DESIGN OF YIELD PILLARS IN THE SOUTHERN COAL FIELD OF NEW SOUTH WALES

By

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ABSTRACT

With increasing demand for more efficient production from the underground coal mines in the Southern Coalfields of New South Wales, their design and operational aspects are constantly being reviewed and improved. One key area in such pursuits is the reliable design of stable and yielding pillars. The current designs of pillars based mainly on experience leads to unnecessary sterilisation of coal or strata control problems. To explore such mine design problems, computer based modelling is increasingly being applied.

In the study described in this paper, the objective was to determine the particular width of pillars separating three roadways in a panel at which the pillars yielded completely and their loads largely transferred to the undermined coal at the flanks of the panel. This was approached through a computer simulation of the behaviour of the strata around a panel, in which the three roadways were separated by pillars of progressively decreasing width. A computer program called FLAC based on the finite difference method was used to simulate the relevant strata behaviour in vertical sections. The appropriate input values of the deformability parameters relating to the coal seam, roof and floor were determined from the back analysis of some displacement measurements in such a panel. The process involved successive modelling of a vertical section through such a panel, starting with realistic values of the parameters and varying them until the measured and the modelled displacements agreed closely.

Based on the results of the numerical modelling, the width of a yielding pillar for the given conditions is suggested.

INTRODUCTION

Black coal is one of the major minerals exported from Australia. In 1990 about 113.18×10^6 t of black coal worth approximately $6.54×10^9 was exported (J.C.B., 1991). Of the total 165.74×10^6 t of black coal produced, about 112.57×10^6 t i.e. 67% was from surface mines. The remainder was produced from underground mines.

Due to considerable operating cost advantages, surface mining of coal has been increasing since the 1970s. However, due to the depths and surface restrictions involved, about 80% of the mineable black coal reserves in Australia can be extracted only by underground methods.

The current underground mining layouts require the development of generally rectangular panels. The boundaries of a panel are delineated by multiple parallel 'headings' i.e. roadways on each side. The parallel headings are separated by 'pillars' of coal of uniform widths and lengths.

Geological conditions and the existence of high horizontal stresses in many of the coal fields in Australia cause serious problems in the support and stability of the roadways. Such problems slow down the mining operations and increase costs. The stability and support of the headings are greatly influenced by the load bearing characteristics of the separating pillars.

For a given set of conditions, the 'strength' i.e. load bearing capacity of a pillar is determined mainly by its width i.e. the shorter lateral dimension. If the width is, say, 3-10% of the pillar's depth below the surface, its load bearing capacity is high and it can isolate neighbouring excavations from affecting one another. Such a pillar is considered to be 'stable'. It, however, sterilizes a large amount of mineable coal and also, increases the length of the cross-cuts connecting the parallel headings and thereby, the time and cost of development.

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If under the same conditions as before, the width of a pillar is, say, 2% of its depth below the surface, it may be unable to sustain the imposed load and it may ‘yield’ i.e. suffer a state of partial failure. Then, the pillar would be unstable and adjacent excavations from affecting one another. In certain circumstances, the use of ‘yielding pillars’ between parallel headings can improve the stability of the latter, by transferring the high stress concentrations from those pillars on to the unmined solid coal flanking the group of headings.

This paper describes the two dimensional modelling by a computer program called FLAC (Itasca, 1989) of the patterns of displacements and stresses in vertical sections through strata containing three headings separated by pillars of progressively decreasing widths. The purpose of the modelling was to extend the understanding of the measurements of displacements and stresses relating to an experimental determination of the width for yielding pillars at West Cliff Colliery, conducted by Kembia Coal and Coke Pty Limited.

PROGRAM FLAC

‘FLAC (Fast Lagrangian Analysis of Continua) is a personal computer based, two-dimensional, explicit finite difference code. It is formulated to simulate the behaviour of structures in materials which undergo plastic flow when their yield limits are reached (Itasca, 1989).

The modelled media are represented by a continuous mesh of quadrilateral zones or elements in a two-dimensional space. Each element is defined by four finite difference grid points which are individually identified in a co-ordinate system. The sizes of the elements can be varied to suit the dimensions of the excavations and the media in which they occur.

In modelling, first the stress-strain relationships for the different rock types represented by the appropriate elements are defined. Next, the boundary conditions for the mesh are defined as well as, the initial stress conditions. Then, the initial equilibrium condition of the mesh is determined. After this, the excavations are created in the mesh in any desired order by specifying the appropriate ‘null’ elements. If necessary, the properties of the rock types and other initial conditions are altered. Following that, the equilibrium condition of the mesh is determined again.

EXPERIMENTAL DETERMINATION OF YIELD: PILLAR WIDTH

The experimental determination of the width of yield-pillars at West Cliff Colliery was conducted at level 315, which was specially developed for that purpose and was away from any previously mined out areas. The panel consisted of three converging headings of average width 5.5m and height 3m, separated by two pillars whose widths tapered progressively from 24 m to 3 m over a length of approximately 154 m with no cross-cuts except at the ends of the pillars. The headings had a sandstone roof and a shale floor.

Considering a vertical cross-section of the panel, the headings were developed sequentially starting from the left. At regular intervals of distance in each heading, the developments were interrupted and instruments were installed in a vertical cross-sectional plane to measure the convergences and displacements of the roof, floor and ‘rib’ (i.e. side walls) of the heading as well as, stresses at the centre of the pillars. Of all the measurements, however, only those of convergences were available to the present authors.

MODELLING TO DETERMINE THE WIDTH OF YIELD - PILLARS

MODELLED GEOMETRY

The pillar with tapering widths in panel 313 could not be represented as such in the modelling. Therefore, some vertical cross-sections of the layout with different widths of the pairs of pillars were modelled. For simplicity in the modelled geometry, the widths and heights of the headings were taken as 6m and 3m respectively.

One group of the modelled vertical sections included pairs of pillars of widths 20m, 10m, 7.5m and 5m respectively separating the headings. In that group, the headings were represented in the actual sequence of their development. The reasons for following the actual sequence were:

1. to use some measured convergences in the first (i.e. left) heading as references for deriving realistic input values of the mechanical properties of the strata by the method of successive approximation through repeated trial modelling.

2. to use other convergences measurement in a check on the accuracy of the results from the subsequent actual modelling.

Another group of the modelled vertical sections included pairs of pillars of widths 4m and 3m separating the headings. In these instances, however, the two outer headings were assumed to have been developed first and the middle one last, to provide the mentioned pillar widths. The reason for this departure from the actual sequence of development of the headings was to simulate
the "Time Control technique" of the stress control methods suggested by Serata (1982).

FINITE DIFFERENCE MESH

The finite difference mesh for modelling the vertical cross-sections of the panel geometry is shown in Figure 1. The mesh contained a total of 2310 elements representing a 114m wide and 69m high cross-section of strata.

The top and bottom boundaries of the mesh were at distances of 11 times the height of a heading (i.e. 34m) from its roof and floor respectively. The left and right boundaries of the mesh were at distances of 7 times the width of a heading (i.e. 45m) from the outer side of the nearest one.

The square or rectangular elements were smaller near an opening and larger farther away. Since, the primary aim of the modelling was to compare the behaviour of pillars of different widths, elements of suitably varied widths e.g. 2m, 1m or 0.5m and constant height 1m were used. The elements representing other zones of interest up to 3m from the boundaries of an opening were 1m squares. The zones beyond were represented by progressively larger elements e.g. of width 6.875m and height 5.3125m at the four outer corners of the cross-section.

The boundary conditions for the mesh are represented by the rollers indicated in Figure 1. Thus, all the grid points i.e. junctions of the elements on the top and bottom boundaries were assumed to move only in the horizontal direction and those on the left and right boundaries only in the vertical direction.

MODELLED STRATA

The strata represented by the mesh consisted of the coal seam, its sandstone roof and shale floor. It was assumed that no slip occurred at the sandstone-coal-shale interfaces and no other geological structure existed. The support provided by the rock bolts and W-straps in the actual roadways was also ignored.

INPUT VALUES OF THE PARAMETERS

Field Stresses

The vertical stress was taken to be 12.9 MPa at the base of the seam, which was at a depth of 475m below the surface. The vertical stress was considered to gradually decrease and increase by 1.7MPa respectively in the top and bottom boundaries of the mesh.

The maximum horizontal stress of 35MPa, as determined from previous measurements at West Cliff Colliery was assumed to act at right angles to the sides of the headings, although the said direction was not strictly correct.

Mechanical Properties of the strata

The mechanical properties of the strata pertinent to the modelling are the Young's Modulus (E), Poisson's Ratio (ν), Uniaxial Compressive Strength (UCS) and Angle of Internal Friction (ϕ) for each type of rock material. Those rocks were also considered to exhibit elastoplastic behaviour and yield according to specified Mohr-Coulomb criteria.

The field values of the mechanical properties used as input in the actual modelling were derived by a process of successive approximation. The process involved trial modelling repeatedly, starting with the laboratory determined values of the mechanical properties and progressively altering them until the modelled strata displacements at two chosen locations in the left heading matched the corresponding values from actual measurements.

It must be noted here that the mentioned strata displacements from the modelling were the roof sag and the floor uplift at mid-span of the cross-section of the heading. The corresponding measured values were not available for use by the present authors, but only the convergence measurements as mentioned earlier. Visual observations in situ suggested, however, that of a measured convergence value, approximately 30% was roof sag and 70% floor uplift. Therefore, the convergence measurements were split accordingly, for comparison with the displacement values from modelling.
The trial modelling to determine the field values of the mechanical properties of the relevant sandstone, coal and shale was carried out in two stages:

1. In the first stage, the convergence in the left heading at mid-span in the cross-section with 20m wide separating pillars was chosen as reference for comparing the results from modelling. The reason for using the convergence at that location as reference was that the 20m width of pillar was found to isolate it from the effects of the development of the subsequent headings. Thus, at the cross-section with 20m wide pillars the left heading behaved as a single opening. The total convergence at that location was 446 mm over a period of 500 days. For the purposes of comparison with the results from modelling, the given convergence was assumed to consist of 141 mm roof sag and 305 mm floor uplift on the basis mentioned earlier. The corresponding displacements obtained from the first trial modelling using the laboratory determined values of the mechanical properties of the rocks were too small. Then those values for the properties of the strata were progressively reduced and the modelling repeated until the displacements from the modelling and measurements agreed within 1%.

2. In the second stage, the convergence measured at mid-span of the left heading at the cross-section with 10 m wide separating pillars was taken as the reference for comparing the modelled displacements. The measured convergence at the mentioned location was found to increase by 12 mm when the adjacent central heading was driven. Further modelling of the geometries first only with the left heading and then both, was carried out by gradually changing the values of the mechanical properties of the strata until the modelled and measured increases in the displacements agreed reasonably well. The changed mechanical properties, however, caused a change in the total convergence at the first location in the left heading. Therefore, the mechanical properties of the strata were changed further and the modelling of the first stage repeated until the total convergence values at the first location agreed again.

The in-situ mechanical properties of the sandstone, coal and shale derived from the described method of successive approximation, which were used in the subsequent modelling of the panel geometries with different pillar widths are shown in Figure 1. These values of the Uniaxial Compressive Strength (UCS) and angle of internal friction (φ) are considerably lower than the laboratory determined values and other ones suggested by Wilson (1980) and Kripak (1981). The indicated uniaxial compressive strength of 6 MPa for the Bulli seam coal is, however, comparable to that of 6.2 MPa for another coal given by Mark (1990). Mark et al (1988) and Laraconino (1989) also suggested that the angle of internal friction for coal measure rocks ranges between the low twenty to low thirty degrees. Regarding the modulus of the rocks, Duncan-Parrish (1991) showed that reducing them in numerical modelling is consistent with the 'deformation theory of plasticity' described by Kachanov (1974).

MODELLING THE BEHAVIOUR OF PILLARS OF DIFFERENT WIDTHS

The vertical sections across the three headings separated by pairs of pillars of different widths and the sequence of development of the headings chosen for modelling have been described earlier. The modelling of all these sections was carried out using the discussed values of in-situ stresses and mechanical properties of the rock types.

ANALYSIS OF THE RESULTS OF MODELLING

The objective in the analyses of the results from the numerical modelling was to determine the width for a yield pillar under the given conditions by assessing the following aspects:

1. the 'stress relief' provided by the first heading to the subsequently developed ones,
2. the influence of the subsequently developed headings on the convergence in the first (i.e. left) heading,
3. the distribution of the principal stresses and the contours of vertical stresses around the headings and in the pillars,
4. the profiles of vertical stress across the pillars and the solid coal on the flanks of the panel.

Of all the results from the modelling (Chaturvedula, 1991), only the following are presented here in graphical form:

1. contours of vertical stress around the three roadways separated by pillar widths of 20m, 5m and 4m respectively in Figures 2, 3 and 4,
2. profiles of vertical stress in pillars of widths 20m, 10m, 7.5m, 5m, 4m or 3m shown in Figure 5,
3. change in (vertical) abutment stress on the flanks of the panel with three headings separated by pillar widths of 20m, 10m, 7.5m, 5m, 4m or 3m shown in Figure 6.
Pillar width 20m

According to the in situ measurements, no effect from the driving of the later headings was noticeable on the preceding ones, where the separating pillars were 20m wide. Thus, the pillars of that width were considered to be stable. The modelled vertical stress profile across the pillars showing a core in Figure 6 also suggests the same.

The modelled vertical stress contours in Figure 2 show the individual primary pressure arches or stress envelopes around each of the headings. The slight asymmetry in the pattern of the contours reflect the development of the headings sequentially from the left within the assumed high horizontal stress field.

Pillar width 5m

The vertical stress contours in Figure 3 show the protective secondary stress envelope developed around the group of headings due to the yielding of the 5m wide separating pillars.
Again, the asymmetry in the pattern of the envelope is due to sequence of driving the headings in the high horizontal stress field. The transfer of load to the abutments on the flanks of the panel, consequent to the yielding of the pillars, is indicated in Figure 6.

Pillar width 4m

The comments about the pillar width of 5m also apply in this instance. The greater yielding of the pillars is indicated by the modelled vertical stress profiles in Figures 5 and 6.

The symmetrical pattern of the envelope in this instance is due to the assumed driving of the middle heading last, instead of the actual sequence.

CONCLUSIONS

The present results suggest the following:

1. The 20m wide pillar indicating the presence of a core in Figure 5 is stable.

2. The minimum width for a stable pillar, indicated by Figures 5 and 6 is 10m.

3. At 7.5m width, the pillar is at the threshold of yielding, as indicated by the disappearing core in Figure 5 and transference of load to the abutments in Figure 6.

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