Mine Subsidence Damage to Building Structures

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Revision A
August 2007

DOCUMENT REGISTER

Revision	Description	Author	Reviewed	Date
A				2/8/07

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CHAPTER 1. MINE SUBSIDENCE DAMAGE TO BUILDING STRUCTURES

1.1. Introduction

The major mining-induced ground movements and subsidence parameters that are used to assess the impacts of subsidence on building structures are discussed in the following sections. The classification system for impact levels due to subsidence induced ground movements are also explained.

1.2. Mining Induced Ground Movements

1.2.1. Vertical Subsidence

Vertical, rigid body, subsidence has little or no effect on buildings or other surface structures where the subsidence occurs uniformly. The structures are, naturally, left at a lower level but normally this has little or no adverse effect upon them. Drainage systems and services to a building normally subside with the building and impact only results when differential subsidence occurs.

1.2.2. Horizontal Displacement

Horizontal displacements due to mining subsidence occur in such a way that points on the surface generally move towards the centre of the subsidence trough. Where one part of a structure is moved differently relative to other parts, then the structure experiences tensile stretching or compressive squashing. Differential horizontal movements give rise to strains but uniform horizontal movement of a surface structure would not normally have any adverse effect as the ground and structure move together.

1.2.3. Tilt

Ground tilt does not generally lead to structural impact. Severe tilts, however, may cause serviceability problems, such as doors tending to close themselves, or drainage problems, resulting from changes in the slopes of roof gutters, wet area floors and external paved areas. Single storey buildings usually remain serviceable when the residual tilts are less than 7 mm/m, although taller structures can be more sensitive to tilt. Swimming pools and large water storage tanks are also sensitive to tilting and, in some cases, are more sensitive than residential buildings.

1.2.4. Curvature

Curvature resulting from differential tilting is one of the major causes of impact to buildings and structures. Normally, curvature is defined as the reciprocal of the radius of curvature but it can also be defined by a deflection ratio for a particular length of structure, or by the radius of curvature itself. The deflection ratio is the maximum vertical displacement occurring between two points along a structure, expressed as a fraction of the horizontal distance between them.

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.

Allowable deflection ratios are given in the Australian Standard AS 2870 (1996) for different types of construction and these, together with ratios established in research by various authors, are discussed in Sections 4.5 to 4.8. Cracking in rendered walls will normally be more apparent than in face brickwork and the allowable deflection ratios are therefore reduced for structures with rendered walls.

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.

1.2.5. Horizontal Strain

Differential horizontal movements give rise to ground strains, however, most of the horizontal movements are proportional to ground curvature. Within the subsidence trough, convex or hogging curvature is accompanied by tensile strain and concave or sagging curvature is accompanied by compressive strain. Both tensile and compressive strains can cause cracking in a building structure but tensile strains are more difficult to accommodate since almost all components of a structure are weaker in tension than compression.

High levels of tensile strain cause stepped cracking in brickwork and masonry, cracking in plaster wall linings, pulled joints in plumbing and separation at joints in paving and roadways. High levels of compressive strain are characterised by crushing and spalling of faces in brickwork and masonry, closure of door and window openings, shear fractures, buckling of pipes, wall linings, floors, ceilings and external paving.

The transfer of ground strains into the structure occurs through friction on the underside of the foundations and ground pressure on the sides of the foundations. The transfer is thus dependent upon the configuration and type of foundation and its orientation to the subsidence trough.

The transfer of strain is also dependent upon the types of soil that are immediately below the foundation. Buildings founded on rock can, in some cases, experience a full transfer of strain whilst those founded on clay or sandy soils generally only attract a proportion of the ground strain. The transfer is a function of soil to foundation interaction and, in many cases, shearing of the soil layers reduces the transfer of strain.

Colwell and Thorne (1991), in their paper that referred to the monitoring of subsidence movements at a house above Longwall 3 at West Wallsend Colliery, indicated that the strains transferred into the walls of a brick veneer home were an order of magnitude less than those measured in the ground.

Horizontal tensile strains will affect all types of structure to the same degree once they have been cracked, since any increase in strain will tend to increase the width of the existing cracks rather than develop new ones.

1.2.6. Strain and Curvature Combinations

In practice, structural impact results from combinations of ground curvature and strain. The ground movements are generally three dimensional, adding the further complication of twisting in a structure. As subsidence occurs, the foundations settle and deform to match the subsided shape of the ground, the deformations being concentrated mainly at weak joints in the structure.

New cracks are generally formed where the shear or tensile strength of structural elements is exceeded. The cracking patterns depend upon the extent of the vertical displacements, the length to height ratio of the walls, the structural capacity of the building elements, and the shear strength and stiffness of the foundations.

In masonry and brickwork, the cracks generally follow the mortar joints either vertically or diagonally in steps. Bending and shear cracks can also occur due to curvature and strain along a wall. Once the cracks have formed, further ground deformations and extensions will be consumed in extending or expanding the cracks.

Where buildings are founded on sandy soils or clays and the ground strains are not fully transmitted into the structure, the level of impact is mostly dictated by curvature rather than horizontal strain.

Generally, the worst impacts will result from a combination of convex (hogging) curvature and tensile strain, rather than concave (sagging) curvature and compressive strain. The impact assessments, given in Chapter 6, have reviewed each combination, but are based upon the worst combination of the bending and horizontal tensile strains, which have been predicted to occur at each structure as the longwalls are mined. For each longwall panel, the travelling and transient strains at each structure have both been considered, and the maximum of these strains was used in the impact assessment for the structure.

1.3. Effect of Building Structure Type

The design and configuration of buildings and the materials of which they are built will determine the effects which mining subsidence will have upon them and the extent to which they will be affected. The bending strains resulting from ground curvature will affect different types of buildings in different ways.

A full masonry building of, for example, 15 metres in length, can tolerate a maximum differential foundation movement of 10 mm before damage occurs, whilst a timber framed building can tolerate a differential movement of 50 mm due to its greater flexibility.

A well designed building on foundations that allow for differential movement of the superstructure, constructed of flexible materials, with proper attention to the design of movement joints, will suffer less than a rigid brick structure on concrete strip foundations.

Buildings founded upon clay strata will not, normally, be subjected to the total horizontal ground strain. Buildings on piled foundations, on the other hand, would be affected to a greater extent due to lateral earth pressure on the piles and if the piles are rigidly connected to the building foundations this could result in a greater level of strain being applied to the building superstructure. Foundations built directly onto bedrock are more likely to transmit the total amount of ground strain into the building causing greater levels of impact.

Buildings that have raft foundations, built on a layer of sand and provided with a sliding membrane, often allow the ground to move without causing damage to the superstructure. Other buildings that are founded on stumps or short brick piers will generally allow the ground to move with only slight impact to the building above. These buildings also provide easy access for temporary and permanent adjustment of the piers and the structure.

The length of the building is also an important factor, since longer buildings will experience greater extension due to direct ground strain and bending strain, and the levels of impact will consequently be increased.

For many long structures, however, the maximum predicted strain will only apply over part of the length of the structure. In normal circumstances, therefore, the movements caused by mine subsidence will not be fully transmitted to the buildings and structures on the surface. However, a cautious approach is normally adopted and impact assessments are generally carried out assuming full transfer of displacements and strains from the ground into the structures. This approach was adopted in the present study.

1.4. Damage Thresholds on Building Structures

Much has been written on the subject of impact to buildings resulting from ground movements and the way in which different types of building, with different forms of construction, are likely to respond to applied curvatures and strains.

In 1974, Burland and Wroth prepared a thorough review of published papers to that date and recorded the findings of various researchers, which are summarised below. They presented the results to a conference of the British Geotechnical Society on the Settlement of Structures. Most of the literature referred to by the authors related to impact resulting from differential settlement or curvature rather than horizontally induced mining strains but it is nevertheless useful in establishing guidelines for determination of the effects of mine subsidence.

Burland and Wroth concluded that for brickwork and blockwork, in cement mortar, the critical tensile strain lay in the range 0.5 mm/m to 1.0 mm/m and for reinforced concrete in the range 0.3 mm/m to 0.5 mm/m. Below these levels, no cracking was apparent.

To place this in context with normal building movements, it is worth noting that strains likely to occur in clay brickwork, due to thermal expansion and contraction, can be of the order of 0.2 mm/m to 0.3 mm/m for a temperature differential of 30°C. Expansion of brickwork due to brick growth can also be of this order of magnitude.

The expansion and contraction of concrete structures, due to changes in temperature or moisture content, can be twice as high as for clay bricks. British Standards permit shrinkage strains of 0.3 mm/m to 0.9 mm/m in walls and panels.

Fig. 11 of the paper by Burland and Wroth compares the relative sag and hog for load-bearing walls and frame buildings, as determined by various researchers, and provides further guidance on the relationship between impact levels, deflection ratios and length to height ratios. The authors' view was that allowable deflection ratios for hogging structures should be less than for sagging structures.

The methods used to define the threshold levels for differential movement and strain varied from author to author and Burland and Wroth clarified the terminology, to enable direct comparisons to be made. Some statements concerning levels of impact were rather subjective and it was not easy to compare 'severe' by Littlejohn, with 'substantial' from Cheney and Burford and 'considerable' from Bjerrum. The relative values of strain provided some assistance in making comparisons.

It is clear that mining induced curvatures and strains will in some cases cause significant impact to building structures unless they are designed to accommodate these movements.

1.5. Allowable Deflection Ratios

Various authors in Australia have considered the effects of differential movement of buildings and many papers have been published which contain valuable data. This information has been incorporated in compiling Table E.1, which shows allowable deflection ratios for various types of building. The table has been extended to show the equivalent radii of curvature, for buildings of different length, at the allowable deflection ratios.

Bray and Branch (1988) provided a table showing allowable deflection ratios and limiting radii of curvature for different types of construction. Dr Lax Holla (1987b) also published a table of allowable deflection ratios, which was derived from a paper by Woodburn (1979), entitled Interaction of Soils, Footings and Structures.

Australian Standard, AS 2870 - 1996, 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 movement in foundations.

Granger (1991) gives tolerable values of deflection ratio and maximum acceptable deflections for reinforced and articulated brick walls. The deflection ratio for brick veneer of 1:600 has been assumed to apply to normal face brickwork and the lower allowable deflection ratio of 1:800 has been adopted for rendered masonry, which is more susceptible to impact.

Where different authors have stated slightly different values, the lower ratio has been assumed in compiling Table E.1. Allowable deflection ratio, for a particular type of building, has been taken to mean the deflection ratio which would cause only slight impact if applied to a building of that type.

Not all structures, however, will be situated at the position of maximum curvature. The curvature and strain will vary considerably throughout the longwall area and the levels of impact on buildings and structures will be dependent upon their positions within the subsidence troughs.

1.6. Classification of Impact Levels to Walls

The 'National Coal Board Classification of Subsidence Damage' for building structures, was given in Table 8 of the *Subsidence Engineers Handbook*, which was published by the National Coal Board, in 1975. The scale of damage was classified by description and was related to specific changes in the lengths of building structures.

The National Coal Board classification would appear to have been in use in 1962, when it was referred to, in a slightly amended form, in a paper presented to the Institution of Structural Engineers by J.D. Geddes (1962). This descriptive classification of impact was adopted and extended by the Department of the Environment, of the U.K., in 1981, at which time the impact categories were linked to crack width, rather than to specific changes in the length of a structure. The classification, in this form, was shown in Table 8.5 of a book titled *Ground Movements and their Effect on Structures* (Geddes, 1984).

Table 1.1 Allowable Deflection Ratios for Building Structures

Form of Construction		Allowable Deflection Ratio	Length in Metres			
			10	**20**	**30**	**40**
Loadbearing walls			**Acceptable Radius of Curvature in Kilometres**			
1	Solid masonry, rendered	1:4000	5.00	10.00	15.00	20.00
2	Solid masonry	1:3000	3.75	7.50	11.25	15.00
Non-loadbearing or lightly loaded walls			**Acceptable Radius of Curvature in Kilometres**			
3	Solid masonry, rendered	1:2000	2.50	5.00	7.50	10.00
4	Solid masonry	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, rendered	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

The same classification has been incorporated, with some minor revisions to the wording, within Appendix C of Australian Standard, AS 2870 - 1996. Table C1 in the standard shows the classification of impact with reference to walls, related to crack width, and Table C2 gives a classification of impact with reference to concrete floors, related to both crack width and differential vertical movement.

The Australian Standard Classification, reproduced from Table C1, is presented in Table 1.2 and has been used in this report as the basis for describing levels of impact to building structures, resulting from mine subsidence. The classification has, however, been extended to include a Category 5, which corresponds to the Very Severe Damage Category of the National Coal Board Classification and represents crack widths greater than 25 mm.

Table 1.2 Classification of Impact with Reference to Walls

Impact Category	Description of typical impact 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

1.7. Classification of Impact Levels due to Tilt

There is no standard method for classifying the level of impact caused by tilt. However, Australian Standard AS 2870 - 1996 indicates that local deviations in vertical or horizontal slope of more than 1 in 100, (10 mm/m), will normally be clearly visible and that slopes greater than 1 in 150 (approximately 7 mm/m) are undesirable.

However, it is recognised that structures are constructed to varying levels of accuracy. As reported by Burton (1995), research commissioned by the Mine Subsidence Board in 1991 indicated that a sample of 83 dwellings built at Woodrising in the preceding ten years in areas unaffected by mining, had a mean deviation from level of 2.39 mm/m, with a maximum deviation of 8.7 mm/m. The Mine Subsidence Board, in its *Annual Review* (1992), published further details of the research project. Fig. 1.1 shows the distribution of measured tilts arising from this and other pre-mining surveys, and indicates that 21% of 156 houses had tilts of more than 4 mm. The maximum tilt measured at a building prior to mining was 15 mm/m, with nine cases being reported between 9 mm/m and 15 mm/m. The acceptable change in tilt, due to mining, will thus vary from case to case and will be dependent upon the tilts existing before mining occurs.

The Mine Subsidence Board has adopted the policy that tilts caused by mine subsidence, which affect serviceability, constitute impact 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 could be required to doors and windows.

Where the tilt is greater than 7 mm/m and the roof drainage, wet area floors or pools can not be correctly graded or levelled without major structural work, then the Board would consider jacking the building to level. If, in extreme cases, the tilt caused impact to a building structure that could not be repaired economically, the Board, depending on the merits of each case, may be prepared to demolish the structure and rebuild it, or negotiate with the owner to pay monetary compensation, or purchase the property.

There appears to be a consensus that final overall tilts in buildings which are less than 7 mm/m are tolerable and that tilts above 10 mm/m are undesirable. Overall tilts in buildings 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 gradients are less than normal design requirements.

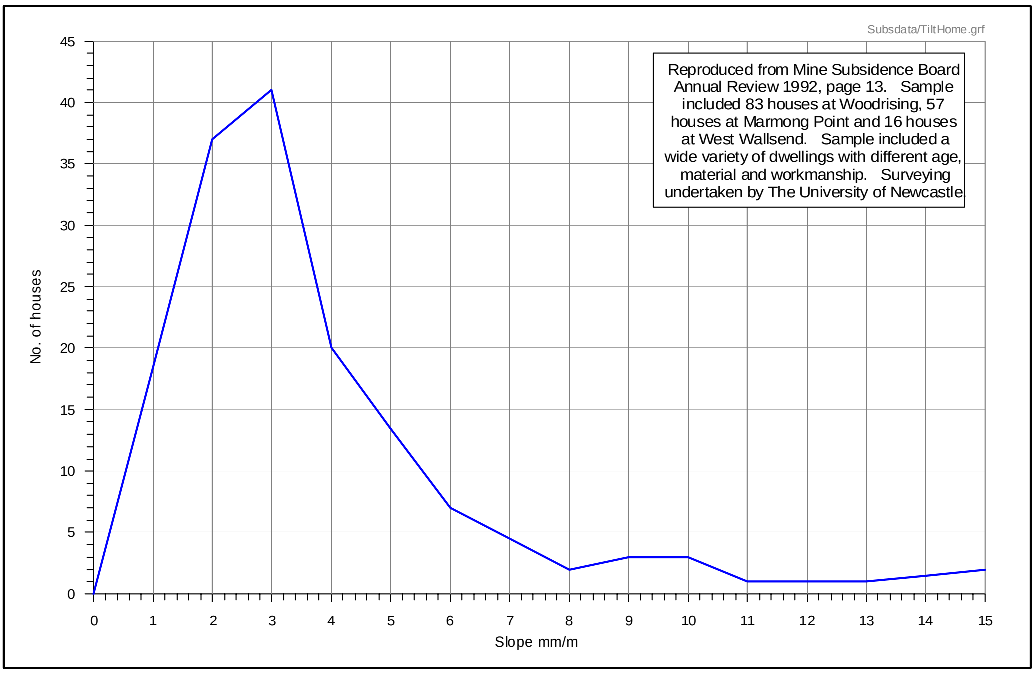


Fig. 1.1 Tilts of Surveyed Dwellings located outside Mine Subsidence Areas

The impact classification shown in Table 1.3, was developed by Waddington Kay & Associates. This has generally been accepted for a number of previous projects and Commissions of Inquiry. It is noted, however, that the Mine Subsidence Board consider jacking houses for Category C levels of tilt.

Table 1.3 Classification of Impact with Reference to Tilt

Impact Category	Mining Induced Ground 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.

1.8. Classification of Impact due to Ground Strains

In 1975, the National Coal Board, in the *Subsidence Engineers Handbook*, published a graph showing the relationship between impact, horizontal ground strain and the length of a building structure. It was based upon empirical data obtained from studying the effects of subsidence along 165 observation lines at numerous collieries in the U.K.

It has been generally accepted as providing a reasonable basis for assessing the levels of impact that are likely to result from mining subsidence and has been adopted in other countries around the world. When used in Australia for the prediction of impact, it has been shown to provide reasonable agreement with observed impact levels (Holla, 1988 and 1995; Bray and Branch, 1988).

The graph is reproduced, in an extended form, in Fig. 1.2 and illustrates the various impact categories, shown in Table 1.2. These are separated by lines that represent specific extensions to the length of a structure. These extensions, which define the various categories of impact, were originally published in Table 8 of the *Subsidence Engineers Handbook* (NCB, 1975). It follows that the strain values referred to in Fig. 1.2, should be seen as those occurring in the building structure. Normally these are taken to be the mining-induced horizontal ground strains. However, ground strains should be converted into structure strains by adding or subtracting the effect of mining-induced hogging or sagging curvature in the structure.

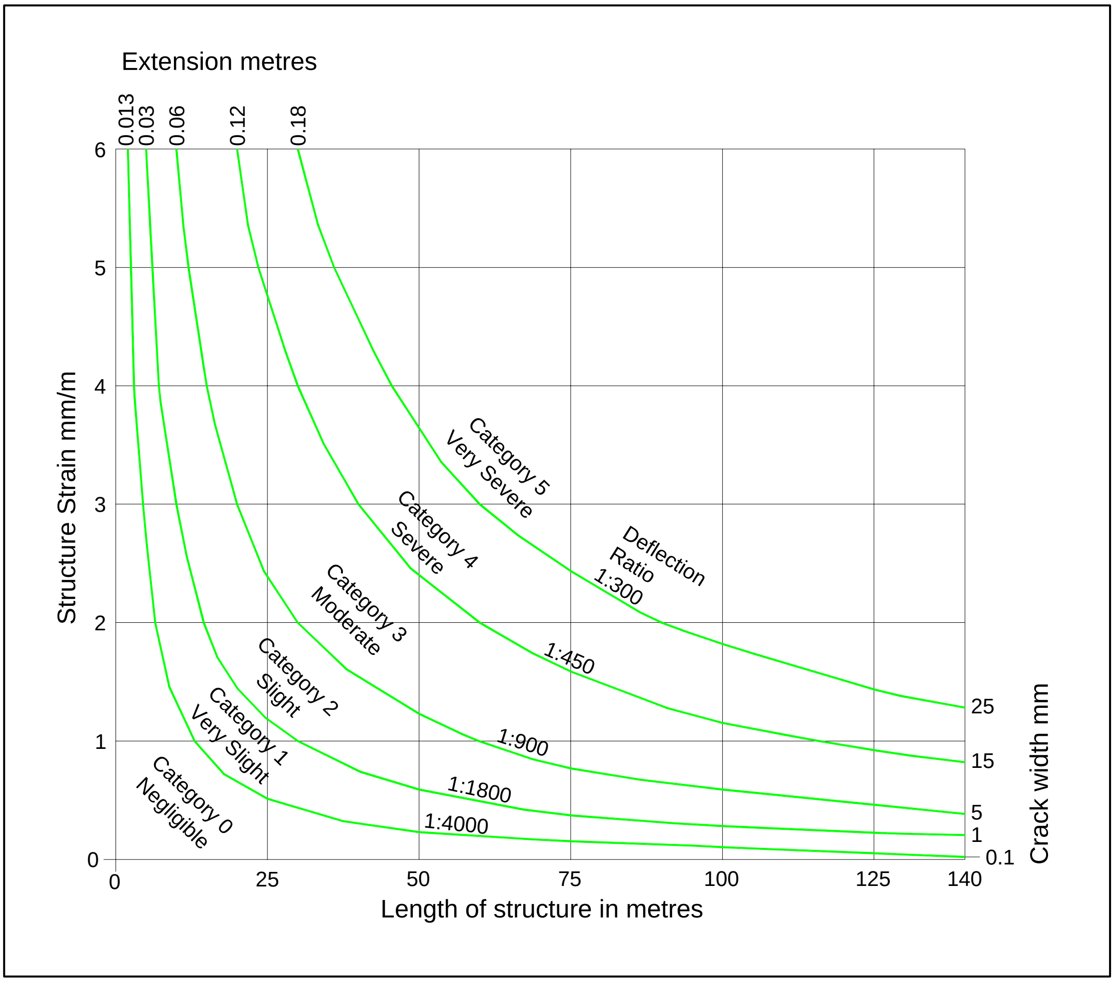


Fig. 1.2 Impact Classification with Deflection Ratios for Two Storey Brick Structures

The impact categories shown in Fig. 1.2 relate to typical two-storey brick or masonry building structures, which were the norm in mining areas in the U.K. Brick veneer homes and timber framed structures, with fibro or weatherboard cladding, which are commonly built in Australia, are not normally found in the mining areas of the U.K. The impact classifications are, therefore, somewhat conservative for these more typical Australian structures.

As previously discussed, the horizontal ground strains are associated with ground curvatures and both contribute to the strain which is experienced by a building structure. Often the horizontal strain is only partially transferred into the building and the curvature, which causes bending strain, provides the greater contribution to the total strain.

The bending strain in a building structure, resulting from hogging curvature of the ground, is dependent upon the height of the building, *H*, and the radius of curvature of the ground, *R*, and can be expressed simply as strain = *H/R*, as shown in Fig. 1.3.

In this calculation, it is assumed that the curvature of the ground, at foundation level, is transferred into the structure by differential settlement of the foundations and that the structure bends to accommodate the curvature. It is assumed that hogging curvature will result in bending about the underside of the foundation. In practice, some shearing may take place in the structure and the calculated bending strain might not be fully developed.

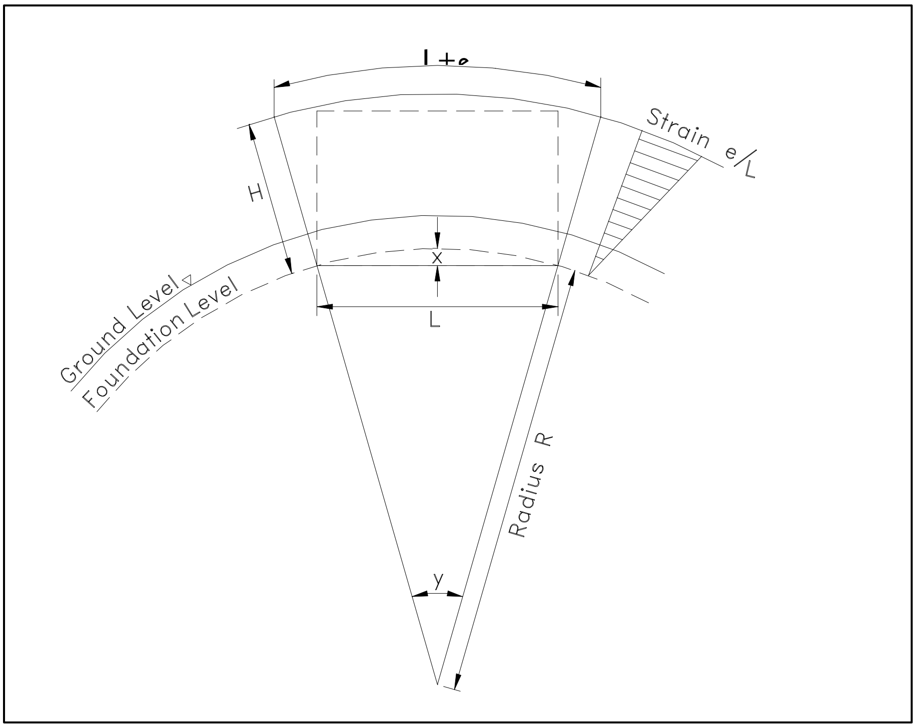
In the sagging mode, some resistance to bending will occur in the lower part of the wall. Normally slippage will occur at damp course level but, if no damp course exists, the foundations or ground slab will provide resistance. The effective neutral axis will therefore be in the lower part of the wall but its location will vary from structure to structure. In general, it seems reasonable to assume that walls, subjected to concave, or sagging, curvature, will bend about their centre line.

To determine the tensile strains in a building structure, the horizontal tensile ground strains have been added to the tensile bending strains, which are determined from a structure height measured from the underside of the foundation. To determine the compressive strains in a building structure, the compressive bending strains, determined from the mid-height of a structure, have been deducted from the horizontal compressive ground strains. This combined strain has then been used in predicting impact intensity from Fig. 1.2.

In practice, much of the horizontal ground strain could be lost in the transfer. The impact assessments, provided in Chapter 6, are therefore cautious assessments that represent the worst possible scenario based upon the predicted subsidence parameters.

1.9. The Relationship between Impact Classification and Allowable Deflection Ratio

The elongation of a structure, due to curvature of the ground is directly related to the deflection ratio of a structure, as shown in Fig. 1.3.



Note: Curvature exaggerated for clarity

Fig. 1.3 Symbols used in the Analysis of Structures Bending by Hogging

From the geometry of a circle it can be shown that:

$$\text{elongation of structure,} \quad e = \text{deflection ratio} \times 8\,H \qquad \text{Equation 2}$$

The relationship between the elongation of a structure, due to bending, and the deflection ratio is therefore dependent upon the height of the structure.

From the curve shown in Fig. 1.2, a two-storey building with a height of 6.75 metres represents an extension of 0.03 metres for an impact category between 1 and 2. This can be related to a deflection ratio using the formula given above.

$$\text{Hence,} \qquad \text{Deflection Ratio} = \frac{\text{elongation}}{8H} = \frac{0.03}{54} = \frac{1}{1800} \qquad \text{Equation 3}$$

Using the method above, the deflection ratios have been calculated for other values of extension and these have been shown in Fig. 1.2. The calculations indicate that for two-storey brick structures, with a height of 6.75 metres, the upper limit of impact for Category 2 represents a deflection ratio of 1:900. Similarly, the upper limits of Impact Categories 3 and 4 are represented by deflection ratios of 1:450 and 1:300, respectively.

It is reasonable to assume that the level of impact at a deflection ratio of less than 1:4000 would be negligible for a two storey brick structure. A curve has been included in Fig. 1.2, based upon this value of deflection ratio, in order to provide a division between Impact Categories 0 and 1.

1.10. Relationship between Impact Classification and Crack Width

The deflection ratios and maximum crack widths which separate each Impact Category, for two-storey brick structures of 6.75 metres height, are shown in Fig. 1.2. Based upon these factors, Fig. 1.4 has been produced, to show the relationship between the inverse of deflection ratio and the maximum crack width.

The impact categories given in Table 1.2 are related to maximum crack widths and these have been shown for each of the categories in Fig. 1.2. Impact Category 0 relates to a maximum crack width of less than 0.1 mm, which would not be visible, and hence represents negligible impact. Categories 1 to 4 relate to maximum crack widths of 1 mm, 5 mm, 15 mm and 25 mm respectively. Category 5 has been added to represent crack widths greater than 25 mm.

In a paper presented by P.F. Walsh (1991), a graph was published showing the relationship between crack widths and inverse deflection ratios for single storey, brick veneer houses, subject to reactive clay movements. The graph was reproduced from a paper which was published in 1981 by D.A. Cameron and P.F. Walsh, and is based upon actual deflections and crack widths.

This graph has been added to Fig. 1.4 to show the comparison between the theoretical relationships and measured results and a very close agreement can be seen. The classification of impact with reference to both extension and crack width would, therefore, appear to have some scientific basis.

It can be seen from Table 1.1, that all other types of building structure have an allowable deflection ratio greater than that of brick structures. A timber-framed building, for example, has an allowable deflection ratio of 1:300 compared with 1:2000 for lightly loaded rendered brickwork. Rendered brick veneer structures have an allowable ratio of 1:800.

The effect of bending strains on building structures is dependent upon their flexibility and their capacity to absorb curvature by shearing. The level of impact caused to a building, by curvature of the ground, therefore reduces as the allowable deflection ratio increases.

The use of the graphs in Fig. 1.2 to predict the levels of impact to buildings of flexible construction would, therefore, be an over-cautious approach and would result in excessively conservative assessments. The management strategies have therefore been adjusted for sheds and other light structures to compensate for this conservatism.

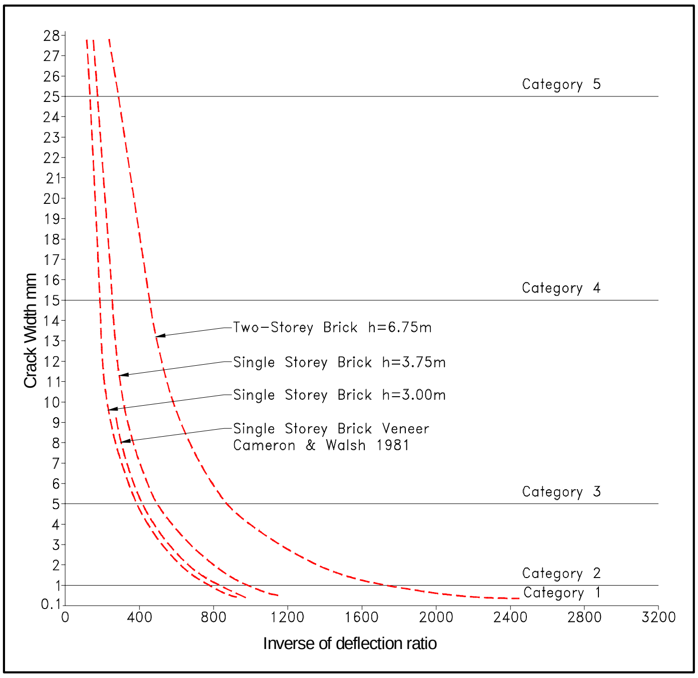


Fig. 1.4 Variation of Crack Width with Deflection Ratio for Brick Structures

CHAPTER 2. REFERENCES