

Modelling of Surface Subsidence in the Southern Coal Field of New South Wales

R.G. GURTUNCA

Principal Engineer, Rock Mechanics Laboratory, Chamber of Mines Research Organisation, South Africa

A.K. BHATTACHARYYA

Senior Lecturer, School of Mines, University of New South Wales

SUMMARY Surface subsidence profiles above completely extracted panels at two mines in the Southern Coal Field of New South Wales were predicted by using several mathematical modelling techniques and compared with those obtained from measurements. The computer program MSEAMS yielded the best prediction for maximum subsidence as well as the complete subsidence profiles.

1 INTRODUCTION

When an excavation is made in a tabular deposit, the virgin state of stress is changed and displacements are induced in the rock. The overburden rock tends to move into the excavation under the influence of gravity. The effects of this type of behaviour are observed at the surface in the form of a subsidence trough.

Field measurements are usually carried out to quantify the magnitude and also to determine the other components (i.e., horizontal displacements, tilt etc.) of subsidence. If there are sufficient subsidence measurements from a region it is possible to derive an empirical subsidence prediction method. The use of mathematical and semi-empirical techniques are of importance, especially when the subsidence measurements are not available or are so limited that a relationship cannot be obtained to represent the subsidence behaviour of the area due to underground mining.

After an initial review of subsidence prediction methods, this paper describes the use of certain mathematical modelling techniques to predict surface subsidence profiles above completely extracted panels at two mines in the Southern Coal Field of New South Wales. The computer modelling results are then compared to the subsidence profiles measured over the same panels.

2 METHODS OF SUBSIDENCE PREDICTION

Four types of subsidence prediction techniques are discussed.

(i) Empirical or statistical methods

These methods are based on a considerable number of field measurements (National Coal Board, 1975). The 'Subsidence Engineers Handbook' establishes the relationship between variables and relates the subsidence values, graphically in a profile prediction chart. The variables are seam thickness, depth and inclination, topography and panel geometry for longwall coal mines. Once the shape of the subsidence profile is defined, the magnitudes of horizontal displacements and consequent strains are then determined from the slope and the curvature of the profile. The application of this method is restricted to areas where the conditions are similar to those analysed in the NCB handbook.

(ii) Profile functions

Profile functions are mainly mathematical equations which are derived on the basis of a curve fitting procedure. Firstly a mathematical function is developed for a measured profile; this function is then used to predict subsidence in other areas.

Although the profile functions have been used successfully particularly in Europe (Hood *et al.*, 1981), due to its two dimensional approach the method is restricted to simple mine geometries, such as longwall mining.

(iii) Influence functions

The influence functions are based on the principle of superposition with respect to the effects of infinitesimal parts of an extracted area. Subsidence at any point can be calculated by integrating the influences of all of these infinitesimal elements of the excavation (Bräuner, 1973).

The advantage of influence functions is that the subsidence caused by irregular geometries can be predicted. A disadvantage of influence functions is that the method can only be used for subsidence profiles which are symmetric about the panel centreline. To alleviate this problem, two different influence functions should be employed to make a reasonable prediction of a complete trough. Another disadvantage of influence functions is that the method assumes the location of the inflection point immediately above the edge of the panel. Where this is not the case, some modification has to be made to the function used in order to shift the predicted curve.

(iv) Mathematical modelling

In mathematical modelling, computer programs based elastic or inelastic theories are used to describe or to predict subsidence. Some of these programs incorporate the influence on subsidence of geological discontinuities such as joints, bedding planes etc., and also simulate different types of rock above the seam.

3 COMPUTER MODELLING TECHNIQUES USED IN THIS STUDY

3.1 Displacement Discontinuity Method

In this study, the computer programs which were based on the Displacement Discontinuity Method 'MINAP', 'MSEAMS' (Crouch, 1976) and 'THREED' (Hebblewhite *et al.*, 1979) were utilized for the prediction of subsidence. The description of the Displacement Discontinuity Method is given elsewhere (Crouch, 1976). The main differences between these three programs are summarized as follows;

- (i) MINAP and MSEAMS are two-dimensional and THREED is a three-dimensional program,
- (ii) MINAP and THREED assume that the host rock is homogeneous, isotropic and linearly elastic,
- (iii) MSEAMS assumes that the surrounding rock is orthotropic and linearly elastic, and
- (iv) the THREED program includes such facilities as a basic caving mechanism, the alternatives of using square or rectangular elements in a mesh, and a realistic definition of the yield zone for the elements on the ribside.

The program MSEAMS was modified so that it could model the individual subsidence profiles for several adjacent panels and then superimpose the subsidence from the different panels and plot the resultant profile. The modified program can also accept the input values for the corresponding measured subsidence profile and plot it in the same diagram as the modelling results.

At the time this study was carried out, THREED could calculate the vertical displacements only at the seam plane. Therefore, the authors had to employ a modified form of the program VEDICA (Oravec, 1973) to use the output of THREED to compute subsidence at any horizon above the seam.

3.2 Modelling Based on the Use of an Electrical Resistance Analogue

The convergences and normal stresses in the plane of a tabular deposit induced by mining can be determined by using the electrical resistance analogue to compute subsidence at a horizon above the seam. The convergence data thus obtained is then used in the digital computer program 'VEDICA' (Oravec, 1973) to determine the vertical displacements at a horizon above the plane of the tabular deposit.

Thus in order to determine the related subsidence, a mining geometry is first modelled on the electrical resistance analogue by sub-dividing the total area into face elements. The analogue solution gives the convergence at the centre of each face element. Using VEDICA, the vertical displacement (i.e. the total subsidence) at the chosen point is then calculated by summing the contribution from each of the face elements (Oravec, 1973).

By following this procedure, the surface or subsidence profiles are obtained for each panel; the profiles were superimposed to obtain an overall subsidence profile for all the panels mined.

4 DETERMINATION OF THE ELASTIC CONSTANTS USED IN THE MODELLING

The values of elastic constants, such as Young's and Shear Moduli and Poisson's ratio of the surrounding rock, were determined by the method of successive approximation through repeated modelling of the maximum subsidence above a given panel until close agreement was achieved between the modelled and actual measured values. The values of the elastic constants were kept unchanged in all of the subsequent models; the program MSEAMS was used for this purpose. The following notation was employed for the elastic constants:

$E_S = E_{xx} = E_{zz}$ = Young's Modulus of the surrounding rock,
 $G_S = G_{xy}$ = Shear Modulus of the surrounding rock,
 ν = Poisson's ratio of the surrounding rock,
 E_C = Young's Modulus of the coal seam, and
 G_C = Shear Modulus of the coal seam.

In the trial computer runs using MSEAMS, the results were found to depend particularly upon the assumed Young's and Shear Moduli of the rock mass overlying the seam. The value of the Shear Modulus used was taken as:

$$G_S = E_S/20$$

The main reason for selecting a low Shear Modulus was to achieve a more realistic subsidence prediction. This reason is based simply on the assumption that the surrounding rock mass is jointed and that a jointed body of rock can be represented as an elastic material with a low shear modulus (Singh, 1973).

It is also considered that the low values of the elastic constants are more realistic than the high values. One possible explanation for this is that the presence of extension cracks, bed separation in the rock mass and caving zone might result in that the in situ modulus of the surrounding rock being reduced. Examples of this type of subsidence modelling can be seen in the literature. For example, Crouch (1976), Grtunca and Schmann (1986) and Aston *et al.*, (1987) reported that the in situ modulus of the surrounding rock had to be reduced considerably in order to obtain reasonable agreement between measured and predicted subsidence profiles.

The rock parameters used in the computer modelling were obtained for supercritical panels. It may be necessary to use a different set of rock parameters for a single panel in virgin ground. For example, the NCB Subsidence Engineers Handbook (1975) states that the subsidence for a panel in a virgin area should be reduced by a multiplying factor of 0,9 if the values predicted by the graphs derived from cases of multi-seam working are used.

4.1 Modelling of Maximum Surface Subsidence at Lambton Colliery

The program MSEAMS was used to determine realistic values of the input elastic constants related to the shortwall Panel 1 at Lambton Colliery (Kapp, 1978) in the Northern Coalfield of New South Wales. The 67 m wide panel was in the 2,1 m thick Dudley seam and at a depth of 102 m which gave a width to depth ratio of 0,66. The flanking roadways and the pillars were 6 m and 28 m wide respectively. The overlying strata consisted

TABLE I
COMPARISON OF THE MEASURED AND MODELLED MAXIMUM SUBSIDENCE

Name of Colliery	Program used in Modelling	E_s (MPa)	E_c (MPa)	G_s (MPa)	G_c (MPa)	ν	Measured max. sub. (m)	Calculated max. sub.	% Diff.
Lambton	MSEAMS	5 000	1 750	250	600	0.25	0.152	0.140	7.9
South Bulli 'B' LW 9, 10 & 11	MSEAMS	5 000	1 750	250	600	0.25	1.041	1.089	5
South Bulli 'B' LW K, L, M & N	MSEAMS	5 000	1 750	250	600	0.25	1.138	1.174	4
South Bulli 'B' LW 9, 10 & 11	MINAP	5 000	1 750	250	600	0.25	1.041	1.206	16
South Bulli 'B' LW K, L, M & N	MINAP	5 000	1 750	250	600	0.25	1.138	1.261	11
West Cliff	MSEAMS	5 000	1 750	250	600	0.25	0.791	0.735	7
West Cliff	VEDICA	5 000	1 750	250	600	0.25	0.791	0.723	8.6
West Cliff	VEDICA	5 000	1 750	250	600	0.25	0.791	0.707	10.6
West Cliff	MINAP	5 000	1 750	250	600	0.25	0.791	0.908	15
West Cliff	THREED	5 000	1 750	250	600	0.25	0.791	0.215	72.8
South Bulli 'B' LW 204	MSEAMS	5 000	1 750	250	600	0.25	0.378	0.340	9
South Bulli LW 204	VEDICA	5 000	1 750	250	600	0.25	0.378	0.321	8.5

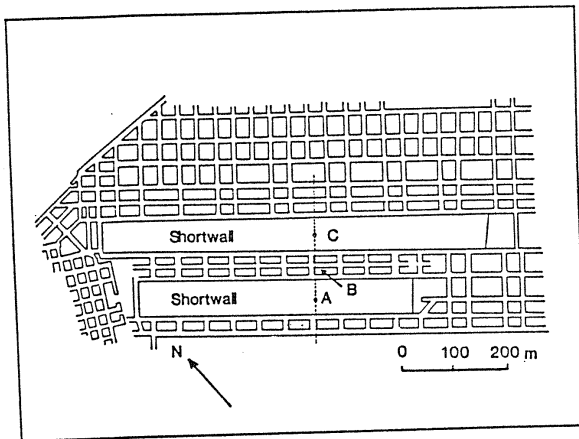


Figure 1 Plan of the modelled area of the Lambton Colliery

mainly of sandstone, conglomerate and shale layers, their relative thicknesses being in that order. The modelled geometry is shown in Figure 1.

The values of the elastic constants determined by successive approximations through modelling with the program MSEAMS, and the degree of agreement between the measured and modelled values of subsidence, are shown in Table 1.

5 PREDICTION OF TRANSVERSE SURFACE SUBSIDENCE PROFILES

The predictions of transverse surface subsidence profiles were carried out above the workings of West Cliff and South Bulli 'B' Collieries in the Southern Coalfield of N.S.W. The mining of the Bulli seam at these collieries was undertaken at about 460 m depth with an average extraction

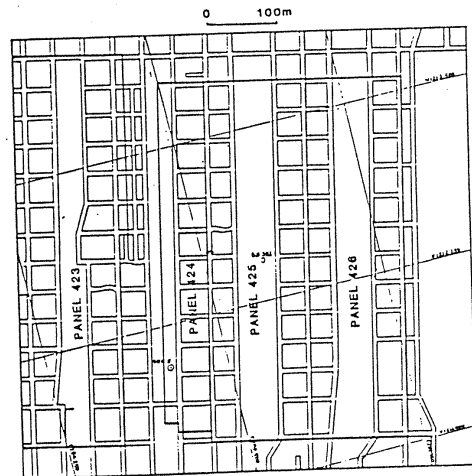


Figure 2 Complete extraction stage of West Cliff Colliery panels

height of 2,6 m. The superincumbent rock consisted of sandstone, shale and clay layers. Although the strata differ slightly from the Lambton Colliery site, the values of elastic constants were kept unchanged for convenience, as stated in Section 4.

5.1 West Cliff Colliery

MSEAMS, MINAP, THREED and the electrical resistance analogue both in conjunction with VEDICA, were used to predict the full subsidence profile above the longwall panels numbered 423, 424, 425 and 426 at West Cliff Colliery. The modelled mine geometry is shown in Figure 2. A comparison of the measured and the modelled profiles is shown in Figure 3.

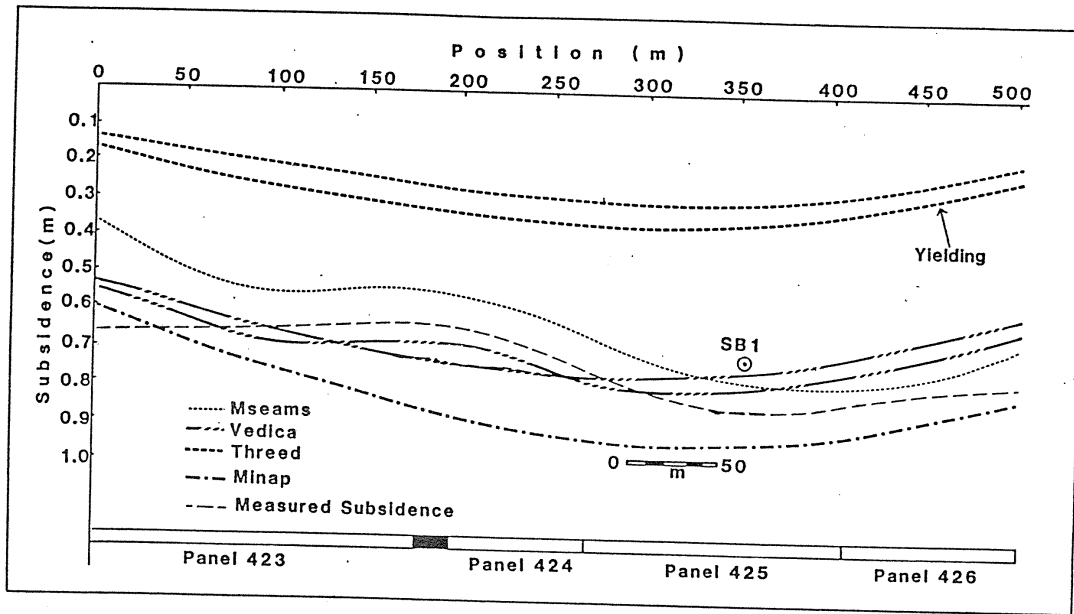


Figure 3 Comparison of predicted and measured subsidence profiles relating to the mining of panels 423 to 426 of the West Cliff Colliery

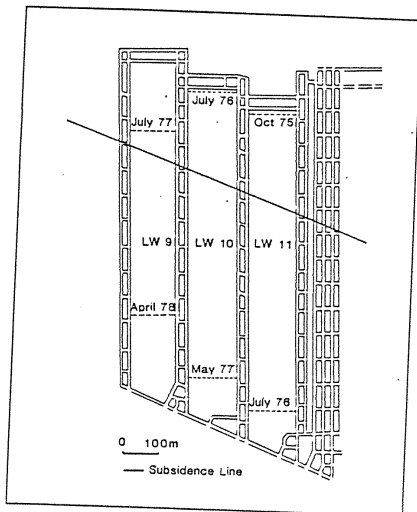


Figure 4 Plan of the modelled area of South Bulli 'B' Colliery longwalls 9, 10 and 11

5.2 South Bulli 'B' Colliery

MSEAMS and MINAP were used in the prediction of surface subsidence at South Bulli 'B' Colliery as a result of the mining of the longwall panels 9, 10 and 11 and K, L, M and N which are shown in Figures 4 and 5. The predicted overall profiles are shown in Figures 6 and 7 respectively.

6 DISCUSSION OF RESULTS

The predicted and the measured maximum subsidences are listed in Table 1. The table shows that the best agreement with measured values was achieved from the modelling using MSEAMS (i.e. 4 to 7 per cent) for each geometry modelled. The analogue based modelling results also achieved reasonable correlation being only 10 per cent less than the measured values.

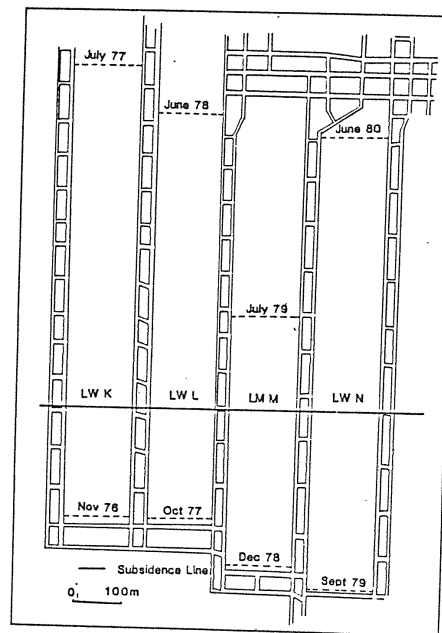


Figure 5 Plan of the modelled area of South Bulli 'B' Colliery longwalls K, L, M and N

The subsidence profile predicted by the program THREED corresponding to the plan geometry of the workings at West Cliff Colliery is shown in Figure 3. In the first run, the surface subsidence profile obtained did not agree well with the measurements. Subsequently, the consideration of the peripheral yielding of pillars was also included but the improvement of the predicted subsidence profile was negligible.

The subsidence profiles obtained using MINAP were also found to be unsatisfactory as illustrated in Figures 3, 6 and 7. The predicted maximum subsidence values were 11 to 16 per cent greater

than the measured ones (Table 1), and more importantly, the predicted profiles did not follow the trend of the measured subsidence profiles, particularly over the ribside of the panels, as shown in Figures 6 and 7.

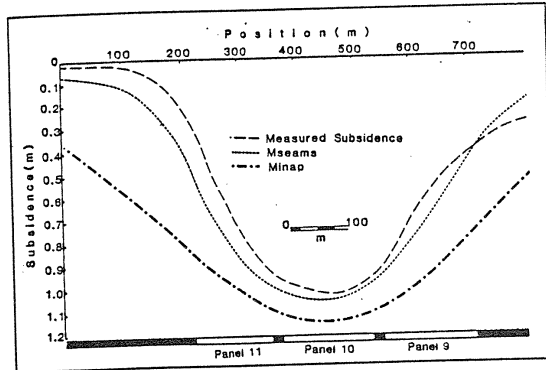


Figure 6 Comparison of the predicted and the measured subsidence profiles of the longwall panels 9, 10 and 11 at South Bulli 'B' Colliery

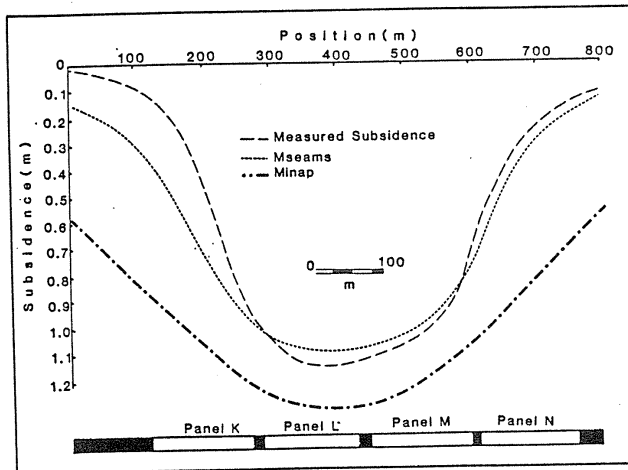


Figure 7 Comparison of the predicted and the measured subsidence profiles K,L,M and N at South Bulli 'B' Colliery

Two subsidence profiles obtained from MSEAMS modelling and the measurements cross each other as shown on the right hand side of Figure 6. This aspect could be due to the crushing of the pillars shown in Figure 4. The percentage of the pillars crushed was not known, the modelled geometry input to the program could not be modified accordingly.

The results obtained from the different programs show that MSEAM is the most suitable program for the prediction of complete subsidence profiles, as shown in Figures 3,6 and 7. The main reason for this could be the transversely isotropic solutions used by MSEAMS. The other programs however, used isotropic solutions which resulted in a poorer agreement between the measured and computed profiles.

7 CONCLUSIONS

A number of computer modelling methods have been utilized to predict the surface subsidence

profiles at the Southern Coalfield of New South Wales. The technique of successive approximation was used to determine the particular values of the parameters relating to the mechanical behaviour of the affected surrounding rock for the prediction of surface subsidence at one of the collieries. The values of these parameters (Table 1) were kept unchanged during the subsequent subsidence modellings at other collieries.

The elastic parameters of surrounding rock used in the programs applied to supercritical panel cases. However it is necessary to determine a new set of parameters for a single panel in virgin ground.

For the computer modelling methods evaluated in this paper, MSEAMS yielded the best prediction for maximum subsidence as well as for the complete subsidence profiles. The main difference between MSEAMS and the other programs is that the former uses an orthotropic solution while the latter ones assume the rock mass to be isotropic.

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