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The Application of Numerical Methods for assessing Impacts of Mining induced Movements

L. Holla
B.E. (Hons), M.P.A., Ph.D., F.I.Struct.E. (London), F.I.E.Aust.
Principal Subsidence Engineer, Department of Mineral Resources, PO Box 536, St Leonards, NSW 2065

V. Sagar
B.Sc.(Geo), B.E.(Civil), M.Eng., M.I.E.Aust.
Subsidence Engineer, Department of Mineral Resources NSW

Summary Surface and sub-surface movements induced by mining were monitored over a longwall panel. The surface monitoring was carried out using standard survey procedures and sub-surface strata movements were monitored at different horizons in a vertical borehole drilled over the longwall panel. The sub-surface monitoring gave information on the goaf height above the coal seam, the angle of fracture and strata movements at various horizons within the overburden. A finite element model was then calibrated, using the observed caving height and angle of fracture, to give the observed surface and sub-surface movements. The use of calibrated numerical models can give a better understanding of the nature of surface and sub-surface ground movements. The total pattern of movement within the overburden could be of assistance when impact assessment of the effect of mining a seam on the overlying features like water bearing strata, other seams or old workings has to be carried out.

1. INTRODUCTION

Coal extraction by underground methods causes surface and sub-surface strata disturbance. The disturbance, if large, could damage structures and natural features. Water resources such as rivers and lakes situated on the surface and those within the undermined strata such as aquifers could also be adversely affected. The prediction of ground movements prior to mining and their effect on the surface environment is an important issue of community concern in New South Wales.

At present, a number of methods are in use for predicting mining induced ground movements. The methods generally fall under two broad categories: empirical and numerical methods. While empirical methods are simple and quick to use, they are site specific. Therefore they cannot be applied to situations outside the area within which the data used to develop such methods has been collected. The empirical results cannot be explained in terms of engineering theories. Furthermore, they deal only with surface movements and do not give any indication of movements within the undermined overburden. Numerical models on the other hand can indicate a total pattern of movements within the overburden. They can also be modified to accommodate site specific factors, provided the basic model is calibrated for field conditions.

This paper deals with the calibration of a finite element model by using the surface and sub-surface strata movement data collected over a longwall panel.

2. SCOPE AND METHODOLOGY

A longwall panel at the Invincible Colliery in the Western Coalfield of New South Wales was selected for the study. The primary objective of the study was to explore the use of numerical models for understanding the behaviour of undermined strata. Surface and sub-surface strata movements had earlier been monitored on the surface and in a borehole drilled vertically from the surface to the extracted seam (Holla 1989, Holla & Buizen 1990). The following were the major stages of the study.

1. The surface and sub-surface strata movements monitored over the longwall panel were analysed and interpreted for fixing the size and shape of goaf and the major disturbed zone above the goaf. (Goaf is the zone of fracture and disturbance immediately above the extracted seam where the pre-mining intact strata break into rubble.)
2. A finite element method was selected for modelling the undermined overburden. Model configurations were optimised for the two dimensional study. Small inclinations of bedding planes that may be present in the field were ignored and all beds were considered as horizontal in the model.
3. After extraction of the coal seam, the strata within the goaf and above it in the centre of the longwall panel was treated as the area of fracture and/or disturbance and strength parameters of beds in this zone were reduced

to obtain a best correlation with the observed data.

4. The model was calibrated using field data of surface and sub-surface strata movements.

3. COLLECTION OF FIELD DATA

3.1. Monitoring Sub-Surface Movement

3.1.1. Details of Monitoring

The sub-surface movements were monitored in a borehole drilled over Longwall Panel 2 at the Invincible Colliery. Longwall Panel 2 was adjacent to the already extracted Longwall Panel 1 (Figure 1). The two longwalls were each 140 m wide separated by coal chain pillars of 19.5 m width. The depth to the seam at the borehole was 116 m and average thickness of Lithgow coal seam was 2.7 m.

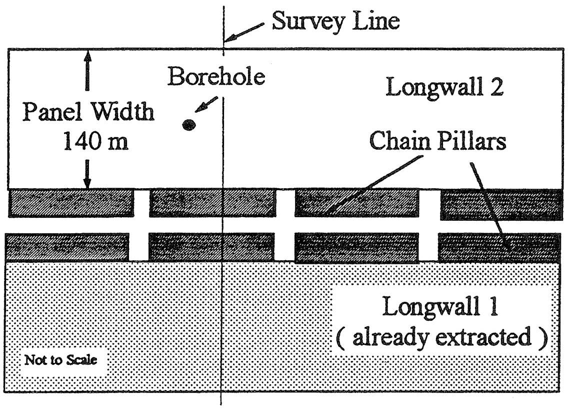


Figure 1. Layout of longwall panel showing borehole location.

The borehole was located over the centre line of the panel and was at a distance of 275 m from the commencing rib. Fourteen mechanical anchors were installed in the borehole at various horizons between the roof of the Lithgow seam and the surface. The deepest anchor was located at a height of 7 m above the seam roof and the shallowest was 13 m below the ground surface. Details of anchors, their installation and monitoring of sub-surface strata movements are given elsewhere (Holla 1989, Holla & Buizen 1990).

3.1.2. Results of Sub-Surface Movement Study

The two major findings of the study (Holla 1989, Holla & Buizen 1990) relevant to this paper relate to caving height and angle of fracture. These two determine the extent of goaf height for use in modelling. Angle of fracture is the angle between the vertical and an imaginary rupture plane leading up through the rock mass from the edge of the extraction panel to cracks on the surface (Figure 2). Since surface cracking is most likely to occur at points of maximum tensile strains, angle of fracture is also defined as the angle between the vertical and the line joining the edge of the extraction panel with the point of maximum tensile strain. Maximum tensile strains on the surface occurred 55 m to 65 m behind the moving longwall face which gave angle of fracture of 26-29 degrees. This value was supported by sub-surface strains which were large along the rupture plane based on an angle of approximately 26 degrees.

Figure 2 shows details of the goaf and the major area of disturbance based on information on the monitored caving height and angle of fracture. The goaf was trapezoidal in shape with the base width equal to the panel width and sides inclined at an angle of 26 degrees to the vertical. Caving extended upwards from the seam floor for a distance of 23 m giving the goaf height of 23 m.

The sub-surface strata movements as monitored in the borehole are shown in Figure 5.

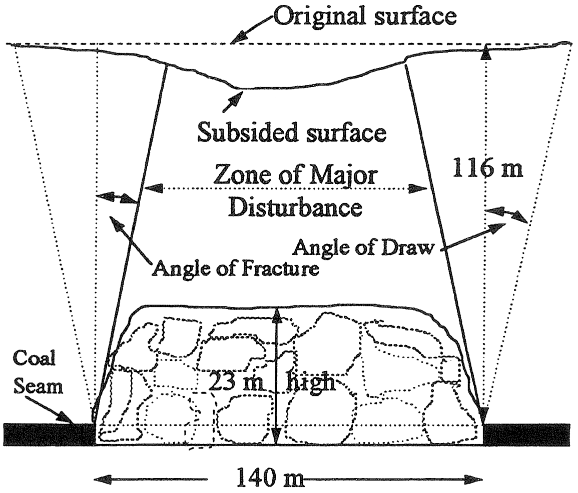


Figure 2. Cross section through the panel showing the goaf and zone of major disturbance.

3.2. Monitoring of Surface Subsidence

The ground movement was monitored along a line of survey pegs established across the longwall panel (Figure 1). The levels of pegs and distances between them were monitored during mining by conventional survey techniques. Figure 6 shows the monitored subsidence profile along the survey line.

4. NUMERICAL MODELLING

4.1. Model Details

A finite element analysis was undertaken to predict surface and sub-surface movements over Longwall Panel 2. The computations were confined to a two dimensional linear elastic analysis. The software package ALGOR® was used with the details of the software given elsewhere (Sagar & Holla 1994). The coal seam and the undermined ground strata

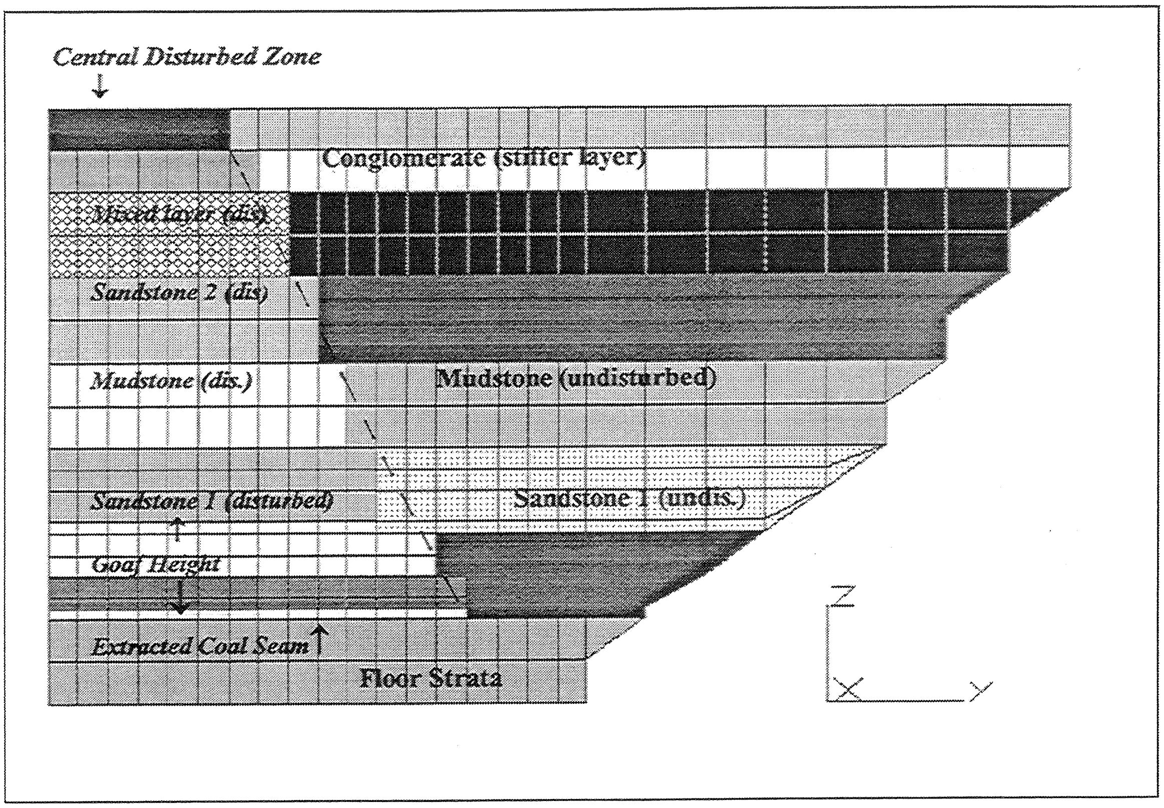
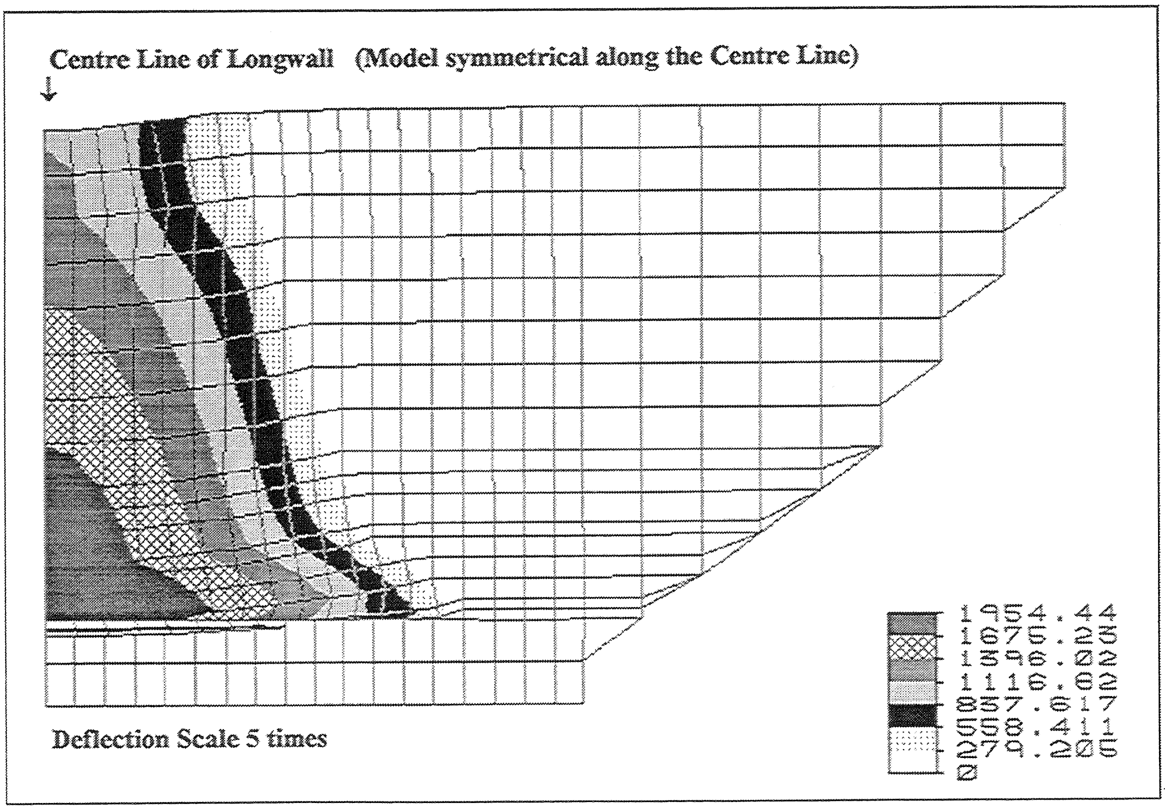


Figure 3. Model showing Different Material used, Coal Seam and Goaf Height


Centre Line of Longwall (Model symmetrical along the Centre Line)

Deflection Scale 5 times

Figure 4. Deflected Model showing the Magnitudes of Displacements (mm)

were modelled across the panel. The strata were considered as horizontal and any small inclinations of bedding planes occurring in the field were ignored. The extent of the modelled section was limited by an angle of about 45° projecting upwards from the base of the model. The model was extended 20 m below the extracted seam level and 30 m to either side of the base of the extracted seam. As the model is symmetrical along the centre line of the extracted panel, only one half of the model was required for analysis. The model is shown schematically in Figure 3.

Boundary elements along the centre line of the model were restrained in the horizontal direction but were free to move in the vertical direction. The boundary elements at the base and on the sloping sides of the model were restrained in both vertical and horizontal directions.

4.2. Properties of Overburden Strata

The modelled sub-surface strata was divided into 8 horizontal layers excluding coal seam to broadly represent the actual strata as identified by borehole core samples. Representative values of rock material properties were adopted for the model based on testing of core samples. (ACIRL report 1986).

Prior to the extraction of coal, each layer of rock was assumed to behave isotropically, as such similar values of the Modulus of Elasticity (E) for rock were used in the model both in horizontal and vertical directions. Shear Modulus (G) for the intact rock was taken as $G = E/2(1+\mu)$ where μ is Poisson's ratio.

After the extraction of coal, the goaf and the rock strata above the goaf bound by angle of fracture of 26 degrees, were treated as fractured and/or disturbed. Consequently, each layer of material had two portions, one falling within the disturbed zone and the other one outside it. In all, the model consisted of layers of 17 different materials, 9 within the disturbed zone and 8 outside it as shown in Figure 3. The post-mining model indicating deflections in mm is shown in Figure 4.

Material properties of overburden strata prior to mining are shown in Table 1. The properties of layers within the disturbed zone were decreased, the extent of decrease increasing with depth below the ground surface so that the computed values of strata movement agreed with the observed values.

5. ANALYSIS OF RESULTS

Initially, the model was analysed with reduced values of elastic properties of the disturbed strata only and assuming no goaf formation. In this case, the computed values of subsidence were much less than those measured on the surface. The goaf as shown in Figure 2 was therefore introduced into the model.

The surface subsidence profile plotted from the field survey data is compared with the profile derived from the model in Figure 6. Even though the two profiles in Figure 6 agreed reasonably well. In the central portion of the subsidence trough, about 45 m from the centre, the observed values were larger than the computed values, though the maximum subsidence values from both data were almost the same. Further adjustment of the value of angle of fracture could possibly bring the modelled profile in closer agreement with monitored field results.

The sub-surface strata movements computed from the model are compared with the monitored values in Figures 5. The sub-surface strata movements were monitored only down to a depth of 110 m from the ground surface where the recorded maximum value of subsidence was 1953 mm.

Table 1 Properties of materials used in the model.

Material Type	Density kg/m^3	Young's Modulus MPa	Poisson's Ratio	Shear Modulus MPa	Strata thickness (m)
Floor strata	2 550	10 000	0.30	3 845	20
Siltstone	2 440	8 000	0.29	3 100	20
Sandstone 1	2 300	8 500	0.24	3 425	20
Mudstone	2 440	5 000	0.29	1 938	20
Sandstone 2	2 300	5 000	0.24	2 020	20
Mixed Layer	2 440	3 000	0.29	1 160	20
Conglomerate	2 335	15 000	0.19	6 300	10
Weathered material (near surface)	2 440	2 000	0.29	775	10

Theoretically, the modelled sub-surface subsidence should keep increasing with depth until reaching the top level of the extracted seam and then abruptly reduce to almost zero at the bottom of the seam. However the model has shown a reduction in subsidence from a peak value at 110 m depth to nearly zero at 120 m depth, which was the base of the seam. This reduction occurred gradually over a distance of 10 m because the model reaction was that of an elastic media, in which each element is connected to the adjoining element. The subsidence profiles from the model, at surface and at different depths, are shown in Figure 7.

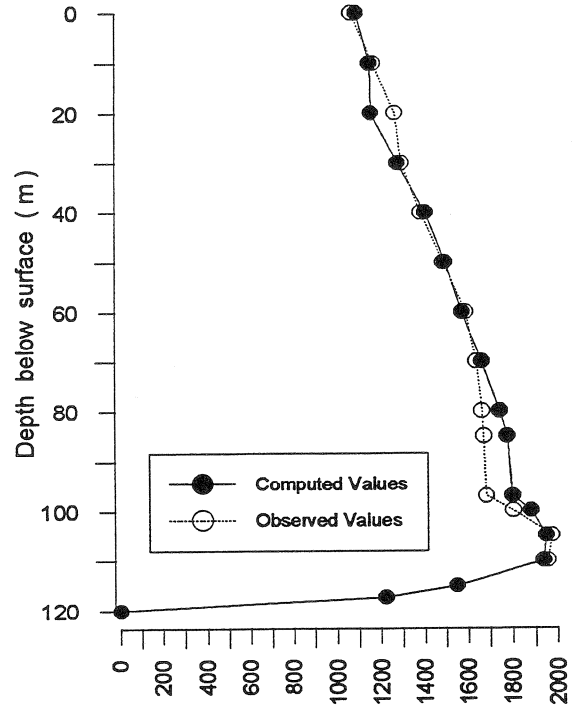


Figure 5. Comparison of computed and monitored movements at the borehole location.

6. POTENTIAL APPLICATION OF NUMERICAL MODELS IN THE CONTEXT OF MINING SUBSIDENCE

The field subsidence observations monitored as sub-strata movements of mechanical anchors located within a borehole cannot be strictly extrapolated to other areas over the longwall panel. The high cost of drilling, equipping and monitoring a borehole makes it impractical to increase the number of such boreholes at other locations over a panel. The cost of numerical modelling represents only a fraction of the cost of drilling additional boreholes that would be required to obtain sufficient information allowing similar level of understanding with regard to sub-surface subsidence.

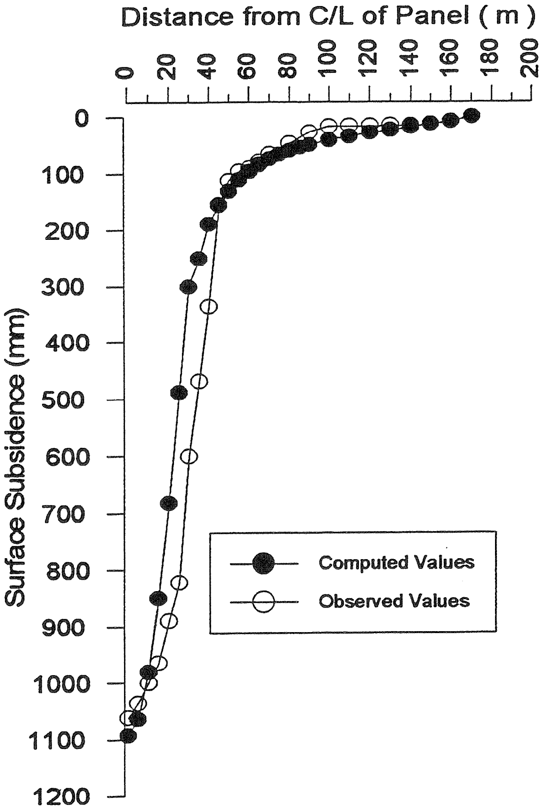


Figure 6. Comparison of monitored and computed surface subsidence across the panel.

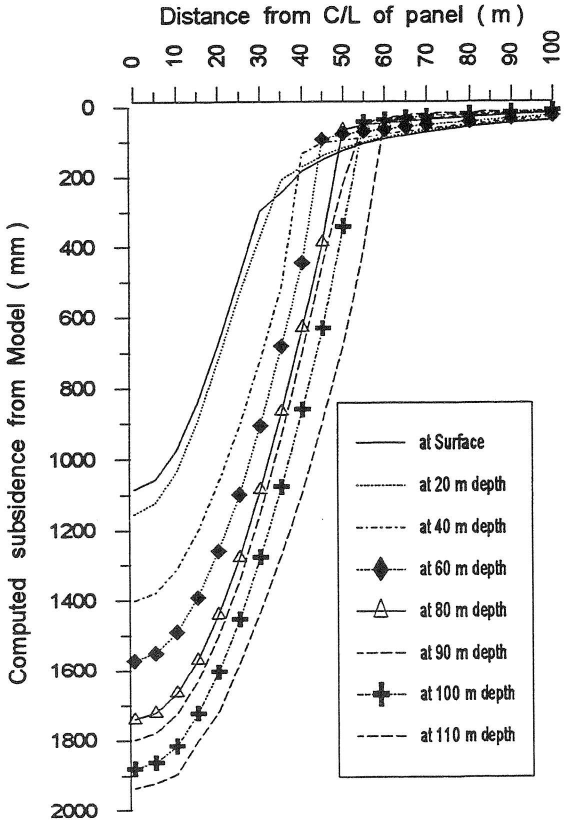


Figure 7. Subsidence profiles at different depths as computed from the model.

A calibrated numerical model, using results obtained from an instrumented borehole, can therefore be used in a convenient and cost-effective manner for getting a more complete picture of sub-surface strata movement over an extraction area. In addition, the calibrated model can easily be modified for further studies of the effect of changes in overburden conditions. Two potential important applications are discussed below.

6.1. The Effect of Variations in Overburden Materials

The magnitude and pattern of ground movements depend largely upon the variable lithology of overburden. Differences in monitored subsidence profiles, even over two adjacent longwall panels, have been recorded and were probably due to such variations of overburden (Holla 1996). To explain these differences, one has to have an understanding of the effect of many variations in overburden characteristics on the ground movement. Such variations, in the form of beds of different kinds, thicknesses and strengths, may be located at different horizons. For example, presence of a hard layer of strata in the overburden may reduce surface subsidence dramatically. Calibrated numerical models are perhaps ideally suited for examining the effects of variations in overburden on development of subsidence. The model can be easily varied by changing the properties of material or thickness of layers. A preliminary study indicates that a stiffer layer located near the surface is more effective in reducing surface subsidence than if a similar layer was located at a deeper horizon below the surface. More work in this area is being carried out.

6.2. The Effect of undermining the Overlying Strata

The effect of mining a coal seam on an overlying feature is critical in some cases. The overlying feature may be an unmined seam, a water bearing bed or overlying workings in another seam. The effect can be assessed by numerical modelling. The total picture of movement indicating areas of large strains and movements is useful for impact assessment of underground mining and for this purpose numerical models can be used effectively.

7. CONCLUSIONS

Field monitoring is essential for gathering the data required for calibrating numerical models. This data comprised information on the caving height above the coal seam, the angle of fracture and on strata movements at various horizons within the overburden. Without calibration, numerical models are unlikely to give reliable results. Calibrated models can be used for gaining a better understanding of the nature of surface and sub-surface strata movements.

The numerical analysis was based on simplistic assumptions with regard to material properties and model dimensions. Some of the assumptions may not be strictly correct, but they were considered appropriate in the context of the study. The main purpose of study was to use the calibrated model for gaining a better understanding of the undermined strata rather than using the model as a predictive tool.

The total pattern of movements within the overburden could be of assistance when an impact assessment of the effect of mining a seam on the overlying features like water bearing strata, other seams or old workings has to be carried out.

8. ACKNOWLEDGMENTS

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