DEVELOPMENT OF STRATA CONTROL AT TAHMOOR MINE

By

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ABSTRACT

Tahmoor Mine is located in the southern Sydney Basin 80km south-west of Sydney and produces 1.2 MT of Bulli Coal annually. Bord and pillar methods used to date will be supplemented by a longwall system.

Difficult roof conditions have been experienced since mining began in 1979. A dominantly horizontal stressfield promotes shear failure in the thinly interbedded roof sequence of shales, laminites, siltstones and fine sandstones. General roof conditions and failure characteristics are related to the angle between the roadway direction and the principal horizontal stress direction. The apparent stressfield changes direction, magnitude and the ratio of principal horizontal components across the mine workings in response to both in situ and mining induced causes.

Initial roof support of 5 x 2.1 m bolts per W-strap at 1m intervals, with mesh, was upgraded to include RSJ’s in order to support areas of failed roof. This support system was inefficient and costly. A third system of support emphasises roof reinforcement with full resin encapsulation of 2.1 m bolts in W-straps. The number of bolts per strap (6-8), extra butterfly straps and bolts, and W-strap spacing is determined for each area by expected roof and stress conditions.

Intersections are pre-bolted and ribs are supported in some areas. Piller dimensions, order of drivage and roadway width have each been altered to improve roof control.

The intensity of roof deformation at the face varies from panel to panel and causes development rates to decrease to 30% of the maximum.

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Roof conditions in each area of the mine are characterised and then projected to future development areas based on the relationship between stressfield orientation, relative roadway direction and face conditions. Planning information available includes expected development rates, roof support requirements and areas of changing conditions.

Future improvements of strata control involve defining support design parameters for the range of mine conditions already seen at Tahmoor.

INTRODUCTION.

Tahmoor Mine is located in the southern Sydney basin some 80km southwest of Sydney. Coal is mined from the Bulli seam, which has an average thickness of 2m, at a depth of 420m. Since production began at Tahmoor in 1979 production has increased, using bord and pillar methods, to an annual ROM production of 1.2Mt. Six production units, each consisting of a Joy 120M and two Joy 15 shuttle cars, mine 19 unit shifts per day. Longwall production will begin in 1987.

Difficult roof conditions have been experienced at Tahmoor since mining commenced. During the initial three years roof conditions at the face of development roadways became more difficult as the mine expanded in a number of directions away from pit bottom. Accordingly the roof support system was progressively upgraded to reinforce and contain the roof strata.

The dominantly horizontal in situ stressfield was recognised as the major cause of roof problems at Tahmoor. This paper describes the development of roof support as mining conditions changed. It further outlines a method of characterising the variations of stressfield and roof conditions across the mine to forecast expected roof conditions, roof support requirements and development rates for new development panels.
GEOLOGICAL CONDITIONS

The immediate roof strata at Tahmoor consists of a sequence, 4 to 9m thick, of thinly interbedded shales, siltstones, laminites and fine sandstones. This interbedded sequence is overlain by the massive Narrabeen group sandstones. Grey shales form the floor strata of the Bull seam.

Tahmoor mine is located in an area of gentle monoclinal flexuring (average gradient of 1 in 30 to the NE) and has the southern extension of the Lapstone Monocline - Nepean Fault structure in the eastern portion of the lease. A number of WNW to NW trending strike-slip fault zones, and joint zones traverse the area mined to date.

In the early stages of mine development a number of in situ stress measurements, using the overcoring method, were carried out by CSIRO (Walton, 1983). The in situ stress field in the three measured sites indicated that the principal horizontal stress direction (sigma 1) was oriented approximately NE and had a magnitude range between 18.0 and 21.3 Mpa. The ratio between the two principal horizontal stress directions (sigma 1 and sigma 2) ranged from 1.6/1 to 1.2/1, and the ratio of the principal horizontal stress to the vertical stress (sigma 3) varied from 1.6/1 to 2.0/1.

GENERAL COMMENTS ON ROOF CONDITIONS

Roof conditions in the mine have varied from moderately good to extremely difficult. The variations have occurred over short distances and have not been totally related to either mining direction or stress magnitude, but usually to a combination of these and other factors.

The initial mine layout was based on surface features (particularly the main southern railway) influencing the main southern development and early "preferred mining direction" indications which suggested roadways be oriented NW and SE, for example, NW Panel (Fig.1).

The early drivages SSE to No 2 Shaft (Fig.1) proved difficult generally (support being bolts, straps and RSJ's) and in areas very difficult requiring extensive additional intersection support. Later investigation delineated areas of highly stressed ground crossing these headings which also proved difficult using the current support techniques.

Fig.1 Orientation of the dominant lateral stress. In situ measurements indicated by bold line.

The NE drivage (200 Panel) proved difficult to extremely difficult along the panel length despite using current support techniques and very dense roof bolting patterns. This area again being influenced by highly stressed areas of strata roof previously delineated.

The general directional mining approach has proved beneficial with some localised problems. Contrary to expectation one area, 300 Panel, heading due South, has the best general mining conditions so far encountered in the mine. The conditions in this panel vary from good to moderate with the roof support cost being the lowest of any major development panel yet driven in Tahmoor.
A number of studies were undertaken at Tahmoor to assess the mining conditions. Walton (1983) reported the results of a programme of in situ stress measurements using an overcoring technique. Observational methods have confirmed the variability of the stress field direction in Tahmoor (Gale et al., 1984). The angle between the roadway the dominant lateral stress direction (92°) was recognised as an important factor in determining roof conditions (Gale et al., 1984; Stone, 1984). For example, where 92° < 35° roadways had the best roof conditions, driveage rates and lowest deformation of roof supports. The relative magnitude of σ1 and σ2 also played a part in determining roof conditions.

Walton (1984) and Richmond et al., (1984) have reported on the deformation of roof supports and strata in development roadways at Tahmoor. Trial cable bolt installations (Gale et al., in press) and an assessment of some profiled roadways mined with an Alpine AH-50 road heading machine (Richmond et al., 1984) are further aspects of investigations into roof control methods at Tahmoor.

As a result of the now proven changing stress directions and magnitude, directional mining principles are having less influence on the mine layout. The mine is now being laid out to suit operational requirements, particularly for longwall blocks, rather than to facilitate development in "preferred" directions.

The techniques to be outlined in the paper are now used in all stages of operational planning. The ability to more accurately forecast development rates and costs is of considerable advantage to develop a more rational planning schedule.

Acceptance by operators at the mine is at a high level with a substantial degree of confidence in the predictions made from using these techniques.

FIRST GENERATION ROOF SUPPORT

First generation roof support was the roof support used when mining commenced at Tahmoor. It consisted of W-straps (4.8m) at 1m spacing containing 5 x 2.1m mild steel bolts point anchored with one 600mm chemical cartridge. Sheets of mesh (3.0 x 2.5m) were fitted prior to the W-straps. Restricted trials were made with 1.5m bolts and wooden half round bars.

This support system was effective for the good mining direction in the early development but proved unsuitable in the 'bad' direction for these reasons.

1. The area of roof exposed in each cut out prior to bolting needed to be large enough to fit the sheets of mesh which allowed too much ply separation and shearing within the roof.

2. Roadways were commonly driven wider than the W-strap could cover, allowing guttering to develop. Additionally, rib deterioration and flaking exposed the roof beyond the coverage of roof support also allowing guttering.

SECOND GENERATION ROOF SUPPORT

For the purpose of adding strength to the support in bad conditions, or important roadways, R3J's were used with the first generation support although the use of mesh diminished. The R3J's were held by 2 x 900mm chemical anchored bolts and placed between every second W-strap. Roadway width was reduced to enable it to be spanned by the W-straps and help prevent the development of guttering.

This support type worked effectively in roadways with moderately deformed roof. In areas of worse severe failure the R3J's were not able to contain heavy sag nor stop the development of guttering and cantilever caused by failure above the bolting horizon. Questions arose as to the number of bolts required, the effectiveness of the point anchored chemical bolts, and whether those bolts were placed close enough to the face.

Guttering developed either: in the unsupported area of roof exposed by rib failure and slumping; or by bolts breaking or pulling through W-straps along the rib or a combination of these factors. These problems were pronounced in some intersections causing a modification of the mining sequence to keep intersection sizes to a minimum by restricting the number of breakaways per cycle.
The limitation of the existing bolting pattern, cost of BSL's and re-support of existing roadways made it necessary to find an alternative support for at least the more difficult mining areas.

**THIRD GENERATION ROOF SUPPORT**

This is the roof support currently used at Tahmoor.

W-straps are spaced a maximum of 1m with at least 6 fully encapsulated 2.1m mild steel bolts. In areas of difficult roof conditions W-strap spacing is reduced to 0.8m, or closer, and hemispherical dome plates (152mm x 152mm x 10mm) or flat 100mm x 100mm plates are used (10mm thick). Fast set (600mm) and slow set (720mm) chemical cartridges are used with each bolt. Intersection sites are cross strapped prior to forming the intersections. Bolting is carried out with 'Wombat' compressed air rotary bolters. The number of bolts per W-strap varies according to conditions:

1. 6 bolts per W-strap for normal conditions, usually in the good driveage direction.

2. 7 bolts per W-strap for a mining direction where an extra bolt is placed on the ribside expected to gutter (as determined from the stress direction).

3. 8 bolts per W-strap in the more severe conditions where shearing or rock fracture occurs on either side of the roadway.

Butterfly straps and bolts are used to support any smaller areas of roof not covered by the prescribed support pattern. Wooden props are not considered as a primary roof support and their present limited use will probably be eliminated in the near future.

The main objective of the third generation support system is to curtail guttering along the roadway and at the corners of intersections. Roof sag still occurs but the roof is held sufficiently. The success of this support system is based on when, where and how much to increase (or decrease) the number of bolts placed as the strata pressure and stress direction change.

**PILLAR DESIGN MODIFICATIONS**

Alteration of pillar dimensions has accompanied roof support techniques to improve roof control.

1. Reduction of roadway width to 4.9m instead of the standard 5.5 width.

2. Reduce pillar widths from 40m to 30m centre to centre distance to maximise the benefit of any stress relief gained from previously driven roadways.

3. The initial pillar panels employed an extraction on the advance system which did not produce the stress relief intended because the dominant lateral stress, sigma 1, was oblique rather than at or near 90° to the panel, as was employed at Oakdale (Nicholls, 1979).

**RIB SUPPORT IN DEVELOPMENT ROADWAYS**

Rib support has been used in certain areas of the mine where the rib conditions were shown to be unstable and promoting the development of guttering.

Three different types of rib support have been used.

1. W-straps placed along the rib side with 900mm bolts.

2. Fibreglass dowels (120mm) placed about in apart in a W pattern along the ribside.

3. Strips of mesh (0.7m wide) fastened with 900mm bolts or more recently fibreglass dowels with a steel tube thread. This is the current rib support and is successful, but alternative machineable materials are required.

**METHODS USED TO DETERMINE THE STRESSFIELD AND ROOF CONDITIONS**

A method of assessing roof conditions is needed at Tahmoor to interpret the wide range of mining conditions. Initial roof investigations suggested that the variations of stressfield orientation and stressfield intensity caused the different roof conditions (Gale et al., 1984). Subsequent work assessed variations of stress conditions and the likely affects on roof conditions of future workings.

The first step toward predicting roof conditions and stressfield orientation is to assess their characteristics in existing mine developments. The characterisation of the mining conditions in an area has two main aspects:

1. determination of the stressfield orientation, and

2. determination of the roof conditions typical of that area.

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Methods required to gather, interpret and use this data for predicting expected roof conditions are outlined below.

**STRESSFIELD ORIENTATION.**

The orientation of the apparent principal horizontal stress is determined from the pattern of mining induced shear fractures and tensile fractures in the immediate roof strata at the mining face. This stress direction generally reflects the in situ virgin stressfield but in some areas it is modified by mine development. Variation of the apparent lateral stress direction in Tahmoor can be either gradual or very rapid (Fig.1), for example, towards No.2 Shaft the dominant stress direction changes some 90° within 100m. The stress direction measured from fracture patterns are comparable to those established by in situ measurements (Fig.1).

Three factors influence the roof fracturing:

1. Roof fracturing is more clearly developed in the finely interbedded strata, as exists at Tahmoor, than in massive sedimentary rocks.

2. A simpler roof fracture pattern occurs if there is one dominant horizontal stress direction. Two principal horizontal stress directions of almost equivalent magnitude, have a more complex roof fracture pattern. Both situations exist at Tahmoor.

3. The intensity of roof fracture patterns varies in roadways dependent on the order of drivage in that mining cycle.

Table 1 lists the features that can be used to determine the apparent principal horizontal stress direction, for a dominant lateral stress direction and for lateral stresses of nearly equivalent strength.

After determining the stressfield direction the side of the roadway most likely to have shear fracturing (guttering) is determined by the following rule of thumb.

"Shearing of the roof strata occurs on the ribside intersected by an imaginary line drawn through the mining face parallel to the principal horizontal stress direction."

<table>
<thead>
<tr>
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<th>DOMINANT LATERAL STRESS</th>
<th>LATERAL STRESS MAGNITUDES NEARLY EQUIVALENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Relative condition of adjacent headings and cut-throughs</td>
<td>One roadway in significantly worse condition</td>
<td>Similar condition in both directions (gives quadrant of stress direction)</td>
</tr>
<tr>
<td>2. Short term roof fractures, (refer to Table 2)</td>
<td>(a) Orientation of low angle conjugate shears. Oblique shears mostly oriented normal to horizontal stress directions. At higher stress magnitudes, or at certain 6° or no oblique shear present. (gives stress direction)</td>
<td>Very few oblique shears. Normally parallel shear.</td>
</tr>
<tr>
<td>3. Mining induced tensile fracture (m.i.f.'s).</td>
<td>Where present preferential location to one side of roadway. (gives quadrant of stress direction)</td>
<td>Where present occur both sides of roadway.</td>
</tr>
<tr>
<td>4. Location of short term shear failure</td>
<td>Preferential location of shear to one side of the roadway. (gives quadrant of stress direction)</td>
<td>No preferential location - common in centre of roadway.</td>
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</tbody>
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The horizontal stress direction is drawn onto all panel plans from which the deputy can pick the likely shear or gutter side of the roadway. During the face bolt-up cycle extra bolts are located on the ribside most likely to shear. Longer term gutting has been successfully countered by these extra bolts.

**CHARACTERISATION OF ROOF CONDITIONS**

**Short Term Roof Conditions**

The roof conditions at Tahmoor can be distinguished as short term and long term roof failure types. Short term failure essentially occurs at the mining face, whereas long term failure develops after the placement of roof supports. Table 2 lists the types of both long term and short term roof failure recognised at Tahmoor.

Short term roof conditions are used to characterise the type of roof failure in an area because they are least affected by mining practices or methods and most easily compared to the stressfield intensity. Likely long term roof conditions can be determined by the short term roof fractures, and Gale et al. (1984) indicated some relationships. However, mining practices do have a large influence on the state of long term roof instability, therefore the same long term failure types may result from almost any of the range of short term failures.

**TABLE 2:**

<table>
<thead>
<tr>
<th>Short Term</th>
<th>Long Term</th>
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<tbody>
<tr>
<td>Arch</td>
<td>Roof Fall</td>
</tr>
<tr>
<td>Severe parallel shear</td>
<td>Cantilever</td>
</tr>
<tr>
<td>Parallel shear</td>
<td>Sag</td>
</tr>
<tr>
<td>Parallel and oblique shear</td>
<td>Good</td>
</tr>
<tr>
<td>Oblique shear</td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**

1. Shear refers to shear failure of immediate roof strata.
2. Oblique shear trends across the roadway and parallel shear runs along the roadway.
3. Mining induced fractures (Neever and Shepherd, 1979) may occur with the short term failures types.

In Tahmoor the short term roof conditions are affected by:

1. the horizontal stressfield orientation,
2. the angle between sigma 1 and the mine roadway (θr),
3. the stressfield magnitude, and
4. the relative strength of both in situ horizontal stress components.

Each of these four factors vary in different areas of Tahmoor and produce a different set of roof conditions which may have different roof support requirements. Short term roof conditions vary with θr, being worst when θr = 90°, but also vary with changes of a stressfield intensity.

**Stressfield Magnitude**

The stressfield magnitude can only be determined from direct in situ measurement. At Tahmoor twelve types of short term roof failures are recognised and ranked by increasing severity of failure (Table 3).

The relative intensity of short term roof failure has been used as a guide to the relative stress magnitude in different mining areas.

**TABLE 3**

| SHORT TERM ROOF CONDITION SCALE AND SUPPORT REQUIREMENTS (Decreasing Severity) |
|---------------------------------|-------------------------------|
| **SHORT TERM ROOF CONDITIONS**  | **SUPPORT REQUIREMENT**       |
| **Number**                      | **Failure Type**              |
| 12 - Arch                       | 8                             |
| 11 - Severe parallel shear, mif* across roadway | 9                             |
| 10 - Severe parallel shear, mif 1 side | 10                             |
| 9 - Parallel shear, mif across roadway | 7                             |
| 8 - Parallel shear, mif 1 side | 8                             |
| 7 - Severe parallel shear       | 6                             |
| 6 - Oblique and parallel shear | 5                             |
| 5 - Parallel shear              | 4                             |
| 4 - Oblique shear, mif 6 or 7   | 3                             |
| 3 - Oblique, parallel shear     | 2                             |
| 2 - Oblique shear               | 1                             |
| 1 - No shear                    |                               |

*mif - mining induced fractures (tensile)*

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Method of Comparing Roof Conditions

The scale of relative stress magnitude, based on short term roof conditions, must be used in conjunction with $\theta_{sr}$ because roof conditions vary as $\theta_{sr}$ changes from 0° to 90°. On a graph of short term roof conditions versus $\theta_{sr}$, a curve can be drawn which will indicate the short term roof conditions expected to occur as the angle between the principal horizontal stress and the roadway changes (Fig.2). This curve is referred to as a Roof Failure Curve (RFC) and is used to define the range of roof conditions possible in a specific area of mine development. An area of the mine which is represented by one RFC has consistent stress field magnitude parameters.

The RFC in Fig. 2 shows a number of characteristics.

1. A distinct change of roof conditions either side of $\theta_{sr} = 45°$, reflects the different roof conditions commonly noticed between headings and cut-throughs.

2. The relative intensity of roof failure, and relative intensity of the stress field, is easily represented for a range of mining directions.

3. A guide to the relative intensity of the two principal horizontal stress components is given by comparison of failure intensity greater and less than $\theta_{sr} = 45°$.

Comparison of Roof Conditions in Tahmoor

Five different RFC's have been identified to describe the range of roof and stress field conditions noted in Tahmoor development panels (Fig. 3). The RFC's, curve 2 apart, are defined only for a limited range of $\theta_{sr}$ (25° to 65°), because no mining has taken place at the extreme values toward 0° and 90°.

Curve 2 shows the rapid deterioration of roof conditions as $\theta_{sr}$ approaches 90°. In Fig. 3 curve 1 represents the best roof conditions and curve 5 the worst roof conditions.

The areas of mine development in Tahmoor which are represented by RFC's 1 to 5 are shown on the mine plan to highlight trends, changes or patterns of roof conditions (Fig. 4). Roof conditions in adjacent planned workings can be projected from this mine plan.

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To determine the expected roof conditions in headings and cut-throughs of a new area, the following is needed:

1. expected sigma 1 trend in the area
2. orientation of headings and cut-throughs
3. determine \( \sigma_{hr} \) (from 1 and 2)
4. use the roof failure curve typical of the area to determine the expected roof conditions for the \( \sigma_{hr} \) values of headings and cut-throughs.

**ROOF SUPPORT OPTIONS**

Essentially three options of support are currently used, that is, 6, 7 or 8 bolts per W-strap. Spacing between W-straips is reduced as conditions deteriorate. Experience at Talmoor has enabled roof support requirements, or bolt density, to be related to the intensity of short term roof conditions (Table 3). Bolt density may differ in headings and cut-throughs dependent on short term roof conditions (Fig. 3).

The roof support options presented in this report are based on current experience. An investigation programme has been commenced to determine the failure horizons, in areas characterised by different RFC's, to allow optimum choice of roof bolt lengths, type and patterns.

**ROOF CONDITIONS AND PRODUCTION RATES**

Development roadway areas which have different characteristic roof conditions, as defined by their respective RFC's, also have different production rates as measured by advance per shift. The average shift advance is calculated on a monthly basis for each development area. The monthly production from development panels have been determined since mining began in 1979 to provide a range of data related to various mining conditions.

The relationship between the development rate and the characteristic roof conditions as rated by the RFC is shown in Fig. 3.

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Fig. 4. Distribution of RFC ratings for development roadway areas.

Fig. 5. Historical variation of development rate with roof conditions.
SUMMARY OF PREDICTION OF ROOF CONDITIONS IN TALMOOR

Predicted roof conditions are determined for each new area based on conditions in adjacent workings, for which an RFC has been determined. The RFC for each new panel allows the expected roof conditions, and roof support requirements for headings and cut-throughs to be determined for appropriate areas. The production rate for the likely roof conditions can be estimated.

At Talmoor roof conditions, and production rates are assigned to the twelve month development plan. The roof conditions of some panels within the development plan are expected to change during mining and therefore have a number of RFC’s each with a different development rate.

CONCLUSIONS

The problems associated with variable mining conditions are partially offset if such changes can be effectively predicted. Mining conditions, the stress field orientation and relative magnitude are assessed at Talmoor to be used in both operational and planning activities.

Expected stress and mining condition information is used at different stages of operational planning.

1. Deputies use the stress directions drawn on panel plans to set extra roof supports on the stress affected side of the roadway.
2. Undermanagers have an indication of where, how and for what time or distance certain roof conditions may persist, and can determine support requirements.
3. Managers and planners have estimated roof conditions and development rates to aid mine sequencing and costing.

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REFERENCES


