Mine Subsidence Impact Study
for the
Rezoning of Maldon Employment Lands

Report Revisions				
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Executive Summary

Wollondilly Shire Council (Council) is investigating the potential impacts and environmental issues associated with the proposed rezoning of rural lands for employment uses at Maldon. The lands in question are shown in Drawing No. MSEC477-01, which is attached in Appendix F, together with all other drawings referred to in this report. The lands are referred to as the Maldon Employment Lands.

Council has invited the assistance of consultants for the preparation of specialist studies to enable Council to prepare a draft Local Environmental Plan to support the application to the Department of Planning for the rezoning of the lands.

Council commissioned Mine Subsidence Engineering Consultants Pty Ltd (MSEC) in December 2010 to carry out a study into the potential impacts of mine subsidence on the Maldon Employment Lands due to future extraction of coal resources from the Bulli Seam.

This report was prepared on completion of the study.

The proposed rezoning of the rural lands will be embodied in the Draft Wollondilly Local Environmental Plan 2011 (DWLEP 2011) - Amendment No.1. The Amendments are intended to apply to the land bounded by Picton Road and the Nepean River, as outlined in Drawing No. MSEC477-01.

Chapter 1 discusses the background to the Mine Subsidence Impact Study, the minimum required output and the agreed scope of works.

Chapter 2 discusses the geology of the area and the known coal resources.

The proposed Maldon Employment Lands are underlain by coal resources in the Bulli and Balgownie Seams. The Bulli Seam is currently being mined by BHP Billiton (BHPB) at Appin Colliery and the coal resources beneath the proposed Employment Lands are accessible from Appin Colliery and fall within the 30 year mining plans of BHPB. The Balgownie Seam is thin in this area and is unlikely to be mined.

The extent of the coal resources and the current mining plans of BHPB have been determined from drawings provided by BHPB.

The Bulli Seam lies at a depth which varies from approximately 450 metres to 510 metres below the surface in the study area, as indicated by the depth of cover contours in Drawing No. MSEC477-04. The depth of cover below the bed of the Nepean River is approximately 410 metres. The Bulli Seam contains valuable reserves of coking coal and varies in thickness from 1.95 metres to 2.2 metres, as indicated by the seam thickness contours in Drawing No. MSEC477-03.

Chapter 3 discusses the existing and future mining plans.

In the next few years, BHPB plans to mine additional longwalls in the Bulli Seam at Appin Colliery. Some of these longwalls are located directly beneath the site of the proposed Maldon Employment Lands and extend further to the northeast of the site. This section of the proposed mining plans of BHPB is the northern part of Area 8 and includes Longwalls 800 to 810. The southern part of Area 8 lies to the south of the site and includes Longwalls 811 to 827. The proposed Longwalls 800 to 802 lie beneath the proposed Maldon Employment Lands, as shown in Drawing No. MSEC477-01.

It should be noted that the proposed layout of longwalls beneath the proposed Maldon Employment Lands is only indicative at this stage. The final dimensions and layout of the longwalls will be determined when further exploration has been completed and when the mining conditions have been more clearly defined.

The longwall mining process and the development of subsidence are discussed in Appendix C. Methods of subsidence prediction are discussed in Appendix D

At this time, the final layout of any future longwalls beneath the proposed Maldon Employment Lands can only be conjectured, but it is almost certain that the resources would be extracted using longwall mining techniques similar to those that are now being used at Appin Colliery.

Since the mine layout has not been finally determined, it is only possible at this stage to make approximate subsidence predictions for the potential future longwalls, based upon the current mining proposals, which were indicated by BHPB Illawarra Coal in its recent Part 3A application for future mining in the area. On this basis, subsidence predictions have been made assuming that the future longwalls beneath the proposed employment lands would be 310 metres wide, with chain pillars between longwalls of 45 metres width.

Chapter 4 presents predicted subsidence parameters.

Figure 4.1 shows the predicted subsidence, tilt and strain profiles across Longwalls 800 to 804, based on longwalls, 310 metres in width, separated by chain pillars of 45 metres width, but with a pillar of 75 metres width between Longwalls 802 and 803 as indicated by BHPB in its conceptual mine plan.

It can be seen from Figure 4.1 that the predicted total subsidence, in the bottom of the subsidence trough, varies from approximately 600 mm to approximately 900 mm.

Figure 4.1 also shows the predicted total tilts and curvatures along the prediction line due to mining the series of longwalls.

The dashed lines show the predicted incremental tilts and curvatures due to mining the longwalls in sequence and the heavier blue lines show the predicted final total tilts and curvatures.

It can be seen that the maximum predicted tilts within the subsidence trough, due to mining Longwalls 800 to 804, lie generally between 2.0 mm/m and 4.0 mm/m, with a tilt at the edge of the subsidence trough of approximately 3.5 mm/m.

It can also be seen that the predicted maximum curvatures, due to mining Longwalls 800 to 804, lie generally between 0.06 km^{-1}, hogging, and 0.10 km^{-1}, sagging, i.e. 17 kilometres radius, hogging, and 10 kilometres radius, sagging.

The predicted maximum strain values given by the Incremental Profile Method for the Southern Coalfield are based upon an approximation that strain in mm/m is equal to 15 times curvature, where curvature is the reciprocal of the radius of curvature in kilometres. The maximum predicted strains, based on the maximum predicted curvatures are, therefore, 0.9 mm/m, tensile, and 1.5 mm/m compressive.

The final subsidence contours due to mining Longwalls 800 to 810 are shown in Drawing No. MSEC477-08.

Chapter 4 also discusses the likely design requirements of the Mine Subsidence Board and presents recommended mine subsidence design parameters for buildings and structures within the proposed Maldon Employment Lands as follows:

- Maximum vertical subsidence 900 mm
- Maximum tilt 6 mm/m
- Maximum tensile strain 2 mm/m
- Maximum compressive strain 2 mm/m
- Minimum radius of curvature 7.5 km

Chapter 5 identifies existing land uses and presents photographs of the main building structures on each property.

Chapter 6 discusses possible types of employment land use and comments on some of the less suitable uses, though most of the potential land uses would be acceptable.

The majority of building structures, assuming that they are properly designed and constructed, will be able to accommodate the predicted ground movements without any significant damage. Predicted tilting of the buildings up to 4 mm/m will not generally present any serviceability problems.

Predicted curvatures of 10 to 17 kilometres radius are well within the acceptable deflection ratios for the majority of building structures, as indicated in Table E 25 in Appendix E.

Similarly, predicted strains of up to 0.9 mm/m tensile and 1.5 mm/m, compressive, are unlikely to result in significant damage to industrial building structures used for employment purposes, particularly since much of the strain in the ground will be lost in the transfer to the building structure.

Some potential uses could, however, by sensitive to very small ground movements and should not be permitted unless special provisions are made in the design to accommodate the predicted movements. Examples of such uses are, radar systems, satellite antenna towers, turbines, high racking in warehouses, and some larger tanks.

Overhead crane rails are sensitive to tilts greater than 3 mm/m, but can be provided with adjustable supports to allow the rails to be relevelled as subsidence occurs.

Chapter 7 discusses building design guidelines for mine subsidence areas and provides some general recommendations for the design of the buildings, structures, equipment, plant and associated services and infrastructure within the proposed Maldon Employment Lands.

In summary, mining subsidence is a complex mechanism which varies from site to site and only when the mining layout and methods have been determined can the potential impact on a surface structure be fully analysed. The response of a building structure is also a complex mechanism which is dependent upon the form of the building and the materials used in its construction.

Design requirements are of necessity conservative and generally provide high factors of safety but the design of a building to resist subsidence also requires an understanding of the mechanism of subsidence and the three dimensional movements which are likely to occur. In some cases the building will be affected four or five times as panels of coal are extracted in sequence and the impact may continue for several years.

If buildings, structures, equipment, plant and associated services and infrastructure are carefully designed and detailed, the impact of mining subsidence upon them should generally be very small. Methods of assessing subsidence impacts are discussed in Appendix E.

Chapter 8 discusses possible development controls and concludes that, so long as all industrial buildings, structures, equipment, plant and associated services and infrastructure are designed in accordance with the recommended design parameters, there will be no reason to apply further controls on the development of the employment sites.

Some employment uses will, however, involve plant and equipment that is sensitive to ground movement and such plant and equipment will have to be designed so that the levels of the plant and equipment can be adjusted as subsidence occurs. Even some of the more sensitive structures, such as radar systems, satellite antenna towers, turbines, high racking systems and larger tanks can be designed in such a way that they can be adjusted in level as subsidence occurs.

Some employment uses have equipment that must be kept perfectly level and would be adversely affected even at low levels of tilt. A typical example is a carpet manufacturing facility in which a latex backing is applied to the back of the carpet to anchor the pile. This is achieved by passing the carpet over a tank of latex solution, which has to be kept perfectly level to avoid spillage from the tank. Such equipment can be designed with a provision for relevelling, so that the equipment can be adjusted as subsidence occurs.

Given that the predicted subsidence parameters are relatively low, any additional costs in designing future developments at Maldon to accommodate subsidence should not be excessive.

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CHAPTER 1 Mine Subsidence Impact Study

1.1 Introduction

Wollondilly Shire Council (Council) is investigating the potential impacts and environmental issues associated with the proposed rezoning of rural lands for employment uses at Maldon. The lands in question are shown in Figure 1.1 and in Drawing No. MSEC477-01, which is attached in Appendix F, together with all other drawings referred to in this report. The lands are referred to as the Maldon Employment Lands.

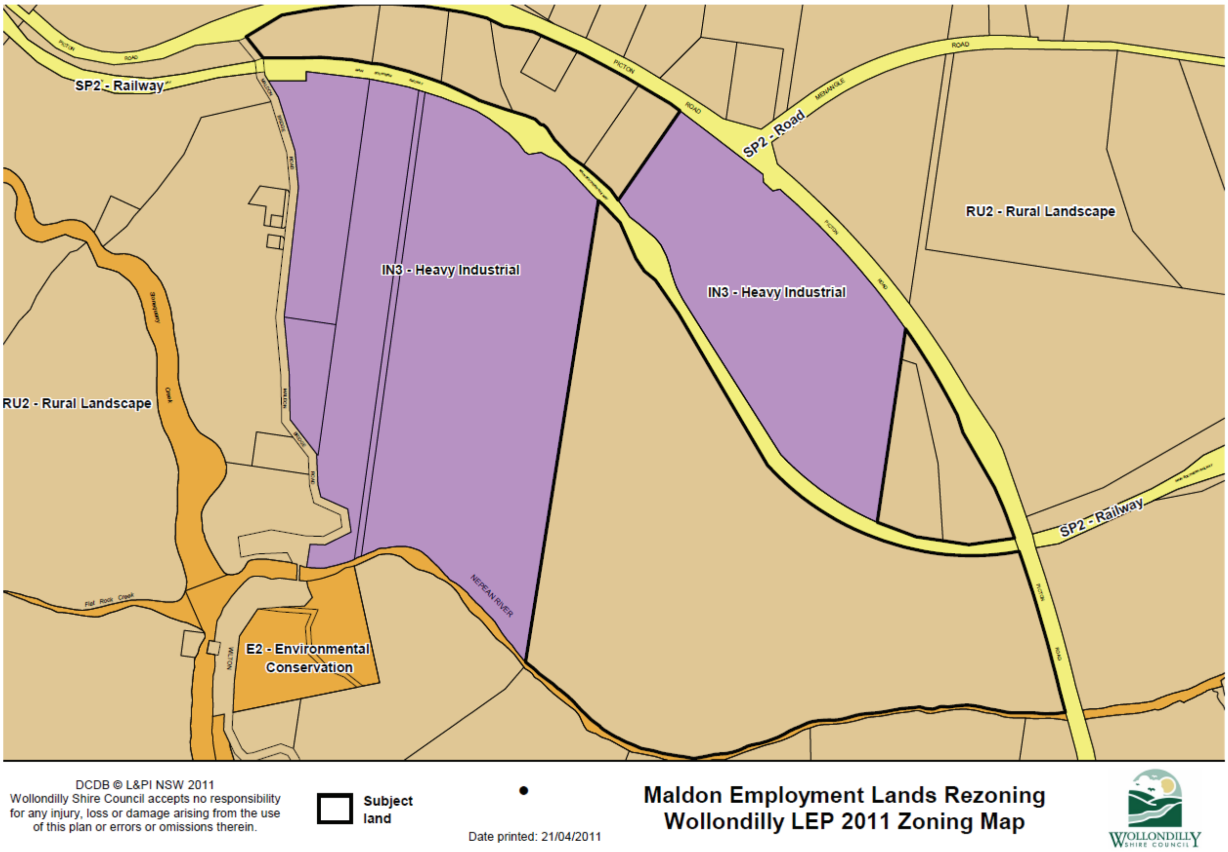

Figure 1.1 Maldon Employment Lands

Council has invited the assistance of consultants for the preparation of specialist studies to enable Council to prepare a draft Local Environmental Plan to support the application to the Department of Planning for the rezoning of the lands.

Council commissioned Mine Subsidence Engineering Consultants Pty Ltd (MSEC) in December 2010 to carry out a study into the potential impacts of mine subsidence on the Maldon Employment Lands due to future extraction of coal resources from the Bulli Seam.

This report was prepared on completion of the study.

1.2 Land Description

The proposed rezoning of the rural lands will be embodied in the Draft Wollondilly Local Environmental Plan 2011 (DWLEP 2011) - Amendment No.1. The Amendments are intended to apply to the land bounded by Picton Road and the Nepean River, as outlined in Figure 1.1 and Drawing No. MSEC477-01.

The land is in the ownership of Allied Mills, together with a number of other landowners and includes:

Lot 2	DP 818975
Lot 1	DP 732582
Lot 2	DP 732582
Lot 3	DP 732582
Lot 1	DP 105348
Lot 31	DP 731012
Lot 30	DP 826690
	DP8731012
Lot 1	DP1128013

1.3 Mine Subsidence Impact Study

The Department of Industry and Investment (DII) initially objected to the proposed rezoning based on the need to secure a 30 year coal mining resources plan for BHP Billiton. The DII agreed to remove their objection subject to the following:

A study being undertaken to quantify likely future mining induced ground subsidence at the site due to longwall mining in the Bulli and Balgownie Coal Seams. The scope of this study should have input and then be reviewed for adequacy by the Mine Subsidence Board and BHP - Illawarra Coal.

That any future Development Control Plan for this site requires that any new buildings and equipment installed within them are:

- *certified by an appropriately qualified person, and*
- *that the structures will withstand future subsidence, and*
- *the operation of equipment will not be unduly affected by subsidence.*

This study should provide a mine subsidence impact plan for the study area which encompasses possible geographic/existing infrastructure constraints that may impact on the levels of possible extraction and undertake the following assessment:

- *Detail the predicted subsidence parameters for each property in the study area.*
- *Identify unsuitable types of employment land uses based on the extent of subsidence (for example, uses which require a conveyor belt system as part of their operation are more likely to be impacted by mine subsidence).*
- *Provide building design guidelines to mitigate the impact of subsidence.*
- *Propose any additional controls on development considered necessary for reducing potential impacts on development from mine subsidence, for example, minimum lot sizes.*

It was later indicated by the DII that the reference to the Balgownie Seam can be removed, since the seam beneath the study area is thin and, by inference, less viable and less likely to be mined.

1.4 Minimum Required Outputs from the Study

The documents required by Council on completion of this study include the following:

- A detailed report that addresses the items outlined in the project brief with suitable references to publications, data sources, personal communications and professional opinion; and including text, maps, diagrams, photographs and descriptions (where appropriate).
- Original reproduction quality copies of all plans, figures and illustrations.
- One unbound hard copy.
- One electronic copy including all figures saved in a suitable and editable format. The electronic copy may be on CD or emailed.
- A4 format (except for maps and diagrams which may be in A3).
- Any colour documents must be able to be reproduced without loss of detail in black and white

The report is to be provided in draft form as it is prepared. Council will provide comments on the draft, from which MSEC is to finalise the material. MSEC is to collaborate with Council staff nominated by the Strategic Planning Department, prior to the preparation of the final documents, to ensure that all relevant issues are considered.

1.5 Agreed Scope of Works

It was agreed that the Scope of Works would include, but would not necessarily be restricted to, the following activities:

1. Attend meeting with Council staff to discuss the project and obtain copies of relevant Council documents and other background information.
2. Prepare a work programme within 14 days of commencement and submit it to Council (It was later agreed that this was not necessary, key dates having been agreed at the meeting with Council staff).
3. Review earlier studies including the Allied Mills EIS and the Bulli Seam Operations' mine subsidence predictions, which were prepared by MSEC for BHP Billiton.
4. Review other documents prepared by MSEC on building design requirements for mine subsidence areas.
5. Identify surface features and infrastructure on the land proposed for rezoning.
6. Prepare predicted subsidence parameters for each property in the study area.
7. Identify unsuitable types of land use based on the extent of subsidence.
8. Prepare building design guidelines to mitigate the impact of subsidence.
9. Identify any additional controls on development considered necessary for reducing potential impacts on development from mine subsidence.
10. Prepare a Draft Report, including all necessary drawings and illustrations.
11. Table the Draft Report and discuss with Council Staff.
12. Prepare a Final Report and ensure that all relevant issues have been considered.
13. Attend meetings and liaise with Council staff as necessary.
14. Provide one unbound hard copy and one electronic copy of the report, including all figures, together with original reproduction quality copies of all plans, figures and illustrations

CHAPTER 2 Geological Details and Known Coal Resources

2.1 Geological Details

The proposed Maldon Employment Lands are located in the southern part of the Permo-Triassic Sydney Basin, within which the main coal bearing sequence is the Illawarra Coal Measures, of Late Permian age. The Illawarra Coal Measures contain four workable seams, the uppermost of which are the Bulli Seam and the Balgownie Seam.

A typical stratigraphic section for the area is shown in Figure 2.1. The seam immediately below the Bulli Seam, which is referred to in this report as the Balgownie Seam is known in the Illawarra area as the Wongawilli Seam.

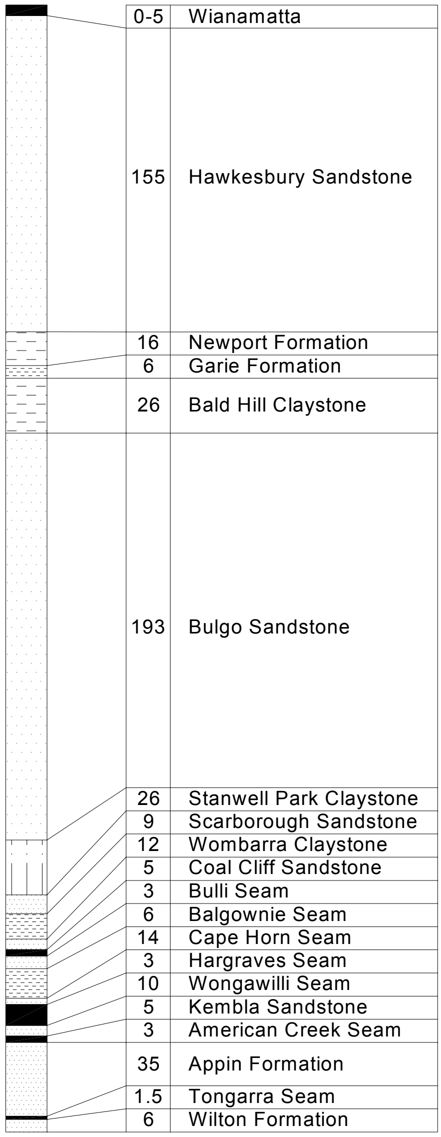

Figure 2.1 Typical Stratigraphic Section – Southern Coalfield

All of the sediments that form the overburden to the Bulli Seam belong to the Hawkesbury Tectonic Stage, which comprises three stratigraphic divisions. The lowest division is the Narrabeen Group, which ranges in age from Lower to Middle Triassic and varies in thickness up to 310 metres. Overlying the Narrabeen Group is the Hawkesbury Sandstone which dates from the Middle Triassic and has a thickness of up to 185 metres.

Above the Hawkesbury is the Wianamatta Group, which is poorly represented in this region, having a thickness of only a few metres.

The major sandstone units are interbedded with other rocks and, whilst shales and claystones are quite extensive in places, the sandstone predominates. The major sandstone units are the Scarborough, the Bulgo and the Hawkesbury Sandstones and these units vary in thickness from a few metres to as much as 200 metres. The rocks exposed in the river gorges and creek alignments belong to the Hawkesbury Group.

The other rocks generally exist in discreet but thinner beds of less than 15 metres thickness, or are interbedded as thin bands within the sandstone. The major claystone unit is the Bald Hill Claystone, which lies above the Bulgo Sandstone at the base of the Hawkesbury Sandstone. This claystone varies in thickness and is, in some places, more than 25 metres thick.

2.2 Mining Authorisations

The proposed Maldon Industrial Lands lie within a coal mining authorization area, Authorisation A396, which is held by BHP Billiton Illawarra Coal (BHPB).

2.3 Known Coal Resources

The proposed Maldon Employment Lands are underlain by coal resources in the Bulli and Balgownie Seams. The Bulli Seam is currently being mined by BHPB at Appin Colliery and the coal resources beneath the proposed Industrial Lands are accessible from Appin Colliery and fall within the 30 year mining plans of BHPB. The Balgownie Seam is thin in this area and is unlikely to be mined.

The extent of the coal resources and the current mining plans of BHPB have been determined from drawings provided by BHPB.

The Bulli Seam lies at a depth which varies from approximately 450 metres to 510 metres below the surface in the study area, as indicated by the depth of cover contours in Drawing No. MSEC477-04. The depth of cover below the bed of the Nepean River is approximately 410 metres. The Bulli Seam contains valuable reserves of coking coal and varies in thickness from 1.95 metres to 2.2 metres, as indicated by the seam thickness contours in Drawing No. MSEC477-03.

CHAPTER 3 Mining Plans

3.1 Existing Mining Plans

The mining by BHP Billiton (BHPB) at Appin Colliery, which has previously been carried out to the east of the proposed Maldon Employment Lands, has been carried out using longwall mining techniques. Further information on the longwall mining process and the development of mine subsidence is given in Appendix C.

3.2 Future Mining Plans

In the next few years, BHPB plans to mine additional longwalls in the Bulli Seam at Appin Colliery. Some of these longwalls are located directly beneath the site of the proposed Maldon Employment Lands and extend further to the northeast of the site. This section of the proposed mining plans of BHPB is the northern part of Area 8 and includes Longwalls 800 to 810. The southern part of Area 8 lies to the south of the site and includes Longwalls 811 to 827. The proposed Longwalls 800 to 802 lie beneath the proposed Maldon Employment Lands, as shown in Drawing No. MSEC477-01.

It should be noted that the proposed layout of longwalls beneath the proposed Maldon Employment Lands is only indicative at this stage. The final dimensions and layout of the longwalls will be determined when further exploration has been completed and when the mining conditions have been more clearly defined.

At this time, the final layout of any future longwalls beneath the proposed Maldon Employment Lands can only be conjectured, but it is almost certain that the resources would be extracted using longwall mining techniques similar to those that are now being used at Appin Colliery.

Since the mine layout has not been finally determined, it is only possible at this stage to make approximate subsidence predictions for the potential future longwalls, based upon the current mining proposals, which were indicated by BHPB Illawarra Coal in its recent Part 3A application for future mining in the area. On this basis, subsidence predictions have been made assuming that the future longwalls beneath the proposed Employment Lands would be 310 metres wide, with chain pillars between longwalls of 45 metres width.

3.3 Potential Mining Constraints

The natural features, surface infrastructure and archaeological and heritage sites in the study area are shown in Drawings Nos MSEC477-05, MSEC477-06 and MSEC477-07, respectively.

The natural features have the potential to limit the extent of mining beneath the proposed Employment Lands and this will be taken into consideration when an application is made by BHPB to DII seeking approval to mine the coal. It is noted, however, that the longwalls, in the conceptual mine layout provided by BHPB, have already been set back from the Nepean River to avoid potential adverse impacts on the river and its clifflines. It is unlikely, therefore, that any additional mining would be approved in the immediate vicinity of the river.

The major items of infrastructure in the study area are the Main Southern Railway, Picton Road, the Picton Road Bridge over the railway, the Maldon Zone Substation, The Allied Mills Flour Mill and the Blue Circle Cement Works. It is unlikely that any of these items of infrastructure will be a constraint to the mining that is proposed in the conceptual mine plan.

There is one archaeological site, named Bulli Seam 12, alongside Carriage Creek, over the end of the proposed Longwall 800 and a number of archaeological sites above the proposed Longwall 802 in the Maldon Aboriginal Heritage Conservation Area. Based on past experience, it seems likely that approval will be given to mine beneath these sites. It is, therefore, unlikely that they will be a constraint to the proposed mining.

CHAPTER 4 Predicted Subsidence Parameters

4.1 Predicted Subsidence Parameters

Subsidence predictions have been made using the Incremental Profile Method to illustrate the way in which the subsidence parameters vary across a series of longwalls. These predictions have been made along the prediction line shown in Drawing No. MSEC477-08. Further information on methods of prediction and the Incremental Profile Method is provided in Appendix D.

Figure 4.1 shows the predicted subsidence, tilt and strain profiles across Longwalls 800 to 804, based on longwalls, 310 metres in width, separated by chain pillars of 45 metres width, but with a pillar of 75 metres width between Longwalls 802 and 803 as indicated by BHPB in its conceptual mine plan. The predicted profiles are based upon the seam thicknesses in the Bulli Seam, which are shown in Drawing No. MSEC477-03, and the depths of cover to the Bulli Seam, which are shown in Drawing No. MSEC477-04.

The dashed lines in Figure 4.1 show the predicted incremental subsidence profiles due to mining each of the longwalls in sequence. The predicted incremental subsidence profile of a longwall shows the additional subsidence that is predicted to occur as that longwall is mined and the shape and position of the profile is influenced by the mining of previous longwalls.

The resulting profile shapes are therefore asymmetrical and the point of maximum incremental subsidence does not coincide with the centre of the longwall. The only exception to this is the incremental subsidence profile of the first longwall in the series, which is symmetrical about the centre of the longwall in flat terrain.

Since the incremental profiles of each longwall overlap those of the neighbouring longwalls, the total subsidence is greater than the incremental subsidence. The thinner blue lines indicate the total subsidence after mining each longwall. The heavier blue line indicates the total subsidence profile due to mining the series of longwalls.

It can be seen that the predicted total subsidence, in the bottom of the subsidence trough, varies from approximately 600 mm to approximately 900 mm.

Figure 4.1 also shows the predicted total tilts and curvatures along the prediction line due to mining the series of longwalls.

The dashed lines show the predicted incremental tilts and curvatures due to mining the longwalls in sequence and the heavier blue lines show the predicted final total tilts and curvatures.

It can be seen that the maximum predicted tilts within the subsidence trough, due to mining Longwalls 800 to 804, lie generally between 2.0 mm/m and 4.0 mm/m, with a tilt at the edge of the subsidence trough of approximately 3.5 mm/m.

It can also be seen that the predicted maximum curvatures, due to mining Longwalls 800 to 804, lie generally between 0.06 km^{-1}, hogging, and 0.10 km^{-1}, sagging, i.e. 17 kilometres radius, hogging, and 10 kilometres radius, sagging.

The predicted maximum strain values given by the Incremental Profile Method for the Southern Coalfield are based upon an approximation that strain in mm/m is equal to 15 times curvature, where curvature is the reciprocal of the radius of curvature in kilometres. The maximum predicted strains, based on the maximum predicted curvatures are, therefore, 0.9 mm/m, tensile, and 1.5 mm/m compressive.

The final subsidence contours due to mining Longwalls 800 to 810 are shown in Drawing No. MSEC477-08.

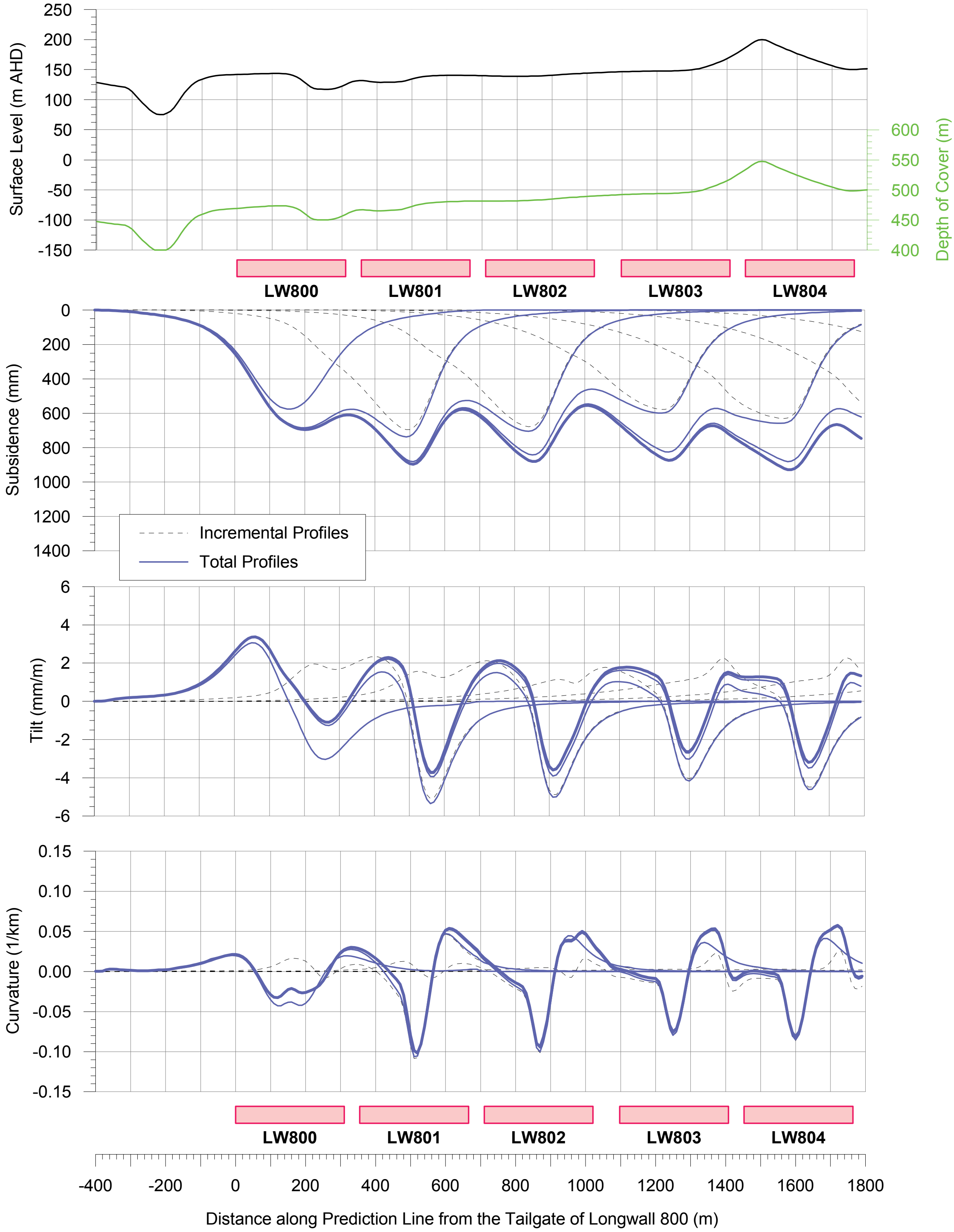

Figure 4.1 Predicted Subsidence Parameters above a Series of Longwalls

A number of small creeks and shallow drainage lines could be impacted by additional mining-induced valley related movements, which could include upsidence in the bottoms of the valleys, closure of the valley sides and localised increases in compressive strain.

This should not significantly affect the designs of the buildings, which would not be built across the drainage lines or valleys, but these movements would need to be taken into account in designing any pipelines or bridges that may cross the drainage lines or valleys.

4.2 Predicted Subsidence Parameters for each Property

An indication of the maximum predicted subsidence parameters for each of the properties within the proposed Maldon Employment Lands is given in the following sections. It should be noted that these are based upon the conceptual mine plan that was indicated by BHPB Illawarra Coal in its recent Part 3A application for future mining in the area. It is possible that the mine plan could be changed in future and that the predicted subsidence parameters could vary from those that are indicated below. The layout of the longwalls and the predicted subsidence contours are shown in Drawing No. MSEC447-08.

4.2.1 200 Picton Road, DP818975 Lot 2

This property is located outside the end of Longwalls 800 and 801 and in that location would be likely to experience vertical subsidence of less than 25 mm and negligible tilt, curvature or strain.

4.2.2 240 Picton Road, DP732582 Lot 1

This property is located outside the end of Longwalls 800 and 801 and in that location would be likely to experience vertical subsidence of less than 100 mm, tilts less than 0.5 mm/m, curvatures less than 0.01 and strains less than 0.2 mm/m.

4.2.3 250 Picton Road, DP732582 Lot 2

This property is located over the end of Longwall 801 and in that location would be likely to experience vertical subsidence between 100 mm and 400 mm, tilts less than 4 mm/m, curvatures less than 0.02 and strains less than 0.4 mm/m.

4.2.4 290 Picton Road, DP732582 Lot 3

This property is located above Longwalls 801 and 802 and in that location would be likely to experience vertical subsidence between 200 mm and 900 mm, tilts less than 4 mm/m, curvatures less than 0.1 and strains less than 1.5 mm/m.

4.2.5 Maldon Zone Substation, DP105348 Lot 1

The Maldon Zone Substation is located adjacent to the end of Longwall 801 over the chain pillar between Longwalls 801 and 802 and in that location would be likely to experience vertical subsidence between 300 mm and 500 mm, tilts less than 4 mm/m, curvatures less than 0.02 and strains less than 0.4 mm/m.

4.2.6 300 Picton Road, DP731012 Lot 31

This property is located above Longwalls 801 and 802 and in that location would be likely to experience vertical subsidence between 600 mm and 900 mm, tilts less than 4 mm/m, curvatures less than 0.1 and strains less than 1.5 mm/m.

4.2.7 390 Picton Road, DP826690 Lot 30

This property is located above the end of Longwall 802 and in that location would be likely to experience vertical subsidence between 50 mm and 600 mm, tilts less than 4 mm/m, curvatures less than 0.1 and strains less than 1.5 mm/m.

4.2.8 400 Picton Road, DP826690 Lot 31

This property is located above the end of Longwall 802 and in that location would be likely to experience vertical subsidence between 50 mm and 600 mm, tilts less than 4 mm/m, curvatures less than 0.1 and strains less than 1.5 mm/m.

4.2.9 Allied Mills Picton Road, DP1128013 Lot 1

This property is located partially above Longwalls 800 and 801 and partially outside the ends of the longwalls. Where it lies above the longwalls it would be likely to experience vertical subsidence between 50 mm and 900 mm, tilts less than 4 mm/m, curvatures less than 0.1 and strains less than 1.5 mm/m. Outside the longwalls it would be likely to experience vertical subsidence of less than 50 mm, tilts less than 0.5 mm/m, curvatures less than 0.01 and strains less than 0.2 mm/m.

4.3 Mine Subsidence Board Design Requirements

Irrespective of what the final mine plans might be, it seems likely that the proposed employment sites at Maldon would be developed before any final mine layout has been determined. Since the future mine layout can only be conjectured, the Mine Subsidence Board will most likely require that all of the employment developments in the Maldon area should be designed to accommodate the maximum predicted subsidence movements rather than predicted site-specific subsidence movements based on a conceptual mine plan.

It seems likely that the required design parameters for the employment developments would be the same as those that the Board required when the Allied Mills Flour Mill was designed. A letter from the Board to Sinclair Knight Merz Pty Limited, dated 29th August 2003, advised as follows:

"The members of the Mine Subsidence Board have decided, subject to BHP Billiton not raising any new issues, to grant their conditional approval of this building application on the condition that the final drawings, to be submitted prior to commencement of construction, contain a certification by a qualified structural engineer, to the effect that any improvement constructed to meet the specifications of such final drawings will be safe, serviceable and repairable, taking into account the following mine subsidence parameters;

- *Maximum vertical subsidence of 600 mm*
- *Maximum ground strains of ±2 mm/m*
- *Maximum tilt of 6 mm/m*

We will provide further advice to you when we have received it from BHP Billiton."

4.4 Recommended Design Parameters

It can be seen that the maximum subsidence indicated by the Board is less than that predicted by MSEC in Section 4.1. The vertical subsidence does not in itself cause damage, so long as the subsidence is uniform, and even if the maximum subsidence was taken to be 900 mm, as predicted by MSEC, it would not significantly alter the design of the buildings and structures in the employment area. The factors that have greater impact on the design of buildings and structures are tilt, curvature and strain. The required tilt and strain parameters provided by the Board for the design of the Flour Mill are greater than those predicted by MSEC in Section 4.1 and are therefore safer, i.e. more conservative. The Board did not provide predicted curvatures, but maximum strains of 2 mm/m would indicate maximum curvatures of approximately 7.5 kilometres radius.

Based upon the above discussions, and bearing in mind that at this stage any future mine layout can only be conjectured, we would recommend that any buildings, structures, plant, equipment and associated services and infrastructure are designed to accommodate the following maximum subsidence parameters:

• Maximum vertical subsidence	900 mm
• Maximum tilt	6 mm/m
• Maximum tensile strain	2 mm/m
• Maximum compressive strain	2 mm/m
• Minimum radius of curvature	7.5 km

CHAPTER 5 Existing Land Uses

5.1 Land Uses

The properties that are included in the proposed Maldon Employment Lands rezoning application are shown in Drawing No. MSEC447-01, in Appendix D, and in Figure 5.1. The existing land uses are described in the following sections.

Figure 5.1 Aerial Photograph showing (shaded) the proposed Maldon Employment Lands

5.2 200 Picton Road, DP818975 Lot 2

This property is cleared land owned by Mr. Anthony Dal Pozzo and operates as a commercial go-carting facility, known as the Picton Karting track.

Plate 5.2 Steel Portal Framed Building at the Picton Karting Track

5.3 240 Picton Road, DP732582 Lot 1

This property is cleared land owned by Mr. John Corbett and operates as a commercial facility trading as Roadworx Profiling Pty Ltd. The company specialises in road maintenance, water and sewer maintenance, civil engineering, asphalt paving, profiling, spray sealing, decorative paving and traffic management.

Plate 5.3 Steel Portal Framed Building at 240 Picton Road

The buildings on the site comprise a steel portal framed building with low height masonry perimeter walls and a weatherboard and steel clad office building, as shown in Plate 5.3.

5.4 250 Picton Road, DP732582 Lot 2

This property is cleared land owned by Blue Circle Southern Cements and is undeveloped.

5.5 290 Picton Road, DP732582 Lot 3

This property is cleared land owned by Mr. Ellewyn Birtles. The buildings on the property comprise a three-bay steel shed and a weatherboard cottage as shown in Plates 5.4 and 5.5.

Plate 5.4 Three-Bay Steel Shed at 290 Picton Road

Plate 5.5 Weatherboard Cottage at 290 Picton Road

5.6 Maldon Zone Substation, DP105348 Lot 1

The Maldon Zone 330kV Substation is illustrated in Plate 5.6. The structures on the property comprise a single storey brick control room and exposed transformers and switchgear.

Plate 5.6 Maldon Zone Substation

5.7 300 Picton Road, DP731012 Lot 31

This property is cleared land owned by Bob & Maureen Fitzsimmons and operates as a commercial vehicle and plant maintenance and repair facility. The buildings on the property comprise steel framed and steel clad buildings with low height masonry perimeter walls, an office building, which is a converted weatherboard cottage, and other demountables. The main buildings are illustrated in Plates 5.7 and 5.8.

Plate 5.7 Vehicle and Plant Repair Facilities at 300 Picton Road

Plate 5.8 Office Building at 300 Picton Road

5.8 390 Picton Road, DP826690 Lot 30

This property is a rural residential property on cleared land, which is owned by R & M Barca. The buildings on the property comprise a single storey brick dwelling with a tiled roof, a large steel garage/machinery shed and smaller steel garden sheds as illustrated in Plates 5.9 to 5.11.

Plate 5.9 Rural Residence at 390 Picton Road

Plate 5.10 Garage/Machinery Shed at 390 Picton Road

Plate 5.11 Garden Sheds at 390 Picton Road

5.9 400 Picton Road, DP826690 Lot 31

This property is a rural residential property on cleared land, which is owned by R & M Barca. The buildings on the property comprise a single-storey weatherboard dwelling with a corrugated steel roof, a large steel garage/machinery shed and other small sheds as illustrated in Plates 5.12 to 5.14

Plate 5.12 Rural Residence at 400 Picton Road

Plate 5.13 Garage/Machinery Shed at 400 Picton Road

Plate 5.14 Other Small Sheds at 400 Picton Road

5.10 Allied Mills Picton Road, DP1128013 Lot 1

This property is partially cleared land owned by Allied Mills and is undeveloped. Parts of the land are covered in natural bush along the riparian zones of the Nepean River and carriage Creek, as illustrated in Drawing No. MSEC477-06.

CHAPTER 6 Possible Types of Employment Land Use

6.1 Employment Land Uses

Industrial land uses generally involve activities that generate employment such as, manufacturing, processing, assembly, storage and distribution. The proposed Maldon Employment Lands could therefore be used to support a wide variety of industries, each of which would require specific facilities.

The possible range of industrial activities that might be permitted at Maldon can be appreciated by referring to the following definitions of industrial and infrastructure land uses, which has been reproduced from Section 1.8.2 of the Wollondilly Development Control Plan 2010, Volume 1.

Industries - group term, which includes:

- hazardous industries
- heavy industries
- light industries including home industries
- offensive industries

Rural industries - group term, which includes:

- agricultural produce industries
- livestock processing industries
- sawmill or log processing industries
- stock & sale yards
- composting facilities & works

Storage premises - group term, which includes:

- self storage units
- warehouse or distribution centres
- hazardous storage establishments
- liquid fuel depots
- offensive storage establishments
- (other types of storage premises)

Other Industrial land uses:

- brothels
- depots
- vehicle body repair workshops
- vehicle repair stations

Passenger transport facilities - group term with no specific defined land uses included

Freight transport facilities - group term, which includes:

- truck depots

Air transport facilities - group term, which includes:

- airport
- airstrip
- heliport
- helipad

Waste or resource management facilities - group term, which includes:

- waste or resource transfer stations
- waste management facility
- resource recovery facilities
- waste disposal facilities

Water supply systems - group term, which includes:

- water reticulation systems
- water storage facilities
- water treatment facilities

Sewerage system - group term, which includes:

- biosolids treatment facilities
- sewage reticulation systems
- sewage treatment plants
- water recycling facilities

Other Transport and Infrastructure land uses:

- car parks
- highway service centres
- transport depots
- biosolid waste application
- electricity generating works
- emergency services facility
- public utility undertaking
- roads
- telecommunications facilities

6.2 Potential Sizes of the Employment Allotments

Council has advised that the Rezoning Scoping Study by Parsons Brinckerhoff has proposed 6 large allotments of approximately 5 hectares on the Allied Mills land. There is an additional 12 hectares of industrial zoned land available for development at the front of the flour mill, which would accommodate 8 allotments of around 1.5 hectares.

In relation to the Allied Mills rural zoned land, constraints in terms of access, bushfire hazard and riparian corridors have been identified to some extent by the Rezoning Scoping Study, the Section 62 consultation responses and the initial bushfire report. Accordingly the proposal for 5 hectare lots on the Allied Mills land should be the basis for the assessment with the aim of determining an acceptable subdivision size based on the constraints and sustainable development potential identified by the draft studies. There is no minimum subdivision size proposed for the current industrial zoned land at Maldon under Draft LEP 2010 and this will be the case for land within the subject rezoning unless the studies determine that there should be a minimum subdivision size.

The smaller properties along Picton Road are more suited to light service type employment industries and the minimum subdivision area in the Draft LEP IN2 industrial zones is 1500 square metres. A recent review of industrial land in this zone throughout the Shire indicates, however, that there is little industrial land of this size, with most industrial land being a minimum of 2000 square metres in area.

Accordingly the 2000m^2 subdivision size is considered a feasible minimum for the smaller properties with the aim being to determine whether this is sustainable based on the constraints identified in the studies.

There is no floor to site ratio for industrial zones proposed under the Wollondilly Shire Draft DCP but a 50% site coverage will be applicable. Under the Height of Buildings Map in the Draft LEP there is no height limit on the existing industrial land in Maldon but there is a 10 metre height limit on industrial land in other industrial areas throughout the Shire. Accordingly the studies may indicate whether a height limit is considered necessary for limiting visual impact or limiting floor space for example.

6.3 Potential Types of Building Construction

Bearing in mind the need to design the l building structures to accommodate subsidence movements, it is anticipated that most of the building structures would be of steel framed construction, with steel cladding, though some buildings could be constructed using tilt-up slabs or articulated masonry. It is also anticipated that buildings will generally be constructed on concrete ground slabs, without basements.

It is preferable to avoid the use of piled foundations in mine subsidence areas, but if this cannot be avoided, the building structure will need to be isolated from the ground movements by introducing a secondary foundation at the heads of the piles with a sliding membrane between it and the building structure.

6.4 Unsuitable Types of Employment Land Use

The majority of building structures, assuming that they are properly designed and constructed, will be able to accommodate the predicted ground movements without any significant damage. Predicted tilting of the buildings up to 4 mm/m will not generally present any serviceability problems.

Predicted curvatures of 10 to 17 kilometres radius are well within the acceptable deflection ratios for the majority of building structures, as indicated in Table E 25 in Appendix E.

Similarly, predicted strains of up to 0.9 mm/m tensile and 1.5 mm/m, compressive, are unlikely to result in significant damage to industrial building structures, particularly since much of the strain in the ground will be lost in the transfer to the building structure.

Some potential uses could, however, by sensitive to very small ground movements and should not be permitted unless special provisions are made in the design to accommodate the predicted movements. Examples of such uses are, radar systems, satellite antenna towers, turbines, high racking in warehouses, and some larger tanks.

Overhead crane rails are sensitive to tilts greater than 3 mm/m, but can be provided with adjustable supports to allow the rails to be relevelled as subsidence occurs.

6.5 The Assessment of Subsidence Impacts

There are various methods used to assess the impacts of subsidence on buildings, structures, plant and equipment and to determine the tolerance of different types of structure to mining-induced ground movements. Some of these methods are discussed in Appendix E.

CHAPTER 7 Building Design Guidelines

7.1 Design Requirements

Any employment facilities constructed at Maldon will have to be designed to meet the design requirements of the Mine Subsidence Board. The Board will provide the developers of the employment sites with design parameters, which normally include maximum values of vertical subsidence, tilt, strain and curvature that need to be accommodated in the design of the buildings and associated structures and services. Design parameters will need to be confirmed by the design structural engineers of each structure with the Mine Subsidence Board prior to the commencement of design.

7.2 Design Principles

In many cases the strains and curvatures resulting from mining subsidence will be within the normal capacity of a building structure and little or no damage will result from mining. In other cases it will be necessary to design buildings to accommodate specific requirements of the Mine Subsidence Board which are rather more stringent than normal design requirements and in these circumstances there are two options open to the designer.

The first of these is to make the building strong enough to withstand the strains likely to be imposed upon it and able to span any gaps likely to occur beneath it.

The second and generally more economical approach is to isolate the building as far as possible from the effects of ground strain and to make it flexible enough to adapt to the curvatures of the ground. In either case residual tilts can sometimes be difficult to accommodate.

The transfer of strain from the ground into the structure can be resisted but will result in additional horizontal stresses in foundations which will require additional reinforcement. The foundation to soil interaction will be complicated by the building's response to bending and this will result in redistribution of bearing stresses beneath the foundations which will increase the bending stresses and increase the design requirements of footings or slabs.

The mechanisms are complex but generally the principles adopted for the design of buildings on reactive clay sites can be used in situations where mining induced ground curvature has to be accommodated.

The principles adopted in design will vary from case to case and will depend on the design parameters, the type of construction and the size and configuration of the building. The recommendations given in AS 2870-2011 should be followed when designing buildings in mine subsidence prone areas. It should be remembered that mining induced movements have to be accommodated in addition to all normal design requirements. AS2870-2011 should be used by the structural engineers within the limitations as stated within this code.

7.3 Design for Vertical Subsidence

Rigid body subsidence will generally cause no problems but differential movements from point to point in a structure have to be accommodated. Generally the ground will settle gradually and though some curvature may develop, stepping at the surface should not occur.

At faults or fissures, however, stepping is possible and a thorough geotechnical survey at design stage is recommended particularly where the building is to be founded directly on rock.

On most sites where no fissures are in evidence and the building is to be founded on a reasonable thickness of subsoil it is extremely unlikely that stepping of the ground will occur. Building directly over or close to a fissure or fault should always be avoided.

If a rigid design of structure is to be provided then the possibility of loss of support beneath the foundation should be taken into account in the design. Normally it is recommended that rigid foundation beams should be designed to span a distance of half their length or cantilever one third of their length. A more rigorous analysis of the foundation to soil interaction should where possible be undertaken when designing any large rigid structure.

7.4 Design to Accommodate Strains

The transfer of ground strains into a structure can occur due to friction beneath or alongside foundations and by earth pressures on the sides of foundations. The foundations should therefore be detailed to reduce the friction between the ground and the foundation and separate the foundation structure from the soil.

This can be achieved by designing slabs and footings to be as smooth as possible on the underside and by providing a sliding layer of sand at least 150 mm thickness beneath the footings with a polythene membrane on top. On reactive clay sites the sand layer should be omitted. Compressive fillers or void formers can be used alongside footings in the ground to reduce the effect of compressive strains but should also be avoided on reactive clay sites.

Alternatively the building may be founded on piers or independent footings but in such cases slabs should be designed as suspended slabs with void former beneath them and with sliding joints where they are supported on the piers or footings. Where strains are high greater attention to the design of sliding joints may be necessary and proprietary joints may be useful in some instances to minimise frictional forces.

Buildings should also be split into smaller sections where appropriate with suitable movement joints carried through the superstructure and this will also assist in accommodating ground curvature.

Care should be taken to ensure that drainage pipes and other services are free to move where they are built into a structure. This can be achieved using protective sleeves with compressible filler surrounding the pipe or service.

7.5 Design to Accommodate Curvature

Buildings should be designed to articulate and hence should be provided with joints to separate the building into smaller elements. Useful guidance for the design of articulated walling is provided in the Cement and Concrete Association’s Technical Note 61. Flexible forms of construction are desirable and storey height openings can be a convenient way of creating vertical joints in the structure.

Masonry arches should be avoided but if these are required they should be tied at foundation level and across the top of the arches and should be rigidly supported on a reinforced concrete foundation. Alternatively, they can be articulated by the provision of vertical joints in the columns between adjacent arches.

Internal linings are normally the first to suffer as subsidence occurs with cracking at wall to wall junctions, wall to ceiling junctions and sometimes at board joints. Suspended ceilings are therefore advantageous but where conventional linings are used, provision for movement should be made by introducing movement joints. These can be provided between cornice and wall and to coincide with any points of articulation or weakness in the linings such as at the head of door or window openings.

Brickwork or masonry should be used in shorter panels where possible and the spacing between vertical joints should not exceed 6 metres. The spacing and width of joints will be determined by the subsidence parameters making due allowance for expansion, brick growth, shrinkage and reactive soil movements. In extreme cases it may be necessary to consider providing cavity walls internally to coincide with articulation joints so that greater freedom of movement can be provided.

When the shape in plan of the building is complex it may be difficult to accommodate the differential movements and twisting of the structure and in such cases it would be advantageous to split the building into separate elements joined by a flexible link.

7.6 Design to Accommodate Tilt

Generally tilts will be quite small and the residual tilt on completion of mining will in most cases still be within acceptable limits.

When the mining plan is known it is possible to be more specific about the probable residual tilt for a particular site but at the time of design it is likely that a conservative approach will be necessary. Some provision should therefore be made in the design of a building for future relevelling of the structure should this be required.

Buildings with suspended floors can be more easily relevelled by jacking than those built on ground bearing slabs. If, however, the slabs are designed with future jacking in mind it is possible to build in provisions for future adjustment.

7.7 Summary

Mining Subsidence is a complex mechanism which varies from site to site and only when the mining layout and methods have been determined can the potential impact on a surface structure be fully analysed. The response of a building structure is also a complex mechanism which is dependent upon the form of the building and the materials used in its construction.

Design requirements are of necessity conservative and generally provide high factors of safety but the design of a building to resist subsidence also requires an understanding of the mechanism of subsidence and the three dimensional movements which are likely to occur. In some cases the building will be affected four or five times as panels of coal are extracted in sequence and the impact may continue for several years.

If buildings, structures, equipment, plant and associated services and infrastructure are carefully designed and detailed, the impact of mining subsidence upon them should generally be very small.

CHAPTER 8 Recommended Development Controls

8.1 General Conclusions

So long as all employment buildings, structures, equipment, plant and associated services and infrastructure are designed in accordance with the recommended design parameters, there will be no reason to apply further controls on the development of the employment sites.

Some employment uses will, however, involve plant and equipment that is sensitive to ground movement and such plant and equipment will have to be designed so that the levels of the plant and equipment can be adjusted as subsidence occurs.

Some industries have equipment that must be kept perfectly level and would be adversely affected even at low levels of tilt. A typical example is a carpet manufacturing facility in which a latex backing is applied to the back of the carpet to anchor the pile. This is achieved by passing the carpet over a tank of latex solution, which has to be kept perfectly level to avoid spillage from the tank. Such equipment can be designed with a provision for relevelling, so that the equipment can be adjusted as subsidence occurs.

Even some of the more sensitive structures, such as radar systems, satellite antenna towers, turbines and larger tanks can be designed in such a way that they can be adjusted in level as subsidence occurs.

High racking systems in warehouses can also be designed so that they can be adjusted in level, though any tilt in the floor slabs greater than 0.5 mm/m could present operational difficulties for high-lift fork lift trucks.

Given that the predicted subsidence parameters are relatively low, any additional costs in designing future industrial developments at Maldon to accommodate subsidence should not be excessive.

APPENDIX A Glossary of Terms and Definitions

Some of the 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.
Cover Depth (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.
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.
Extracted Seam Thickness	The thickness of coal that is extracted. The extracted seam thickness is 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 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.
Goaf End Factor	A factor applied to reduce the predicted incremental subsidence at points lying close to the commencing or finishing ribs of a panel.
Horizontal Displacement	The horizontal movement of a point on the surface of the ground as it settles above an extracted panel.
Inflection Point	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.
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 Centreline	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.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points.
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.
Super-critical area	An area of panel greater than the critical area.
Tilt	The difference in subsidence between two points divided by the horizontal distance between the points.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	The difference between the observed subsidence profile within a valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

APPENDIX B References

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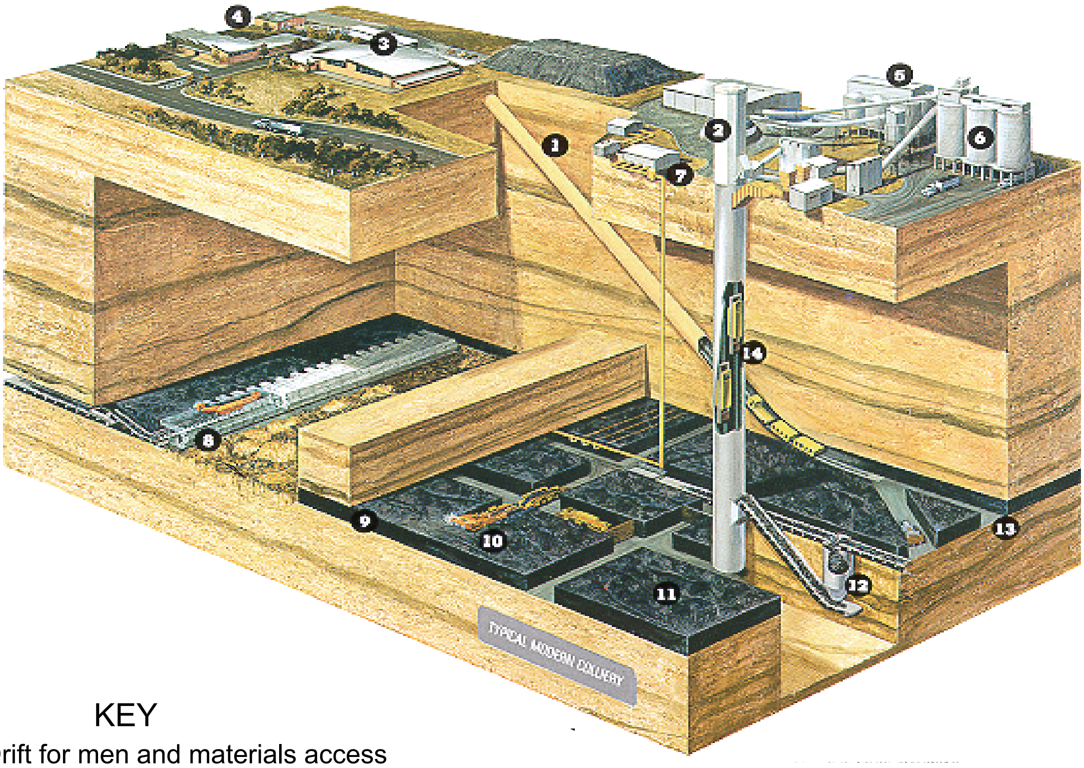
APPENDIX C Introduction to Longwall Mining and Subsidence

C1 The Longwall Mining Process

Figure C1 shows a cutaway diagram of a typical longwall mine. The main features of the mine are indicated in the key below the diagram. The longwall face is indicated by the number 8 in the diagram.



KEY

1. Drift for men and materials access
2. Shaft winder house
3. Bathhouse and administration building
4. Workshops
5. Coal preparation plant
6. Coal storage bins
7. Gas drainage system
8. Longwall face equipment
9. Coal seam
10. Continuous miner unit
11. Coal pillar
12. Underground coal bin
13. Main roadway or heading
14. Coal skips to carry coal to the surface

Figure C1 Cutaway View of a Typical Longwall Mine

In longwall mining, a panel of coal, typically around 150 to 400 metres wide, 1000 to 3500 metres long and 2 to 5 metres thick, is totally removed by longwall shearing machinery, which travels back and forth across the coalface. A typical section through a coal face is shown in Figure C2 and a photograph of typical longwall face equipment is shown in Figure C3. The shearer cuts a slice of coal from the coalface on each pass and a face conveyor, running along the full length of the coalface, carries this away to discharge onto a belt conveyor at the end of the face, which carries the coal out of the mine.

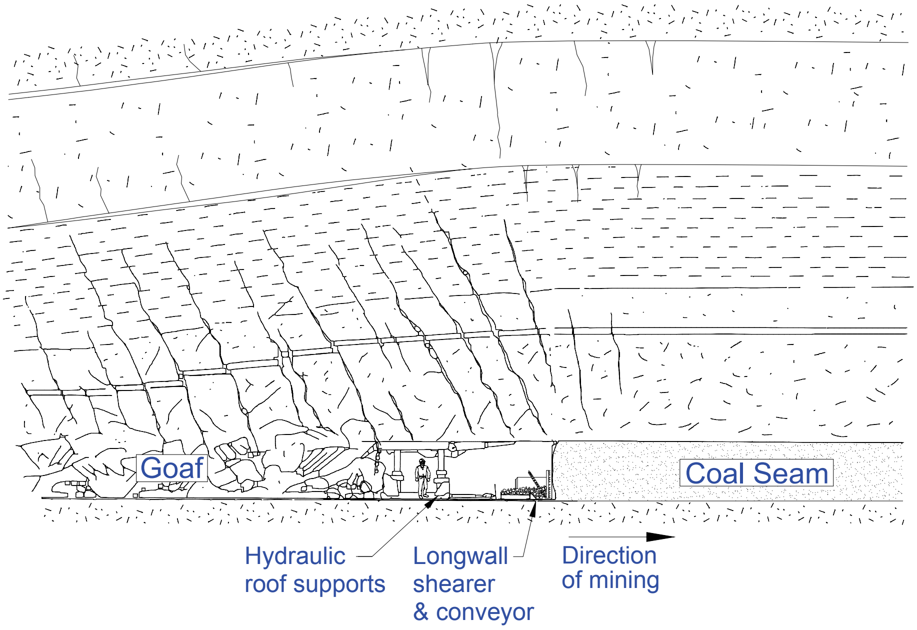


Figure C2 Cross Section of a Typical Longwall Face

The area immediately in front of the coalface is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata and provide a working space for the shearing machinery and face conveyor. After each slice of coal is removed, the hydraulic roof supports, the face conveyor and the shearing machinery are moved forward. Figure C3 shows the arrangement of machinery on a typical longwall face, with the hydraulic roof supports on the left hand side and the coal face on the right hand side of the picture. The drum in the background is the rotating cutting head of the coal shearer and the chain conveyor can be seen in the foreground.

Fig. C.1 Typical Longwall Face Equipment

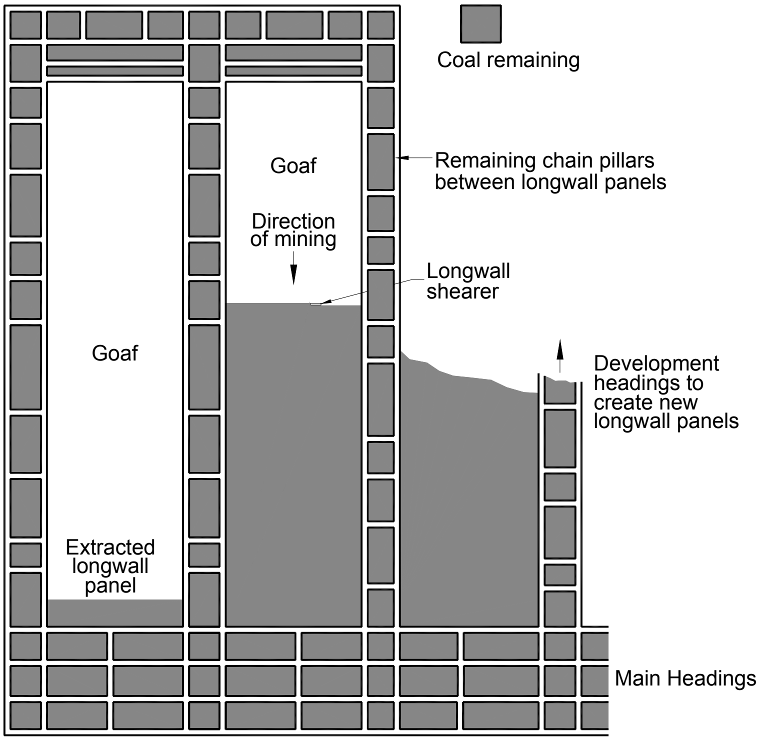


Figure C4 Typical Plan View of a Series of Longwall Panels

Figure C4 shows a typical layout of a group of longwalls. Before the extraction of a longwall panel commences, continuous mining equipment extracts coal to form roadways (known as headings) around the longwall panel. These roadways form the mine ventilation passages and provide access for people, machinery, electrical supply, communication systems, water pump out lines, compressed air lines and gas drainage lines. The roadways, which provide access from the mine entrance to the longwalls, are referred to as the main headings. Once the main headings have been established additional roadways, known as development headings, are driven on both sides of the longwall panel and are connected together across the end of the longwall.

The longwall face equipment is established at the end of the panel that is remote from the main headings and coal is extracted within the panel as the longwall equipment moves towards the main headings. This configuration is known as retreat mining. Typically, a longwall face retreats at a rate of 50 metres to 100 metres per week, depending on the seam thickness and mining conditions. The coal between the development headings and between the main headings is left in place as pillars to protect the roadways as mining proceeds. The pillars between the development headings are referred to as chain pillars.

When coal is extracted using this method, the roof immediately above the seam is allowed to collapse into the void that is left as the face retreats. This void is referred to as the goaf. Miners working along the coalface, operating the machinery, are shielded from the collapsing strata by the canopy of the hydraulic roof supports. As the roof collapses into the goaf behind the roof supports, the fracturing and settlement of the rocks progresses through the overlying strata and results in sagging and bending of the near surface rocks and subsidence of the ground above, as illustrated in Figure C2.

If the width of an extracted panel of coal is small and the rocks above the seam are sufficiently strong, it is possible that the roof will not collapse and hence no appreciable subsidence will occur at the surface. However, to maximise the utilisation of coal resources and for other economic reasons, wide panels of coal are generally extracted and, in most cases, the roof is unable to support itself.

C2 The Development of Subsidence.

C2.1 Subsidence Mechanisms.

As the immediate roof strata, i.e. the rocks immediately above the seam, collapse into the goaf, the rocks above them lose support and sag to fill the void beneath them. The mechanism progresses towards the surface and the affected width increases so that at the surface, an area somewhat larger than the extracted panel of coal undergoes settlement. Figure C5 shows a typical subsidence profile above an extracted longwall panel and it can be seen that the majority of the subsidence occurs over the centre of the longwall and tapers off around the perimeter of the longwall. The subsidence is typically less than the thickness of coal extracted underground.

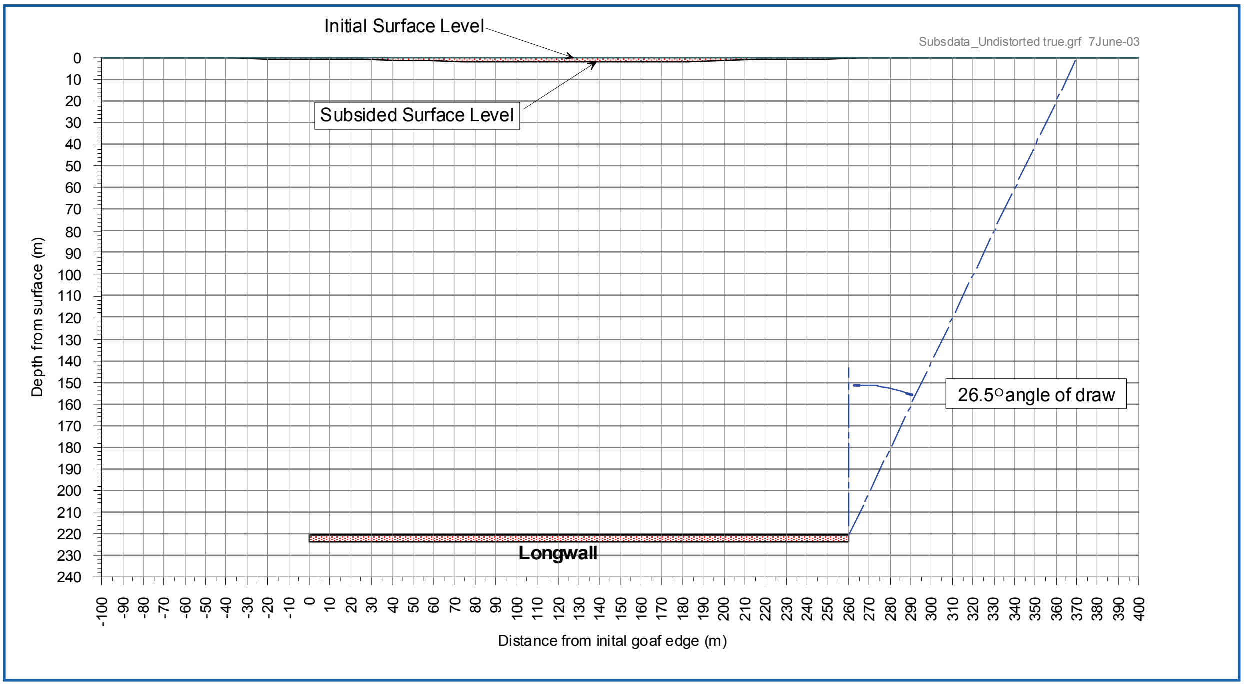


Figure C5 Typical Subsidence Profile Drawn to a True Scale

The angle at which the subsidence spreads out towards the limit of subsidence, at the surface, is referred to as the angle of draw. The angle of draw depends upon the strength of the strata and the depth of cover to the coal seam and typically lies between 10 and 35 degrees from the vertical, depending on how the limit of subsidence is defined.

It is generally accepted that subsidence of less than 20 mm will have negligible effect on surface infrastructure and this is generally adopted as the cut-off point for determination of the angle of draw. In the Coalfields of NSW, if local data is not available, the cut-off-point is taken as a point on the surface defined by an angle of draw of 26.5 degrees from the edge of the extraction, i.e. a point on the surface at a distance of half the depth of cover from the goaf edge. Where local data exists and it can be shown that the angle is generally less than 26.5 degrees, then, the lower angle of draw can be used.

The subsidence of the surface is considerably less than the thickness of coal removed, due to the voids that are left within the collapsed strata. The extent of the settlement at the surface is therefore dependent upon the strength and nature of the rocks overlying the coal seam and is a direct function of their capacity to bridge over the voids.

When a panel has a width that is small, relative to the depth of the seam below the surface, the fractured rocks have a tendency to bridge over the goaf by arching between the solid abutments on each side of the panel, thus reducing the amount of subsidence.

As the panel width is increased, however, the overlying rocks are less able to arch over the goaf and a limiting panel width is reached where no support is available and maximum subsidence occurs. This limiting panel width is referred to as the critical width and is usually taken to be 1.4 times the depth of cover. It does, however, depend upon the nature of the strata.

Where several panels are mined in a series and chain pillars are left between the panels, the maximum subsidence does not occur unless each panel is, at least, of critical width. The chain pillars crush and distort as the coal is removed from both sides of them, but, usually, they do not totally collapse and, hence, the pillars provide a considerable amount of support to the strata above them.

Where large supercritical areas are extracted, the maximum possible subsidence is typically 55% to 65% of the extracted seam thickness, but, because chain pillars are normally left in place, and provide some support, this maximum possible subsidence is rarely reached.

Research has shown that the incremental subsidence of a second or subsequent panel in a series is greater than the subsidence of an individual isolated panel of identical geometry. Because the subsidence effects above a panel extend beyond its goaf edges, these effects can overlap those of neighbouring panels.

Where the width-to-depth ratios of the panels in a series are sub-critical, which is normally the case, the amount of subsidence in each panel is determined by the extent of these overlaps, which are further influenced by the widths of the chain pillars. In this situation, the first panel in a series will generally exhibit the least subsidence and the second and subsequent panels will exhibit greater subsidence due to disturbance of the strata caused by mining the preceding panels and consequential redistribution of stresses within the strata.

The subsidence at the surface does not occur suddenly but develops progressively as the coal is extracted within the area of influence of the extracted panel. In many cases, when the cover over the coal seam is deep, a point on the surface will be affected by the extraction of several adjacent panels.

When extraction of coal from a panel is commenced, there is no immediate surface subsidence, but as the coal within this first panel is extracted and the extracted void increases in size, subsidence develops gradually above the goaf area. As mining continues, a point is reached within the panel where a maximum value of subsidence occurs and despite further mining beyond this point, within the panel, this level of subsidence is not increased.

As further adjacent panels are extracted, additional subsidence is experienced, within the previously mined panels. However, a point is also reached where a maximum value of subsidence is observed over the series of panels irrespective of whether more panels are later extracted.

The subsidence effect at the surface occurs in the form of a wave, which moves across the ground at approximately the same speed as the longwall face retreats within the longwall panel. The extraction of each panel creates its own wave as the panels are mined in sequence.

The development of subsidence at any point on the surface of the ground can be seen to be a very complex mechanism and the cumulative effect of a number of separate movements.

C2.2 Subsidence Parameters

Subsidence, tilt, horizontal displacement, curvature and strain are the subsidence parameters normally used to define the extent of the surface movements that will occur as mining proceeds and generally form the basis for the assessment of the impacts of subsidence on surface infrastructure. These parameters are illustrated in Figure C6.

Subsidence

Subsidence usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements can in many cases be greater than the vertical subsidence. The amplitude of subsidence is usually expressed in millimetres.

Tilt

Tilt 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. The sign of tilt is not important, but the convention usually adopted is for a positive tilt to indicate the ground increasing in subsidence in the direction of measurement.

The maximum tilt, or the steepest portion of the subsidence profile, occurs at the point of inflection in the subsidence trough, where the subsidence is roughly equal to one half of the maximum subsidence. Tilt is usually expressed in millimetres per metre.

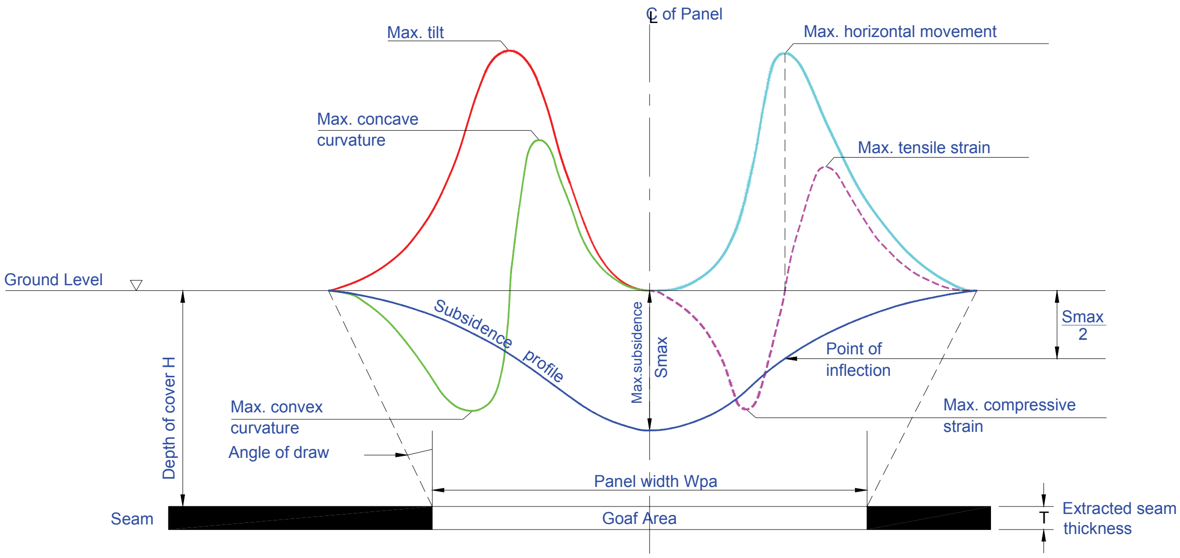


Figure C6 Subsidence Parameter Profiles above a Single Longwall Panel

Horizontal Displacement

The horizontal component of subsidence, or horizontal displacement, is greatest at the point of maximum tilt and declines to zero at the limit of subsidence and at the point of maximum subsidence. Horizontal displacement is usually expressed in millimetres.

Curvature

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/km, or km-1, but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in kilometres.

Curvature is convex or 'hogging' over the goaf edges and concave or 'sagging' toward the bottom of the subsidence trough. The convention usually adopted is for convex curvature to be positive and concave curvature to be negative.

Strain

Strain is caused by bending and differential horizontal movements in the strata. Measured strain is determined from monitored survey data by calculating the horizontal change in length of a section of a subsidence profile and dividing this by the initial horizontal length of that section.

If the section has been extended, the ground is in tension and the change in length and the resulting strain are positive. If the section has been shortened, the ground is in compression and the change in length and the resulting strain are negative.

The unit of measurement adopted for strain is millimetres per metre. The maximum strains coincide with the maximum curvature and hence the maximum tensile strains occur towards the sides of the panel whilst the maximum compressive strains occur towards the bottom of the subsidence trough.

C3 Subsidence Impacts at the Surface

The most significant impacts on surface infrastructure are experienced during the development of the subsidence trough, when maximum ground movements normally occur.

As the subsidence wave approaches a point on the surface, the ground starts to settle, is displaced horizontally towards the mined void and is subjected to tensile strains, which build from zero to a maximum over the length of convex or hogging curvature, as shown in Figure C7

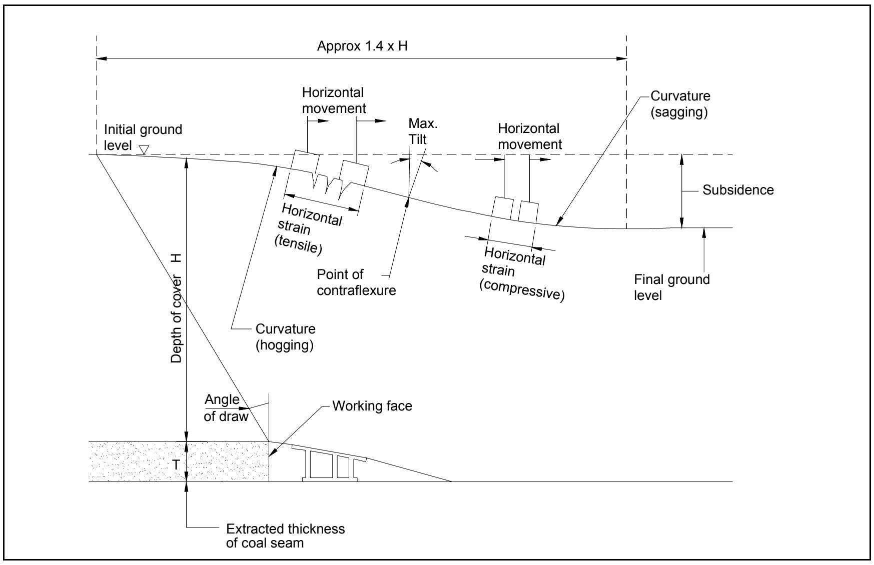


Figure C7 Development of a Subsidence Trough (to an exaggerated vertical scale)

The position of maximum hogging curvature is the position of maximum tensile strain. When vertical subsidence is approximately half of the maximum subsidence, i.e., as the face passes under the surface point, the ground reaches its maximum horizontal displacement and the strain reduces to zero again.

As the longwall face moves further away from the surface point the settlement continues, horizontal displacement reduces and the ground is subjected to compressive strains, which build from zero to a maximum over the length of concave or sagging curvature and then decline to zero as maximum subsidence is reached. The position of maximum sagging curvature is the position of maximum compressive strain. When the subsidence is complete, the ground is commonly left with no horizontal displacement and little residual tilt or strain.

Between the tensile and compressive zones is the point of inflection, which is the point at which maximum tilt and maximum horizontal displacement occurs. For critical extraction conditions, it is also the point at which the subsidence is, approximately, equal to half the maximum subsidence.

As the longitudinal wave passes, the transverse subsidence profile gradually develops and is completed as maximum subsidence is reached. The transverse subsidence profiles over each side of the panel are similar in shape to the longitudinal subsidence profile and have the same distribution of tilts, curvatures and strains.

Most of the points on the surface will thus be subjected to three-dimensional movements, with tilt, curvature and strain in both the transverse and longitudinal directions. The impact of subsidence on surface infrastructure is therefore dependent upon its position within the trough.

The above sequence of ground movements, along the length of a panel, only applies to surface structures if they are located at a point where the maximum subsidence is likely to occur. Elsewhere, the impacts, in the both the transverse and longitudinal direction are reduced.

If a structure is located on the perimeter of the subsidence trough, it will be only slightly affected, will suffer little settlement and will have little residual tilt or strain.

A structure or surface feature on the side of the trough between the tension and compression zones will experience some subsidence, and will be left with residual horizontal displacement and tilt, but will be subjected to lower curvatures and strains. Structures or surface features located at the positions of maximum curvature and strain would generally suffer the greatest damage.

As each panel within a series is extracted in turn, an incremental subsidence trough is formed above it. If the width-to-depth ratios of the panels are low, the incremental subsidence troughs overlap at the surface and the resulting subsidence at any point, in these circumstances, is a combination of the effects of a number of panels.

A point on the surface may then be subjected to a series of subsidence waves, which occur as each panel is extracted, and the duration of these impacts will depend upon the position of the point relative to each of the subsidence troughs that are formed.

APPENDIX D Methods of Subsidence Prediction

D1 Alternative Methods of Prediction

Several alternative methods have been used in the past to predict subsidence parameters, including:

- Graphical Methods, such as the National Coal Board Method used in the U.K.
- Profile Function Methods.
- Influence Function Methods.
- Numerical Modelling Methods.
- Empirical Methods.

Profile function methods seek to define the shape of the subsidence profile using a single mathematical formula. These are generally only applicable to single panels, since they assume the profiles to be symmetrical and fail to recognise the way in which subsidence profile shapes are modified over adjacent and previously mined goaf areas.

Influence function methods predict subsidence profiles based on the theory of an area of influence around a point of extraction. These methods can be applied to a wide range of mining geometries, but are more difficult to calibrate and check than profile function methods.

Numerical modelling techniques have been developed in recent years using finite element and discrete element models such as FLAC, UDEC and FLOMEC. These are particularly useful tools for investigating strata mechanisms and hydrological impacts, but have not been found to produce sufficiently accurate predictions of mine subsidence.

Empirical methods can be developed for the prediction of subsidence parameter whenever a large database of measured subsidence parameters is available. These methods can be advantageously employed over a wide range of mining geometries, taking into account local variations in strata lithology. Other modelling methods can also be successful where sufficient local data is available for model calibration. To be successful, all methods of prediction have to be checked against measured data and calibrated to reflect local geology.

An empirical approach has generally been adopted in the coalfields of New South Wales, and this has been expanded in recent years by the development of the Incremental Profile Method. The Standard Empirical methods and the Incremental Profile Method are described in the following sections. Further information on alternative methods of subsidence prediction can be found in Kratzsch (1983) and Whittaker and Reddish (1989).

D2 Standard Empirical Methods

At collieries in New South Wales, the maximum subsidence of the surface has generally been predicted using empirical methods. In the past, subsidence predictions were based upon the methods outlined in the Subsidence Engineers Handbook, first published by the National Coal Board of the United Kingdom in 1965 and revised in 1975. This involved the use of a series of graphs derived from numerous field observations in British mines, which allowed the shapes of the subsidence, tilt and strain profiles to be predicted.

The method gave good results when applied to British mining situations, but when the method was adopted in Australia, it became clear that the field observations differed considerably from predicted values and were generally much less than theory would suggest.

This is because the strata that overlie the coal seams in British coalfields differ from those that occur in the coalfields of Australia and because the subsidence measurements in British coalfields were in some cases affected by multi-seam mining.

The rocks in Britain are generally less competent and less able to bridge the extracted voids and, therefore, for a given seam thickness, the maximum subsidence is greater than it would normally be for the same mining geometry in Australian conditions.

An intensive research program was therefore undertaken by the New South Wales Department of Mineral Resources (DMR) to develop a predictive model that was more appropriate for Australian conditions. It was noted that the subsidence behaviour varied significantly between the Southern Coalfield, the Newcastle Coalfield and the Western Coalfield of New South Wales. Subsidence data from collieries in New South Wales were therefore studied separately for the three coalfields.

The work resulted in three publications which provide guidelines for the prediction of mine subsidence parameters in each coalfield. The handbook for the Southern Coalfield was completed in 1975 (Holla, 1975) and the handbooks for the Newcastle and Western Coalfields were completed in 1987 (Holla, 1987a) and 1991 (Holla, 1991a) respectively. It should be noted that the method of prediction given in the New South Wales handbooks is only applicable to single, isolated panels.

Additional research by Dr L. Holla of the DMR led to the publishing of a paper (Holla, 1988) which included a graph which can be used to predict the maximum subsidence above a series of longwall panels, for critical extraction conditions. This graph is reproduced as Figure D1, where S max is the maximum subsidence, T is the seam thickness and H is the depth of cover.

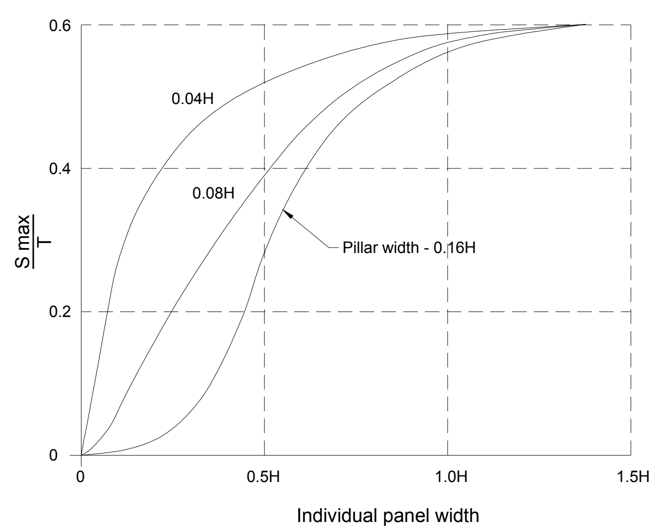


Figure D1 Graph for the Prediction of Maximum Subsidence over a Series of Panels for Critical Extraction Conditions (after Holla, 1988)

Following further study, a revised handbook was produced by the DMR for the Southern Coalfield in 2000 (Holla and Barclay). This later handbook included graphs that allow prediction of the maximum subsidence over a series of longwall panels. The handbook can also be used to establish an approximate subsidence profile and to predict the maximum tilt, curvature and strain above a mined area, for single panels.

When the width of an extracted panel, the depth of cover, and the extracted seam thickness are known, the following parameters can be predicted:

- The maximum subsidence value
- The location of the inflection point
- The average goaf edge subsidence
- The limit of subsidence

Once these parameters have been determined, a subsidence profile can be produced as a line of best fit between the points of maximum subsidence, inflection, goaf edge subsidence and limit of subsidence. This method thus allows the approximate shape of subsidence profile to be determined for a single isolated panel.

The predicted maximum tensile strain, compressive strain and tilt can be determined from the maximum subsidence and depth of cover, using, respectively, factors obtained from the graphs shown in Figs. 4.6, 4.7 and 4.10 of the DMR handbook (Holla and Barclay, 2000). The predicted maximum curvatures can be derived from the predicted maximum strains using the graph shown in Fig. 4.9 of the handbook.

The limit of subsidence is determined from the depth of cover and the angle of draw. The DMR recommends a practical angle of draw of 26.5° for general use in the Southern Coalfield, and hence the limit of subsidence would generally be positioned at half the depth of cover from the perimeter of the extracted area.

Whilst the DMR method normally provides reasonable predictions of the maximum subsidence above a series of longwall panels, it does not predict the subsidence profiles across a series of panels and does not allow the variations in tilt, curvature and strain to be determined across a series of longwalls. This method therefore could not be used to provide the detailed predictions required for this study. However, it was used to provide a check on the accuracy of the maximum predicted subsidence parameters which have been obtained using the Incremental Profile Method.

D3 The Incremental Profile Method

The Incremental Profile Method was developed by Mr. A.A. Waddington and Mr. D.R. Kay during the course of a study for BHP Collieries Division, the Water Board and AGL during the latter part of 1994 (Waddington and Kay, 1995). The purpose of the study was to develop an empirical method which could be used to predict the subsidence, tilts, curvatures and strains likely to be experienced as longwall mining occurred at Appin and Tower Collieries, and to assess the likely effects of mining on surface infrastructure.

The first step in the development of the model was to study detailed records of subsidence movements which had been observed over previous longwalls at Appin and Tower Collieries and over longwalls at neighbouring mines, including Tahmoor, West Cliff, Cordeaux and South Bulli Collieries. The measured subsidence data was plotted in a variety of ways to establish whether or not any regular patterns of ground behaviour could be found. The most significant patterns were illustrated in the shapes of the incremental subsidence parameters measured along survey lines located transversely across the longwalls.

The incremental subsidence profile for each longwall was derived by subtracting the initial subsidence profile (measured prior to mining the longwall) from the final subsidence profile (measured after mining the longwall). The incremental subsidence profile for a longwall therefore shows the change in the subsidence profile caused by the mining of the individual longwall.

The consistency in the shapes of the incremental subsidence profiles led to the development of the Incremental Profile Method. This consistency can be observed in the typical incremental subsidence profiles presented in Figure D2

The Incremental Profile Method of prediction is based upon predicting the incremental subsidence profile for each longwall in a series of longwalls and then adding the respective incremental profiles to show the cumulative subsidence profile at any stage in the development of a series of longwalls.

The incremental subsidence profiles are also used to derive incremental tilts, systematic curvatures and systematic strains which can be added to show the transient and final values of each parameter as a series of longwalls are mined.

Profiles can be predicted in both the transverse and longitudinal directions, thus allowing the subsidence, tilts, systematic curvatures and systematic strains to be predicted at any point on the surface above a series of longwalls. The method also explains the development of undulations that occur within the subsidence trough and allows the magnitude of both transient and residual tilts and curvatures within the trough to be determined.

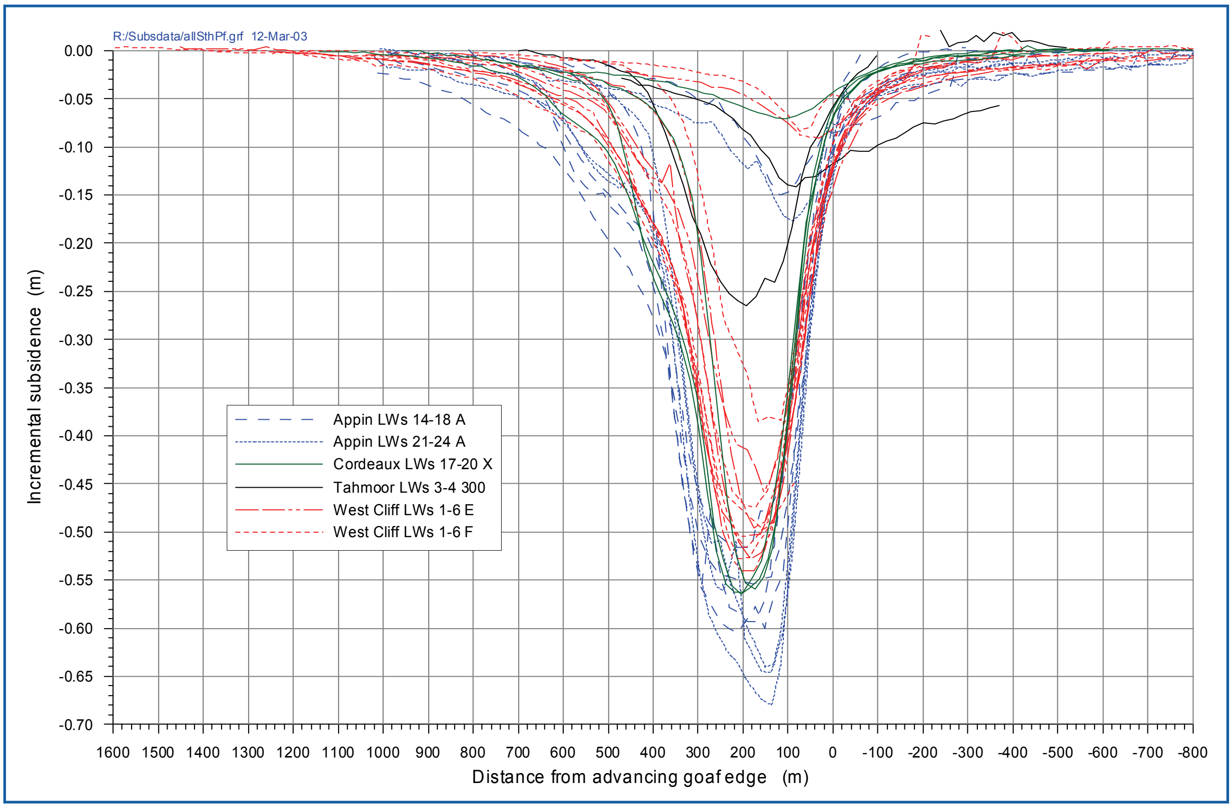


Figure D2 Typical Incremental Subsidence Profiles – NSW Southern Coalfield

The model was initially tested by comparing the predicted values of subsidence, tilt, curvature and strain against the measured values for a number of longwalls at Appin, Cordeaux, Tahmoor and West Cliff Collieries. Following that study, the method was used to analyse and predict subsidence over other longwall panels at Appin, South Bulli, Bulli, Corrimal, Tahmoor, Teralba, North Cliff, Metropolitan, Tower and West Cliff Collieries. These studies found that the shapes of the measured incremental profiles conformed to the patterns and magnitudes observed during the initial 1994 study.

During 1996 and 1997, the method was extended for use in the Newcastle Coalfield. The shapes of incremental profiles over extracted longwall panels at Cooranbong, West Wallsend, Newstan, Teralba, and Wyee Collieries were studied and a subsidence model was developed for the Cooranbong Life Extension Project. These studies have shown that the shapes of the incremental profiles in the southern part of the Newcastle Coalfield conform to the patterns observed in the Southern Coalfield. Since that study, the method has been used to analyse and predict subsidence over other longwall panels at West Wallsend, Cooranbong, Wyong and South Bulga Collieries.

The collection of additional data has allowed further refinement of the method and the database now includes more than 450 measured examples. A wide range of longwall panel and pillar widths and depths of cover is included within the database and hence, the shapes of the observed incremental profiles in the database reflect the behaviour of typical strata over a broad spectrum.

Further research during the last few years has identified the shapes of the incremental profiles in a number of multi-seam situations. These profiles are generally greater in amplitude than the single seam profiles and differ in shape from the standard profiles over single seams.

The incremental profiles have been modelled in two halves, the point of maximum subsidence being the point at which the two halves of the profile meet. A library of mathematically defined profile shapes has been established, which allows the incremental profiles to be modelled, depending on the width-to-depth ratio of the longwall and the position of the longwall in the series.

The mathematical formulae that define the profile shapes are of the form given in Equation 1 below. The library of profile shapes simply comprises the values a to k in these formulae.

$$y = \frac{a + cx + ex^2 + gx^3 + ix^4 + kx^5}{1 + bx + dx^2 + fx^3 + hx^4 + jx^5} \qquad \text{Equation 1}$$

Different formulae apply, with unique a to k values, for first, second, third, fourth, and fifth or subsequent panels in a series, and for different width-to-depth ratios, within the range 0.3 to 5.0. For second, third, fourth and fifth or subsequent panels, the left and right hand sides of the profiles have different formulae.

The library of profile shapes thus contains a to k values for 693 different half-profile shapes for single-seam mining situations. In addition the library contains 236 different half-profile shapes for a range of multi-seam mining situations. A selection of model incremental subsidence profiles for various width-to-depth ratios is shown in Figure D3.

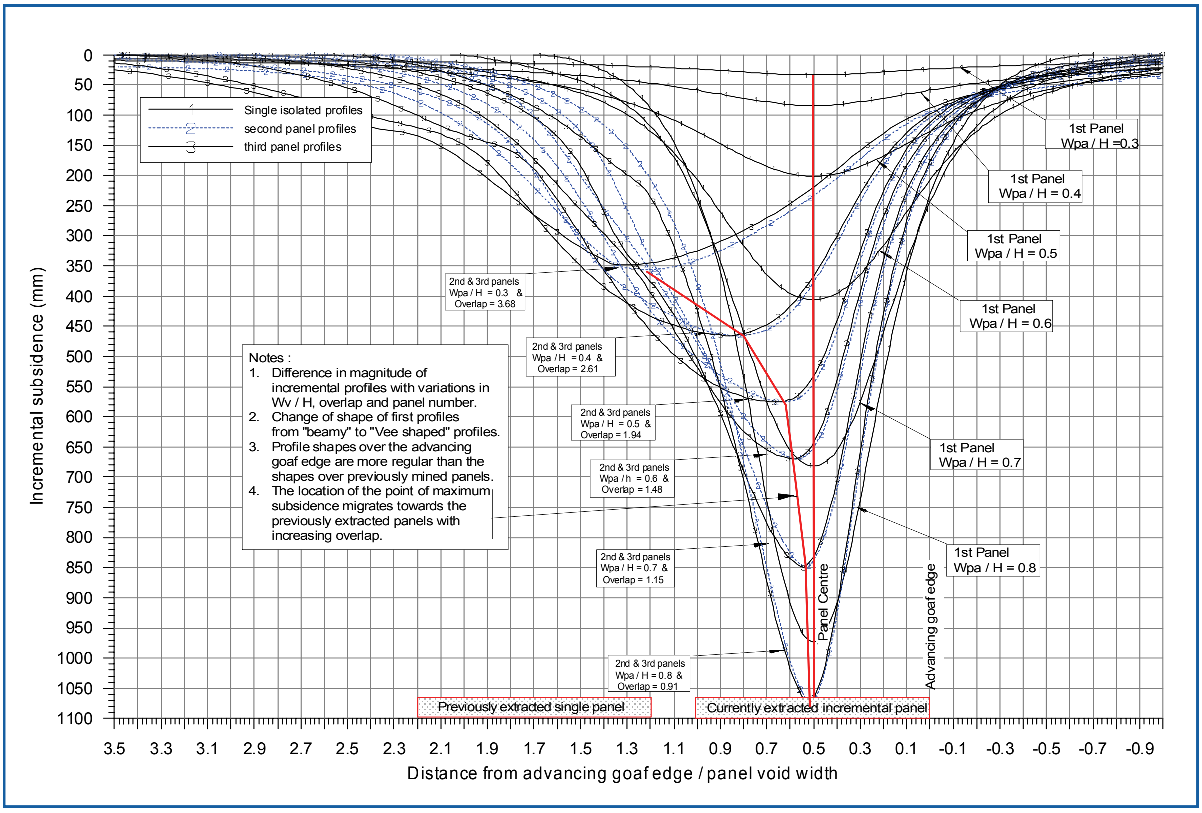


Figure D3 Incremental Subsidence Profiles obtained using the Incremental Profile Method

The method has a tendency to over-predict the subsidence parameters because a conservative approach was adopted in preparing the graph that is used for predicting the maximum incremental subsidence. Figure D4 shows the maximum incremental subsidence, expressed as a proportion of seam thickness, versus panel width-to-depth ratio.

Since this graph is used to determine the amplitude of the incremental subsidence profile, any over-prediction of the maximum subsidence value also leads to over-predictions of the tilt, curvature and strain values. Once the geometry of a longwall panel is known, the shapes of the two halves of the incremental subsidence profile of the panel can be determined from the appropriate formulae to provide a smooth non-dimensional subsidence profile across the longwall.

The actual incremental profile is obtained by multiplying vertical dimensions by the maximum incremental subsidence value and horizontal dimensions by the local depth of cover. Smooth tilt and curvature profiles are obtained by taking the first and second derivatives of the subsidence profile. Strain profiles are obtained directly from the curvature profiles.

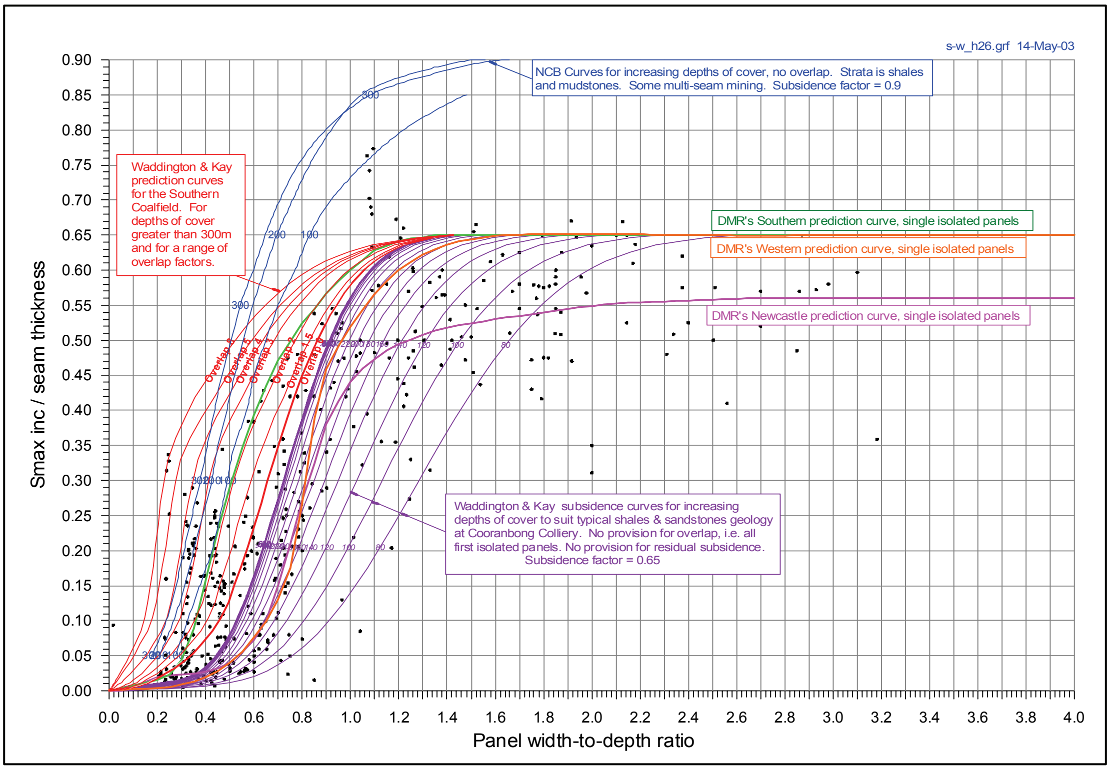


Figure D4 Prediction Curves for Maximum Incremental Subsidence

It can be seen from Figure D3 that, as the panel width-to-depth ratio (W/H) decreases, the magnitude of the incremental subsidence profile is reduced and the position of the point of maximum subsidence moves closer to the previously extracted panels.

In order to determine strain values from the curvature profiles, it is necessary to select an empirical relationship that will generally provide conservative results. The NCB Subsidence Engineers Handbook (1975) adopts a relationship in which the reciprocal radius of curvature, K, is equal to strain squared divided by 0.024.

This relationship does not provide a good fit when strains derived from predicted curvatures, are compared with measured values. However, if a linear relationship of strain = 15 × curvature is chosen, then a closer fit is achieved between predicted and observed data from the Southern Coalfield. This equates to the bending strain in a beam of 30 metres depth, bending about its centre line.

The relationship of 15 × curvature is also reasonably close to the graph of radius of curvature versus maximum strain given in Figure 4.9 of the DMR's handbook for the Southern Coalfield (Holla and Barclay, 2000), for depths of cover between 300 metres and 400 metres. It will, however, give lower values of strain for greater depths.

Predicted horizontal displacements in the direction of the prediction line (normal to the longwall), can be derived by accumulating the predicted strains multiplied by the bay lengths, after distributing any displacement closure errors over all bay lengths in proportion to the predicted strains. Alternatively, the predicted horizontal ground movement profiles can be derived by applying a proportionality factor to the predicted tilt profiles, which they resemble in both magnitude and direction.

Experience has shown that the subsidence and tilt profiles predicted using the Incremental Profile Method usually match the systematic observed profiles reasonably well. It is not possible to match the predicted and observed curvature and strain profiles to the same standard, due to the large amount of scatter generally found in the measured data. The range of systematic strains is, however, adequately predicted.

The scatter in the strains is caused by random variations in stratigraphy, rock strength, fracture characteristics and spacing of joints which dictate the way in which the near surface rocks will respond as subsidence occurs. The scatter sometimes results in anomalous peaks of strain, though in many cases these peaks can be predicted.

It should be remembered that the predicted strains obtained using the Incremental Profile Method are the systematic strains, which can, in some cases, be exceeded by local anomalous peaks of strain. In the Incremental Profile Method, such anomalous peaks of strain are dealt with statistically.

The Incremental Profile Method provides a greater understanding of the mechanism of subsidence over a series of panels and allows a detailed prediction of subsidence parameters to be made for any point on the subsidence profile.

Other benefits of the Incremental Profile Method are as follows:

- The method can be used even where the seam thicknesses, pillar and panel widths and depths of cover vary from panel to panel across a series of longwalls. This is possible because the total subsidence predictions are an accumulation of incremental subsidence profiles for each longwall, based on their individual panel and pillar widths, the seam thickness and depth of cover and the position of each longwall within the series of longwalls.
- After superimposing the influence of the incremental subsidence profiles for each longwall it has been found, in the syntheses carried out to date, that the total subsidence profiles are predicted quite accurately.
- Because the total subsidence profiles are well represented, this method provides improved predictions of tilts, and general background or 'systematic' curvatures and strains.
- The method can be used to model the effects of alternative mine layouts with different pillar and panel configurations and to compare the impact of tilts, curvatures and strains for each alternative.
- By varying the proposed widths of panels and pillars, it is possible to show the variations in the predicted magnitude of the maximum total subsidence and the shape of the subsidence trough.

Because of the inherent advantages of the Incremental Profile Method, this method has been used to make the detailed subsidence predictions for this project.

D4 Typical Subsidence Predictions

Typical predicted incremental and cumulative total subsidence, tilt and strain profiles over a series of longwalls are shown in Figure D5. It can be seen that the subsidence parameters vary throughout the subsidence trough.

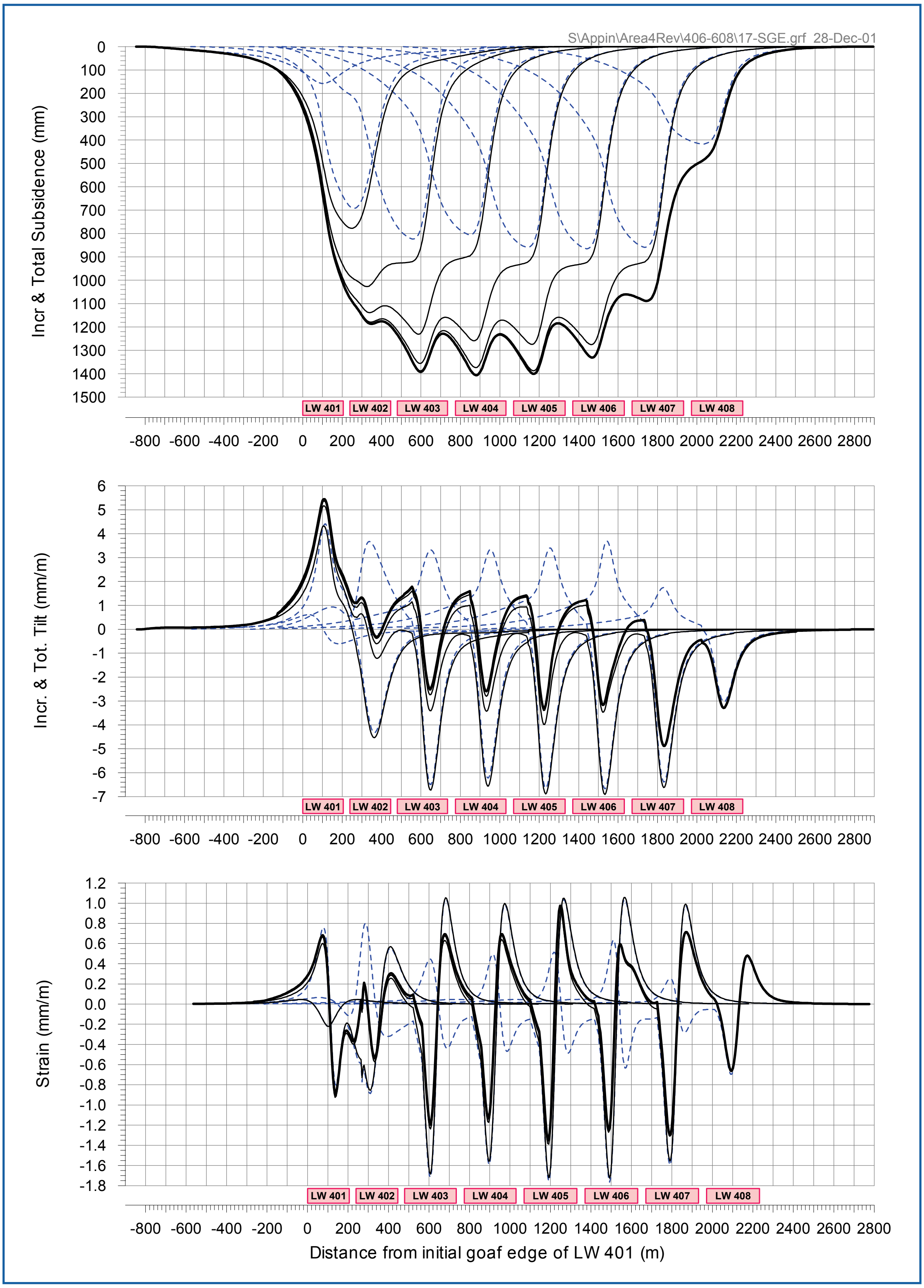


Figure D5 Typical Predicted Incremental and Total Subsidence, Tilt and Strain Profiles

Subsidence predictions are generally made at points in a regular grid orientated parallel to and at right angles to the centrelines of the longwalls. The points in the grid are generally positioned 10 metres to 20 metres apart, depending on the depth of cover, and extend outwards as far as the limit of subsidence.

The predicted subsidence data is then used to develop a three-dimensional model of the subsidence trough, from which subsidence contours are derived.

A typical longwall layout showing predicted subsidence contours over a series of four longwalls is illustrated in Figure D6 The variations in these contours reflect the changes in seam thickness and depths of cover from place to place over the area of the longwalls.

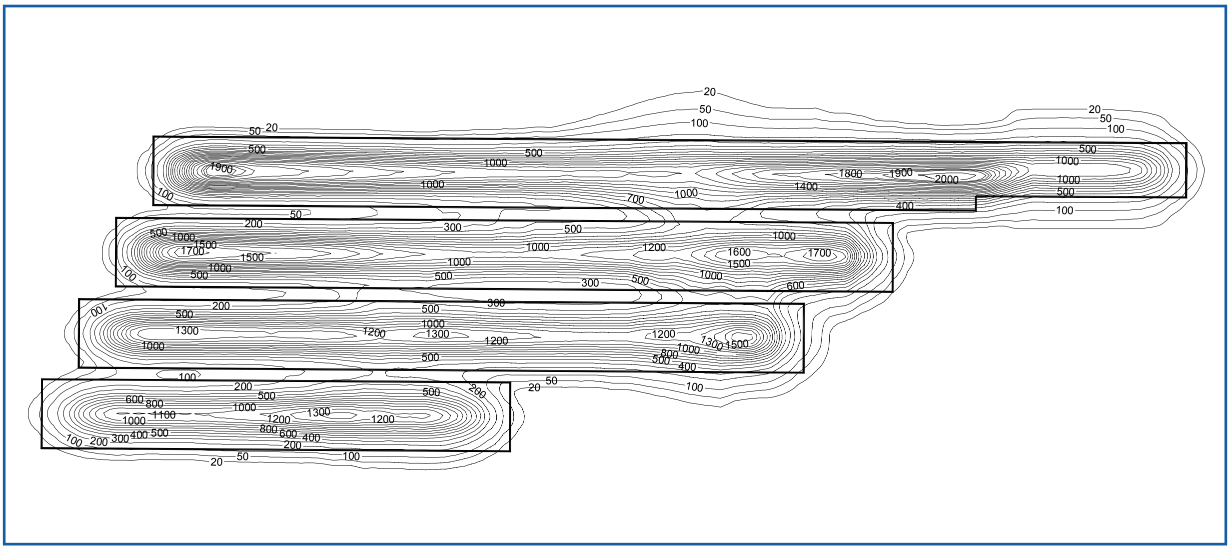


Figure D6 Typical Predicted Subsidence Contours over a Series of Longwalls

Timing and Direction of Predicted Tilts and Strains

It is generally found that the maximum tilts and strains within a mined area are aligned in the transverse direction across the longwalls and occur after the longwalls are extracted. However, there are some cases in which the maximum tilts and strains are not aligned in the transverse directions. For example, at the ends of the longwalls the maximum tilts and strains are aligned at right angles to the subsidence contours.

There are also instances where the maximum tilts and strains at a particular point occur during the extraction of a particular longwall and are later reduced by extraction of subsequent longwalls. Treatment of these cases is discussed below.

Travelling, Transient and Final Subsidence Parameters

The Incremental Profile Method allows subsidence parameters to be predicted at any point on the surface when the longwall face is at any position in a panel, and hence for any:

- **travelling** scenario, *during* extraction of a longwall,
- **transient** scenario, *following* the extraction of *each* longwall, or
- **final scenario,** *following* the extraction of all longwalls in a series.

This is particularly relevant for assessing the impacts of curvature and strain on an item of surface infrastructure, which can be greater at a travelling stage than on completion of mining a particular longwall or all longwalls in a series.

A review of subsidence data from several collieries in the Southern Coalfields, in particular West Cliff Colliery, has indicated that the magnitude of the observed travelling strains in the longitudinal direction are generally smaller than the observed transient or final longitudinal strains over the ends of the longwalls.

Using the Incremental Profile Method, the travelling strains at any point in the subsidence trough can be determined by taking into account the maximum predicted longitudinal strains over the ends of each longwall, the maximum predicted incremental subsidence value for the longwall and the predicted subsidence at the point of interest.

Tilts and Strains in the Transverse and Longitudinal Directions

The predicted maximum tilts and strains within the mined areas are, generally, those which are aligned in the transverse direction across the longwalls. However, at the ends of the longwalls, the maximum tilts and strains are at right angles to the subsidence contours, which can be aligned in various directions relative to the longwalls. Also, in some cases, the travelling wave that occurs during the extraction of each longwall can produce travelling longitudinal tilts and strains which can be greater than the transverse values. These cases typically occur at those points within the subsidence trough at which maximum subsidence is developed.

At points where it is found that longitudinal tilts and strains are greater than those in the transverse direction, it is extremely rare for these tilts and strains to be greater at a transient stage than on completion of mining. There may be isolated cases where the maximum tilts and strains are aligned in a diagonal direction to the orthogonal axes of the longwalls. In such cases, the magnitude of these tilts and strains will exceed the transverse and longitudinal values by a small proportion only and are unlikely to influence the final assessment of potential damage or development of management plans to mitigate this potential damage.

Statistical Analysis of Curvature and Strain

The peak values of curvature and strain that have frequently been noted along measured monitoring lines have generally been found to be localised effects associated with escarpments, river valleys, creek alignments or geological anomalies. Consequently, many of them are predictable.

A histogram of measured strains at Appin Colliery, where the depth of cover is approximately 500 metres, is shown in Figure D7.

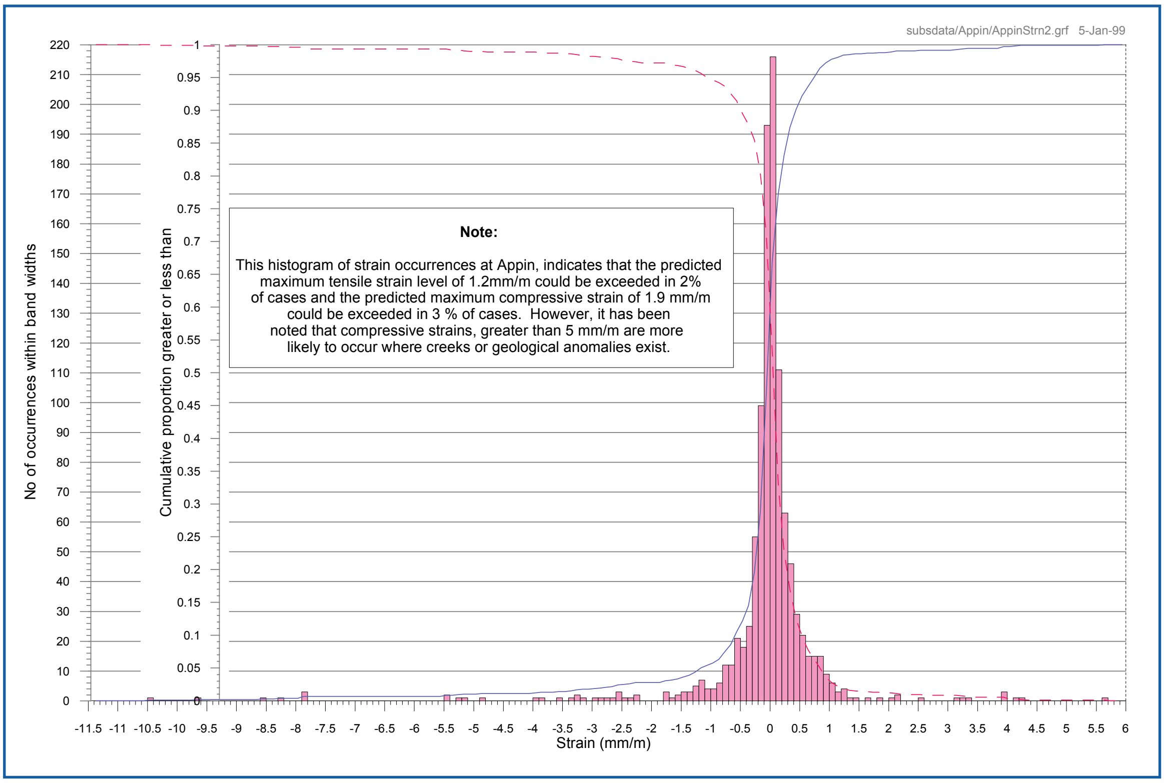


Figure D7 Graph showing Histogram of Strain Occurrences at Appin Colliery

It can be seen that the majority of the measured strains were between 1.5 mm/m, tensile, and 2.0 mm/m, compressive, with approximately 2% to 3% of all strains lying in the range 2.0 mm/m to 5.5 mm/m. Very few of the measured strains exceeded 5.5 mm/m.

Higher values of measured strain can also arise from buckling of near-surface strata at shallow depths of cover, from disturbance of survey pegs and from survey errors. There are, therefore, some anomalies that can not be predicted and it has to be accepted that there is a small risk of peak values of strain and curvature occurring, at some point, in addition to the predicted systematic background strains and the predictable local peaks. It is preferable to deal with such anomalies on a statistical basis and wherever measured records are available, frequency analyses should be prepared in order to determine the likely incidence of such occurrences.

APPENDIX E Methods of Assessment of Subsidence Impacts

E.1 Damage Classification Methods

E.1.1 Introduction

A number of different methods have been used in the past in Australia and in other countries to classify levels of damage to building structures. Some of these have related specifically to damage caused by mining subsidence, whilst others have related to damage caused by settlement of soils or by swelling and shrinking of soils due to changes in moisture content. The movements caused by swelling and shrinking of reactive clay soils have often been likened to those caused by mining subsidence and the patterns of damage caused by such movements are in many cases very similar.

The classification of levels of damage is very subjective, particularly when the method of classification is then used to define an acceptable level of damage. What might be considered acceptable to one person may well be intolerable to another. Levels of damage that leave the building in a serviceable condition, which do not affect the structural stability of the building and which only require cosmetic repairs, are generally considered to be acceptable. Damage classification methods used in the past have generally been based upon visible physical damage in the form of cracking and distortion of the building, rather than on tilting of the building, though some methods have also included reference to tilt.

E.1.2 Damage Classification used in Poland in 1956 (attributed to Budryk and Knothe).

An early method of classification specifically related to mining subsidence was in use in Poland in the 1950's and was reproduced as Table 1 in a paper by Dzegniuk et al, 1997. The authors attributed this method of damage classification to W. Budryk and S. Knothe, 1956. The damage classification table is reproduced in Table E.1.

This classification adopted five categories of damage, which were designated I to V and were described as slight damage, small damage, serious damage, very serious damage and extremely serious damage. Limiting values of tilt, curvature and strain were provided for each category of damage and the types of buildings and structures that might be able to accommodate the various levels of damage were indicated. The levels of protection that might be required for each category of damage were also shown in the table.

It is perhaps worth noting that small single family houses were linked with 'other less important constructions' and were apparently permitted to suffer very serious damage with tilts up to 15 mm/m, curvatures as high as 4 km radius and strains up to at least 9 mm/m. Dzegniuk et al did not clarify the significance of the column headed strain+$\Delta\varepsilon$ that is shown in the table. Clearly these values are the strain values plus an additional 33%, but the reasoning behind this is not known.

Dzegniuk et al went on to explain that the evaluation of the resistance of a single surface structure to the effects of mining subsidence was carried out using a points scoring system, based upon an evaluation of seven attributes of the structure. A table outlining the method was presented by the authors and this was attributed to Lejczak et al, 1969. The point scoring table is reproduced as Table E.2.

The authors also presented a graph showing the relationship between the number of points scored and the potential level of damage for ground strains up to 6 mm/m. This graph has been reproduced as Figure E.1. Having determined a score for a particular structure using Table E.2, this graph could be used to evaluate the resistance of a structure and to determine a permissible limit of deformation (i.e. allowable ground strain).

The authors noted that when compared with the classifications used by Budryk and Knothe, the point scoring table of Lejczak et al had been extended to include a Category zero, which was introduced to cover objects of very high sensitivity to mining processes. They also indicated that the level of building damage was related to the methods of mining, the rate of mining and any changes or stoppages to the rate of mining and that future assessments should reflect this.

The authors concluded that the methods used at that time to determine the resistance and risk of damage to structures were incoherent and did not guarantee appropriate protection of the land surface.

Table E.1 Damage Classification used in Poland in 1956

Cat.	Permissible Deformations				Possible damage degree: Construction object types	Suitability for construction development
	Tilt mm/m	Curvature km	Strain mm/m	Strain $+\Delta\varepsilon$ mm/m		
I	2.5	20	1.5	2.0	Slight damages may occur, easy to restore. Monumental constructions, factory plants particularly sensitive in relation to life hazard or recognised as especially important, main gas pipelines: when damaged a gas blow out hazard may happen, water reservoirs.	Secure areas not requiring construction protection.
II	5.0	12	3.0	4.0	Small damages to construction objects can occur, relatively easy to restore. Some more important industrial plant constructions, iron blast furnaces, OH furnaces, coke ovens, winding machines and drawing shafts, industrial reinforced concrete-solid slab constructions or buildings with overhead cranes, public buildings and facilities (hospitals, theatres, churches with vault ceilings), river beds and water reservoirs, main railways and railway stations, tunnels, vault bridges, water mains not protected from ground movement, big apartment houses of over 20 metres in length. Large cities.	Areas where a partial protection of all objects is non cost-effective
III	10.0	6.0	6.0	8.0	Serious damages to construction objects can occur yet without danger of being destroyed. Main roads, railways and small railway stations, industrial buildings (with no overhead cranes) less sensitive to ground movement, cooling stack facilities, high chimneys, smaller apartment houses (10-20 metres at bottom view), municipal sewage treatment plants, main intercepting sewers, sewage pipelines, gas steel pipelines.	Areas requiring partial protection of constructions (the protection extent depends on the type of object, its sensitivity, bed-ground properties, deformation extent
IV	15.0	4.0	9.0	12.0	Very serious damages occur with danger of destruction. Sports stadiums, small single family houses and other less important constructions.	Areas where construction objects require better protection.
V	>15.0	<4.0	>9.0	-	Extremely serious damages and destruction of objects.	Areas not suitable for construction development
	And areas with high degree of probability of the occurrence of discontinuity in ground movement (collapse, depressions, large fissures)					

The Polish classification of damage, shown in Table E.1 was also referred to in the textbook by Professor Helmut Kratzsch, 1983, which he attributed to Rimant, 1968. The Polish classification, the classification of the National Coal Board of the UK and the classifications adopted in the Donetz and Karaganda coal mining districts of the Soviet Union were shown in Table 30 of the textbook That table is reproduced as Table E.3.

Table E.2 Point Scoring System for the determination of the Resistance Category for a Building Structure.

1. Dimensions (bottom view)								
Building Length	Up to 10	11-15	16-20	21-25	26-30	31-35	36-40	Over 40
Score	4	7	11	16	22	29	37	42

2. Building solid shape	**Score**	**5. Building structure**	**Score**
• regular, compact	0	• rigid	0
• little dismembered	3	• low-rigid	4
• well dismembered	6	• non-rigid	8
• regular vast	6		
• dismembered vast	8		
3. Building foundation		**6. Existing protection from mining operation effects**	
• on flat level, buildings with or without basement	0	• bolting	0
• on uneven elevation surface	3	• fractional bolting	4
• on uneven elevation surface with partial basement	6	• none	6
• as above but with a passage gate	8		
4. Building foundation (ground)		**7. Technical condition of the building**	
• compressible	0	• good	0
• low-compressible	4	• average	6
• incompressible	12	• bad	12

Building Classification					
Score	Up to 20	21-27	28-36	37-47	48 and over
Resistance	4	3	2	1	0

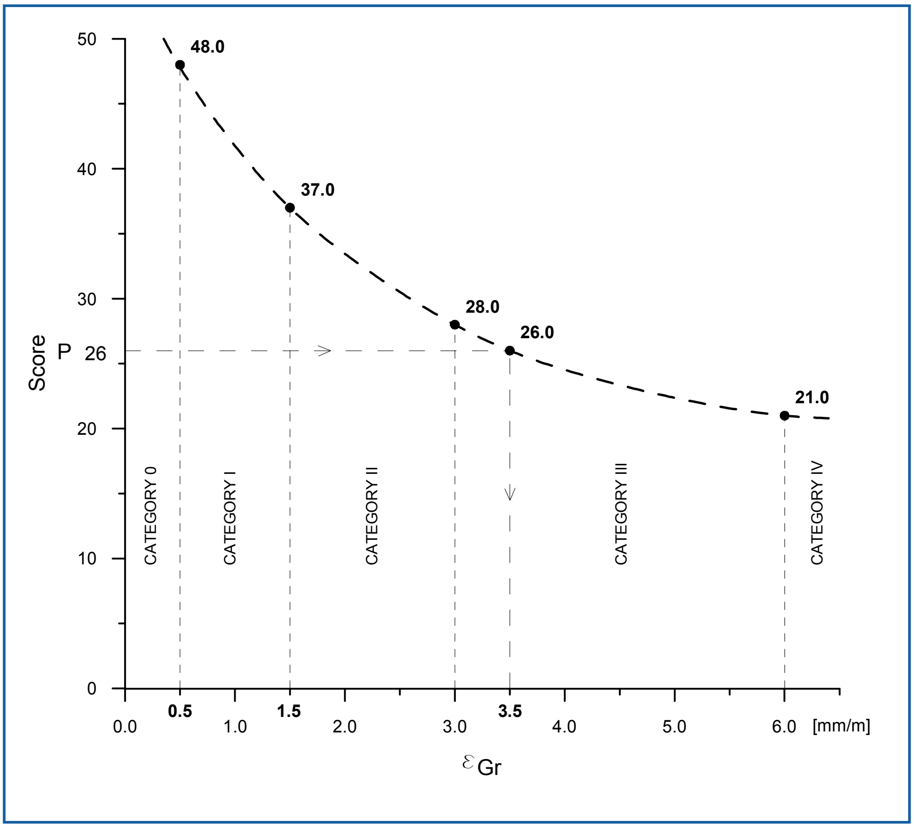


Figure E.1 Determination of the Limit Horizontal Deformation for an Object by the Points Scoring System.

Table E.3 Classification of Structure and Damage in Certain Mining Districts (Kratzsch 1983)

Class	United Kingdom	Poland	Soviet Union	
			Donetz	Karaganda
I	Small cracks in plaster. Linear change in structure: Δs = 3 cm; for 60 m length: ε = 0.5 mm/m	Only hair cracks in plaster accepted Acceptable tilt: 2.5 mm/m Acceptable linear change: 1.5 mm/m ρ_z > 20 km	Accepted: Tilt 4 mm/m Radius of curvature 20 km Linear change 2 mm/m	Accepted: Tilt 6 mm/m Radius of curvature 3 km linear change 4 mm/m
II	Several small cracks in internal walls: Δs = 3 - 6 cm ε = 0.5 - 1 mm/m	Damage must be repairable v'_z = 5 mm/m ε = 3 mm/m ρ_z > 12 km	Over 5 storeys v'_z = 4.5 mm/m ρ_z = 18 km ε = 2.5 mm/m	v'_z = 11 mm/m ρ_z = 1.5 km ε = 7 mm/m
III	Small cracks in external walls; doors jam: Δs = 6 - 12 cm ε = 1 – 2 mm/m	Damage should not affect functioning of structure v'_z = 10 mm/m ε = 6 mm/m ρ_z > 6 km	3 & 4 storeys v'_z = 5 mm/m ρ_z = 12 km ε = 3.5 mm/m	v'_z = 16 mm/m ρ_z = 1 km ε = 10 mm/m
IV	Severe damage Open cracks Δs = 12 - 20 cm ε = 2 – 3 mm/m	Structures must resist adequately v'_z = 15 mm/m ε = 9 mm/m ρ_z > 4km	2 storeys v'_z = 8 mm/m ρ_z = 5.5 km ε = 6 mm/m	-
V	Very severe damage Partial reconstruction necessary Δs over 20 cm ε > 3 mm/m	v'_z > 15 mm/m ε > 9 mm/m ρ_z < 4 km	1 storey v'_z = 10 mm/m ρ_z = 3 km ε = 7.5 mm/m	-
VI	-	-	1 storey v'_z = 25 mm/m ρ_z = 1 km ε = 14 mm/m	-

It is rather unfortunate that Professor Kratzsch chose to illustrate these different classifications in a tabular form, since it gives the impression, at least at first glance, that the classifications in Poland and the Soviet Union are directly comparable with the classifications of damage adopted by the National Coal Board of the United Kingdom, when in fact this is clearly not the case.

When the Polish classifications are compared to the United Kingdom classifications in the table they can be seen to be quite different. The acceptable subsidence parameters in the Donetz Coalfield of the Soviet Union were based upon the heights of the building structures, rather than the levels of damage.

It is interesting to note that in Poland, tilts up to 10 mm/m and strains up to 6 mm/m were indicated as being representative of damage that should not affect the functioning of the structure. It also appears that in the Donetz mining district of the Soviet Union, tilts of 10 mm/m and strains of 7.5 mm/m were acceptable for single storey buildings.

E.1.3 Damage Classification Published by the National Coal Board, UK, 1975.

Another method of damage classification, specifically related to mining subsidence, was that published by the National Coal Board of the UK in the Subsidence Engineers Handbook, in 1975. The NCB Classification is reproduced in Table E.4.

The NCB Classifications, ranging from negligible to very severe, were based upon the total change in the length of the building structure and provided descriptions of the typical damage that would be anticipated for each class of damage, based upon the total change in length.

The graph shown in Figure E.2 was also published in the Subsidence Engineers Handbook by the NCB and can be used to assess the potential damage to a building structure based upon the predicted ground strain in mm/m and the length of the structure in metres, assuming a full transfer of the ground strain into the structure.

Table E.4 NCB Classification of Subsidence Damage

Change in Length of Structure	Class of Damage	Description of Typical Damage
Up to 0.03 m	1. Very slight or negligible	Hair cracks in plaster. Perhaps isolated slight fracture in the building, not visible on outside.
0.03 - 0.06 m	2. Slight	Several slight fractures showing inside the building. Doors and windows may stick slightly. Repairs to decoration probably necessary.
0.06 - 0.12 m	3. Appreciable	Slight fracture showing on outside of building (or one main fracture). Doors and windows sticking. Service pipes may fracture.
0.12 - 0.18 m	4. Severe	Service pipes disrupted. Open fractures requiring rebonding and allowing weather into structure. Window and door frames distorted. Floors sloping noticeably. Walls leaning or bulging noticeably. Some loss of bearing in beams. If compressive damage, overlapping of roof joints and lifting of brickwork with open horizontal fractures.
More than 0.18 m	5. Very Severe	As above, but worse, and requiring partial or complete rebuilding. Roof and floor beams lose bearing and need shoring up. Windows broken with distortion. Severe slopes on floors. If compressive damage, severe buckling and bulging of roof and walls

According to Professor J D Geddes, 1977, the original data considered by King and Orchard (1959) in compiling this graph only included 17 field cases for which measurements of ground strain were available, linked to different degrees of damage. The structures involved were brick built for the most part, ranging in length from about 50 feet to 450 feet.

Shadbolt, 1977, in the discussion following presentation of his state-of-the-art paper in Cardiff said, "As stated by Professor Geddes, the original damage chart devised by Orchard was based on 17 case studies, the structures involved being mainly of conventional brickwork. Since its introduction, many hundreds of cases have been compared with the damage categories used in the chart and in the vast majority of cases good comparisons have been achieved. So far as the majority of subsidence claims are concerned, these apply to traditional brick/stone structures and therefore the original chart is still very useful and widely used."

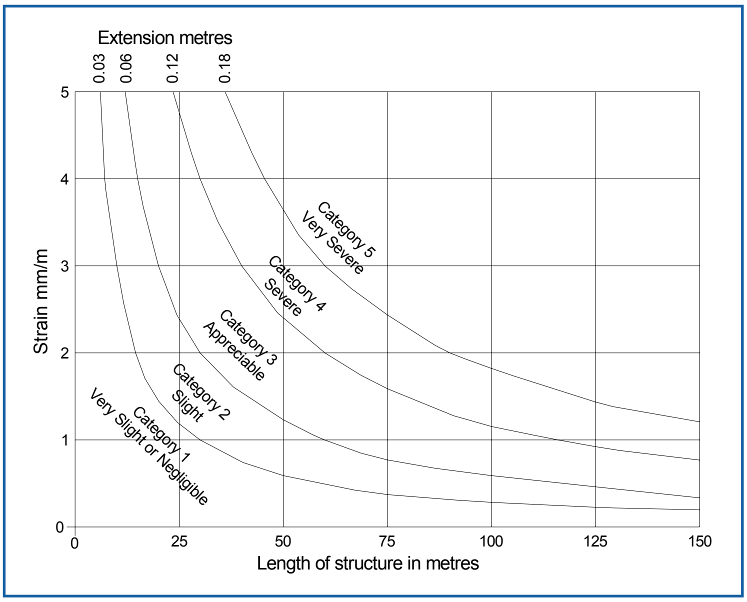


Figure E.2 Relationship of Damage to Length of Structure and Horizontal Ground Strain

E.1.4 Damage Classification Proposed for the Northern Appalachian Coalfield, Western Pennsylvania, USA, 1981.

A slightly different damage classification was proposed by Bruhn et al (1981) for the Northern Appalachian Coalfield of Western Pennsylvania, USA. This was developed following a detailed review of 134 cases of subsidence damage to dwellings above active mines for the US Bureau of Mines, under Contract J0295014. All of the dwellings studied were conventional homes of 1 to 2.5 storeys, all with basements. The classification proposed by Bruhn et al is shown in Table E.5.

Table E.5 Subsidence Damage Classification - Northern Appalachian Coalfield

Class	Characteristic Basement Damage	Severity Index
I Slight	○ Hairline Cracks in one or more basement walls and possibly floor slab. ○ Some cracks in perimeter walls causing loss of water tightness. ○ Repointing required in some or all walls	0 | |
II Moderate	○ Cracks in one or more basement walls and floor slab. ○ Some wall/footing reconstruction and floor slab replacement required, as well as local repointing.	1 | |
III Severe	○ Cracks in one or more basement walls and floor slab. ○ Possible wall instability and loss of superstructure support, requiring shoring and bracing. ○ Extensive repair work involving wall/footing reconstruction and floor slab replacement.	2 | | | |
IV Very Severe	○ Cracks typically in all basement walls, as well as floor slab. ○ Possible instability of several walls and loss of superstructure support, requiring extensive shoring and bracing. ○ Possible significant tilt to home. ○ General reconstruction of basement walls, footings and floor slab required.	4 | | | | 5

In this classification, four categories of damage were identified, ranging from slight to very severe, and damage levels were classified with reference to cracking, instability and loss of support, as well as the type of repair that might be required. Damage was also categorized by a Severity Index, with numerical values ranging from 0 to 5.

E.1.5 Damage Classification presented by O'Rourke et al, 1977.

In the late 1980's, Thorne published a paper entitled "Mine Subsidence and Structures". In that paper he reproduced a table showing various categories of building damage related to angular distortion and tensile strain at the ground surface, which he attributed to O'Rourke et al 1977. The table is reproduced as Table E.6. Thorne notes that the data used by the authors in compiling the table related to buildings adjacent to braced excavations.

Table E.6 Damage related to Building Distortion for Brick Bearing Wall Structures

Description of Damage	Angular Distortion and Tensile Strain at the Ground Surface*
Threshold of architectural damage.	1.0×10^{-3}
Architectural damage. Sticking doors. Maybe conspicuous concentrations of cracks. Cracks and separations as large as 0.3 to 0.6 cm wide.	1.0×10^{-3} to 3.0×10^{-3}
Damage is an inconvenience to building occupants. Jammed doors and windows. Broken window panes. Building services may be restricted. Cracks and separations may be as large as 1.5 to 5.0 cm wide.	3.0×10^{-3} to 7.0×10^{-3}
Spalling of stone cladding and possible collapse of cornices along the façade wall (differential movements parallel to brick bearing walls).	7.0×10^{-3} to 8.0×10^{-3}
* Note: Angular distortion and tensile strain are assumed to be approximately equal	

Thorne also referred to work by Maher et al in 1981 and presented a graph which showed categories of damage from negligible to very severe plotted against horizontal strain and angular distortion, for masonry bearing wall structures. The graph has been reproduced in Figure E.3.

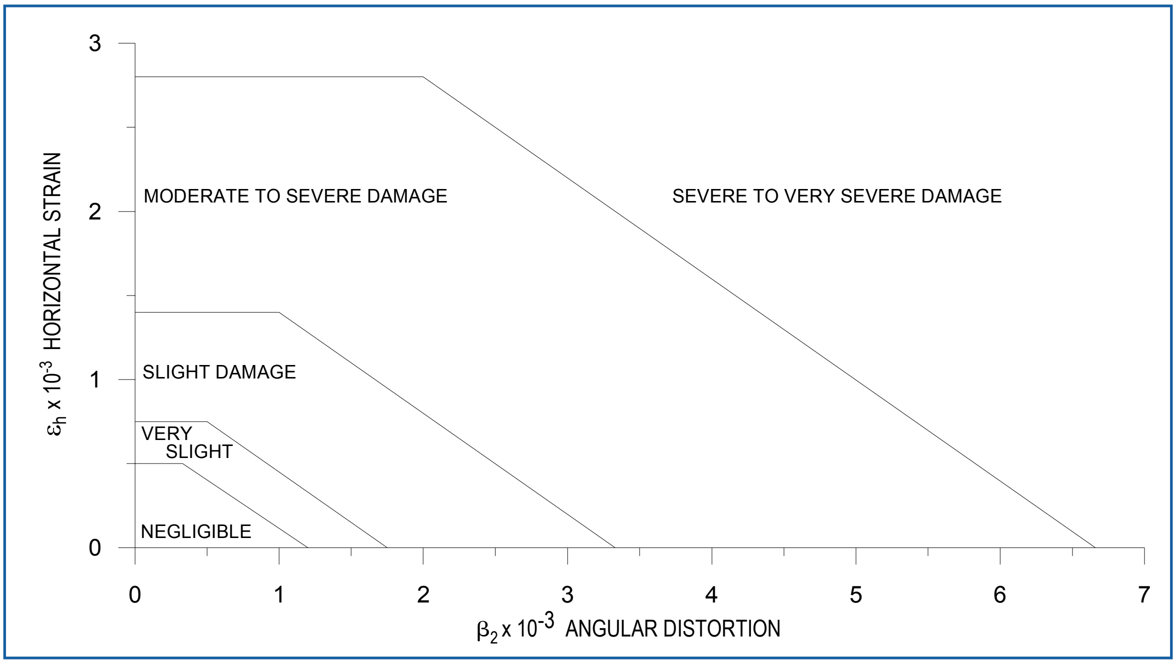


Figure E.3 Damage Criteria for Masonry Bearing Wall Structure (Maher et al, 1981)

E.1.6 Damage Classification used by the Building Research Establishment, UK, 1981.

It would appear that the NCB Classification, described earlier, formed the basis of the damage classification system that was adopted by the Department of the Environment, Building Research Establishment of the UK (BRE), which was published in BRE Digest Number 251, in 1981 and was reproduced in the paper by Geddes, 1984.

The BRE Classification used the same descriptions for each category of damage as the NCB Classification and extended them to include typical repairs. The ‘appreciable’ category of the NCB Classification was renamed ‘moderate’ and the negligible and very slight categories were separated. In addition, the limiting changes in length of structure of the NCB classification were replaced with limiting crack widths. The BRE Classification from 1981 is shown in Table E.7.

Table E.7 Classification of Visible Damage to Walls with Particular Reference to Ease of Repair of Plaster and Brickwork or Masonry (BRE 1981)

Degree of damage	Description of typical damage (*ease of repair in italic type*)	Approximate crack width (mm)
0 Negligible	Hairline cracks of less than about 0.1 mm width are classed as negligible	< 0.1
1 Very slight	*Fine cracks which can easily be treated during normal decoration.* Perhaps isolated slight fracturing in building. Cracks rarely visible in external brickwork.	< 1.0
2 Slight	*Cracks easily filled. Redecoration probably required. Recurrent cracks can be masked by suitable linings.* Several slight fractures showing inside building. Cracks not necessarily visible externally. *Some external repointing may be required to ensure weathertightness*. Doors and windows may stick slightly.	< 5.0
3 Moderate	*The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced.* Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired	5 to 15 or a number of cracks □3.0
4 Severe	*Extensive repair work involving breaking out and replacing sections of walls, especially over doors and windows.* Window and door frames distorted. Floors sloping noticeably. Walls leaning or bulging noticeably. Some loss of bearing in beams. Service pipes disrupted	15 to 25 but also depends on number of cracks
5 Very Severe	*This requires a major repair job involving partial or complete rebuilding.* Beams lose bearing. Walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	Usually > 25 but depends on number of cracks

At that time, the researchers, therefore, appear to have been satisfied that the change in length of a building and the consequential crack width could be correlated. The table presented by Geddes was accompanied by the following footnotes:

- *It must be emphasized, in assessing the degree of damage, that account must be taken of the location in the building or structure at which it occurs and also the function of the building or structure.*
- *Crack width is one factor in assessing degree of damage and should not be used on its own as a direct measure of it.*
- *Local deviation of slope, from the horizontal or vertical of more than 1/100 will normally be clearly visible. Overall deviations in excess of 1/150 are undesirable.*

E.1.7 Damage Classification used in Illinois, USA, 1986.

A slightly modified version of this table was also shown in the US Bureau of Mines Information Circular by Marino et al, 1986, which was attributed to Burland, Broms and de Mello. This was used to classify damage caused to building structures by subsidence over an abandoned room-and-pillar coal mine at Hegeler, Illinois.

E.1.8 Damage Classification for Houses used in the Peoples Republic of China, 1984.

Thorne (late 1980's) published a damage classification for houses used in the Peoples Republic of China, which he attributed to Cui Ji-xian (1984). This classification was based on observations on "civil buildings with strip foundations, brick and masonry walls" in several mine areas and is shown in Table E.8. It can be seen that the lowest class of damage was based on a maximum tilt of 3 mm/m and a maximum strain of 2 mm/m. For houses up to 30 metres in length, this would equate to 'very slight' to 'slight' damage in the NCB Classification.

Table E.8 Classes of Damage to Houses (Cui Ji-xian, 1984)

Damage Class	Description of Typical Damage	Ground Strains			Degree of Repair Needed
		Tilt (mm/m)	Radius of Curvature (km)	Horiz. Strain (mm/m)	
I	A small number of fine cracks in wall, not exceeding 4 mm.	3	5	2	Basically no
II	4 mm-10 mm wall cracks. Plaster comes off in local places. Doors and windows slightly slant. Abnormality is seen at beam supporting points.	3 - 6	5 - 2.5	2 - 4	Minor repair
III	Walls slope with cracks 10 mm - 20 mm wide. Beam ends are seen to have been displaced. Floor cracks or heaves.	6 - 10	2.5 – 1.7	4 - 6	Medium repair
IV	Wall cracks exceeding 20 mm. Wall shows horizontal cracks and even displacement and undergoes severe slant, outward or inward bulging. Failure is seen at local places and wall tends to collapse in severe cases. Beam ends severely displaced and roof heaves	10	1.7	6	Major repair

E.1.9 Revised Damage Classification of the Building Research Establishment, UK.

BRE Digest 251 was revised and was republished by the Building Research Establishment in 1995 in a different format, with slight rewording of the descriptions of damage and with the omission of the adjectives 'negligible' to 'very severe', which were originally used to describe the degree of damage. The revised table simply uses the numerals 0 to 5 to indicate the six degrees of damage. The degrees of damage were again assigned typical crack widths. The table was accompanied by the following footnotes:

- *Crack width is one factor in assessing category of damage and should not be used on its own as a direct measure of it.*
- *Local deviation of slope, from the horizontal or vertical, of more than 1/100 will normally be clearly visible. Overall deviations in excess of 1/150 are undesirable.*

The damage classification shown in the BRE Digest 251 in 1995 is reproduced in Table E.9. This table also appears in Appendix 1 of the BRE publication entitled, "Cracking in Buildings", by Bonshor and Bonshor, 1996.

Table E.9 Classification of Visible Damage to Walls with Particular Reference to Ease of Repair of Plaster and Brickwork or Masonry (BRE 1995)

Category of Damage	**Description of Typical Damage** (*Ease of repair in italic type*)
0	Hairline cracks of less than about 0.1 mm which are classed as negligible. *No action required*.
1	Fine cracks which can *be treated easily using normal decoration*. Damage generally restricted to internal wall finishes; cracks rarely visible in external brickwork. Typical crack widths up to 1 mm.
2	Cracks *easily filled*. *Recurrent cracks can be masked by suitable linings.* Cracks not necessarily visible externally; *some external repointing may be required to ensure weather-tightness*. Doors and windows may stick slightly and *require easing and adjusting*. Typical crack widths up to 5 mm.
3	Cracks which *require some opening up and can be patched by a mason*. *Repointing of external brickwork and possibly a small amount of brickwork to be replaced*. Doors and windows sticking. Service pipes may fracture. Weather tightness often impaired. Typical crack widths are 5 to 15 mm, or several of, say, 3 mm.
4	Extensive damage which *requires breaking-out and replacing sections of walls*, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably, some loss of bearing in beams. Service pipes disrupted. Typical crack widths are 15 to 25 mm, but also depends on number of cracks.
5	Structural damage which *requires a major repair job, involving partial or complete rebuilding*. Beams lose bearing, walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25 mm, but depends on number of cracks

The BRE Digest emphasises that the following points should be noted when using the classification table:

- *The classification applies only to brick or blockwork and is not intended to apply to reinforced concrete elements.*
- *The classification relates only to visible damage at a given time and not its cause or possible progression which should be considered separately.*
- *Great care must be taken to ensure that the classification of damage is not based solely on crack width since this factor alone can produce a misleading concept of the true scale of the damage. It is the ease of repair of the damage which is the key factor in determining the overall category of damage for the whole building.*
- *It must be emphasised that Table 1 (Table E.9 above) relates to visible damage and more stringent criteria may be necessary where damage may lead to corrosion, penetration or leakage of harmful liquids and gases or structural failure.*

E.1.10 Damage Classification adopted by Standards Australia, 1988-1996.

It would appear that the BRE classification was adopted by Standards Australia, in Australian Standard AS 2870-1988, where it appeared as Table A1, of Appendix A. Some changes were made to the wording of the descriptions of typical damage for each category, but the categories were numbered and named in an identical fashion and were related to the same limiting crack widths. The 'Very Severe' Category 5 of the BRE classification was not included in the Australian Standard.

The earlier Standard was superseded by AS 2870-1996, which includes the same damage classification in Table C1, of Appendix C of the Standard, which is reproduced in the following Table E.10.

Table E.10 AS2870-1996 Classification of Damage with Reference to Walls

Description of Damage and Required Repair	Approximate Crack width limit	Damage Category
Hairline cracks	<0.1 mm	0
Fine cracks which do not need repair	<1.0 mm	1
Cracks noticeable but easily filled. Doors and windows stick slightly.	<5.0 mm	2
Cracks can be repaired and possibly, a small amount of wall will need to be replaced. Doors and windows stick. Service pipes can fracture. Weathertightness often impaired.	5 mm to 15 mm (or a number of cracks 3 mm or more in one group)	3
Extensive repair work involving breaking out and replacing sections of walls, especially over doors and windows. Window and door frames distort. Walls lean or bulge noticeably. Some loss of bearing in beams. Service pipes disrupted.	15 mm to 25 mm but also depends on number of cracks	4

Footnote 1 to Appendix C of the Standard states that whilst crack width is the main factor by which damage to walls is categorized, the width may be supplemented by other factors, including serviceability, in assessing the category of damage.

Footnote 2 states that in assessing the degree of damage, account shall be taken of the location in the building or structure where it occurs, and also of the function of the building or structure.

Footnote 3 states that where the cracking occurs in easily repaired plasterboard or similar clad-framed partitions, the crack width limits may be increased by 50% for each damage category.

Appendix C to AS 2870 1996 also includes a damage classification for damage to concrete floors, which is reproduced as Table E.11.

Table E.11 AS2870-1996 Classification of Damage with Reference to Concrete Floors

Description of Typical Damage	Approximate crack width limit in floor	Change in offset from a 3 metre straightedge centered	Damage Category
Hairline cracks, insignificant movement of slab from level.	< 0.3 mm	< 8 mm	0
Fine, but noticeable cracks. Slab reasonably level.	< 1.0 mm	< 10 mm	1
Distinct cracks. Slab noticeably curved or changed in level.	< 2.0 mm	< 15 mm	2
Wide cracks. Obvious curvature or change in level.	2 mm to 4 mm	15 mm to 25 mm	3
Gaps in slab. Disturbing curvature or change in level	4 mm to 10 mm	> 25 mm	4

E.1.11 Damage Classification adopted by MSEC 1998 to 2006.

The methods of classifying damage to building structures caused by mining subsidence were reviewed by MSEC in 1998 and the following methods were developed. These methods have been used for the assessment of damage in all studies carried out by MSEC since that time. Separate classifications were developed for damage with reference to walls and damage with reference to tilt.

The classification of damage with reference to walls was based upon Table C1 of Australian Standard AS2870, 1996. The classification was, however, extended to include a Category 5, which relates to the very severe damage Category of the National Coal Board Classification and represents crack widths greater than 25 mm. This classification is shown in Table E.12.

Table E.12 Classification of Damage with Reference to Walls

Damage Category	Description of typical damage to walls and required repair	Approximate crack width limit
0	Hairline cracks.	< 0.1 mm
1	Fine cracks which do not need repair.	0.1 mm to 1.0 mm
2	Cracks noticeable but easily filled. Doors and windows stick slightly	1 mm to 5 mm
3	Cracks can be repaired and possibly a small amount of wall will need to be replaced. Doors and windows stick. Service pipes can fracture. Weather-tightness often impaired	5 mm to 15 mm, or a number of cracks 3 mm to 5 mm in one group
4	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Window or door frames distort. Walls lean or bulge noticeably. Some loss of bearing in beams. Service pipes disrupted.	15 mm to 25 mm but also depends on number of cracks
5	As above but worse, and requiring partial or complete rebuilding. Roof and floor beams lose bearing and need shoring up. Windows broken with distortion. If compressive damage, severe buckling and bulging of the roof and walls.	> 25 mm

Damage assessments carried out by MSEC have generally been based upon the strain transmitted into the building structure (due to a combination of bending and axial strain) and have been made using the graphs in Figure E.4.

This is a modified version of the National Coal Board classification shown in Figure E.2, with the addition of crack widths, deflection ratios for two storey brick structures and an additional line in the graph to separate the negligible and very slight damage categories.

In 1998, there was no standard method for classifying the level of damage with reference to tilt, but Australian Standard AS 2870 - 1996 indicated that local deviations in vertical or horizontal slope of more than 1 in 100, (10 mm/m), would normally be clearly visible and that slopes greater than 1in 150 (approximately 7 mm/m) were undesirable.

In Table C2 of the Standard, which provides a classification of damage to concrete floor slabs, damage Category 0 is characterised by a crack width less than 0.3 mm and a change in offset from a 3 metre straightedge of less than 8 mm. If the offset of 8mm were central on the straightedge, this would represent a local change in slope of approximately 5 mm/m. Damage within this Category, according to the description given in the Standard, would be insignificant.

In the United Kingdom, the policy adopted by the, former, National Coal Board was that tilts greater than 7 mm/m could lead to diminution in value of domestic properties and that, in such cases, the Board would have a liability to compensate the owner. Below 7 mm/m, no compensation was payable.

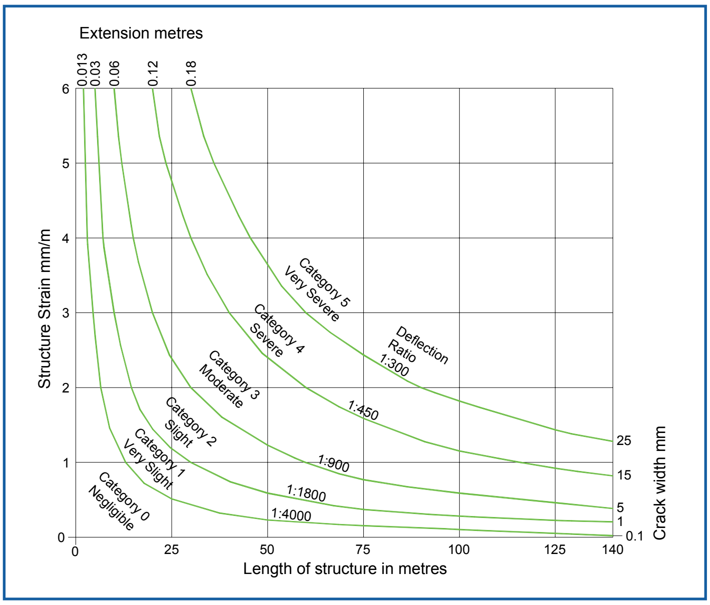


Figure E.4 Damage Classifications with Deflection Ratios for Two Storey Brick Structures

Where tilts were greater than 10 mm/m, it was accepted that some work might be necessary to rectify tilt but it was considered impossible to be specific as to the extent of the repairs since this depended upon the form of construction and could vary from building to building. Where the tilts exceeded 33 mm/m, it was indicated that consideration should be given to jacking the building to level and, if this proved to be too costly, to demolition and rebuilding.

The Mine Subsidence Board NSW has adopted the policy that tilts caused by mine subsidence, which affect serviceability, constitute damage that is to be compensated. When the tilts are between 4 mm/m and 7 mm/m, the Board recognises that the tilt, in some instances, could cause problems to roof drainage and wet area floors and, in those circumstances, would expect to carry out remedial works. It is also possible that some adjustment to doors and windows could be required.

Where the tilt is greater than 7 mm/m and the roof drainage, wet area floors or pools can not be correctly graded or relevelled, without major structural work, then, the Board would consider jacking the building to level. Where the tilt exceeds 10 mm/m, demolition and rebuilding may be necessary in the worst cases.

Based upon the above considerations, the damage classification, shown in Table E.13, has been used by MSEC since 1998 for the assessment of damage with reference to tilt.

Table E.13 Classification of Damage with Reference to Tilt

Damage Category	Tilt (mm/m)	Description
A	< 5	Unlikely that remedial work will be required.
B	5 to 7	Adjustment to roof drainage and wet area floors might be required.
C	7 to 10	Minor structural work might be required to rectify tilt. Adjustments to roof drainage and wet area floors will probably be required and remedial work to surface water drainage and sewerage systems might be necessary.
D	> 10	Considerable structural work might be required to rectify tilt. Jacking to level or rebuilding could be necessary in the worst cases. Remedial work to surface water drainage and sewerage systems might be necessary.

E.1.12 Damage Classification by The Institution of Structural Engineers, 2000.

A publication by The Institution of Structural Engineers, entitled, "Subsidence of low-rise buildings", in August 2000, includes further modifications to the BRE Classification and presents two classification tables, which are recommended for guidance when considering crack severity and possible repair in low-rise buildings. The first of the two tables relates to potential serviceability/seriousness of the structural distress and the second relates to the type of repair and rectification considerations. These tables are reproduced as Tables E.14 and E.15.

Table E.14 Institution of Structural Engineers (2000) Classification of Visible Damage to Walls

Category of damage	Approximate crack width (mm)	Definition of cracks and description of damage
0	Up to 0.1	Cracks defined as HAIRLINE; generally considered to have negligible structural implications, and can be expected to occur in almost all buildings at any location. They are not generally related to subsidence/foundation movement. (refer to Bonshor and Bonshor, 1996)
1	0.2 to 2	Cracks defined as FINE. These cracks may occasionally have some structural significance, but are not generally deemed serious. Often these cracks are more visible inside buildings than in external brickwork. Would generally be located at points of structural weakness in a building, e.g. window/door openings. Indicates slight foundation movement, particularly if isolated. An array/series or large number of closely located fine cracks is unusual, but could signify more substantial foundation movement.
2	2 to 5	Cracks defined as MODERATE. These cracks are likely to have some structural significance and will almost always occur at points of weakness or hinge points. Generally cracks will be visible internally and externally and will indicate foundation or other structural movement enough to distort door and window frames and make doors and windows stick. Weathertightness may be an issue that needs to be investigated as may the structural integrity of the building.
3	5 to 15	Cracks defined as SERIOUS. There will almost certainly be some compromise of the integrity of the structure and weathertightness may be impaired. Serious distortion may be occasioned to door and window frames, and glass fracturing is possible, as could be service fractures and strains.
4	15 to 25	Cracks defined as SEVERE. Structural integrity severely compromised. Floors sloping, walls leaning or bulging. Bearings of beams/lintels suspect. Pipe fractures and straining likely. Windows broken.
5	Greater than 25	Cracks defined as VERY SEVERE. Potential danger from failed or fractured structural elements and for instability. Safety issues must be considered.

The authors of the publication note that, "Other informed opinions have taken the view that cracks of less than 2 mm are trivial in structural terms, provided they are not varying in size seasonally by more than 1 mm, or are not part of an array of cracks of greater total size, which is in part or whole increasing in size. Some opinion may permit this limit to be up to 5 mm after monitoring has shown that the crack is not progressing."

The authors go on to state that, "It is now generally accepted by Experts in the matter of subsidence damage that it is not really the size of the crack or cracks that is important, but whether it is likely to increase in size if nothing is done.

If a crack has reached or is likely to approach 5 mm in width at its greatest dimension then it is essential to be satisfied that:

- The stability and integrity of the property has not been affected by the damage, and
- The damage is not likely to increase yet further.

Provided these two important factors are satisfied, then the size of the crack or its effect on the appearance of the property is primarily cosmetic and only justifies localised treatment. In the case of an array of cracks, the above factors need to be satisfied if the widths of individual cracks total 15 mm or more.

The authors conclude that, “Cracks of the order of 2 mm to 5 mm are sometimes described as being at the damage threshold or serviceability limit beyond which the houseowner, Lenders and Insurers may consider that further technical investigation or assurance is required. Cracks below this size, provided they are not increasing in size, should be considered as acceptable.”

When Table E.14 is compared with the BRE Classification in Table E.7, it can be seen that there are some differences in terminology. Table E.7 defines Category 2 damage, with crack widths up to 5 mm, as “slight” damage, whilst Table E.14 defines cracks of 2 mm to 5 mm width as “moderate”. A new category of crack, defined as “serious”, has been included for crack widths between 5 mm and 15 mm.

Table E.15 Classification of Visible Damage to Walls with Particular Reference to Type of Repair, and Rectification Considerations.

Category of damage	Approximate crack width (mm)	Definition of cracks and repair types/considerations
0	Up to 0.1	HAIRLINE – Internally cracks can be filled or covered by wall covering, and redecorated. Externally, cracks rarely visible and remedial works rarely justified.
1	0.2 to 2	FINE - Internally cracks can be filled or covered by wall covering, and redecorated. Externally, cracks may be visible, sometimes repairs required for weather tightness or aesthetics. Note: Plaster cracks may, in time, become visible again if not covered by a wall covering.
2	2 to 5	MODERATE – Internal cracks are likely to need raking out and repairing to a recognised specification. May need to be chopped back, and repaired with expanded metal/plaster, then redecorated. The crack will inevitably become visible again in time if these measures are not carried out. External cracks will require raking out and repointing. Cracked bricks may require replacement.
3	5 to 15	SERIOUS – Internal cracks repaired as for MODERATE, plus perhaps reconstruction if seriously cracked. Rebonding will be required. External cracks may require reconstruction perhaps of panels of brickwork. Alternatively, specialist resin bonding techniques may need to be employed and/or joint reinforcement.
4	15 to 25	SEVERE – Major reconstruction works to both internal and external wall skins are likely to be required. Realignment of windows and doors may be necessary.
5	Greater than 25	VERY SEVERE – Major reconstruction works, plus possibly structural lifting or sectional demolition and rebuild may need to be considered. Replacement of windows and doors, plus other structural elements, possibly necessary. Note: Building and CDM Regulations will probably apply to this category of work.

Another significant difference between the two tables is that Category 2 damage, in Table E.14, is indicated as being likely to have some structural significance, although the integrity of the structure will not necessarily be compromised, but might require investigation. Category 3 Damage, in Table E.14, is indicated as being almost certain to cause some compromise of the integrity of the structure.

It is noted that only Category 5 damage, in Table E.14, with crack widths greater than 25 mm is considered likely to cause instability and potentially become dangerous due to failed or fractured structural elements. At that stage, safety issues must be considered.

Table E.15 presents an alternative means of classifying damage with reference to the extent of repairs that might become necessary. This table, however, is based upon building and interior decorating practices in the UK and is not completely applicable to Australian building structures.

For example, the reference in Category 2 to the repair of internal cracks using expanded metal and plaster is based upon the assumption that the internal walls are constructed of masonry and rendered with plaster, which is common in the UK, but is not generally the case in Australia.

Also, reference is made in the descriptions of Category 0 and Category 1 damage to plaster cracks being covered with wall coverings to prevent them becoming visible again after they have been repaired. This is based upon the common practice in the UK of applying wallpapers to internal walls in order to decorate them, a practice that is rarely adopted in Australia.

E.1.13 Methods of Damage Classification recommended by MSEC

Some of the different methods of damage classification that have been used in the past are described in the earlier sections of this chapter.

Based upon these methods, and in particular the classifications recommended by the Institution of Structural Engineers in Section E.1.12, a more comprehensive method of damage classification has been proposed by MSEC and this is shown in Table E.16.

This classification includes external and internal wall crack widths, loss of bearing, the extent of damage and the types of repair likely to be required. It includes Damage Categories 0 to 5, negligible to very severe, in line with the classifications given previously in the Subsidence Engineers Handbook of the National Coal Board and Australian Standard AS2870. It also includes limiting tilt values for each damage category.

Based upon the generally adopted standards, the acceptable levels of damage from an aesthetic point of view would be categories 0, 1 and 2. Categories 3 and 4 would be considered unserviceable and Category 5 would be considered potentially unsafe. The proposed classification includes the post-mining tilt of the building, but the limiting tilt values given in the classification relate only to uniform tilts. Isolated floor tilts up to 12.5 mm/m should be considered as acceptable, so long as they do not affect the serviceability of the building, in line with the recommendations of the Institution of Structural Engineers (2000).

An alternative damage classification, which is based upon the extent of repairs, is presented in Table E.17. This alternative classification recognises that there is often a difference between the extent of the damage from a structural or physical point of view and the extent of the repairs that may be necessary. For example, cracked bricks or tiles might indicate a cosmetic level of damage, but if the bricks or tiles cannot be replaced like for like, then whole panels of brickwork or tiling may have to be replaced to carry out a repair to the satisfaction of the owner. Similarly, if slippage occurs on a damp proof course, the structural impact might be classified as moderate, but the repair could involve total reconstruction of the external brick skin of the building.

Table E.16 Proposed Classification of Damage based upon the Extent of Damage and the Types of Repair Likely to be Required

Damage Category	External cracking	Internal cracking	Loss of bearing	Extent of damage	Types of repair likely to be required
NO DAMAGE	None	None	None	No visible damage.	No repairs required.
0 NEGLIGIBLE	Several hairline cracks in one or more walls.	Several cracks up to 1mm in one or more walls.	Displacement at end of beam or lintel or at damp-proof course less than 1 mm.	Difficult to distinguish between mine subsidence impact and normal pre-existing cracks. Any cracks in the building are generally considered to have negligible structural implications. This type of damage can be expected to occur in almost all buildings at any location and are not generally related to subsidence or foundation movement. Tilts less than 2mm/m.	Internally, repairs are generally not required, but minor cracks can be filled and the walls and ceilings can be redecorated if necessary. Externally, cracks are rarely visible and remedial works are not normally required. Minor adjustment may be required to one or two doors.
1 VERY SLIGHT	Several cracks up to 2mm in one or more walls that can be easily repaired.	Several cracks 1mm to 2mm in one or more walls that can be easily repaired.	Displacement at end of beam or lintel or at damp-proof course 1 mm to 2 mm.	These cracks may occasionally have some minor structural significance. Often these cracks are more visible inside buildings than in external brickwork. Would generally be located at points of structural weakness in a building, e.g. window/door openings. Some doors or windows might stick slightly and need adjustment. Tilts 2mm/m to 5mm/m.	Internally cracks can be repaired. Wall coverings may need to be replaced. Wall tiles may need to be re-grouted. Cracked tiles may need to be replaced. Minor adjustment may be required to multiple doors and windows. Externally, cracks may be visible and sometimes repairs will be required for weathertightness or aesthetic reasons. Some adjustment to roof gutters might be required.
2 SLIGHT	Several cracks 2mm to 5mm, in one or more walls that require only localised repairs.	Several cracks 2mm to 5mm in one or more walls that require only localised repairs.	Displacement at end of beam or lintel or at damp-proof course 2 mm to 5 mm.	Larger cracks could have some structural significance and will almost always occur at points of weakness or hinge points. In some cases the structural integrity of the building might need to be checked. Generally cracks will be visible internally and externally and will indicate foundation or other structural movement enough to distort door and window frames and make doors and windows stick. Weathertightness may be an issue that needs to be investigated. Tilts 5mm/m to 7mm/m.	It is likely that internal cracks will need to be raked out and repaired to a recognised specification. Wider cracks may need to be cut back and repaired with expanded metal and plaster, prior to redecoration. Wall coverings will need to be replaced. Doors and windows will need adjustment. Small areas of tiling may need to be replaced. Externally, cracks will require raking out and sealing. Small sections of cracked brickwork may require replacement. Roof gutters and wet area floor levels might need adjustment.
3 MODERATE	Several cracks 5mm to 15mm	Several cracks 5mm to 15mm	Displacement at end of beam or lintel or at damp-proof course 5 mm to 15 mm.	There will almost certainly be some compromise of the integrity of the structure and weathertightness may be impaired. Serious distortion may be occasioned to door and window frames, and glass fracturing is possible, as could be service fractures and straining. Tilts 7mm/m to 10mm/m.	Internally cracks will need to be raked out and repaired to a recognised specification. In some cases, sections of plasterboard may need to be replaced. Large areas of tiling may need to be replaced. Realignment of door and window frames may be required. External cracks might require reconstruction of a panel of brickwork. Building might require relevelling.
4 SEVERE	Several cracks 15mm to 25mm	Several cracks 15mm to 25mm	Displacement at end of beam or lintel or at damp-proof course 15 mm to 25 mm.	Structural integrity severely compromised. Floors sloping, walls leaning or bulging. Bearings of beams/lintels suspect. Pipe fractures and straining likely. Windows broken. Tilts 10 mm/m to 20 mm/m.	Major reconstruction works to both internal and external wall skins are likely to be required. Replacement and realignment of window and door frames may be necessary. Building will probably require relevelling due to tilt or curvature. Cost of repairs is less than cost of rebuilding.
5 VERY SEVERE	Several cracks greater than 25mm.	Several cracks greater than 25mm.	Displacement at end of beam or lintel or at damp-proof course greater than 25 mm.	Potential danger from failed or fractured structural elements and potential instability of the building structure. Safety issues must be considered. Tilts greater than 20mm/m.	Major reconstruction works to both internal and external wall skins will be required and relevelling will almost certainly be required. Replacement of windows and doors, plus other structural elements, likely to be necessary. Demolition and rebuild will need to be considered. Cost of repairs could exceed cost of rebuilding.

Table E.17 Alternative Classification based on the Extent of Repairs

Repair Category	Extent of Repairs
Nil	No repairs required
R0 **Adjustment**	One or more of the following, where the damage does not require the removal or replacement of any external or internal claddings or linings:- - **Door** or **window** jams or swings, or - Movement of **cornices**, or - Movement at external or internal **expansion joints**.
R1 **Very Minor Repair**	One or more of the following, where the damage can be repaired by filling, patching or painting without the removal or replacement of any external or internal brickwork, claddings or linings:- - Cracks in **brick mortar** only, or isolated cracked, broken, or loose **bricks** in the external façade, or - Cracks or movement < 5 mm in width in any external or internal wall **claddings**, **linings**, or **finish**, or - Isolated cracked, loose, or drummy floor or wall **tiles**, or - Minor repairs to any **services** or **gutters**.
R2 **Minor Repair**	One or more of the following, where the damage affects a small proportion of external or internal claddings or linings, but does not affect the integrity of external brickwork or structural elements:- - Continuous cracking in **bricks** < 5 mm in width in one or more locations in the total external façade, or - Slippage along the **damp proof course** of 2 to 5 mm anywhere in the total external façade, or - Cracks or movement ≥ 5 mm in width in any external or internal wall **claddings**, **linings**, **finish**, or - Several cracked, loose or drummy floor or wall **tiles**, or - Replacement of any **services**.
R3 **Substantial Repair**	One or more of the following, where the damage requires the removal or replacement of a large proportion of external brickwork, or affects the stability of isolated structural elements:- - Continuous cracking in **bricks** of 5 to 15 mm in width in one or more locations in the total external façade, or - Slippage along the **damp proof course** of 5 to 15 mm anywhere in the total external façade, or - Loss of bearing to isolated walls, piers, columns, or other load-bearing elements, or - Loss of stability of isolated structural elements.
R4 **Extensive Repair**	One or more of the following, where the damage requires the removal or replacement of a large proportion of external brickwork, or the replacement or repair of several structural elements:- - Continuous cracking in **bricks** > 15 mm in width in one or more locations in the total external façade, or - Slippage along the damp proof course of 15 mm or greater anywhere in the total external façade, or - Relevelling of building, or - Loss of stability of several structural elements.
R5 **Re-build**	Extensive damage to house that requires it to be re-built as the cost of repair is greater than the cost of replacement.

E.2 Tolerable Deflection Ratios

Curvature resulting from differential tilting is one of the major causes of damage to buildings and structures. Normally, curvature is defined as the reciprocal of the radius of curvature, or by the radius of curvature itself, but it can also be defined by a deflection ratio for a particular length of structure.

All buildings have some degree of flexibility and to some extent are able to withstand differential ground movements due to shrinking and swelling clay soils, settlement of filled ground or mine subsidence. The degree of bending that can be tolerated in the foundations of a building is referred to as the allowable deflection ratio. This ratio is the ratio of the upward or downward deflection of the centre of the foundation, relative to a straight line between its ends, expressed as a proportion of the length of the foundation.

An acceptable, or allowable, deflection ratio is that which can be tolerated by a structure without impairing its structural adequacy or serviceability, despite visible cracking that may occur in the superstructure. It is therefore a measure of the resistance of a structure to bending and shear strain.

A number of authors have considered the effects of curvature on building structures, caused by differential vertical settlement and have realised that different forms of building construction are able to accommodate differing degrees of curvature without suffering significant damage. The allowable deflection ratios in buildings, according to each of these authors, are presented below.

Burland and Wroth, 1974, referred to work by Littlejohn who described the performance of solid brick walls subject to mine subsidence. The walls had exceptionally high length to height ratios of between 12.5 and 17. The observations showed that the brick walls underwent significant hogging, which was maintained after the passage of the subsidence wave. As the subsidence wave passed, the cracking in one of the walls extended rapidly through the brickwork as the hogging ratio (deflection ratio) reached a value of 1/1390. At a hogging ratio of 1/920 the damage was classed as ‘severe’.

Burland and wroth pointed out that the behaviour reported by Littlejohn was complicated by the presence of direct strains in the ground as well as the differential settlements. Nevertheless, the observations appeared to be broadly in agreement with the predictions of the cracking of simple beams undergoing hogging.

Dr Lax Holla, 1987, published a table of allowable deflection ratios, which was derived from a paper by Woodburn, 1979, entitled, “Interaction of Soils, Footings and Structures”. This is reproduced in Table E.18.

Table E.18 Allowable Deflection Ratios for Different Types of Wall Construction

Type of Wall	Deflection Ratio	Controlling Element	Radius of Curvature(km)
Solid Masonry	1/2000	Plaster	3.75
Articulated Masonry	1/800	Internal Brickwork	1.5
Brick Veneer	1/500	External Brickwork	0.94
Articulated Brick Veneer	1/300	Internal Plaster	0.56
Timber or Prefabricated	1/200	Internal Linings and Door and Window openings	0.38

The radii of curvature given in Table E.18 are based upon a building length of 15 metres and the deflection ratios for solid and articulated masonry are based upon walls having rendered finishes. For different lengths of building, different allowable radii would be applicable.

A similar table was provided in the paper by Dr Lax Holla, 1995, which has been reproduced in Table E.19.

Table E.19 Relative Differential Movement for Different Constructions

Type of Construction	Limit as a function of span	Maximum differential settlement (mm)	Radius of Curvature(km)
Clad frame	1/300	40	0.7
Articulated masonry veneer	1/400	30	0.94
Masonry veneer	1/600	20	1.4
Articulated full masonry	1/800	15	1.9
Full masonry	1/2000	10	3.75

This was based upon the table given in Australian Standard AS 2870, 1990, with the addition of an extra column showing the radius of curvature based upon a building length of 15 metres and the maximum differential settlement given in column three of the table.

Dr Lax Holla,1995, also published a table, which he attributed to Burland and Wroth, showing limiting values of deflection ratio at the onset of cracking, together with the corresponding radius of curvature for walls of 15 metres length, with different length to height ratios, bending in the sagging and hogging modes. This has been reproduced in Table E.20.

Table E.20 Limiting Values of Deflection Ratio for the Onset of Cracking

Mode	L/H	Deflection Ratio	Radius of Curvature
Sagging	1	1/2500	4.7
	2.5	1/1800	3.4
	5	1/1250	2.3
Hogging	1	1/5000	9.4
	2.5	1/3500	6.6
	5	1/2500	4.7

Bray and Branch, 1988, provided a table showing allowable deflection ratios, which they also attributed to Woodburn, 1979, and limiting radii of curvature for different types of construction, which is reproduced in Table E.21.

Modern brick structures are generally built with vertical joints at frequent intervals to allow for thermal expansion and other building movements. These structures can normally accommodate some curvature without damage but older brick structures, which were not designed to accommodate such movements, are more likely to be adversely affected by mine subsidence.

Table E.21 Deflection Ratios for Different Types of Wall Construction

Wall Construction	Wall Finish	Allowable Deflection Ratio	Limiting Radius of Curvature (km) (length 15 metres)	Limiting Radius of Curvature (km) (length 30 metres)
Load Bearing				
Solid Masonry	Rendered	1/4000	7.5	15
	Face brickwork	1/3000	5.6	11.3
Non Load Bearing				
Solid Masonry	Rendered	1/2000	3.8	7.5
	Face brickwork	1/1500	2.8	5.6
Articulated Masonry	Rendered	1/800	1.5	3.0
	Face brickwork	1/500	0.9	1.9
Masonry Veneer	Rendered	1/500	0.9	1.9
	Face brickwork	1/300	0.6	1.1
Non-Masonry	Timber or Prefabricated	1/200	0.4	0.8

Granger, 1991, gave tolerable values of deflection ratio and maximum acceptable deflections for reinforced and articulated brick walls. These are shown in Table E.22.

Table E.22 Allowable Deflection Ratios for Different Forms of Construction

Articulated Wall Construction Type	Deflection Ratio	Maximum deflection (mm)
Reinforced Brick Veneer.	1:300	40
Reinforced full-brick sheeted and/or face	1:400	30
Reinforced full-brick rendered or painted.	1:600	20

Granger also showed how the allowable deflection ratio for brick veneer structures could be increased with appropriate spacing of articulation joints. This is reproduced in Table E.23.

Table E.23 Allowable Deflection Ratios for Different Joint Spacings

Deflection Ratio	Articulation Joint Spacing for Brick Veneer Construction (m)	Maximum Distance from any Corner to the Articulation Joint (m)
1:400	6	3
1:500	9	4.5
1:600	Up to 12	4.5

The deflection ratio for brick veneer of 1:600, given by Granger, has been taken to apply to normal face brickwork, whilst the lower allowable deflection ratio of 1:800, given by Bray and Branch, applied to rendered masonry, which is more susceptible to damage.

Li and Cameron, 1995, included in their paper a copy of Table E1 from Australian Standard AS 2870.2, 1990, which shows suggested relative differential vertical movement limits for different types of house construction. This has been reproduced in Table E.24.

Table E.24 Relative Differential Movement Limits for Houses

Type of construction	Limit as a function of span (L)	Maximum differential movement (mm)
Clad frame	1/300	40
Articulated masonry veneer	1/400	30
Masonry veneer	1/600	20
Articulated full masonry	1/800	15
Full masonry	1/2000	10

Australian Standard, AS 2870 - 1996, also provides guidance on the allowable deflection ratios for various types of structure, to be used in the design of foundations for domestic buildings, and also gives tolerable levels of differential vertical movements in foundations. These deflection ratios have been established based upon many years of experience and research into the performance of building structures.

Waddington and Kay, 1997, compiled a comprehensive list of allowable deflection ratios for building structures, based upon a review of available literature, and this is included as Table E.25. The table also includes the allowable radii of curvature for different lengths of building based upon the allowable deflection ratios.

Where different authors have stated slightly different ratios, the more conservative ratio was used in compiling Table E.25. The allowable deflection ratio, for a particular type of building structure, has been taken to mean the deflection ratio that would cause only 'slight' damage if applied to a building structure of that type.

It has to be recognised that the building structures in some cases might have to accommodate bending due to reactive soil movements as well as the mining induced curvatures, though in some cases the bending of a structure due to mining-induced curvature could counteract the bending due to expansive soil movements and reduce the pre-existing stresses in the structure.

It can be seen, from Table E.25, that all types of non load bearing building structures, up to 40 metres in length, are able to accommodate curvatures less than 10 kilometres radius. In reality, however, the building structure has to accommodate both strain and curvature and the level of damage is determined by a combination of these effects.

When assessing the potential levels of damage due to mine subsidence, it is generally more conservative to calculate the maximum strain in the building structure, assuming that all of the ground strain and curvature are transmitted into the structure, though in practice, much of the ground strain can be lost in the transfer due to slippage between the soil and the structure.

Table E.25 - Allowable Deflection Ratios for Building Structures

Type of Building Structure		Allowable Deflection Ratio	Length in Metres			
			10	20	30	40
			Acceptable Radius of Curvature in Kilometres			
1	Solid masonry, rendered, loadbearing	1:4000	5.00	10.00	15.00	20.00
2	Solid masonry, loadbearing	1:3000	3.75	7.50	11.25	15.00
3	Solid masonry, rendered, non-loadbearing	1:2000	2.50	5.00	7.50	10.00
4	Solid masonry, non-loadbearing	1:1500	1.87	3.75	5.62	7.50
5	Articulated masonry, rendered	1:800	1.00	2.00	3.00	4.00
6	Articulated masonry	1:600	0.75	1.50	2.25	3.00
7	Reinforced articulated masonry, rendered	1:600	0.75	1.50	2.25	3.00
8	Reinforced articulated masonry	1:400	0.50	1.00	1.50	2.00
9	Masonry veneer, rendered	1:800	1.00	2.00	3.00	4.00
10	Masonry veneer	1:600	0.75	1.50	2.25	3.00
11	Articulated masonry veneer, rendered	1:600	0.75	1.50	2.25	3.00
12	Articulated masonry veneer	1:500	0.62	1.25	1.87	2.50
13	Reinforced articulated masonry veneer,	1:400	0.50	1.00	1.50	2.00
14	Reinforced articulated masonry veneer	1:300	0.38	0.75	1.12	1.50
15	Timber or steel clad in fibro or weatherboard	1:300	0.38	0.75	1.12	1.50
16	Steel or concrete frame with brick infill	1:1000	1.25	2.50	3.75	5.00
17	Steel or concrete frame without infill	1:500	0.62	1.25	1.87	2.50

E.3. Tilts in Building Structures.

E.3.1 Introduction

Mining-induced tilts in building structures can be a major problem when they are large enough to affect serviceability, particularly when buildings have to be relevelled. This issue is becoming increasingly important as mining is planned beneath more densely populated areas.

The assessment of tilt impacts on building structures needs to take into account:

- the existing pre-mining tilts of each element of the structure
- the observed tilts at the structure during mining and on completion of mining, and
- the sensitivity of the structure to tilting.

The existing pre-mining tilt of a structure is difficult to define since each element of a structure can exhibit different degrees of tilting. If the tilts of all elements of a building structure were consistent and uniform throughout, then the tilt could be readily determined, but in most cases the tilts in building structures are not uniform and the tilt cannot be accurately defined as a single value.

E.3.2 Policy adopted by British Coal in the United Kingdom

In the United Kingdom in 1986, British Coal, which was formerly known as the National Coal Board, published its Mining Subsidence Damage Manual which laid down its policy with regard to subsidence claims. British Coal adopted the policy that tilts to domestic properties greater than 7 mm/m could lead to diminution in value and that in such cases it would have a liability to compensate the owner. Below 7 mm/m, no compensation was payable.

Where tilts were higher than 10 mm/m, it was accepted that some work might be necessary to rectify tilt, but it was considered impossible to be specific as to the extent of the repairs, since this depended upon the form of construction and could vary from building to building. Where the tilts exceeded 33 mm/m, it was indicated that consideration should be given to jacking the building to level and, if this proved to be too costly, to demolition and rebuilding.

A personal communication between the writer and Mr. Graham Agnew of International Mining Consultants Limited (IMCL) in the UK, in 1998, revealed that the Coal Authority, which became responsible for historical, current and future mining subsidence damage claims in the UK when British Coal was privatized in 1997, had not committed anything in writing regarding tilt gradings and pertinent actions. The ‘norm’ in dealing with tilt in dwellings, however, was that no claim for tilts flatter than 1 in 150 was entertained (based on a general building tolerance of 1 inch in 12 feet) and that in practice nothing much was considered until tilts approached 1 in 100 (10 mm/m).

At that time, IMCL was responsible for investigating and settling claims for subsidence damage on behalf of the Coal Authority.

E.3.3 Policy adopted in Poland

The Polish damage classification shown by Dzegniuk et al, 1997, and Professor Kratzsch, 1983, (See Tables E.1 and E.3, respectively) was based upon various classes of damage associated with specific limiting values of tilt, strain and curvature. The lowest classification, Class I, was associated with a tilt of 2.5 mm/m and it was indicated that this would be the limiting value of tilt, together with a strain of 1.5 mm/m and a curvature of 20 km radius, if only hair cracks in plaster were acceptable.

According to Holla and Barclay, 2000, the acceptable tilt of 2.5 mm/m in Poland related to ‘negligible’ damage.

It was indicated that within this class ‘slight damages’ may occur, which would be easy to restore and that the limiting values of tilt and strain would apply to monumental constructions, factory plants particularly sensitive in relation to life hazard or recognised as especially important, main gas pipelines, which if damaged could cause a gas blow out hazard, and water reservoirs.

Class II tilts of 5 mm/m coupled with strains of 3 mm/m and curvatures of 12 km radius was considered to be the level at which ‘small levels’ of damage to structures could occur, but which would be relatively easy to restore. This limitation applied to important industrial plants and big apartment houses over 20 metres in length.

Class III tilts of 10 mm/m coupled with strains of 6 mm/m and curvatures of 6 km radius was considered to be the level at which ‘serious damages’ to structures could occur yet without danger of them being destroyed. This limitation applied to less sensitive industrial plants and to ‘smaller apartment houses (10-20 metres at bottom view)’.

Class IV tilts of 15 mm/m coupled with strains of 9 mm/m and curvatures of 4 km radius was considered to be the level at which ‘very serious damages’ to structures could occur with a danger of the structure being destroyed. This limitation applied to less important structures such as sports stadiums and small single family houses.

E.3.4 Policies adopted in the USSR

In the USSR, different classifications of damage applied in different coal mining districts

The USSR damage classification in the Donetz mining district, shown by Professor Kratzsch, 1983, (See Table E.3) indicates that the allowable tilt for single-storey buildings was 10 mm/m, whilst for two-storey buildings it was 8 mm/m. Taller buildings were permitted lower levels of tilt. According to Holla and Barclay, 2000, the acceptable tilt of 4 mm/m in the Donetz mining district related to ‘negligible’ damage.

In the Karaganda mining district, there appears to have been three classifications with maximum acceptable tilts of 6 mm/m, 11 mm/m and 16 mm/m. According to Holla and Barclay, 2000, the acceptable tilt of 6 mm/m related to ‘negligible’ damage.

E.3.5 Policy adopted in Germany

In Germany, according to Professor Kratzsch, 1983, it was recognised that the value of buildings could be affected by mining induced tilts of 2 mm/m and upward. The courts declared a scale that provided for a reduction in value of 1% for each 2 mm/m of tilt. In 1962, an extended agreement was reached between the Ruhr mining industry and the representative association of property owners that for tilts above 20mm/m the scale should be increased to 2% for each 2mm/m of tilt.

Professor Kratzsch notes, however, that the reduction in value also included structural loosening and other losses in value. The value of the building used in calculating the reduction in value due to mining was discounted to allow for diminution in value with age and was further adjusted to allow for the technical life expectancy of the building. Presumably, when compensation was paid to cover the reduction in value, the owner had to undertake any remedial works at his own expense.

E.3.6 Tilt Thresholds established in Ipswich, Queensland, Australia

Maconochie et al, 1992, reported that as monitoring of houses affected by mine subsidence at Ipswich progressed, and the volume of data increased, it became evident that, with regard to tilt, certain thresholds could be established in general terms. Those thresholds were:

- 1 in 150 (6.66 mm/m) to 1 in 100 (10 mm/m) tilt. Minor damage requires to be considered as possible potential loss of structural integrity. Tilt is becoming visibly noticeable.

- 1 in 100 (10mm/m) to 1 in 75 (13.33 mm/m) tilt. Tilt is visible, crack widths increasing. Structural integrity deserves serious evaluation by calculation. Closer visual inspection required at monitoring times.
- Greater than 1 in 75 (13.33 mm/m) tilt. Possible loss of structural integrity. Temporary works may be necessary to maintain such integrity.

It was further reported that one house attained a tilt of 1 in 47 (21 mm/m), though in this case it was found that the combination of lateral wind loads and out of plane vertical dead loads exceeded the capacity of the bracing walls in the house and the house was demolished following the provision of additional lateral support to one of the external walls of the building.

E.3.7 Policy adopted in Texas, USA

The Guidelines for the Evaluation and Repair of Residential Foundations, Version 1, by the Texas Section of the American Society of Civil Engineers states that, "…tilting foundation(s) only becomes a performance issue when floor slopes become noticeable. The guidelines state in Section 5.7 that a floor slope greater than 1 percent is usually noticeable."

E.3.8 Policy adopted in NSW Australia with regard to Tilt Damage

The Mine Subsidence Board NSW, published a Policy Statement on the 20th May 1993 regarding subsidence claims, which included the following reference to building tilts resulting from mine subsidence.

"Tilts caused by mine subsidence which affect serviceability are damage which is to be compensated. The assessment and measurement of tilt is to be made by visual inspection and surveys of level in plumb.

Where damage is of a minor nature, such as non-alignment of windows and doors, or where wet area floors or stormwater guttering require regarding, repairs are to be made to remedy those problems. (As a guide, this will occur only in the range of 4 mm/m to 7 mm/m of tilt).

Where stormwater guttering, wet area floors and swimming pools cannot be correctly graded or relevelled without structural work being carried out (such as removal of external brickwork, increasing the heights of piers, etc.), the whole building is to be relevelled. As a guide, this will only occur when the degree of tilt exceeds 7 mm/m.

Where tilt causes damage which can only be made good by demolition of the structure and rebuilding it, the amount of compensation will be the cost of reinstatement of the asset."

The Mine Subsidence Board NSW, 1999, in its publication entitled "Designing for Subsidence", notes that, "Normal usage of residences is not affected by tilts of up to 7 mm/m."

Holla and Barclay, 2000, restated the Mine Subsidence Board's 1993 policy regarding tilt and pointed out that the omission of tilt from the damage classifications of the National Coal Board, UK, was in contrast to the practice in the former USSR and Poland, where limiting tilt was an additional criterion. The range of limiting tilt for 'negligible' damage varied from 2.5 mm/m to 6 mm/m (Kratzsch 1983, Table 30, reproduced as Table E.3 of this report).

Holla and Barclay did not, however, point out that the limiting tilt in the Donetz mining district of the USSR was 10 mm/m for single storey buildings and 8 mm/m for two storey buildings, as shown in Table E.3. Nor did they point out that the allowable tilt in Poland was dependent upon the type of structure and that the lowest classification, with an acceptable tilt limit of 2.5 mm/m, was applicable only to the most sensitive structures. Much greater levels of tilt were permissible for less sensitive and smaller structures such as single family houses.

The reader should also note that the damage classifications used in the United Kingdom and those used in Poland and the USSR, which were published by Professor Kratzsch, are not directly comparable, and that the format in which they are presented in Table E.3 can be rather misleading in this regard.

E.3.9 The Tilt Classification which has been adopted by MSEC since 1998

The tilt classification which has been used by MSEC since 1998 is discussed in Section E.1.11 of this report and is shown in Table E.13. This tilt classification was developed by MSEC in 1997 in connection with the, then, proposed Commission of Inquiry into the Cooranbong Colliery Life Extension Project, which later became the Mandalong Mine.

It was accepted at the Inquiry in 1998, and in the subsequent development consent, that levels of tilt within Categories A and B of the Classification were acceptable, i.e. tilts up to 7 mm/m. Such tilts are not generally high enough to affect the serviceability or safety of a building, though in some cases it may be necessary to adjust roof drainage or relay wet area floors to maintain satisfactory drainage.

The same tilt classification was subsequently accepted by the Commissions of Inquiry for the Tahmoor North Underground Extension Project and the Dendrobium Mine.

It was also used in the EIS for the Beltana Mine and has been used to support numerous applications for longwall approval under both the old Section 138 procedures and the new SMP procedures.

The classification was developed by MSEC because there was no standard method for the classification of tilt in 1997 and it was desirable to classify tilt damage in the same way as damage due to curvature and strain had been classified in the past.

The classification was developed based upon overseas experience and on the stated policy of the Mine Subsidence Board, NSW, at that time. A draft of the classification was sent to the Mine Subsidence Board for editing prior to publication to ensure that the Board's policy was accurately stated. Some minor changes were made to the draft in September 1997 following discussions between the staff of the Board and MSEC.

E.3.10 Further Background Information on Tilts in Buildings.

Digest 475, published by the Building Research Establishment of the UK in 2003, on tilts in low-rise buildings, states that the consequences of unacceptable ground movement can be grouped into the following three broad categories:

- Aesthetic - the appearance of the building is adversely affected.
- Serviceability - some function of the building, or services such as drains, gas and water supply pipes, is impaired.
- Stability - there is a danger of collapse of the building or some part of it.

The Digest points out that, "Where differential ground movement causes a building to tilt as a rigid body, with little if any deformation or cracking of the walls, it is necessary to decide at what point the tilt will become unacceptable from a perceptional, serviceability or stability standpoint. The problems caused by tilt will depend on the type of building and its purpose. The tolerable tilt will, therefore, vary greatly depending on the type and usage of the building.

The theoretical maximum tilt of a free-standing wall prior to toppling can be readily calculated, but the critical tilt at which collapse of a building occurs will be dependent on, among other factors, the quality of construction and the extent to which the walls of the building are tied together. In practice, the limiting factors for tolerable tilt of a building are likely to be related to noticeability and serviceability rather than ultimate collapse."

This wide variation in the tilt limits for different buildings and applications is illustrated in Table 1 of the Digest, which is reproduced in Table E.26.

The Digest notes that, "For buildings containing some types of specialist equipment, there is a small tolerance of tilt. The necessity of such small tolerances needs to be critically examined because they are likely to require expensive foundation solutions.

Table E.26 Limit Values of Tilt for Different Types of Structure.

Structure or component	Tilt
Radar system	1/50,000
Satellite antenna tower	1/6,000
Machine operation – turbine	1/5,000
Warehouse – high racking	1/2,000
Concrete tanks	1/500
Crane rails	1/333
Chimneys, towers	1/250
Stacking of goods	1/100
Floor drainage	1/100 – 1/50

The Digest also notes that for low-rise residential buildings, particularly where there are owner occupiers, noticeability is crucial to tolerability. Not only will the powers of observation of occupiers show considerable differences, but also the sensitivity to tilt will differ between individuals. For example, in regions where mining subsidence is commonly encountered, a small amount of tilt is less likely to be noticed and more likely to be tolerated than in other parts of the country.

Some indicative values of tilt for low-rise dwellings are summarised in Table 2 of the Digest, which is reproduced in Table E.27.

Table E.27 Indicative Values for Tilting of Low-Rise Buildings

Classification	Tilt (ratio)	Tilt (mm/m)	Comment
Design limit value	1/400	2.5	The maximum acceptable differential settlement across the building is related to the design limit value for tilt. If the building is likely to tilt more than this limit value, ground treatment or deep foundations may be required.
Noticeability	1/250	4	The point at which the tilt of a building becomes noticeable will depend on the type and purpose of the building and the powers of observation and perception of the occupiers. Typically, tilt of low-rise housing is noticed when it is in the region of 1/250 to 1/200.
Monitoring	1/250	4	When tilting is noticed it is advisable to make some measurements to confirm that the building has tilted. If the measured tilt is greater than 1/250, monitoring should be carried out to determine whether the tilt is increasing.
Remedial action	1/100	10	Where tilts of this magnitude are measured, or the measured rate of increase of tilt indicates that this degree of tilt will be exceeded, some remedial action should be taken. This is likely to include re-levelling the building, perhaps by grouting or underpinning and jacking.
Ultimate limit	1/50	20	If tilt reaches this level, the building may be regarded as in a dangerous condition and remedial action either to re-level or to demolish the building will be required urgently.

It should be noted that Table E.27 indicates that tilts of 1/250 (4mm/m) to 1/200 (5mm/m) in low-rise buildings are noticeable and that tilts of 1 in 100 (10 mm/m) can be tolerated before remedial measures become necessary. From a serviceability point of view the tilt of a floor can be quite high before it impacts on the normal function and use of the building. Even greater tilt is possible before the safety of the building is impaired.

Buildings usually remain serviceable when the residual tilts are less than 7 mm/m. This level of tilt is rarely apparent in single storey buildings though taller structures can be noticeably affected. Swimming pools and large water storage tanks are also sensitive to tilting and, in these instances, tilts less than 7 mm/m can sometimes be unacceptable. The impact of tilt is dependent upon the pre-existing tilt in the building before mining occurs.

Australian Standard 2870 – 1996 indicates that tilts greater than 7 mm/m are undesirable and that tilts of 10 mm/m are clearly visible. However, the Standard permits a deviation in the levels of a floor slab of 8 mm/m in a 3 metre straight edge, which could locally give rise to tilts of at least 5.3 mm/m.

British Standard BS5606 1978, Accuracy in Building, updated in 1991, allowed variations in verticality of 5mm/m for brickwork and 10 mm/m for timber construction, whilst screeded floors were allowed a tolerance of 6 mm/m. The levels of windowsills and the plumbness of door jambs were also permitted a tolerance of 5 mm/m in the British Standard.

It was reported by Polshin and Tokar, in 1957, that the 1955 Building Code of the USSR permitted differential tilts of 5 mm/m due to settlement of foundations, which would apply in addition to normal building tolerances.

The publication by the Institution of Structural Engineers, 2000, is a revised edition of the original guide that was published in 1994 and is the authoritative reference on the subject of subsidence of low-rise buildings.

The guide points out that “From a practical point of view, a slope in a floor of up to 50 mm in a distance of 4 metres, i.e. 1 in 80 or 12.5 mm/m, is probably quite acceptable, even if not in conformity with modern building standards”.

It is perhaps worth noting that the recommended tilt for the proper drainage of wet area floors is between 1 in 60 and 1 in 80, i.e. approximately 16.7 mm/m to 12.5 mm/m. Surely, if a wet area floor is considered to be safe and serviceable at a slope of 1 in 60, a carpeted floor elsewhere in the building at a slope of 1 in 60 cannot be considered to be unsafe or unserviceable. Individual pre-mining floor tilts of 11 mm/m were measured at Tahmoor during a recent research project and floor tilts up to 15 mm/m were recorded in the past by the Mine Subsidence Board in an area unaffected by mining. In neither case would the building be considered unsafe or unserviceable.

From a safety point of view, floor slopes of up to 1 in 8 (125 mm/m) are acceptable for general use in buildings, whilst maximum slopes of 1 in 12 (83 mm/m) are acceptable in areas used by people in wheelchairs.

The acceptability of tilt in a building is not necessarily based upon safety and serviceability however. It is often based upon its noticeability and its apparent effect on the aesthetics of the building. Both the noticeability and the aesthetic impact are, however, very subjective.

The Institution of Structural Engineers, 2000, notes, with regard to subsidence of low-rise buildings, that uniform movement will only require repairs to drains and other incoming services unless the amount of tilt in the property is unacceptable. It goes on to state, “What is acceptable and what is unacceptable is very much a matter for debate. Many old properties have quite exceptionally distorted or uneven floors, walls, etc., and such distortion is often considered to add character and sometimes value to those buildings. Most buildings over a hundred years old have some degree of distortion and it is rare that sloping floors or distorted walls cause concern to occupiers or owners of these properties providing the properties are stable. The picturesque timber-framed buildings of Suffolk and Cheshire are typical examples of this.

There appears to be some agreement that tilts less than 7 mm/m are tolerable and that tilts above 10 mm/m are undesirable. Tilts less than 5 mm/m would generally have negligible impact on building structures though this level of tilt could affect swimming pools and could possibly affect roof, floor or land drainage systems, where existing falls are less than normally recommended standards.

E.3.11 Summary.

The impacts of tilt are difficult to categorise in terms of safety or serviceability or ease of repair. Up to a point, tilt will not cause structural instability and only in unusual circumstances will it affect the safety of a building. Tilts can affect the serviceability of a building due to reversal of falls in drainage systems and wet area floors but all of these are repairable. The serviceability of doors and windows might also be affected but these can be adjusted where the tilts are not excessive. Tilt can also be easily repaired where buildings are of modest size with suspended floors and access to the under floor area is available. Even buildings on slabs can in many cases be relevelled by jacking or grout injection.

The overall structural stability of a building would generally not be affected by tilting of 20mm/m and in many cases buildings have remained stable at much greater levels of tilt.

At a tilt of 20mm/m, the slope component of the roof or upper floor loads would be only 2% of the vertical loads. The overturning moment on the walls or columns of the building structure would increase marginally due to this factor but the loads involved are very small compared to the allowances made in design for wind loading. Buildings that are designed in accordance with normally accepted codes are adequately braced to accommodate such minor load variations.

However, walls that are freestanding, such as garden walls, or fences, and those that are not adequately braced in the lateral direction could be adversely affected in some instances by tilt and should be analysed by a structural engineer if their stability is in doubt.

Tilts of around 10 mm/m are noticeable and can to some be aesthetically undesirable. In older properties, some people consider such distortions 'quaint' and characteristic of their era. The matter is therefore clearly subjective.

The report by the Institution of Structural Engineers, in 2000, points out that, "…since the early 1970s, there has been a tendency for an increasing public expectation of the structural performance, e.g. tolerance to minor cracking of buildings, and also for a much higher quality service from their professional advisors. As a consequence, a number of court cases brought against professional advisors proved successful with the inevitable result that these advisors became more conservative in the advice which they gave. Surveyors and Engineers, when asked to value or assess properties suffering from suspected 'subsidence' damage or structural movement, found it easier to recommend remedial works rather than appraise the properties more objectively, even when the damage was relatively trivial. By adopting this approach, they reduced the risk of legal actions against them for negligence." It appears that the situation got out of hand.

The report by the Institution of Structural Engineers was produced in an attempt to bring some common sense into this situation and to provide a more technically appropriate and a more reasonable approach to the assessment of damage to low-rise buildings caused by subsidence and heave. The report advises that, "*The major drought in the UK in 1975 / 1976 caused such widespread damage that for many years after it Lenders were cautious about lending on subsidence and heave damaged properties, even after they had been repaired. Originally, Insurers and their Experts adopted an over cautious approach, which meant that thousands of properties suffering from relatively minor damage, caused by subsidence or heave, were underpinned. In the vast majority of cases this has proved to be technically unnecessary.*

The problem could have been dealt with much more economically and objectively by taking the time needed to identify and deal with the actual cause of damage. However, the demand to get properties repaired promptly generally meant that this option was not pursued.

Further dry summers have exacerbated an already unsatisfactory state of affairs to such an extent that there now exists a large industry geared solely to the underpinning of domestic properties suffering from ground movement.

Statistics show that an extraordinary amount of money, running into hundreds of millions of pounds, has been spent on largely unnecessary underpinning works and general maintenance repairs. Most Civil and Structural Engineers would consider such sums substantially unjustified in the context of technically appropriate repairs."

It seems logical and sensible that we should learn from the experience of engineers and surveyors in the UK and that we should adopt the same standards when assessing the impact of tilting caused by mine subsidence, particularly when committing to expensive remedial measures.

The report by the Institution of Structural Engineers, in 2000, states that, "*The relevelling of floors can cause more problems than it solves. It is advised that floors should not be relevelled unless the degree of slope in them is genuinely unacceptable or there is some other major reason for relevelling them."*

Digest 475, published by the Building Research Establishment of the UK, 2003, on tilts in low-rise buildings, states that, "For low-rise residential buildings where progressive ground movement is taking place, remedial action is likely to be required when tilt has reached 1/100."

The writer generally agrees with these recommendations and is of the view that it is not necessary to relevel a building until the uniform tilt exceeds 7 mm/m at the very least. In some cases a residual tilt of 10 mm/m or even 12.5 mm/m may be acceptable in particular elements of a building structure. In the majority of cases, the impacts of tilt can be overcome by the adjustment of roof gutters, relaying of wet area floors and the adjustment of doors, rather than relevelling the whole building.

When assessing the potential impacts of mine subsidence due to tilting, it has generally been accepted that tilts up to 7 mm/m can be considered as falling within the safe, serviceable and repairable criteria of the Mine Subsidence Board NSW and the Department of Primary Industry, Minerals. It can be seen that in reality much greater tilt can be accommodated by building structures before they become unserviceable or unsafe. Any amount of tilt is repairable, though for tilts greater than 7 mm/m the cost of correcting tilt might be unacceptably high.

The establishment of a cut-off value of tilt of 7 mm/m has not really been determined, therefore, on the basis of safety, serviceability or repairability, but on the basis of what should be considered as acceptable, both in terms of aesthetic impact and the cost of rectification.

When deciding upon remedial measures, each case should be considered on its merits and the relevelling of a building should be seen as a last resort, so long as the serviceability of the building and the safety of its occupants can be ensured by appropriate remedial measures.

Naturally, in some cases, the tilting of the equipment in a building will be more important than the tilting of the building and the limiting tilt in such cases will be determined by the sensitivity of the equipment. Crane rails are particularly sensitive and it is generally recommended that tilt should not exceed 1 in 300, i.e. 3.3 mm/m.

APPENDIX F Drawings

This Appendix includes the following Drawings:

MSEC477-01	General Layout
MSEC477-02	Surface Level Contours
MSEC477-03	Bulli Seam Thickness Contours & Geology
MSEC477-04	Depth of Cover Contours
MSEC477-05	Natural Features
MSEC477-06	Surface Infrastructure
MSEC477-07	Archaeological and Heritage Sites
MSEC477-08	Predicted Total Subsidence Contours