

# Effects of Underground Mining on Domestic Structures - Prediction versus Performance

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**SUMMARY** The extraction of coal seams by underground mining methods causes deformations in the overlying ground surface. These deformations, if large, could damage structures erected on the surface. The prediction of subsidence therefore has to be made and its effects on surface improvements assessed before approval to mine the coal is granted. In New South Wales, empirical curves have been developed for predicting ground movements prior to mining. The movement - damage relationship has been established by a number of studies involving performance surveys of civil engineering structures. The various classes of damage for brick dwellings in mining subsidence areas have also been established in the UK. These two criteria are extended to predict the performance of dwellings in the coalfields of NSW. The predicted performance of dwellings is compared with the observed performance after they are undermined by longwall mining and the two appear to agree reasonably well.

## 1 INTRODUCTION

The decision as to whether or not total extraction of coal should occur in an area with extensive surface improvements largely depends upon the extent of damage to the improvements resulting from mining induced ground movement. The extent of damage depends upon the level of ground movement and the type of structure. In many cases of total extraction of deep coal seams, the resulting ground movements are small and as such can be accommodated by the conventional domestic structures. For a given level of movement, timber structures sustain less damage than brick structures and structures of smaller plan area perform better than those of larger area.

The NSW Department of Mineral Resources is often faced with the difficult issue of achieving optimum coal recovery consistent with minimum damage to surface improvements, while dealing with proposals for extracting coal by underground mining methods. The satisfactory resolution of the issue requires that the potential damage be predicted prior to mining so that decisions are based on facts. The prediction of damage involves two stages, prediction of ground movement resulting from the proposed coal extraction and assessment of damage due to the predicted ground movements.

## 2 NATURE OF MINING SUBSIDENCE

Figure 1 illustrates the concept of trough subsidence over an isolated extracted panel of width  $W$  and at a depth  $H$  below the surface. The vertical settlement of a point along the trough is subsidence ( $S$ ) which in the absence of anomalies is maximum ( $S_{max}$ ) at the trough centre. Tilt ( $G$ ) is the differential subsidence between two points divided by their distance apart and is expressed in mm/m. Tilt changes along the trough, and the rate of change of tilt causes ground curvature. Curvature is usually expressed as radius ( $R$ ) in Km.

The ground surface in the central area over the extracted panel shortens and that over and outside the panel edge stretches resulting respectively in compressive ( $-E$ ) and tensile strains ( $+E$ ).

Strains are expressed in mm/m and are measured in the field by monitoring the change in length between two surface points during mining.

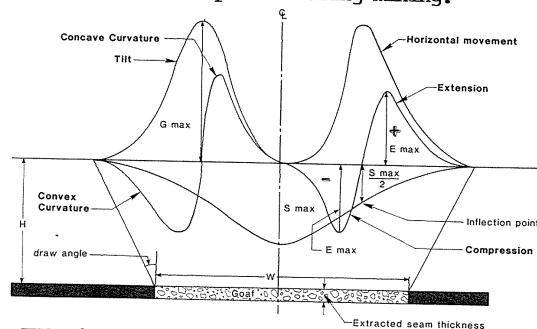


FIG. 1 - Characteristics of ground subsidence  
 (left half profile : vertical components)  
 (right half : horizontal components)

Some ground movements are permanent and others transient in the sense that deformations disappear after the completion of mining. Subsidence, i.e. vertical settlement is permanent. Transient movements are generally associated with a moving extraction face. Strains and tilt are permanent only over and adjacent to panel edges. The maximum tilt ( $G_{max}$ ) or strains ( $E_{max}$ ) occur over short lengths of say 10 to 20m whereas the total length of the trough may be in the order of several hundred metres.

## 3 SUBSIDENCE PREDICTION

### 3.1. Basis of Prediction

The prediction is based on empirical curves developed from actual ground movements monitored over mine workings in the NSW coalfields. The curves predict subsidence and the associated parameters for an isolated rectangular extraction panel or for a series of panels at any depth and extraction thickness.

### 3.2. Prediction for a Single Panel

The maximum possible subsidence ( $S_{max}$ ) at a surface point generally varies between 55 and 65 per cent of the extracted seam thickness ( $T$ ) as shown in

Fig. 2 and an average value of 60 per cent may be taken for damage prediction (Holla, 1985 and 1987a). At low width to depth (W/H) ratios, subsidence in the Newcastle Coalfield has been found to be significantly less than that in the Southern Coalfield because of stronger overburden characteristics in the former coalfield.

For  $S_{max}$  to occur, the extraction width and length should each be at least equal to 1.4 times the depth of mining and the extraction within the panel should be complete. The extraction in such cases is termed critical and total. Extractions larger than the critical extraction are supercritical and those smaller subcritical. In partial extraction cases, coal recovery is not total.

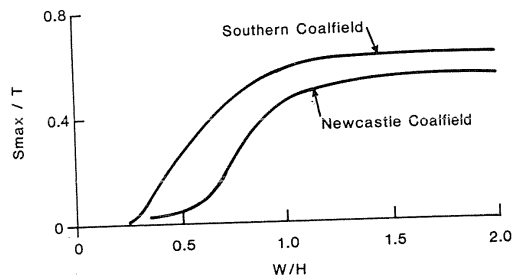


Fig. 2 - Maximum subsidence for isolated panels

### 3.3. Prediction for a Series of Panels

Longwall mining layouts in NSW usually consist of rectangular extraction panels laid side by side with interpanel coal pillars, which are usually referred to as chain pillars, separating the panels. Panels of 2Km length are not uncommon and the width generally varies between 130m and 200m. The chain pillars may be in one or two rows and their width may vary between 20m and 40m. The critical width of  $1.4H$  in such cases may be reached after the completion of mining in two or three panels, depending upon the width of individual panels in relation to the depth of mining. The extraction within the critical area is however not total because of the chain pillars. The pillars provide yielding support to the seam roof and reduce surface subsidence. The resulting subsidence depends upon the size of pillars and may vary between 25 and 50 per cent of the extracted seam thickness as shown in Fig. 3 (Holla, 1985).

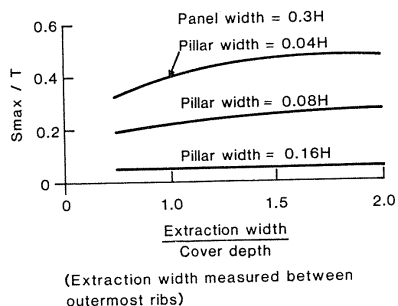


Fig. 3 - Maximum subsidence over a series of panels for different W/H ratios

The curves in Fig. 3 are applicable to mining layouts with individual panels of  $0.3H$  width, separated by pillars of  $0.04H$ ,  $0.08H$  or  $0.16H$  width. The data from Figs. 2 and 3 are redrawn

in Fig. 4, which can be used for predicting the maximum subsidence for critical extraction conditions for other pillar widths by interpolation. The curves are strictly applicable to the Southern Coalfield, where overburden strata mainly consist of massive sandstone, but can be extended to the Newcastle Coalfield especially for critical extraction conditions.

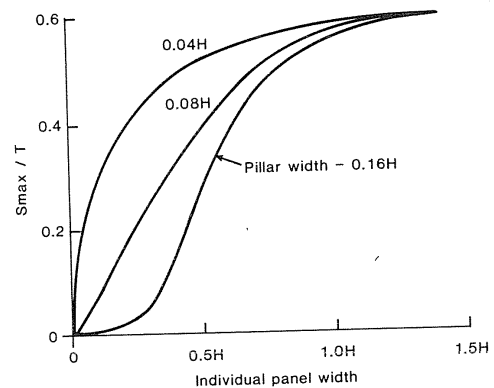


Fig. 4 - Maximum subsidence over a series of panels for critical extraction conditions

### 3.4. Prediction of Strains

A rapid estimate of the maximum values of ground strain and tilt for critical extraction conditions may be made from the known maximum subsidence by using the curves in Fig. 5 (Holla, 1985 and 1987a). The curves are drawn for one metre subsidence and the values of strain and tilt for other subsidence levels are proportional to the subsidence. The ground curvature is a function of strain and cover depth.

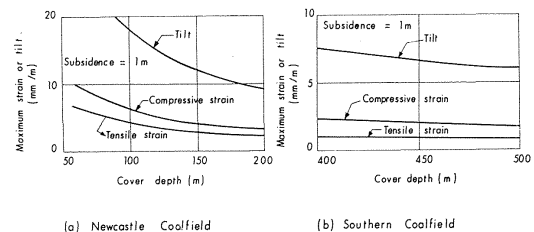


Fig. 5 - Relationship between cover depth and maximum strains and tilt (critical extraction conditions)

### 3.5. Use of Maximum Values for Damage Prediction

Structures located over the area of influence of mining undergo different levels of movement depending upon their location in relation to the extraction panel. For example, structures located outside the panel would undergo less deformation than those located inside the panel. Again, some structures may suffer permanent deformations whereas others may undergo only transient deformations. Also structures may experience reversal of strains as the extraction face moves under them. In theory, all these factors should be taken into account in damage assessment. In practice, however, such an approach is not realistic because of the following reasons.

1. In many cases, mining layouts are not finalised at the time of damage assessment. It is therefore not possible to determine the subsidence parameters for each of the affected structures.
2. Even when details of mining layouts are available, determining the parameters for each affected structure is both time consuming and labourious.

On the other hand, the use of maximum subsidence parameters for the whole area undermined by a series of extraction panels is a simple and quick method, though conservative.

The deformation of a structure is always smaller than the ground deformation. The practice of equating linear changes in the structure with those of ground surface represents an oversimplification and produces too high a deformation value in the structure. Nevertheless, the practice is justified as it provides an additional safety margin if used as the basis of design of structures and has been extensively used in both Europe and Britain.

#### 4 EFFECTS OF SUBSIDENCE ON DOMESTIC STRUCTURES

Most damage to structures is caused by the differential ground movements. Differential horizontal movement of soil particles causes friction at the soil-structure interface and stresses in the structure. Effects of these strains on brick structures are well documented in the UK (Ministry of Works, 1951; National Coal Board, 1975). Tensile strains are characterised by the opening of joints in brickwork or the fracturing of brickwork. Compressive strains are characterised by the squeezing-in of voids such as doors and windows and the horizontal movement of brickwork where a continuous length has been thrust above or below the restrained part of the structure.

Differential vertical movement results in simple bending, shear distortion or a combination of both. In the context of dwellings comprising masonry walls set on concrete strip footings bending deformation is predominant and direct tensile cracks originate at foundation level travelling up the wall (Kratzsch, 1983).

Experience, however, shows that all structures can endure a degree of differential movement without exhibiting damage. If the magnitudes of acceptable differential subsidence and horizontal strains are available for different classes of structure, then structural damage can be avoided by selecting the appropriate type of structure for the given level of ground movement or by designing mining layouts to limit movements to acceptable levels.

#### 5 ACCEPTABLE LIMIT OF DIFFERENTIAL SUBSIDENCE

A number of studies have gone some way towards establishing reliable criteria for acceptable differential subsidence (or acceptable damage) through extensive performance surveys of existing structures. A guide to allowable deflection ratios for the various types of structures derived from these studies is prepared by Woodburn (1979) and is reproduced in Table I. The deflection ratio is the maximum vertical displacement between two points along a structural element expressed as a fraction of the distance between the two points. The allowable ratio is based on a limiting or critical strain associated with the onset of visible cracking in the superstructure. Polshin

and Tokar (1957) used a value of 0.5mm/m for unreinforced brickwalls. Burland and Wroth (1975) chose a value of 0.75mm/m and made an important distinction between the hogging and sagging modes of cracking. They observed that cracking in a hogging mode occurred at very low deflection ratios. This was explained by the fact that in the sagging mode, the foundation offered considerable restraint and deformation occurred fairly uniformly. In the hogging mode, however, once a crack formed at the top of the building, there was nothing to prevent it from propagating downwards to the foundation.

The radii of curvature corresponding to the allowable deflection ratios are calculated for two lengths of structures, 15m and 20m (Table I). If the mining induced radius of curvature is more than the allowable radius of curvature for the given type of superstructure, then the resulting damage from mining subsidence is acceptable. Clearly, all types of structures have considerable in-built strength to resist mining induced ground curvature.

TABLE I

ALLOWABLE DEFLECTION RATIOS

Type of wall	Deflection ratio	Controlling element	Radius (Km)	
			L=15m	L=20m
solid masonry	1/2000	plaster	3.75	5.0
articulated masonry	1/800	internal brickwork	1.50	2.0
brick veneer	1/500	external brickwork	0.94	1.25
articulated brick veneer	1/300	internal plaster	0.56	0.75
timber or prefabricated	1/200	internal linings, door & window openings	0.38	0.50

#### 6 ACCEPTABLE LIMIT OF HORIZONTAL STRAIN

On the basis of experience gained over many years, a damage classification for brick residential structures has been devised in the UK (National Coal Board, 1975). The five classes of damage are: "very slight or negligible", "slight", "appreciable", "severe" and "very severe". Damage is based on change in the length of structures calculated from ground strains and length of the structure. The classification does not distinguish between tensile and compressive strains. The two classes at the bottom end of the scale (least damage) are described below.

1. "Very slight or negligible" damage is caused by change in the length of structure of up to 30mm and is in the form of hair cracks in plaster and slight fractures in brickwork.
2. "Slight" damage is due to change in the length of between 30 mm and 60 mm. Damage may be in the form of several slight fractures and sticking doors and windows.

Figure 6, drawn from the British data, indicates that most domestic structures with long dimension not exceeding 15m suffer "very slight" damage when subjected to strains of up to 2mm/m. Damage is "slight" even under moderately high strains

of 4mm/m.

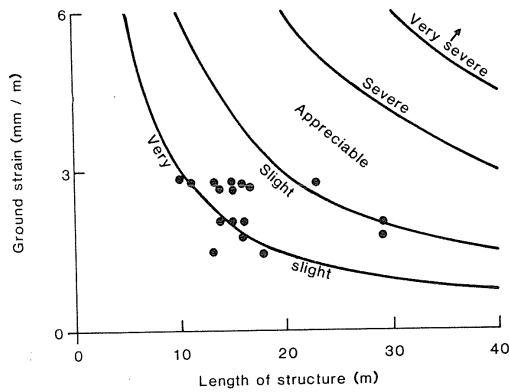


Fig. 6 - Damage for different lengths of structures and strains

7 CASES OF MINING UNDER DWELLINGS

7.1. Details of Mining and Subsidence Prediction

The seventeen dwellings were located over mine workings in four collieries (Table II). The extraction in collieries A and D was critical but not total because of chain pillars. The dwellings were undermined in Colliery C by a single sub-critical longwall panel and there were first workings in an overlying 2.5m thick seam, 25m above. The pillars had remained stable until they were undermined by longwall mining causing additional surface subsidence. The subsidence prediction in this case was based on the following assumptions.

1. The coal extraction in the overlying seam was around 30 per cent. In other words, the effective extracted seam thickness was 0.75m. The extracted thickness in the lower seam was 1.6m. The total effective extracted seam thickness of two seams was 2.35m.
2. The effective cover depth was taken to the roof of the overlying seam.

The predicted values of maximum subsidence parameters are shown in Table II.

7.2. Description of Houses

The Seventeen dwellings undermined are listed in Table III with their type of construction and approximate plan area.

TABLE III

DETAILS OF HOUSES  
 bv - brick veneer; fb - full brick  
 ss - single storey; ds - double storey

case	construc- tion type	approx. plan area (m x m)	observed damage
1	bv; ss;	18 x 10	cracks in brickwork.
2	bv; ss;	13 x 8	cracks in brickwork.
3	bv; ss;	15 x 11	cracks in brickwork; movement in internal timber walls.
4	bv; ss;	29 x 12	cracks in garage door arches and brickwork.
5	bv; ss;	14 x 14	fractured waste pipe leading to septic tank.
6	bv; ss;	16 x 15	tiles dislodged from bathroom wall.
7	bv; ss;	11 x 10	no damage reported.
8	bv; ss;	12 x 13	roof gutters tilted.
9	bv; ss;	10 x 10	cracking of storm water drain & bathroom tiles.
10	bv; ss;	12 x 13	cracks in brickwork.
11	bv; ss;	23 x 10	no damage reported.
12	fb; ss;	16 x 12	cracks in internal brick work, sticking door.
13	bv; ss;	10 x 15	no reported damage.
14	bv; ss;	9 x 16	no reported damage.
15	bv; ss;	15 x 9	cracks in ceiling, external brickwork & bathroom tiles.
16	bv; ss;	29 x 11	no reported damage.
17	bv; ds;	16 x 8	no reported damage.

7.3. Prediction of Damage

The potential damage to seventeen dwellings due to the predicted subsidence movements was considered "very slight" or "slight" because of the following.

1. The calculated change in length of dwellings was less than 60mm. (Damage to the seventeen dwellings is marked on Fig. 6).
2. The radius of curvature induced by mining subsidence was in no case less than 6km. Under acceptable differential subsidence criterion (Table I), brick dwellings should not suffer any damage.

On this basis, mining layouts in all four cases were considered acceptable.

TABLE II

MINING DETAILS AND PREDICTED SUBSIDENCE PARAMETERS  
 (For explanation of symbols see Fig. 1)

colliery (cases)	extrac- tion type	mining depth (m)	extracted thickness (m)	panel extract- width width	pillar width	maximum S <sub>max</sub> (mm)	predicted +E <sub>max</sub> (mm/m)	-E <sub>max</sub> (mm/m)	parameters G <sub>max</sub> (mm/m)	basis for pre- diction
A (1&2)	longwall	500	2.8	0.35H critical	0.08H	810	0.7	1.5	5.0	Figs. 4 & 5
B (3-6)	pillar extraction	430	1.9	1.40H critical	-	1000	0.9	2.1	7.0	Figs. 2 & 5
C (7-15)	longwall	265	2.6	0.80H sub- critical	-	660	1.5	2.8	6.7	Figs. 2 & 5
D (16&17)	longwall	370	3.5	0.41H critical	0.08H	1120	1.2	1.8	5.3	Figs. 4 & 5

## 8 PREDICTION VERSUS PERFORMANCE

### 8.1. Subsidence Movements

The predicted movements were compared after mining with the actual monitored movements (Table IV). The latter movements did not include time dependent residual movements. On the other hand, the predicted subsidence included the residual subsidence which would be generally between 5 and 10 per cent of the total subsidence. For the purpose of comparison, therefore, the monitored subsidence was increased by 5 per cent to include the residual subsidence.

TABLE IV

COMPARISON OF PREDICTED AND MONITORED SUBSIDENCE

colliery	maximum predicted subsidence	subsidence monitored	percentage discrepancy
A	810mm	790mm	3%
B	1000mm	900mm	11%
C	660mm	735mm	10%
D	1120mm	1020mm	10%

The discrepancy in all cases is under or around 10 per cent. This level of discrepancy is expected as the empirical prediction curves are the upper bound curves and overestimate subsidence by up to 10 per cent (Holla, 1985).

### 8.2. Subsidence Damage

Damage observed after the dwellings are undermined is listed in the last column of Table III. Damage may be summarised as follows.

1. minor cracking of ceilings, brickwork and arches over garage doors.
2. fracturing of a waste pipe.
3. dislodging and cracking of wall tiles.
4. change in gradient of rainwater gutters.

Clearly, the observed damage falls into the class of "very slight" or "slight" as predicted.

## 9 CONCLUSION

Subsidence of the ground surface occurs due to extraction of coal by underground mining methods. The magnitude and pattern of movement can be predicted with a reasonable degree of confidence. Damage to surface structures could occur due to differential ground movements. The extent of structural damage depends upon the level of ground movement and the type of structure.

Damage to seventeen dwellings was assessed from the predicted ground movements on the basis of the damage classification established by studies

involving performance surveys. Both predicted movements and the resulting damage were found to agree well with the monitored movements and observed damage respectively.

It is recognised that the sample size is small and there is a need to expand the database to improve the confidence of predictability. Nevertheless, a simple and quick approach has been established for assessing damage to dwellings due to mining subsidence. The method can be used for rational decision making with regard to mining applications affecting domestic structures.

## 10 ACKNOWLEDGEMENTS

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## 11 REFERENCES

- BURLAND, J.B. and WROTH, C.P. (1975). Settlement of buildings and associated damage, Proc. Conf. on Settlement of Structures, British Geotech. Soc., London, pp. 611-654.
- HOLLA, L. (1985). Mining subsidence in New South Wales, 1. Surface subsidence prediction in the Southern Coalfield, Sydney, N.S.W. Department of Mineral Resources.
- HOLLA, L. (1987a). Mining subsidence in New South Wales, 2. Surface subsidence prediction in the Newcastle Coalfield, Sydney, N.S.W. Department of Mineral Resources.
- HOLLA, L. (1987b). The response of domestic structures to ground movement caused by mining subsidence. Proc. First National Structural Engineering Conf., Melbourne, pp. 472-477.
- KRATZSCH, H. (1983). Mining subsidence engineering, Berlin, Springer-Verlag.
- MINISTRY OF WORKS (1951). Mining subsidence effects on small houses, HMSO, Special Rept. No. 12 HMSO, London.
- NATIONAL COAL BOARD (1975). Subsidence Engineers Handbook, London.
- POLSHIN, D.E. and TOKAR, R.A. (1957). Maximum allowable non-uniform settlement of structures, Proc. 4th Int. Conf. on Soil Mechanics and Foundation Engg., London, pp. 402-405.
- WOODBURN, J. (1979). Interaction of soils, footings and structures, Proc. Symp. on Footings and Foundations for small Buildings in Arid Climates, Instn. Engrs., Adelaide, pp. 79-89.