Fourth Australia - New Zealand
Conference on Geomechanics,
Perth, 14-18 May 1984

The Failure of Coal Pillar Ribs and Possible Methods of Control

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SUMMARY. The stability of coal ribs has been investigated at several collieries particularly Buchanan Lemington No. 1 (BBC) in New South Wales and Huntly No. 1 West in New Zealand.

In the collieries studied the coal ribs were classified according to a visual assessment of condition and measured values of spall depth and visible fracturing. Coal fractures have been identified as cleat and mining induced fractures and their orientations measured. At several underground sites the coal brightness was logged and critical opening dimensions measured. Wire extensometers were used to measure pillar deformations, and roadway roof to floor convergence measurements were made. A novel method of measuring rib side movements has been devised to record displacement at various seam horizons by measuring to a fixed vertical stand erected near the rib side. This method locates the origins of the rib movement in order to compare it with the coal ply structure and strength.

Failures of the ribs appear to be due to vertical (or near vertical) tensile fractures leading on to 'buckling and kinking' failures and possibly even shear failures. In one mine where most major roadways were driven at a high angle to the principal coal cleat direction, the condition of the ribs was generally seen to be good. If cleat directions can be identified for virgin blocks of coal, then rib stability can be improved by laying out entries at a high angle to the principal cleat trend.

A knowledge of the modes of rib failure and type of rib side fracturing is a prerequisite for the optimum installation of active rib support because support needs vary locally. Friable coal ribs require a liner support, whereas stronger coals (tentatively >5 MPa uniaxial strength) in ribs which fail in slabs or blocks, can be supported by mesh, point anchor bolts or wooden dowels or by some combination of these.

1. INTRODUCTION

As part of the ongoing research into the mining of thick coal seams, Australian Coal Industry Research Laboratories Limited was commissioned by the Queensland Coal Owners' Association to investigate the phenomenon of rib failure and associated control methods, with special emphasis on coal seams greater than 4.0 m thick. The control of coal ribs is seen as a major stage in the design of many thick seam mining methods and even more so in the relatively weak coals often encountered in Queensland.

Despite the fact that rib side failures have beset the industry for many years very little documented experience can be located although several authors consider the problem in different environments. (Hahn, 1982; Hobbs, 1969; Jeremic, 1979, 1980; Qld Mines Department, 1983; Whittaker et al 1974). Several Australian collieries have tried some methods of remedial support and with variation in success but the results have not been published. Some of these mines were visited by the authors.

Coal rib failures are seen to have two serious consequences, namely:

1. Safety problems associated with the falling of large coal blocks or slabs. These blocks can be up to 1 tonne mass.

2. Large scale pillar instability because of extension of the rib side yield zone into coal that is normally a part of a solid pillar core.

It is suggested that a comprehensive knowledge of the coal structure, and the formation patterns of mining induced fracturing, can be used by planning engineers to minimise the occurrence of rib failures. The basic concepts of preferred directions in mining to account for structure are known, however, detailed studies do not appear to be undertaken on a routine basis. When remedial methods are required both active and passive types can be used but the choice needs to be based on a clear understanding of the structural conditions prevailing.

2. THE BASIS OF RIB INSTABILITIES

2.1 Signs of Rib Degradation

The deterioration of pillar ribs is generally described as spall. It is possible to semi-quantitatively define spall severity using simple measures such as the depth and height of rib decay, amount of fracturing and the presence of buckles and kinks. The intensity of coal fracturing is important because spall mechanisms appear to be dependent on it.

There are two common types of fractures in coal in addition to the sub-horizontal partings (bedding or ply structure): first cleats or coal joints which are natural, pre-mining fractures which may be either ply dependent or more penetrative through a seam section, and second, mining induced fractures (MIF) which form during the cutting process or afterwards in response to re-distribution of the stress field (Hanes and Shepherd, 1981). However, MIF have rarely been correctly identified and adequately analysed in coal, but are better known in hard rocks (Hoek and Brown, 1980). The interaction of such fracture sets (since groups of fractures are systematically developed in coal i.e. non-random) produce most of the deleterious effects in pillar margins.

In the collieries studied cleats and MIF result in the development of coal slivers and slabs or coal blocks depending upon the geometrical configuration of the fractures (Figure 1). In extreme cases under difficult mining conditions coal slabs are buckled and kinked in a manner similar to geological kinks in other rocks (Gay and Weiss, 1974). A typical ribside buckle is shown in Figure 2. The mechanism of formation of these structures is largely outside the scope of this paper and is currently under investigation, but the method of recording these for the purpose of strain calculations is given in Figure 3. The notation in Figure 3 follows Gay and Weiss, 1974.

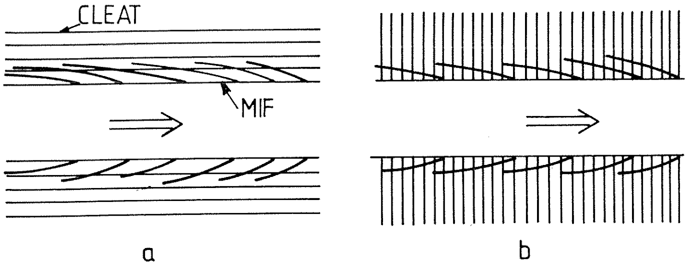

Figure 1.
Interaction of MIF and cleat according to different drivage directions (a) parallel to cleat (b) perpendicular to cleat.

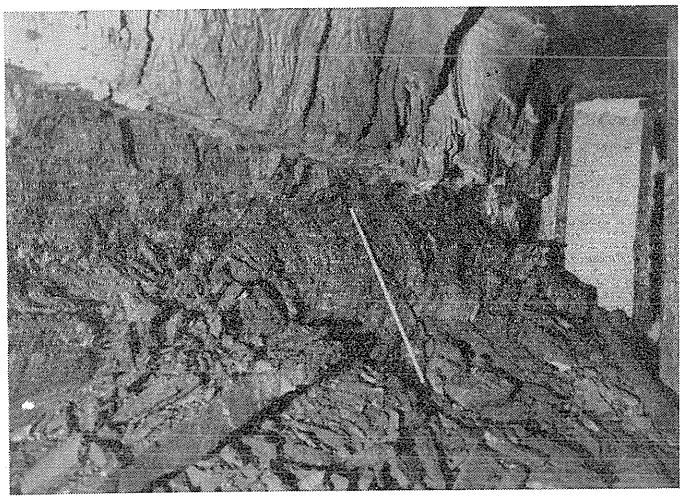

Figure 2
Typical ribside buckle at BBC No.1 Colliery

2.2 Effects of Cleat Geometry

The nature of rib failures varies with mining direction and the geometry of the prevailing coal cleats. There are two extreme cases of drivage parallel (end-on) or perpendicular (face-on) to cleats (Figure 1). More common cases arise as shown in Figure 4. As well as cleat plane trend, inclination is also recorded and a simple system of notation developed to account for cleat trend and inclination. The rib condition and location of failure can then be compared with this as shown in Figure 4b.

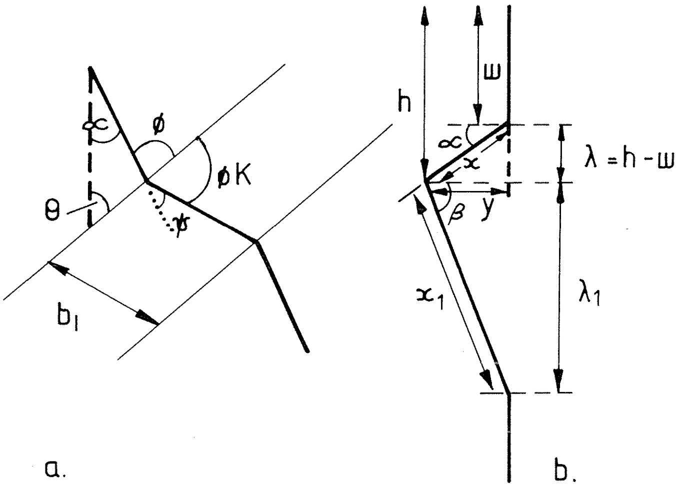

Figure 3
Geometrical profile parameters of kinks and buckles (a) kink (b) buckle

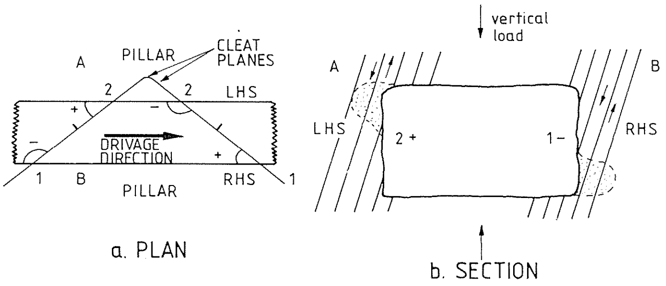

Figure 4
Classification of cleat orientation according to drivage direction (a) plan (b) section A-B, stippled areas show position of rib failures. (LHS and RHS are left hand and right hand sides respectively).

3. PILLAR AND RIB MONITORING

3.1 Introduction

The mechanisms behind rib movements have been described earlier and this section will describe some of the effects seen to date. Each of the collieries under study has different conditions ranging from negligible spall at Moura No. 4 Colliery even months after mining to major face fracturing at Huntly immediately upon mining.

3.2 BBC No. 1 Colliery

The first method utilised to monitor rib degradation was simple scaled sketches supplemented by photography. This was rapidly upgraded to include horizontal wire extensometers into the pillar. Figure 5 illustrates one such set of sketches in conjunction with a coal brightness log of a site at BBC. This figure shows the pivot points of the buckle within bright coal bands whilst the axis is on a major claystone band. The buckle was not seen to move up the rib into the slightly harder coals but simply expand outwards until failure. The top coal was then undermined and the fracturing/cracking became more intense. This is potentially a dangerous situation as the top coal is likely to fall with little warning. Figure 6 illustrates the roof to floor convergence and bay strain results from a pillar extensometer installed adjacent to the sketch location. This figure confirms that the 0.3 m to 1.2 m bay is the location for the bulk of the strain and this does not occur until the pillar is being finally extracted.

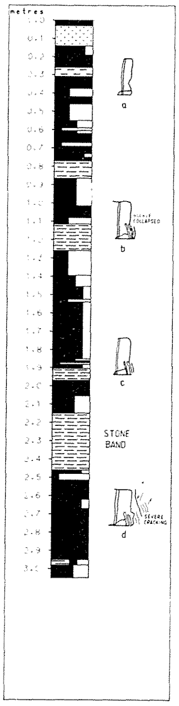

Figure 5
Rib profile changes and coal brightness log near site 9EB, BBC No. 1 Colliery. Progressive rib failure shown in a-d. Coal brightness is expressed as a percentage of total brightness (100% bright = solid black).

In Figure 6a the growth of the buckle (E5) occurred at a rather faster rate than that indicated from convergence readings, although the final vertical shortening found from the two methods is similar at 30 - 40 mm. Buckle shortening for E5 was calculated using the method given in the Appendix. In some cases, however, calculation of the buckle shortening using "the brittle rotation method" appears to over-estimate the vertical movement. Shortening calculated from a kink (Figure 3a) yields similar results with a vertical strain of 27 mm at the same E5 site after a period of 30 days. The rib degradation observed is therefore confined to the 0.0 m to 0.3 m bay until extraction time. As a result, pillar stability is not at risk through this type of failure.

Later work at BBC and other collieries utilised a steel reference stand (called a stanchion) to monitor the changing rib profile. A stanchion is illustrated in Figure 7. The stanchion is constructed from mild steel R.H.S. with one tube sliding inside the other. The unit is affixed to both roof and floor and at approximately 200 mm to 300 mm from the rib. Rib to stanchion distances are recorded each 200 mm vertically and plotted as in Figure 8. This stanchion was installed immediately behind the face and was monitored until the adjacent pillar was being extracted. In this case the buckle (and general decay) is seen to begin immediately and with 28% of the movement occurring after only 10 days. Again, at this site the buckling is near the floor and produces the dangerous situation of undermined coal. In Figure 7 a large slab of coal is seen to have fallen from this process. The extensometer plot from this site is shown in Figure 9 and again shows the bulk of the strain confined to the 0.30 m to 0.75 m bay. The stanchion plot at the extensometer level shows 44 mm of rib side deformation with the extensometer only recording 20.63 mm.

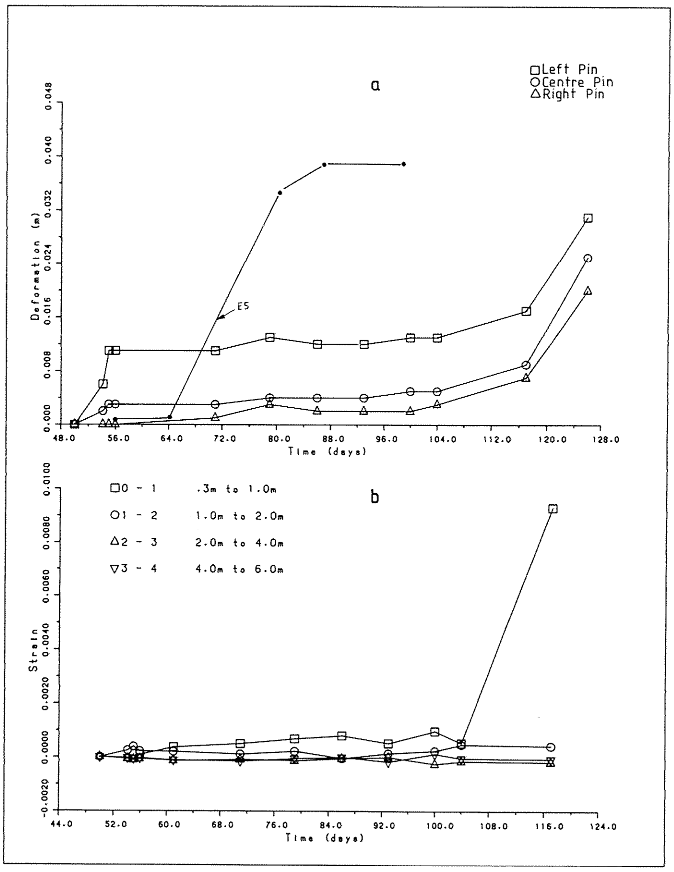

Figure 6
Roof to floor and pillar movements at site 9EB, BBC No.1 Colliery (a) convergence (b) pillar strains expressed as a relative value given by the change in length of a segment divided by its total length of the bay. (Note E5 graph is vertical shortening in pillar rib due to buckle shown in Figure 5).

This difference is accounted for by the fact that the rib side reference station for the extensometer was installed 0.30 m into the rib to prevent loss due to degradation. It is interesting to note that this considerable horizontal movement coincides with only 3 mm of stanchion closure. It is suggested that this movement is caused by the combined effect of pillar swell (Poisson effect) and a column (or plate) buckling of the immediate rib. This is illustrated in Figure 10.

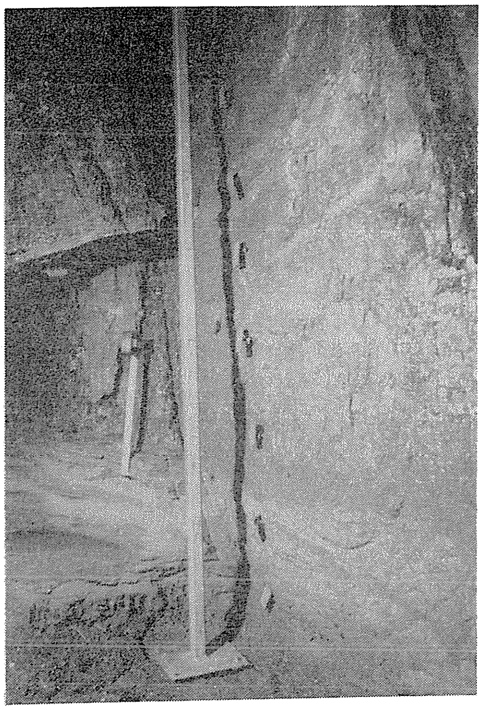

Figure 7
Rib monitoring stanchion at site 1NWD, BBC No. 1 Colliery

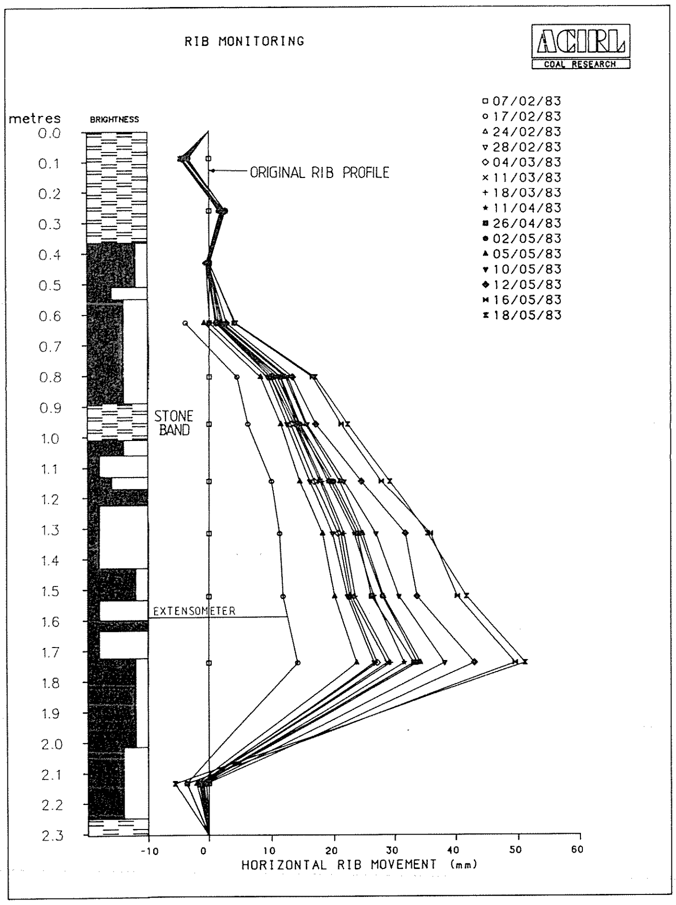

Figure 8
Stanchion data plot showing horizontal rib movements according to coal brightness. (Brightness plotted as in Figure 5.)

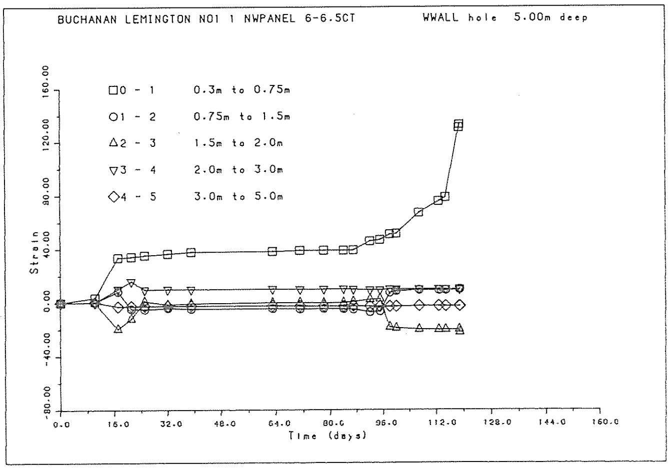

Figure 9
Measured strains from wire extensometer in 1NW Panel, BBC No. 1 Colliery (strain values expressed in identical manner to Figure 6b).

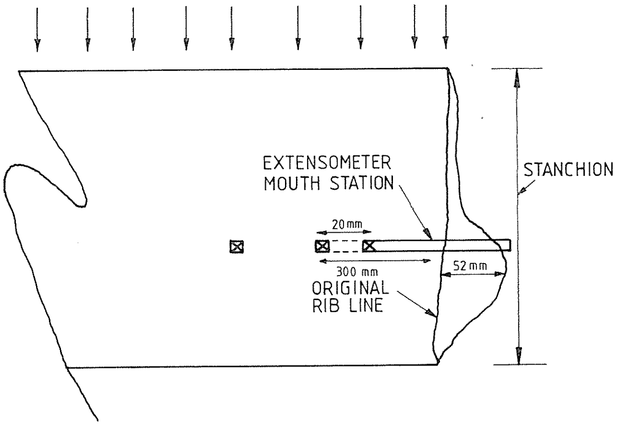

Figure 10
Rib deformation schematic at site 1NWD, BBC No. 1 Colliery.

3.3 Huntly Colliery

Investigations at Huntly proceeded in a slightly different manner as the coal cleat was seen to be a dominant factor. Initial investigations were conducted in five lengths of roadway (total 2100 m) covering all major drivage directions. These roadways were examined for face and butt cleat directions, faults, support systems, drivage machine type, drivage direction and ribs classified according to type location and severity of failure. The classification system used is illustrated in Figure 11. Results from this work clearly indicated prominent face cleat directions of 060° - 070° and an optimum drivage direction of 315° - 330°. This optimum direction was based on a statistical analysis of the rib classification data and primarily on the incidence of the more severe rib failure types, i.e. classes four to seven.

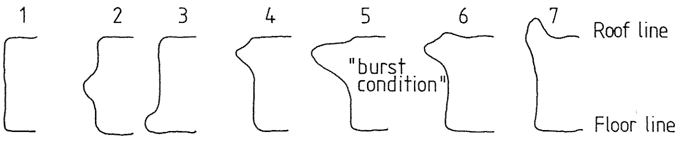

Figure 11
Rib classification system,
Huntly No.1 West Colliery

Rib degradation at Huntly is seen to occur immediately upon mining with small scale bursting being observed in several locations (Figure 11). Whilst stanchions were used to monitor the profile change some data was lost prior to installation. Failure at Huntly is typically thin slivers of coal peeling off buckles or highly pulverised coal simply falling away. These failure types are generally attributed to the friable, non-banded nature of the Huntly sub-bituminous coal.

The headings at Huntly have been driven with continuous miners and roadheaders, and the result is that a wide variety of profiles exist. Two contrasting shapes are shown in Figure 12. Preliminary studies indicate that MIF development is strongly influenced by change of shape, and this, together with cleat inclination changes along a heading, result in different failure positions opposite each other.

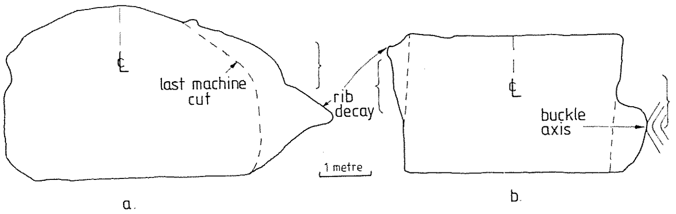

Figure 12
Heading profiles at Huntly No.1 West Colliery showing rib decay (a) driven by roadheader (b) driven by continuous miner (brackets indicate rib section supported by mesh and 1.2 m long steel bolts).

Rib support methods have been tried at Huntly and a typical attempt is shown in Figure 13. The nature of the coal failure is clearly seen as is the ineffectiveness of the bolt and mesh support in such highly fractured coals.

4. POSSIBLE CONTROL MEASURES

4.1 Passive

At Huntly as mentioned above statistical amounts of roadway data were collected concerning the rib conditions and fracture (especially cleats) directions. Based on various roadway directions driven the optimum heading direction was determined to be 315° - 330° with an average face cleat trend of 060° - 070°. Although the conditions are improved in the preferred direction rib failures are not completely prevented. The method, however, has the advantage of relative cheapness.

The worst possible direction for headings is generally parallel or sub-parallel to the face cleat as shown in Figure 14a. In this case at BBC No. 1 Colliery, MIF reinforced the cleat planes and forms highly unstable ribs. A partial solution to this would be to turn the headings 30 - 45° from the cleat direction. A knowledge of coal structures is, therefore, a fundamental means of mine planning.

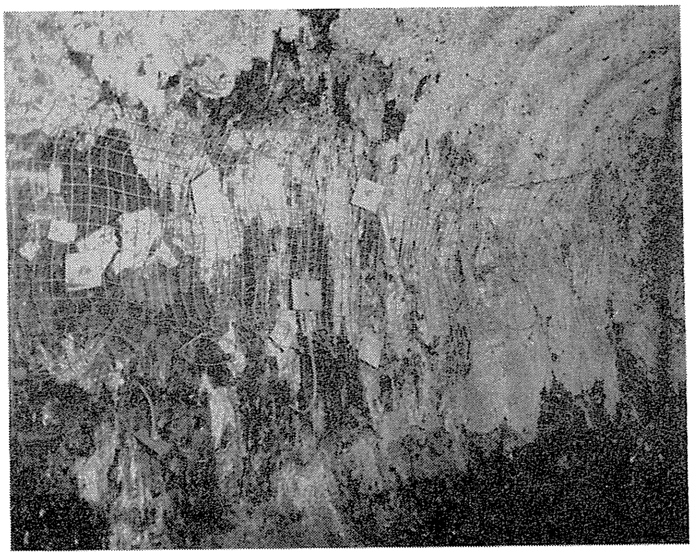

Figure 13
Rib failure and supports
at Huntly No. 1 West Colliery

4.2 Active Support

The first consideration is to define the cleat and MIF directions in order to optimise reinforcement methods. It will be advisable in trials, to be run shortly, to direct support approximately perpendicular to the MIF and cleats if this is possible. Two different configurations are given in Figure 14a, b. In the case of Figure 14b the LHS requires different treatment to the RHS.

The analysis of ribs in different collieries has shown that several support methods are needed according to cleat and MIF spacing. For exceptionally weak coals with a UCS of <5 MPa or for coals that are closely cleated or sheared at spacings of <0.05 m, some form of liner support is required, because spot bolting or meshing simply permits the rib to continue decaying. Where slab failures occur with coal slabs <0.2 m, short steel bolts or timber dowels would be sufficient. For large coal blocks (commonly 1 - 2 m wide, 2 m high and >0.2 m thick, mesh with bolts or dowels are needed and the support pattern will be arranged to suit block dimensions.

5. CONCLUSIONS

At the time of writing (August 1983) the research into coal rib failures is continuing with field trials of various support systems about to begin. Work to date has revealed that:-

a. The coal structure and mainly cleat, plays a dominant role in the ability of coal to slab or block fail in ribs.

b. Mining induced fracturing (MIF) can aggravate cleat based failures and side to side variations in rib conditions can often be explained through the interaction of cleat, MIF and roadway drivage direction.

c. Pillars created with their long axis parallel, or sub-parallel to the major cleat direction carry a high risk of rib side slabbing on their longest sides. Roadways created perpendicular to the major cleat direction are generally the optimum for rib stability.

d. Support requirements for ribs can only be determined once a detailed analysis of the inherent coal structure and MIF has been made. Support requirements can often be minimised through the selection of optimum drivage directions for long term roadways.

e. Support systems can be broadly categorised as either liner type or bolt/dowel type. In general, liner type supports are only necessary with extremely weak, friable coals. Bolt/dowel type supports can be extremely effective in slab failures whilst with blocky failures a mesh of appropriate size is required in association with the bolts.

f. Any form of active rib support must be installed as close as practical to the face line. Location and directions of bolts or dowels are determined through the structural studies previously described.

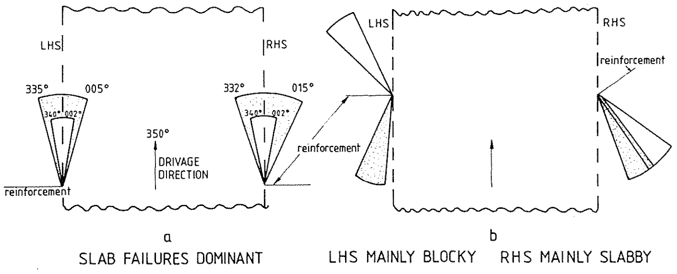

Figure 14
Sketch plans of headings driven parallel to and 45° to cleats showing reinforcement needs (stippled segments indicate MIF angles).

6. ACKNOWLEDGEMENTS

ACIRL is grateful for the financial support given by the Mining Technology Committee of the Queensland Coal Owners' Association. Special thanks are due to the managements and mine personnel for on-site assistance at the following collieries: Buchanan Lemington No. 1 (Buchanan Borehole Collieries Pty. Limited), Huntly No. 1 West (State Coal Mines of New Zealand), Moura No. 4 (Thiess-Dampier-Mitsui Pty. Limited), Box Flat No. 9 (Westfalen Collieries Pty. Limited).

Special underground help was given to us by Keith Rixon of ACIRL Ltd., Ken McLaren and Bruce Muir of BBC and Roger Gregg and Derrick DePledge of New Zealand State Coal Mines. Computing help was freely given by Ivan Paunсz and Roy Barlow of ACIRL Ltd.

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APPENDIX

The amount of vertical shortening (S) due to a kink band can be calculated using Paterson and Weiss' (1966) formula where,

(1) $S = 2b_1, \cos\theta \cot\phi$ (refer Figure 3a)

Similarly, shortening (S) can be estimated from buckles by adopting a "brittle rotation model" involving the rotation of the buckle limbs about pivot points as shown in Figure 3b, and thus

(2) $$S = x + x_1 - (\lambda + \lambda_1)$$

To find x, x_1, λ and λ_1

the following calculation is required:

$$\lambda = h - w$$

$$\sin\alpha = \frac{\lambda}{x}$$

therefore $$x = \frac{\lambda}{\text{Sin}\,\alpha}$$

then $$x_1 = \frac{y}{\tan\beta}$$

and $y^2 = x^2 + \lambda^2$,

therefore $$x_1 = \frac{\sqrt{x^2 + \lambda^2}}{\tan\beta}$$

$$\lambda_1 = y\tan\beta,$$

so $$\lambda_1 = \sqrt{x^2 - \lambda^2}\,\tan\beta$$

Hence, $$S = \frac{\lambda}{\text{Sin}\,\alpha} + \frac{\sqrt{x^2 + \lambda^2}}{\tan\beta} - \lambda - \sqrt{x^2 - \lambda^2}\,\tan\beta$$

$$= \lambda\left(\frac{1}{\text{Sin}\,\alpha} - 1\right) + \sqrt{x^2 - \lambda^2}\left(\frac{1}{\tan\beta} - \tan\beta\right)$$