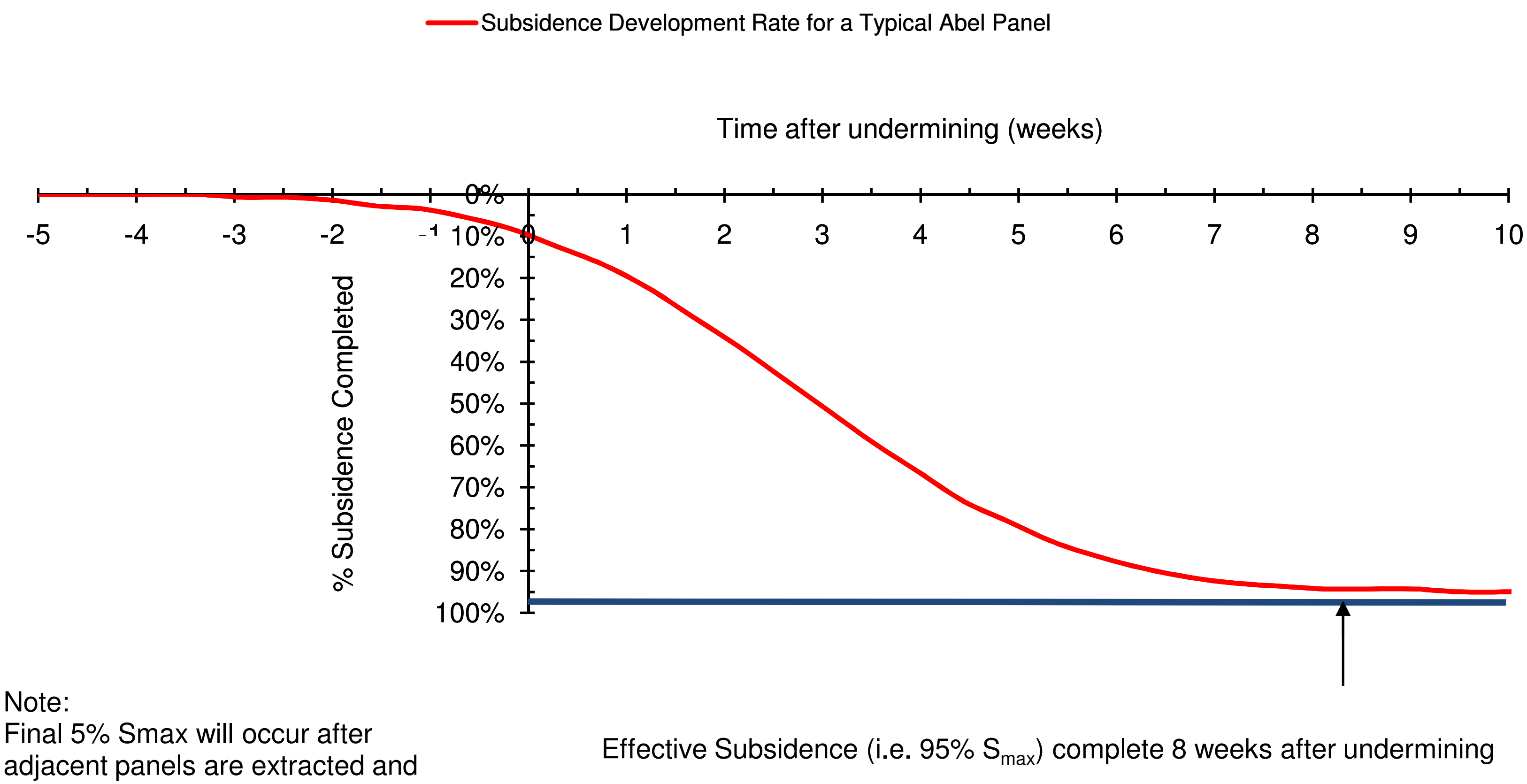
Note: Crosslines are not located at same location and have varying seam thickness present.

Key
SMP (XL1)
EA (XLA)

DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	08.11.09	Title:	Predicted U95%CL Subsidence Profiles Along XL A and XL1 for the Proposed Abel Mine EA and SMP Pillar Extraction Panels Respectively - see **Figure 49a** for Location		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	49c



DgS	Engineer:	S.Ditton	Client:	Donaldson Coal Pty Limited ABL-001/1		
	Drawn:	S.Ditton				
	Date:	20.11.09	Title:	Empirical Single Longwall Centreline Subsidence Development Prediction Model (based on Newcastle Coalfield Measurements)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	50a



Note:
Final 5% Smax will occur after adjacent panels are extracted and develop over similar time frames.

DgS	Engineer: S.Ditton		Client:	Donaldson Coal Pty Limited
	Drawn: S.Ditton			ABL-001/1
	Date: 20.11.09		Title:	Predicted Subsidence Development Profile Prediction above a Typical Pillar Extraction Panel at the Abel Mine (based on Newcastle Coalfield Measurements and SDPS Model)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	50b

APPENDIX A – Summary of ACARP, 2003 and Updates

ACARP, 2003 EMPIRICAL SUBSIDENCE PREDICTION MODEL

A1 Introduction

This appendix provides a description of how subsidence develops above longwall panels and provides a summary of the empirical subsidence prediction models used in this study: **ACARP, 2003** and SDPS (Surface Deformation Prediction System).

The **ACARP, 2003** model was originally developed by Strata Engineering (Australia) Pty Ltd under ACARP funding with the goal of providing the industry with a robust and reliable technique to utilise the significant amount of geological and testing information already gathered by mining companies.

Over the past six years the **ACARP, 2003** model has been used successfully by the model's author, Steven Ditton, at several longwall mines in the Newcastle, Hunter Valley, Western and Southern Coalfields of NSW and the Bowen Basin, Queensland.

Subsidence prediction work for Stage 1 of the Moolarben Coal Project in 2006 resulted in further external scrutinization of the model and the robustness of the methodology by an Independent Hearing and Assessment Panel (IHAP), which was set up to assess Environmental Impact Assessments for new coal mining projects by NSW Department of Planning (DoP).

The outcomes of the IHAP for Moolarben resulted in several refinements to the model, as requested by the independent subsidence expert, Emeritus Professor J M Galvin, UNSW School of Mining and Director of Galvin and Associates Pty Ltd.

The refinements generally included several technical adjustments and clarification of the terminology used, to enable a better understanding of the model by the wider technical community.

Over the past two years, Ditton Geotechnical Services Pty Ltd (DgS) has modified the **ACARP, 2003** model to be able to use it to calibrate an influence function model (SDPS®) that was developed by the Polytechnical Institute for the US Coalfields. The SDPS® program allows a wider range of topographic and complex mining layouts (including longwall and pillar extraction panels) to be assessed.

This appendix summarises the **ACARP, 2003** model in its current format and explains the refinements made to the original model. Details of the **SDPS®** model itself are provided at the back of this appendix and discussed further in the main body of the report.

A2 Description of Subsidence Development Mechanisms Above Longwalls

After the extraction of a single longwall panel, the immediate mine roof usually collapses into the void left in the seam. The overlying strata or overburden then sags down onto the collapsed material, resulting in settlement of the surface.

The maximum subsidence 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. For the case of single seam mining, the maximum subsidence invariably does not exceed 60% of the mining height in the NSW and Qld 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 (spanning) behaviour generally occurs when the panel width (W) is <0.6 times the cover depth (H). If relatively thick and strong massive strata exist, then sub-critical spanning behaviour can occur for panel W/H ratios up to1.8 (but usually limited to W/H < 1.4). The maximum subsidence for this scenario is usually significantly < 60% of the extraction height and could range between 10% and 30% of the extraction height.

Beyond the sub-critical range, the overburden is unable to span and fails or sags down onto the collapsed or caved roof strata immediately above the extracted seam (i.e. the panel is critical or super-critical). Critical panels refer to panels with widths where maximum possible subsidence starts to develop, and supercritical panels refer to panels with widths that cause complete collapse of the overburden. In the case of super-critical panels, maximum panel subsidence does not usually continue to increase significantly with increasing panel width.

The effect of extracting several adjacent longwall panels is dependent on the stiffness of the overburden and the chain pillars left between the panels. Invariably, ‘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.

A longwall chain pillar undergoes the majority of life-cycle compression when subject to double abutment loading (i.e. the formation of goaf on both sides of it, 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. If the chain pillars go into yield, the load on the pillars will be mitigated to some extent by load transfer to adjacent fallen roof material or goaf.

The surface subsidence usually extends outside the limits of extraction for a certain distance (i.e. the angle of draw). The angle of draw distance is usually less than or equal to 0.5 to 0.7 times the depth of cover (or angles of draw to the vertical of 26.5^o to 35^o) in the NSW and QLD Coalfields.

A3 ACARP Project Overview

The original **ACARP, 2003** model was originally developed for the Newcastle Coalfield to deal with the issue of making reliable subsidence predictions over longwall panels by using both geometrical and geological information.

The project was initially focused on the behaviour of massive sandstone and conglomerate strata in the Newcastle Coalfield, but has now been successfully used in other coalfields since development over the past six years. This has occurred naturally due to the expansion of the model's database with data from other coalfields and has resulted in generic refinements to the model to deal with the wider range of geometrical and geological conditions.

In regards to geometry, the subsidence above a series of longwalls is strongly influenced by the panel width, the cover depth, the extraction height and the stiffness of the interpanel pillars (i.e. the chain pillars) and immediate roof and floor strata.

In regards to geology, the presence of massive strata units, such as conglomerate and sandstone channels above longwall panels, has resulted in reduced subsidence compared to that measured over longwall panels with similar geometry and thinner strata units.

Geological structure, such as faults and dykes, can cause increases in subsidence due to their potential to adversely affect the spanning capability of the overburden.

During the original development of the model, a database of maximum single and multi longwall panel subsidence and associated massive strata units was compiled for the Newcastle Coalfield. The database draws on subsidence data from over fifty longwall panels and covers a panel width to cover depth (W/H) ratio from 0.2 to 2.0 (cover depth ranges between 70 m and 351 m), as shown in **Figure A1**.

The original project database includes single seam longwall mining data from eleven collieries within the Newcastle Coalfield, as presented in **Table A1**.

Table A1 - Empirical Database Sources from Newcastle Coalfield

Colliery	Colliery	Colliery
Cooranbong	Lambton	Wyee
New Wallsend No. 2 (Gretley)	Teralba	
Moonee	Burwood	
Stockton Borehole	West Wallsend	
Newstan	John Darling	

The wide range of single longwall panel W/H ratios in the database was considered unique compared to the other Australian coalfields and enabled the study to focus on overburden and chain pillar behaviour effects separately.

Pillar extraction or multiple seam data was not used to produce the subsidence prediction curves, as it invariably makes the assessment of geological influences more difficult.

Other NSW and QLD longwall and high pillar extraction mine data that have been added to the model database over the past 6 years are shown in **Table A2**.

Table A2 - Empirical Longwall Database Sources from Other Coalfields

Coalfield	**Colliery**	**Colliery**
Newcastle	West Wallsend	Newstan
	Tasman	
Hunter Valley	United	Wollemi
	Austar	
Southern	Berrima	Appin
	Elouera	Dendrobium
Western	Springvale	Angus Place
	Ulan	
Queensland	Cook	Oaky Creek
	Moranbah North	

In summary, the key features of the **ACARP, 2003** model are that it:

- Is derived from a comprehensive database of measured subsidence, strain, tilt and curvature above longwalls in the Newcastle, Hunter Valley, Western and Southern Coalfields.

- Has been validated with measured subsidence profile data over the past 6 years.

- Adds to the **DMR, 1987** model for the Newcastle Coalfield, as it addresses multiple panels and contains significantly more longwall data.

- Includes the effects of massive sandstone/conglomerate lithology on subsidence, based on the linking of borehole and subsidence data.

- Allows reliable predictions of maximum single panel subsidence, chain pillar subsidence, tilt, curvature, strain and the angle of draw within a 90% Confidence Interval.

- Enables ‘greenfield’ sites (i.e. where there is no subsidence data) to be assessed rapidly and accurately.

- Provides maximum subsidence predictions based on Upper 95% Confidence Limits (or 5% Probability of Exceedence limits), which in practice have rarely been exceeded.

  The confidence limits have been derived by the application of central limit theory and the likely normal distribution of residuals about lines of best fit or regression lines determined for the model database.

- Utilises historical information directly - predictions are based on actual data.

- Enables prediction of secondary tilt, curvature and strain magnitudes. Effects such as 'skewing' due to rapid surface terrain variations, surface 'hump' or step development and cracking can result in tilt, curvature and strain magnitudes significantly greater than predicted 'smooth' profile values.

  This issue has been addressed empirically by linking measured impact parameters with key mining geometry variables. Strain concentration factors and database confidence limits have been developed to estimate the likely range of subsidence impact parameters.

- Is amenable to subsidence contouring and allows the impacts on surface features to be assessed, including post-mining topography levels for watercourse impact assessment.

- Predictions of subsidence at specific locations can be done to provide an indication of likely subsidence magnitude; however, depending on the sensitivity of the feature, it may be prudent to adopt maximum predicted subsidence for a given panel.

- Incorporates an empirical model of sub-surface fracturing and far-field displacements.

Recent far-field horizontal displacement model work in the Newcastle Coalfield suggests the empirical model is conservative.

The following key input parameters are required to make subsidence predictions using the model:

- Panel Width (W)

- Cover Depth (H)

- Seam Working Height (T)

- Overburden lithology details, specifically the thickness and location of massive strata units (t, y).

- Chain Pillar Height (h), Width (w_{cp}) and Length (l) [solid dimensions]

- Roadway width

- Number of panels to be extracted

The statistical inferences and estimates of the model uncertainty associated with the prediction methodology are presented in the following sections.

A4 Single Panel Subsidence Predictions

A4.1 Geometrical Factors

The major finding of the **ACARP, 2003** project in regards to mining geometry was that the historical relationship between subsidence and panel width to cover depth ratio (W/H) is not a constant for the range of cover depths (H) involved.

Figure A2 shows the range of maximum subsidence that can occur above longwall panels with similar mining geomtries and a range of cover depths. The apparent differences between the DMR's Southern NSW and Newcastle Coalfield curves and laminated overburden theory (**Heasley, 2000**) also support the above finding.

For an overburden consisting of sedimentary rock layers, **Heasley, 2000** applied laminated beam theory by **Salamon, 1989** to form the basis of the pseudo-numerical subsidence prediction program LAMODEL ("LAyered MODEL" of overburden) that has been found to have reasonable success in the US Coalfields.

According to Lamodel theory, the maximum seam roof convergence (C_{max}) above a longwall panel of mining height (T), width (W) and cover depth (H), with an idealised overburden of uniform lamintation thickness (t), Youngs Modulus (E), unit weight (γ) and Poisson's Ratio (v) is:

$$C_{max} = \sqrt{(12(1-v^2)/t)}\ (\gamma H/E)\ (W^2/4) \text{ or T (whichever is the lower value)}$$

In terms of traditional empirical models of estimating subsidence, the above equation indicates that the maximum single panel subsidence is a function of ($W^2/t^{0.5}$), (γH/E) and T.

The **ACARP, 2003** model surmised that single panel subsidence was a function of W/H, γH/E or H, T, W/t and y/H. The first three parameters are related to panel geometry (Width, Cover Depth and Mining Height, whilst the last two parameters (strata unit thickness, t , and distance ,y, to the unit above the workings) infer geological influences of massive strata units (*Note: that the W/t parameter was incorrectly inversed in **ACARP, 2003***).

Based on the above, surface subsidence increases with increasing cover depth (H) for the same W/H ratio, and is primarily a function of the increasing panel width (W). For constant single panel width (W), subsidence will therefore decrease with increasing cover depth (H).

The subsidence data was subsequently separated into three cover depth categories of H = 100, 200 and 300 m +/-50 m and is presented in **Figures A3** to **A5**.

The influence of overburden lithology was found to be readily apparent, once the database was filtered using the above cover depth ranges.

A4.2 Geological Factors

Once the first stage in the development of the subsidence prediction model had addressed the influence of cover depth the effect of “significant” overburden lithology above single longwall / miniwall panels could be addressed.

Figure A6 illustrates a physical model, showing the subsidence reducing effects of a massive strata unit.

Borehole data was used to derive the thickness and location of massive strata units considered to be critically important for surface subsidence prediction, for a given panel width and depth. The methodology takes into account the maximum massive strata unit thickness (t) at each location and the height to the base of the unit above the longwall panel (y).

The subsidence above a panel, given cover depth (H) and panel width (W) decreases significantly when a massive strata unit is thicker than a certain minimum limit value. The thickness is also reduced when the unit is closer to the surface. The strata unit is considered to have a 'high' subsidence reduction potential (SRP) when it exceeds a minimum thickness for a given y/H ratio, as shown in **Figures A7.1** to **A7.3** for each cover depth category.

For a thin strata unit located relatively close to a panel, the ‘Subsidence Reduction Potential (SRP) will be 'low'. However, there is also an intermediate zone, where a single strata unit (or several thinner units) below the 'high' subsidence reduction thickness can result in a 'moderate' reduction in subsidence. A second limit line can therefore be drawn, which represents the threshold between 'moderate' and 'low' SRP.
It is considered that the ‘high’ SRP limit line represents the point between elastic and yielding behaviour of a spanning beam. The ‘moderate’ SRP limit line represents the point between yielding behaviour and collapse or failure of a spanning beam (which has been yielding).

The limit lines have been determined for the strata units located at various heights (y) above the workings in each depth category, as shown in **Figures A8** to **A10**.

A4.3 Summary of Model Concepts

The **ACARP, 2003** model introduces several new parameters, to improve the definition of various types of overburden behaviour and the associated mechanics.

As outlined in **Section A4.2**, the ‘Subsidence Reduction Potential’ (SRP) of massive or thickly bedded geological units above single longwall panels for the Newcastle Coalfield has been introduced to describe the influence that a geological unit may have on subsidence magnitudes. The massive geological units are defined in terms of 'high', 'moderate' or 'low' SRP.

Massive unit thickness, panel width, depth of cover and height of unit above the workings are considered to be key parameters for assessing overburden stiffness and spanning capability over a given panel width, controlling surface subsidence. A conceptual model for overburden behaviour is illustrated in **Figure A11**.

Variation in subsidence along the length of a panel may therefore be due to the geometry and / or SRP variation of geological units within the overburden.

The database also indicates the presence of a ‘Geometrical Transition Zone’, whereby subsidence increases significantly regardless of the SRP of the geological units, as shown in **Figure A12**. This behaviour occurs when panel width to cover height ratio (W/H) ranges from 0.6 to 0.8. This phenomenon can be simply explained as a point of significant shift in structural behaviour and the commencement of overburden breakdown.

The model allows the user to determine the range of expected subsidence magnitudes and the location of geology related SRP and/or 'geometrical transition zones' along a panel. Identification of the transition zones is an important factor in assessing potential damage risks of differential subsidence to important infrastructure, buildings and natural surface features, such as rivers, lakes and cliff lines etc.

For W/H ratios <0.7, the overburden spans across the extracted panel like a ‘deep’ beam or linear arch, whereby the mechanics of load transfer to the abutments is governed by axial compression along an approximately parabolic shaped line of thrust, see **Figure A13**.

For W/H ratios >0.7 the overburden geometry no longer allows axially compressive structural behaviour to dominate, as the natural line of thrust now lies outside of the overburden. Bending action due to subsequent block rotation occurs. Provided that the abutments are able to resist this rotation, flatter lines of thrust still develop within the overburden, but the structural action is now dominated by bending action. This type of overburden behaviour has been defined as ‘shallow’ beam behaviour, which in structural terms is fundamentally less stiff than ‘deep’ beam behaviour. This results in a significant increase in subsidence or sag across an extracted longwall panel (all other factors being equal), as shown **Figure A13**.

“Voussoir beam” or “fractured linear arch” theory can be used to explain both types of overburden behaviour, as deep seated or flatter arches develop in the strata in an attempt to balance the disturbing forces.

The ‘strata unit location factor’ (y/H) was developed to assist in assessing the behaviour of massive strata units above the workings. The y/H factor is a simple way to include the influence of the unit location above the workings in terms of the effective span of the unit and the stresses acting upon it.

The key elements of this factor and their influence on the behaviour of the strata unit are:

- y, the height of the beam above the workings, which determines the effective span of the beam, and
- H, cover depth over the workings, which exerts a strong influence on the stress environment and, hence, the propensity for buckling or compressive failure of the beam.

Essentially beam failure due to the action of increasing horizontal stress (i.e. crushing or buckling) appears more likely as y decreases and H increases. The ratio of y/H may therefore be used to differentiate between the SRP of a beam of similar thickness, but at varying heights above the workings. The model also demonstrates that as the depth of cover increases, a thicker beam is required to produce the same SRP above a given panel width.

A5 Multiple Longwall Panel Subsidence Prediction

A5.1 General

The effect of extracting several adjacent longwall panels is governed by the stiffness of the overburden and the chain pillars left between the panels. Invariably, 'extra' subsidence occurs above a previously extracted panel and is caused primarily by cracking of the overburden and the compression of the chain pillars and adjacent strata between the extracted longwall panels.

A conceptual model of subsidence mechanisms above adjacent longwall panels in a single seam is shown in **Figure A14**.

A5.2 Predicting Subsidence above Chain Pillars (ACARP, 2003 Model)

A 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 of up to three or four previously extracted panels. The stiffness of the overburden and chain pillar system will determine the extent of load transfer to preceding chain pillars.

Multiple-panel effects have therefore been included in the model by adding empirical estimates of surface subsidence over chain pillars to the maximum subsidence predictions for single panels.

The empirical model presented in **ACARP, 2003** for estimating the subsidence above a chain pillar, was based on the regression equation presented in **Figure A15**. The model compares the ratio of chain pillar subsidence (Sp) over the extraction height (T), to the width of the chain pillar divided by the cover depth multiplied by the total extracted width (1000w/W'H).

A regression analysis on the data indicates a strong exponential relationship for 1000wcp/W'H values up to 0.543. For values > 0.543, the relationship becomes constant.

$S_p/T = 7.4044e–10.329F$ ($R^2 = 0.92$) for $F< 0.543$, and

$S_p/T = 0.023$ for $F > 0.543$

where

F = 1000w/W'H

W' = The total extracted width which includes the width of the panels extracted on both sides of the subject chain pillar, and the width of the chain pillar itself (i.e. W' = Wi + w(i) + Wi+1).

Note that the final subsidence for a longwall panel with several subsequent extracted panels was then determined empirically by adding 50% of the predicted chain pillar subsidence (S_p) to the single panel S_{max} estimate.

This approach however, did not include an abutment angle to estimate pillar loads, which are likely to vary significantly between sub-critical and supercritical panel layouts.

The chain pillar model has now been amended to include better predictions of chain pillar load that are consistent with ALTS methodology (refer ***ACARP, 1998a****) and has resulted in the modified version presented in Section A5.2.*

A5.2 Predicting Subsidence above Chain Pillars (DgS, 2008 Model)

After the **ACARP, 2003** model was published; further studies on chain pillar subsidence measurements were undertaken at several mine sites in the Western (Springvale, Angus Place and Ulan) and Southern Coalfields (Appin and Elouera). The measured subsidence above the chain pillars was significantly greater than the Newcastle Coalfield pillars and considered to be linked to the stress acting on the pillars and the longwall mining height.

Maximum subsidence above the chain pillars invariably occurred after the pillars were subject to double abutment loading conditions (i.e. goaf on both sides).

The **ACARP, 2003** model for estimating chain pillar subsidence was subsequently superseded by the pillar stress v. strain type approach presented in **Figure A16**. The chain pillar stress was estimated by assuming a design abutment angle of 21^o for the pillar load, according to the methodology presented in **ACARP, 1998a**.

Prediction of subsidence above the chain pillars (S_p) was determined based on the following regression equation using the mining height, T and pillar stress, σ:

$$S_p/T = 0.238469/(1+e^{-[(\sigma-25.5107)/7.74168]}) \qquad (R^2 = 0.833)$$

The uncertainty of the predictions was estimated by calculating the variance of the residuals about the regression lines and calculating 90% Confidence Limits for the database as follows:

90% CL S_p error = 0.048T

It was also considered necessary to test if the above stress v. strain type approach was adequate for reliable predictions, by comparing the subsidence outcomes with the pillar Factor of Safety; see **Figure A17**.

The strength of the chain pillars was estimated using the rectangular pillar strength formulae presented in **ACARP, 1998b**. The FoS was derived by dividing the pillar strength by the pillar load (i.e. stress).

Generally it has been found that significant surface subsidence above the chain pillar (i.e. 10 - 30% of pillar height) starts to occur when the pillar FoS is < 2. For FoS values greater than 2, subsidence above the pillars is virtually independent of FoS and the pillars generally perform elastically under load.

The database indicates that when the FoS is < 2, the stiffness of the pillar starts to decrease, due to the development of load induced fracturing within the pillar. FoS values of < 2 represent pillar stresses that exceed 50% of the pillar strength. Laboratory testing of coal and sandstone samples also show sample 'softening' as the ultimate load carrying capacity of the sample is approached.

For pillars with FoS values < 1, the subsidence above the chain pillars tend to a maximum limit of approximately 25 to 30% of the mining height. This type of behaviour is expected for chain pillars that have width to height ratios w/h > 5, which is the point where 'strain hardening' deformation starts to develop with increased confinement of the 'pillar core'.

A5.3 Calculation of First and Final Subsidence for Multiple Longwall Panels

Multiple panel predictions can be made by adding the predicted single panel subsidence to a proportion of the chain pillar subsidence (including the residual subsidence) to estimate first and final subsidence above a given longwall panel.

The definition of first and final S_{max} is as follows:

First S_{max} = the total subsidence after the extraction of a longwall panel, including the effects of previously extracted longwall panels adjacent to the subject panel.

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

First and final S_{max} values for a panel are predicted by adding 50% and 100% of the predicted subsidence over the chain pillars (i.e. between the previous and current panel) less the goaf edge subsidence (see **Section A5**).

Residual subsidence above chain pillars and longwall blocks tends to occur after extraction due to (i) increased overburden loading on pillars and (ii) on-going goaf consolidation or creep effects. Based on the final chain pillar subsidence measurements presented in **Figure A16**, the residual movements can increase subsidence by a further 10 to 30%.

An example of measured multiple longwall subsidence behaviour is presented in **Figure A18**.

Final subsidence is normally estimated by assuming a further 20% of the chain pillar subsidence will occur. However, this may be increased or decreased, depending on local experience.

The prediction of first and final subsidence originally presented in **ACARP, 2003** involved the use of several empirical coefficients, which have proven to be difficult to apply in practice. The interested may refer to this methodology, however, the above method is considered easier to apply and likely to result in a similar outcome.

In summary, the mean values of the first S_{max} and final S_{max} are calculated as:

First S_{max} = Single S_{max} + $0.5(S_{p(i-1)} - S_{goe})$

Final S_{max} = First S_{max} + 1.2(Final $S_{p(i)}$ - First S_{goe})

The U95% Confidence Limits or Credible Worst Case Values are then:

U95% First S_{max} = mean First S_{max} + 1.64 (U95% S_{max} error + U95% S_p error)$^{1/2}$.

U95% Final S_{max} = mean Final S_{max} + 1.64 (U95% S_{max} error + U95% S_p error)$^{1/2}$.

A6 Subsidence Profile and Impact Parameter Predictions

Part of the **ACARP, 2003** project included the development of several models to predict the maximum panel deformation parameters and surface profiles associated with subsidence. The following models were developed:

- panel goaf edge or rib subsidence,
- angle of draw,
- maximum transverse and longitudinal tilt, curvature and strain,
- the locations of the above parameters over the longwall panel for the purposes of subsidence profile development, and
- heights of continuous and discontinuous fracturing above the longwall, based on measured surface tensile strains and fracture limit horizons over extracted panels (see **Section A7** for details).

A conceptual model of surface deformation profiles that develop above longwall panels is given in **Figure A19**.

All of the above subsidence parameters have been statistically linked to key geometrical parameters such as the cover depth (H), panel width (W), working height (T) and chain pillar width (w_{cp}) and shown in **Figures A20 to A27**.

A summary of all the empirical model relationships between the key subsidence profile parameters that were developed in **ACARP, 2003** and DgS are presented in **Table A3**.

Table A3 - Summary of Subsidence Impact Parameter Prediction Models Developed from ACARP, 2003

Parameter	Regression Equation and +/- 90% Confidence Limits or Upper95%CL	Coefficient of Determination (R^2)	Figure No.
Subsidence Reduction Potential (SRP) of Strata Unit in Overburden with thickness t, panel width, W and location factor, y/H above workings for Cover Depth Category	**High** SRP t for a given panel W plots above line for given strata unit y/H. **Moderate** SRP t plots between High SRP line and next y/H line below it. **Low** SRP t plots below Moderate SRP limit line.	N/A - curve location determined by successful re-prediction of >90% of cases I databases	**Figure A8** for H<150m; **Figure A9** for H< 250m; **Figure A10** for H< 350m
Single Maximum Longwall Panel Subsidence (Single S_{max}) for Assessed Strata Unit SRP of Low, Moderate or High	Upper and Lower bound prediction lines for a given SRP are used to estimate range of S_{max}/T for a given Panel W/H. Average of limit lines value is mean Single S_{max} value +/- 0.03T for $W/H < 0.6$; +/- 0.1T for $0.6 < W/H < 0.9$; +/-0.05T for $W/H > 0.9$	N/A - curve location determined by successful re-prediction of >90% of cases I databases	**Figure A3** for H<150m; **Figure A4** for H< 250m; **Figure A5** for H< 350m
Chain Pillar Subsidence, S_p (m)	Mean $S_p/T = 0.238469/(1+e^{-[(\sigma DAL-25.5107)/7.74168]})$ +/- 0.048T	$R^2 = 0.833$	**Figure A16**
Goaf Edge Subsidence	Mean $S_{goe}/S_{max} = 0.0722(W/H)^{-2.557}$ U95%CL $S_{goe}/S_{max} = 0.0719(W/H)^{-1.9465}$	$R^2 = 0.82$	**Figure A20**
Angle of Draw	Mean AoD = $7.646Ln(S_{goe})+32.259$ U95%CL = Mean AoD + 8.7°	$R^2 = 0.56$	**Figure A21**
Maximum Tilt T_{max} (mm/m)	$T_{max} = 1.1925(S_{max}/W')^{1.3955}$ +/- $0.4T_{max}$ (W' = lesser of W and 1.4H)	$R^2 = 0.94$	**Figure A22**
Maximum Convex Curvature C_{max} (km^{-1})	Mean $C_{max} = 15.60(S_{max}/W'^2)$ +/- 0.5Mean	$R^2 = 0.7925$	**Figure A23**
Maximum Concave Curvature C_{min} (km^{-1})	Mean $C_{min} = 19.79(S_{max}/W'^2)$ +/- 0.5Mean	$R^2 = 0.7946$	**Figure A24**
Maximum Tensile Strain E_{max} (mm/m)	Mean 'smooth' $E_{max} = 5.2C_{max}$ +/- 0.5 Mean Mean 'Cracked' $E_{max} = 14.4C_{max}$	$R^2 = 0.72$ $R^2 = 0.32$	**Figure A25**
Maximum Compressive E_{min} (mm/m)	Mean $E_{max} = 5.2(C_{min})$ +/- 0.5 Mean Mean 'Cracked' $E_{min} = 14.4C_{min}$	$R^2 = 0.72$ $R^2 = 0.32$	**Figure A25**
Critical Panel Width	W_{crit} = 1.4H where H = cover depth	N/A	**ACARP, 2003**

Table A3 (Continued) - Summary of Subsidence Impact Parameter Prediction Models Developed from ACARP, 2003

Subsidence at Inflexion Point or Maximum Tilt STmax	Mean S_{Tmax}/S_{max} = -0.0925(W/H)+0.7356 +/- 0.2	$R^2 = 0.5$	**ACARP, 2003**
Distance to Inflexion Point, d/H	d/H = 0.2425Ln(W/H) + 0.3097	$R^2 = 0.734$	**Figure A27**
Distance to Peak Tensile Strain (mm/m)	d_t/H = 0.1643Ln(W/H) + 0.2203	$R^2 = 0.2802$	**Figure A27**
Subsidence at Peak Tensile Strain (mm/m)	$SC_{max} = C_{max}/1000)*0.008684*W'^2 + 0.299*S_{goe} + 0.70*ST_{max}$ Note: W'= the lesser of W and 1.4 H (but may be calibrated to measured profiles).	N/A	Adapted from **ACARP, 2003**
Distance to Peak Compressive Strain (mm/m)	d_c/H = 0.3409Ln(W/H) + 0.3996	$R^2 = 0.5906$	**Figure A27**
Subsidence at Peak Compressive Strain (mm/m)	$SC_{min} = (C_{min}/1000)*0.004536*W'^2 + 0.4375*S_{max} + 0.5625*ST_{max}$ Note: W'= the lesser of W and 1.4 H (but may be calibrated to measured profiles).	N/A	Adapted from ACARP, 2003

* - If H within 25 m of depth category boundary, then average result with overlying or underlying depth category value.

- Centreline profile parameters are not presented here (refer to **ACARP, 2003**).

A7 Subsidence Profile Predictions above Longwall Panels

Predicted 'smooth' subsidence profiles above single and multiple longwall panels have been determined based on cubic spline curve interpolation through seven key points along the subsidence trough (i.e. maximum in-panel subsidence, inflexion point, maximum tensile and compressive strain, goaf edge subsidence, subsidence over chain pillars and 20 mm subsidence or angle of draw limit).

The locations of these points have been determined empirically, based on regression relationships between the variables and the geometry of the panels (see **Table A3**). Both transverse and longitudinal profiles have been derived in this manner.

First and second derivatives of the fitted spline curves provide 'smooth' or continuous subsidence profiles and values for tilt and curvature. Horizontal displacement and strain profiles were derived by multiplying the tilt and curvature profiles by an empirically derived constant associated with the bending surface beam thickness (based on the linear regression relationship between the variables, as discussed in **ACARP, 2003**).

An allowance for the possible horizontal shift in the location of the inflexion point (within the 95% Confidence Limits of the database) has also been considered, for predictions of subsidence at features located over the goaf or extracted area.

A8 Subsidence Contour Predictions above Longwall Panels

Subsidence contours can be derived with geostatistical kriging techniques over a 10 m square grid using Surfer 8® software and the empirically derived subsidence profiles along cross lines, centre lines and corner lines around the ends of the longwall panels. Vertical 'slices' may taken through the contours to (i) determine subsidence profiles along creeks or infrastructure, and (ii) assess the likely impacts on the relevant surface features.

A8.1 Subsidence Contours

Subsidence contour predictions have been made in this study using SPDS®, which is an influence function based model that firstly calculates seam convergence and pillar displacements empirically around the workings. The influence of an extracted element of coal is transmitted to the surface via a 3-D influence function, which also takes varying topography into account.

The model is usually calibrated to measured maximum subsidence values by adjusting key parameters such as influence angles and inflexion point location from extracted panel sides.

A8.2 Tilt and Curvature Contours

The predicted principal tilt and curvature contours were derived using the calculus module of the Surfer8® program and the predicted subsidence contours from the SPDS® runs. The subsidence contours were based on a 10 m grid.

Principal tilts (i.e. surface gradient or slope) were calculated by taking the first derivative of the subsidence contours in x and y directions as follows:

$$T_p = [(\partial s/\partial x)^2 + (\partial s/\partial y)^2]^{0.5}$$

where ∂s = subsidence increment over distances ∂x and ∂y along x and y axes.

Principal curvatures (i.e. rate of change in slope or surface bending) were calculated by taking the second derivative of the subsidence contours in x and y directions as follows:

$$C_p = [(\partial^2 s/\partial x^2)(\partial s/\partial x)^2 + 2(\partial^2 s/\partial x\partial y)(\partial s/\partial x)(\partial s/\partial y) + (\partial^2 s/\partial y^2)(\partial s/\partial y)^2]/pq^{2/3}$$

where $p = (\partial s/\partial x)^2 + (\partial s/\partial y)^2$ and $q = 1+p$

A8.3 Strain

Before predictions of strain can be made, the relationship between the measured curvatures and strain must be understood. As discussed in **NERDDP, 1993b** and **ACARP, 2003**, structural and geometrical analysis theories indicate that strain is linearly proportional to the curvature of an elastic, isotropic bending 'beam'; see **Figure A28**. This proportionality actually represents the depth to the neutral axis of the beam, or in other words, half the beam thickness. **NERDDP, 1993b** studies returned strain over curvature ratios 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.

ACARP, 2003 continued with this approach and introduced the concept of secondary curvature and strain concentration factors due to cracking. The peak strain / curvature ratio for ‘smooth’ subsidence profiles in the Newcastle Coalfield was assessed to equal 5.2 m (mean) and 7.8 m (U95%CL) with the possibility that surface cracking could increasing the ‘smooth-profile’ strains to 10 or 15 times the curvature. The above values may also be affected by the thickness of near surface geology.

Reference to **DMR, 1987** also suggests a curvature to strain multiplier of 10 for high pillar extraction and longwall panels in the Newcastle Coalfield.

Attempts by others to reduce the variability in strain and curvature data by introducing additional parameters, such as the radius of influence, r, by **Karmis et al, 1987** and cover depth, H, by **Holla and Barclay, 2000**, appear to have achieved moderate success in the coalfields in which they were applied. However, when these models were applied to the Newcastle Coalfield data presented in **ACARP, 2003**, the results did not appear to improve things unfortunately; see **Figures A29.1** and **A29.2**.

It is therefore considered that the variability in behaviour is probably due to other parameters, which are very difficult to measure (such as the thickness and flexural, buckling and shear strengths of the near surface strata).

Provided that the likelihood of cracking can be ascertained from the strain predictions, then appropriate subsidence management plans can still be implemented.

A9 Prediction Of Subsidence Impact Parameters And Uncertainty Using Regression Analysis Techniques

A9.1 Regression Analysis

Key impact parameters have been predicted using normalised longwall subsidence data from the Newcastle Coalfield. This approach allows a reasonable assessment of the uncertainty involved using statistical regression techniques. A linear or non-linear regression line has been fitted to the database for each impact parameter, normalised to easily measured parameters, such as maximum subsidence, panel width and cover depth. The quality or significance of the regression line is influenced by the following parameters:

(i) the size of the database,

(ii) the presence of outliers, and

(iii) the physical relationship between the key parameters.

The regression curves were reviewed carefully, as such curves can be (i) affected by outliers, and (ii) misleading, in that by adopting a mathematical relationship which gives the best fit (i.e. R^2) the curves are controlled by the database and may not reflect the true underlying physical dependencies or mechanisms that the data represents.

These issues are inherent in all prediction modelling techniques because, for example, all models must be calibrated to field observations to validate their use for prediction or back analysis purposes.

The regression techniques presented in the **ACARP, 2003** was done by firstly assessing conceptual models of the mechanics and key parameter dependencies (based on established solid mechanics and structural analysis theories), before generating the regression equations.

Several outliers in the model databases were excluded in the final regression equations, but only when a reasonable explanation could be given for each anomaly (i.e. multiple seam subsidence, geological faults and surface cracking effects).

The regression equations in **ACARP, 2003** have R^2 (i.e. Coefficients of Determination) values generally greater than 50%; indicating that the relationships between the variables are significant. For cases where the R^2 values are < 50%, the regression lines are almost horizontal (i.e. the parameter doesn't change significantly over the range of the database), and the use of the regression line will be close to the mean of the database anyway.

A9.2 Prediction Model Uncertainty

The level of uncertainty in the model predictions has been assessed using statistical analysis of the residuals or differences between the measured data and regression lines (i.e. lines of best fit). The *Standard Error* of the prediction has been derived from the residuals, which has then been multiplied by the appropriate 'z' or 't' statistic for the assumed normal probability distribution, to define Upper (and Lower) Confidence Limits.

The residual population errors for single panel subsidence are shown in **Figure A30**.

The empirical database therefore allows an assessment of variance and standard error such that the required subsidence parameter's mean and upper 95% Confidence Limit (Credible Worst Case) values can be determined for a given mining geometry and geology.

Provided there are (i) more than 10 data points in the data sets covering the range of the prediction cases, and (ii) the impact parameter and independent variables have an established physical relationship based on solid or structural mechanics theories, then it is considered unlikely that the regression lines will be significantly biased away from the underlying physical relationship between the variables by any limitations of the data set.

On-going review of each of the regression equations over the past six years by DgS has not required significant adjustment of the equations to include new measured data points. The regression equations derived are also amenable to spreadsheet calculation and program automation.

It is also important to make the distinction between the terms confidence *limit* and confidence *interval*. The Credible Worst Case terminology used in the model is **not** the upper limit of the 95% Confidence **Interval** - which would encompass 95% of the data. Since the lower 95% Confidence Limit is rarely used in practice, it was considered appropriate to adopt the 5% Probability of Exceedence values instead (this by definition represents the upper limit of the **90% Confidence Interval**).

Further, the term *Upper 95% Confidence Limit* used in the **ACARP, 2003** model is considered acceptable in the context of 'one-tailed' probability distribution limits (i.e. the Lower 95% Confidence Limit is generally of little practical interest).

A10 Subsidence Model Validation Studies

A10.1 Model Development

The **ACARP, 2003** model was developed such that the outcomes would re-predict > 90% of the database. Validation studies also included comparison of measured and predicted subsidence, tilt and strain profiles above several longwall panel crosslines and centrelines. Examples of predicted and measured profiles above multiple panels for the Newcastle Coalfield are shown in **Figures A31** to **A34** using the **ACARP, 2003** model. Subsequent predictions v. measured subsidence profiles are presented in **Figures A35** to **A38** using the updated version of the model discussed herein.

DgS is usually required to review predicted v. measured subsidence profiles after the completion of a longwall panel and report the results to DPI . Over the past six years, the model has generally over predicted measured subsidence, with the data falling somewhere between the mean and U95%CL values.

The predictions of curvature and strain, however, are generally problematic due to the common effects of discontinuous or cracking behaviour (i.e. lithological variation and cracking), resulting in measured strains that can be two to four times greater than predicted ‘smooth’ profile strains. This issue is discussed further in **Section A10.2**.

A10.2 Field Testing of Strain Predictions

Strain and curvature concentrations can increase ‘smooth’ profile strains by 2 to 4 times in the Newcastle Coalfield, when the panel width to cover depth ratio (W/H) exceeds 0.8 or radius of curvature is less than 2 km, see **ACARP, 2003**.

In the context of subsidence surveys, the definition of strain is the change in length (extension or compression) of a bay-length, divided by the original value of the bay length.

Where cracking occurs, measured strains will be highly dependent on the bay-length, and where rock exposures exist with widely spaced or adversely orientated jointing exist, much larger crack widths (than for the deep soil profile case) can occur.

For example, for a measured strain of 3 to 6 mm/m along a recently observed cross line above a longwall panel in the Newcastle area, several cracks developed in the soil surface, which ranged in width between 10 and 30 mm, whilst within 10 m of the area, a single 100 mm wide crack developed in a sandstone rock exposure of medium strength and with widely spaced jointing, see **Figure A39**.

At the moment, it is not possible to predict the magnitude of strains accurately, however, it is possible to make reasonable predictions that strains > 2 mm/m will cause cracking within the tensile strain zones and shearing, buckling within the compressive zones above a longwall with shallow surface rock. The strains and cracking can therefore be managed effectively by assuming cracks will occur and may need to be repaired after each longwall is completed.

A11 Sub-Surface Fracturing Model Development Outcomes

A11.1 Whittaker and Reddish Physical Model

It is considered that the published physical modelling work in **Whittaker and Reddish, 1989** provides valuable insight into the mechanics of sub-surface fracturing over longwall panels. The outcomes included specific guidelines (over and above such work as the Wardell Guidelines) for the prevention of inundation of mine workings beneath surface and sub-surface water bodies.

Their model was developed in response to the water ingress problems associated with early longwall extraction at the Wistow Mine in Selby, UK. The longwall panel was located at 350 m depth and experienced groundwater inflows of 121 to 136 litres/sec when sub-surface fracturing intersected a limestone aquifer 77 m above the seam.

The model identifies two distinct zones of fracturing above super-critical width extractions (continuous and discontinuous fracturing) and relates the height of each to "measured maximum tensile strain at the surface". As such, its use is also based upon being able to make credible subsidence predictions. The basis of the model is summarised in **Figure A40**.

The definition of the extent of 'continuous' fracturing refers to the height at which a direct connection of the fractures occurs within the overburden and the workings; it represents a 'direct' hydraulic connection for groundwater inflows.

The definition of the extent of 'discontinuous' fracturing refers to the height at which the horizontal permeability increases as a result of strata de-lamination and fracturing. Direct connection of fractures within the overburden and workings is still considered possible, but will depend on the geology (e.g. massive units and / or the presence of persistent vertical structure, such as faults and joints).

A review of the methodology applied to develop the model and its key features are summarised below:

- The model was based on laboratory experiments of longwall extraction physical models.

- The physical model was constructed from multiple layers of coloured sand and plaster fixtures, with sawdust bond breakers placed between each successive layer. The model was initially devoid of vertical joints.

- The scale and mechanical properties of the model satisfied dimensional analysis and similtude laws.

The model was used to simulate the overburden behaviour of a panel with a W/H ratio of 1.31 and a progressively increasing working height range that commenced at 1.2 m and finished at 10.8 m. The advancing longwall face was simulated by removing timber blocks at the base of the model in 1.2 m to 2.0 m lift stages.

The extent or heights of ‘continuous’ and ‘discontinuous’ fracturing above the longwall ‘face’ was measured and plotted with the associated peak tensile strain predictions at the surface.

The fracturing path progressed up at an angle from the solid rib and inwardly towards the centre of the panel; see **Figure A40**.

The fracturing in question occurred close to the rib-side only, as fracturing in the overburden above the middle portion of the panel tended to ‘close’ and did not appear to represent an area in which groundwater inflows into the workings would be generated.

Any inflow conditions were therefore considered to be “mainly associated with the longwall rib-side fracture zone [or tensile strain zone]”.

A case study at Oaky Creek Colliery in the Bowen Basin was presented in Colwell, 1993; this attempted to calibrate the Whittaker and Reddish model with actual drilling and strain measurement data. Three fully cored boreholes were drilled over previously extracted longwall panels with a W/H ratio of 2.11 and strain measurement data was obtained from a nearby operating panel with a W/H of 1.37. The results of the study were very positive and have been subsequently collated with further case histories in **Section A8.2**.

A11.2 Preliminary Sub-Surface Fracturing Prediction Model For Australian Coalfields

The database of drilling data from previously published documents is summarised ACARP, 2003. Australian data was initially plotted with the UK Model results and a regression analysis was used to define a convenient relationship between the parameters and assessing whether other parameters of significance could be identified.

The results are presented in **Figure A41** and summarised below:

{A-Line} $A = a/H = 0.2077 \, Ln(E_{max}) + 0.150$, $R^2 = 0.44$

{B-Line} $B = b/H = 0.1582 \, Ln(E_{max}) + 0.651$, $R^2 = 0.49$

where

a, b = height above workings to A and B Horizons,
H = cover depth,
E_{max} = the maximum predicted tensile strain for a ‘smooth’ profile,

The Australian database appears to be similar to the Whittaker and Reddish model, however the predicted surface strains are much lower for a given height of ‘continuous’ and ‘discontinuous’ fracturing above the workings. It is also apparent that the model relies on the measured surface strain data, which has been noted previously for its high variability.

To overcome this issue it was decided to re-plot the database using the previously derived S_{max}/W^2, term to provide a readily measurable field parameter that would not be compromised by surface strain concentration effects. The revised regression results are shown in **Figure A42** and summarised below:

{A-Line} $A = a/H = 0.2295 \, Ln(S_{max}/W'^2) + 1.132$, $R^2 = 0.44$;

{B-Line} $B = b/H = 0.1694 \, Ln(S_{max}/W'^2) + 1.381$, $R^2 = 0.46$;

where

a, b = height above workings to A and B Horizons,
H = cover depth (m).
S_{max}/W'^2 = Overburden Curvature Index,
W' = lesser of W and 1.4H

Based on the alternative approach, the same apparent differences still remain between the Australian height of fracturing database and the UK physical modelling results. The apparent discrepancies between the model and measured values indicate that there are fundamental differences present (i.e. in particular the physical model had no preexisting subsurface fracturing present).

The A and B horizons in the sub-surface fracturing model presented in **Whittaker and Reddish, 1989** also appear to be the similar in regards to definition to the heights to the top of the 'Fractured Zone' and 'Constrained Zone' above an extracted longwall panel defined in **Forster, 1993**. There is also a departure in this model from assessing heights of fracturing based on the extraction height only, although the predicted tensile strain or S_{max} is directly related to the extraction height. It is considered that sub-surface fracture heights are a function of overburden bending and therefore primarily a function of the significant geometrical parameters Smax, W, H and T. The influence of massive lithology is included in the Smax prediction.

Overall, the **ACARP, 2003** sub-surface fracturing model was considered preliminary, more drilling data was required. The heights of fracturing derived, however, did appear to be conservative based on reference to several NSW and Queensland case studies.

It was also noted in **ACARP, 2003** that future calibration work on the model would be required to improve confidence in its use.

A11.3 Influence of Geology on Sub-Surface Fracture Heights

For the purposes of study completeness, an assessment was made on whether the geology had the potential to control or limit the height of fracturing above a longwall panel. Reference to the database presented in **ACARP, 2003**, indicates that two of the case studies were assessed to have High SRP and had A Horizons that coincided with the base of the massive strata units. The other data points had low SRP with no massive units present.

The massive strata unit affected data, however, did not appear to plot at lower than predicted levels compared to the low SRP cases, although this observation was based on a small sample of data. At this stage, the potential for a spanning strata unit to mitigate the height of continuous fracturing above the workings cannot be ignored.

Overall, the results suggest that the presence of massive sandstone or conglomerate lithology could control the height of direct hydraulic fracturing. Due to the complex nature of this problem, it is usually recommended that a mine undertake a sub-surface fracture-monitoring program, which includes a combination of borehole extensometer and piezometer measurements during extraction in non-sensitive areas of the mining lease. Mitigation strategies for longwall mining are generally limited to (i) reducing the extraction height and (ii) decreasing the panel width.

A12 References

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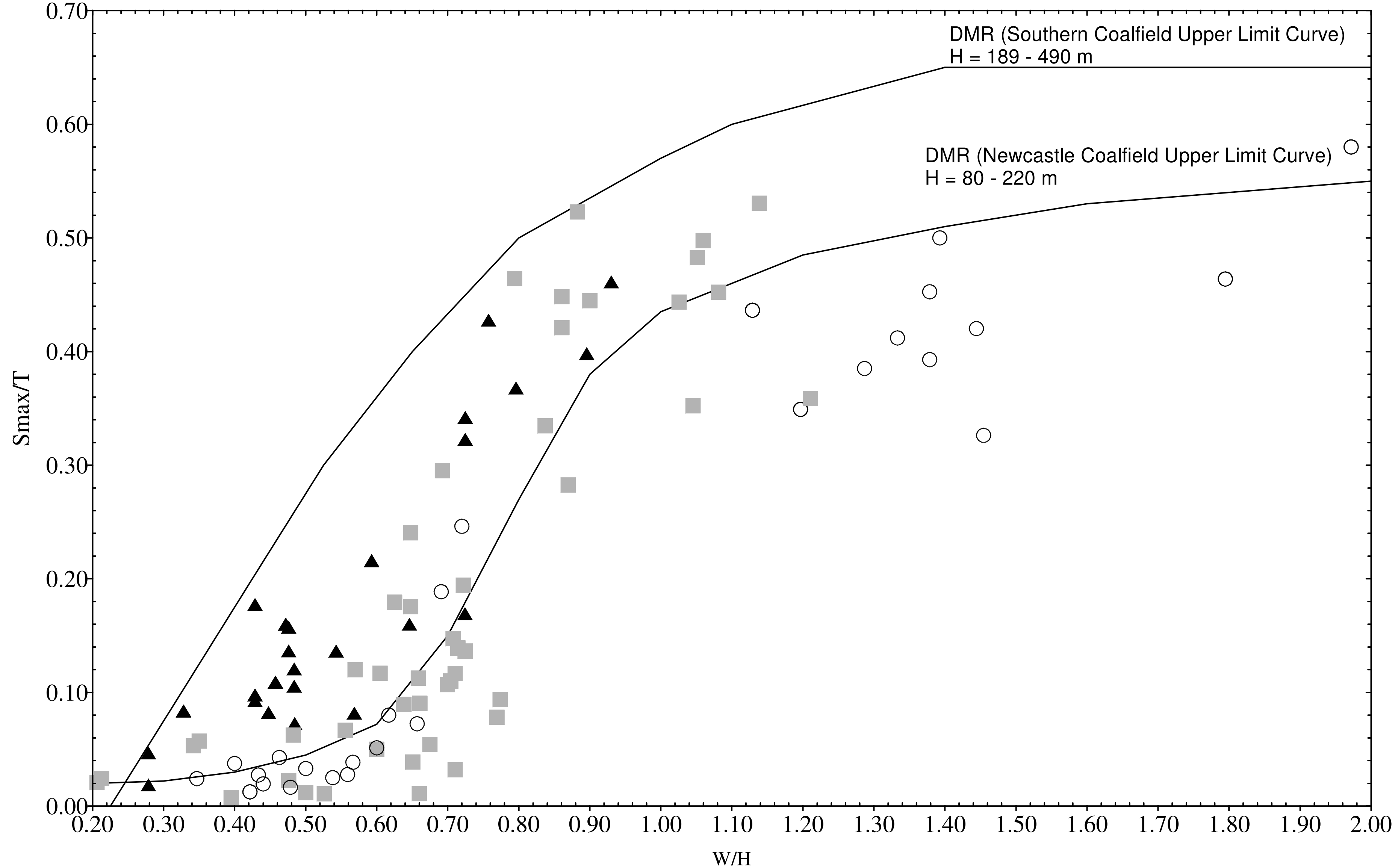
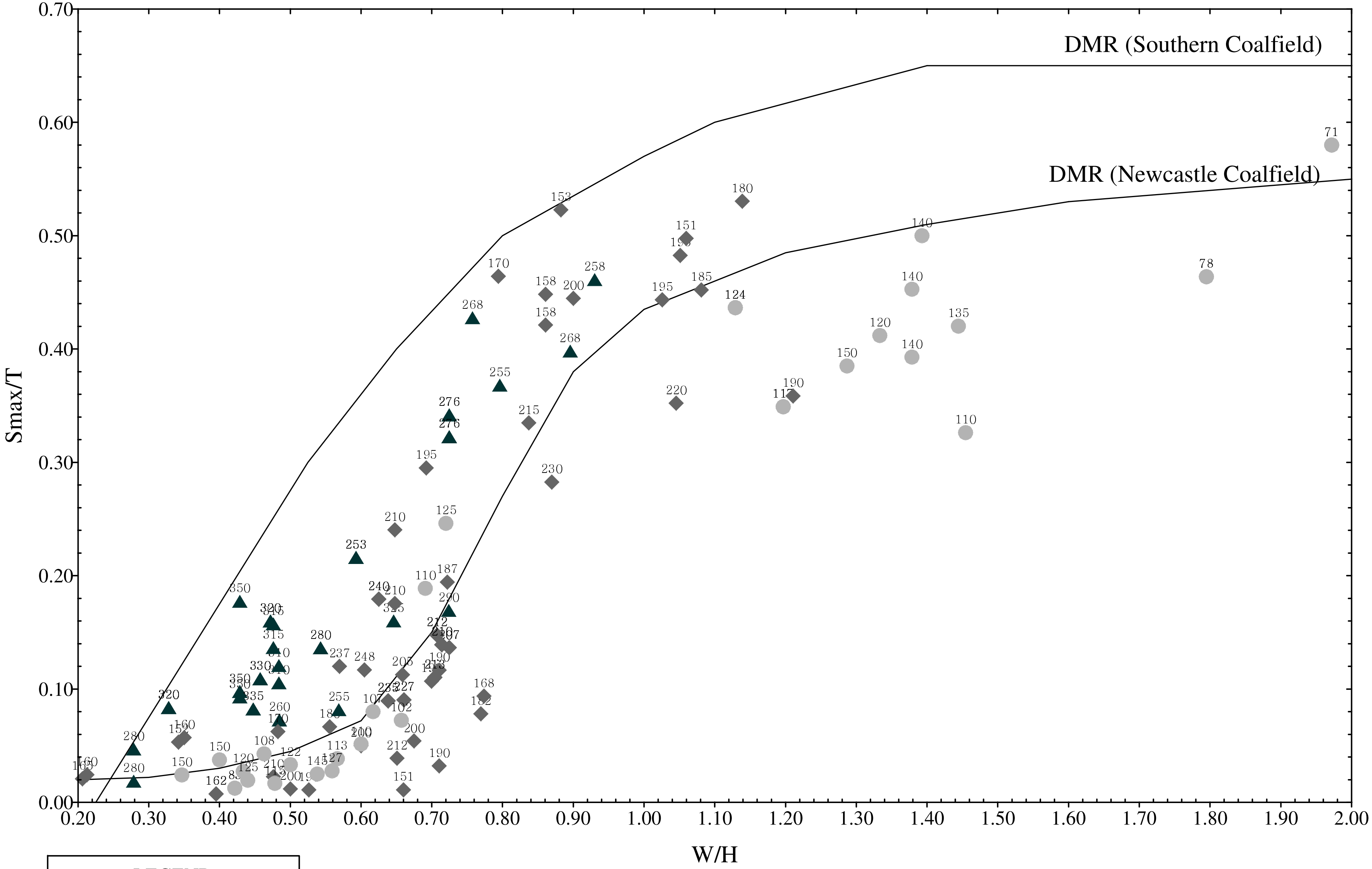


LEGEND
Cover Depth, H (m)

- ○ H = 70m to H = 151m
- ■ H = 151m to H = 251m
- ▲ H = 251m to H = 350m

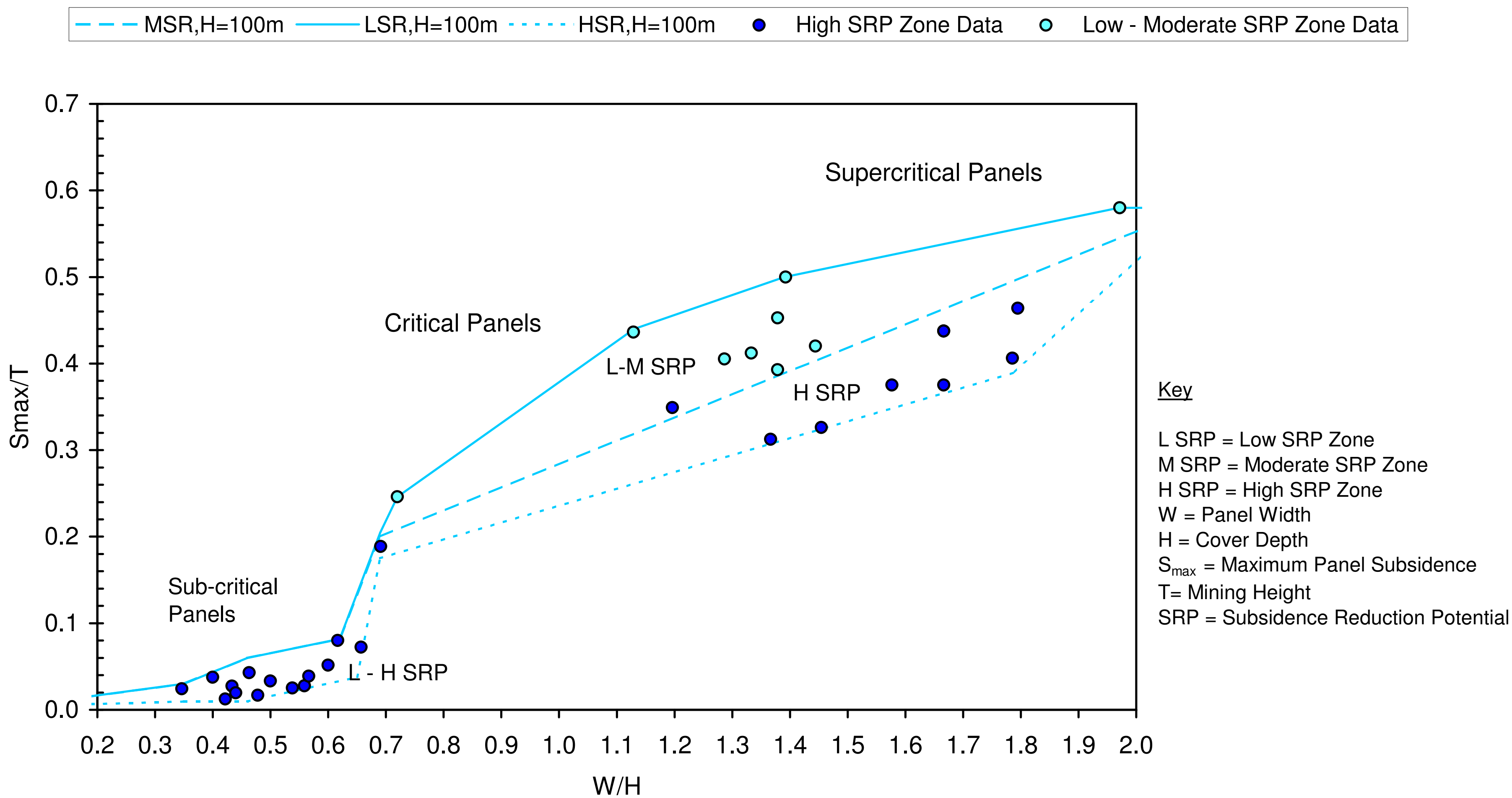
DgS	Engineer:	S.Ditton	Client:	Adapted from ACARP, 2003	
	Drawn:	S.Ditton			
	Date:	08.06.08	Title:	Project Database and DMR Subsidence Prediction Curves for Single Longwall Panels in Newcastle Coalfield	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: A1



LEGEND
Data Point
Cover Depth, H (m)

- H = 70m to H = 151m
- H = 151m to H = 251m
- H = 251m to H = 350m

DgS	Engineer: S.Ditton	Client:	Adapted from ACARP, 2003
	Drawn: S.Ditton		
	Date: 08.08.08	Title:	Project Database for Single Longwall Panels in Newcastle Coalfield showing Cover Depth for Each Point
Ditton Geotechnical Services Pty Ltd		Scale:	NTS
		Figure No:	A2



Note: No SRP distinguishment for panels with W/H<0.65

DgS	Engineer:	S.Ditton	Client:	Adapted from ACARP, 2003		
	Drawn:	S.Ditton				
	Date:	08.08.08	Title:	Empirical Model for Predicting Subsidence Above Panels with Cover Depths Between 50 and 150 m and Low to High SRP Zones		
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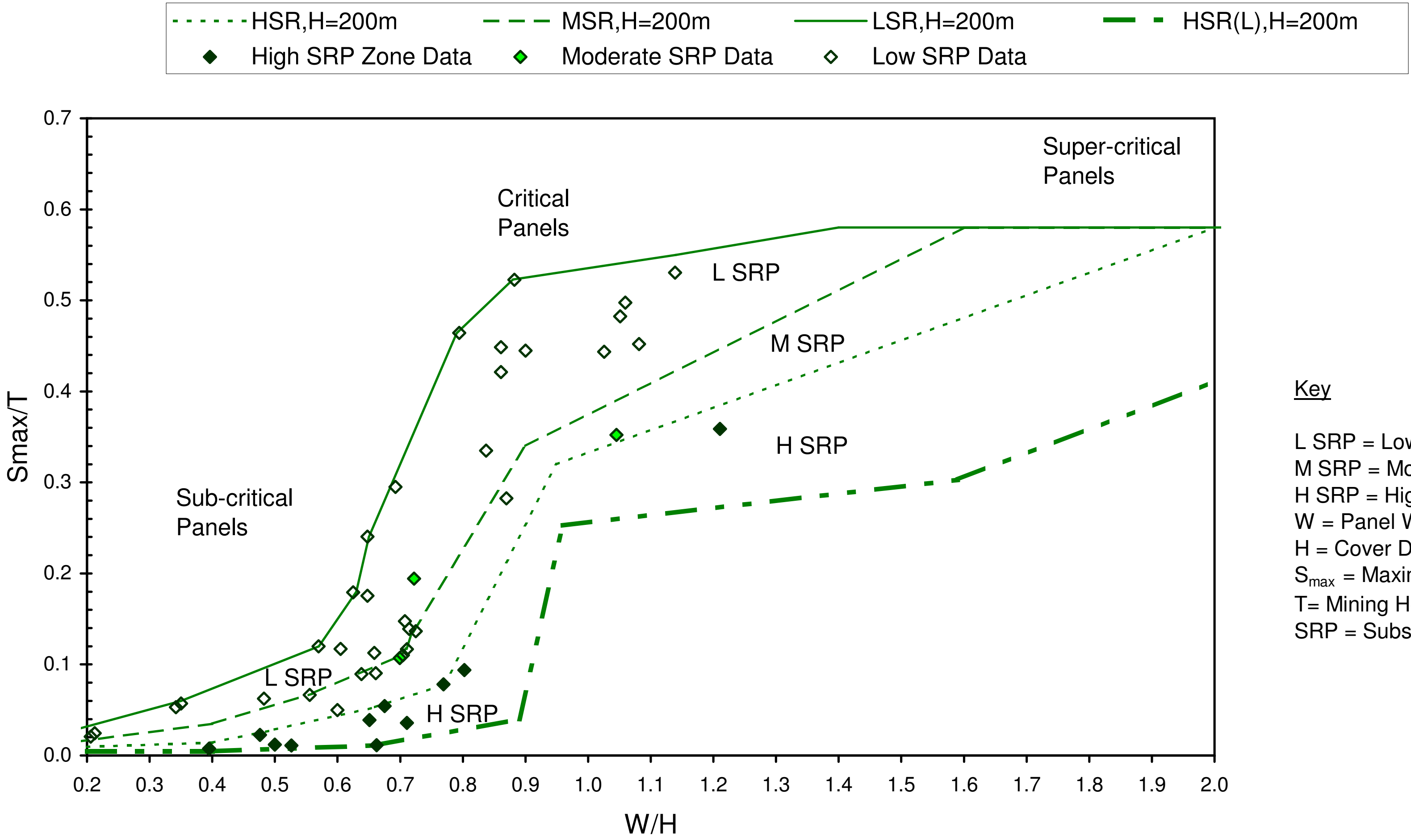

Key

L SRP = Low SRP Zone
M SRP = Moderate SRP Zone
H SRP = High SRP Zone
W = Panel Width
H = Cover Depth
S_{max} = Maximum Panel Subsidence
T= Mining Height
SRP = Subsidence Reduction Potential

DgS	Engineer:	S.Ditton	Client:	Adapted from ACARP, 2003		
	Drawn:	S.Ditton				
	Date:	08.08.08	Title:	Empirical Model for Predicting Subsidence Above Panels with Cover Depths Between 250 and 350 m and Low to High SRP Zones		
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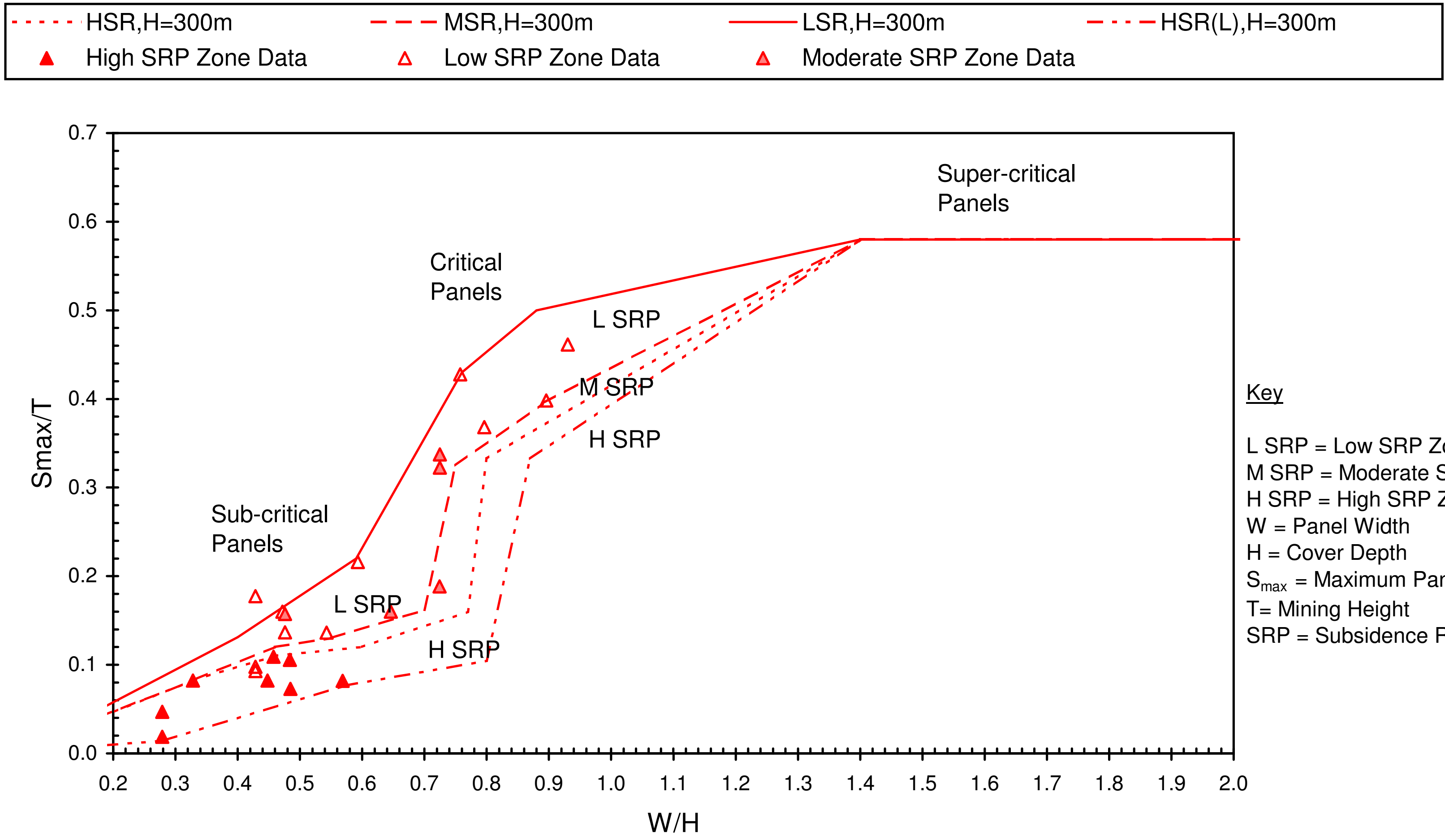

Key

L SRP = Low SRP Zone
M SRP = Moderate SRP Zone
H SRP = High SRP Zone
W = Panel Width
H = Cover Depth
S_{max} = Maximum Panel Subsidence
T= Mining Height
SRP = Subsidence Reduction Potential

DgS	Engineer:	S.Ditton	Client:	Adapted from ACARP, 2003
	Drawn:	S.Ditton		
	Date:	08.08.08	Title:	Empirical Model for Predicting Subsidence Above Panels with Cover Depths Between 250 and 350 m and Low to High SRP Zones
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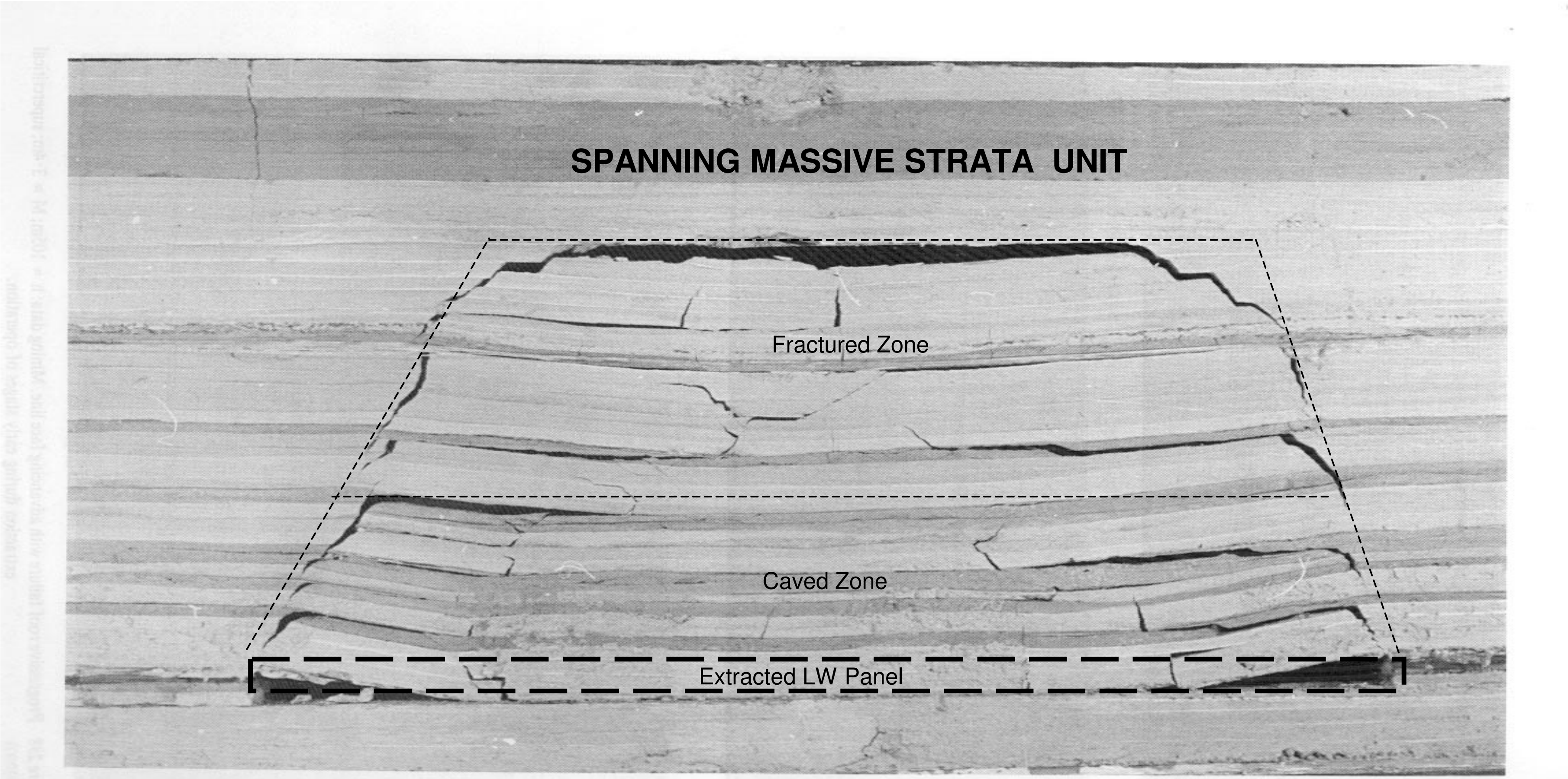

Physical model of caved strata above longwall extraction with strong overburden. Mining data: h = 84m; w = 118m; M = 4m.

DgS	Engineer:	S.Ditton	Client:	Adapted from ACARP, 2003	
	Drawn:	S.Ditton			
	Date:	08.08.08	Title:	Physical Overburden Model Showing the Subsidence Reducing Effect of a Massive Strata Unit At the Surface	
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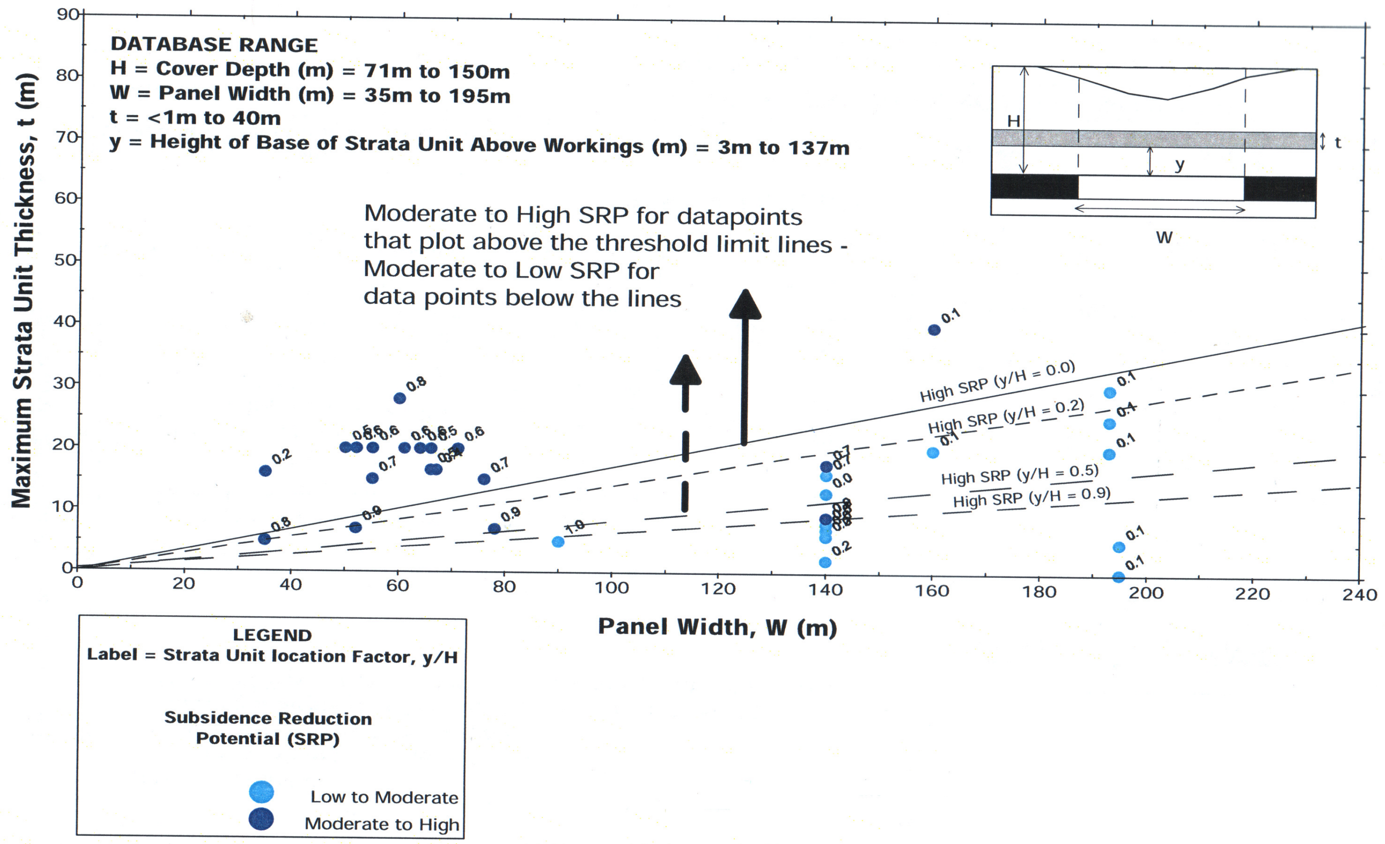

DgS	Engineer:	S.Ditton	Client:	Extract from ACARP, 2003		
	Drawn:	S.Ditton				
	Date:	08.08.08	Title:	Project Database of Maximum Strata Unit Thickness and SRP Threshold Limit Lines for H=50 m to 150 m		
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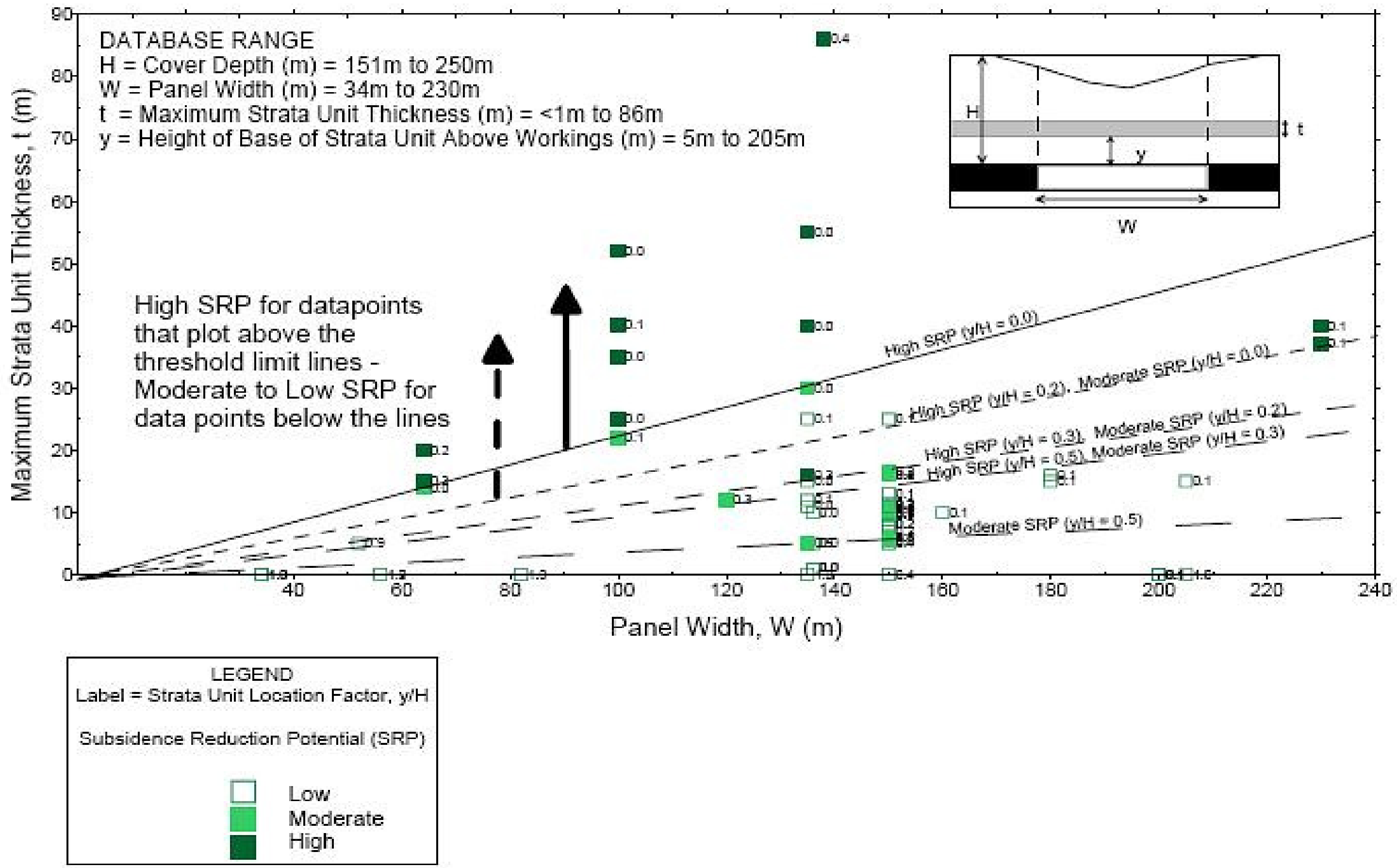

DgS	Engineer:	S.Ditton	Client:	Extract from ACARP, 2003		
	Drawn:	S.Ditton				
	Date:	08.08.08	Title:	Project Database of Maximum Strata Unit Thickness and SRP Threshold Limit Lines for H=150 m to 250 m		
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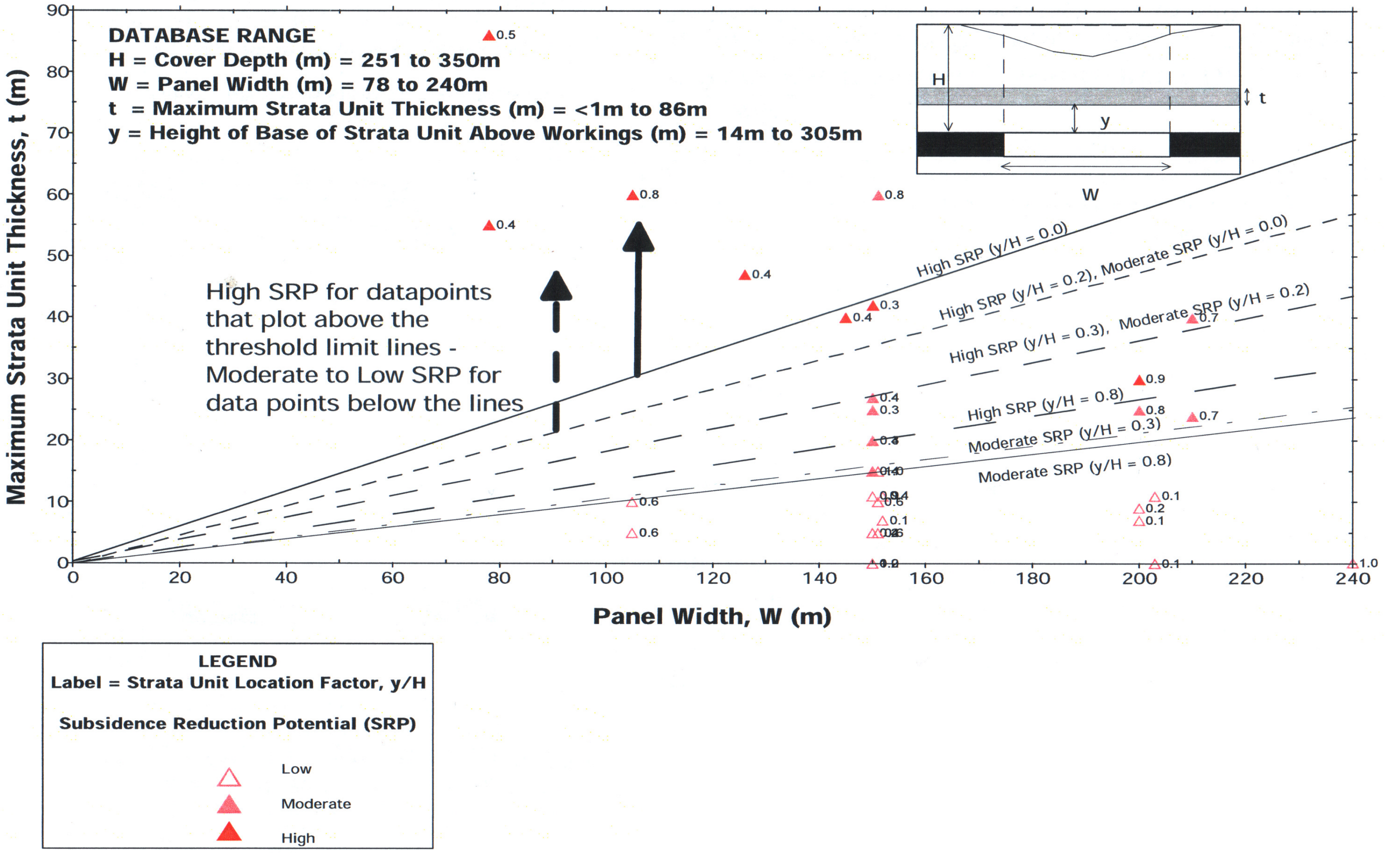

DgS	Engineer: S.Ditton		Client:	Extract from ACARP, 2003
	Drawn: S.Ditton			
	Date: 08.08.08		Title:	Project Database of Maximum Strata Unit Thickness and SRP Threshold Limit Lines for H=250 m to 350 m
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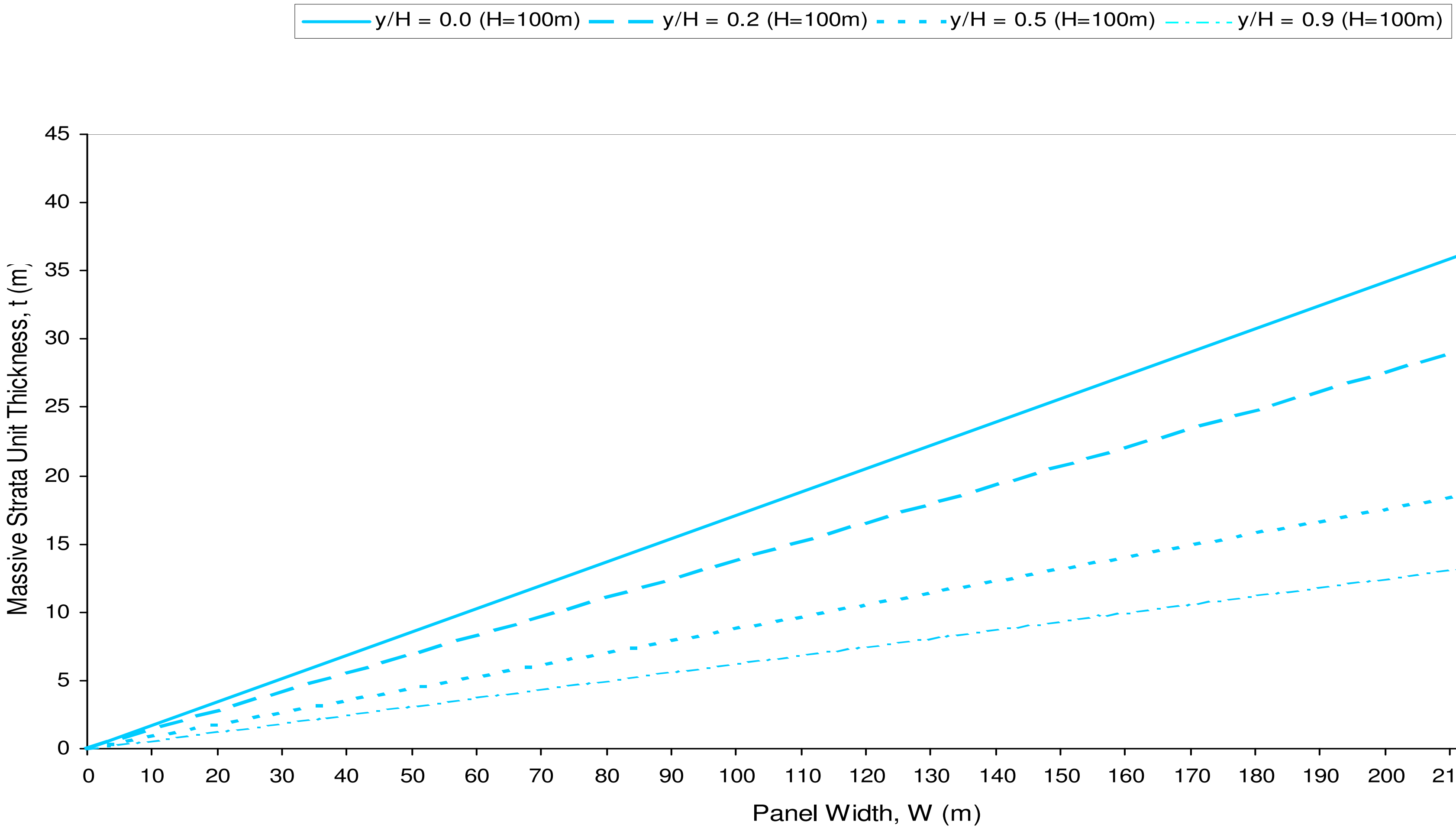

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	Drawn:	S.Ditton				
	Date:	08.08.08	Title:	Empirical Model for Predicting Subsidence Reduction Potential Above Panels with Cover Depths Between 50 and 150 m		
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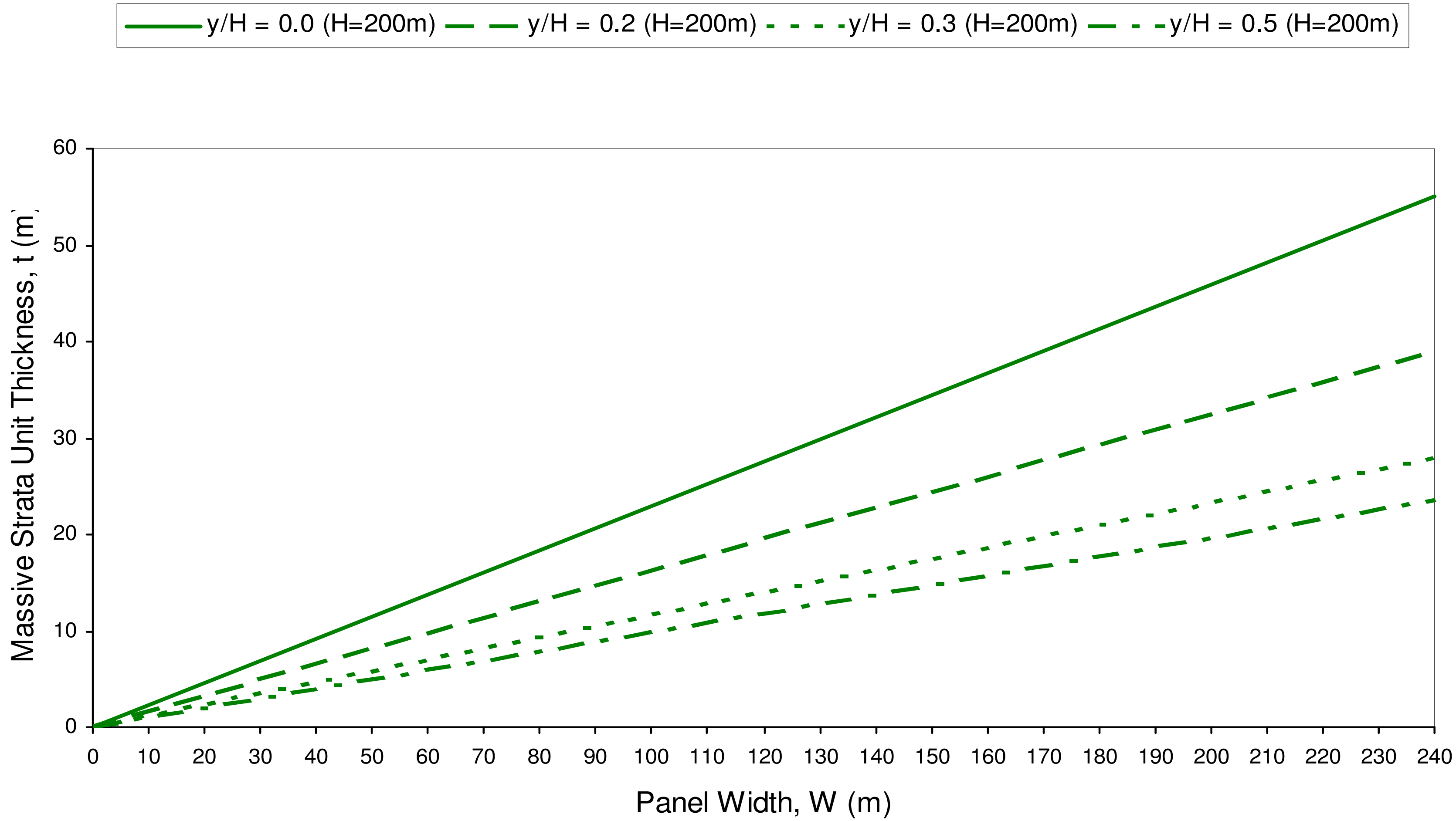

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	Date: 08.08.08		Title:	Empirical Model for Predicting Subsidence Reduction Potential Above Panels with Cover Depths Between 150 and 250 m
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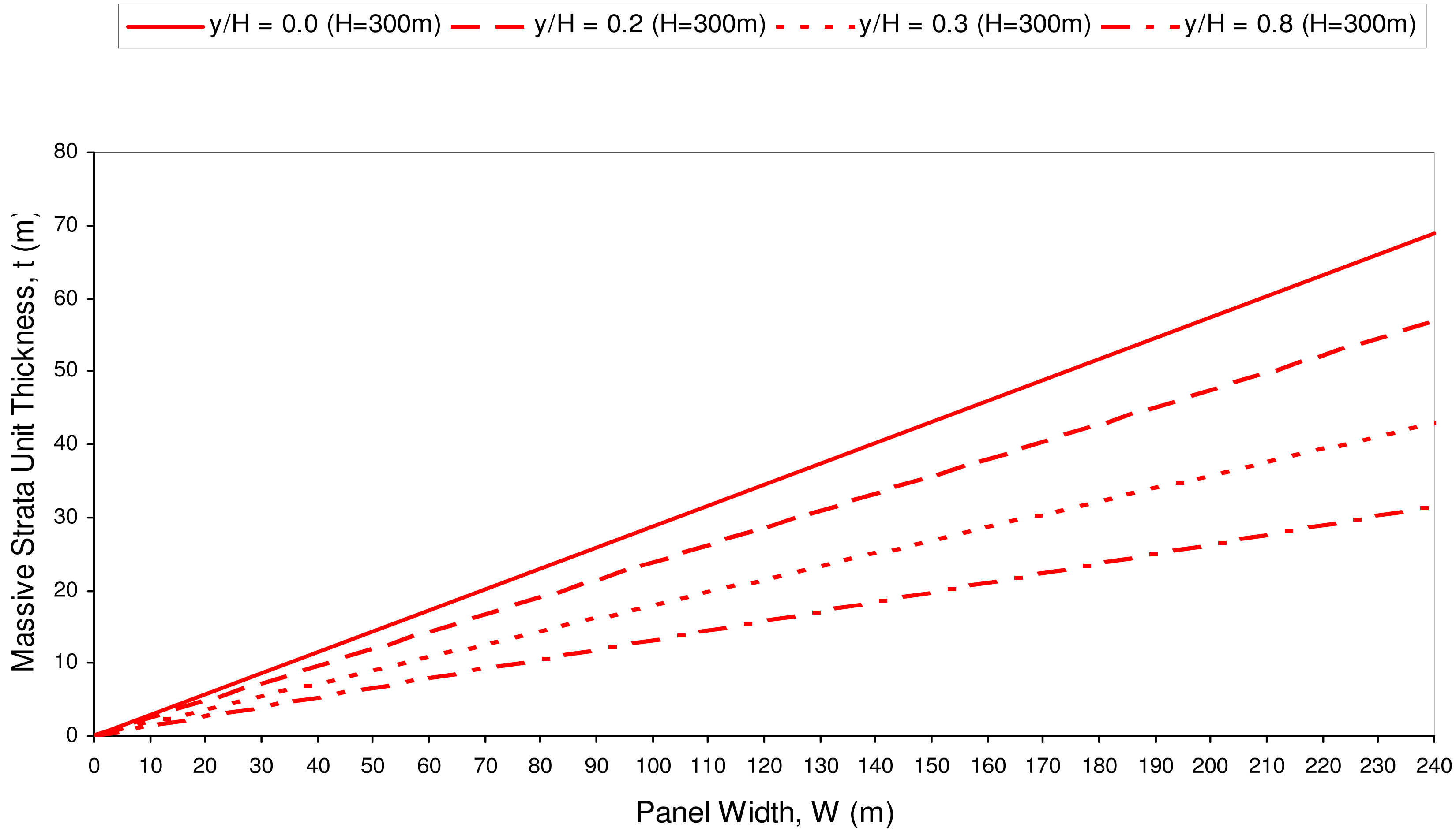

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	Drawn:	S.Ditton			
	Date:	08.08.08	Title:	Empirical Model for Predicting Subsidence Reduction Potential Above Panels with Cover Depths Between 250 and 350 m	
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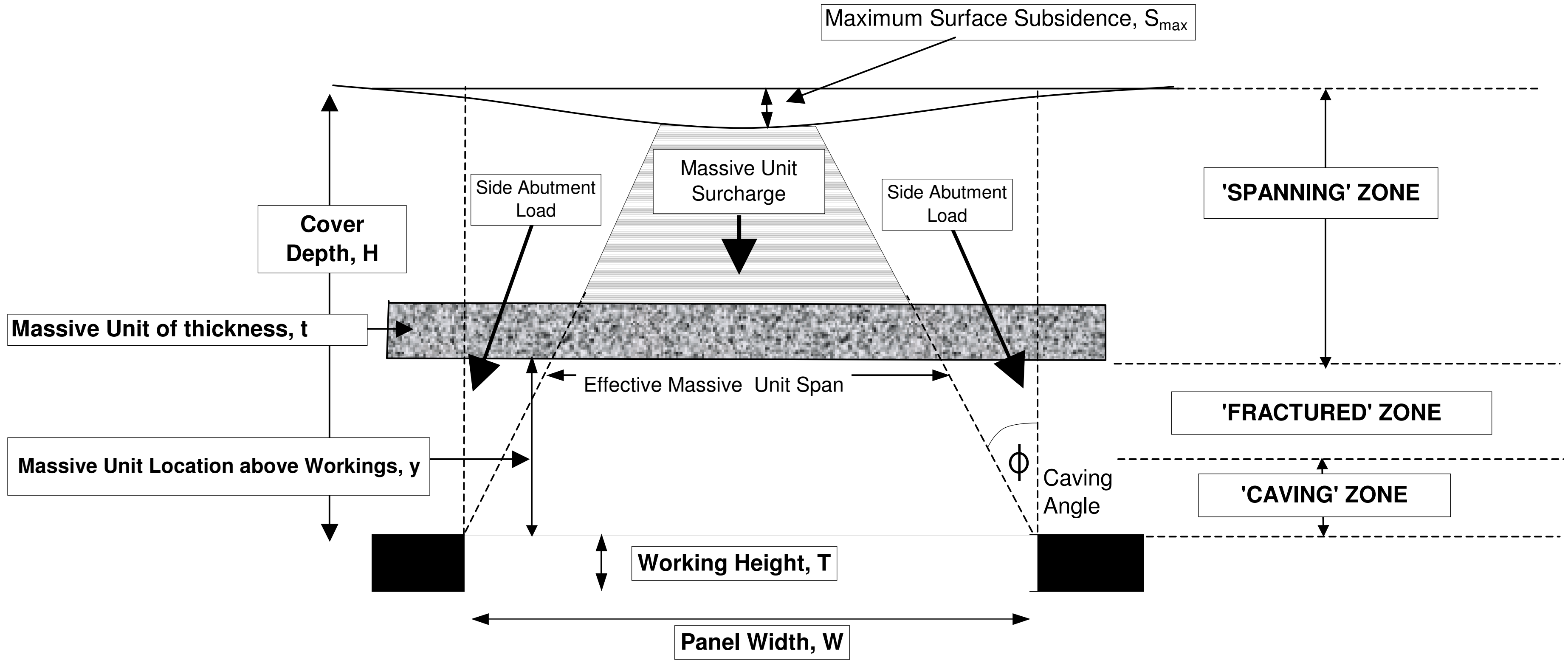

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Engineer:	S.Ditton	Client:	Adapted from ACARP, 2003	
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Date:	08.08.08	Title:	Overburden with Massive Strata Unit Behaviour Concept Model and Key Parameter Definitions	
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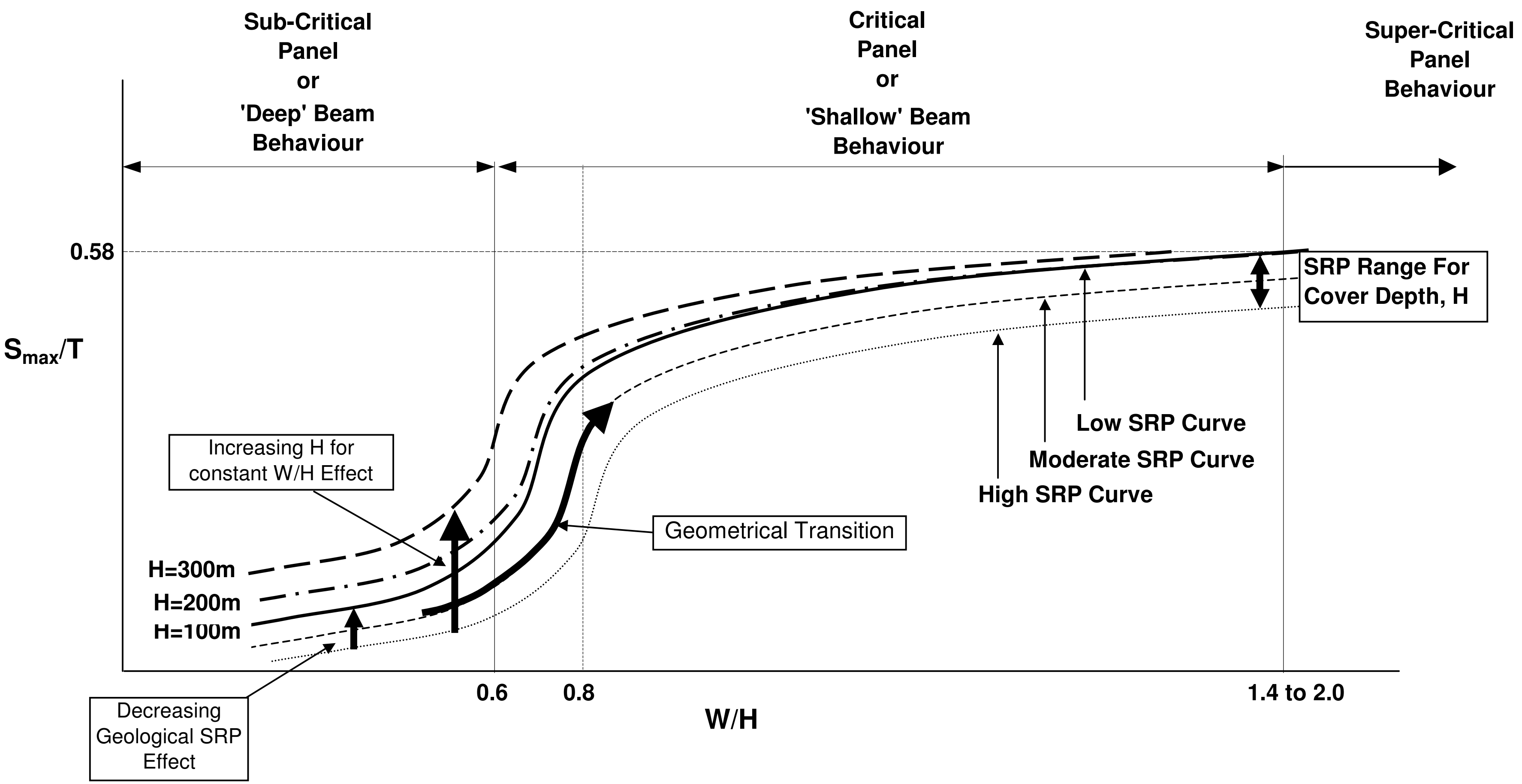

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	Date:	08.08.08	Title:	Geomechnical and Geological Effects of Overburden Behaviour on Maimum Subsidence for Single Panels
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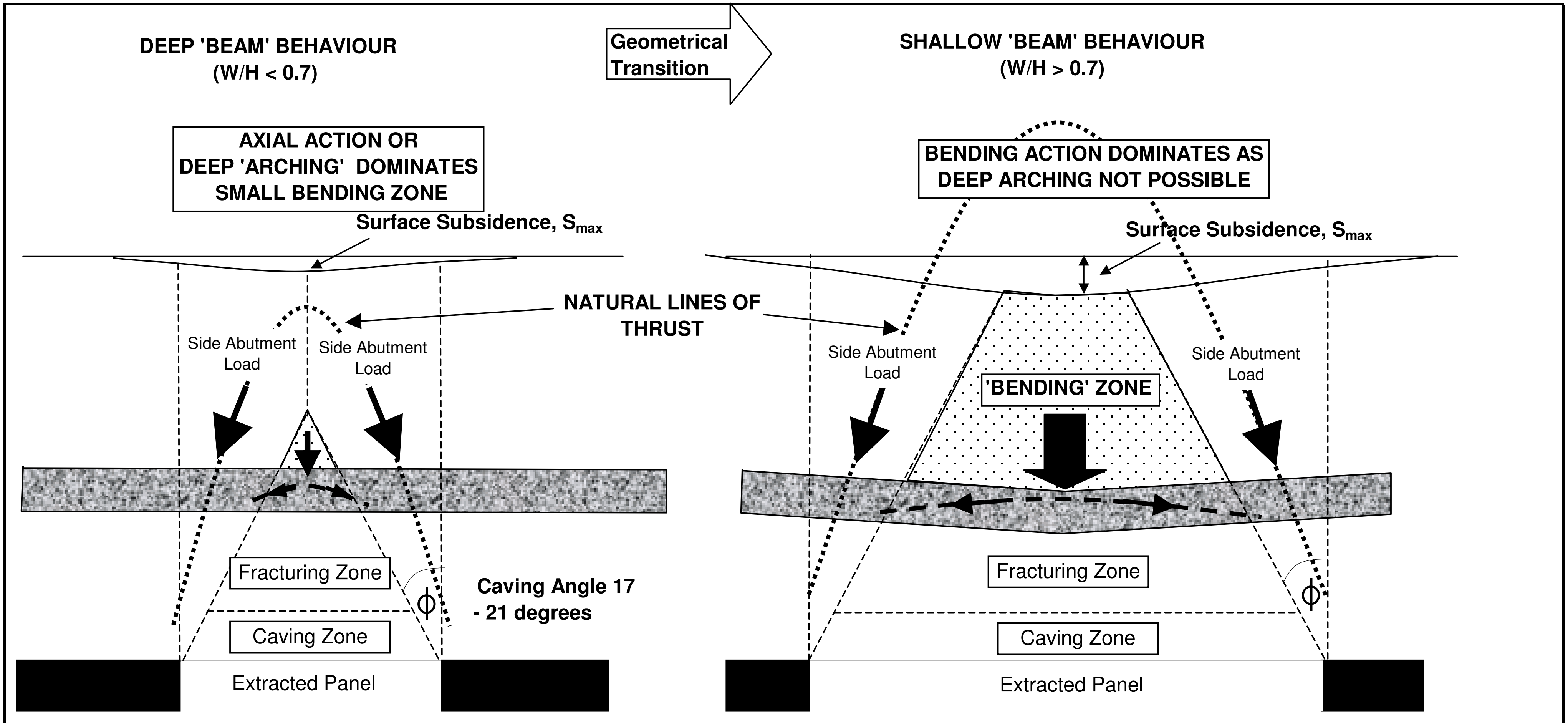

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	Date:	08.08.08	Title:	Overburden with Massive Strata Units Behaviour Concept Models of Beam Action Types for Subcritical and Supercritical Longwall Panels
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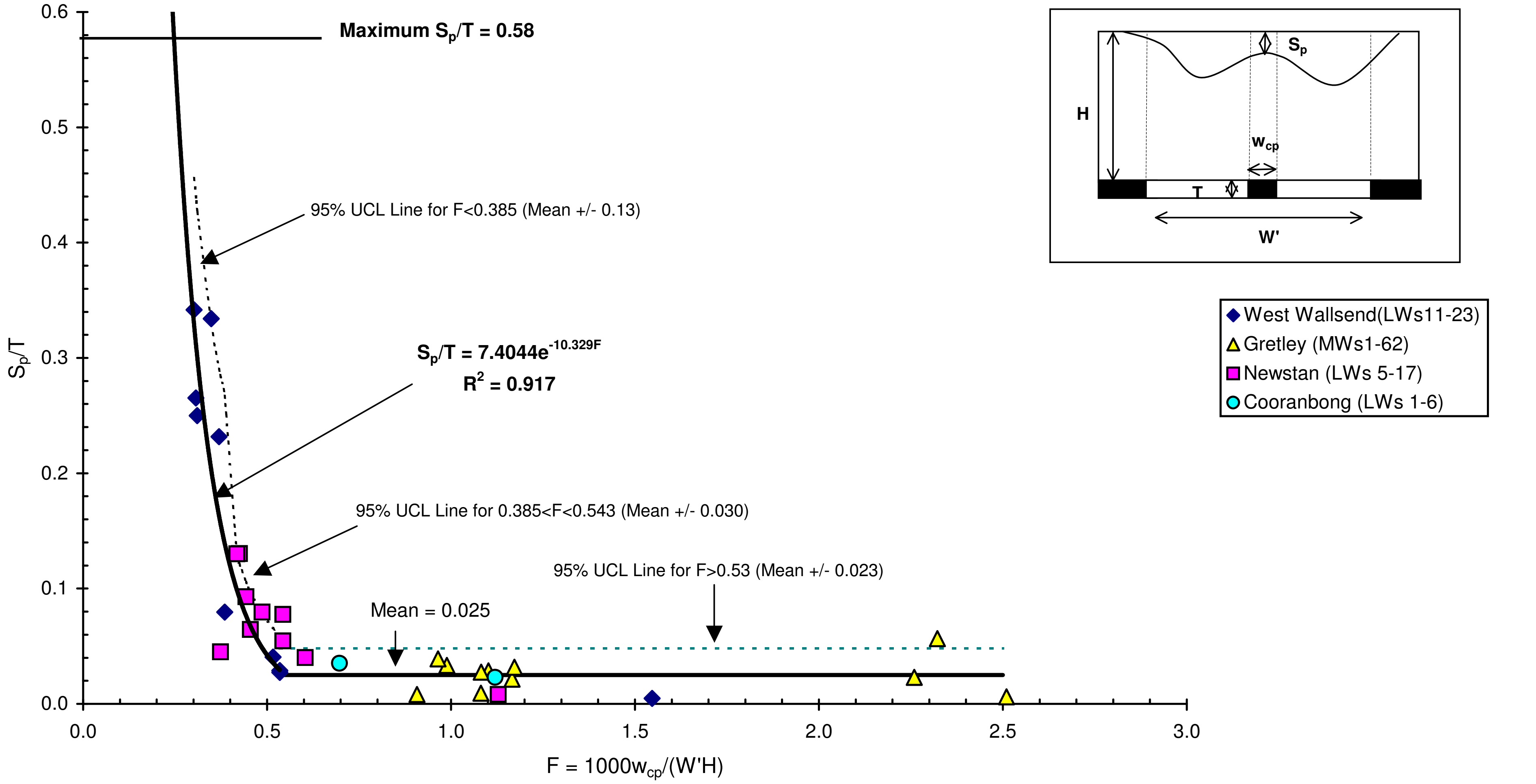

DgS	Engineer:	S.Ditton	Client:	Extract from ACARP, 2003
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	Date:	08.08.08	Title:	2003 Empirical Model for Predicting Subsidence above Chain Pillars Subject to Double Abutment Loading
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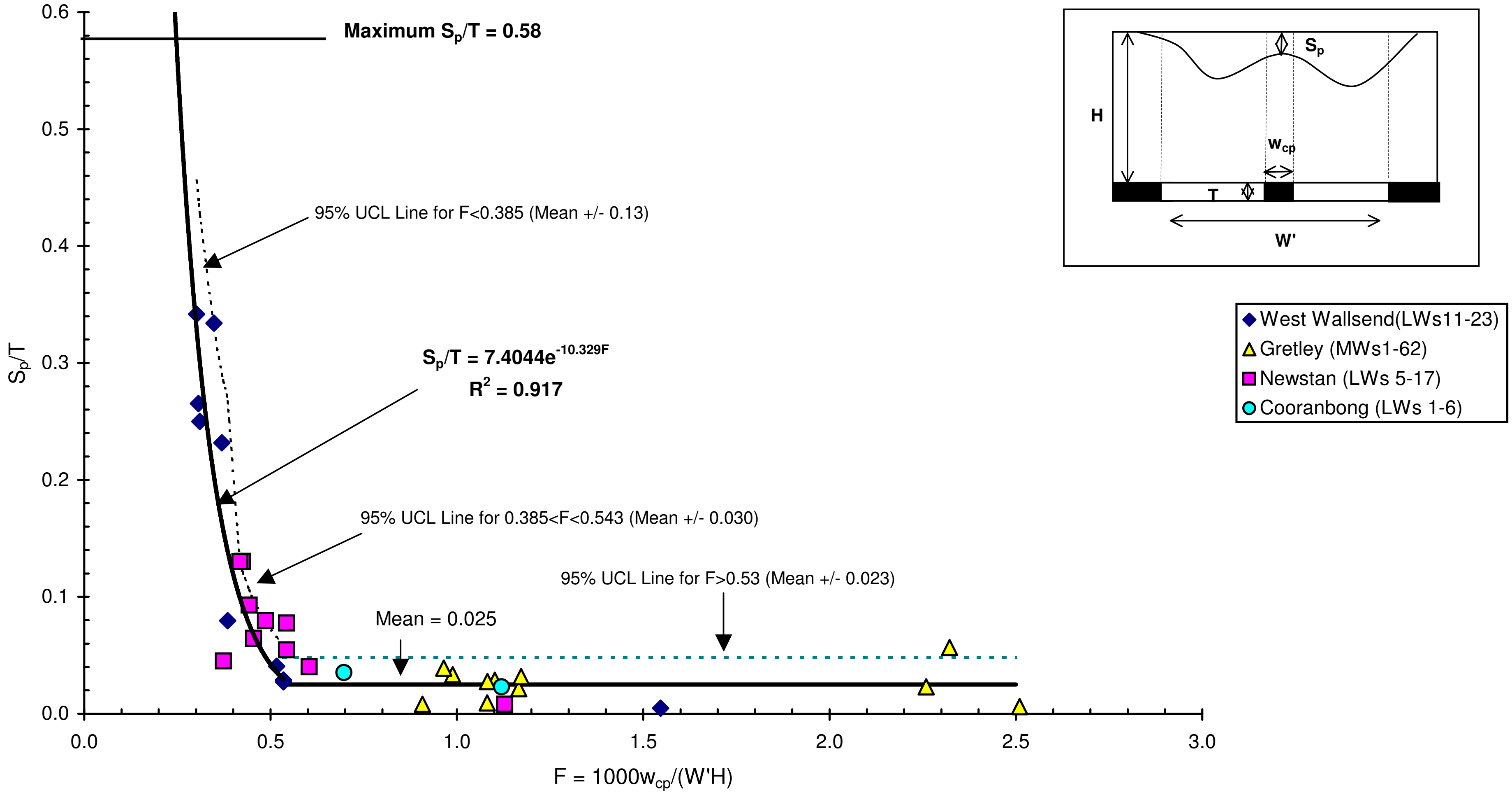

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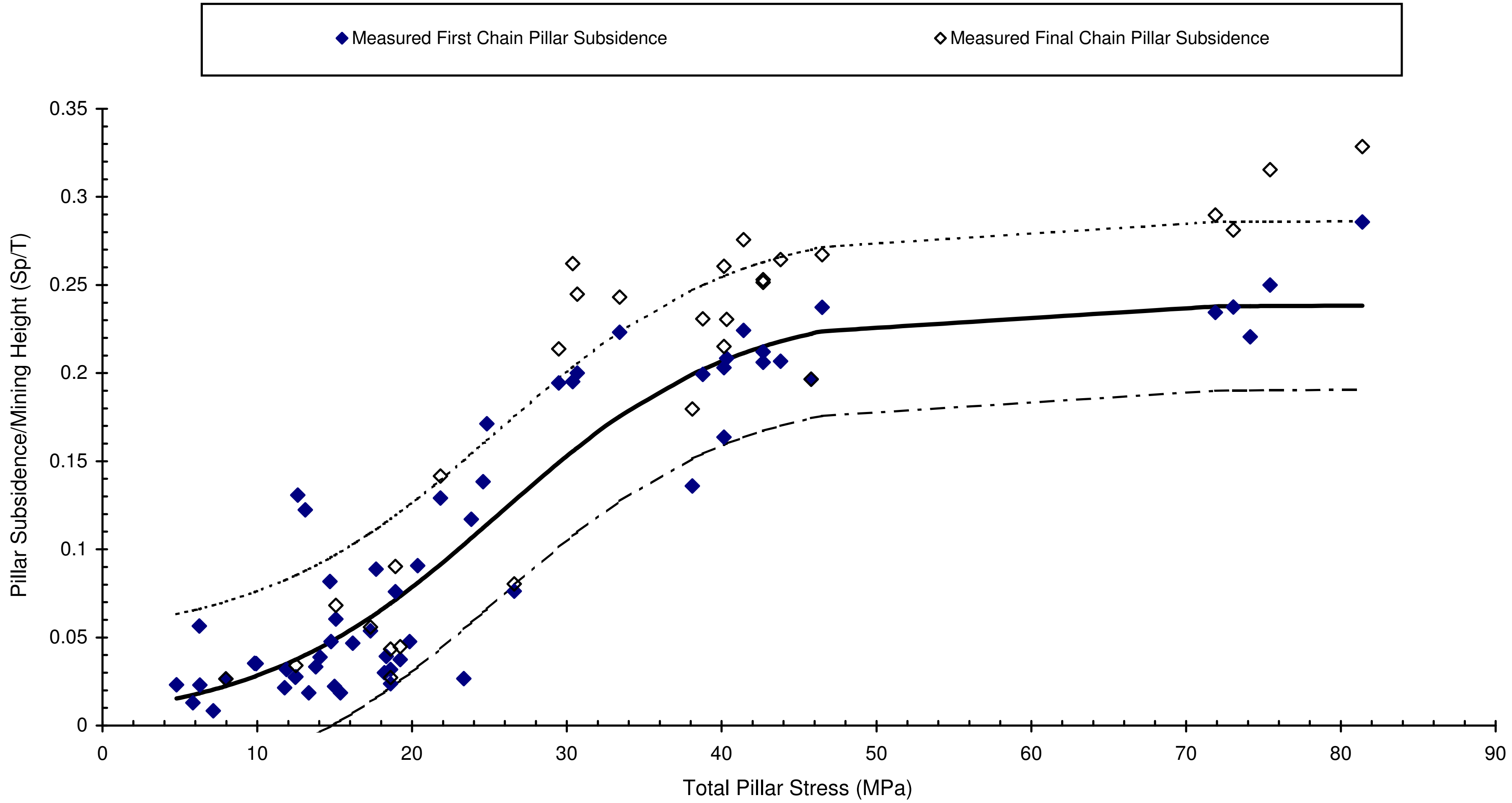

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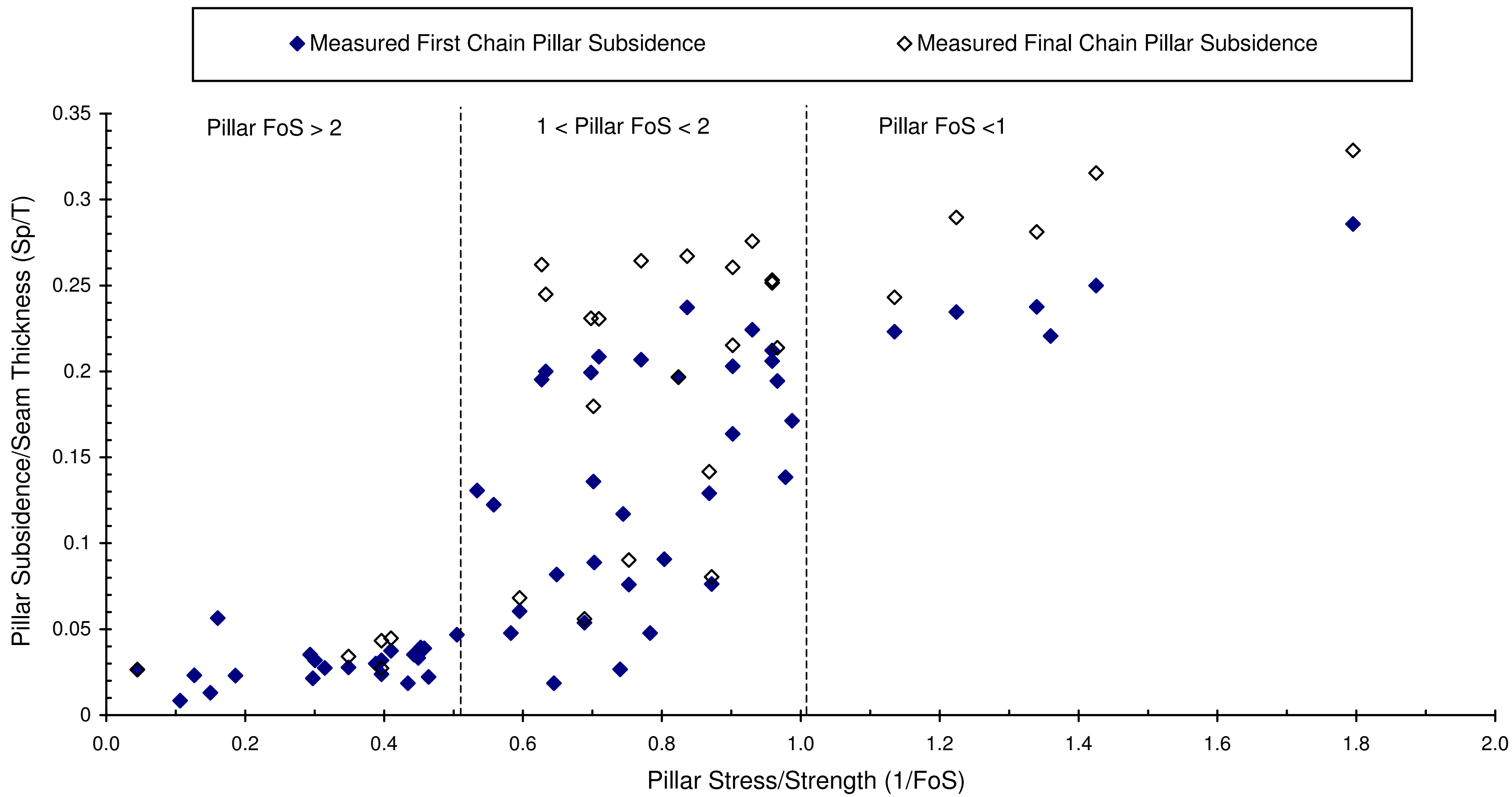

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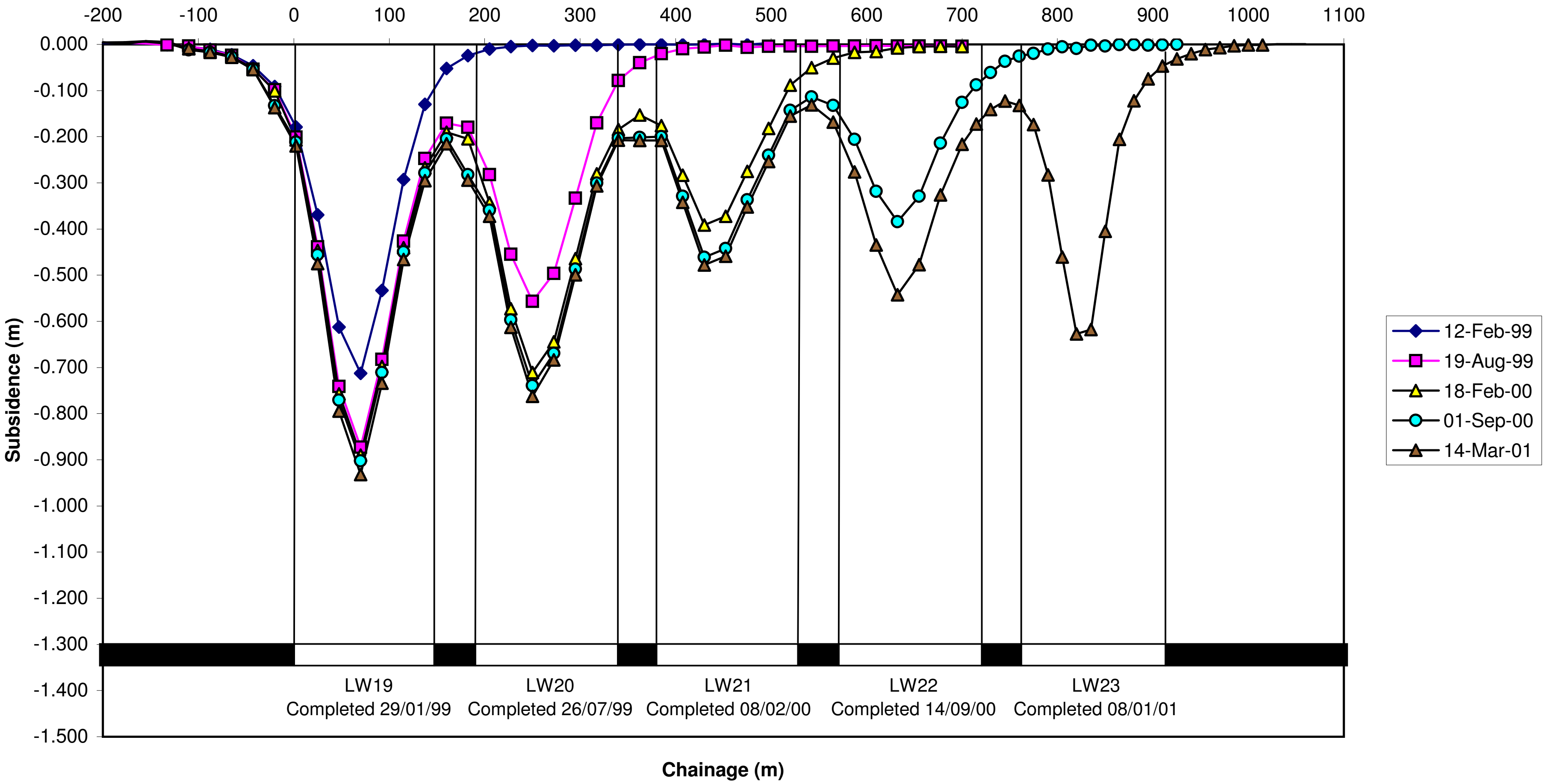

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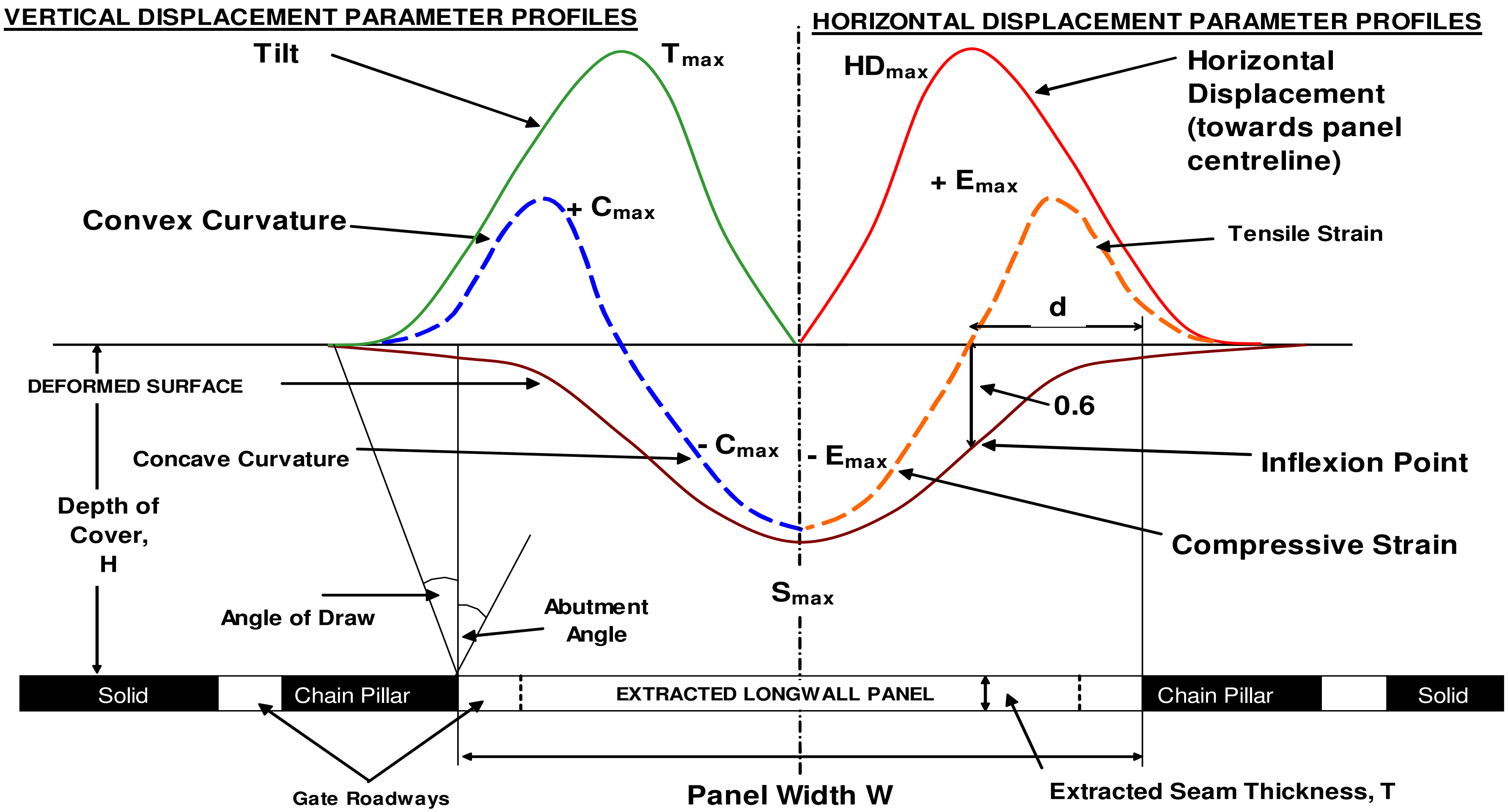

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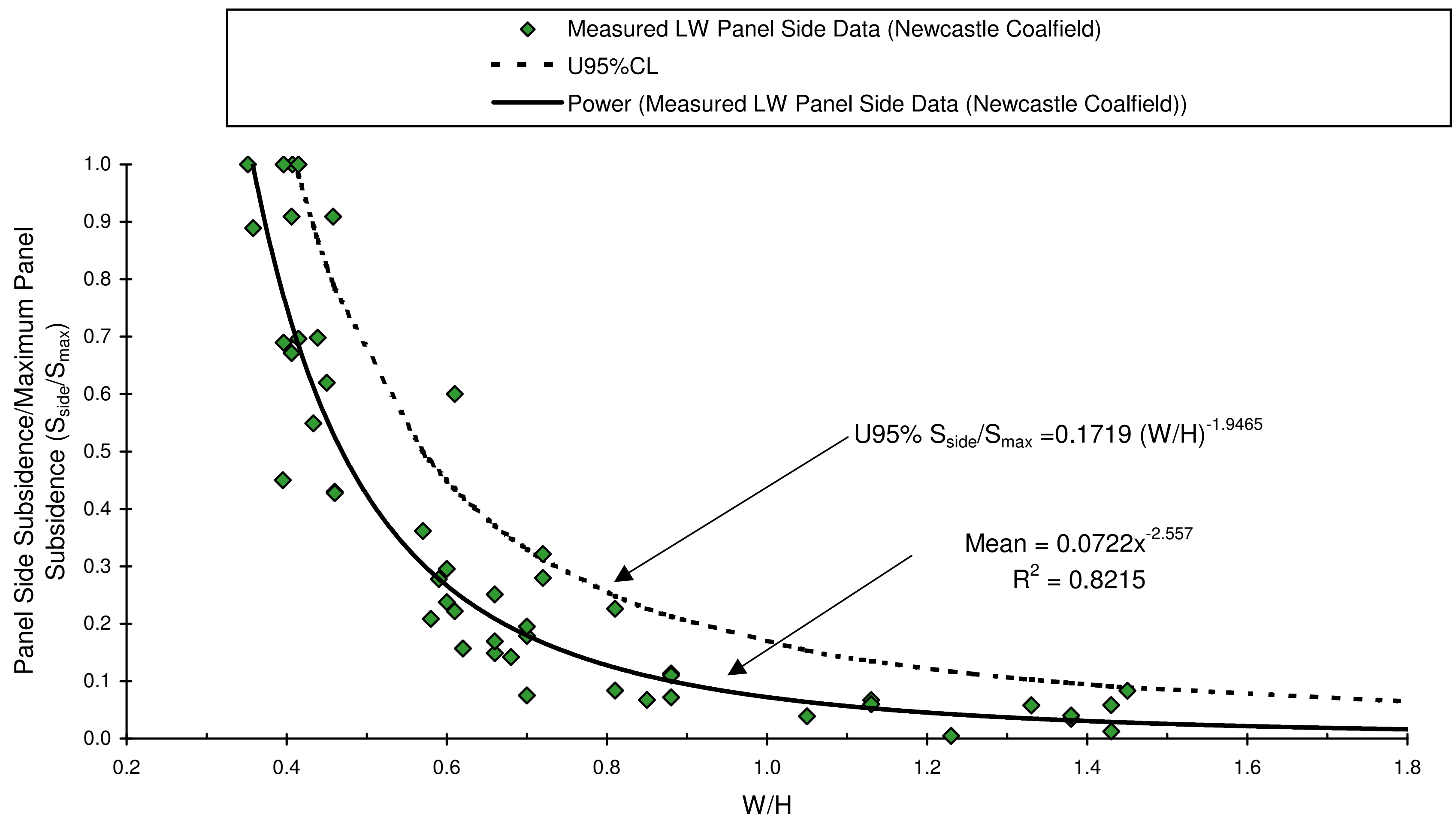

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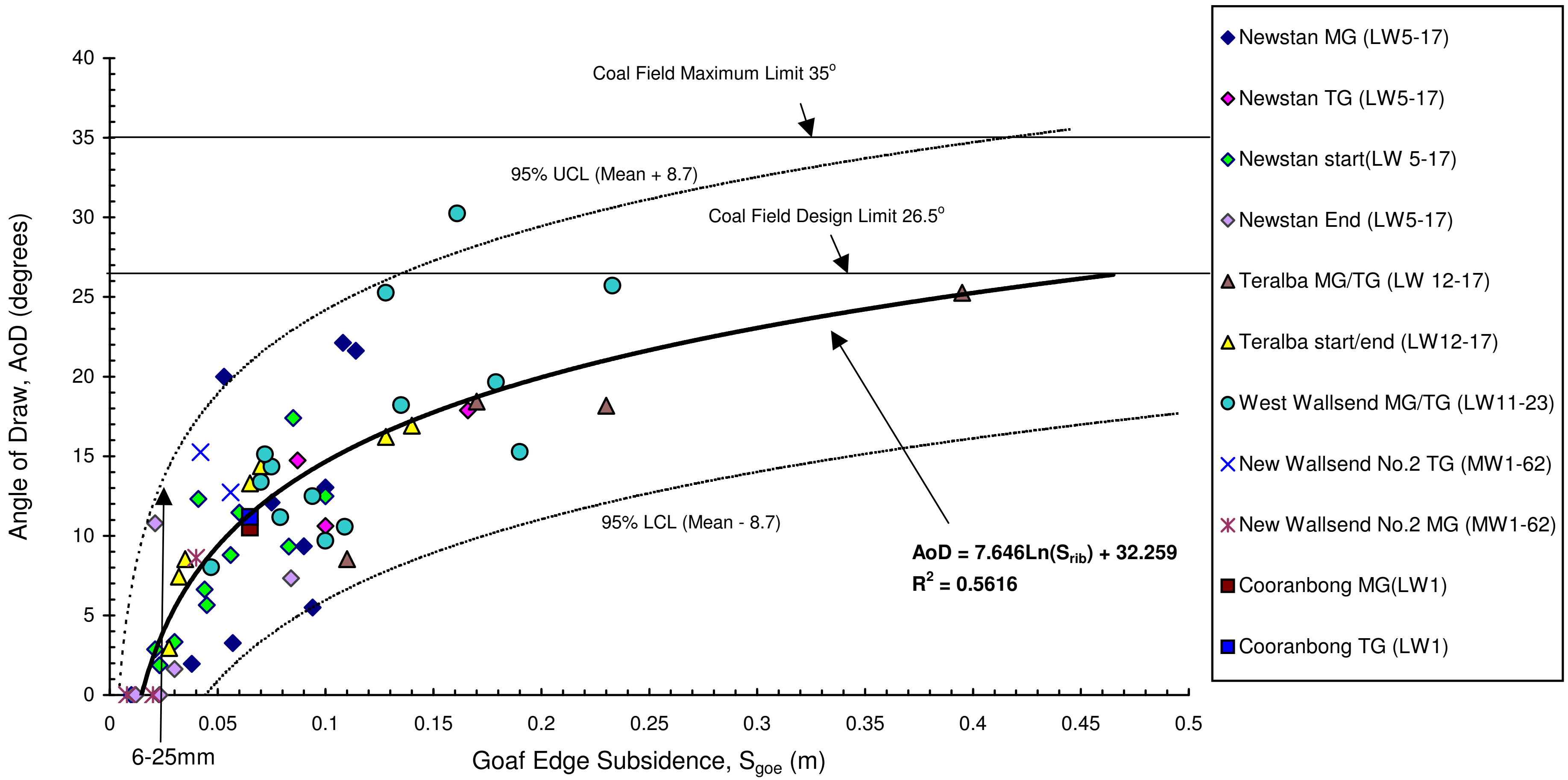

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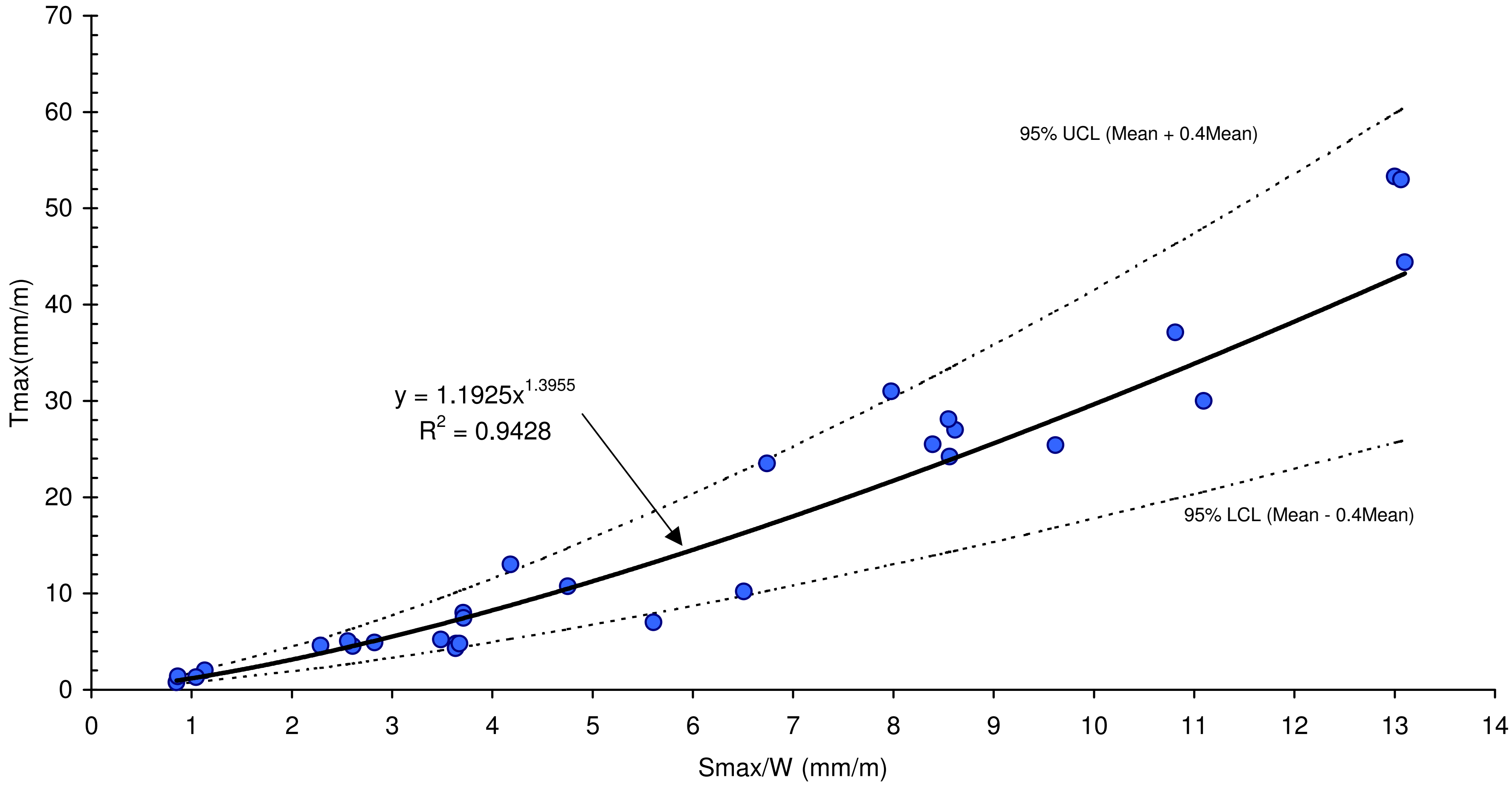

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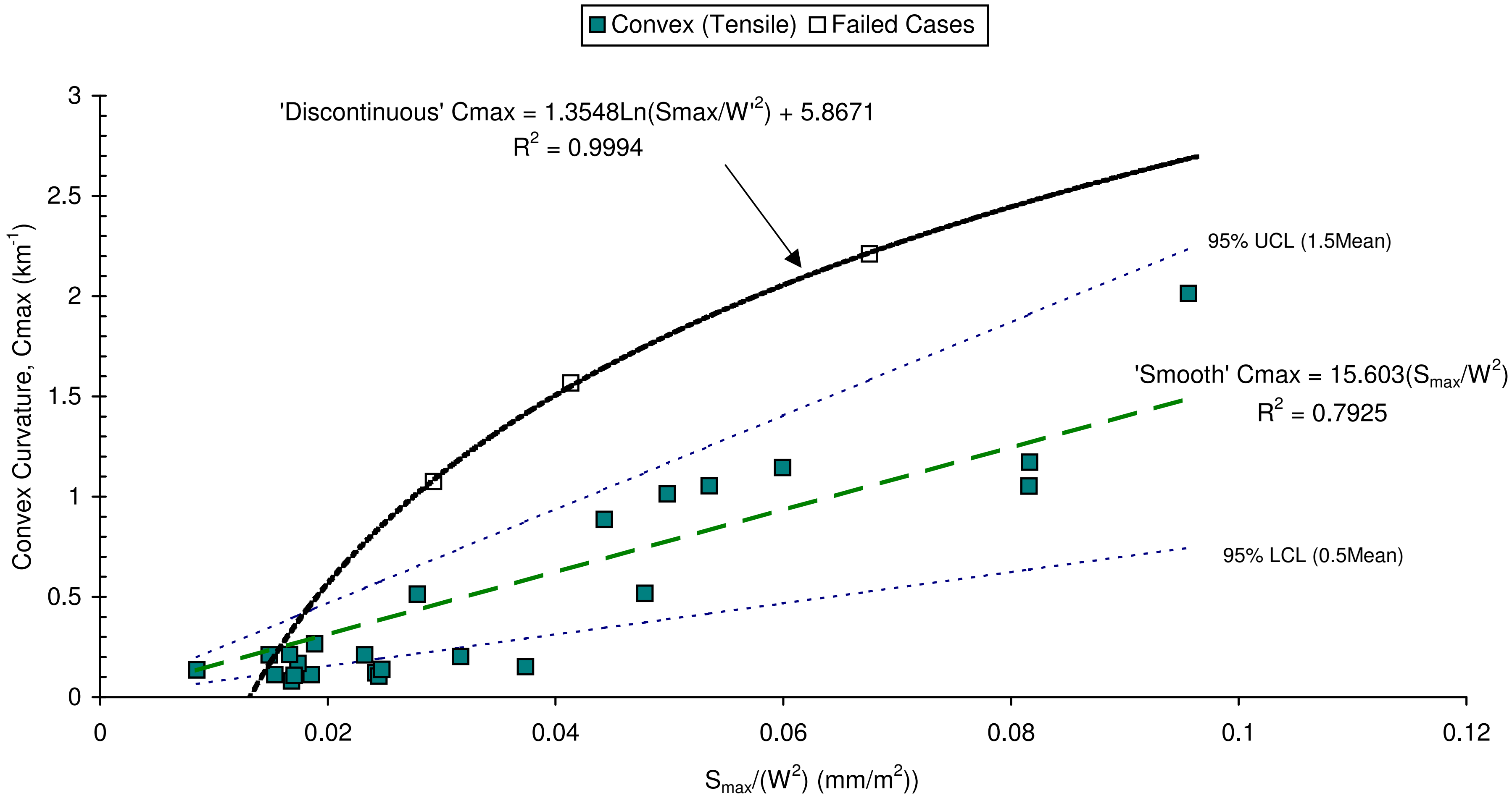

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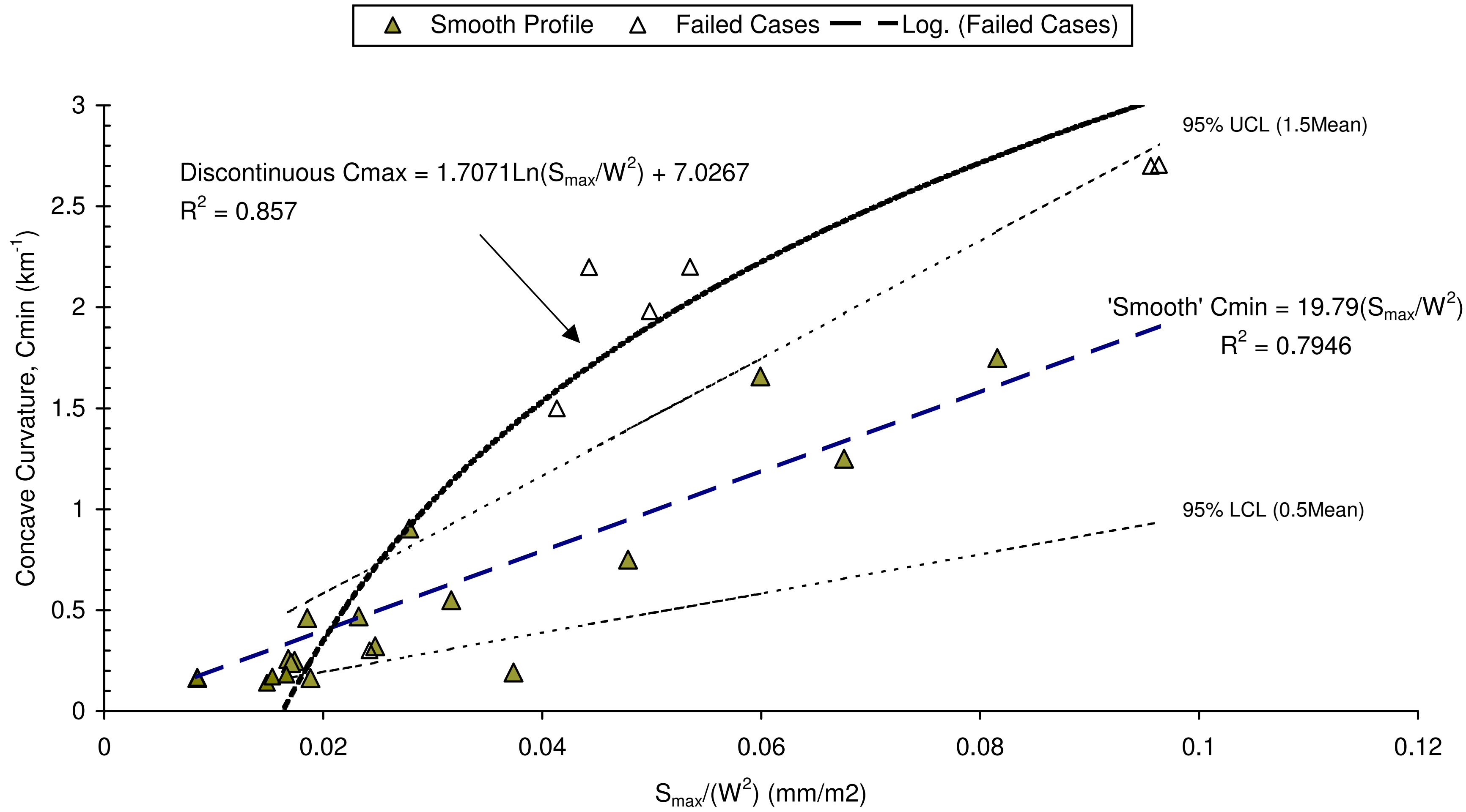

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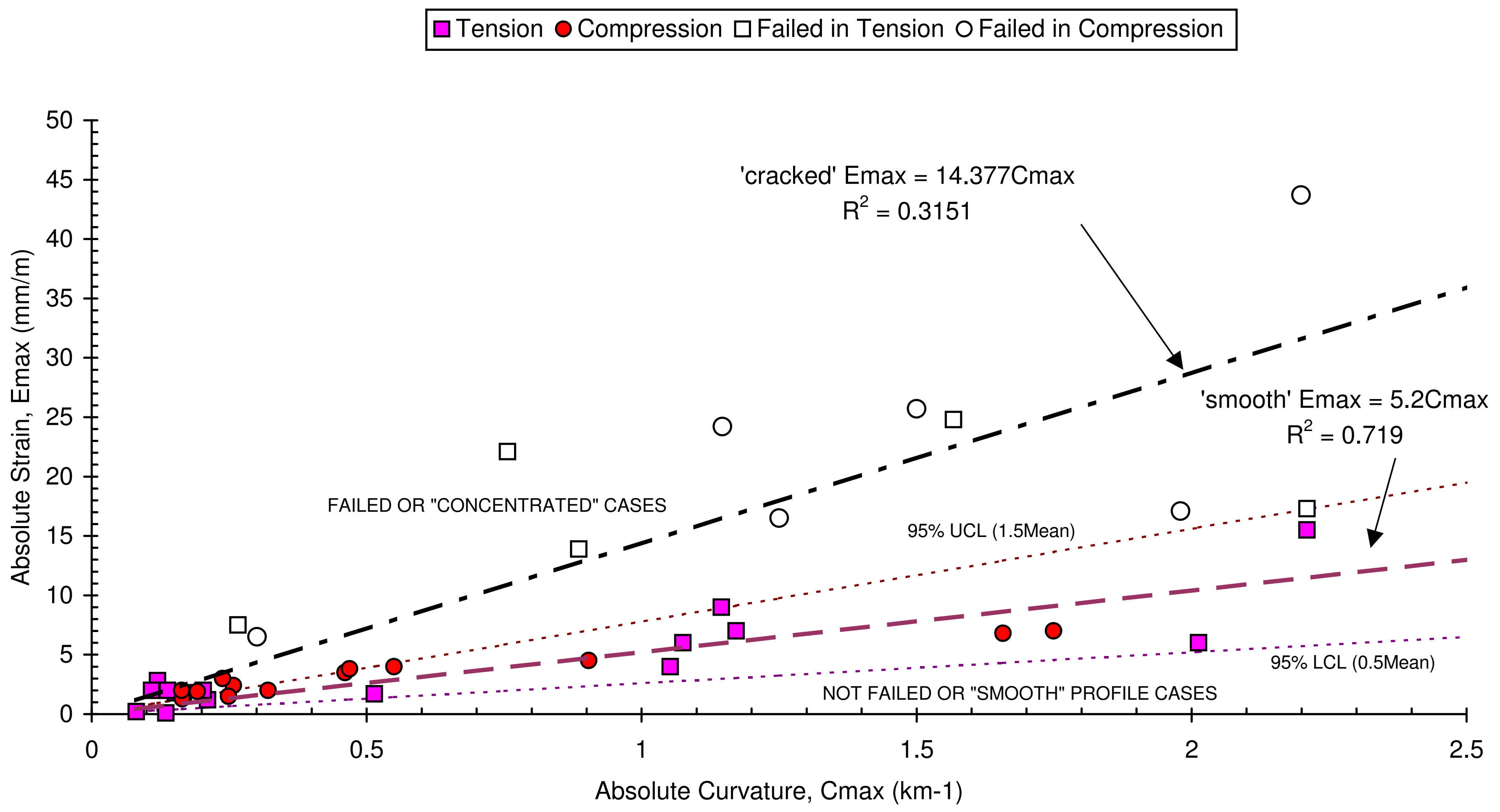

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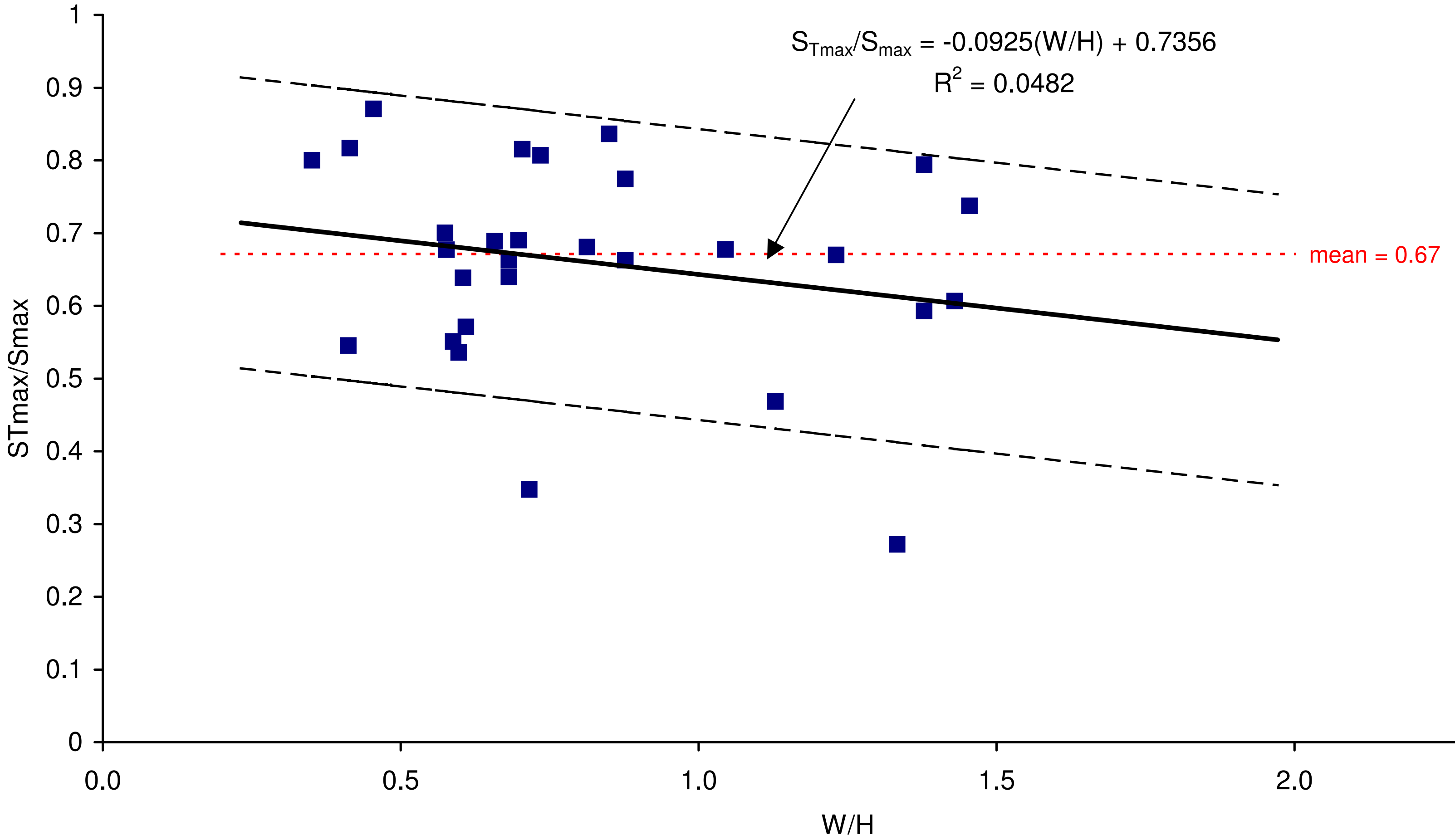

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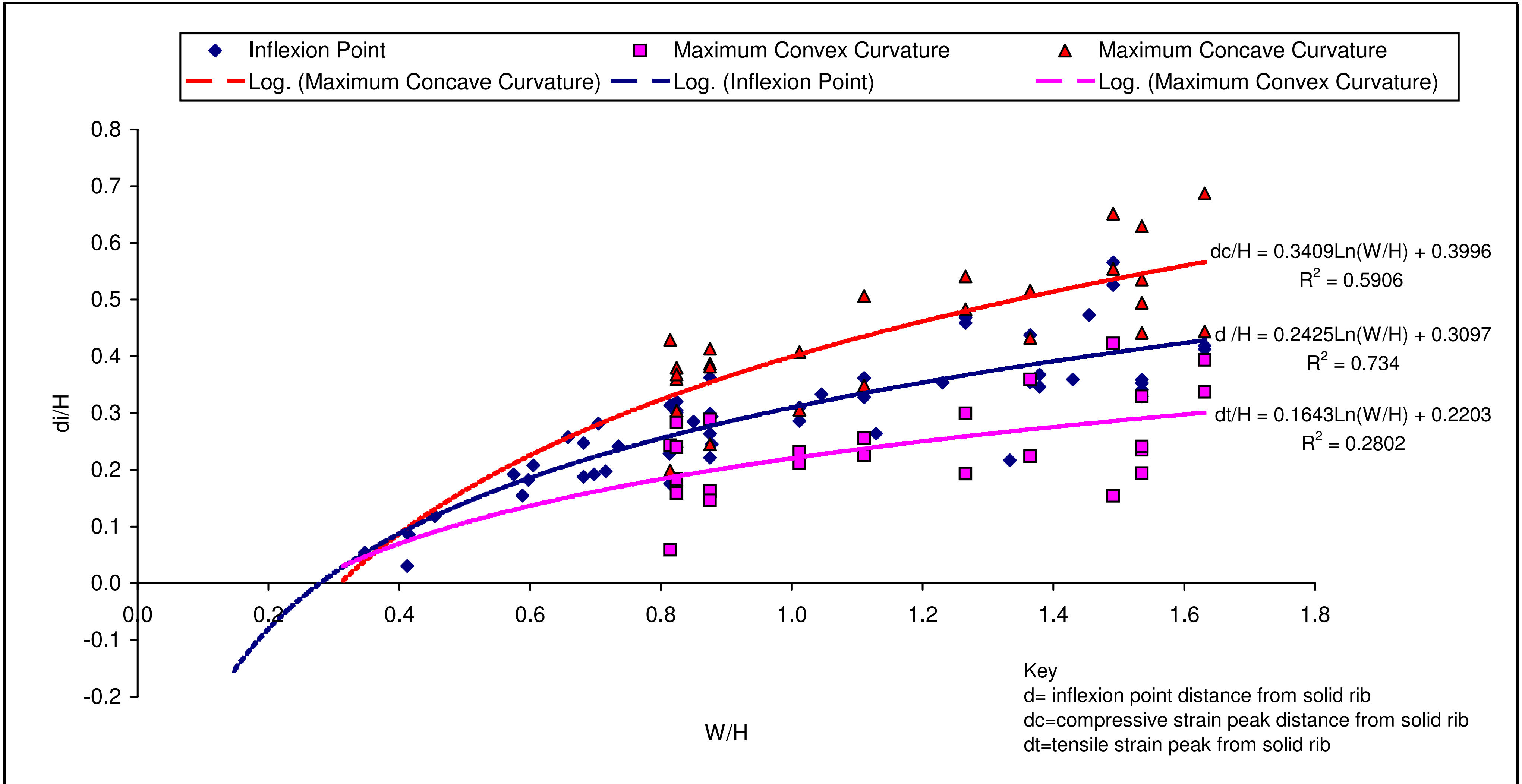

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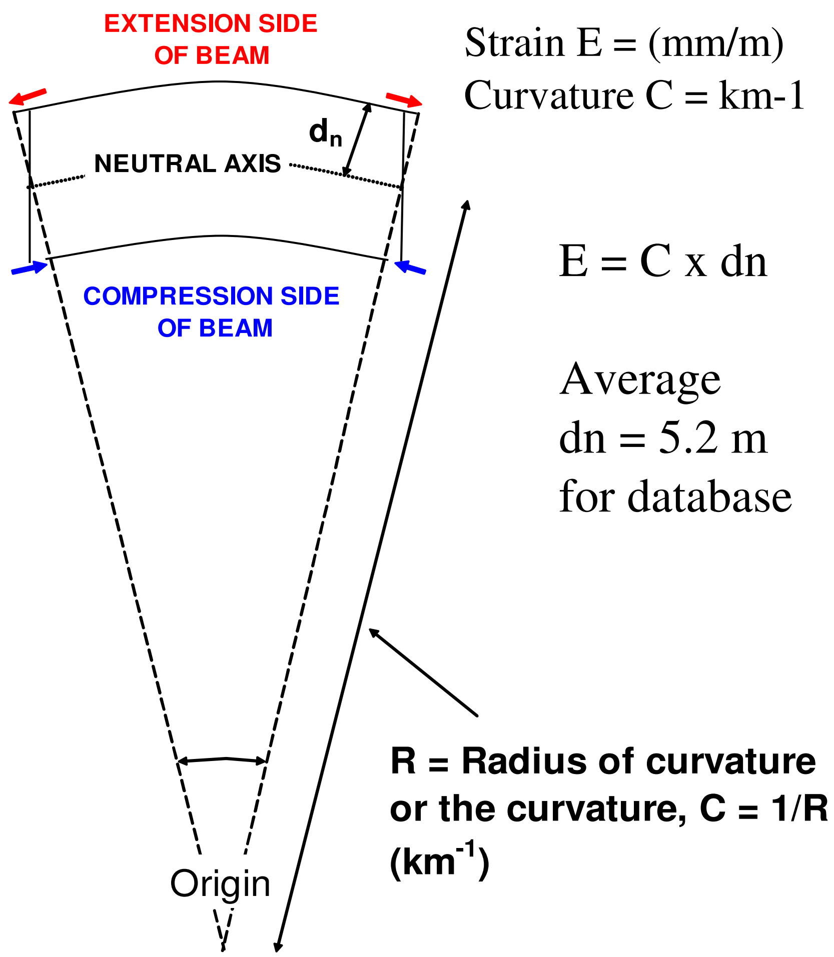

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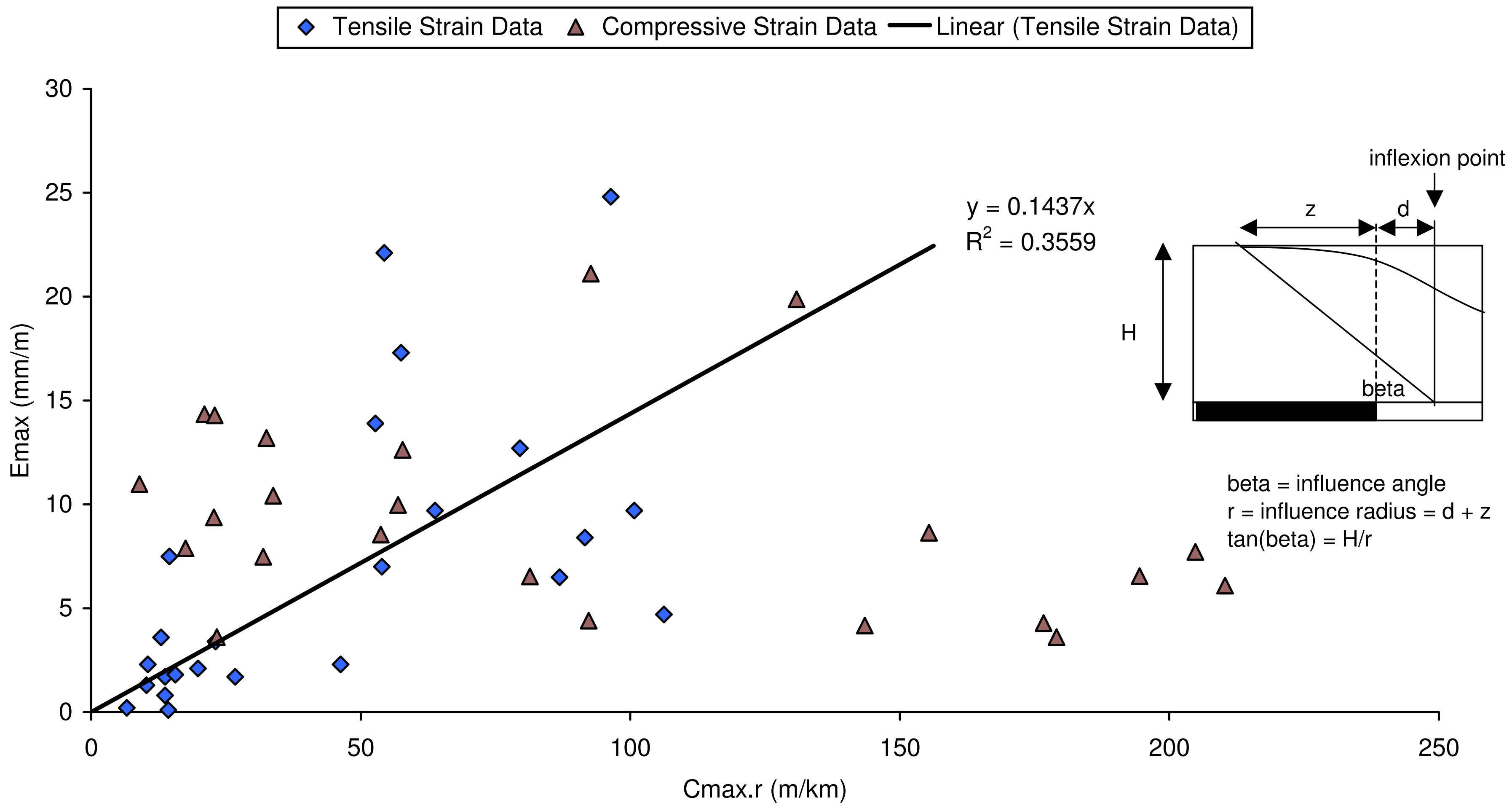

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	Date:	08.08.08	Title:	Empirical Model Recommended by Karmis et al, 1987 for Predicting Strain from Curvature Above Longwall Panels in Newcastle Coalfield	
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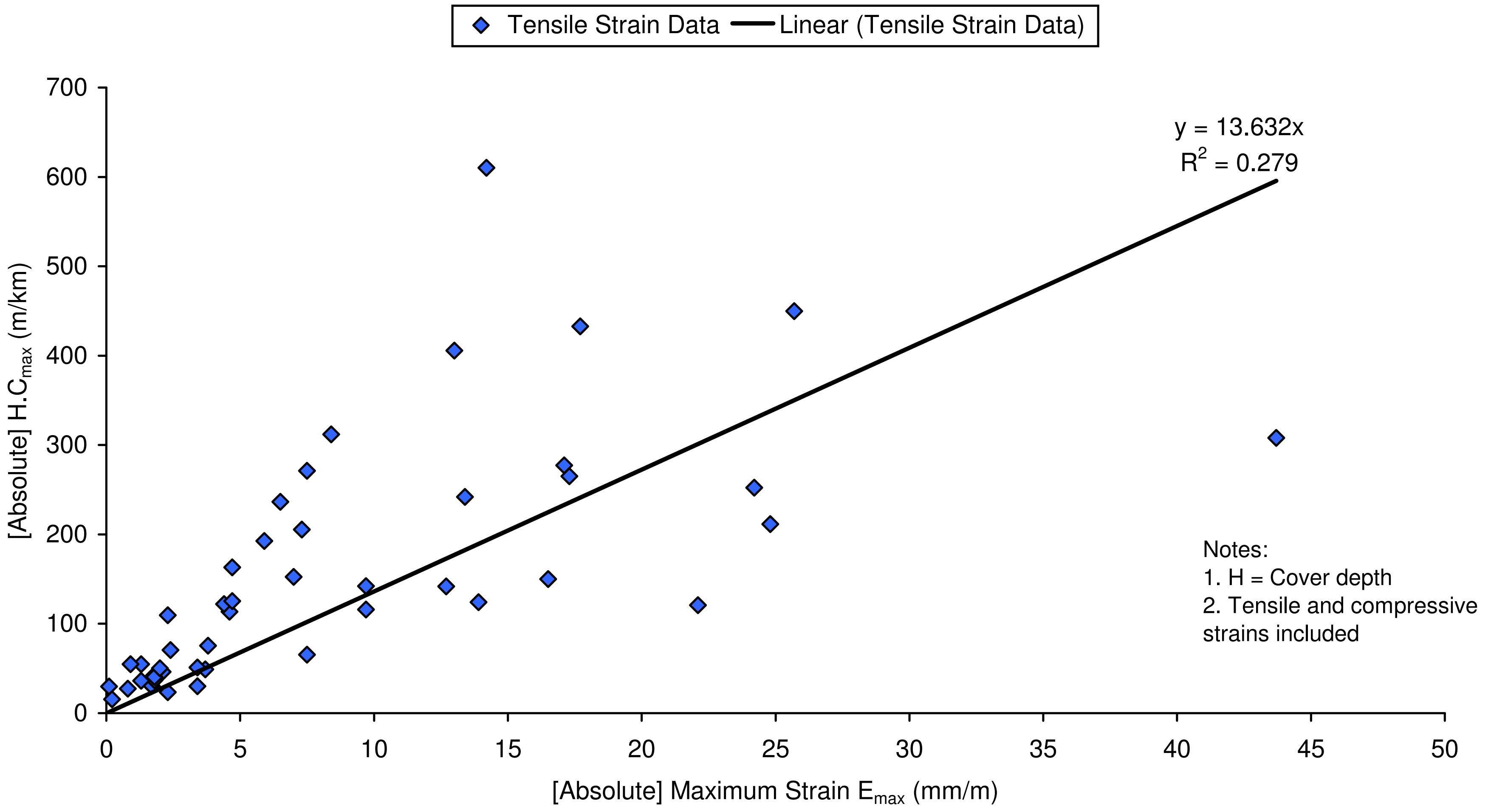

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	Date:	08.08.08	Title:	Empirical Model Recommended by Holla and Barclay, 2000 for Predicting Curvature from Maximum Strain Above Longwall Panels in the Newcastle Coalfield			
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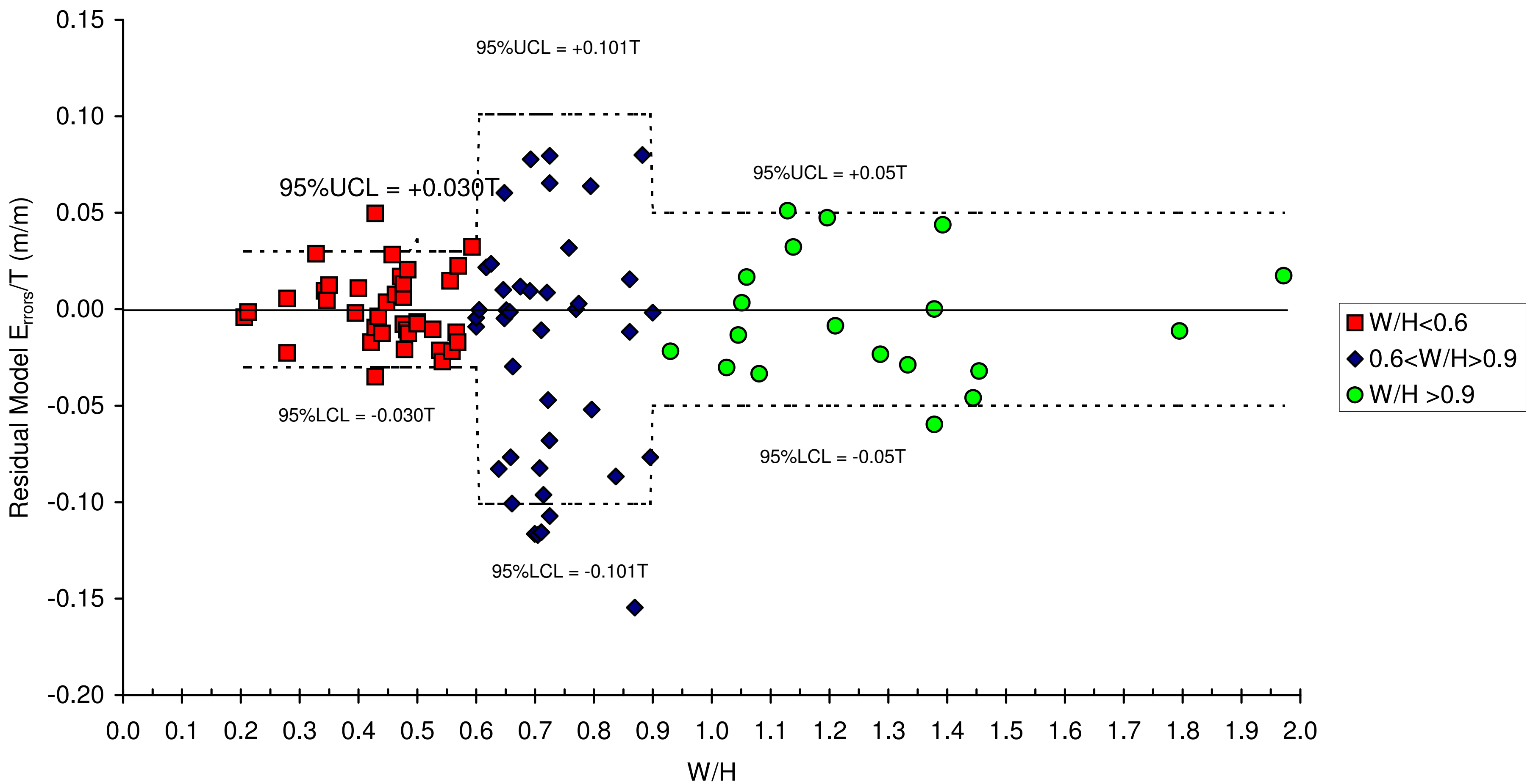

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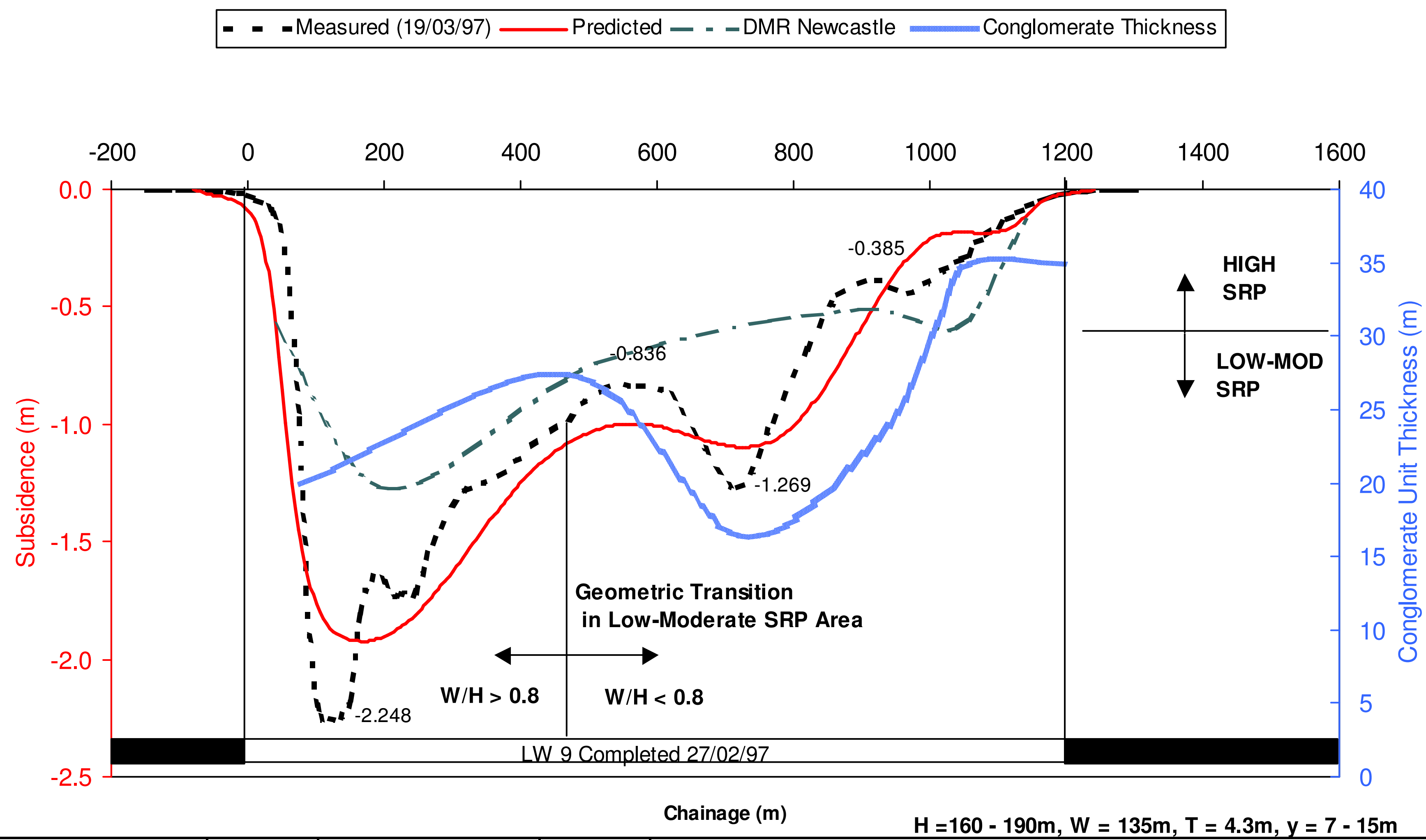

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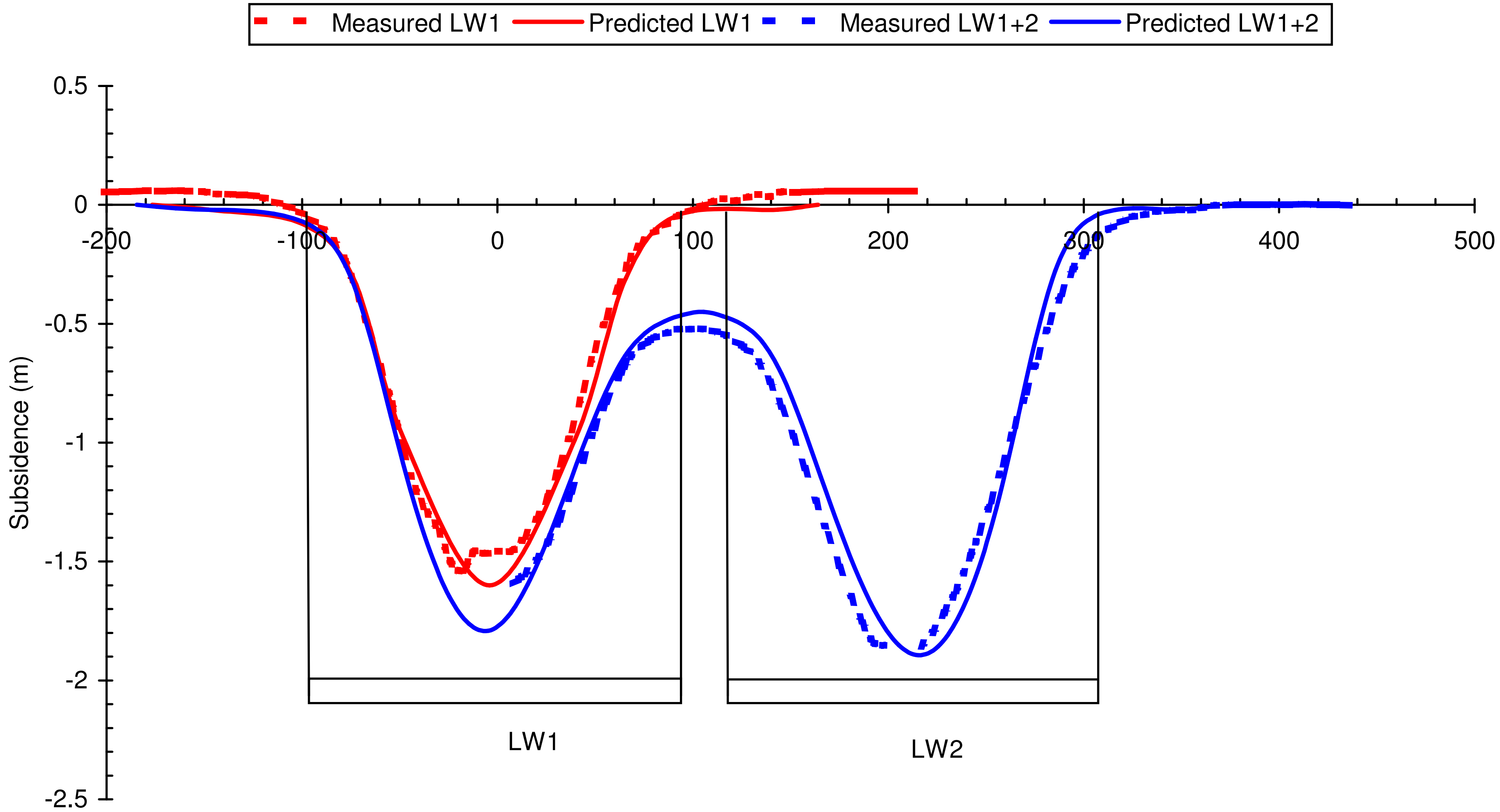

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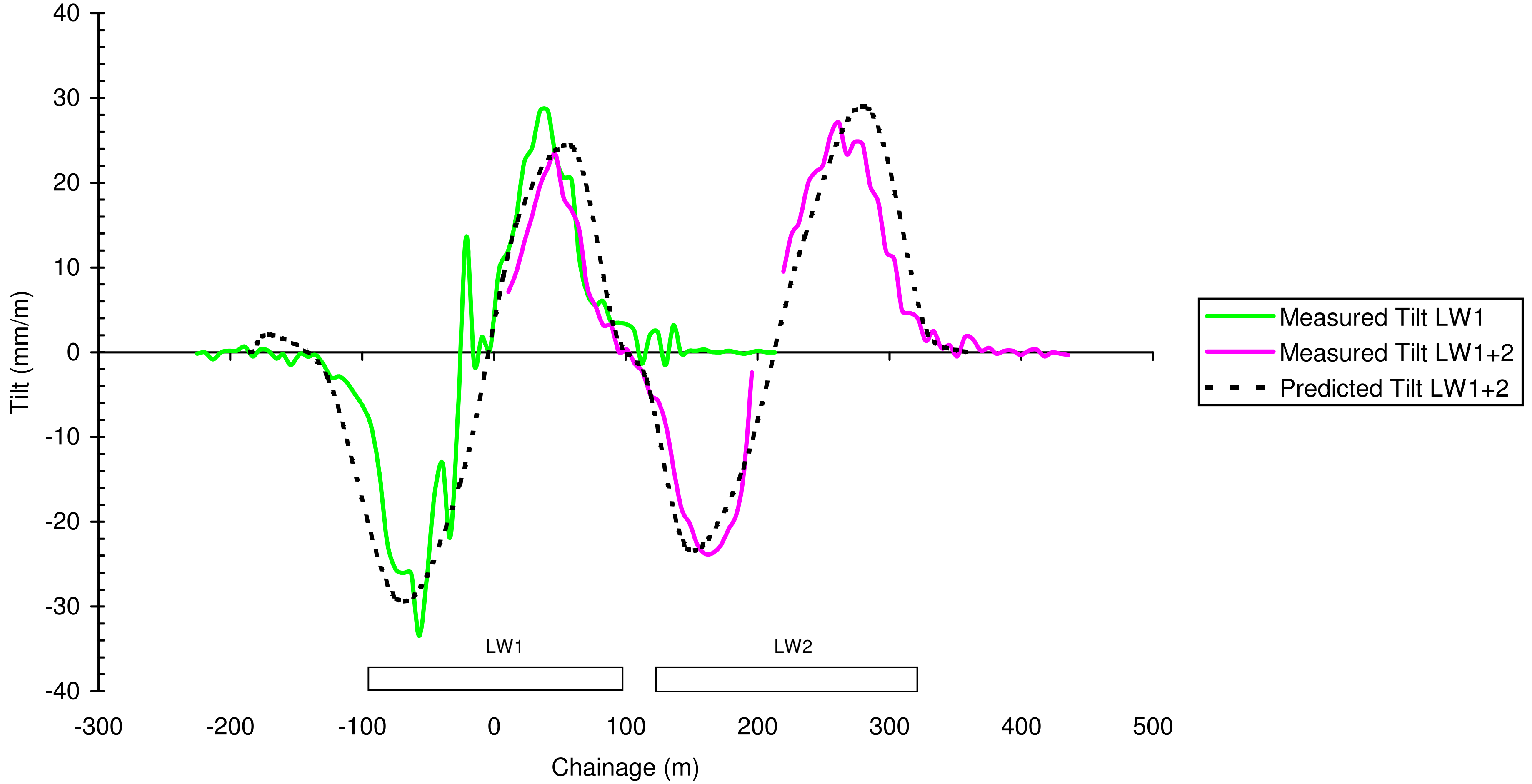

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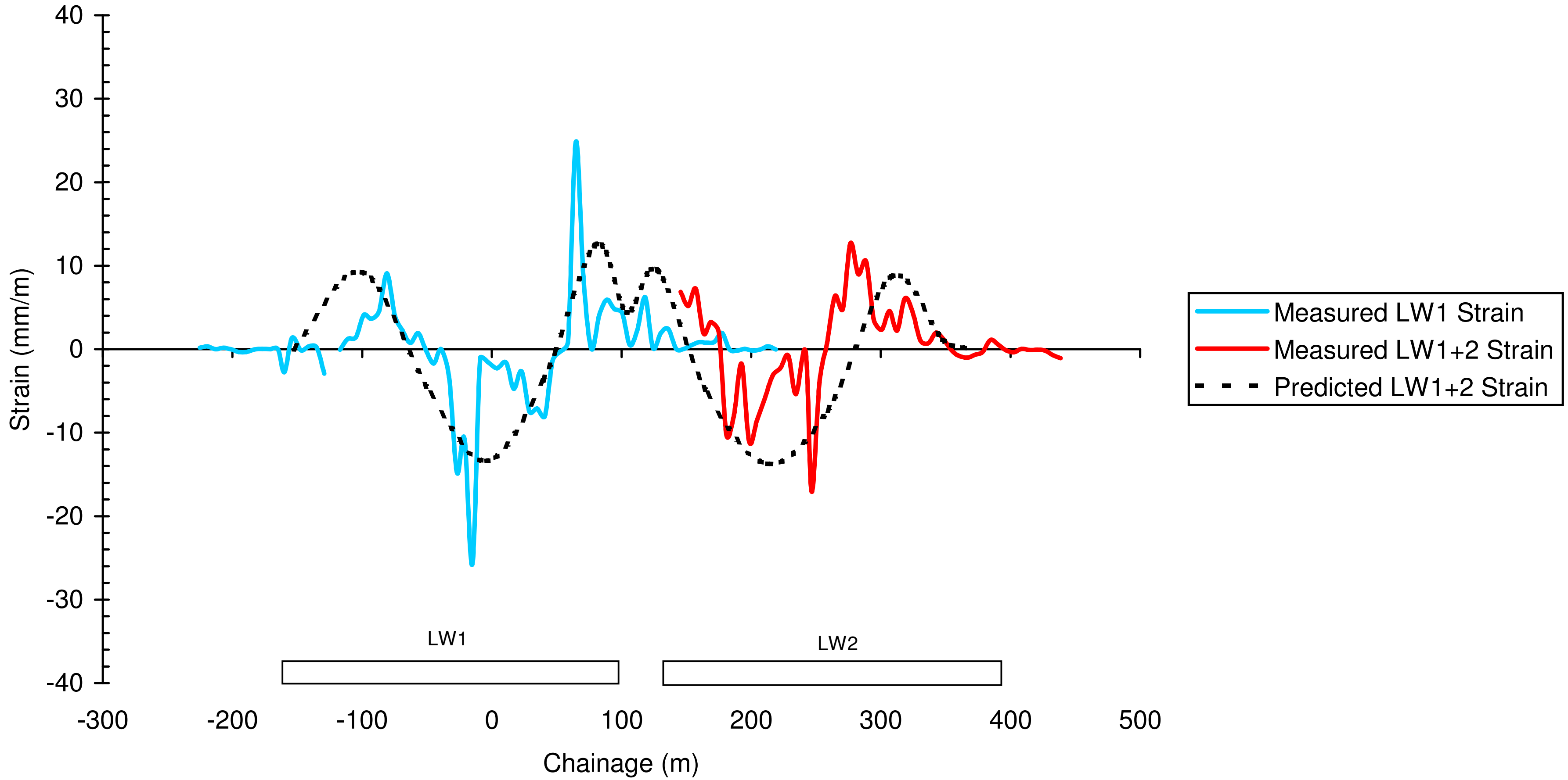

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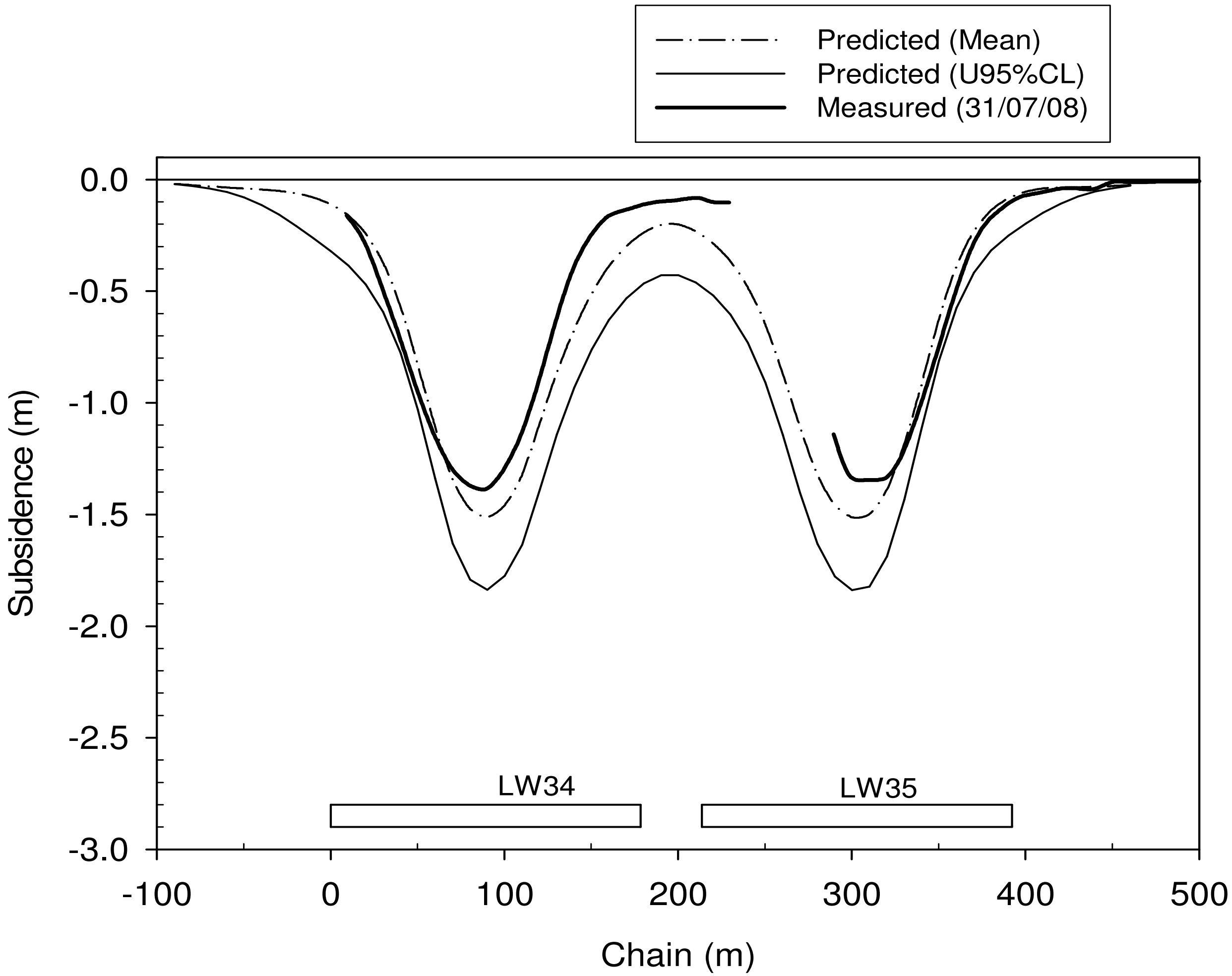

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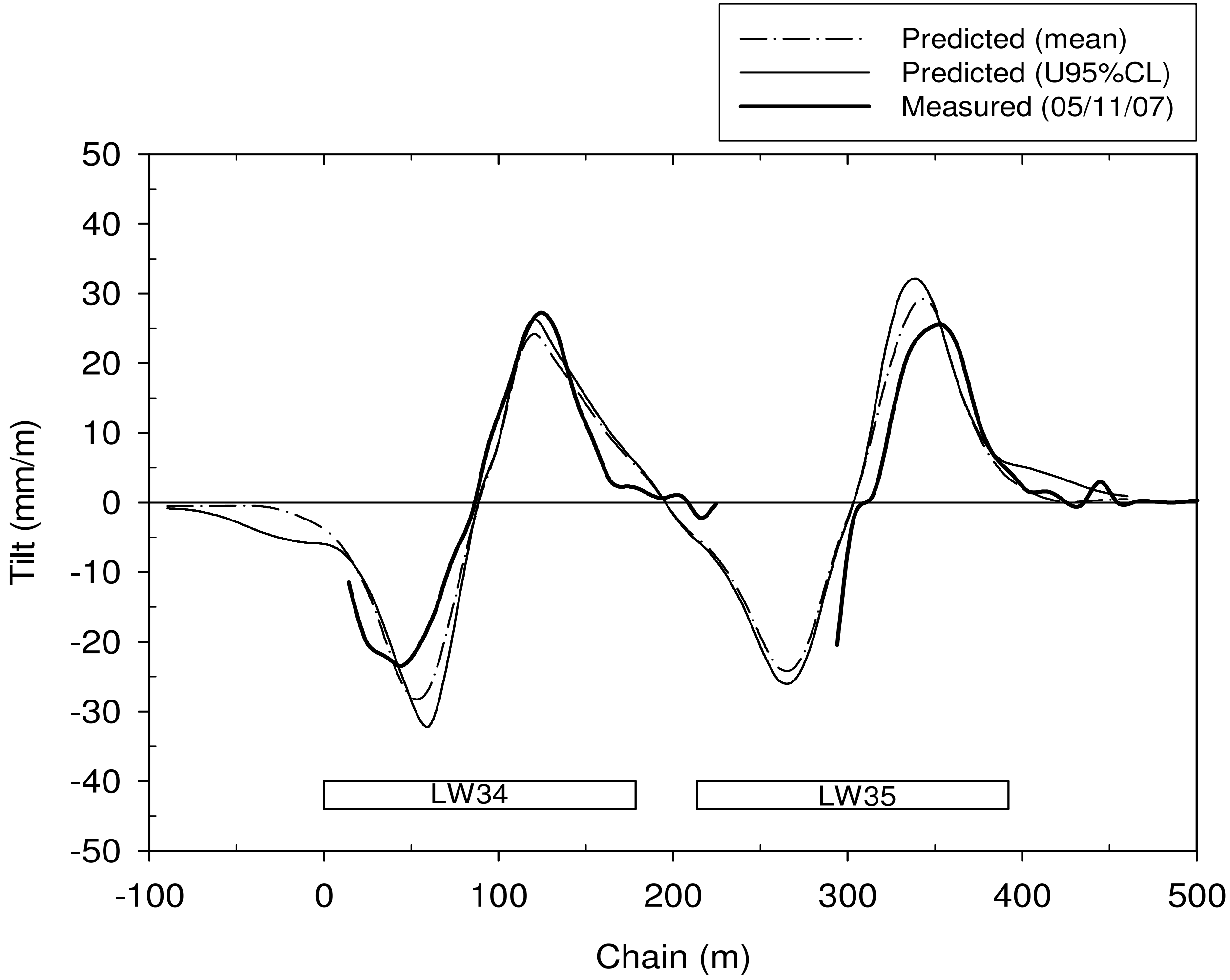

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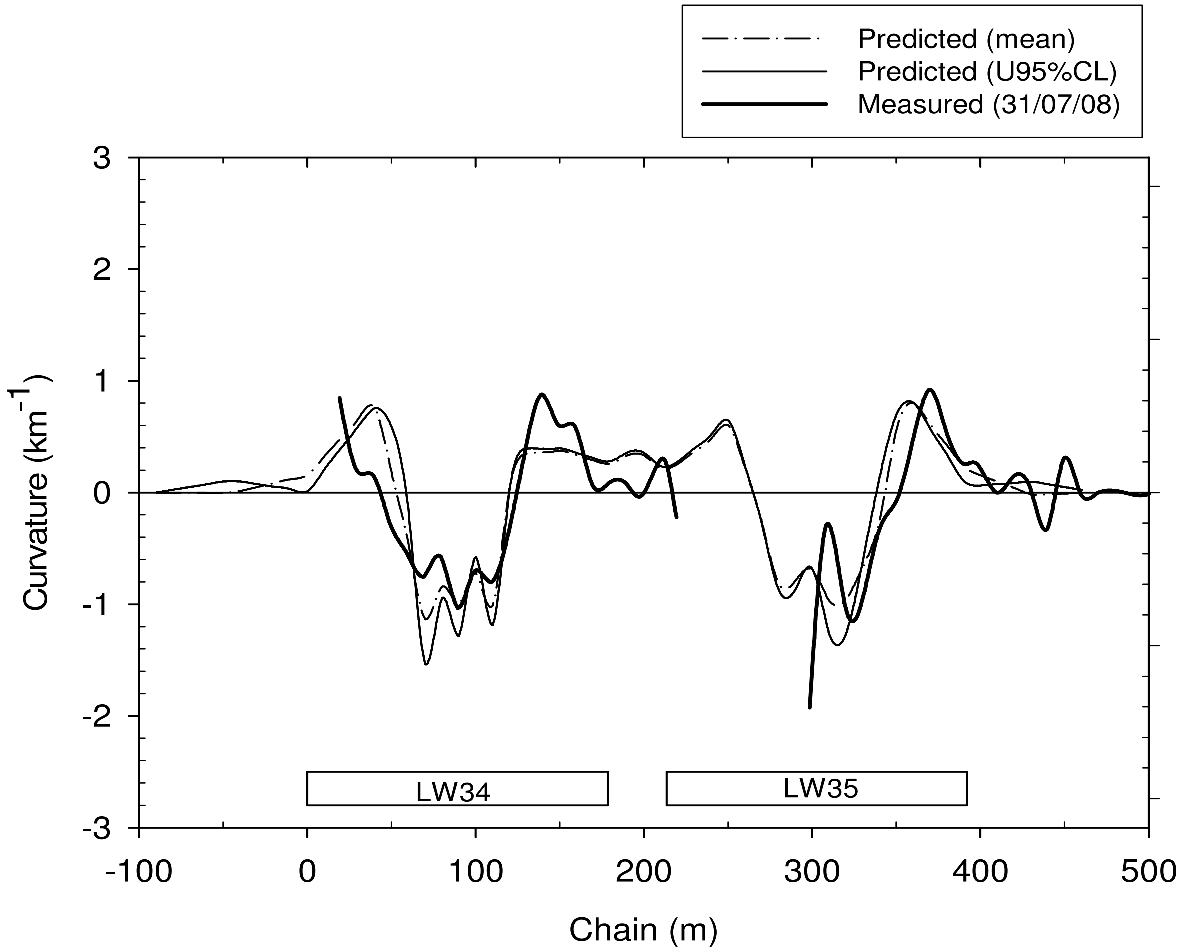

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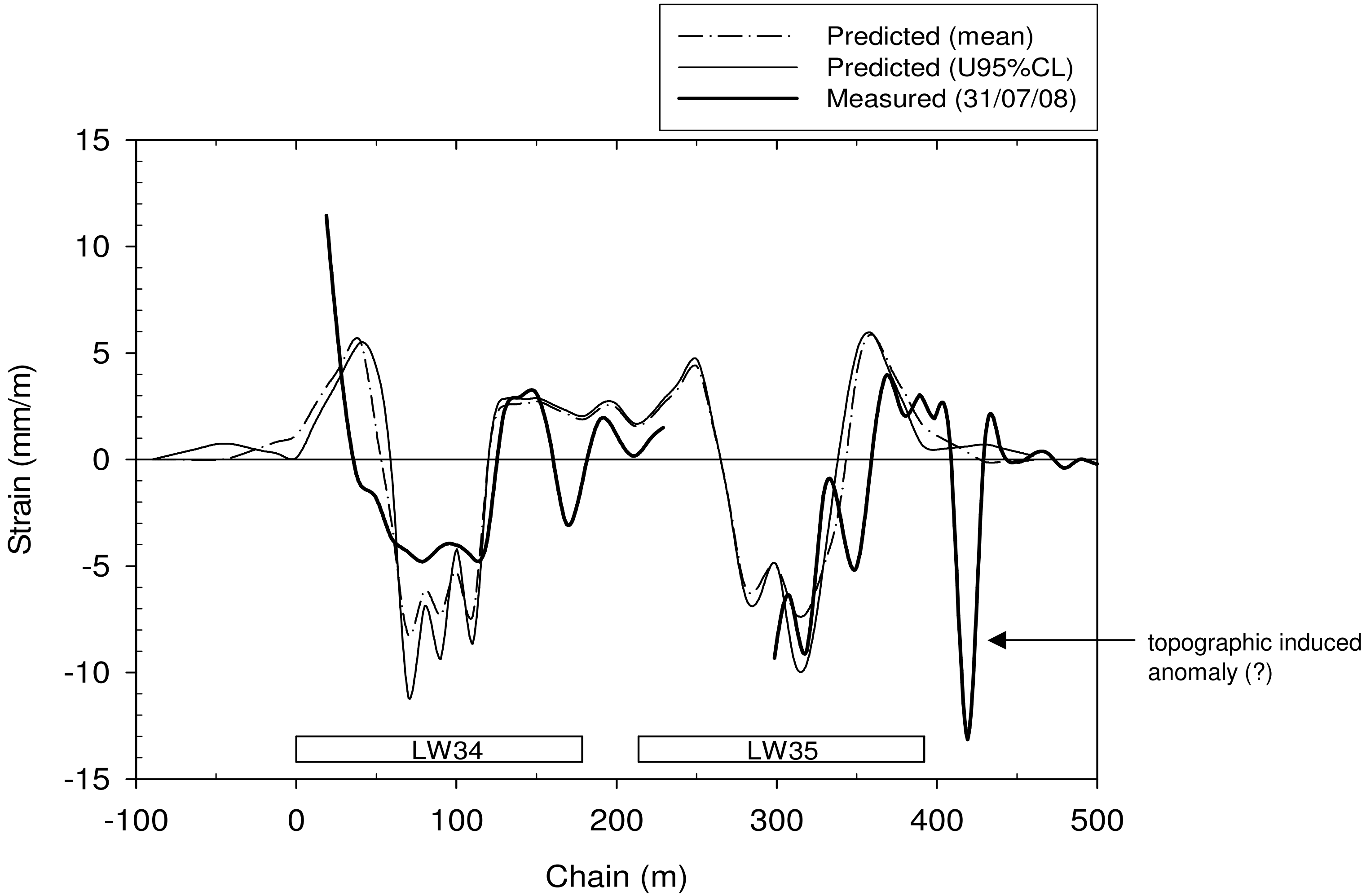

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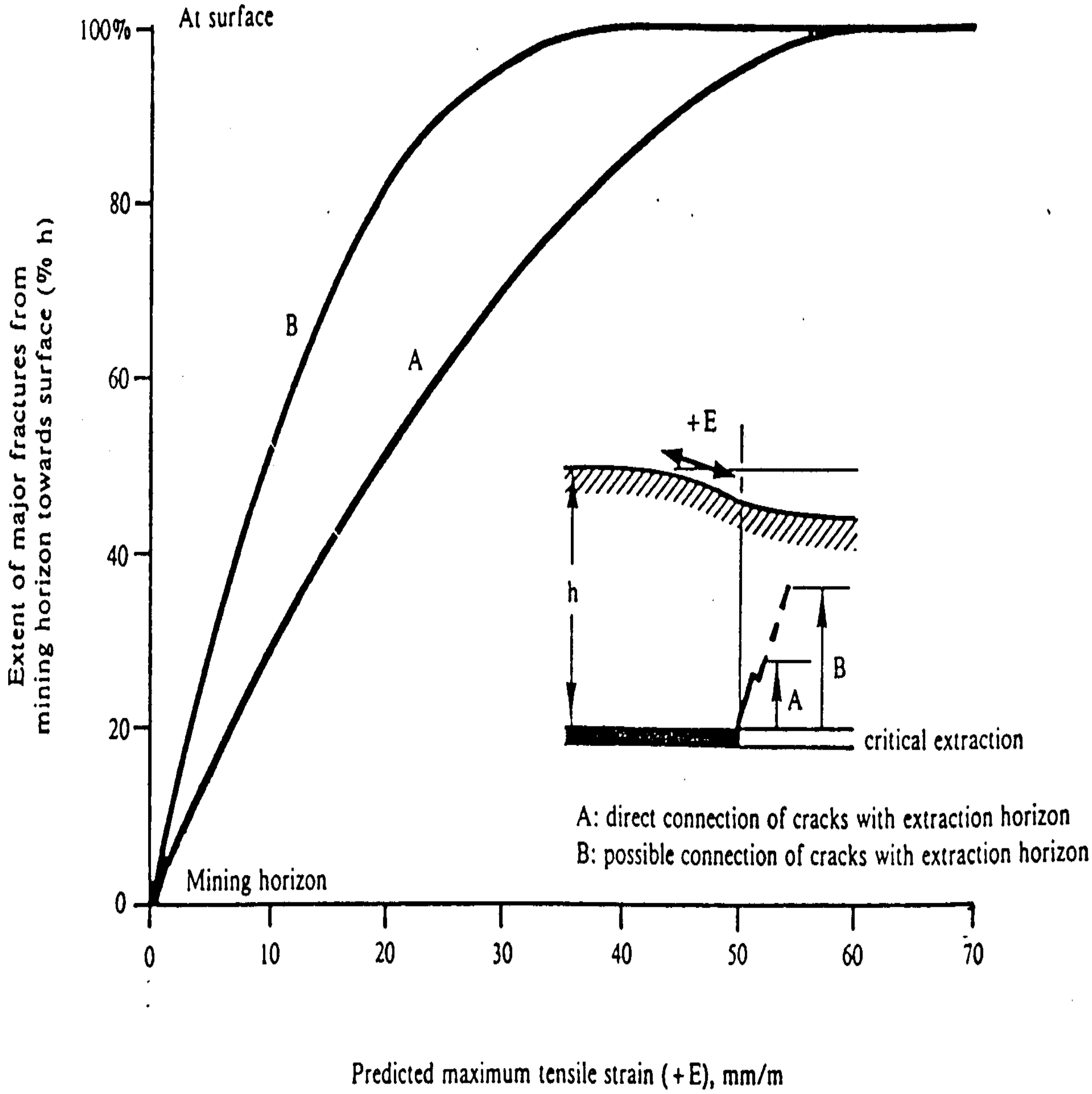

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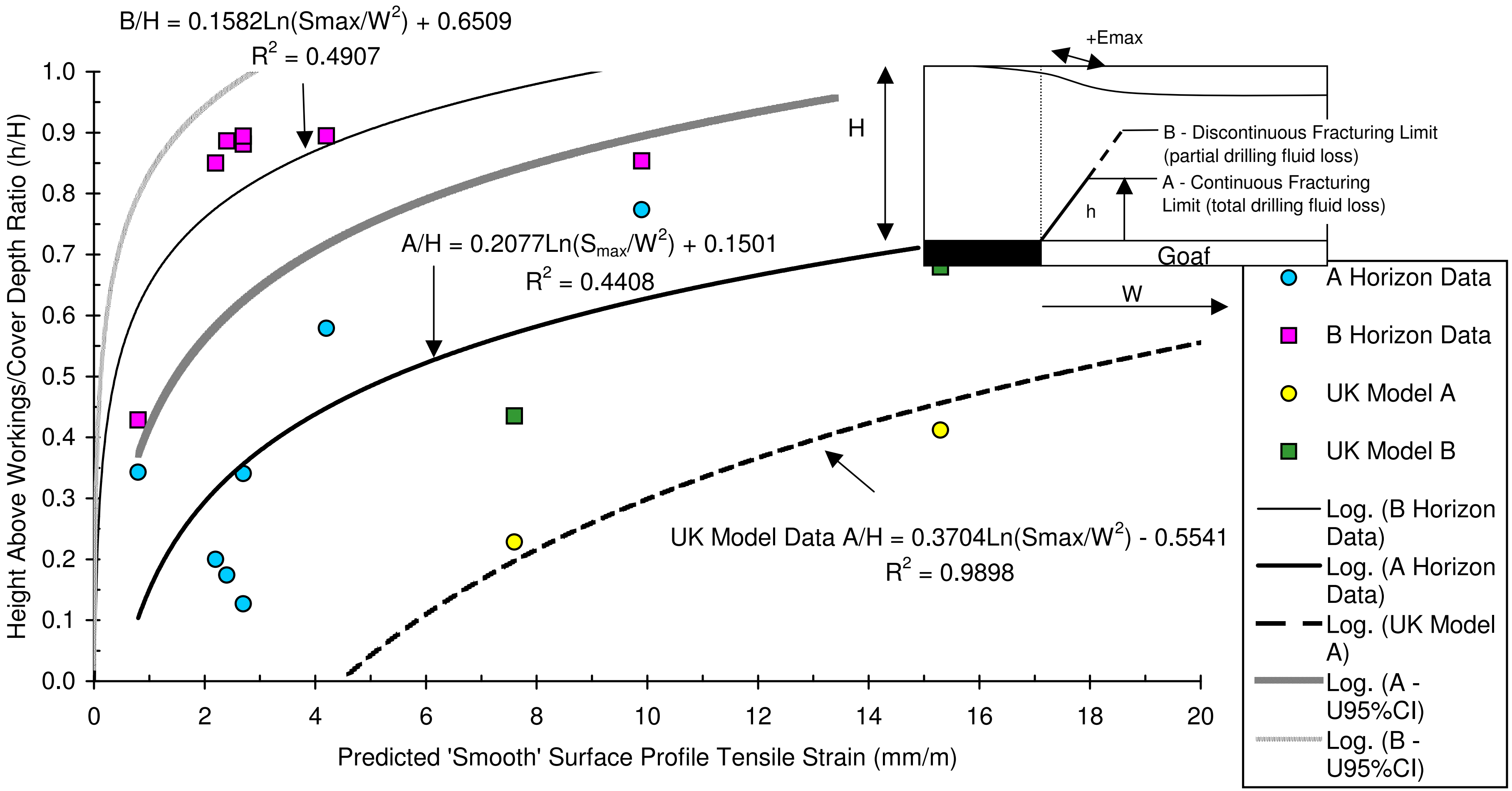

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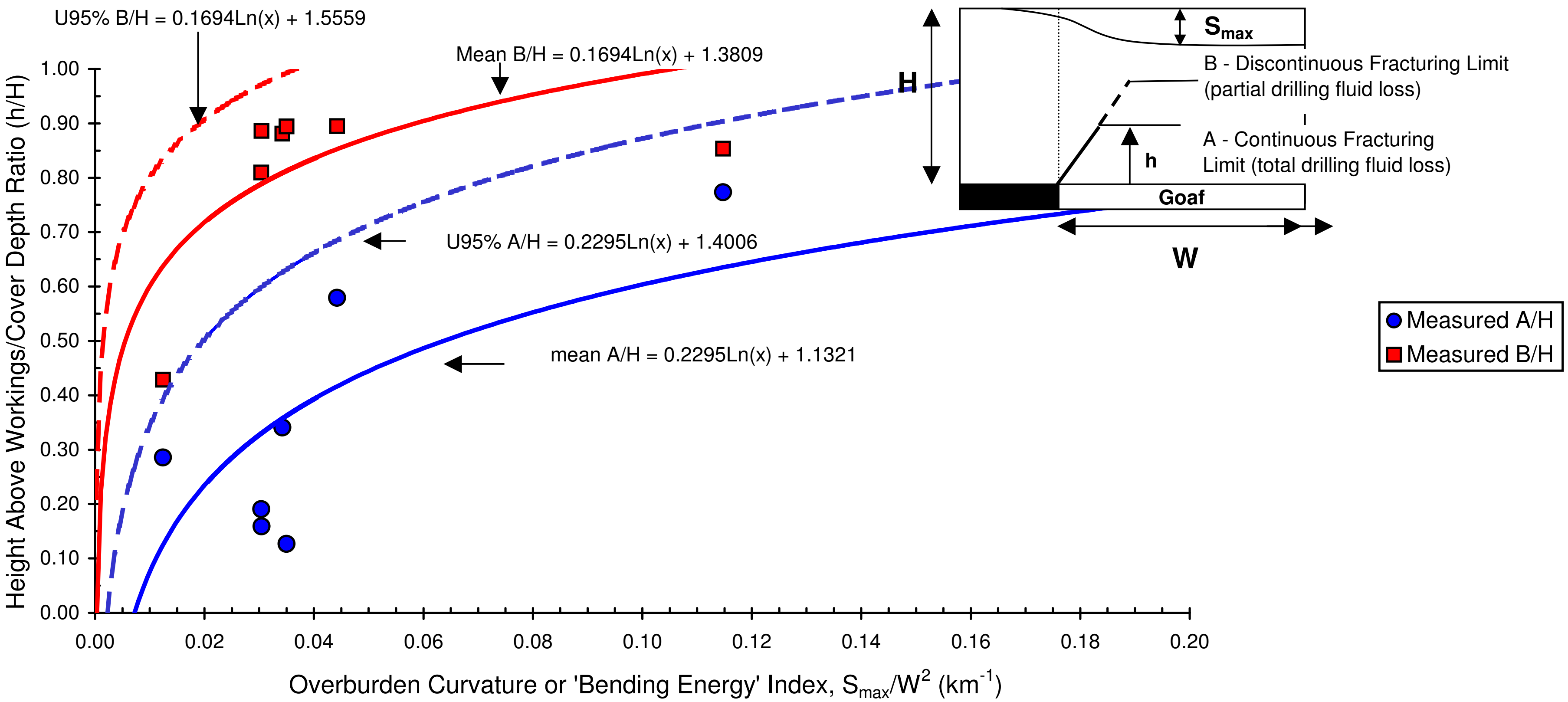

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	Date:	12.08.08				
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APPENDIX B – Extracts from the SDPS® User Manual

S D P S

Surface Deformation Prediction System
for Windows
version 5.2

Quick Reference Guide and Working Examples

by

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February 2002

List of Symbols

w	the panel width; the minimum dimension of a panel
h	panel depth; the vertical distance between the mining horizon and the surface; also known as the overburden thickness
m	the seam thickness; the extraction thickness (note that the extraction thickness may be different than the seam thickness)
R	the extraction ratio
R*	the adjusted extraction ratio
d	the distance of the inflection point from the rib (a positive value indicates that the position of the inflectionpoint is inby); also referred to as the “edge effect”
β	the influence angle
r	the influence radius
Smax	the maximum subsidence
a	the maximum subsidence factor
Bs	the strain coefficient
%HR	the percent hardrock in the overburden
Wp	the pillar width
Hp	the pillar height
Wo	the opening width

1.7 Overview of Subsidence Parameters

Maximum Subsidence Factor
The values of maximum subsidence factor, as function of the width-to-depth ratio and the percent hardrock in the overburden, are shown in the supercritical subsidence factor tables for longwall panels and for room-and-pillar panels respectively. When using the profile function method, the subsidence factor is calculated for the actual width-to-depth ratio of the panel. For example, for a panel with W/h = 0.8 (subcritical) and %HR = 50% the subsidence factor is equal to 0.38.

When using the influence function method, the technique requires knowledge of the supercritical subsidence factor, which will subsequently be adjusted through the superposition concept by the program itself. For example, for a panel with W/h = 0.8 (subcritical) and %HR = 50% the subsidence factor is found for W/h = 1.5 (supercritical) and equal to 0.40.

Notes:
A panel is considered supercritical for W/h greater than 1.2. Due to numerical approximations there may be slight variations to the supercritical subsidence factors presented in the supercritical subsidence factor tables.

Inflection Point
The location of the inflection point from the rib, with respect to overburden depth (d/h), can be estimated based on two empirical curves (see the Inflection Point Diagram). Both curves were statistically generated from the available field data. The first is an average curve based on a least squares estimator, while the second is considered an envelope or conservative curve in the sense that it tends to overpredict the surface impact of a given excavation area. In essence, this means that for average data the predicted subsidence profile could be either inside or outside of the measured subsidence line, whereas for conservative (envelope) data, an attempt is made to keep the prediction lines outside the measured ones, i.e. overestimate the influence of the mined area to the surface.

From experience and constant validation of the programs, the authors recommend that, for Appalachian predictions, improved accuracy is obtained by using the following rule: determine the d/h ratio using the conservative curve for subcritical panels (W/h < 1.2) determine the d/h ratio using the average curve for supercritical panels (W/h >= 1.2).

Notes:
Always use the actual width-to-depth ratio.

Angle of Influence
The angle of principal influence (β, beta) is one of the basic parameters used in the influence function method since it has a major impact on the distribution of the deformations on the surface. It is measured in degrees from the horizontal and the

average value determined for the Appalachian coalfields is beta=67 deg. The parameter required for these calculations is the tangent of this angle (i.e. $\tan\beta = 2.31$). The angle of influence is related to the radius of influence as shown in the equation:

$$\tan\beta = \frac{h}{r}$$

where
h = the overburden depth
r = the radius of influence

This value should be determined for each site by fitting a calculated subsidence profile to a measured subsidence profile. If this is not possible, the influence angle can be approximately set as the complementary angle to the angle of draw.

Supercritical Subsidence Factor Tables
The supercritical subsidence factors used in the calculations are presented in Tables 1.7.1 and 1.7.2.

Table 1.7.1: Calculation of maximum subsidence factors (Smax/m) for longwall panels

	Percent Hardrock in the Overburden							
W/h	10%	20%	30%	40%	50%	60%	70%	80%
0.6	0.64	0.59	0.51	0.42	0.34	0.26	0.21	0.16
0.7	0.69	0.63	0.55	0.46	0.36	0.28	0.22	0.18
0.8	0.71	0.65	0.57	0.47	0.38	0.29	0.23	0.18
0.9	0.72	0.66	0.58	0.48	0.38	0.30	0.23	0.19
1.0	0.73	0.67	0.58	0.49	0.39	0.30	0.24	0.19
1.1	0.74	0.68	0.59	0.49	0.39	0.31	0.24	0.19
1.2	0.74	0.68	0.59	0.49	0.39	0.31	0.24	0.19
1.3	0.74	0.68	0.60	0.49	0.40	0.31	0.24	0.19
1.4	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.5	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.6	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.7	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.8	0.75	0.69	0.60	0.50	0.40	0.31	0.24	0.19
1.9	0.76	0.69	0.60	0.50	0.40	0.31	0.24	0.19
2.0	0.76	0.69	0.60	0.50	0.40	0.31	0.24	0.19

Table 1.7.2: Calculation of maximum subsidence factors (Smax/(m R*)) for high extraction room-and-pillar panels

	Percent Hardrock in the Overburden							
W/h	10%	20%	30%	40%	50%	60%	70%	80%
0.6	0.52	0.48	0.42	0.35	0.28	0.22	0.17	0.13
0.7	0.57	0.53	0.46	0.38	0.30	0.24	0.19	0.15
0.8	0.60	0.55	0.48	0.40	0.32	0.25	0.19	0.15
0.9	0.61	0.56	0.49	0.41	0.32	0.25	0.20	0.16
1.0	0.62	0.57	0.49	0.41	0.33	0.26	0.20	0.16
1.1	0.62	0.57	0.50	0.41	0.33	0.26	0.20	0.16
1.2	0.63	0.58	0.50	0.42	0.33	0.26	0.20	0.16
1.3	0.63	0.58	0.51	0.42	0.34	0.26	0.20	0.16
1.4	0.64	0.58	0.51	0.42	0.34	0.26	0.21	0.16
1.5	0.64	0.59	0.51	0.42	0.34	0.26	0.21	0.16
1.6	0.64	0.59	0.51	0.42	0.34	0.26	0.21	0.16
1.7	0.64	0.59	0.51	0.43	0.34	0.27	0.21	0.16
1.8	0.64	0.59	0.51	0.43	0.34	0.27	0.21	0.17
1.9	0.64	0.59	0.51	0.43	0.34	0.27	0.21	0.17
2.0	0.64	0.59	0.52	0.43	0.34	0.27	0.21	0.17

Horizontal Strain Factor

The value of this factor is directly related to the magnitude of the calculated strains and curvatures over an undermined area. It can be empirically estimated by the average ratio of measured strain and curvature over a set of surface points.

The average value determined for the Appalachian coalfields is:

$$Bs = (0.35 \pm 0.05)\ \frac{h}{\tan\beta}$$

where h is the excavation depth and tanβ is the influence angle. The horizontal strain factor is expressed in units of length. The horizontal strain coefficient is unitless and its default value is 0.35.

Note: The higher the value for this coefficient, the larger the predicted strains and displacements.

Chapter 3: The Influence Function Method

3.1 Overview of the Influence Function Method

Influence function methods for subsidence prediction have the ability to consider any mining geometry, to negotiate superposition of the influence from a number of excavated areas having different mining characteristics and, also, to calculate horizontal strains as well as other related deformation indices. The function utilized in SDPS is the bell-shaped Gaussian function. This method assumes that the influence function for the two-dimensional case is given by:

$$g(x,s) = \frac{S_o(x)}{r} \exp\left[-\pi \frac{(x-s)^2}{r^2} \right]$$

where:

r	=	the radius of principal influence = h / tan(beta);
h	=	the overburden depth;
beta	=	the angle of principal influence;
s	=	coordinate of the point P, where subsidence is considered;
x	=	coordinate of the infinitesimal excavated element; and
So(x)	=	convergence of the roof of the infinitesimal excavated element.

Subsidence at any point P(s), therefore, can be expressed by the following equation:

$$S(x,s) = \frac{1}{r} \int_{-\infty}^{+\infty} s_o(x) \exp\left[-\pi \frac{(x-r)^2}{r^2} \right]$$

where:

So(x)	=	m(x) a(x);
m(s)	=	extraction thickness; and
a(x)	=	roof convergence (subsidence) factor.

The influence function formulation can thus be applied to calculate surface deformations (subsidence, strain, slope, curvature, displacements) above longwall and room-and-pillar panels, given the geometry of the excavation, information on the overburden geology, as well as the location of the prediction points on the surface. More specifically, the required data include:

- the geometry of the mine plan and the associated properties (extraction thickness, subsidence factor for supercritical conditions)

- the location (coordinates) of the points on the surface for which prediction of the deformation indices (subsidence, strain, slope, curvature, horizontal displacement) is to be performed
- the empirical parameters that numerically represent the behavior of the overburden

The typical steps required to calculate surface deformations using the influence function method, are shown below. The corresponding flowchart is also shown in Figure 3.1.1. Figure 3.1.2 presents a schematic diagram for creating the input data. Figure 3.1.3 presents typical distributions for the deformation indices that can be calculated by the influence function method. Table 3.1.1 shows all the indices that can be calculated by the influence function method.

✓ Load the Influence Function Program
✓ Input Data
✓ Mine Plan Data
  - Prediction Point Data
  - Empirical Parameters
✓ Select calculation options
  - Subsidence
  - Horizontal Strain
  - Horizontal Displacement
  - Slope
  - Curvature
✓ Save Project File
✓ Calculate Surface Deformations
✓ Load Graphing Program
✓ View Calculated Deformations

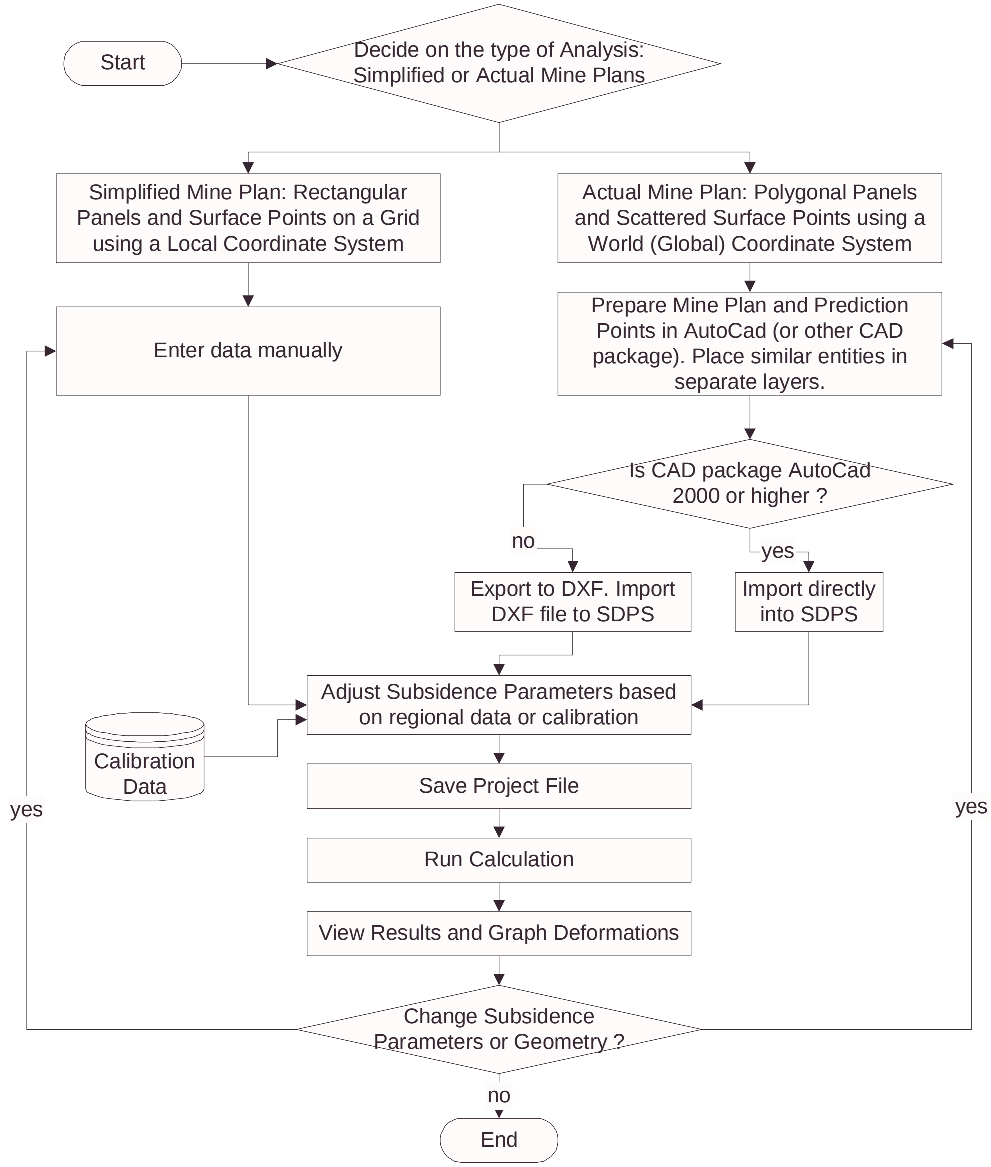

Figure 3.1.1: Flowchart diagram for using the influence function module

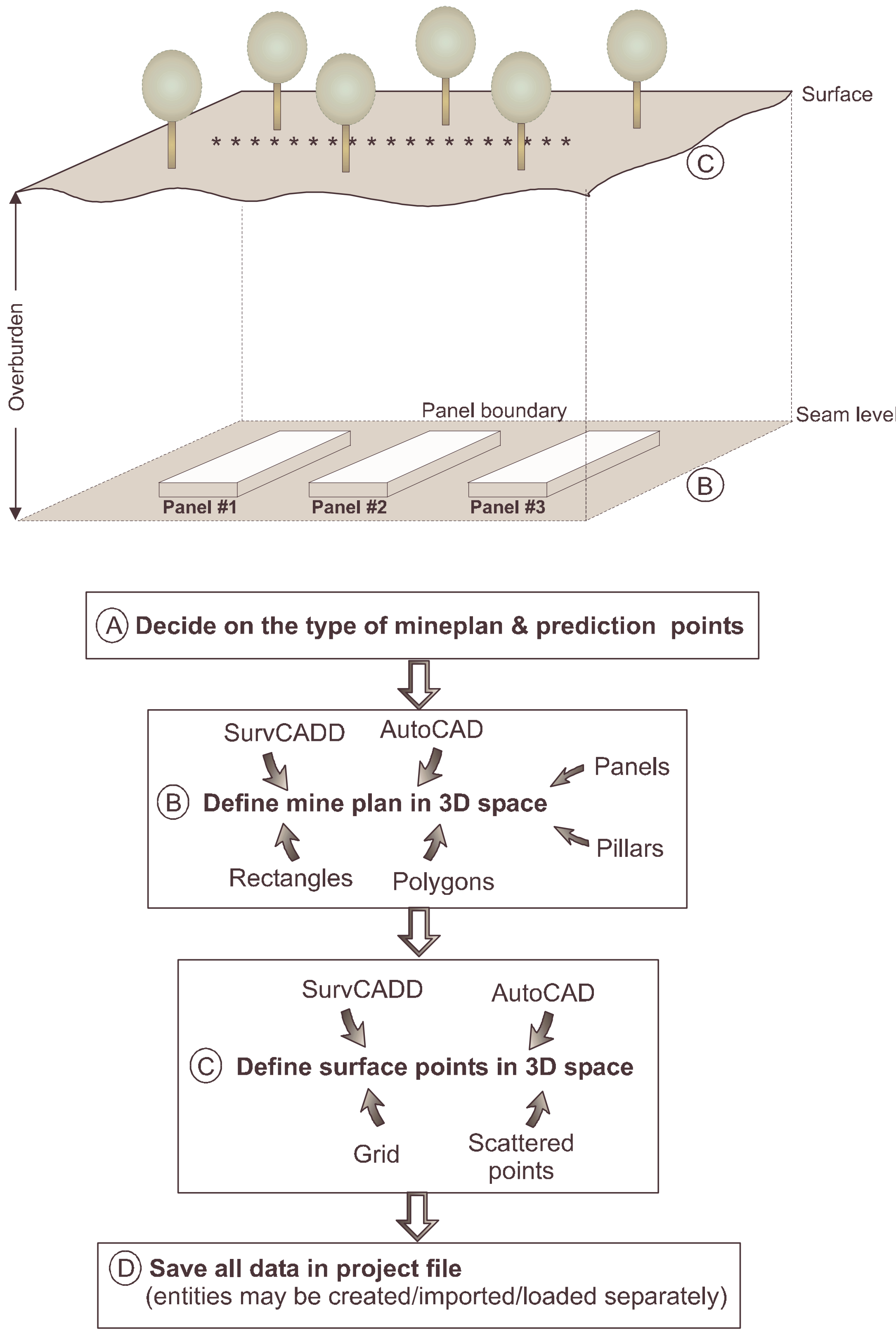

Figure 3.1.2: Steps in defining a project file

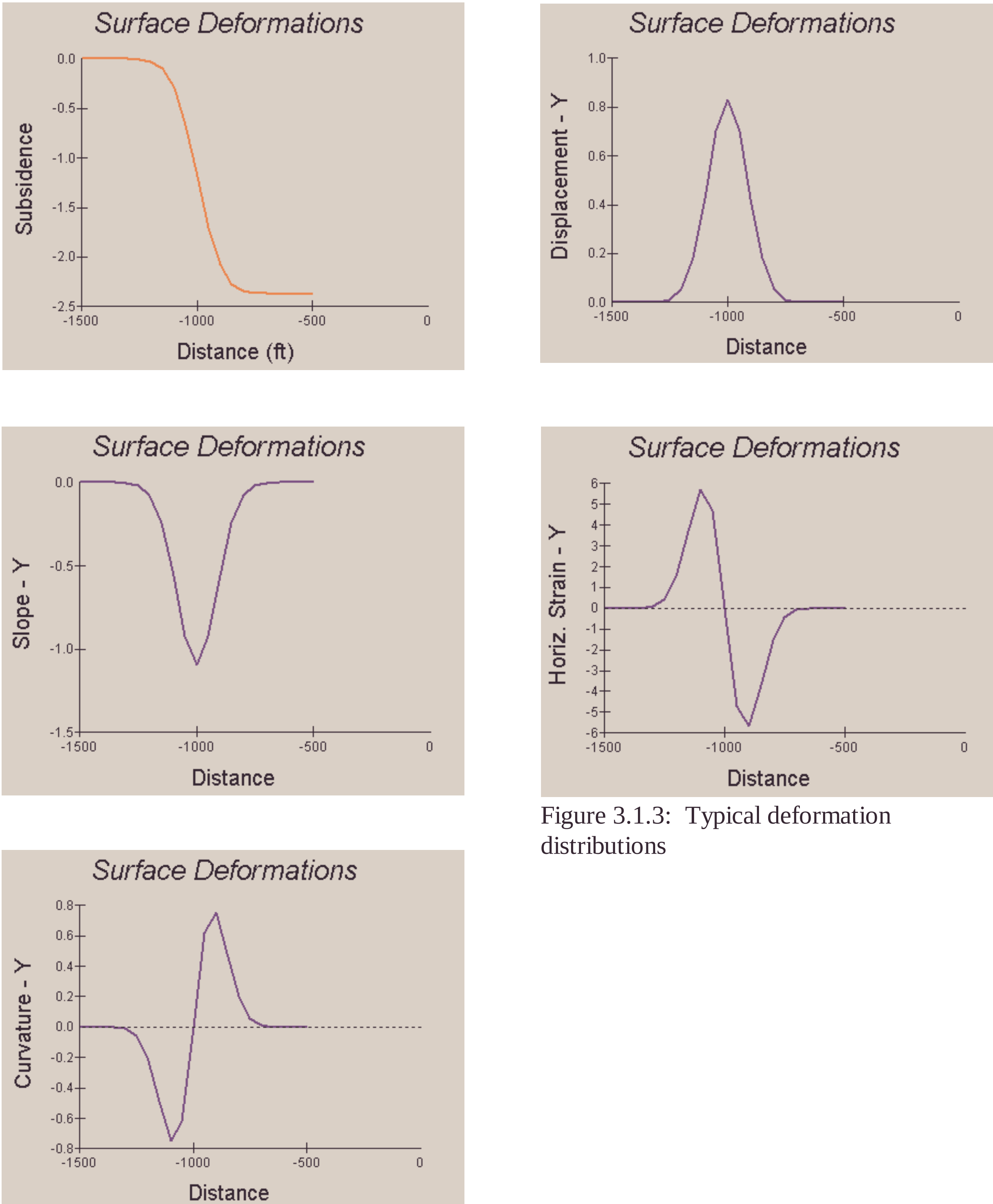

Figure 3.1.3: Typical deformation distributions

Table 3.1.1: Identification codes for deformation indices

Number	Deformation Index Name	Code	Units
1	Subsidence	SU	ft or m
2	Slope in the X-direction	TX	%
3	Slope in the Y-direction	TY	%
4	Directional Slope	TA	%
5	Maximum (Total) Slope	TM	%
6	Angle[1] of Maximum Slope	TE	deg
7	Horizontal Displacement in the X-direction	VX	ft or m
8	Horizontal Displacement in the Y-direction	VY	ft or m
9	Directional Horizontal Displacement	VA	ft or m
10	Maximum (Total) Horizontal Displacement	VM	ft or m
11	Angle[1] of Maximum Horizontal Displacement	VE	deg
12	Curvature in the X-direction	KX	1/ft or 1/m [2]
13	Curvature in the Y-direction	KY	1/ft or 1/m [2]
14	Directional Curvature	KA	1/ft or 1/m [2]
15	Maximum Principal Curvature	K1	1/ft or 1/m [2]
16	Minimum Principal Curvature	K2	1/ft or 1/m [2]
17	Maximum Curvature	KM	1/ft or 1/m [2]
18	Angle[1] of Maximum Principal Curvature	KE	deg
19	Horizontal Strain in the X-direction	EX	- [3]
20	Horizontal Strain in the Y-direction	EY	- [3]
21	Directional Horizontal Strain	EA	- [3]
22	Maximum Strain	EM	- [3]
23	Maximum Principal Strain	E1	- [3]
24	Minimum Principal Strain	E2	- [3]
25	Angle[1] of Maximum Principal Strain	EE	deg

[1] This angle is calculated in degrees from the positive x-axis in a counter-clockwise direction. It gives the direction of the maximum value of the corresponding index on the x-y plane.

[2] expressed in tenths of ppm (divide by 10.000 to obtain result)

[3] expressed in millistrains (divide by 1000 to obtain result)

3.2 Definition of the Mine Plan in the Influence Function Program

Mine plan data describe the extraction area under consideration using various conventions. An extraction area is always defined in three-dimensional space by specifying the X,Y,Z coordinates of the points defining that area. Mine panels and pillars are referred to as excavation parcels. A parcel can be either active or not active. A parcel, which is not active, is not deleted from the file, but it does not participate in the calculations.

Geometry and Boundary Adjustment:

The geometry of a mine plan is determined by the geometry of the excavation panels adjusted by the edge effect. This parameter represents the distance between the actual rib of the excavation and the position of the inflection point, as determined by panel geometry and site characteristics. The location of the inflection point, which defines the transition between horizontal tensile and compressive strain zones, is very important for the application of the influence function method. The distance of the inflection point from the rib using either an average and a conservative estimate as a function of the width-to-depth ratio of a panel can be estimated using this graph.

Thus, the magnitude of the edge effect can be determined as follows:

- ✓ from the graph estimating the location of the inflection point for the conservative or average estimate (Figure 3.1.1),
- ✓ by clicking on the *Subs.Parm* button in the rectangular mine plan form of the influence function program,
- ✓ by analyzing subsidence curves measured at a specific site or region.

Panel Representation:

- ✓ Simple mine layouts can usually be approximated using sets of rectangular extraction areas. In this case, the input required for every parcel includes the parcel number; the coordinates of the west, east, south, and north borders; the seam elevation; the extraction thickness (mining height); and the average supercritical subsidence factor (in percent) associated with it. These coordinates can be specified in a local or a global coordinate system with axes parallel to the parcel sides. In the Influence function module, this option is implemented as **Rectangular Mine Plans.**

- ✓ Complex mine layouts can usually be approximated by a closed polygon (i.e. a piece-wise linear shape). In this case, the input required for every point within a parcel includes the point reference number; the northing (Y), easting (X), and elevation (Z); the extraction thickness (mining height); and the supercritical subsidence factor (in percent) associated with it. The mine plan editor can provide access to all points in a parcel, add new points, and add new parcels provided that the current parcel is defined by three or more points. The points should be entered in a counter-clockwise fashion. The location of each point should be adjusted to reflect the edge effect, or the relative position of the inflection point. The maximum number of parcels and points per parcel can be adjusted within the limits of the available memory. In the Influence function module, this option is implemented as Polygonal Mine Plans.

Warning:

Pillars can not exist outside extracted areas. If a pillar is defined outside an extracted area the results are unpredictable. Currently, the parcel definition module of the program can not check for such inconsistencies. Examples of erroneous panel definitions are given in Appendix 3.

Notes:

- ✓ If no adjustments are made to the geometry of the mine plan, the program assumes that the inflection point is over the rib of the excavation.
- ✓ The user must specify whether each parcel represents an extracted panel or a pillar within an extracted panel. A pillar is mathematically represented as a parcel with a negative subsidence factor. Setting the pillar option on a parcel will reset the subsidence factor associated with this parcel. In that sense, an extraction area can be either positive (i.e. longwall panel) or negative (i.e. pillar in the middle of a panel). Thus, a mine plan that consists only of pillars (without an extraction boundary) will produce a mathematically positive! subsidence.
- ✓ It should be emphasized that the subsidence factor used here is the subsidence factor for supercritical conditions.
- ✓ The reason for supporting more than one format for input data is for the user's convenience. For example, certain panels or pillars can be easily represented as rectangles and can be entered as single entities, compared to four or more entries required if these panels are digitized point by point. Additionally, calculations for rectangular parcels are much faster compared to calculations for parcels defined by individual points.

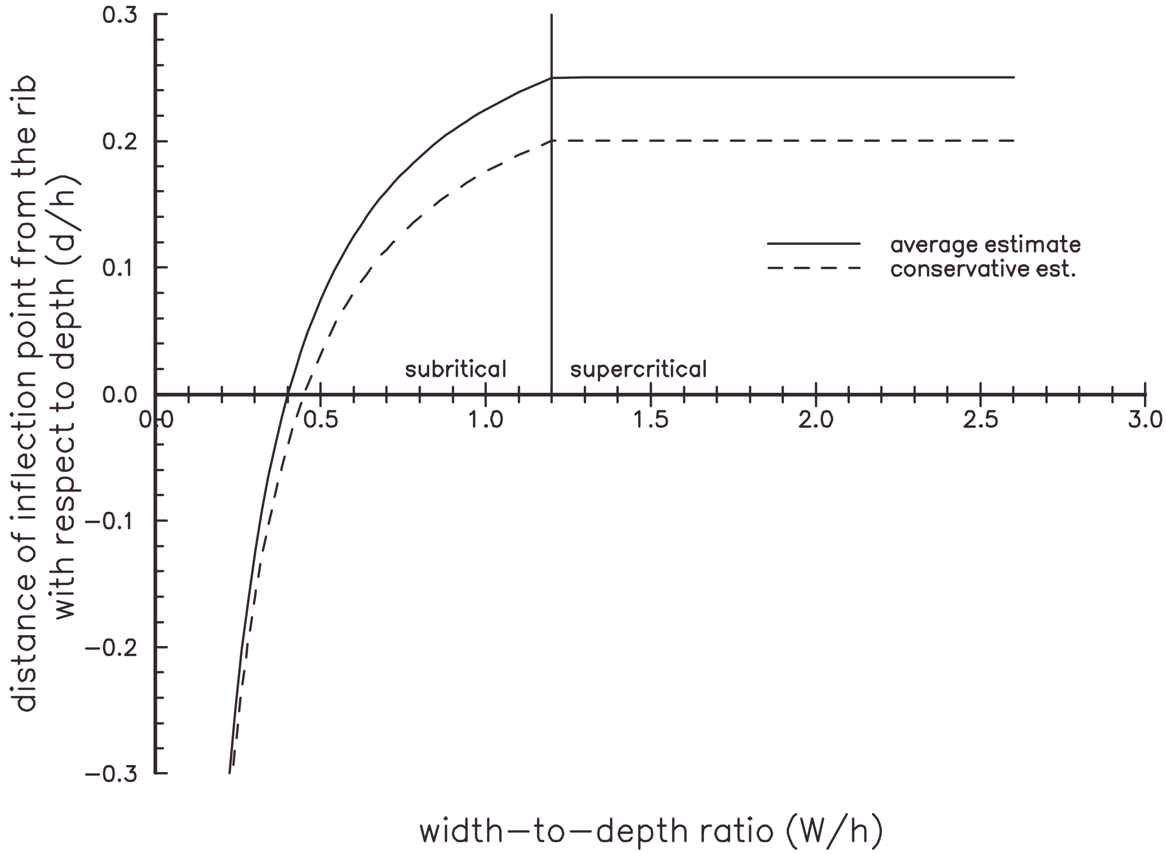

Figure 3.2.1: Determination of the offset of the inflection point.

3.3 Definition of the Prediction Points in the Influence Function Program

Prediction point data describe the surface points where the deformation indices will be calculated. Prediction points are always defined in three-dimensional space, by specifying the X,Y,Z coordinates of these points. A point can be either active or not active. A point which is not active is not deleted from the file but will not be included in the calculations.

Scattered Points

A scattered point set may consist of any number of points that are randomly located on the surface. If such points can be specified as part of a grid, then the Grid Points option should be used. Required parameters for each point include:

- ✓ the point reference code which can be any alphanumeric string,
- ✓ the easting, northing and elevation of each point,
- ✓ the point status, i.e. active or not active (an inactive point will not be displayed in the View option and will not participate in any of the calculations)

Grid Points

A grid point set may consist of any number of points in a window. This window is defined by minima and maxima in the X- and Y- directions as well as the cell size in each direction.

The grid can only be oriented parallel to the current coordinate system. If the grid needs to be oriented at an angle to the current coordinate system, the grid points should be generated by a different tool and imported as scattered points into the Influence Function module.

The user has two options regarding grid elevations.

- ✓ to consider a flat surface and specify a uniform elevation for all points, and
- ✓ to consider each point on an individual basis and specify individual point elevations.

Surface Deformation Characteristics Above Undermined Areas: Experiences from the Eastern United States Coalfields

M. KARMIS, A. JAROSZ, P. SCHILIZZI & Z. AGIOUTANTIS*

SUMMARY Damage resulting from surface movements due to underground mining may range from simple land settlement to severe structural damage. Since subsidence prevention is not feasible, it is important that accurate ground movement prediction techniques are developed, so that damage due to underground mining as well as the amount of coal lost due to the protection of surface structures can be minimized.

To facilitate the mitigation of the deleterious effects of subsidence in the Eastern U.S. region, empirical subsidence prediction techniques for longwall mining were developed from 45 case studies collected within the coalfield. From these subsidence prediction techniques a strain prediction model was also formulated. These subsidence and strain prediction methods can be used to predict ground movements as part of the mining plan and to evaluate the impacts of underground mining on the surface.

1 INTRODUCTION

Surface subsidence is rapidly gaining emphasis as an important environmental consequence of underground coal mining in the United States. Its impact has been witnessed in both rural and urban areas, and can be associated with active as well as abandoned mining operations. The damage associated with this phenomenon may include land settlement and fracturing, structural damage to surface buildings or facilities and disruption or contamination of ground water supplies.

As the need for energy increases, coal production will undoubtedly be accelerated, and since over 99 percent of all subsidence recorded in the United States arises from underground mining, it is evident that the incidence of subsidence will increase. With this increase in production and as underground mining moves into more populous areas, the prediction of surface subsidence, horizontal displacements, strains, and associated damages will surely become a requisite.

To exemplify the significance of this problem, a recent U.S. Bureau of Mines report indicated that over 32,000 km^2 have been undermined in the United States in extracting coal, metals and nonmetallic ores. Over one-fourth of this area, or approximately 8100 km^2, has been disturbed by subsidence, with underground mining of bituminous coal accounting for 7700 km^2 and metal and nonmetallic ores accounting for 68 km^2 of disturbed land. Thus, over 99 percent of all subsidence incidents are attributed to underground coal mining. Moreover, the Bureau of Mines estimates that an additional 10,000 km^2 will be undermined in the United States by the year 2000 (Chen et al., 1982), thus increasing considerably the number of areas in the country affected by subsidence.

Even though, under present technological and economic conditions, subsidence prevention is not feasible, it has been demonstrated in many coalfields that surface subsidence can be predicted and controlled, thus minimizing the deleterious effects of ground movement. Therefore, it is imperative that reliable methods of surface movement prediction and control be established for the United States. With such techniques available, ground movements can be predicted as part of the mining plan, and if environmentally, economically or legally unacceptable situations are foreseen, remedial measures can be implemented.

2 TYPES OF MINING SUBSIDENCE EXPERIENCED IN THE UNITED STATES

Underground excavations disturb the natural equilibrium of the rock mass, causing redistribution of loads in the medium and thus producing horizontal and vertical displacements. Subsidence occurs when these displacements propagate from the mine opening, through the overlying strata, to the surface and can manifest two principle modes of ground settlement: sinkhole and trough subsidence (Figure 1).

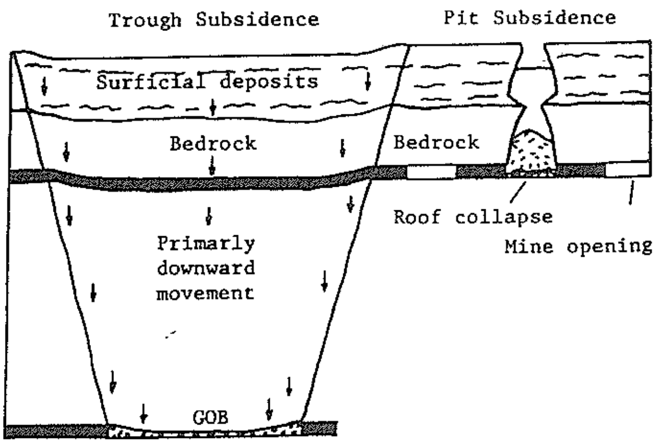

Figure 1 Trough and pit subsidence (after Wildanger et al., 1980).

2.1 Sinkholes, or Pit Subsidence

Sinkholes, or pit subsidence, are characterized by a sudden and sometimes violent collapse of the surface and usually occur above shallow, abandoned room and pillar mines with incompetent overburden; in rare instances, however, this type of subsidence can also occur over active mines, given the proper mining and geological conditions. Pit subsidence is expressed by an abrupt drop in the surface and has vertical to bell-shaped walls. The washing of bedrock and surficial deposits into the mine void may cause the depth of sinkhole to exceed the mining height.

Obviously, the effects of pit subsidence can be serious. The damage caused is the result of a loss of support over all or part of the structure. Also, due to the uncertainty of mine and geologic parameters, the time, location and extend of such a subsidence event is very difficult to predict. Since the goal of subsidence and strain prediction is to minimize the cost of extracting coal in active mines that are below structures, the characteristics of trough subsidence have been studied more extensively than those of sinkholes.

2.2 Trough Subsidence

Trough subsidence is expressed by a gradual and general movement over an observed area with a subsidence basin being formed. Trough theory considers the phenomenon of subsidence to be represented by a complicated combination of material movement and interaction, as depicted in Figure 2. Caving occurs above the mine opening (zone a). The strata above the caving zone moves toward the excavation, experiencing fracturing (zone b) and beam bending phenomena (zone c). This representation of ground movement around a mining excavation is considerably complex to analyze and model; therefore, this concept is simplified by treating only the effects of underground excavation on the surface, or other strata levels within the bending zone.

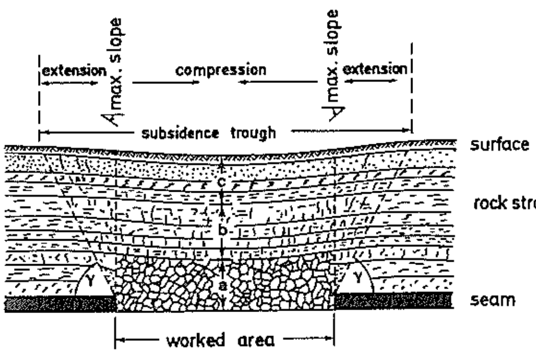

Figure 2 Strata movements above an extracted area (after Kratzsch, 1983)

Trough theory considers a zone of influence in which movement occurs and which spreads from the excavation to the surface, forming a subsidence trough. When an excavation is made at depth, the movement of the strata extends to the surface and manifests itself as vertical displacement (subsidence) and horizontal displacement within a zone of influence. The zone of influence is bounded by a plane that extends from the edge of extraction to the line on the surface where movement ceases. A vertical cross-section of the subsidence trough along with its associated parameters is shown in Figure 3. The angle defined by the vertical from the rib and the line of influence is the angle of draw (or limit angle).

3 DEVELOPMENT OF SUBSIDENCE PREDICTION METHODS

A number of different methods have been proposed for or applied to prediction of surface ground movements due to underground mining. These

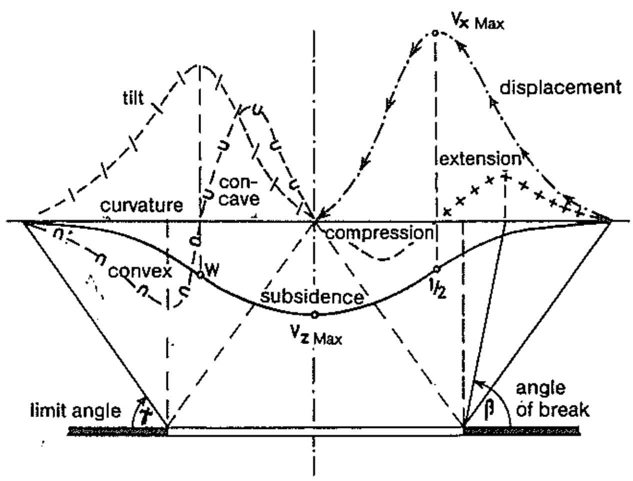

Figure 3 Components of ground movement (after Kratzsch, 1983)

approaches can be broadly divided into three groups. The first two are:

- Theoretical models based on the elastic, plastic, viscoelastic or other phenomenological models which are widely used in other engineering fields (Voight and Pariseau, 1970).
- Numerical methods, mostly used as solutions to complex situations involving the phenomenological methods.

Both these approaches assume that the strata in the overburden behaves in a specific and predictable manner. In using these models, considerable information describing the behavior of the overburden is required, which has often limited the applicability of these methods. Furthermore, in order to adapt their results to field data, a large number of adjusting coefficients may have to be determined.

The third approach can be defined as:

- Empirical or semi-empirical methods such as profile functions, influence functions, the zone area method (Brauner, 1973; Karmis et al., 1981b and 1983).

In this research, the latter approach was pursued since empirical methods are realistic, flexible, and easy to use. Their application, however, requires that a significant number of field measurements be made in order to determine the essential input parameters of the equations.

3.1 Data Collection and Analysis

During the initial stages of this research effort, a large number of subsidence case studies were collected from literature, the coal industry and government agencies. In total, data from 45 longwall panels and 70 room and pillar panels were collected. The limitations of the collected case studies data, i.e. accuracy of surveys, frequency of monitoring, lack of horizontal movement measurements, etc, led Virginia Polytechnic Institute and State University to the initiation of a detailed subsidence and strain monitoring program above a number of active mines, located in three major coal producing counties of Virginia. The aim of this program was to enhance the data base with accurate and complete measurements of surface movements and to subsequently allow the refinement of the prediction techniques.

In this major monitoring effort, a total of sixteen room and pillar sections and seven longwall panels, in nine mines, were instrumented. Above each panel or section a number monument lines were installed. The lines were extended on either side of the panel well beyond the maximum expected area of influence. The final effort included approximately 1,200 stations over 35,000 feet of monitoring lines (Schilizzi et al., 1986).

This data bank was used to determine some basic ground movement relationships between the basic mining and subsidence parameters, in order to allow the evaluation of the various prediction methods for the Appalachian coal region.

Analysis of the subsidence information has revealed some interesting subsidence characteristics for Appalachian longwall panels. The observed angles of draw varied considerably; however, the angle of draw appears to approach a constant value of approximately 30 degrees at width-to-depth (W/h) ratios in excess of 1.2 (Figure 4). The range of maximum subsidence factors for the collected case studies is shown in Figure 5. It shows two lines constructed from the data. Line (1) represents the average values S_{max}/m, whereas line (2) is an envelope line, covering all data points. The figure also shows that this parameter asymptotes to a constant value at a width-to-depth ratios greater than 1.2. These results suggest that critical conditions are reached for W/h ratios of about 1.2,

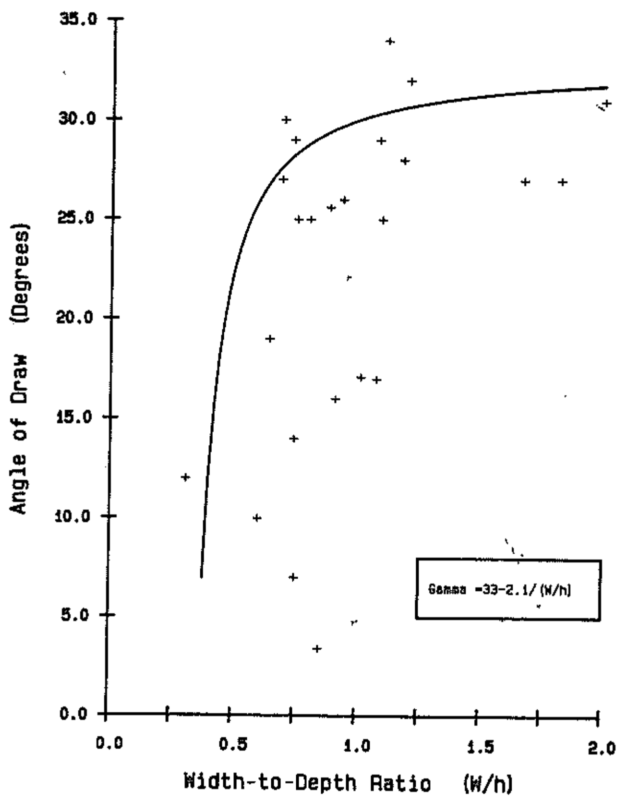

Figure 4 Observed angles of draw for various case studies

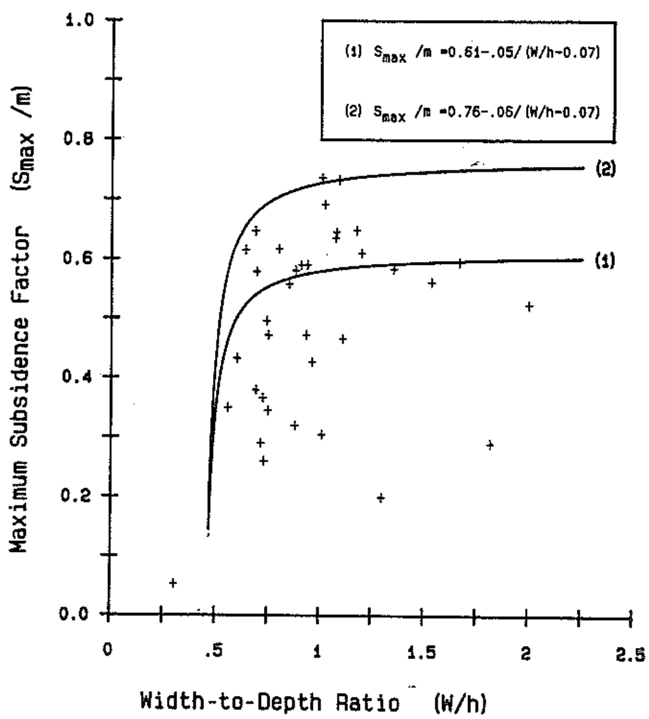

Figure 5 Influence of W/h ratio on maximum subsidence factor

as confirmed by the relationship between the position of the inflection point and the width-to-depth ratio of the panel shown on Figure 6.

According to the collected data and their dispersion, it was hypothesized that two factors influenced the subsidence: geology of the overburden and geometry of the panel. In order to establish the relationship between geology (lithology) and subsidence, the subsidence factor was plotted against the percent of hardrock (percent of limestone and sandstone) in the overburden for critical and supercritical panels only (Figure 7). Since the effect of panel geometry was thus eliminated, a relationship between subsidence and geological conditions was established. Once this correlation was possible, a complete relationship between subsidence and panel geometry was developed for varying lithologies (Figure 8).

To determine characteristic subsidence profiles, different empirical or semi-empirical methods were tested and adopted. Data collected during the monitoring program were primarily used, because of their completeness and accuracy.

3.2 Profile Function Methods

A profile function method defines the distribution of subsidence or strain values on the surface along a profile, orthogonal to the boundary of (theoretically) an infinitely long underground excavation. In general, a function which is tangent or asymptotic to two horizontal lines is required. The parameters to be used for this equation must be determined from field data.

The advantage of such a method is that it can be implemented easily through the use of a computer, or of pre-calculated tables. The main disadvantage is that it cannot negotiate excavations of complex shape or significant variations in mining

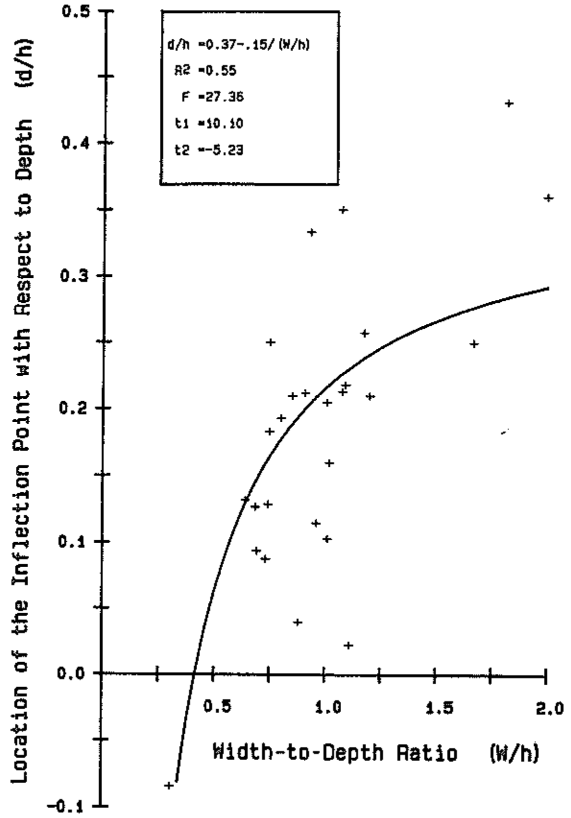

Figure 6 Effect of W/h ratio on inflection point location

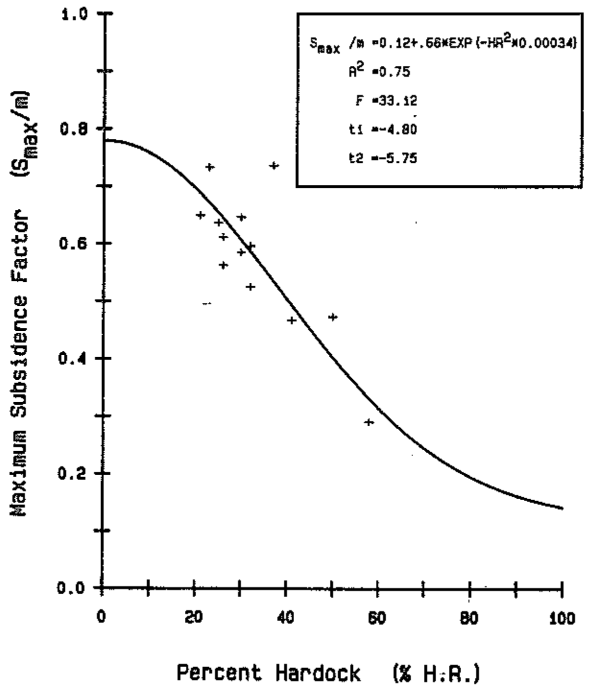

Figure 7 Effect of lithology on maximum subsidence factor

parameters such as mining height, percent of extraction, and depth of the excavation (Brauner, 1973; Karmis et al., 1981a).

In this approach, a number of accepted profile functions were fitted to the subsidence profiles

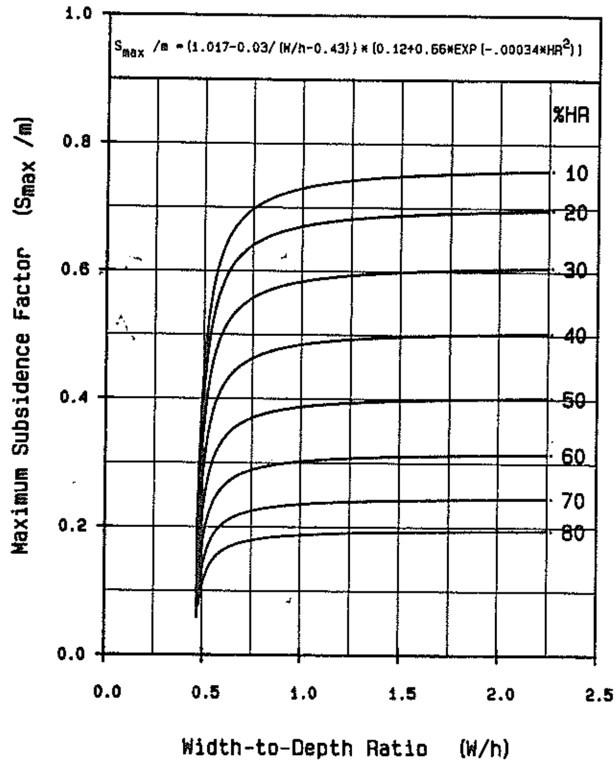

Figure 8 Nomograms for maximum subsidence prediction

developed from collected case studies. This analysis demonstrated that the hyperbolic tangent function given by the following equation, provided the best fit curve (Karmis et al., 1981b and 1984):

$$S(x) = 0.5\ S_{max}[1-\tanh(cx)/B] \qquad (1)$$

where,

- $S(x)$ = subsidence at a given point on the surface;
- S_{max} = maximum subsidence (obtained from a table [Table 1] or nomogram [Figure 8]);
- c = constant, calculated as 1.8 for critical or supercritical panels and 1.4 for subcritical panels;
- x = distance from the inflection point to the point in question; and,
- B = distance from the inflection point to S_{max} (which can be assessed from tables or nomograms [Figure 6] as a function of panel geometry and width-to-depth ratio).

The latter equation can be used in conjunction with predictions of S_{max} (Figure 8) and position of the inflection point (Figure 6) to allow for complete subsidence pre-calculation.

3.3 Influence Function Methods

This approach to subsidence prediction was initially developed by Dutch and German engineers (Bals, 1932) and has been extensively used in the Central and Eastern European coalfields. An influence function describes the distribution of vertical ground movement, i.e. subsidence, on the surface or other levels of the overburden, caused by an infinitesimal underground excavation. Considering the two dimensional situation:

$$dS(x_1,z) = f(x_1-x_2,z)dV \qquad (2)$$

where,

$dS(x_1,z)$ = subsidence at point $P(x_1,z)$;
dV = infinitesimal underground excavation (void);
$f(x_1-x_2,z)$ = influence function;
x_1 = coordinate of surface point;
x_2 = coordinate of infinitesimal excavation; and,
z = vertical distance from excavation to prediction point $P(x_1,z)$.

The Budryk-Knothe influence function method (Knothe, 1957), developed in Poland, was selected for this research as the most appropriate function for use in the Eastern U.S. coalfields. Initially, a two-dimensional situation was considered for the analysis of data obtained from panels of an almost orthogonal shape and with uniform mining conditions i.e. mining height, percent extraction, depth. The equation used is as follows:

$$f(x,z) = -\frac{1}{r}\exp\left(-\pi\frac{x^2}{r^2}\right) \qquad (3)$$

where,

r = the radius of influence ($r=z/\tan(b)$);
b = angle of influence; and,
x,z = coordinates of surface point on a system where the origin is located at the infinitesimal excavation.

For the three-dimensional approach:

$$f(x,y,z) = \frac{1}{r^2}\exp\left[-\pi\frac{(x^2+y^2)}{r^2}\right] \qquad (4)$$

where,

r = the radius of influence; and,
x,y,z = coordinates of a surface point on a system where the origin is located at the infinitesimal excavation.

Subsidence at any point will be:

$$S(x,y,z) = \frac{S_{max}}{r^2}\iint_A \exp\left[-\frac{\pi}{r^2}(x^2+y^2)\right]dxdy \qquad (5)$$

where,

$S(x,y,z)$ = subsidence at a point having coordinates x,y,z;
S_{max} = maximum subsidence for supercritical excavation;
r = the radius of influence; and,
A = the area of excavation.

The above integral was transformed and solved in polar coordinates, for polygonal excavations.

For this method, as with most mathematical models, the inflection point of the subsidence profile is located above the rib of the excavation. In practice, however, the inflection point is displaced at a distance, d, from the rib. In order to accommodate this, the outer boundaries of the excavation have been adjusted accordingly.

3.4 Zone Area Method

This method was initially developed in Britain for irregular longwall or room and pillar panels (Marr, 1975). It assumes that movement at a specific point on the surface is affected by the excavation of a circular underground area which is further sub-divided into a series of angular rings. To determine the amount of movement caused by each ring, the extracted area of the ring is calculated and multiplied by the zone factor of the respective ring. Appropriate zone factors for Appalachia have been calculated from the field data (Goodman, 1980; Karmis et al., 1981b and 1984). The same procedure is followed for all rings, and the superimposed results will yield total movement.

4 DEVELOPMENT OF STRAIN PREDICTION METHODS

One of the most damaging manifestations of surface subsidence is the development of horizontal strains. As noted previously, subsidence measured in Appalachia is smaller than that found in certain other coalfields, such as the U.K. However, the strains experienced in the U.S. often appear to be greater than those predicted for British conditions. Thus, an effort was directed toward the identification of the cause of these higher strains and toward the subsequent formulation of an acceptable strain prediction model for Appalachia.

As a first step, the relationship between strain and curvature had to be determined. Factor B was used to calculate horizontal strain as a function of curvature, i.e.:

$$\text{Horizontal Strain} = -B * \text{Curvature} \qquad (6)$$

In the original stages of this research a direct relationship between strain and curvature was sought which could describe B independent of any other mining parameters (Karmis et al., 1983). As more case studies were made available through this project, it became apparent that such a relationship will be difficult to establish (Figure 9). As a result, a different approach was adopted, based on the work of Awershin (1947), Budryk (1953) and Akimov and Zemicev (1970), which suggested that the magnitude of the horizontal strain factor (B) is a function of the excavation depth or the radius of principal influence (r).

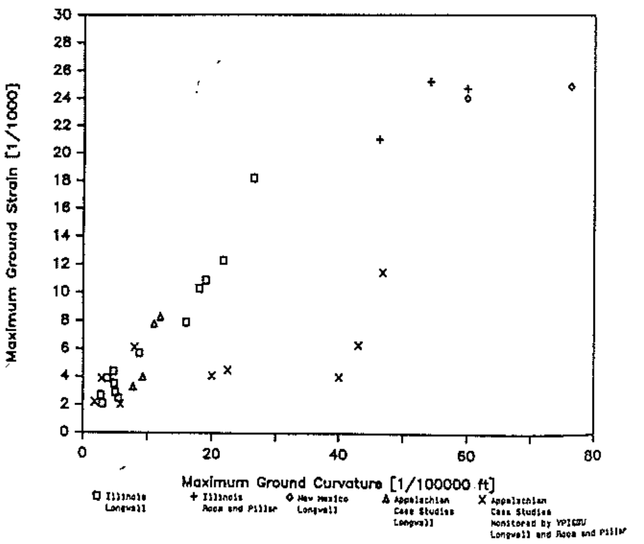

Figure 9 Maximum ground strain and curvature data

For each of the collected case studies, factor B was determined by comparing the measured strains and the fitted curvature profiles.

Using the established values of parameter B and the corresponding values of excavation depth (h), radius of influence (r), and angle of principal influence (b), a statistical relationship was found (Figure 10) as expressed by the equation:

$$B = (0.35 \pm 0.05)\, r \qquad (7)$$

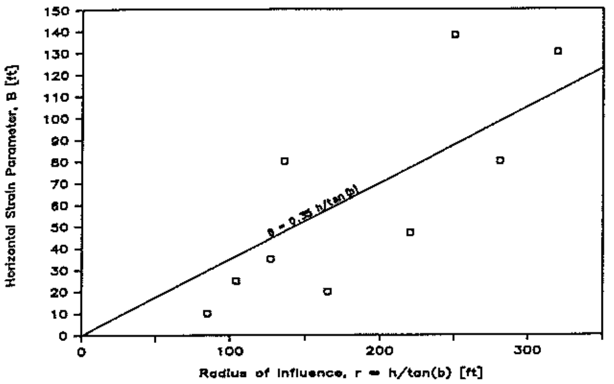

Figure 10 Effect of radius of influence on the horizontal strain parameter

or

$$B = (0.35 \pm 0.05)\ h/\tan(b) \qquad (8)$$

where,

r = radius of the principal influence;
h = depth of the excavation; and,
b = angle of the principal influence.

5 DEVELOPMENT OF COMPUTER SOFTWARE

The development of a comprehensive software package was necessary in order to facilitate the analysis of the field measurements. All field data were stored in an 880-line memory incorporated in the surveying instrument, and then transferred to magnetic diskettes for further processing on an HP micro-computer system. Stored field data included coordinates, sometimes on a localized system, elevations and the values of subsidence and strain for individual stations on the monitoring lines for each date.

Computer software for the application of the prediction methods under consideration was developed for two widely used personal computer systems.

For the profile function, the program is rather simple and involves the calculation of subsidence values along a line orthogonal to the rib of the excavation. The parameters used for this calculation depend on the given geologic conditions, width-to-depth ratio and mining height, and must be obtained from tables or nomograms and entered manually. The origin of the coordinates can be adjusted manually if necessary.

For the application of the influence function method, a number of programs were developed, each of them for specific conditions. For general cases involving complex mining conditions, where the mining section under consideration must be divided into polygons of uniform conditions, the influence function equation was converted to polar coordinates and was used in the program in this form. The computer program calculates subsidence at any point along a polygonal line or on a grid. For mine sections of irregular shape or where areas of different mining height, extraction ratio or seam elevation exist, the section is separated into homogeneous polygonal sub-sections. Subsidence and other related indices of deformation, in any given direction, caused by each of these sub-sections is calculated and their total value is determined by superposition. This procedure, however, requires considerable computational time for each point.

For simple conditions, however, where areas of different mining height, extraction ratio or seam elevation can be described by rectangular homogeneous sub-sections, different programs have been written for considerably faster execution on a microcomputer, yielding comparable results. Furthermore, a program using the two dimensional approach has been written for single panels of uniform overall parameters.

The program for the zone area method was initially developed for mainframe computers (Karmis et al., 1982); however, it is currently being adapted for use with personal computers.

It should be noted that these programs also produce data compatible with commercially available plotting and contouring software packages. Mine plan coordinates and the corresponding parameters can be entered manually or by a digitizer or by a plotter with digitizing capabilities.

6 APPLICATION OF PREDICTION METHODS

In this paper, data obtained from three case studies are presented to demonstrate and compare the prediction methods. The first two are from room and pillar mining operations, whereas the last one is from a longwall case study.

In the first example, the two dimensional approach was used. Predicted and fitted subsidence curves, using the profile and influence function methods, are presented in Figure 11.

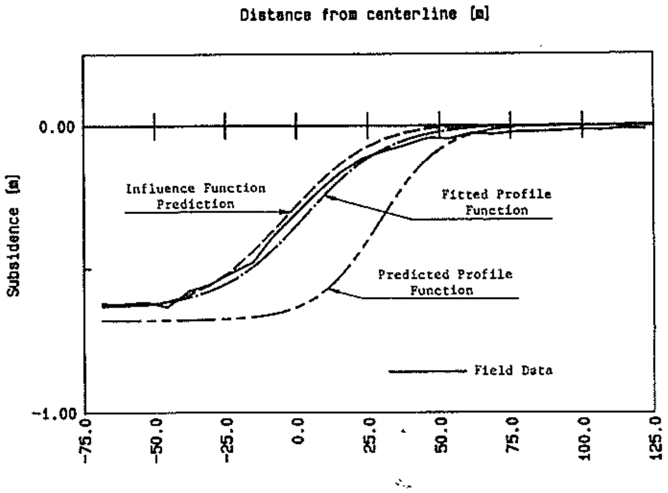

Figure 11 Example #1: Field data and prediction curves

In the second example (Figure 12), a three dimensional influence function approach was used to take into account a number of pillars left in place for roof control purposes. This case demonstrates the accuracy which can be obtained through adjustment of the influence function parameters, especially for subsidence predictions.

In the last example (Figure 13), a three dimensional influence function method was used for a longwall operation with considerable variation in overburden depth. Subsidence and horizontal strain values, calculated using this technique, show excellent correlation with the corresponding measured values.

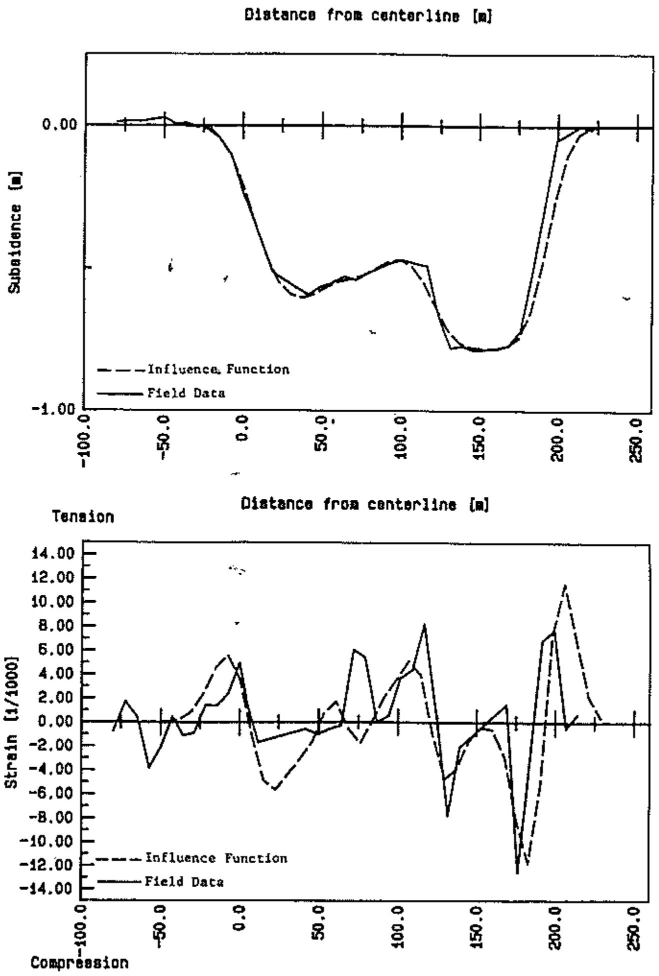

Figure 12 Example #2: Field data and prediction curves for subsidence and horizontal strain

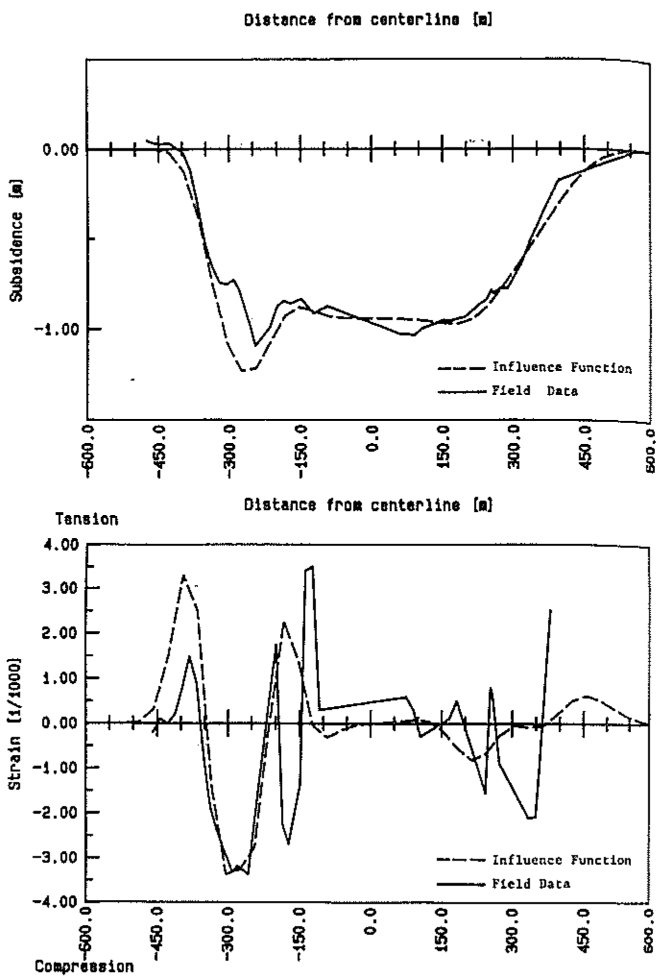

Figure 13 Example #3: Field data and prediction curves for subsidence and horizontal strain

7 CONCLUSIONS

The expansion of underground mining into more populous areas, and the resultant increase in the potential for surface and structural damage, have rendered the formulation of accurate surface deformation models an important requisite. To meet this demand, accurate subsidence and strain prediction techniques have been formulated for the Eastern U.S. coalfield. The semi-empirical subsidence prediction techniques discussed in this paper were developed from a substantial number of case studies collected within the Appalachian coalfield. Using the subsidence model as a base, the strain model was formulated using empirically and mathematically derived relationships. These models can greatly facilitate mine planning and allow the amount of coal lost due to the protection of surface structures to be minimized.

8 ACKNOWLEDGEMENTS

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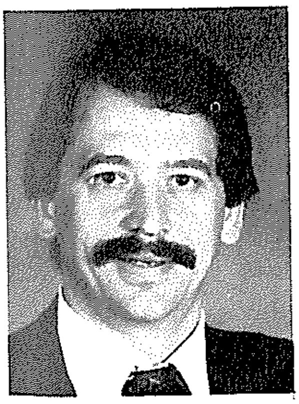

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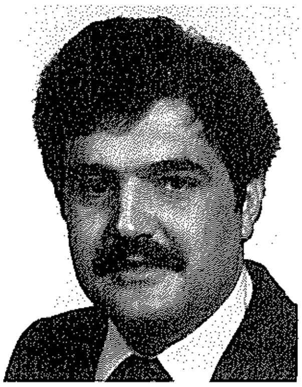

P P G SCHILIZZI

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APPENDIX C – Chain and Barrier Pillar Stability Calculations

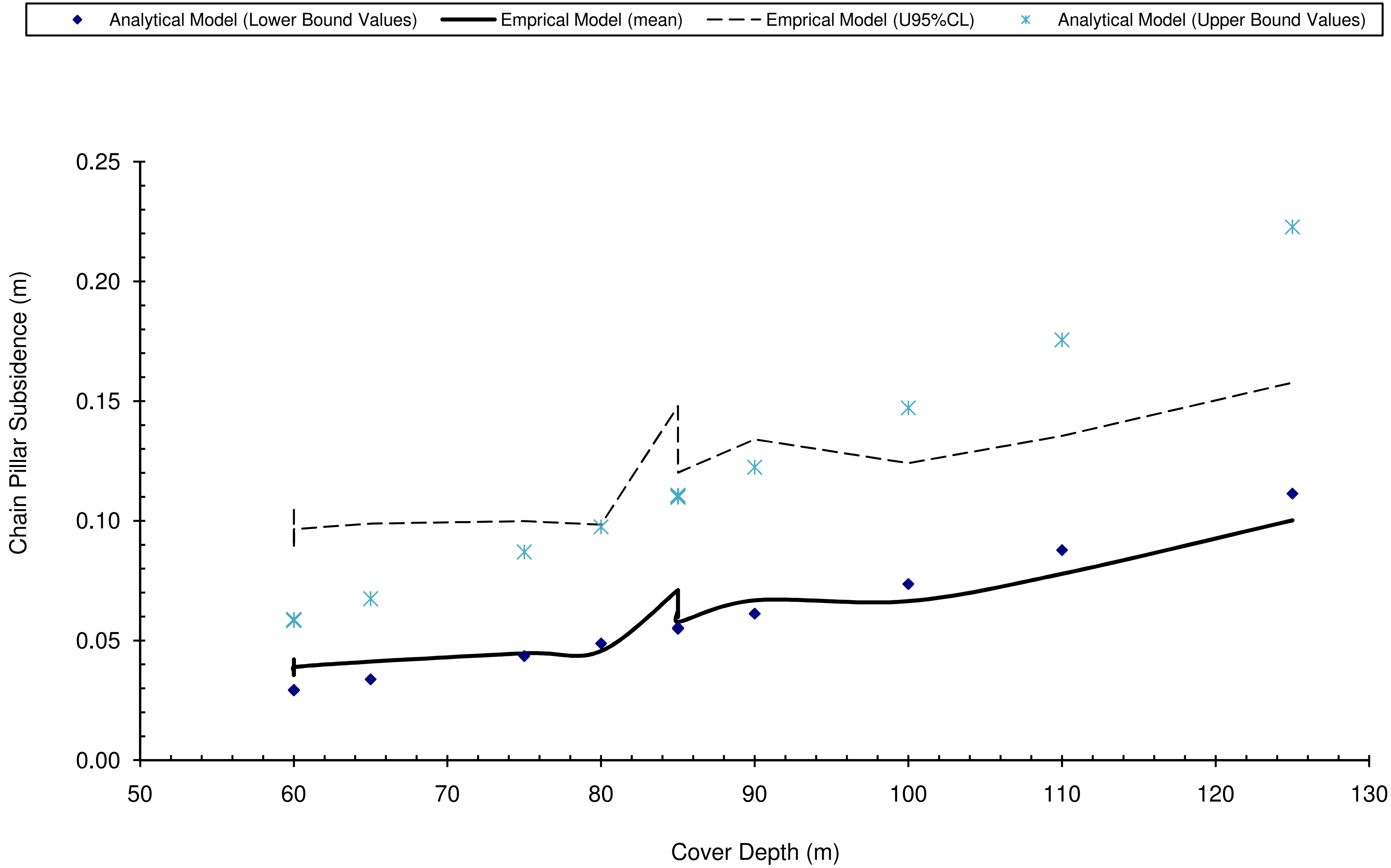
UNSW Pillar Design Spreadsheet

Abel Mine - Upper Donaldson Seam	P2	P2	P3	P3	P4	P4	P5
INPUT DATA							
Depth of Cover (m)	60	85	60	85	60	90	60
Development Height (m)	2.6	3	2.6	3	2.4	2.8	2.2
Pillar Length - centres (m)	**500.0**	**500.0**	**500.0**	**500.0**	**500.0**	**500.0**	**500.0**
Pillar Width - centres (m)	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**
Roadway Width for maximum pillar dimension	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Roadway Width for minimum pillar dimension	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Cut-Through Angle (degrees)	90	90	90	90	90	90	90
Average Panel Span (m) {rib-rib width}	**160.5**	**160.5**	**160.5**	**160.5**	**160.5**	**160.5**	**160.5**
SG (tonnes/m^3)	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Conversion (tonnes to N)	10000	10000	10000	10000	10000	10000	10000
Abutment Angle (^{o})	21	21	21	21	21	21	21
INTERMEDIATE CALCULATIONS							
Maximum Rib to Rib Pillar Length (w_2)	**494.5**	**494.5**	**494.5**	**494.5**	**494.5**	**494.5**	**494.5**
Minimum Rib to Rib Pillar Width (w_1)	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**
w, Minimum Rib to Rib Pillar Width (ie $w_1 \sin\theta$)	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**
Minimum Pillar Width/Height Ratio	**7.5**	**6.5**	**7.5**	**6.5**	**8.1**	**7.0**	**8.9**
Extraction Ratio (%)	**22.9%**	**22.9%**	**22.9%**	**22.9%**	**22.9%**	**22.9%**	**22.9%**
Abutment Angle (Radians)	0.367	0.367	0.367	0.367	0.367	0.367	0.367
Cut-Through Angle (Radians)	1.571	1.571	1.571	1.571	1.571	1.571	1.571
Is the Panel Super-Critical?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
D (Peng & Chiang Loading Factor)	39.737	47.296	39.737	47.296	39.737	48.667	39.737
R (Pillar 2nd Abutment Component)	0.95	0.90	0.95	0.90	0.95	0.88	0.95
Dimensionless Pillar 'Rectangularity'	1.92	1.92	1.92	1.92	1.92	1.92	1.92
Width/Height Ratio Exponent	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Effective Width Factor (Omega)	1.92	1.92	1.92	1.92	1.92	1.92	1.92
Effective Width Interim	37.52	37.52	37.52	37.52	37.52	37.52	37.52
Effective Pillar Width (m)	37.52	37.52	37.52	37.52	37.52	37.52	37.52
Effective Pillar Loading Height (m)	60.00	85.00	60.00	85.00	60.00	90.00	60.00
RESULTS							
Tributary Area Loading (MPa)	**1.94**	**2.75**	**1.94**	**2.75**	**1.94**	**2.92**	**1.94**
Pillar Strength (UNSW Squat Pillar 1999)	**27.27**	**22.57**	**27.27**	**22.57**	**30.73**	**24.62**	**35.39**
Pillar Strength (UNSW w/h<5)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Safety Factor under FTA Loading (Squat Pillar)	**14.02**	**8.19**	**14.02**	**8.19**	**15.81**	**8.44**	**18.20**
Safety Factor under FTA Loading (w/h<5)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
No. SAs, n	2	2	2	2	2	2	2
Single Abutment Loading (3D) - full	0.90	1.80	0.90	1.80	0.90	2.02	0.90
Single Abutment Loading (3D) - pillar	**0.85**	**1.61**	**0.85**	**1.61**	**0.85**	**1.78**	**0.85**
Single Abutment Loading (3D) - solid	0.05	0.19	0.05	0.19	0.05	0.23	0.05
Cell Sensitivity (MPa)	0	0	0	0	0	0	0
Total Pillar Loading with Single Abutment Loading	2.79	4.36	2.79	4.36	2.79	4.70	2.79
Safety Factor (under Single Abutment Loading)	**9.76**	**5.17**	**9.76**	**5.17**	**11.00**	**5.24**	**12.67**
Total Pillar Loading @ nA	3.74	6.35	3.74	6.35	3.74	6.95	3.74
Safety Factor @ nA	**7.30**	**3.55**	**7.30**	**3.55**	**8.23**	**3.54**	**9.47**
Total Pillar Loading under Double Abutment Loading	3.74	6.35	3.74	6.35	3.74	6.95	3.74
Safety Factor (under Double Abutment Loading)	**7.30**	**3.55**	**7.30**	**3.55**	**8.23**	**3.54**	**9.47**
Notes: Mining Height (m)	2.6	3.2	2.6	3.2	2.4	2.8	2.2
Effective w/h	7.50	6.09	7.50	6.09	8.13	6.96	8.86
FTA Sp/T	0.011	0.012	0.011	0.012	0.011	0.012	0.011
FTA Sp(m)	**0.028**	**0.036**	**0.028**	**0.036**	**0.026**	**0.034**	**0.024**
FTA Sp/T (U95%)	0.059	0.060	0.059	0.060	0.059	0.060	0.059
FTA Sp (U95%)	**0.153**	**0.180**	**0.153**	**0.180**	**0.141**	**0.169**	**0.129**
nA Sp/T	0.014	0.019	0.014	0.019	0.014	0.020	0.014
nA Sp First (m)	**0.035**	**0.059**	**0.035**	**0.059**	**0.032**	**0.056**	**0.030**
nA Sp/T (U95%)	0.038	0.043	0.038	0.043	0.038	0.044	0.038
nA Sp First (U95%)	**0.098**	**0.136**	**0.098**	**0.136**	**0.090**	**0.123**	**0.083**
Max ER Subs	**0.59**	**0.73**	**0.59**	**0.73**	**0.55**	**0.64**	**0.50**
nA Sp Final (m)	**0.042**	**0.071**	**0.042**	**0.071**	**0.039**	**0.067**	**0.036**
nA Sp Final (U95%)	**0.10**	**0.15**	**0.10**	**0.15**	**0.10**	**0.13**	**0.09**
nA Sp Final (L95%)	**-0.055**	**-0.065**	**-0.055**	**-0.065**	**-0.051**	**-0.056**	**-0.047**
Ecoal(GPa)	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**
Efloor(GPa)	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**
Eroof(GPa)	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**
Poissons Ratio floor/roof	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**
virgin stress (MPa)	**1.50**	**2.13**	**1.50**	**2.13**	**1.50**	**2.25**	**1.50**
final vertical stress (MPa)	**3.74**	**6.35**	**3.74**	**6.35**	**3.74**	**6.95**	**3.74**
final pillar stress	**3.74**	**6.35**	**3.74**	**6.35**	**3.74**	**6.95**	**3.74**
Mean Pillar Compression (m)	**0.001**	**0.003**	**0.001**	**0.003**	**0.001**	**0.003**	**0.001**
Mean Roof Compression (m)	**0.026**	**0.048**	**0.026**	**0.048**	**0.026**	**0.054**	**0.026**
Mean Floor Compression (m)	**0.017**	**0.032**	**0.017**	**0.032**	**0.017**	**0.036**	**0.017**
Mean Total Compression (m)	**0.044**	**0.084**	**0.044**	**0.084**	**0.044**	**0.093**	**0.044**
Ecoal(GPa)	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**
Efloor(GPa)	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**
Eroof(GPa)	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**
Poissons Ratio floor/roof	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**
virgin stress (MPa)	**1.50**	**2.13**	**1.50**	**2.13**	**1.50**	**2.25**	**1.50**
final vertical stress (MPa)	**3.74**	**6.35**	**3.74**	**6.35**	**3.74**	**6.95**	**3.74**
final pillar stress	**3.74**	**6.35**	**3.74**	**6.35**	**3.74**	**6.95**	**3.74**
Mean Pillar Compression (m)	**0.003**	**0.007**	**0.003**	**0.007**	**0.003**	**0.007**	**0.002**
Mean Roof Compression (m)	**0.051**	**0.097**	**0.051**	**0.097**	**0.051**	**0.108**	**0.051**
Mean Floor Compression (m)	**0.034**	**0.065**	**0.034**	**0.065**	**0.034**	**0.072**	**0.034**
WC Total Compression (m)	**0.088**	**0.168**	**0.088**	**0.168**	**0.088**	**0.186**	**0.088**

UNSW Pillar Design Spreadsheet

Abel Mine - Upper Donaldson Seam	P5
INPUT DATA	
Depth of Cover (m)	85
Development Height (m)	2.7
Pillar Length - centres (m)	**500.0**
Pillar Width - centres (m)	**25.0**
Roadway Width for maximum pillar dimension	5.5
Roadway Width for minimum pillar dimension	5.5
Cut-Through Angle (degrees)	90
Average Panel Span (m) {rib-rib width}	**160.5**
SG (tonnes/m^3)	2.5
Conversion (tonnes to N)	10000
Abutment Angle (^{o})	21
INTERMEDIATE CALCULATIONS	
Maximum Rib to Rib Pillar Length (w_2)	**494.5**
Minimum Rib to Rib Pillar Width (w_1)	**19.5**
w, Minimum Rib to Rib Pillar Width (ie $w_1$sinθ)	**19.5**
Minimum Pillar Width/Height Ratio	**7.2**
Extraction Ratio (%)	**22.9%**
Abutment Angle (Radians)	0.367
Cut-Through Angle (Radians)	1.571
Is the Panel Super-Critical?	Yes
D (Peng & Chiang Loading Factor)	47.296
R (Pillar 2nd Abutment Component)	0.90
Dimensionless Pillar 'Rectangularity'	1.92
Width/Height Ratio Exponent	1.00
Effective Width Factor (Omega)	1.92
Effective Width Interim	37.52
Effective Pillar Width (m)	37.52
Effective Pillar Loading Height (m)	85.00

RESULTS	
Tributary Area Loading (MPa)	**2.75**
Pillar Strength (UNSW Squat Pillar 1999)	**25.86**
Pillar Strength (UNSW w/h<5)	**N/A**
Safety Factor under FTA Loading (Squat Pillar)	**9.39**
Safety Factor under FTA Loading (w/h<5)	**N/A**
No. SAs, n	2
Single Abutment Loading (3D) - full	1.80
Single Abutment Loading (3D) - pillar	**1.61**
Single Abutment Loading (3D) - solid	0.19
Cell Sensitivity (MPa)	0
Total Pillar Loading with Single Abutment Loading	4.36
Safety Factor (under Single Abutment Loading)	**5.93**
Total Pillar Loading @ nA	6.35
Safety Factor @ nA	**4.07**
Total Pillar Loading under Double Abutment Loading	6.35
Safety Factor (under Double Abutment Loading)	**4.07**
Notes: Mining Height (m)	2.7
Effective w/h	7.22
FTA Sp/T	0.012
FTA Sp(m)	**0.032**
FTA Sp/T (U95%)	0.060
FTA Sp (U95%)	**0.162**
nA Sp/T	0.019
nA Sp First (m)	**0.050**
nA Sp/T (U95%)	0.043
nA Sp First (U95%)	**0.115**
Max ER Subs	**0.62**
nA Sp Final (m)	**0.060**
nA Sp Final (U95%)	**0.12**
nA Sp Final (L95%)	**-0.055**
Ecoal(GPa)	**4.00**
Efloor(GPa)	**7.50**
Eroof(GPa)	**5.00**
Poissons Ratio floor/roof	**0.25**
Shape Factor, I	**1.500**
virgin stress (MPa)	**2.13**
final vertical stress (MPa)	**6.35**
final pillar stress	**6.35**
Mean Pillar Compression (m)	**0.003**
Mean Roof Compression (m)	**0.048**
Mean Floor Compression (m)	**0.032**
Mean Total Compression (m)	**0.084**
Ecoal(GPa)	**2.00**
Efloor(GPa)	**3.75**
Eroof(GPa)	**2.50**
Poissons Ratio floor/roof	**0.25**
Shape Factor, I	**1.500**
virgin stress (MPa)	**2.13**
final vertical stress (MPa)	**6.35**
final pillar stress	**6.35**
Mean Pillar Compression (m)	**0.006**
Mean Roof Compression (m)	**0.097**
Mean Floor Compression (m)	**0.065**
WC Total Compression (m)	**0.167**

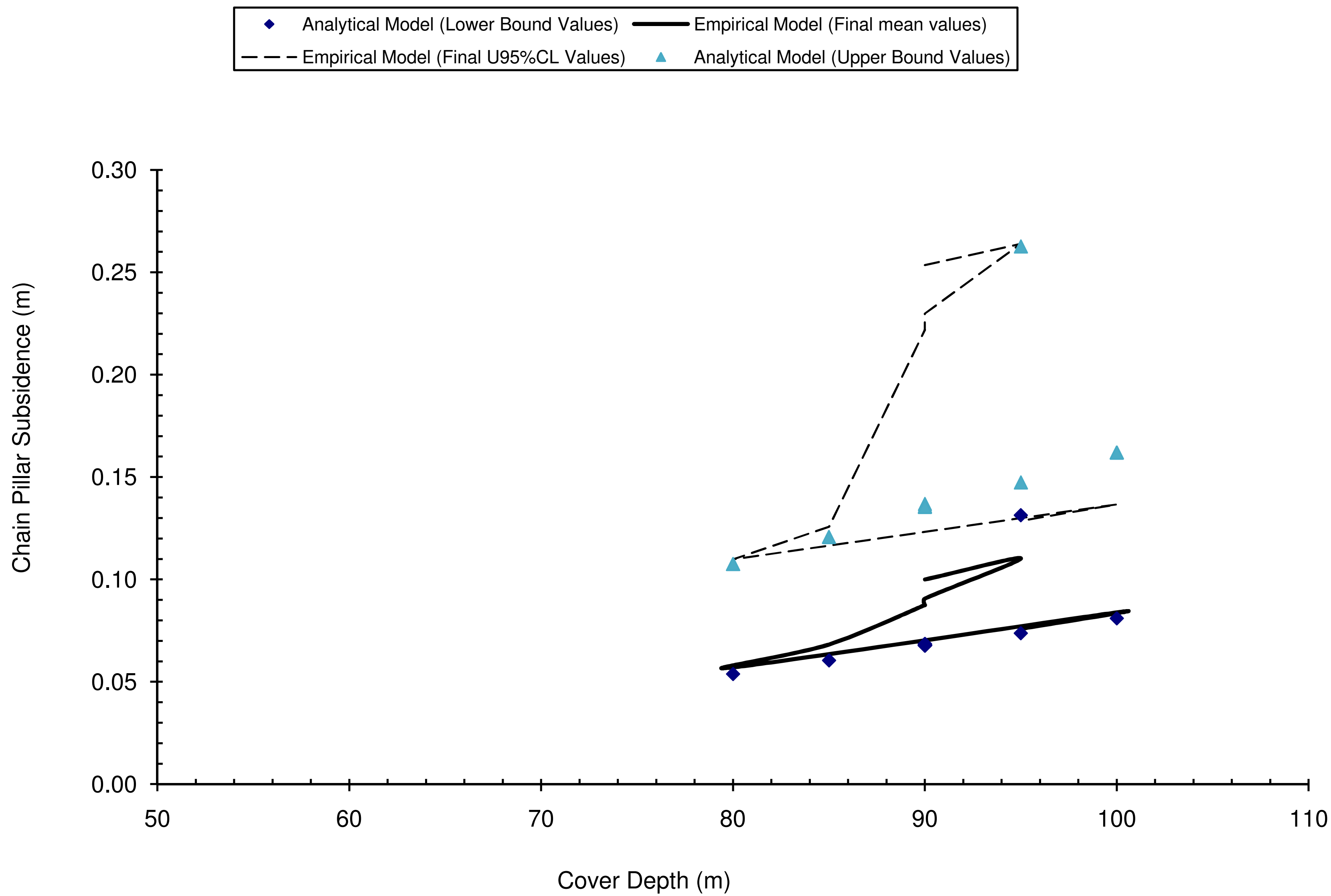

Analytical Model (Lower Bound Values)
Emprical Model (mean)
Emprical Model (U95%CL)
Analytical Model (Upper Bound Values)
0.25
0.20
0.15
0.10
0.05
0.00
Chain Pillar Subsidence (m)
50
60
70
80
90
100
110
120
130
Cover Depth (m)

UNSW Pillar Design Spreadsheet

Abel Mine - Upper Donaldson Seam	P2	P3	P4	P5	P6	P7	P8
INPUT DATA							
Depth of Cover (m)	90	95	90	90	90	90	85
Development Height (m)	3	3	2.9	2.8	2.8	2.8	2.4
Pillar Length - centres (m)	**64.0**	**64.0**	**64.0**	**64.0**	**64.0**	**64.0**	**64.0**
Pillar Width - centres (m)	**20.0**	**20.0**	**20.0**	**20.0**	**20.0**	**20.0**	**20.0**
Roadway Width for maximum pillar dimension	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Roadway Width for minimum pillar dimension	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Cut-Through Angle (degrees)	90	90	90	90	90	90	90
Average Panel Span (m) {rib-rib width}	**131.25**	**131.25**	**131.25**	**131.25**	**131.25**	**131.25**	**131.25**
SG (tonnes/m^3)	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Conversion (tonnes to N)	10000	10000	10000	10000	10000	10000	10000
Abutment Angle (^{o})	21	21	21	21	21	21	21
INTERMEDIATE CALCULATIONS							
Maximum Rib to Rib Pillar Length (w_2)	**58.5**	**58.5**	**58.5**	**58.5**	**58.5**	**58.5**	**58.5**
Minimum Rib to Rib Pillar Width (w_1)	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**
w, Minimum Rib to Rib Pillar Width (ie $w_1 \sin\theta$)	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**
Minimum Pillar Width/Height Ratio	**4.8**	**4.8**	**5.0**	**5.2**	**5.2**	**5.2**	**6.0**
Extraction Ratio (%)	**33.7%**	**33.7%**	**33.7%**	**33.7%**	**33.7%**	**33.7%**	**33.7%**
Abutment Angle (Radians)	0.367	0.367	0.367	0.367	0.367	0.367	0.367
Cut-Through Angle (Radians)	1.571	1.571	1.571	1.571	1.571	1.571	1.571
Is the Panel Super-Critical?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
D (Peng & Chiang Loading Factor)	48.667	50.001	48.667	48.667	48.667	48.667	47.296
R (Pillar 2nd Abutment Component)	0.80	0.78	0.80	0.80	0.80	0.80	0.81
Dimensionless Pillar 'Rectangularity'	1.60	1.60	1.60	1.60	1.60	1.60	1.60
Width/Height Ratio Exponent	0.61	0.61	0.67	0.73	0.73	0.73	1.00
Effective Width Factor (Omega)	1.33	1.33	1.37	1.41	1.41	1.41	1.60
Effective Width Interim	19.34	19.34	19.86	20.42	20.42	20.42	23.24
Effective Pillar Width (m)	19.34	19.34	19.86	20.42	20.42	20.42	23.24
Effective Pillar Loading Height (m)	90.00	95.00	90.00	90.00	90.00	90.00	85.00
RESULTS							
Tributary Area Loading (MPa)	**3.40**	**3.58**	**3.40**	**3.40**	**3.40**	**3.40**	**3.21**
Pillar Strength (UNSW Squat Pillar 1999)	**NA**	**NA**	**16.02**	**16.75**	**16.75**	**16.75**	**20.83**
Pillar Strength (UNSW w/h<5)	**15.48**	**15.48**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Safety Factor under FTA Loading (Squat Pillar)	**N/A**	**N/A**	**4.72**	**4.93**	**4.93**	**4.93**	**6.50**
Safety Factor under FTA Loading (w/h<5)	**4.56**	**4.32**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
No. SAs, n	2	2	2	2	2	2	2
Single Abutment Loading (3D) - full	2.93	3.27	2.93	2.93	2.93	2.93	2.62
Single Abutment Loading (3D) - pillar	**2.33**	**2.56**	**2.33**	**2.33**	**2.33**	**2.33**	**2.11**
Single Abutment Loading (3D) - solid	0.60	0.71	0.60	0.60	0.60	0.60	0.50
Cell Sensitivity (MPa)	0	0	0	0	0	0	0
Total Pillar Loading with Single Abutment Loading	5.73	6.15	5.73	5.73	5.73	5.73	5.32
Safety Factor (under Single Abutment Loading)	**2.70**	**2.52**	**2.80**	**2.92**	**2.92**	**2.92**	**3.92**
Total Pillar Loading @ nA	9.26	10.12	9.26	9.26	9.26	9.26	8.44
Safety Factor @ nA	**1.67**	**1.53**	**1.73**	**1.81**	**1.81**	**1.81**	**2.47**
Total Pillar Loading under Double Abutment Loading	9.26	10.12	9.26	9.26	9.26	9.26	8.44
Safety Factor (under Double Abutment Loading)	**1.67**	**1.53**	**1.73**	**1.81**	**1.81**	**1.81**	**2.47**
Notes: Mining Height (m)	3.2	3.2	2.9	2.8	2.8	2.8	2.4
Effective w/h	4.53	4.53	5.00	5.18	5.18	5.18	6.04
FTA Sp/T	0.009	0.009	0.009	0.009	0.009	0.009	0.009
FTA Sp(m)	**0.545**	**0.545**	**0.545**	**0.545**	**0.545**	**0.545**	**0.545**
FTA Sp/T (U95%)	0.057	0.057	0.057	0.057	0.057	0.057	0.057
FTA Sp (U95%)	**0.170**	**0.170**	**0.164**	**0.158**	**0.158**	**0.158**	**0.136**
nA Sp/T	0.026	0.029	0.026	0.026	0.026	0.026	0.024
nA Sp First (m)	**0.083**	**0.092**	**0.076**	**0.073**	**0.073**	**0.073**	**0.057**
nA Sp/T (U95%)	0.074	0.077	0.074	0.074	0.074	0.074	0.048
nA Sp First (U95%)	**0.237**	**0.246**	**0.215**	**0.207**	**0.207**	**0.207**	**0.114**
Max ER Subs	**0.56**	**0.52**	**0.58**	**0.61**	**0.61**	**0.61**	**0.83**
nA Sp Final (m)	**0.100**	**0.110**	**0.091**	**0.087**	**0.087**	**0.087**	**0.068**
nA Sp Final (U95%)	**0.25**	**0.26**	**0.23**	**0.22**	**0.22**	**0.22**	**0.13**
nA Sp Final (L95%)	**-0.137**	**-0.135**	**-0.124**	**-0.120**	**-0.120**	**-0.120**	**-0.046**
Ecoal(GPa)	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**
Efloor(GPa)	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**
Eroof(GPa)	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**
Poissons Ratio floor/roof	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**
virgin stress (MPa)	**2.25**	**2.38**	**2.25**	**2.25**	**2.25**	**2.25**	**2.13**
final vertical stress (MPa)	**9.26**	**10.12**	**9.26**	**9.26**	**9.26**	**9.26**	**8.44**
final pillar stress	**9.26**	**10.12**	**9.26**	**9.26**	**9.26**	**9.26**	**8.44**
Mean Pillar Compression (m)	**0.006**	**0.062**	**0.005**	**0.005**	**0.005**	**0.005**	**0.004**
Mean Roof Compression (m)	**0.038**	**0.042**	**0.038**	**0.038**	**0.038**	**0.038**	**0.034**
Mean Floor Compression (m)	**0.025**	**0.028**	**0.025**	**0.025**	**0.025**	**0.025**	**0.023**
Mean Total Compression (m)	**0.068**	**0.131**	**0.068**	**0.068**	**0.068**	**0.068**	**0.060**
Ecoal(GPa)	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**
Efloor(GPa)	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**
Eroof(GPa)	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**
Poissons Ratio floor/roof	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**
virgin stress (MPa)	**2.25**	**2.38**	**2.25**	**2.25**	**2.25**	**2.25**	**2.13**
final vertical stress (MPa)	**9.26**	**10.12**	**9.26**	**9.26**	**9.26**	**9.26**	**8.44**
final pillar stress	**9.26**	**10.12**	**9.26**	**9.26**	**9.26**	**9.26**	**8.44**
Mean Pillar Compression (m)	**0.011**	**0.124**	**0.010**	**0.010**	**0.010**	**0.010**	**0.008**
Mean Roof Compression (m)	**0.075**	**0.083**	**0.075**	**0.075**	**0.075**	**0.075**	**0.068**
Mean Floor Compression (m)	**0.050**	**0.056**	**0.050**	**0.050**	**0.050**	**0.050**	**0.045**
WC Total Compression (m)	**0.137**	**0.263**	**0.136**	**0.135**	**0.135**	**0.135**	**0.121**

UNSW Pillar Design Spreadsheet

Abel Mine - Upper Donaldson Seam	P9	P12	P13
INPUT DATA			
Depth of Cover (m)	80	100	95
Development Height (m)	2.2	2.2	2.2
Pillar Length - centres (m)	**64.0**	**64.0**	**64.0**
Pillar Width - centres (m)	**20.0**	**20.0**	**20.0**
Roadway Width for maximum pillar dimension	5.5	5.5	5.5
Roadway Width for minimum pillar dimension	5.5	5.5	5.5
Cut-Through Angle (degrees)	90	90	90
Average Panel Span (m) {rib-rib width}	**131.25**	**131.25**	**131.25**
SG (tonnes/m^3)	2.5	2.5	2.5
Conversion (tonnes to N)	10000	10000	10000
Abutment Angle (^{o})	21	21	21
INTERMEDIATE CALCULATIONS			
Maximum Rib to Rib Pillar Length (w_2)	**58.5**	**58.5**	**58.5**
Minimum Rib to Rib Pillar Width (w_1)	**14.5**	**14.5**	**14.5**
w, Minimum Rib to Rib Pillar Width (ie $w_1$sinθ)	**14.5**	**14.5**	**14.5**
Minimum Pillar Width/Height Ratio	**6.6**	**6.6**	**6.6**
Extraction Ratio (%)	**33.7%**	**33.7%**	**33.7%**
Abutment Angle (Radians)	0.367	0.367	0.367
Cut-Through Angle (Radians)	1.571	1.571	1.571
Is the Panel Super-Critical?	Yes	Yes	Yes
D (Peng & Chiang Loading Factor)	45.884	51.300	50.001
R (Pillar 2nd Abutment Component)	0.82	0.77	0.78
Dimensionless Pillar 'Rectangularity'	1.60	1.60	1.60
Width/Height Ratio Exponent	1.00	1.00	1.00
Effective Width Factor (Omega)	1.60	1.60	1.60
Effective Width Interim	23.24	23.24	23.24
Effective Pillar Width (m)	23.24	23.24	23.24
Effective Pillar Loading Height (m)	80.00	100.00	95.00
RESULTS			
Tributary Area Loading (MPa)	**3.02**	**3.77**	**3.58**
Pillar Strength (UNSW Squat Pillar 1999)	**23.06**	**23.06**	**23.06**
Pillar Strength (UNSW w/h<5)	**N/A**	**N/A**	**N/A**
Safety Factor under FTA Loading (Squat Pillar)	**7.64**	**6.11**	**6.43**
Safety Factor under FTA Loading (w/h<5)	**N/A**	**N/A**	**N/A**
No. SAs, n	2	2	2
Single Abutment Loading (3D) - full	2.32	3.62	3.27
Single Abutment Loading (3D) - pillar	**1.90**	**2.80**	**2.56**
Single Abutment Loading (3D) - solid	0.42	0.82	0.71
Cell Sensitivity (MPa)	0	0	0
Total Pillar Loading with Single Abutment Loading	4.92	6.57	6.15
Safety Factor (under Single Abutment Loading)	**4.69**	**3.51**	**3.75**
Total Pillar Loading @ nA	7.65	11.01	10.12
Safety Factor @ nA	**3.01**	**2.09**	**2.28**
Total Pillar Loading under Double Abutment Loading	7.65	11.01	10.12
Safety Factor (under Double Abutment Loading)	**3.01**	**2.09**	**2.28**
Notes: Mining Height (m)	2.2	2.2	2.2
Effective w/h	6.59	6.59	6.59
FTA Sp/T	0.009	0.009	0.009
FTA Sp(m)	**0.545**	**0.545**	**0.545**
FTA Sp/T (U95%)	0.057	0.057	0.057
FTA Sp (U95%)	**0.124**	**0.124**	**0.124**
nA Sp/T	0.022	0.032	0.029
nA Sp First (m)	**0.048**	**0.070**	**0.063**
nA Sp/T (U95%)	0.046	0.056	0.053
nA Sp First (U95%)	**0.100**	**0.123**	**0.116**
Max ER Subs	**1.02**	**0.71**	**0.77**
nA Sp Final (m)	**0.057**	**0.084**	**0.076**
nA Sp Final (U95%)	**0.11**	**0.14**	**0.13**
nA Sp Final (L95%)	**-0.043**	**-0.039**	**-0.040**
Ecoal(GPa)	**4.00**	**4.00**	**4.00**
Efloor(GPa)	**7.50**	**7.50**	**7.50**
Eroof(GPa)	**5.00**	**5.00**	**5.00**
Poissons Ratio floor/roof	**0.25**	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**	**1.500**
virgin stress (MPa)	**2.00**	**2.50**	**2.38**
final vertical stress (MPa)	**7.65**	**11.01**	**10.12**
final pillar stress	**7.65**	**11.01**	**10.12**
Mean Pillar Compression (m)	**0.003**	**0.005**	**0.004**
Mean Roof Compression (m)	**0.030**	**0.046**	**0.042**
Mean Floor Compression (m)	**0.020**	**0.031**	**0.028**
Mean Total Compression (m)	**0.054**	**0.081**	**0.074**
Ecoal(GPa)	**2.00**	**2.00**	**2.00**
Efloor(GPa)	**3.75**	**3.75**	**3.75**
Eroof(GPa)	**2.50**	**2.50**	**2.50**
Poissons Ratio floor/roof	**0.25**	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**	**1.500**
virgin stress (MPa)	**2.00**	**2.50**	**2.38**
final vertical stress (MPa)	**7.65**	**11.01**	**10.12**
final pillar stress	**7.65**	**11.01**	**10.12**
Mean Pillar Compression (m)	**0.006**	**0.009**	**0.009**
Mean Roof Compression (m)	**0.061**	**0.092**	**0.083**
Mean Floor Compression (m)	**0.041**	**0.061**	**0.056**
WC Total Compression (m)	**0.108**	**0.162**	**0.147**


Analytical Model (Lower Bound Values)
Empirical Model (Final mean values)
Empirical Model (Final U95%CL Values)
Analytical Model (Upper Bound Values)
Chain Pillar Subsidence (m)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
50
60
70
80
90
100
110
Cover Depth (m)

UNSW Pillar Design Spreadsheet

Abel Mine - Upper Donaldson Seam	P1	P1	P1	P1	P1	P1	P1	P1
INPUT DATA								
Depth of Cover (m)	80	85	90	95	95	80	85	90
Development Height (m)	2.2	2.4	2.6	3	3	2.2	2.4	2.6
Pillar Length - centres (m)	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**
Pillar Width - centres (m)	**18.5**	**18.5**	**18.5**	**18.5**	**18.5**	**18.5**	**18.5**	**18.5**
Roadway Width for maximum pillar dimension	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Roadway Width for minimum pillar dimension	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Cut-Through Angle (degrees)	90	90	90	90	90	90	90	90
Average Panel Span (m) {rib-rib width}	**131.25**	**131.25**	**131.25**	**131.25**	**131.25**	**160.5**	**160.5**	**160.5**
SG (tonnes/m^3)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Conversion (tonnes to N)	10000	10000	10000	10000	10000	10000	10000	10000
Abutment Angle (^{o})	21	21	21	21	21	21	21	21

INTERMEDIATE CALCULATIONS								
Maximum Rib to Rib Pillar Length (w_2)	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**
Minimum Rib to Rib Pillar Width (w_1)	**13.0**	**13.0**	**13.0**	**13.0**	**13.0**	**13.0**	**13.0**	**13.0**
w, Minimum Rib to Rib Pillar Width (ie $w_1$sinθ)	**13.0**	**13.0**	**13.0**	**13.0**	**13.0**	**13.0**	**13.0**	**13.0**
Minimum Pillar Width/Height Ratio	**5.9**	**5.4**	**5.0**	**4.3**	**4.3**	**5.9**	**5.4**	**5.0**
Extraction Ratio (%)	**45.2%**	**45.2%**	**45.2%**	**45.2%**	**45.2%**	**45.2%**	**45.2%**	**45.2%**
Abutment Angle (Radians)	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367
Cut-Through Angle (Radians)	1.571	1.571	1.571	1.571	1.571	1.571	1.571	1.571
Is the Panel Super-Critical?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
D (Peng & Chiang Loading Factor)	45.884	47.296	48.667	50.001	50.001	45.884	47.296	48.667
R (Pillar 2nd Abutment Component)	0.79	0.77	0.76	0.75	0.75	0.79	0.77	0.76
Dimensionless Pillar 'Rectangularity'	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Width/Height Ratio Exponent	0.97	0.81	0.67	0.44	0.44	0.97	0.81	0.67
Effective Width Factor (Omega)	1.19	1.16	1.13	1.08	1.08	1.19	1.16	1.13
Effective Width Interim	15.51	15.06	14.68	14.10	14.10	15.51	15.06	14.68
Effective Pillar Width (m)	15.51	15.06	14.68	14.10	14.10	15.51	15.06	14.68
Effective Pillar Loading Height (m)	80.00	85.00	90.00	95.00	95.00	80.00	85.00	90.00

RESULTS								
Tributary Area Loading (MPa)	**3.65**	**3.88**	**4.11**	**4.33**	**4.33**	**3.65**	**3.88**	**4.11**
Pillar Strength (UNSW Squat Pillar 1999)	**18.14**	**16.37**	**15.05**	**NA**	**NA**	**18.14**	**16.37**	**15.05**
Pillar Strength (UNSW w/h<5)	**N/A**	**N/A**	**N/A**	**13.18**	**13.18**	**N/A**	**N/A**	**N/A**
Safety Factor under FTA Loading (Squat Pillar)	**4.97**	**4.22**	**3.67**	**N/A**	**N/A**	**4.97**	**4.22**	**3.67**
Safety Factor under FTA Loading (w/h<5)	**N/A**	**N/A**	**N/A**	**3.04**	**3.04**	**N/A**	**N/A**	**N/A**
No. SAs, n	2	2	2	2	2	2	2	2
Single Abutment Loading (3D) - full	3.03	3.42	3.83	4.27	4.27	3.03	3.42	3.83
Single Abutment Loading (3D) - pillar	**2.38**	**2.65**	**2.92**	**3.20**	**3.20**	**2.38**	**2.65**	**2.92**
Single Abutment Loading (3D) - solid	0.64	0.77	0.91	1.07	1.07	0.64	0.77	0.91
Cell Sensitivity (MPa)	0	0	0	0	0	0	0	0
Total Pillar Loading with Single Abutment Loading	6.03	6.52	7.03	7.54	7.54	6.03	6.52	7.03
Safety Factor (under Single Abutment Loading)	**3.01**	**2.51**	**2.14**	**1.75**	**1.75**	**3.01**	**2.51**	**2.14**
Total Pillar Loading @ nA	9.71	10.71	11.77	12.87	12.87	9.71	10.71	11.77
Safety Factor @ nA	**1.87**	**1.53**	**1.28**	**1.02**	**1.02**	**1.87**	**1.53**	**1.28**
Total Pillar Loading under Double Abutment Loading	9.71	10.71	11.77	12.87	12.87	9.71	10.71	11.77
Safety Factor (under Double Abutment Loading)	**1.87**	**1.53**	**1.28**	**1.02**	**1.02**	**1.87**	**1.53**	**1.28**

Notes: Mining Height (m)	2.2	2.4	2.6	3.2	3.2	2.2	2.4	2.6
Effective w/h	5.91	5.42	5.00	4.06	4.06	5.91	5.42	5.00
FTA Sp/T	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
FTA Sp(m)	**0.213**	**0.213**	**0.213**	**0.213**	**0.213**	**0.213**	**0.213**	**0.213**
FTA Sp/T (U95%)	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
FTA Sp (U95%)	**0.124**	**0.136**	**0.147**	**0.170**	**0.170**	**0.124**	**0.136**	**0.147**
nA Sp/T	0.027	0.031	0.035	0.039	0.039	0.027	0.031	0.035
nA Sp First (m)	**0.060**	**0.074**	**0.090**	**0.125**	**0.125**	**0.060**	**0.074**	**0.090**
nA Sp/T (U95%)	0.075	0.079	0.083	0.087	0.087	0.075	0.079	0.083
nA Sp First (U95%)	**0.141**	**0.120**	**0.106**	**0.089**	**0.089**	**0.141**	**0.120**	**0.106**
Max ER Subs	**0.84**	**0.69**	**0.58**	**0.46**	**0.46**	**0.84**	**0.69**	**0.58**
nA Sp Final (m)	**0.072**	**0.088**	**0.108**	**0.150**	**0.150**	**0.072**	**0.088**	**0.108**
nA Sp Final (U95%)	**0.18**	**0.20**	**0.23**	**0.30**	**0.30**	**0.18**	**0.20**	**0.23**
nA Sp Final (L95%)	**-0.094**	**-0.100**	**-0.107**	**-0.129**	**-0.129**	**-0.094**	**-0.100**	**-0.107**
Ecoal(GPa)	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**	**4.00**
Efloor(GPa)	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**	**7.50**
Eroof(GPa)	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**
Poissons Ratio floor/roof	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**
virgin stress (MPa)	**2.00**	**2.13**	**2.25**	**2.38**	**2.38**	**2.00**	**2.13**	**2.25**
final vertical stress (MPa)	**9.71**	**10.71**	**11.77**	**12.87**	**12.87**	**9.71**	**10.71**	**11.77**
final pillar stress	**9.71**	**10.71**	**11.77**	**12.87**	**12.87**	**9.71**	**10.71**	**11.77**
Mean Pillar Compression (m)	**0.004**	**0.052**	**0.062**	**0.084**	**0.084**	**0.004**	**0.052**	**0.062**
Mean Roof Compression (m)	**0.025**	**0.028**	**0.031**	**0.035**	**0.035**	**0.025**	**0.028**	**0.031**
Mean Floor Compression (m)	**0.017**	**0.019**	**0.021**	**0.023**	**0.023**	**0.017**	**0.019**	**0.021**
Mean Total Compression (m)	**0.047**	**0.099**	**0.114**	**0.142**	**0.142**	**0.047**	**0.099**	**0.114**
Ecoal(GPa)	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**
Efloor(GPa)	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**	**3.75**
Eroof(GPa)	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**	**2.50**
Poissons Ratio floor/roof	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**
virgin stress (MPa)	**2.00**	**2.13**	**2.25**	**2.38**	**2.38**	**2.00**	**2.13**	**2.25**
final vertical stress (MPa)	**9.71**	**10.71**	**11.77**	**12.87**	**12.87**	**9.71**	**10.71**	**11.77**
final pillar stress	**9.71**	**10.71**	**11.77**	**12.87**	**12.87**	**9.71**	**10.71**	**11.77**
Mean Pillar Compression (m)	**0.008**	**0.103**	**0.124**	**0.168**	**0.168**	**0.008**	**0.103**	**0.124**
Mean Roof Compression (m)	**0.051**	**0.057**	**0.063**	**0.069**	**0.069**	**0.051**	**0.057**	**0.063**
Mean Floor Compression (m)	**0.034**	**0.038**	**0.042**	**0.046**	**0.046**	**0.034**	**0.038**	**0.042**
WC Total Compression (m)	**0.093**	**0.198**	**0.229**	**0.284**	**0.284**	**0.093**	**0.198**	**0.229**

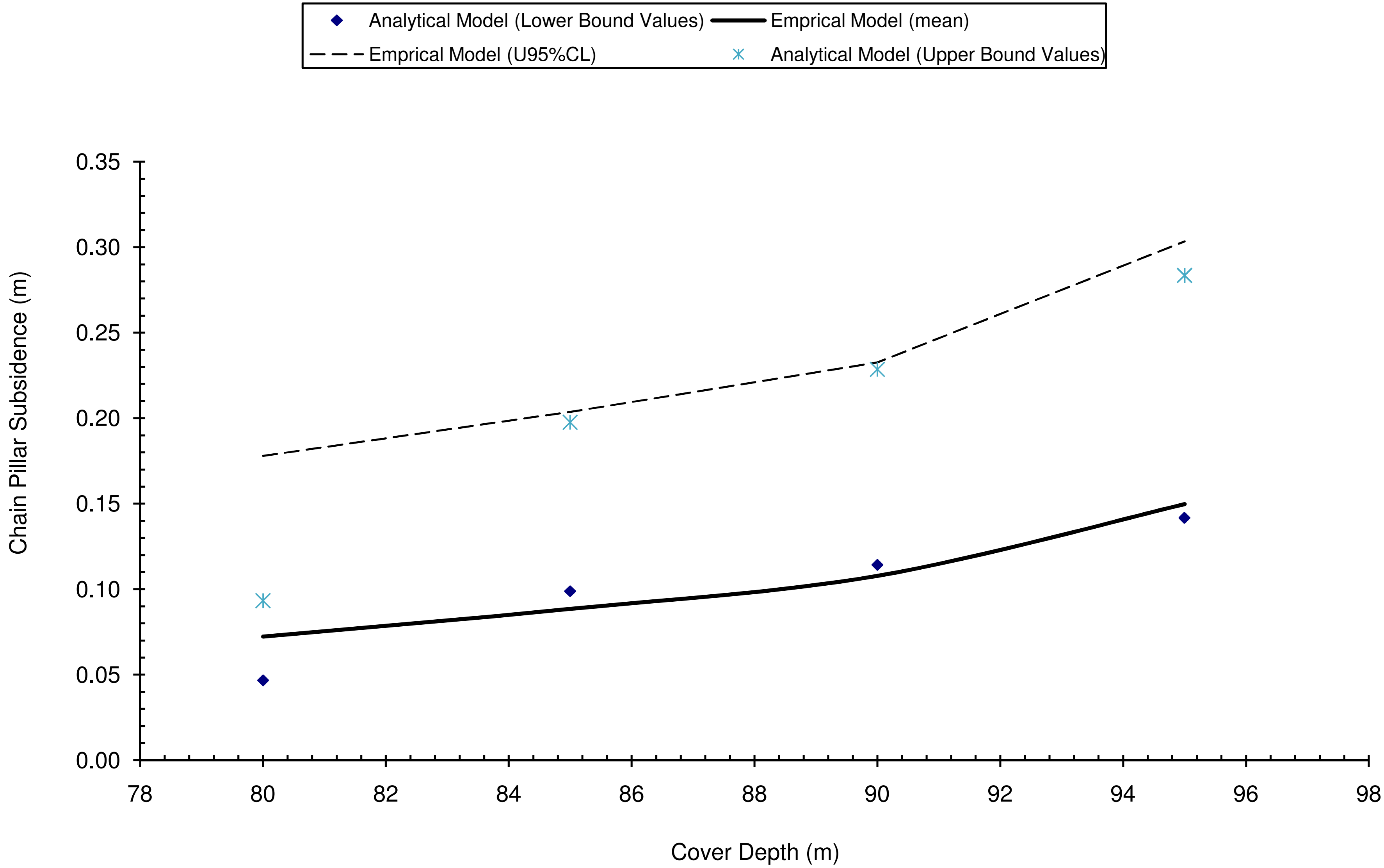
UNSW Pillar Design Spreadsheet

Abel Mine - Upper Donaldson Seam	P1	P1
INPUT DATA		
Depth of Cover (m)	95	95
Development Height (m)	3	3
Pillar Length - centres (m)	**25.0**	**25.0**
Pillar Width - centres (m)	**18.5**	**18.5**
Roadway Width for maximum pillar dimension	5.5	5.5
Roadway Width for minimum pillar dimension	5.5	5.5
Cut-Through Angle (degrees)	90	90
Average Panel Span (m) {rib-rib width}	**160.5**	**160.5**
SG (tonnes/m^3)	2.5	2.5
Conversion (tonnes to N)	10000	10000
Abutment Angle (^{o})	21	21

INTERMEDIATE CALCULATIONS		
Maximum Rib to Rib Pillar Length (w_2)	**19.5**	**19.5**
Minimum Rib to Rib Pillar Width (w_1)	**13.0**	**13.0**
w, Minimum Rib to Rib Pillar Width (ie $w_1$sinθ)	**13.0**	**13.0**
Minimum Pillar Width/Height Ratio	**4.3**	**4.3**
Extraction Ratio (%)	**45.2%**	**45.2%**
Abutment Angle (Radians)	0.367	0.367
Cut-Through Angle (Radians)	1.571	1.571
Is the Panel Super-Critical?	Yes	Yes
D (Peng & Chiang Loading Factor)	50.001	50.001
R (Pillar 2nd Abutment Component)	0.75	0.75
Dimensionless Pillar 'Rectangularity'	1.20	1.20
Width/Height Ratio Exponent	0.44	0.44
Effective Width Factor (Omega)	1.08	1.08
Effective Width Interim	14.10	14.10
Effective Pillar Width (m)	14.10	14.10
Effective Pillar Loading Height (m)	95.00	95.00

RESULTS		
Tributary Area Loading (MPa)	**4.33**	**4.33**
Pillar Strength (UNSW Squat Pillar 1999)	**NA**	**NA**
Pillar Strength (UNSW w/h<5)	**13.18**	**13.18**
Safety Factor under FTA Loading (Squat Pillar)	**N/A**	**N/A**
Safety Factor under FTA Loading (w/h<5)	**3.04**	**3.04**
No. SAs, n	2	2
Single Abutment Loading (3D) - full	4.27	4.27
Single Abutment Loading (3D) - pillar	**3.20**	**3.20**
Single Abutment Loading (3D) - solid	1.07	1.07
Cell Sensitivity (MPa)	0	0
Total Pillar Loading with Single Abutment Loading	7.54	7.54
Safety Factor (under Single Abutment Loading)	**1.75**	**1.75**
Total Pillar Loading @ nA	12.87	12.87
Safety Factor @ nA	**1.02**	**1.02**
Total Pillar Loading under Double Abutment Loading	12.87	12.87
Safety Factor (under Double Abutment Loading)	**1.02**	**1.02**

Notes: Mining Height (m)	3.2	3.2
Effective w/h	4.06	4.06
FTA Sp/T	0.009	0.009
FTA Sp(m)	**0.213**	**0.213**
FTA Sp/T (U95%)	0.057	0.057
FTA Sp (U95%)	**0.170**	**0.170**
nA Sp/T	0.039	0.039
nA Sp First (m)	**0.125**	**0.125**
nA Sp/T (U95%)	0.087	0.087
nA Sp First (U95%)	**0.089**	**0.089**
Max ER Subs	**0.46**	**0.46**
nA Sp Final (m)	**0.150**	**0.150**
nA Sp Final (U95%)	**0.30**	**0.30**
nA Sp Final (L95%)	**-0.129**	**-0.129**
Ecoal(GPa)	**4.00**	**4.00**
Efloor(GPa)	**7.50**	**7.50**
Eroof(GPa)	**5.00**	**5.00**
Poissons Ratio floor/roof	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**
virgin stress (MPa)	**2.38**	**2.38**
final vertical stress (MPa)	**12.87**	**12.87**
final pillar stress	**12.87**	**12.87**
Mean Pillar Compression (m)	**0.084**	**0.084**
Mean Roof Compression (m)	**0.035**	**0.035**
Mean Floor Compression (m)	**0.023**	**0.023**
Mean Total Compression (m)	**0.142**	**0.142**
Ecoal(GPa)	**2.00**	**2.00**
Efloor(GPa)	**3.75**	**3.75**
Eroof(GPa)	**2.50**	**2.50**
Poissons Ratio floor/roof	**0.25**	**0.25**
Shape Factor, I	**1.500**	**1.500**
virgin stress (MPa)	**2.38**	**2.38**
final vertical stress (MPa)	**12.87**	**12.87**
final pillar stress	**12.87**	**12.87**
Mean Pillar Compression (m)	**0.168**	**0.168**
Mean Roof Compression (m)	**0.069**	**0.069**
Mean Floor Compression (m)	**0.046**	**0.046**
WC Total Compression (m)	**0.284**	**0.284**


Analytical Model (Lower Bound Values)
Emprical Model (mean)
Emprical Model (U95%CL)
Analytical Model (Upper Bound Values)
Chain Pillar Subsidence (m)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
78
80
82
84
86
88
90
92
94
96
98
Cover Depth (m)