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B Hebblewhite

University of New South Wales

B Lin

University of New South Wales

J Galvin

University of New South Wales

R Walker

ANI Arnall

Justine D. Calleja

University of New South Wales, jcalleja@uow.edu.au

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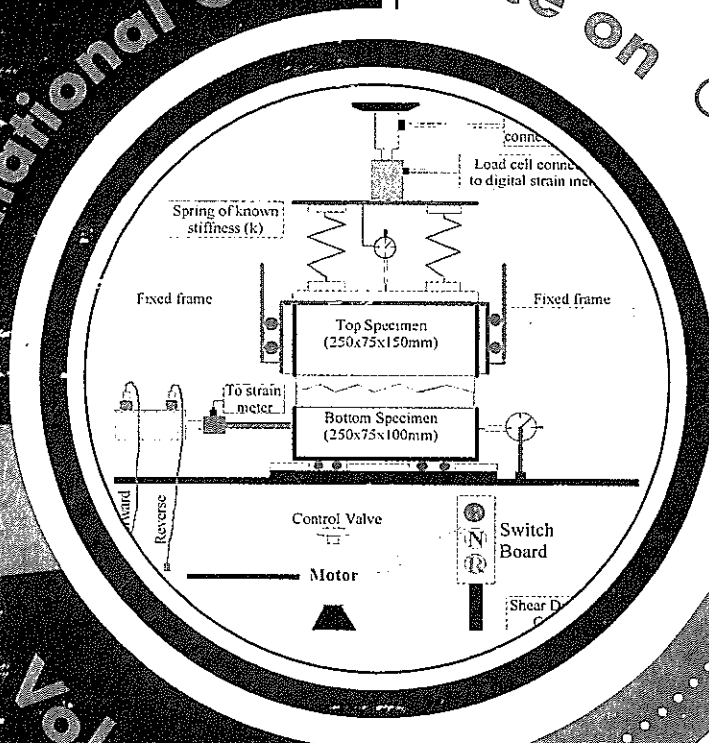
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Wollongong NSW Australia

Coal Mine Rib Mechanics – An Improved Understanding of Rib Behaviour and Support Requirements

B Hebblewhite¹, B Lin¹, J Galvin¹, R Walker², J Drew³

1. School of Mining Engineering, The University of New South Wales, Sydney, NSW 2052, Australia.
2. ANI Arnall, PO Box 370, Charlestown, NSW 2290, Australia
3. Formerly School of Mining Engineering, The University of New South Wales, Sydney, NSW 2052, Australia.

Abstract: The role of reinforcement elements in coal mine ribs has not been well understood. Various approaches to rib support and reinforcement are in use in the industry with mixed results. Rib spall is not uncommon and can vary from small nuisance fragments of coal to large scale collapse of the full rib surface, often with serious safety implications. This paper describes the outcomes of an ACARP research project which investigated rib behaviour to identify the geotechnical mechanics involved and then evaluated some prototype reinforcement strategies based on the concept of yielding support elements.

Key Words: rib geomechanics, yielding support, reinforcement, pillar stability, abutment loads.

Introduction

The control of coal mine rib stability is an increasingly important issue in underground coal mines, particularly with a trend towards narrower roadways, greater depths, more rapid development and the need to accommodate fast moving abutment stresses from retreating longwall and other extraction systems. Rib control management is a priority both for reasons of personnel safety and productivity, not to mention the implications for pillar stability.

Traditional approaches to rib control and rib reinforcement have essentially taken roof support concepts and hardware, rotated them through 90° and applied them to the coal ribside. There have been very few attempts to truly understand the engineering behaviour and mechanics of rib deformation, load transfer and response to reinforcement elements.

Through a research project funded by the Australian Coal Association Research Program (ACARP), the School of Mining Engineering at The University of New South Wales (UNSW), together with ANI Arnall (ANI) have been investigating the mechanics of coal rib behaviour and this has led to the identification of certain engineering parameters for potential rib reinforcement hardware.

In particular, the yielding characteristics of the immediate ribside have been quantified for several different coal seams by a program of extensometry and bolt load monitoring. This has identified the very localised effect of a stiff reinforcement element (eg. Conventional AX bar steel bolt, fully grouted) in an essentially soft and weak material, with the development of relatively high bolt loads but an inability to

achieve effective load transfer from the bolt to the surrounding coal beyond a very small radius of influence. (Clearly this behaviour depends on the in-situ strength and structural characteristics of each coal seam).

Arising from the investigations has been a determination of potential engineering specifications for a softer, yielding rib reinforcement element. Several alternative prototype systems were developed and evaluated in the laboratory and from these a selection were field tested. This paper presents a summary of the ACARP research investigations and findings. The results from the field investigations at both Angus Place Colliery and Dartbrook Colliery are described.

Rib Reinforcement

Reinforcement of coal mine ribs has seen a wide variety of approaches adopted throughout the industry – ranging from no reinforcement to total coverage by steel or plastic mesh products. In both these extreme reinforcement strategies, there is still a large body of evidence that indicates that the reinforcement approach is less than satisfactory with loss of control of the ribsides and extensive failure.

It is important, therefore to develop an improved understanding of the geomechanics of rib behaviour, in order to improve the design of reinforcement strategies. The key components influencing rib stability include the following:

- (1) Vertical loading of the ribs driven by roof and/or floor closure, leading to buckling on the outer rib layers.
- (2) Horizontal deformation due to the Poisson's Effect generated by vertical loading of the main body of the pillar or solid blocks of coal.
- (3) The source of loading for both (1) and (2) can be pre-mining stress redistribution around the initial roadway excavation, plus dynamic regional abutment stresses generated by approaching extraction operations, such as a longwall face.
- (4) The nature of the coal, its low strength, the structure within it (primarily cleat) results in a very inelastic response in the region of the rib side. This can produce inelastic yield zones and even failed 'crush' zones on the outer edges of the ribs.
- (5) Rib reinforcement is essentially acting in a 'displacement driven' geomechanical environment and is usually a passive reinforcement.

Angus Place Investigations

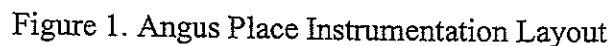
Objectives

A program of instrumentation was installed in LW21 Maingate, between Cut-throughs 19 and 20 at Angus Place Colliery. The Colliery mines the Lithgow Seam at a depth of approximately 350m, with a working height of approximately 2.7m in a 3m coal seam with a heading width of 4.8m. The Lithgow Seam at Angus Place has a number of horizontal marker bands and a high degree of near-vertical cleat, resulting typically in very friable rib conditions, especially below the main marker band, 2m above the floor.

- (1) The nature and extend of the ribside yield zone.
- (2) The region of influence of a single steel reinforcement bolt.
- (3) The influence of development face proximity and subsequently longwall abutment influence.

Instrumentation used included:

- Figure 1 shows the instrumentation layout, installed 2.1m from the development face.



The following is a broad summary of the data obtained and analysed from the Angus Place monitoring site. Figure 2 (a and b) shows the raw displacement data and processed ‘bay strain’ data relative to time for Borehole 4, located 1.4m from the strain gauged bolt and 2.1m from the face.

Features of this data set include:

- In excess of 55mm deformation as soon as the development face moves away (up to 50m), at least 25mm of which originates deeper than the 1.2m anchor depth (corresponding to the rib reinforcement length normally in use, ie. 30mm within the immediate 1.2m rib region).
- As the longwall abutment approaches, total rib deformation doubles to 110mm but virtually all of this increase is within the immediate 1.2m. (Abutment influence commences from a distance of 150m from the longwall)
- Strain levels within the first 0.2m-0.7m bay exceed 4% on development and 6% under the longwall abutment (2% and 6% for the 0.7m-1.2m bay). (This compares with a theoretical failure strain of approximately 4% using simple elastic properties for the coal). Beyond the 1.2m depth, strain values were negligible for all boreholes. (This is also illustrated in Figures 3 and 4 being an alternative presentation of the same data set).
- 1.2m (or approximately 45% of mining height) appears to be the limit of the yield zone at Angus Place

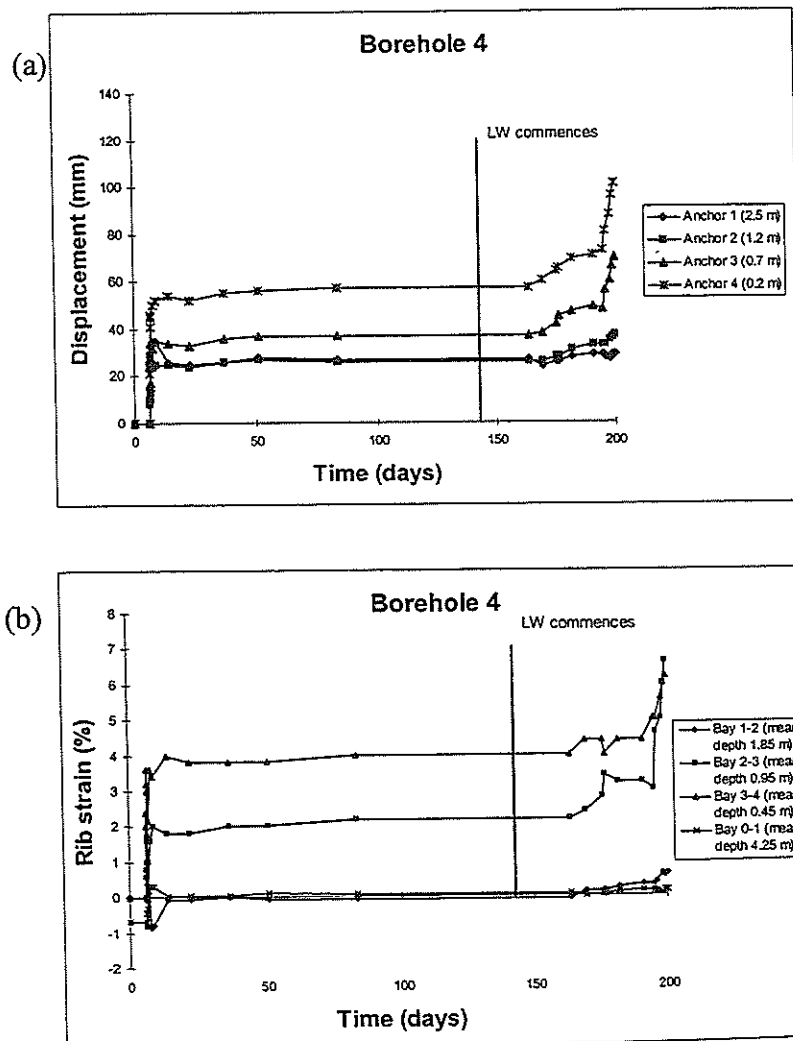


Figure 2(a and b). Borehole 4: Results (Deformation and Strain v. Time)

Figure 5 illustrates the relative influence of the strain gauged bolt on the four extensometer sites. The bolt is located 160mm, 435mm, 860mm and 1410mm away from Boreholes 1 to 4 respectively. Clearly, at least in the first half of the data set (subject to development loading only).

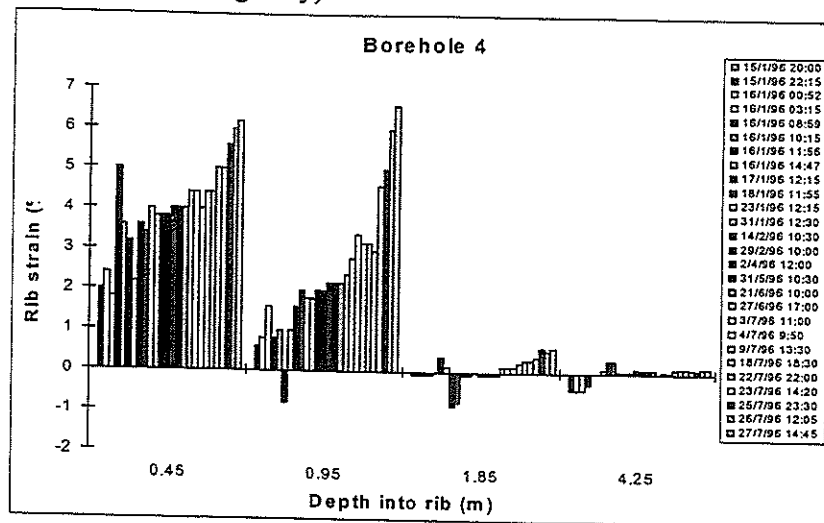


Figure 3. Borehole 4: Strain v. Depth

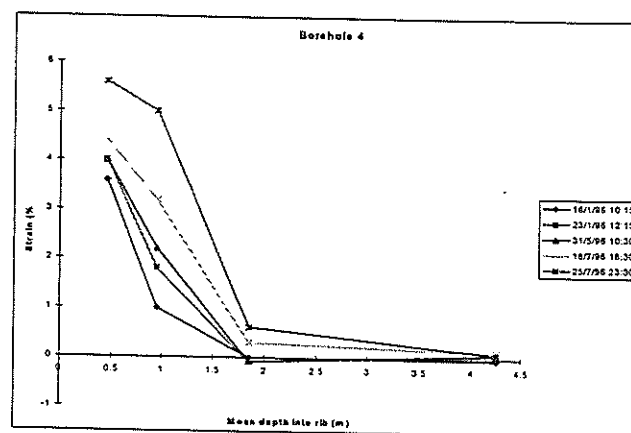


Figure 4. Borehole 4: Strain v. Depth

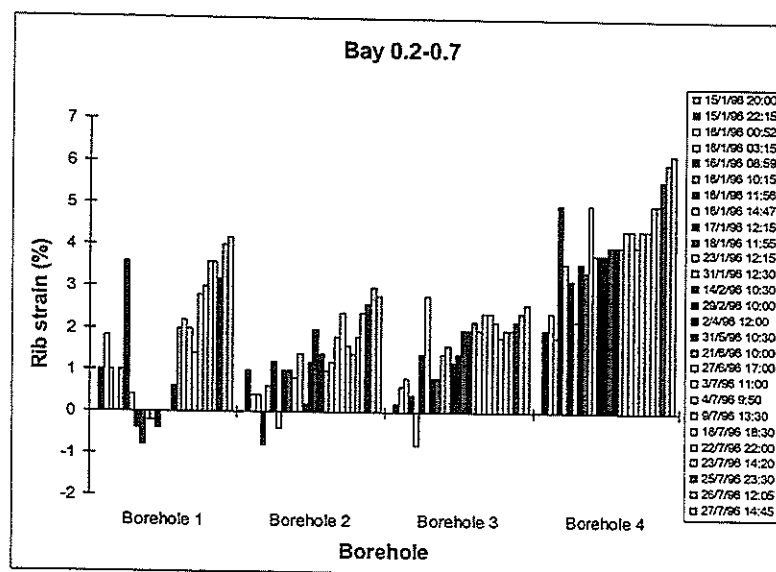


Figure 5. Region of Influence of Bolt

Borehole 4 is exhibiting far higher strains than the others, suggesting it is outside the influence of the bolt's reinforcement effects. This is also true, but to a lesser extent, for the longwall abutment influence, where even in the close vicinity of the bolt, strain levels are excessive, suggesting failure of the coal (and hence inability to effect load transfer). The raw deformation values for Boreholes 1 to 3 were also close to half those for Borehole 4. Figure 6 is an alternative plot of these results, confirming the same behaviour across the full bolt interval of 1.2m.

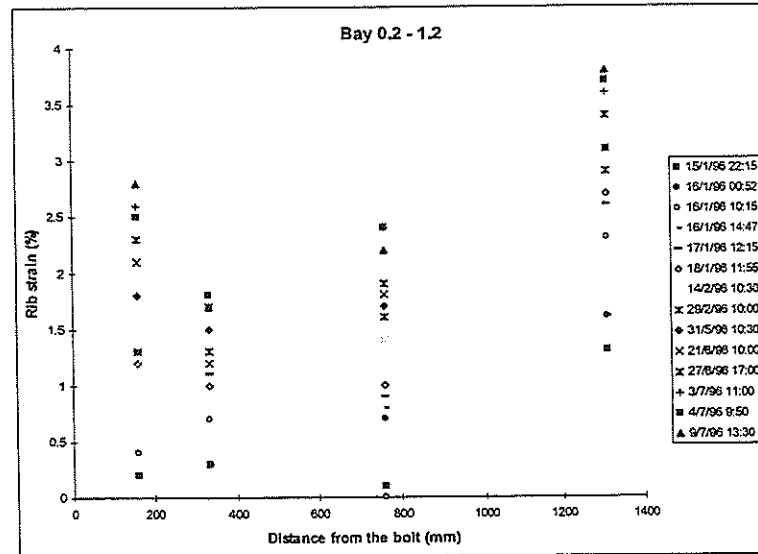


Figure 6. Region of Influence of Bolt

Figure 7 is a plot of the load distribution along the fully grouted strain-gauged bolt. The left hand end of the plot (O axis) represents the back of the hole and shows a peak load of approximately 120kN after development rising to 140kN under the longwall abutment. The peak load is located approximately one third distance from the back of the hole or 0.8m from the rib.

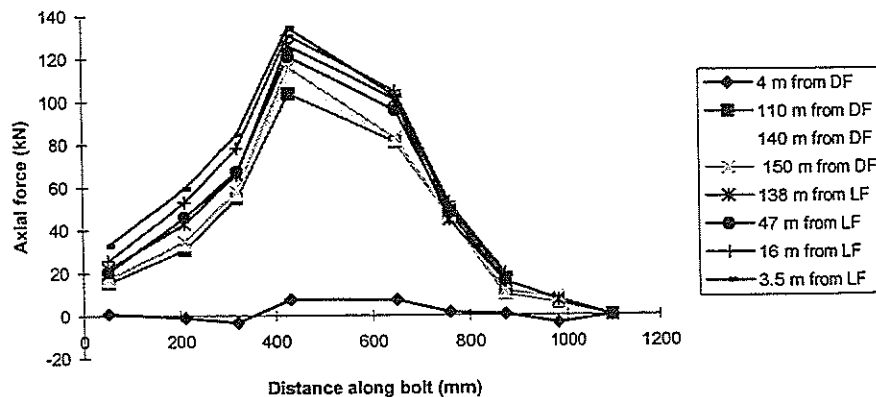


Figure 7. Bolt Load v. Length

This level of load corresponds to a maximum total bolt elongation of 0.7mm. Given that the adjacent extensometer, Borehole 1 (only 160mm away) indicated 25mm extension between 0.2 and 1.2m on development and 55mm on longwall extraction, it appears that there is very limited load transfer (to the extent that it limits deformation) between the bolt and the coal 160mm away.

The fact that bolt load only increased by 1-2 tonnes (17% increase) as the longwall's abutment approached, also suggests that the surrounding coal is acting almost independently of the bolt, since the coal deformation more than doubled under the longwall abutment. And yet, the bolt did retain its load, indicating that even through failed coal surrounding it, friction and confinement has assisted some load transfer and prevented unloading from occurring.

Dartbrook Investigations

Objectives

The monitoring program at Dartbrook was intended to provide a contrast to Angus Place with the coal being far more competent (high strength and less structure). The installation was in 101 Panel (Longwall 1 Tailgate) between Cut-throughs 14 and 15. The seam being mined was the Wynn Upper Seam, with roadway dimensions of 5.2m width and 3.9m height. The objective at Dartbrook was purely to monitor the rib (and pillar) behaviour, under the standard reinforcement regime, subject to the longwall abutment effect.

Instrumentation

Similar instrumentation to that at Angus Place was used, together with hydraulic borehole flatjacks for stress change monitoring. Instrumentation (wire extensometers) was installed through the full width of the chain pillar in order to continue monitoring after the face had passed (from the adjacent heading) as well as providing data on the overall stability of the chain pillar across its full width.

Results

Unfortunately, major gas and ventilation problems in the vicinity of the monitoring site severely restricted access for monitoring, particularly during the crucial 'mine past' stage, so only very limited results were obtained. Several highlights are described below. Figures 8 and 9 present the composite wire extensometer data across the full width of the 30m chain pillar. The longwall was on the right hand side as this data is presented and passed the instrumentation site during April 1997 (ie. last two results are adjacent to goaf, after the longwall has passed – all other data is subject to development loading only).

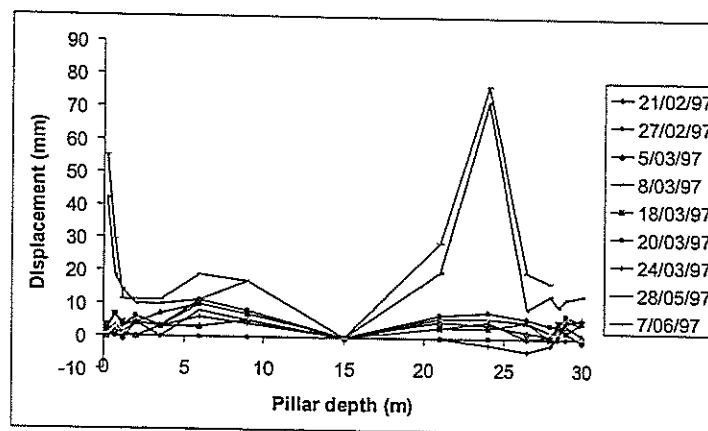


Figure 8. Displacement v. Depth

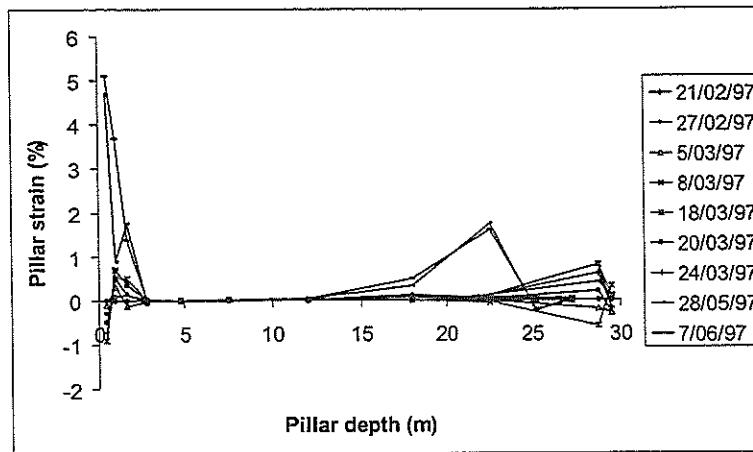


Figure 9. Strain v. Depth

Points to note from this data set are:

- Negligible deformation/strain in immediate ribs under development loading (correlates with excellent conditions assessed visually).
- Negligible deformation on goaf rib side even after longwall has passed.
- Significant deformation (up to 55mm) on opposite ribside and yield zone extending beyond 1.2m (less than 2m) under abutment loading with strains up to 5%.
- In comparison with Angus Place, 45% of mining height at Dartbrook would be 1.7m which is in reasonable agreement with these results for depth of yield.
- Unusually high region of strain 7.5m into the pillar from the goaf side.

Figure 10 presents the results of a strain gauged bolt located in the travelling roadway (across the chain pillar from the goaf) adjacent to the left hand side of the Figures 8 and 9 extensometer data. This also illustrates negligible load under development but extremely high loads (in excess of 25 tonne) towards the back of the bolt, after extraction. Subsequent visual inspection of the travelling road revealed that the ribs were failing as large intact slabs, detaching from the top of the rib and rotating. This would account for the very high strains detected by the extensometers and high bolt loads. This behaviour was evident along most of the travelling road and led to the need for subsequent installation of secondary rib support, up to 2m in length, to contain the unstable ribs.

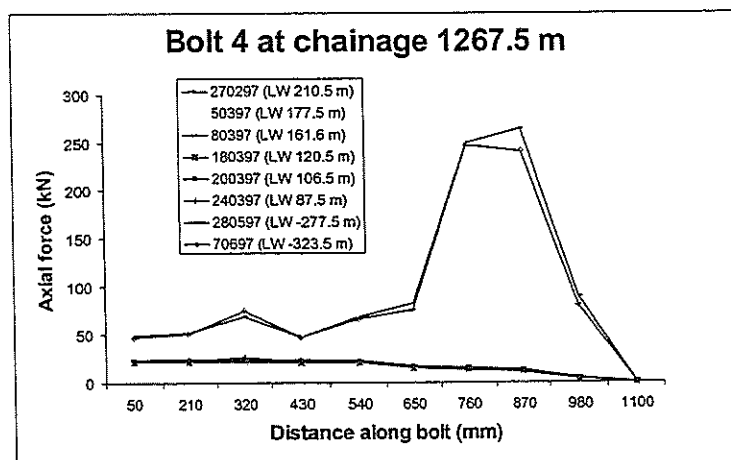


Figure 10. Bolt Load v. Length

Prototype Yielding Supports

In the light of the Angus Place results, the need for a yielding support capable of deforming at least 30mm (and possibly up to 50mm+) and then providing a stiffer resistance was recognised. It was felt that this would enable the support to accommodate the initial rib relaxation under development loading, without the coal failing, so that subsequent conditions on extraction would be more akin to the current development conditions. In friable coal such as at Angus Place, it is envisaged that even with a yielding support, some form of overall rib surface constraint may be required to provide confinement and connectivity between adjacent supplement elements. It was also determined that longer rib reinforcement would not be effective at Angus Place, unless it incorporated a yielding component.

Laboratory studies were conducted using birdcaged cable bolts as a means of providing a yield element in an otherwise stiff system. In these studies, it was found that each birdcage could provide up to 10mm of yield. Furthermore, a soft material (such as a weak plaster mix) was placed into the birdcages as a means of delaying the yield process until a certain threshold load was reached, at which time, the straightening of the birdcage would crush out the plaster. This in-fill material could also serve to prevent the cable grout from filling the birdcage (if fully grouted).

Figure 11(a and b) illustrates some of the comparative laboratory test results using different numbers of birdcages and fill materials.

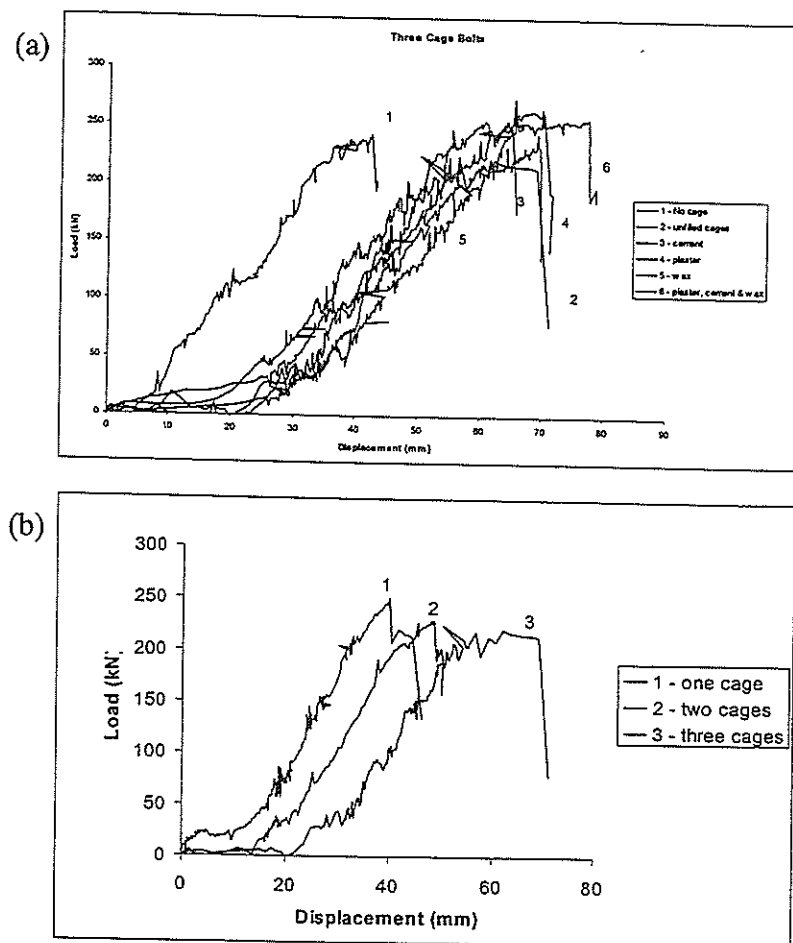


Figure 11. Laboratory Tests of Birdcaged Tendons

A series of prototype cables plus several alternative yieldable supports were installed in on outbye section of Maingate 21 at Angus Place just prior to the longwall retreat. This was purely a qualitative test of the designs, but results visually indicated some degree of improved rib control - enough to warrant further development of the concept.

Conclusions

The research investigations described in this paper have identified the following conclusions regarding the mechanics of rib behaviour and reinforcement requirements:

- (1) Different coal seams can exhibit markedly different behaviours ranging from highly cleated and friable coal at Angus Place to the much stronger, blocky nature of the Dartbrook coal ribs.
- (2) In the Angus Place environment, in spite of surprisingly high bolt loads, the ability to effect and maintain high levels of load transfer is extremely limited.
- (3) Failed and yield zones exist within the first 1.2m of the ribsides, with some deformation, but greatly reduced magnitude, beyond 1.2m at Angus Place (45% of mining height).
- (4) The behaviour identified suggests the need for a yieldable reinforcement element, capable of providing up to 30mm and possibly as high as 50mm yield, but then retaining a reasonable level of stiffness.
- (5) A flexible rib surface constraint, providing total coverage between bolts would be an effective supplementary support to a yielding bolt system at Angus Place.
- (6) In the case of Dartbrook, the depth of yield is slightly greater than at Angus Place (commensurate with increased mining height) but only under longwall abutment conditions, and only on the opposite side of the pillar to the goaf. This also suggest that a wider pillar may be required to minimise the abutment conditions in the adjacent roadway.
- (7) Rib behaviour at Dartbrook is characterised by detached blocks buckling and/or rotating from the ribside generating very high bolt loads. In this type of behaviour, only high capacity, stiff systems will offer any degree of rib control and they must be anchored well beyond the yield zone.

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