MATHEMATICAL MODELLING OF THE CONVERGENCE AND VERTICAL STRESS PATTERNS AROUND A LONGWALL PANEL IN NEW SOUTH WALES

By

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ABSTRACT

Mathematical modelling was carried out to determine the probable convergence and vertical stress patterns around a retreating longwall panel in an underground coal mine in New South Wales. An 'Electrical Resistance Analogue' and a program called 'THERMID' based on the displacement discontinuity method were used for the modelling.

Parts of the obtained results are presented here and compared with some measurements of convergence at the site. The modelled and measured data agree better qualitatively, than quantitatively.

INTRODUCTION

The convergence and vertical stress patterns in the plane of the seam, relating to the geometry of the retreating longwall panel no. 1 at West Cliff Colliery at various stages of mining was simulated by mathematical modelling (Pattinaja, 1986). Some results of the modelling are presented in this paper and compared with convergence measurements in the three tail-gate roadways of longwall panel no. 1. The latter were part of a comprehensive programme of measurements conducted at two separate locations by Kestia Coal and Coke Pty. Ltd., to study the effect of mining the longwall panel on the surrounding strata.

WEST CLIFF COLLIEHY

West Cliff Colliery is situated about 80 km to the South-west of Sydney. In 1965, about 1.5 x 10^6t of high quality hard coking coal was produced by the colliery (Joint Coal Board, 1965) from the workings which are restricted to the Bulli seam. Previously the production was obtained from the almost total extraction of panels by the pillar and 'Wongaville' (Martin, 1980) method. The retreating longwall method was included in

July, 1982, in order to increase production.

RETREATING LONGWALL PANEL NO. 1

The layout of longwall panel no. 1 is shown in Figure 1. The 1500m long and 135m wide panel was flanked by:

1. Panel 470, consisting of two 70m wide roadways denoted as A and B, which served as the main-gates. They were separated by rectangular pillars of dimensions 63m x 27m;

2. Panel 471 consisting of three 70m wide roadways denoted at C, D and E, which served as the tailgates. The

![Figure 1 - Layout of retreating Longwall Panel No. 1 at West Cliff Colliery](attachment:figure_1.png)

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roadways were separated by
rectangular pillars of dimensions 50m x 25m between the first two and 82 x 10m between the last two.

The panel was approximately 420m below
the surface. The thickness of the Bulli seam at the panel was about 2.7m. The immediate
roof of the seam was massive sandstone over
much of the length of the panel from the
starting end, changing to a comparatively thin
layer of mudstone towards the other end. Deterioration in roof conditions was generally
experienced with the mudstone. The immediate
floor was mainly composed of a moderately
strong shale.

Six to twelve metres below the Bulli
seam was the Halcrowrie seam which was about 1m
thick and contained a large amount of methane
gas.

The equipment at the longwall face were
as follows:
1. An Anderson Strathclyde, AM 500,
375kW ranging drum shearer weighing
45t,
2. 82 units of Gallick Dobson, 4 legged,
900t, chock-shield support, each
weighing 23.7t,
3. A Mining Supplies, 1250t/hour
armoured face conveyor and a bean
stage loader,
4. Ancillary equipment.

MEASUREMENTS RELATING TO THE BEHAVIOUR OF
STRATA AROUND RETREATING LONGWALL PANEL 1

The plan layout of the measuring
stations at the first of the two locations are
shown in Figure 1. The measurements broadly
consisted of the following:
1. Convergence (i.e. relative vertical
displacement) between opposite points
on the roof and floor at mid-span in
the roadways and cross-cut, using a
graduated tape or telescopic rod.
2. Vertical displacements at different
depths within the roof and floor
strata, using the borehole wire
extensometer method (Medley, 1969).
3. Lateral displacements at different
depths within the sides of the
pillars and the solid rib of coal,
using the borehole wire extensometer
method.
4. Hydraulic pressure measurements in
the pairs of front and rear legs of
the shield-type face supports.

As indicated at the beginning, only the
convergence measurements at the first location
during the first 300m retreat of the face are
presented in Figures A(a) and (b) of this
paper.

MATHMATICAL MODELLING OF THE EFFECTS OF
MINING LONGWALL PANEL NO. 1 ON THE SURROUNDING
STRATA

The object of the mathematical modelling
was to improve the capability of predicting
the behaviour of strata affected by mining,
through the comparison with in situ
measurements. Two different techniques of
modelling were used:
1. The Electrical Resistance Analogue;
2. A computer program called 'THREED'.

Both the techniques provide the patterns of
convergence and vertical stress caused by
mining of irregular geometries in the plane of
a tabular deposit like a coal seam.

MODELLING BY THE ELECTRICAL RESISTANCE
ANALOGUE

The theoretical bases for modelling by
the Electrical Resistance Analogue have been
given by Salomon (1963) and Cook and Schumann
(1965). The analogue at the School of Mines,
University of New South Wales is basically a
large, upright, rectangular prism shaped
network of resistors. The front one of its
two larger vertical faces contains 111 x 111
junctions of resistors called 'nodes'. At
each node, a socket is incorporated, in which
variable resistors (of 0 to 10 k range) can
be inserted for connecting to the earth. To
the opposite face of the network, a steady
D.C. 10 V potential is applied.

Modelling of a mine excavation by the
analogue is based on the following
assumptions:
1. The strata associated with the
excavation are homogeneous, isotropic
and linear elastic media.
2. The excavation is at an infinite
depth from the surface, which in
reality requires the depth to be
greater than the maximum width (i.e.
the shorter dimension) of its plan
geometry.
3. The excavation is within a tabular
deposit i.e. the latter's thickness
compared to the lateral extent is
small enough to allow it to be
considered as negligible and the
deposit to be a plane.
4. The virgin principal stresses at the
plane of the deposit are constant
over the area being modelled. They
are oriented parallel and
perpendicular to that plane, thus
excluding any shear stress in that
plane. The vertical (i.e. major)
principal stress depends on the depth
of cover and the horizontal stresses
are equal and related to the former
through the Poisson's effect.

Modelling without considering yielding of coal

In this type of modelling, no fracturing
or yielding of coal was considered to occur,
whatever the magnitude of stress.

The variable resistors were set at a value 'r' given by the following equation
(Keenan and Gravetz, 1970):

\[ R = \frac{E}{k(1-v^2)} \frac{N_n}{L} \]

where, 
- \( R \) = resistance of an unit cube
- \( E \) = Young's Modulus of the
- \( v \) = Poisson's ratio of the
- \( N_n \) = number of nodes representing
- \( L \) = linear distance 'L′ in the

The variable resistors were all set at the value 'r' and inserted into the sockets in
the addressable area at the front face of the
analog. The surrounding boundary nodes, which represented multiples of the areas
corresponding to the addressable nodes,
required appropriately equivalent lower
resistances. The voltages 'Vn' at all the
addressable nodes were then sequentally
measured by an automatic scanning circuit and
recorded.

The plan geometry of the excavation at
the chosen scale was created next, by removing
the resistances 'r' from the nodes in an
appropriate pattern. The voltages 'Vn' at all
the nodes were measured and recorded again.

From the two corresponding voltage
measurements, the vertical stress at any node
in the unmined area and the convergence at
any node could be calculated using the
following equations:

Vertical stress, \( \sigma_z = \frac{V_n}{V_u} \)

Convergence, \( z = \frac{V_n}{E_H} \left( \frac{V_n}{V_u} - 1 \right) \)

where, \( Q \) = virgin vertical stress

A computer was used for the large number
of calculations and a plotter for drawing
contours of vertical stress and convergence.

Modelling, considering yielding of insufficiently constrained coal

The fracturing or yielding of coal in
underground mines is commonly observed, where
coal is insufficiently constrained e.g. at the
side of an excavation. At the periphery of
such exposed blocks of coal, the concentration
of vertical stress can easily exceed the in
situ compressive strength of the material.
The magnitude of vertical stress necessary to
cause yielding would depend on the degree of
constraint on the coal. At the exposed face
of the coal, the state of stress would be
uniaxial i.e. there would not be any
constraint. Progressively inward from the
exposed face, the state of stress would become
triaxial due to increasing constraint and the
compressive strength of the coal would
increase correspondingly.

The modelling of the yielding of coal
must be preceded by the modelling without
considering yielding. The subsequent
incorporation of the aspect of yielding would
require the following additional information:

1. The magnitude of compressive stress
at which yielding begins.

In the modelling being discussed, the
averaged value of vertical stress profile across the yielded zone
suggested by Wilson (1972) was used.
Accordingly, the compressive stress for yielding was taken as the estimated
vertical stress of 11.52 MPa at the
relevant depth. By coincidence, that
magnitude was close to the uniaxial
compressive strength of 12 MPa for the
particular coal and for convenience, the latter value was
actually used.

2. The width of the yield zone.

In the modelling, the width was taken
to be 6a, following the empirical
relationship suggested by Wilson
(1972):

Maximum width of the yield zone = 0.006 \( h \) (meters)
where, \( h \) = depth of the seam from
the surface;
and \( a \) as defined earlier.

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3. The existing state of yielding in the zone.

This state is determined by the interaction of the load-convergence characteristic of the coal in the post-failure stage and that of the composite roof and floor strata.

As regards the load-convergence characteristic of the coal for the modelling, an idealised one similar to that shown as OBC in Figure 2 was constructed by combining the results of uniaxial compression tests published by Crouch and Fairhurst (1973) and Van Heerden (1975).

It would be impractical to directly determine the in situ load-convergence characteristic of the composite roof and floor strata. It could however be determined indirectly on the analogue (Nikula, 1980). Let, the initial modelling without considering yielding determine the vertical stress at a node representing a peripheral zone of coal to correspond to the point D in Figure 2 which is higher than the coal's compressive strength. The effect of removing the inserted resistance 'r' from that node would be as indicated by the line D D', which would represent the load-convergence characteristic of the roof and floor strata at the particular location.

The state of yielding of the coal at the particular node would be as indicated by point F, which is the intersection of the load-convergence characteristic of the fractured coal and that of the roof and floor strata. To incorporate the yielded state of the coal, the corresponding resistance 'r_y' reflecting the apparent lower modulus of the material, needs to be inserted at the node. The value of 'r_y' can be determined from the following relationship:

\[ r_y = \frac{r}{\frac{\gamma}{\gamma}} \]

Appropriate values of 'r_y' would also be required at other nodes subject to yielding. However, the alteration of the resistance from 'r' to 'r_y' at any node, would also affect the conditions at other nearby nodes. Therefore, an iterative process would be needed to represent the overall yielding at the appropriate nodes.

The laboriousness of the described method can be reduced by using a digital-analogue hybrid system (Crouch and Fairhurst, 1973; Hardy et al, 1977; Hardy and Christianson, 1974).

Modelling of retreating longwall panel no.1

The geometries of longwall panel no. 1
The elements can be assigned as appropriate to represent roadways, artificial supports, goaf and unmined coal in the elastic or yielded state. The program first assumes an initial magnitude of convergence at all the elements and uses a relaxed Gauss-Seidel iteration technique to determine the final convergence at each element. The corresponding vertical stresses are also calculated.

The input data includes an assumed stress-strain characteristic for the coal seam material. It consists of a linear elastic part of positive slope for intact coal and another of negative slope for yielded coal as in Figure 2. The width of the yielded zone is specified. The material properties in the yielded zone is defined only by the degree of confining stress and is independent of the location of the relevant element.

Regarding the caved elements, the input data specifies the caving height, bulking factor and the stress-strain characteristic for the caved material. The characteristic consists of linear segments of increasing positive slopes to represent the bulking and subsequent recompression of the caved material.

Modelling of retreating longwall panel no. 1

The geometry of longwall panel no. 1 after 200m retreat of the face was modelled assuming peripheral yielding of unmined coal. Where possible, the values of the relevant parameters were kept the same as in the analogue modelling. The height of caving was taken to be 8m (i.e. about three times the height of extraction of 2.75m) and the bulking factor for the caved rock as 1.25.

The transverse profiles of vertical stress and convergence at an arbitrary distance of 3.5m ahead of the face line are shown in Figures 3(a) and (b).

ANALYSIS OF THE MODELLING RESULTS

Profile of convergence across longwall panel no. 1

In Figure 3(a) the much greater magnitudes of convergence from the modelling by 'THREED' represents much greater yielding of coal 3.5m ahead of the face line, than in the modelling by the analogue. This seems to reflect the ease of modelling the yielding phenomenon by 'THREED'.

The absence of significant variation of convergence across panels 470 and 471 appears to suggest that the respective widths of 21m and 20m for their larger pillars were inadequate for withstanding the abutment loads arising from the mining of the intervening longwall panel no. 1. The indicated large values of convergence across panels 470 and 471 are however contradicted by the measurements of convergence shown in Figures 4(a) and (b). The most likely cause for such differences would be the assumed values of the load-deformation parameters for the rock materials and the dimensions of the elements used in the modelling.

Profile of vertical stress across longwall panel no. 1

In Figures 3(b), low levels of vertical stress have been indicated across the wider pillars in panels 470 and 471 from the modelling by 'THREED'. If correct, this would signify the failure of the intended approach.

Fig. 1 - Transverse profiles of modeled (a) convergence and (b) vertical stress, 3.5m ahead of the face-line after 200m retreat of Longwall Panel No. 1.

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of employing a combination of stiff and yielding pillars in panel 471 to permit the use of the two outer roadways as intakes for the future longwall panel no. 2. Furthermore, the high abutment stress indicated at the edge of the future longwall panel no. 2 would lead to serious support problems during its extraction.

In contrast, the vertical stress profile from the analogue modelling suggests the success of the design approach.

Again, the differences can be attributed to the same reasons as in the instance of convergences.

Comparison of measured and analogue modelled convergences in the roadways of panels 470 and 471

The convergence values from measurements and analogue modelling (ignoring yielding) in the roadways of panels 470 and 471 (Figure 1) corresponding to the mining of longwall panel no. 1 are shown in Figure 4(a) and (b) respectively. The sudden cessation of measurements in roadways 'A' and 'C' after about 75% retreat of the face was due to the measuring stations becoming part of the goaf.

The convergence values from modelling are larger than those from measurements, obviously because the values of the load-deformation parameters used in the modelling. The similarities in the patterns of the two types of convergences are however evident.

CONCLUSIONS

The usefulness of mathematical modelling by the electrical resistance analogue or the program "THREED", in qualitatively assessing the stability of complex mine layouts in tabular deposits like a coal seam is obvious. Yielding in appropriate zones of the umained coal can be modelled in both the methods, although very laboriously in the analogue.

"THREED" permits the inclusion in the modelling of face support systems, caving and the recompression of the caved material, but not the analogue. The existence of high horizontal stresses cannot be accomodated by either of the methods.

The quantitative accuracy of the results from such modelling can be improved by the prior determination of realistic values of the parameters defining the deformability of rock materials through the back-analyses of in-situ measurements. Even without quantitative accuracy, modelling can indicate the relative superiority of a particular layout compared to others.

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REFERENCES


