ANGLO COAL (GROSVENOR):

G200s Project – Subsidence Assessment

Subsidence Predictions in Support of the Environmental Assessment Report
## CONTENTS

1.0 INTRODUCTION 1

1.1. Background 1

1.2. Mining Geometry 4

1.3. Surface Topography 4

1.4. Seam Level Information 4

1.5. Overburden Geology 5

2.0 INTRODUCTION TO COAL MINING AND METHOD OF PREDICTING SUBLIMATION 7

2.1. Introduction 7

2.2. Overview of Longwall Mining 7

2.3. Overview of Subsidence Parameters 9

2.4. Methods of Predicting Subsidence 10

2.5. The Incremental Profile Method 11

2.6. Testing and Calibration of the Incremental Profile Method at Moranbah North Mine 11

2.7. Investigation of potential influence of fresh basalt on subsidence behaviour 16

2.8. Predicted Strains 16

2.9. Reliability of the Predicted Subsidence Parameters 16

3.0 PREDICTED SUBLIMATION PARAMETERS FOR THE PROPOSED LONGWALLS 17

3.1. Introduction 17

3.2. Maximum Predicted Subsidence, Tilt, Curvature and Strain 17

3.3. Predicted Limit of Subsidence 17

4.0 CONCLUSION 20

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS 21

APPENDIX B. REFERENCES 24

APPENDIX C. FIGURES 25

APPENDIX D. DRAWINGS 26
## Figures

Figure numbers are prefixed by the number of the chapter or the letter of the appendix in which they are presented.

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 1.1</td>
<td>Project Setting</td>
<td>2</td>
</tr>
<tr>
<td>Fig. 1.2</td>
<td>Project Layout</td>
<td>3</td>
</tr>
<tr>
<td>Fig. 1.3</td>
<td>Permian-Triassic Stratigraphy of the Northern Bowen Basin</td>
<td>6</td>
</tr>
<tr>
<td>Fig. 2.1</td>
<td>Photograph of a typical Shearer, Conveyor and Hydraulic Support Chocks and Cross-section along the Length of a Typical Longwall at the Coal Face</td>
<td>7</td>
</tr>
<tr>
<td>Fig. 2.2</td>
<td>An Operating Longwall Face</td>
<td>8</td>
</tr>
<tr>
<td>Fig. 2.3</td>
<td>Typical Profiles of Subsidence Parameter for a Single Longwall Panel</td>
<td>9</td>
</tr>
<tr>
<td>Fig. 2.4</td>
<td>Location of monitoring lines relative to extracted longwalls at Moranbah North Mine</td>
<td>12</td>
</tr>
<tr>
<td>Fig. 2.5</td>
<td>Comparison between Observed and Predicted Subsidence at Moranbah North Mine after calibration</td>
<td>14</td>
</tr>
<tr>
<td>Fig. 2.6</td>
<td>Predicted and Observed Subsidence along Centreline of MNM LW601</td>
<td>15</td>
</tr>
<tr>
<td>Fig. 2.7</td>
<td>Predicted and Observed Subsidence along Centreline of MNM LW602</td>
<td>15</td>
</tr>
<tr>
<td>Fig. 3.1</td>
<td>Comparison between locations of observed and predicted 20 mm subsidence at Moranbah North Mine</td>
<td>18</td>
</tr>
<tr>
<td>Fig. 3.2</td>
<td>Predicted limit of subsidence relative to Grosvenor Mining Lease</td>
<td>19</td>
</tr>
</tbody>
</table>

The following figures are included in Appendix C of this report.

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. C01</td>
<td>Moranbah North – Total Subsidence Profiles along Area 1 Crossline 1</td>
<td></td>
</tr>
<tr>
<td>Fig. C02</td>
<td>Moranbah North – Total Subsidence Profiles along Area 1 Crossline 2</td>
<td></td>
</tr>
<tr>
<td>Fig. C03</td>
<td>Moranbah North – Total Subsidence Profiles along Area 1 Crossline 3</td>
<td></td>
</tr>
<tr>
<td>Fig. C04</td>
<td>Moranbah North – Total Subsidence Profiles along Area 1 Crossline 4</td>
<td></td>
</tr>
<tr>
<td>Fig. C05</td>
<td>Moranbah North – Total Subsidence Profiles along Area 1 Crossline 4a</td>
<td></td>
</tr>
<tr>
<td>Fig. C06</td>
<td>Moranbah North – Total Subsidence Profiles along LW101 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C07</td>
<td>Moranbah North – Total Subsidence Profiles along LW102 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C08</td>
<td>Moranbah North – Total Subsidence Profiles along LW103 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C09</td>
<td>Moranbah North – Total Subsidence Profiles along LW104 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C10</td>
<td>Moranbah North – Total Subsidence Profiles along LW105 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C11</td>
<td>Moranbah North – Total Subsidence Profiles along LW106 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C12</td>
<td>Moranbah North – Total Subsidence Profiles along LW107 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C13</td>
<td>Moranbah North – Total Subsidence Profiles along LW108 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C14</td>
<td>Moranbah North – Total Subsidence Profiles along 200 Crossline 1</td>
<td></td>
</tr>
<tr>
<td>Fig. C15</td>
<td>Moranbah North – Total Subsidence Profiles along 200 Crossline 2</td>
<td></td>
</tr>
<tr>
<td>Fig. C16</td>
<td>Moranbah North – Total Subsidence Profiles along LW201 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C17</td>
<td>Moranbah North – Total Subsidence Profiles along LW202 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C18</td>
<td>Moranbah North – Total Subsidence Profiles along LW203 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C19</td>
<td>Moranbah North – Total Subsidence Profiles along LW109 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C20</td>
<td>Moranbah North – Total Subsidence Profiles along LW110 Centreline</td>
<td></td>
</tr>
<tr>
<td>Fig. C21</td>
<td>Grosvenor Mine G200s – Predicted Profiles of Subsidence, Tilt and Curvature across Prediction Line 1</td>
<td></td>
</tr>
</tbody>
</table>
Drawings

Drawings referred to in this report are included in Appendix D at the end of this report.

<table>
<thead>
<tr>
<th>Drawing No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSEC830-01</td>
<td>General Layout</td>
</tr>
<tr>
<td>MSEC830-02</td>
<td>Surface Level Contours</td>
</tr>
<tr>
<td>MSEC830-03</td>
<td>Seam Floor Contours</td>
</tr>
<tr>
<td>MSEC830-04</td>
<td>Proposed Extraction Heights</td>
</tr>
<tr>
<td>MSEC830-05</td>
<td>Depth of Cover Contours</td>
</tr>
<tr>
<td>MSEC830-06</td>
<td>Base RL of Fresh Basalt</td>
</tr>
<tr>
<td>MSEC830-07</td>
<td>Fresh Basalt Thickness Contours</td>
</tr>
<tr>
<td>MSEC830-08</td>
<td>Base RL Weathering</td>
</tr>
<tr>
<td>MSEC830-09</td>
<td>Predicted Total Subsidence due to LW201 to LW208</td>
</tr>
</tbody>
</table>
1.0 INTRODUCTION

1.1. Background

Mine Subsidence Engineering Consultants (MSEC) was commissioned by Hansen Bailey on behalf of Anglo Coal (Grosvenor) Pty Ltd (the proponent) to complete a Subsidence Assessment for the G200s Project (the project). A referral for the project is being made under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and this Subsidence Assessment forms part of the Environmental Assessment Report (EAR) that has been prepared in support of the EPBC Act referral.

The project is located wholly within the existing mining lease for the Grosvenor Coal Mine (ML 70378), near Moranbah, Central Queensland (Figure 1.1). Figure 1.1 shows the area that is currently subject to underground longwall mining within the Grosvenor ML. This area is termed the “approved Grosvenor mining area” in this report. The project involves extending longwall mining into an area to the west of the approved Grosvenor mining area, in an area termed the G200s mining area (Figure 1.2). The G200s mining area is proposed to be developed and mined using equipment from the Grosvenor Mine, and the underground mining area will be accessed via the existing portals and drifts at the Grosvenor Mine. A single coal seam is proposed to be mined (the Goonyella Middle [GM] Seam), which is the same seam being mined at the Grosvenor Mine. Coal from the G200s mining area is proposed to be mined at a maximum coal production rate of 10.5 million tonnes per annum (Mtpa) run of mine (ROM).

The project will also make use of the Grosvenor Mine’s existing surface infrastructure, with no upgrades of the infrastructure required for the project. As per the arrangement at the Grosvenor Mine, coal from the project will be processed at the adjacent Moranbah North Mine (MNM).

Mining in the G200s mining area will extend the mine life of the Grosvenor Mine by approximately six years.
Fig. 1.1 Project Setting
Fig. 1.2  Project Layout

Courtesy Hansen Bailey
The Scope of Works for this mine subsidence impact assessment includes:-

a) Review relevant information on surface features that lie within the proposed underground mining areas.

b) Review available information on seam and overburden geology.

c) Provide a summary of available subsidence data from other Anglo American mines, particularly Moranbah North Mine.

d) Advise on the reliability of MSEC’s subsidence prediction model based on the subsidence data provided.

e) Undertake subsidence predictions for the project site.

Chapter 1 of this report provides a general introduction to the study, which also includes a description of the mining geometry and geological details of the proposed mining area.

Chapter 2 includes overviews of longwall mining, the development of mine subsidence and the methods used to predict mine subsidence movements. Descriptions of the uncertainties in subsidence predictions are also provided in this chapter.

Chapter 3 provides the maximum predicted subsidence parameters resulting from the extraction of the proposed longwalls.

1.2. Mining Geometry

The proposed layout of Longwalls 201 to 208 is shown in Drawing No. MSEC830-01 in Appendix D.

The widths of the longwalls are approximately 312 metres, rib to rib. The mine layout has been designed such that the orientation of the longwalls are slightly splayed relative to each other. Whilst the panel width remains constant, the widths of the chain pillars between the longwall panels vary according to the depth of the coal seam below the surface. The minimum chain pillar width is approximately 30 metres solid between Longwalls 206 and 207 at the southern end. The maximum chain pillar width is approximately 64 metres solid between Longwalls 201 and 101 at the northern end.

1.3. Surface Topography

The surface level contours in the vicinity of the proposed longwalls are shown in Drawing No. MSEC830-02 in Appendix D.

The surface topography within the project site consists of low-lying gently sloping plains of generally less than 2% gradient. The Isaac River is the regional drainage line in the area, which flows towards the southeast, directly above along the northern parts of Longwall 201 and 202.

The lowest points on the surface directly above the proposed longwalls are at 219 m AHD, in the base of the Isaac River directly above the proposed Longwall 201. The highest point is at approximately 253 m AHD above the proposed Longwall 208. The localised rises are associated with Tertiary basalt flows.

1.4. Seam Level Information

The discussion on geology provided in this section of the report and the following section is based on data gathered by the proponent as part of its exploration program.

The principal coal-bearing sequence at Grosvenor Mine is the Moranbah Coal Measures, which is extensively mined for prime quality coking coal in the northern Bowen Basin.

The target seam for the proposed longwalls is the Goonyella Middle (GM) seam. The GM seam floor contours, and depth of cover contours for the GM Seam are shown in Drawings Nos. MSEC830-03 and MSEC830-05, respectively in Appendix D.

The seam dips towards the northeast within the proposed mining area from an elevation of 140 m AHD to -158 m AHD. Given the relatively flat terrain and dipping seam, the depth of cover varies within the proposed mining area from approximately 100 metres in the southwestern corner of the project site above proposed Longwalls 205 to 207, to approximately 380 metres in the northeastern corner of the project site above proposed Longwall 201.

The proposed extraction heights within the target seam are shown in Drawing No. MSEC830-04 in Appendix D. The proposed extraction heights of the Goonyella Middle Seam vary between a minimum of 3.4 metres and a maximum of 4.3 metres.
1.5. **Overburden Geology**

The project site lies within the Bowen Basin in central Queensland. The Grosvenor deposit lies on the north-western flank of the Permo-Triassic Bowen Basin. Elements of two major coal bearing formations, both of Late Permian age, are present in the area, these being the Moranbah Coal Measures and overlying Fort Cooper Coal Measures. Accumulation of these coal measures occurred within a major southerly flowing fluvial system, supplied from uplifted source terrains to the west, north and east.

The Moranbah Coal Measures are regarded as fluvial and fluvi-o-deltaic in origin and formed in an upper delta plain depositional environment. A similar depositional environment is suggested for the Fort Cooper Coal Measures, although the highly tuffaceous and volcanic lithic nature of this unit reflects resurgent volcanism in the east during deposition. The Fort Cooper Coal Measures overlie the Moranbah Coal Measures and consists of strong sandstone, siltstone, siltstone, shale and coal bands. While sedimentation in the northern Bowen Basin continued through to the mid-Triassic, the Triassic and uppermost Permian rock units sub-crop to the east of the project site.

The overburden stratigraphy within the project site is shown on Fig. 1.3 and comprises:

- Quaternary alluvium associated with the present day Isaac River channel and its floodplain;
- Tertiary sediments comprising the Suttor Formation, colluvial deposits and regolith associated with weathering of the underlying Permian strata;
- Tertiary basalt associated with paleochannels in the underlying Permian strata;
- Tertiary basal sands comprising localised deposits of unconsolidated sediments associated with paleochannels in the underlying Permian strata;
- The Permian Fort Cooper Coal Measures; and
- The Permian Moranbah Coal Measures.

The Quaternary alluvium comprises unconsolidated sand, gravel and clay. Within the present day Isaac River channel, the Quaternary alluvium is typically up to 5 metre thick and dominated by sand and gravels. River terrace and floodplain deposits are typically thicker (up to 23 metres on the river terraces) and are more heterogeneous due to the presence of clay and silt. The Quaternary deposits are absent beyond the floodplain of the Isaac River and its major tributaries.

The surface geology within the remainder of the project site comprises up to 72 metres of Tertiary sediments. The Tertiary Suttor Formation comprises a heterogeneous profile of semi-consolidated quartz sandstone, clayey sandstone, mudstone and conglomerate; fluvial and lacustrine sediments; minor interbedded basalt. The Suttor Formation has been extensively weathered and reworked during the Tertiary period resulting in a regolith profile and colluvial sheetwash deposits that comprise clay, silt, sand and gravel.

Tertiary basalt underlies the Tertiary sediments and overlies weathered Permian sediments at the project site and typically occurs as a single composite unit comprising massive and vesicular lava, tuff and ash flows. Within the project site, the basalt flows are thickest within the paleochannel of the Isaac River where they are up to 102 metres thick. The upper 0 to 55 metres of the basalt profile is highly weathered and comprises a basaltic clay. The weathered Tertiary basalt outcrops in the southeast of the project site. Contours of combined thickness of fresh basalt are shown in Drawing No. MSE830-07, where it can be seen that the maximum overall thickness of fresh basalt is 65 metres above Longwall 202.

The Tertiary basalt is underlain by highly localised deposits of Tertiary alluvium that was present within the paleochannels at the time the basalt flows occurred. The Tertiary alluvium comprises medium to coarse grained sand and is informally referred to as Tertiary basal sand due to its association with the base of the basalt unit. Where present, the Tertiary basal sand is less than 5 m thick and laterally discontinuous.

The Fort Cooper Coal Measures form the younger Permian profile at the project site and conformably overlie the older Moranbah Coal Measures. The Fort Cooper Coal Measures comprise interbedded mudstone, sandstone, conglomerate, shale, tuff and coal of the Fair Hill Formation. The base of the Fort Cooper Coal Measures is delineated by the Fair Hill seam which sub-crops within the project site. The Fort Cooper Coal Measures reach a maximum thickness of approximately 200 metres within the east of the project site.

The underlying Moranbah Coal Measures comprise thin to massive sandstones, siltstones, interlaminated siltstone and sandstone units, mudstones and a number of coal seams. The Moranbah Coal Measures subcrop approximately 2 km west of the project site and dip to the east. The Moranbah Coal Measures are approximately 250 metres thick in the west of the project site, and reach 300 metres thick in the east of the project site.

The target coal seam is the Goonyella Middle (GM) seam which is 4.5 to 5.5 metres thick at the project site, splitting and thinning towards the southeast. The GM seam is located at a depth of 80 to 390 metres within the G200s mining area, and 100 to 380 m above the G200s longwall panels. Other economic coal seams in the Moranbah Coal Measures include Q seam, P Seam, Harrow Creek, and Dysart coal seams. A tuffaceous claystone interval known as the P Tuff provides a useful marker horizon within the Moranbah Coal Measures, and it occurs between the P seam and the GM seam. The P Tuff is generally located within 70 metres of the roof of the GM seam.
The thickness of cover between the target GM seam and the base of the weathered Permian rock varies from 40 metres to 340 metres. Elevation contours at the base of the Permian weathering profile (i.e. rockhead) are shown in Drawing No. MSEC830-08.

Fig. 1.3  Permian-Triassic Stratigraphy of the Northern Bowen Basin
2.1 Introduction

This chapter provides a brief overview of longwall mining, the development of mine subsidence and the methods that have been used to predict the mine subsidence movements resulting from the extraction of the proposed longwalls.

2.2 Overview of Longwall Mining

Longwall mining is a method used to extract large rectangular panels (i.e. blocks) of coal, typically 150 metres to 400 metres wide and 1 kilometre to 6 kilometres long. The coal is progressively mined by a shearer that shaves off slices of coal up to 1 metre thick from the longwall face, under the protection of hydraulic supports, until all the panel is fully extracted. While the technology has changed considerably over the years, the basic idea of longwall mining is to maintain a safe working space for the miners along a wide coal face whilst removing all of the coal and allowing the roof and overlying rock to collapse into the void behind. The G200s Project proposes to extract coal using longwall mining techniques.

Firstly a large rectangular panel or pillar is initially formed using continuous miners or road headers. Gate roads are first driven all around the large rectangular pillar before longwall mining begins. The gate road along one long side of the panel is called the maingate where fresh air and mine workers are carried to the face and the extracted coal is conveyed along conveyors. The gate road on the other side of the panel is called the tailgate where air is carried away from the face and also provides a secondary means of egress.

It takes two longwall development heading panels to delineate the first longwall block. Thereafter, only one set of longwall gateroads needs to be driven for each new adjacent longwall panel because the new panel also makes use of one of the gateroads left over from the previous panel. The interpanel pillars that separate each gateroad are known as chain pillars. The formation of the gateroads are called first workings and as they are supported against collapse, their extraction results in no measureable subsidence at the surface.

A longwall consists of a number of hydraulic jacks (called powered roof supports, chocks or shields) that provide support to the roof along the coalface at one end of the longwall panel. Each chock or shield is typically 1.75 metres wide and the supports are placed in a long line, side by side, for the full width of the coal face. An individual support can weigh 30 tonnes to 40 tonnes, extend to a maximum cutting height of up to 6 metres and can support 1,000 tonnes to 1,250 tonnes of the overlying strata weight. Each chock can hydraulically advance itself around 1 metre forward after each slice of coal is extracted.

![Figure 2.1](image-url)"
Fig. 2.2  An Operating Longwall Face

Note: The following features can be seen: coal seam under extraction, the coal shearer, the face conveyor and system of self-advancing hydraulic roof supports (‘chocks’ or ‘shields’).

The coal is cut in slices from the coalface by a shearer and the coal falls onto an armoured face conveyor (AFC), which is placed in front of the powered roof supports, and carries the coal from the longwall face to the maingate. From here it is loaded onto a network of conveyor belts for transport to the surface. At the maingate, the coal is often reduced in size in a crusher and loaded onto the first conveyor belt by the beam stage loader (BSL). As the shearer removes the coal, the AFC is snaked over behind the shearer and the powered roof supports move forward into the newly created cavity.

As the longwall face progresses through the seam, the overlying roof strata falls into the mined void (goaf) and the subsidence process of the overburden strata commences. The collapsed roof strata comprises loose blocks and can contain large voids depending on the loading and compaction that follows. Immediately above the mined void and the collapsed zone, the strata can remain relatively intact and bends into the void, resulting in new vertical fractures, opening up of existing vertical fractures and bed separation. The strata layers above that bend and shear with the amount of strata sagging, fracturing and bed separation reducing towards the surface.

The basic idea behind longwall mining was developed many years ago, but it has only been in the last thirty years that mining equipment has become powerful and reliable enough to successfully and safely extract large longwall blocks. Safety, productivity and cost considerations dictate that longwall mining is now the major, viable, high production method of coal mining adopted in the majority of Australian underground coal mines that operate at depths greater than about 300 metres.

Longwall mining has a better level of resource recovery when compared to older methods of extraction, such as the bord and pillar extraction method. It has less need for roof support consumables, has higher volume coal clearance systems and has minimal manual handling. In addition, the safety of the miners is enhanced by the fact that they are always under the hydraulic roof supports when they are extracting coal.
2.3. Overview of Subsidence Parameters

The ground movements resulting from the extraction of pillars or longwalls are described by the following parameters:-

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of millimetres (mm).

- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of millimetres per metre (mm/m). A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.

- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of 1/kilometres (km\(^{-1}\)), but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in kilometres (km).

- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of millimetres per metre (mm/m). **Tensile Strains** occur where the distance between two points increases and **Compressive Strains** occur when the distance between two points decreases. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

Whilst mining induced normal strains are measured along monitoring lines, ground shearing can also occur both vertically and horizontally across the directions of monitoring lines. Most of the published mine subsidence literature discusses the differential ground movements that are measured along subsidence monitoring lines, however, differential ground movements can also be measured across monitoring lines using 3D survey monitoring techniques.

- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is not possible, however, to determine the horizontal shear strain across a monitoring line using 2D or 3D monitoring techniques.

High deformations along monitoring lines (i.e. normal strains) are generally measured where high deformations have been measured across the monitoring line (i.e. shear deformations) and vice versa.

A cross-section through a typical single longwall panel showing typical profiles of subsidence, tilt, curvature and strain is provided in Fig. 2.3.

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**Fig. 2.3** Typical Profiles of Subsidence Parameter for a Single Longwall Panel
The incremental subsidence, tilts, curvatures and strains are the additional parameters which result from the extraction of each longwall. The total subsidence, tilts, curvatures and strains are the final parameters at the completion of a series of longwalls. The travelling tilts, curvatures and strains are the transient movements as the longwall extraction face mines directly beneath a given point.

Typical subsidence, tilt, curvature and strain profiles as shown in Fig. 2.3 are smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata spanning the extracted void. Typical subsidence movements due to longwall extraction are easy to identify where longwalls are regular in shape, the extracted coal seams are relatively uniform in thickness, the geological conditions are consistent and surface topography is relatively flat.

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near surface strata layers. At shallow depths of cover (e.g. less than 100 metres), the observed subsidence profiles along monitoring lines can often become irregular with much higher localised tilts, curvatures and strains because the collapsed zone above the extracted longwalls can extend up to or near to the surface. As the depth of cover increases, the frequency of irregular movements reduces. When mining occurs at depth (e.g. depths of cover greater than 400 metres), the observed subsidence profiles along monitoring survey lines are generally smooth. Irregular subsidence movements are only occasionally observed due to localised behaviour of near surface strata.

### 2.4. Methods of Predicting Subsidence

The magnitude of the maximum vertical subsidence at the surface will vary depending on a number of factors including the longwall panel and pillar widths, the chain pillar stability, the presence of nearby previously extracted mined panels, the depth of cover, the extracted seam thickness, the geology of the strata layers between the surface and coal seam and on the geology of the strata layers in the floor below the seam.

The maximum subsidence observed normally where there are strong and massive conglomerate and sandstone strata units present, is typically between 55% and 60% of the extracted seam thickness, for single seam extractions, which is lower than the 65% of the extracted seam thickness for overburdens where there are fewer massive strong units. These maximum subsidence percentages would be observed wherever the widths of the panels are super-critical, i.e. greater than 1.4 times the depths of cover. Lower levels of subsidence are generally observed where the panels are sub-critical and where unmined coal is left in chain pillars.

Techniques for predicting surface subsidence effects can be classified under three categories, namely empirical, analytical/numerical and hybrid methods. Empirical techniques are based on the back analysis of previous field outcomes. Reliability of outcomes is dependent, therefore, on the overall size and representativeness of the database and considerable care is required if the techniques are applied to conditions that are outside of this database. The more common empirical prediction methods are:

- **Graphical**, which involves plotting suites of curves showing relationships between various parameters and subsidence outcomes;
- **Upper Bound**, which involves constructing an envelope over measured maximum or worse case outcomes and predicting on the basis of that envelope;
- **Profile Function**, which attempts to define the shape of the vertical displacement curve by a mathematical equation and is confined in general to single (isolated) excavations; and
- **Incremental Profile Method**, which involves constructing the overall vertical displacement profile by summing the incremental vertical displacement that occurs each time a panel is extracted.

Analytical techniques are based on applying mathematical solutions derived from first principles to calculate how the rock mass will behave when an excavation is made within it. Most of the mathematical formulae have been known for decades; however, until the advent of computers, they could only be solved for very simple, two dimensional mining layouts. Advances in computational power now enables more complex mathematical equations to be solved, thereby enabling more detailed mining layouts, geological and geotechnical conditions and ground behaviour mechanisms to be analysed. Such analysis has now come to be known as mathematical modelling, numerical analysis or computer modelling. No one mathematical model is currently capable of fully describing rock behaviour and so numerical models still require a database for calibration purposes.

A number of techniques are capable of producing reasonably accurate predictions of vertical subsidence displacement, typically within ±150 mm. The more noteworthy of these are the Incremental Subsidence Prediction technique, the Influence Function technique and a number of numerical modelling codes. The accuracy of any subsidence prediction technique depends to some extent on input parameters being representative of the specific site conditions. Particular care has to be taken when predicting subsidence for a greenfield site due to a lack of site specific data. A number of panels need to be extracted before subsidence prediction models can be properly calibrated and validated.

In this case, the observations from the nearby Moranbah North Mine (MNM) provide valuable site specific subsidence data from which predictions for the project can be made with confidence.
2.5. The Incremental Profile Method

The predicted subsidence parameters for the proposed longwalls were determined using the Incremental Profile Method, which was developed by MSEC, formerly known as Waddington Kay and Associates. The method is an empirical model based on a large database of observed monitoring data that essentially involves two steps; first the prediction of incremental subsidence profiles over each longwall based on many parameters, including: the local seam thickness; the incremental panel and pillar widths; the presence of adjacent previously mined panels; and the local depths of cover. The second step is the addition of all the incremental subsidence profiles to form the total subsidence profiles over the series of longwalls.

It has been shown, by predicting the subsidence movements using this two step process, that more accurate and more site specific subsidence parameters can be derived than otherwise obtained using methods that attempt to predict the total subsidence profiles in one step.

The empirical database that has been used to develop and calibrate the IPM model includes mine subsidence ground monitoring data from collieries within the Bowen Basin, including Grasstree, Kestrel, Moranbah North, Cook and Carborough Downs. The database also consists of detailed ground monitoring data from collieries in NSW, including Angus Place, Appin, Baal Bone, Bellambi, Beltana, Blakefield South, Bulli, Chain Valley, Clarence, Coalgill, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Eastern Main, Ellalong, Fernbrook, Glennies Creek, Greta, Invincible, John Darling, Kemira, Lambton, Liddell, Mandalong, Metropolitan, Mt. Kembla, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, South Bulga, South Bulli, Springvale, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

The Incremental Profile Method is based upon a large database of observed subsidence movements and has been found, in most cases, to give reasonable, if not, conservative predictions of maximum subsidence, tilt and curvature. The method was accepted by the NSW government inquiry report titled “The Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield - Strategic Review”, prepared by the NSW Department of Planning (DOP, 2008), where it stated “This prediction technique offers a number of benefits over other empirical techniques because variations in depth, seam thickness and seam dip can be taken into account, as well as the influence of multiple mining panels - and subsidence predictions can be produced at any nominated point on the surface.”

2.6. Testing and Calibration of the Incremental Profile Method at Moranbah North Mine

The standard prediction curves used by the Incremental Profile Method have previously been tested and calibrated against observed subsidence data from the nearby MNM. The findings at MNM are relevant to the G200s Project because the mined panels at MNM are directly adjacent to the G200s mining area, the target seam is the same and the overburden is similar. The locations of monitoring lines are shown in Fig. 2.4. The location of the G200s Project relative to MNM is shown in Figure 1.1.
Fig. 2.4   Location of monitoring lines relative to extracted longwalls at Moranbah North Mine
The predictions were initially made using MSEC’s standard prediction curves that have been previously calibrated based on observed subsidence data from the Northern (Newcastle and Hunter) Coalfields in NSW. The Newcastle and Hunter Coalfields, north of Sydney, were chosen as the depth of cover and geology are reasonably similar to the depth of cover and geology at MNM.

Overall, it was found that there was a reasonable correlation between both the general shapes of the observed and predicted subsidence profiles and the magnitudes of the observed and predicted maximum subsidence and tilt at MNM. It was noted, however, that the observed subsidence profiles at MNM were slightly wider than the initial predicted profiles and it was decided to make some minor adjustments to the predicted profiles to improve the correlation between predicted and observed subsidence profiles at MNM.

The reasons for the slight differences between the observed subsidence profile shapes at MNM and typical observed subsidence profiles in the Northern Coalfields of NSW may be associated with slight differences in the sandstone overburden geology, as noted by Gale (ACARP C13013, 2008) and Mills et al (2009), and/or the presence of a shale overburden immediately above the seam at MNM, and/or the presence of Quaternary and Tertiary deposits on the surface, and/or differences in the design of the chain pillars.

While there was a difference in location between predicted and observed profiles, there was a reasonable correlation between predicted and observed maximum tilts. In some cases, observed maximum tilts were greater than predicted maximum tilts, and in other cases, observed maximum tilts were less than predicted maximum tilts. The differences were, however, relatively small.

While a similar observation was made when comparing predicted and observed curvatures, a greater variation existed. This was considered to be due in part to survey limitations at MNM, which is significant for peg spacings of 10 metres. It may also have been due to the influence of small bumps or steps in the observed subsidence profiles, which were visually observed in the ground surface.

In light of the above findings, the prediction curves used in the Incremental Profile Method for the G200s Project were adjusted based on subsidence data collected from MNM. The purpose of the adjustment was to improve the accuracy of the predictions, particularly along the sides of each panel, and increase the degree of conservatism. When compared to our standard prediction curves, the calibrated curves are wider and greater in magnitude.

A comparison between predicted and observed subsidence profiles after calibration along each of the monitoring lines at MNM is shown in Appendix C in Fig. C01 to C20. A summary graph showing predicted and observed subsidence at each survey peg is shown in Fig. 2.5. It can be seen that predicted subsidence is generally more conservative than the observed subsidence, though there are some exceedences in some cases. It is noted that slightly more subsidence has been observed above the chain pillars than predicted at some locations, particularly in locations of deeper cover.

Recent high accuracy surveys during the extraction of MNM Longwalls 601 and 602 have shown that there is a good correlation between predicted and observed subsidence, as shown in Fig. 2.6 and Fig. 2.7.
Fig. 2.5 Comparison between Observed and Predicted Subsidence at Moranbah North Mine after calibration.
Fig. 2.6 Predicted and Observed Subsidence along Centreline of MNM LW601

Fig. 2.7 Predicted and Observed Subsidence along Centreline of MNM LW602
2.7. Investigation of potential influence of fresh basalt on subsidence behaviour

Fresh basalt is present in the overburden above the central portions of the proposed longwalls. Information on the depth of the fresh basalt floor from the surface, and thickness of the fresh basalt was provided by the proponent and has been reproduced in Drawing Nos. MSEC830-06 and MSEC830-07. Over much of the G200s mining area, the combined maximum logged thickness of the basalt is less than 30 m, or basalt is not present. The basalt is, however, thicker across the central portions of the G200s mining area, extending to a maximum thickness of 65 m above Longwall 202. In areas where basalt is present, the combined thickness of the fresh basalt layer generally comprises two homogeneous or massive fresh basalt layers of about 25 metres thickness that were separated by either a weathered basalt layer, or a peat layer, or a mudstone layer. The maximum measured thickness of intact basalt from borehole logs is 45 metres.

The presence of a potentially very strong and stiff rock mass within the overburden and close to the surface may influence the magnitude and nature of vertical subsidence movements on the surface. If the overlying basalt is capable of spanning the mined void width, it is possible that reduced vertical subsidence would be observed in those areas. A literature search has found, for example, that dolerite sills with exceptional strength have reduced or delayed subsidence behaviour in South Africa (Deats, 1971, Galvin, 1981, Wagner and Shümann, 1991). In these cases it was found that dolerite sills with thicknesses greater than 30 to 40 metres can span several hundred metres, resulting in significantly reduced or delayed subsidence.

Although the literature indicates that there is some potential for the presence of basalt to influence subsidence, this has not been observed at MNM. A number of longwall panels have been mined at MNM in areas where layers of fresh basalt up to 20 metres were present. There does not appear to be any significant difference in the monitored subsidence behaviour at MNM between areas where fresh basalt is located and areas where it is not located. Given the experience at MNM, it is considered that the fresh basalt layers above the proposed G200s longwalls are unlikely to result in reduced subsidence and/or large steps or cracks in localised areas above any interface between areas with and without thick, fresh basalt.

The G200s subsidence prediction model has therefore not been adjusted to reflect the presence of the basalt. This represents a conservative approach to the subsidence modelling in terms of predictions of vertical subsidence (i.e. the subsidence predictions may slightly over-predict subsidence). In the event of any localised stepping or cracking occurring due to the presence of the basalt, these effects could be remediated in a manner similar to the remediation undertaken for buckling or tension cracking. Further detail on buckling and tension cracking is provided in the report prepared by Gordon Geosciences Pty Ltd.

2.8. Predicted Strains

The prediction of strain is more difficult than the predictions of subsidence, tilt and curvature. The reason for this is that strain is affected by many factors, including curvature and horizontal movement, as well as local variations in the near surface geology, the locations of pre-existing natural joints at bedrock, and the depth of bedrock. Survey tolerance can also represent a substantial portion of the measured strain, in cases where the strains are of a low order of magnitude. The profiles of observed strain, therefore, can be irregular even when the profiles of observed subsidence, tilt and curvature are relatively smooth.

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the tensile and compressive strains. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones, as shown from recently measured high accuracy survey data measured during the mining of Longwall 601 (refer Fig. 2.6) and Longwall 602 (refer Fig. 2.7). Based on this information, it has been found that a factor of 20 provides a reasonable relationship between the maximum predicted curvatures and the maximum observed strains at this depth of cover.

2.9. Reliability of the Predicted Subsidence Parameters

The Incremental Profile Method has been tested and calibrated against observed monitoring data at MNM. The reliability of predictions of maximum subsidence is demonstrated by the consistent observation that predictions of maximum subsidence above longwall panels at MNM are conservative when compared to measured values. It also has been found that there is a reasonable correlation between observed and predicted subsidence profiles, where the prediction model generally produces conservative results.

As demonstrated in the above sections and attached figures, some variations will occur between predicted and observed movements at specific points on the surface, particularly for predictions of ground strain for the reasons discussed in Section 2.8. The Incremental Profile Method approach nevertheless allows appropriate site specific predictions of subsidence, tilt and strains to be provided for each natural feature or item of infrastructure. It provides a more realistic assessment of the mining induced impacts than by predicting the maximum predicted parameters at every point, which would be overly conservative and would yield an excessively overstated assessment of the potential subsidence impacts.
3.0 PREDICTED SUBSIDENCE PARAMETERS FOR THE PROPOSED LONGWALLS

3.1. Introduction

The following sections provide the maximum predicted subsidence parameters resulting from the extraction of the proposed G200s Longwalls 201 to 208 in the Goonyella Middle Seam.

The predicted total subsidence contours, resulting from the extraction of Longwalls 201 to 208, are shown in Drawing No. MSEC830-09, in Appendix D. A cross-section showing predicted profiles of subsidence, tilt and curvature due to the extraction of Longwalls 201 to 208 is provided in Fig. C21, which is included in Appendix C.

The subsidence, tilt and curvature have been obtained using the Incremental Profile Method, with prediction curves that have been calibrated based on observed subsidence data from the nearby Moranbah North Mine, as described in Section 2.6.

The proposed G200s longwall panels are a continuation in sequence from the adjacent G100 longwall panels at Grosvenor Mine. The predictions for the G200s longwall panels take into account the influence of the G100 longwall panels as if they have already been mined and take into account adjacent longwall panels at MNM.

3.2. Maximum Predicted Subsidence, Tilt, Curvature and Strain

The maximum predicted vertical subsidence, resulting from the extraction of the proposed Longwalls 201 to 208, is 3300 mm, which represents around 77 % of the maximum extraction height of 4.3 metres.

The maximum predicted tilt is approximately 100 mm/m (i.e. 10 %), which represents a change in grade of 1 in 10. The maximum predicted curvatures are both approximately 6 km⁻¹, which represents a minimum radius of curvature of less than 170 metres.

It can be seen from Drawing No. MSEC830-09 that surface areas with predicted subsidence at the higher end of the predicted range are located where proposed extraction heights are greatest. The location of maximum subsidence is above the southern end of Longwall 206, where both the proposed extraction height is greatest and the depth of cover is the shallowest. Predicted subsidence generally reduces for surface areas where the depths of cover are greater, or proposed extraction heights are reduced, such as above the northern end of Longwall 201, where it can be seen that maximum subsidence is approximately 2000 mm. For the same reason, predicted tilts and curvatures above longwalls at deeper cover are reduced compared to the predicted maxima.

The predicted subsidence parameters vary across the project site as the result of, amongst other factors, variations in the longwall geometry, depths of cover and extraction heights. To illustrate this variation, the predicted profiles of subsidence, tilt and curvature have been determined along Prediction Line 1, the location of which is shown in Drawing No. MSEC830-09, and the results of which are shown in Fig. C21, in Appendix C.

The maximum strains are predicted to be greater than 30 mm/m. The maximum predicted strains occur in the southern part of the proposed G200s mining area, where the depths of cover are the shallowest. Elsewhere, the predicted strains are less as the depths of cover are greater. The predicted strains in the north-eastern part of the mining area, based on applying a factor of 20 to the predicted curvatures in this area, are in the order of 6 to 10 mm/m tensile and compressive, respectively.

3.3. Predicted Limit of Subsidence

The limit of subsidence is generally used to define a boundary outside of the proposed mining area where vertical subsidence is negligible. The angle at which the subsidence spreads out towards the limit of subsidence, at the surface, is referred to as the angle of draw.

It is generally accepted that subsidence of less than 20 mm will have negligible effect on surface features and this is generally adopted as the cut-off point for determination of the limit of subsidence. The value of 20 mm has also been adopted in recognition that surface soils naturally shrink and swell on a seasonal basis in response to changes in moisture. In reality, ground surveys have demonstrated natural seasonal variations at magnitudes less than and greater than 20 mm, but this value has generally been accepted as a reasonable figure.

The observed values of angle of draw vary and it appears to depend upon a number of factors including; the strength and properties of the strata layers, the in-situ horizontal stress in the various strata layers, the magnitude of the mining induced subsidence, the dip of the strata layers and the depth of cover to the coal seam. Observed angles of draw are typically between 10 and 35 degrees from the vertical, depending on how the limit of subsidence is defined. Unfortunately some of the variations in the observed angles of draw have resulted from differences in survey tolerances, where survey methods have typically been designed for the purposes of measuring large scale subsidence movements directly above longwall panels.

An analysis of the available subsidence monitoring data at MNM has been undertaken to check on the reliability of the Incremental Profile Method. The average angle of draw at MNM was 28 degrees, which compares reasonably well with, but is slightly higher than the generally accepted angle of draw of 26.5 degrees.
The subsidence data included observations during the mining of Longwalls 101 to 110. A comparison between the locations of observed 20 mm subsidence and the predicted 20 mm subsidence contour are shown in Fig. 3.1. It can be seen that a reasonable correlation was found.

It is therefore concluded that determining a limit of subsidence using the predicted 20 mm subsidence contour provides a reasonable prediction of the limit of subsidence. If the predicted location of the limit of subsidence is exceeded, the amount of subsidence at these offset distances will remain very small and well below a magnitude that would result in subsidence impacts on the surface.

As shown in Fig. 3.2, the predicted limit of subsidence for the proposed G200s longwall panels is located within the Grosvenor mining lease.

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Fig. 3.1  Comparison between locations of observed and predicted 20 mm subsidence at Moranbah North Mine
Fig. 3.2  Predicted limit of subsidence relative to Grosvenor Mining Lease
4.0 CONCLUSION

Mine Subsidence Engineering Consultants (MSEC) was commissioned by Hansen Bailey on behalf of Anglo Coal (Grosvenor) Pty Ltd (the proponent) to complete a Subsidence Assessment as part of the Environmental Assessment Report (EAR) for the G200s Project (the ‘project’).

The project involves the extension of longwall mining into the western portion of the Grosvenor Mining Lease into an area termed the G200s mining area. Longwalls 201 to 208 are proposed to be extracted in the Goonyella Middle (GM) seam. The extraction panels are proposed to be 312 metres wide, rib to rib.

The seam dips towards the northeast within the proposed mining area by approximately 300 metres in elevation. Given the relatively flat terrain and dipping seam, the depth of cover varies within the proposed mining area from 100 metres in the southwestern corner of the project site to 380 metres in the northeastern corner. The proposed extraction height of the Goonyella Middle Seam is a minimum of 3.4 metres and a maximum of 4.3 metres.

Predictions of subsidence, tilt and curvature have been obtained using the Incremental Profile Method, with prediction curves that have been calibrated based on observed subsidence data from the nearby Moranbah North Mine (MNM).

The predicted subsidence parameters vary across the project site as the result of, amongst other factors, variations in longwall geometry, depths of cover and extraction heights. The maximum predicted vertical subsidence, resulting from the extraction of the proposed Longwalls 201 to 208, is 3300 mm, which represents around 77% of the maximum extraction height of 4.3 metres. The predicted limit of subsidence is located within the project site.

The maximum predicted tilt is 100 mm/m (i.e. 10%), which represents a change in grade of 1 in 10. The maximum predicted curvatures are both approximately 6 km⁻¹, which represent a minimum radius of curvature of less than 170 metres. The maximum strains are predicted to be greater than 30 mm/m.

The maximum predicted tilts, curvatures and strains occur in the southern part of the mining area, where the depths of cover are the shallowest. Elsewhere, the predicted differential movements are less as the depths of cover are greater.
APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS
Glossary of Terms and Definitions

Some of the more common mining terms used in the report are defined below:

**Angle of draw**  
The angle of inclination from the vertical of the line connecting the goaf edge of the workings and the limit of subsidence (which is usually taken as 20 mm of subsidence).

**Chain pillar**  
A block of coal left unmined between the longwall extraction panels.

**Critical area**  
The area of extraction at which the maximum possible subsidence of one point on the surface occurs.

**Curvature**  
The change in tilt between two adjacent sections of the tilt profile divided by the average horizontal length of those sections, i.e. curvature is the second derivative of subsidence. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of 1/kilometres (km-1), but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in kilometres (km). Curvature can be either **hogging** (i.e. convex) or **sagging** (i.e. concave).

**Depth of Cover (H)**  
The depth from the surface to the top of the seam. Cover depth is normally provided as an average over the area of the panel.

**Extracted seam**  
The thickness of coal that is extracted. The extracted seam thickness is thickness normally given as an average over the area of the panel.

**Effective extracted seam thickness (T)**  
The extracted seam thickness modified to account for the percentage of coal seam left as pillars within the panel.

**Face length**  
The width of the coalface measured across the longwall panel.

**Goaf**  
The void created by the extraction of the coal into which the immediate roof layers collapse.

**Horizontal displacement**  
The horizontal movement of a point on the surface of the ground as it settles above an extracted panel.

**Incremental subsidence**  
The difference between the subsidence at a point before and after a panel is mined. It is therefore the additional subsidence at a point resulting from the excavation of a panel.

**Panel**  
The plan area of coal extraction.

**Panel length (L)**  
The longitudinal distance along a panel measured in the direction of (mining from the commencing rib to the finishing rib.

**Panel width (Wv)**  
The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side.

**Panel centre line**  
An imaginary line drawn down the middle of the panel.

**Pillar**  
A block of coal left unmined.

**Pillar width (Wpi)**  
The shortest dimension of a pillar measured from the vertical edges of the coal pillar, i.e. from rib to rib.

**Point of Inflection**  
The point on the subsidence profile where the profile changes from a convex curvature to a concave curvature. At this point the strain changes sign and subsidence is approximately one half of S max.
The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including: horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.

Shear deformations

The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation.

Strain

Tensile Strains are measured where the distance between two points or survey pegs increases and Compressive Strains where the distance between two points decreases. Whilst mining induced strains are measured along monitoring lines, ground shearing can occur both vertically, and horizontally across the directions of the monitoring lines.

Sub-critical area

An area of panel smaller than the critical area.

Subsidence

The vertical movement of a point on the surface of the ground as it settles above an extracted panel, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of millimetres (mm). Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured.

Super-critical area

An area of panel greater than the critical area.

Tilt

The change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the horizontal distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of millimetres per metre (mm/m). A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
APPENDIX B. REFERENCES


