Joint Structure and Coal Strength as Controls on Rib Stability

Ross W. Seedsman  
*University of Wollongong, seedsman@uow.edu.au*

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JOINT STRUCTURE AND COAL STRENGTH AS CONTROLS ON RIB STABILITY

Ross Seedsman

ABSTRACT: The assessment of the stability of coal ribs needs to consider not only the impact of the cleating and jointing in the coal but also the possible onset of failure of the coal itself. The same planar, wedge and toppling failure modes seen in pitwall slopes can be present in underground roadways. A 20° offset of the roadway from the strike of the through-going joints reduces the fall hazard, but a 35° offset may be required to reduce delays in installing support. Mining-induced fractures (MIF) in coal may be a manifestation of brittle rock behaviour and its preferential location at the top and bottom of the rib and its continuing development outbye of the face can be explained by a dominantly vertical stress field within the coal.

INTRODUCTION

Ribs can present as great a hazard to the underground workforce as the roof. Until recently, most of the focus of mine operations and geotechnical researchers was on improving roof stability. A range of roof support hardware has been developed, bolter miners are used to bolt as close to the face as possible, and the alignment of roadways with respect to the horizontal stress field is now a fundamental principal of mine layout planning. By contrast, ribs have received lesser attention. In a 2001 feasibility study in which the author was involved, the discussion on roof support was 11 times longer than the discussion on rib support, and this is probably a good reflection of the relative state of the art.

Colwell (2005) highlighted the paucity of research into rib behaviour in Australian underground coal mines and went on to develop a comprehensive empirical design method for rib support. The 2001 feasibility study referred to above prompted the author to review the available literature on rib instability, with a particular focus on analytical methods. The analogy to pitwall instability had already been made, and recent work on brittle rock failure in hard rock mines (Martin et al, 1999) appeared to provide an explanation for the mining induced fractures (MIF) that had been identified by O’Beirne at al (1987).

This paper canvasses the range of rib failure modes that have been encountered by the author over the last 10 years and outlines how feasibility studies and mine operations can better incorporate rib stability considerations into the mine layouts. It provides an analytical framework to the empirical work of Colwell (2005).

RIB INSTABILITY

The primary hazard presented by ribs is related to large blocks of coal falling under gravity from the side of the roadway. There is a secondary hazard related to rib collapse leading to an increase in roof span, but it is considered that this is very much a lesser issue. Small spalling of coal ribs into small blocks does not represent a hazard unless it undercuts blocky coal higher in the rib.

There is a range of ways in which large blocks can be defined. Coal seams are characterized by the presence of discontinuities, referred to as cleats or joints. Strictly speaking, the term cleat is better restricted to the small scale fractures in the bands of bright coal; the through-going features of interest to the geotechnical engineer are joints. Depending on the dip, orientation and spacing of the coal joints with respect to the roadway driveage, toppling slabs (Figure 1a), planar slides (Figure 1b) and wedges can be defined. Depending on the thickness of the plates defined by the cleat, thin slabs can also undergo buckling, leading to the formation of detached blocks that can then collapse – this is the origin of the irregular rib line in Figure 1a.

1 Visiting Fellow, University Of Wollongong
Fig. 1 - Rib instability associated with discontinuities

In other cases, where the roadway is aligned away from the strike of the joints, the top and bottom of the rib can deteriorate (Figure 2). If not supported, this fracturing can eventually define thin slabs of coal that can slide or topple into the roadway (Figure 3a). The surface that is developed parallel to the roadway, and hence defines the slab, is rough and irregular and appears vastly different from the natural joints (Figure 3b).

Fig. 2 - Stress facturing in the rib near the roof line
As well as the primary issue of supporting these blocks, there is also a need to optimize the installation time and quality of the support used. An irregular rib line can cause delays in the collaring of drill holes, and any open joints surfaces or broken coal can lead to the collapse of the holes on withdrawal of the drill rod or loss of resin and less than full encapsulation.

**MECHANISMS AND SUPPORT**

**Structure control**

If joints are present at the necessary alignment and spacing, the slide, wedge, toppling and buckling modes can develop at all depths and large blocks of coal mobilised. It is important not to ignore the impact of the dip of the coal seam. With coal joints being dominantly vertical, with perhaps a natural variation of $+/10^\circ$ a cross dip of even 2-3$^\circ$ can add a significant differentiation between the up-dip and down-dip rib. The blocky nature of the rib may allow the use of spot bolts.

Rock slope stability text books present details of planar, wedge and toppling modes. There is readily available software for planar slides and wedges to simplify the calculation of the bolting support (www.rocscience.com). Sagaseta et al (2001) provide a simple method for the assessment of toppling and the necessary ground support. Support densities of less than about 3 tonne/m run of rib are typically obtained from the application of these tools. For buckling, a standard Euler analysis provides a good appreciation of the problem with thicker slabs buckling as the depth of cover increases (Figure 4). In all of these modes, there is a need to consider the need to provide skin restraint between the bolts and the presence of soft clay bands that may define smaller blocks.
There are three observations that must be made with respect to the analogy to rock slope stability. Firstly, standard practice to "remove" the planar slide hazard is to recommend a face alignment of more than 20° with respect to the joints in order. This certainly applies to the underground situation but it may not be sufficient. Based on recent observations in a Bowen Basin mine, the rib conditions with a 25° offset were still not satisfactory – an irregular rib line meant that the workforce was not confident that the rib was adequately supported, collaring the holes was difficult, and there was a large degree of hole collapse. A survey of other roadways indicated that the 35° offset was necessary to optimise the rib. The explanation may be related to the different stress field induced around an advancing coal mine roadway compared to that induced with an overburden blast in a surface mine. An analysis of the induced shearing along coal joints suggests that this could be the cause of the additional deterioration.

Secondly, the optimum layout of a surface mine avoids "noses" in the pit wall. Underground, every intersection defines either two or four equivalent noses. The implication is that even the ideal layout underground will require particular attention to the stability of the ribs near intersections.

Thirdly, the coal rib is mechanically excavated to a maximum height of about 3.5 m high and the workforce is located within 1 m of its immediate toe. In surface mines, the rock batter is blasted and then scaled, is often 20 m or more high at angles less than about 75°, and the workforce is protected in cabins and there is an imposition of no-go zones. All this means that there needs to be a different appreciation of the specific hazards. Toppling and buckling can produce relatively small blocks falling from high (potential head, neck and chest exposure), while slides and wedges provide large volumes of rock directed at the lower torso and legs.

**Stress controlled**

It is now believed that the stress field in coals is significantly different from that in the stone, with the major principal stress being approximately vertical with the horizontal stresses related to the Poisson’s Ratio effect (Seedsman 2004). As a coal seam is depressurised by the drainage of water ahead of mining, the coal compresses in response to the increase in effective stress. As it compresses it decouples from the overlying stone and any "tectonic stress" is redirected into the stone. As the area of coal compression extends outwards, the overlying stone sags and reloads the coal. Horizontal stresses are induced under this lithostatic loading condition, with their magnitude related to the Poisson’s Ratio of the coal. As a result, the horizontal stresses in coal can be as low as 20 % of the vertical stress. The vertical stresses may also increase with time depending on the rate of drainage and mining advance – there is evidence that at the face in a virgin coal seam the vertical stress may be about 50 %
of that related to simple overburden loading and that it increases to the expected level with a few hundred metres outbye of the face. Possible depressurisation of the mined seam by adjacent workings in the same seam or in seams above and below needs to be considered. Retreat of the longwall will increase the vertical stresses near the face.

This alternative stress model for coal, when combined with the evolving understanding on the behaviour of brittle rock, provides a better understanding of mining-induced fracturing (MIF) that was the focus of ACIRL research in the 1980s (O’Bierne et al., 1986). Coal can be considered to be a brittle material and hence the ideas from Canada (Martin et al., 1999) on brittle rock can be applied – the key one being that cohesion and friction are not mobilised simultaneously at low confining stresses. The implication is that the failure criterion for coal near to an excavation should be based on the Hoek Brown criterion with \( m = 0 \) and \( s = 0.11 \).

The combination of the stress and brittle coal models leads to the prediction that the onset of poor ribs occurs when the unconfined compressive strength/vertical stress ratio exceeds 0.27. The strength of coal in this case can be the laboratory values, and the range of strength is 10 MPa for high quality coking coal to in excess of 30 MPa for some of the dull thermal coals. Note that the onset of rib deterioration may be progressive if the vertical stress magnitude increases outbye as proposed above. The predicted rib failure is localised initially at the roof and floor corners, with the tendency to define a vertical failure surface inside the rib (Figure 5). The similarities to Figures 2 and 3a are striking.

MIF can interact with existing joints and define slender columns of coal that may fall, or it may form extensive slabs (Figure 3a). It is possible that the common occurrence of “buckling” reported by Colwell (2005), which according to the definitions in this paper would require an alignment of roadway sub-parallel to the coal joints, is actually MIF. The deterioration of the rib at the roof line can be problematic as it is an area where it is difficult to install support. At UCS/cervical stress ratio close to 0.27, it may be possible to use spot bolts but as the ratio increases the coal may need skin restraint to prevent collapse between the bolts.

Bolt designs

With these collapse modes, the approach to support design is to locate the anchorage behind the identified failure surface. Anchorage lengths can be designed using civil engineering ground anchorage approaches (Littlejohn and Bruce, 1975), with high factors of safety greater than 2.5 to allow for the uncertainties regarding resin loss (Figure 6).
It is important to note that many of the failures are not deep-seated and are in fact very shallow. If the bolts are not fully encapsulated right to the collar, there needs to be attention paid to the durability of the bolt/plate assembly – especially for cuttable bolts.

Limitations of the drill rig locations may mean that bolts cannot be located in the ideal places. Rigid straps and panels may assist.

**AN EXAMPLE**

This example is a composite of a number of recent mining operations in both New South Wales and Queensland.

Consider a development roadway in a steaming coal mine with a coal UCS of 20 MPa and roadways at depths of 150 m increasing to 250 m. There has been mining in the overlying seam 30 m above. The coal seam dips to the right so there is a bias in the relative dip of the coal joints to the left. The extreme dip of the joints is 65°. The joints are generally widely spaced but there are zones where the joint spacing is about 0.3 m. The roadway is aligned at 20° to the strike of the joints. There are two mid-seam clay bands.

The coal seam is 5 m thick and the development roadways are 3.4 m high. The bolter miner has rib bolters that can install bolts above 1.7 m from the floor and within 0.36 m of the roof (Figure 7).
At depths less than 200 m, the ribs should behave in a blocky mode. On the left hand rib, there is no buckling hazard because the joints are adequately widely spaced. The left hand ribs can be adequately supported using spot bolts located above the clay bands. Given the use of a bolter miner, it must be assumed that the wedge defined by the flattest dipping joint on the right-hand side will not fail near the face and must be supported with the rib bolts. The top of the right hand rib can be adequately supported with spot bolts but there is a problem with how to retain the lower rib below the clay bands. Longer bolts are needed for the right hand rib than for the left hand rib. Because of the alignment with respect to the cleat, some difficulties in installing rib bolts are to be expected (hole collapse, loss of resin). For the steeper dipping joints, there is a need to be sure that the bolts are fully encapsulated right to the collar or there is an effective plate – this is a particular concern if cuttable bolts are being used. Outbye deterioration of the rib is not anticipated for this mine because previous mining has already altered the stress field in the coal. The retreat of the longwall may induce a change in conditions related to the increase in vertical stresses in the abutment zone at the maingate corner. The impact will be similar to the rib conditions on driveage beyond 200 m depth.

Beyond 200 m depth, the ribs will start to deteriorate at the face with the onset of MIF. This will make the collaring of the bolts more complicated for the face crews. The spalling at the roof and floor corners will change the hazards significantly. The MIF at the floor will undercut the coal up to the clay bands and exacerbate the problem introduced by the lower bolt location. The MIF at the top of the ribline may need to be restrained somehow. At these depths the introduction of straps and panels may assist in controlling the coal between the bolts. Spray membranes will assist in controlling the rib until the pillar is rib is compressed by the next vertical stress change.

SUMMARY

Ribs present a range of hazards related to the joint structure of the coal and the onset of brittle failure. The failure modes can be anticipated and there are options available in terms of mine layouts and the specification of selection of the bolters and bolter miners. Rib support designs can be checked against a range of simple failure mechanisms. It is recommended that the ideas in the paper be used as a complement to the empirical methods, and that the choice of input values be recalibrated to the coal strength and joint orientations and joint spacing at each site.
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REFERENCES


