ROOF SUPPORT IN GATEROADS IN MULTIPLE SEAM LONGWALLS - LESSONS FROM ULTRACLOSSE MINING AT GIBSON'S COLLIERY

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ABSTRACT: Gibsons Colliery is mining the Balgownie Seam at less than 10m below the extracted Bulli Seam. The mine enters the Illawarra Escarpment and the depth of cover increases rapidly over the first 500m until it plateaus at approximately 220m. A number of roof falls have developed in intersections – the roadways have mostly been free of falls unless aligned parallel and coincident with roof joints. Underground observations are that the falls are associated with a roof that has no horizontal confining stress – the falls are either joint bounded blocks or failed cantilevers. A roof support strategy based on forming thick cantilevers and if necessary standing support has been developed. A model for how similar stress regimes could develop in multiple seam longwalls has been developed.

INTRODUCTION

History

Thin Seam Mining Pty Ltd began mining in the Balgownie Seam in late 2001. The Gibsons Colliery portal is located at the Russell Vale site of Bellambi West Mine and enters the Illawarra Escarpment immediately adjacent to earlier entrances to the Bulli and Balgownie Seams. The area has been extensively mined, with workings in both the Balgownie Seam and particularly the Bulli Seam. The Bulli Seam workings date from the late 19th Century, with the last mining being pillar extraction in the late 1930's and early 1940's.

At Gibsons Colliery the Balgownie Seam is located 6m - 10m below the Bulli Seam. The initial mining was under first workings in the Bulli Seam and mining conditions were excellent. Later, the workings intersected pre-existing roadways (1970s vintage) in the Balgownie Seam (Figure 1) and found a wide range of conditions – either the roadways were open and still supported on wooden props and beams, or there had been major roof falls. The falls were comprised of massive joint-bounded blocks of sandstone. At the same time, new roadways were being driven under the edges of pillar-extraction Bulli Seam goafs and a number of intersection falls developed.

The nature of these falls, the formulation of a geotechnical model to explain their occurrence, and how the lessons from this can be applied to multiple-seam longwalls is discussed.

Mine plan

The Balgownie Seam is approximately 1.2m thick and lies between 6m and 10m below the Bulli Seam. Depth of cover increases rapidly from 0m to 210m as the workings enter the Illawarra Escarpment (Figure 1). The roof of the Balgownie Seam is a thickly bedded sandstone with an estimated average spacing of bedding partings of about 0.75m in the immediate roof ; the upper roof is probably more thickly bedded. The thickly bedded nature of the sandstone makes it well suited to extended-cut mining. There are three well developed joint sets in the sandstone – 355^o, 100^o, 050^o. The unconfined compressive strength ranges from 55 MPa to 124 MPa, and averages 88 MPa.

The low seam thickness allows stable pillars to be formed on relatively small pillar centres. The mine layout is based on 5.2m wide roads driven on 20m centres; pillars are 1.4 -1.5m high once the floor is graded to a width/height ratio of 9 to 10 applies.

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FIG. 1 - Gibsons Colliery workings in March 2002 (shaded area shows unmined Bulli Seam coal, contours are depth of cover to Balgownie Seam)

In developing the mine plan, consideration was given to the experience in the USA whereby a pillar factor of safety of 2.0-2.2 is recommended for pillars located under goaf/solid transitions. The USA literature also recommends a minimum factor of safety of 2.5 under remnant pillars or stooks in the goaf – this was not adopted as the knowledge of the Bulli Seam does not allow the identification of such remnant pillars.

MINING METHOD

Place-change mining methods are utilized with a Joy continuous miner and a Fletcher roof bolter. Extended cuts of up to 12m are taken.

Roof support design is based on the recognition that extended plunges are possible and that there are no stress change after development – i.e. no subsequent extraction. From a design viewpoint, the demonstrated stability of the unbolted plunges challenges the usual assumptions regarding roof failure mechanisms against which support is specified.. The design approach is based on dead-weight suspension of the immediate roof, and this is implemented as four mild-steel bolts, 1.2m long at 1.2m centres.. As will be discussed, this support was to be supplemented in areas of seam interaction. The Jennmar Insta'L system has been used. It is important to note that the limited head room means that a header bolt must be used. Mild steel was specified as a pit standard so that if there was a need for longer bolts they could be readily bent to allow insertion. An important feature of the Fletcher Bolter is that it can only install vertical bolts.

ULTRA-CLOSE MINING

Record tracings and the original linen plans for the Bulli Seam are available and these have been shown to be accurate to within about 2-4m. The Bulli Seam mining used Welsh Bords and there were two generations of pillar extraction, one apparently some time soon after mining and a later extraction. It would appear that the extraction is reasonably well recorded in the record tracings in as much as ground conditions in the Balgownie Seam do relate to some degree to the goaf edge shown on the tracings. It would also appear that there are significant stooks or remnant pillars within the areas marked as goaf.

The Balgownie longwalls of the 1970's were also located under pillar extraction goaf about 1 – 2km to the west of Gibsons Colliery. Some of the early physical models conducted by ACIRL examined the possible conditions under the Bulli pillars (Figure 2). The experiences of some of the miners and the geologists who worked in the Balgownie longwalls were sought. A range of ground conditions were experienced during gateroad development and these were generally in agreement with the physical models. The ability of the operation to control the roof improved as the transition was made from timber to some of the first roof bolts. The physical models did not include joints: joint-control of roof falls was identified by the Balgownie geologists, and this was incorporated in the Gibsons layout whereby the roadways were oriented to bisect the major joint sets.

FIG. 2 - Example of ACIRL physical model of Bulli/Balgownie seam interaction

ROOF FALLS

Minor roof falls are a characteristic of extended-cut mining. Whilst the sandstone roof is thickly to massively bedded, there are cases where more closely spaced bedding partings define beams that cannot span across the 5.2m wide cuts. The few occurrence of this resulted in falls of less than 0.5m in height and the fall debris was readily cleared from the miner.

When mining has been carried out near goaf edges, and particularly at intersections, or when a roadway was driven parallel to and coincident with a joint, larger roof falls have developed. The likely onset of falls associated with multiple parallel joint sets was evident as the cut was taken, so the plunges were reduced in length and standing support installed.

The intersection falls are of particular interest. Joints could be seen to be open as the face was driven but there was no evidence of movement. The roof was supported with bolts, and W straps were introduced to span the joints. The roof drilling would reveal high-strength massive sandstone in the immediate roof. If standing support was not installed, a fall would develop some time over the next five day period.

Typical falls are shown in Plates 1 to 4. They all had some, if not all, of the following characteristics:

- Thick to massive bedded sandstone
- At least one joint plane exposed in the fall, with rock 'flour' on the surface
- An arcuate fracture surface reminiscent of feather edging in massive sandstone roofs during pillar extraction.

Occasionally very large falls occurred with joints on all sides

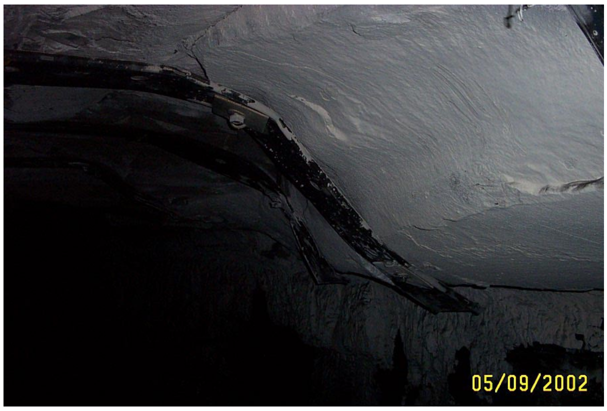


Plate 1 Vertical joint bounding roof fall that roadway to joint in Plate 1.

Plate 2 Feather-edge developed on other side of developed prior to bolting

FAILURE MECHANISM

In developing a failure mechanism, the key observations were the presence of open joints located at any position across the roof – either centreline or towards the ribline, the exposed joint planes in the sides of the falls, the development of feather edges in some cases, and often the presence of water drippers.

It is considered that the falls relate to the mobilization of joint blocks in massive sandstone. The average joint spacing in the massive sandstone roof is probably in the order of 5m and given the statistical distribution of joint spacing, this can result in some occurrences of relatively closed spaced joints. If there is a joint down the centerline of the roadway the roof is stable. If there is a joint down one ribline an unstable cantilever develops (Figure 3a) and if there are 2 joints exposed then a block fall develops (Figure 3b).

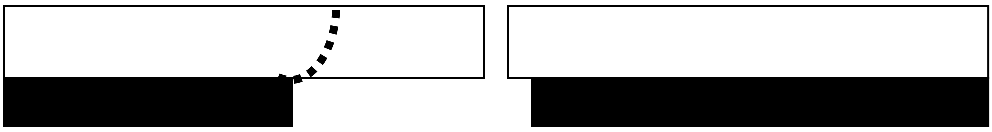


Figure 3a Onset of cantilever failure when one joint exposed along ribline.

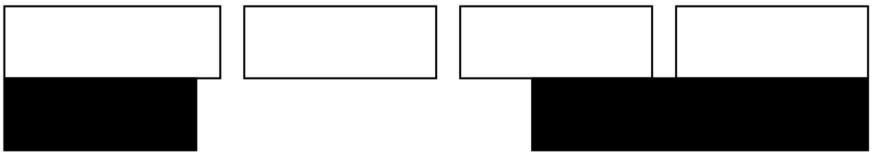


FIG. 3b - Joint block failure when two joints exposed in the roof

An analysis of cantilever behaviour using a tensile strength of 2.5 MPa and a factor of safety of 2.0 indicated that beams with a thickness of less than about 1m could not span across a 5m roadway and this increases to 2.5m for a 7m span as is developed over an intersection (Figure 4). These beam thicknesses are very similar to the height of the roof falls that have been observed above extended cuts in the roadways and in the intersections respectively.

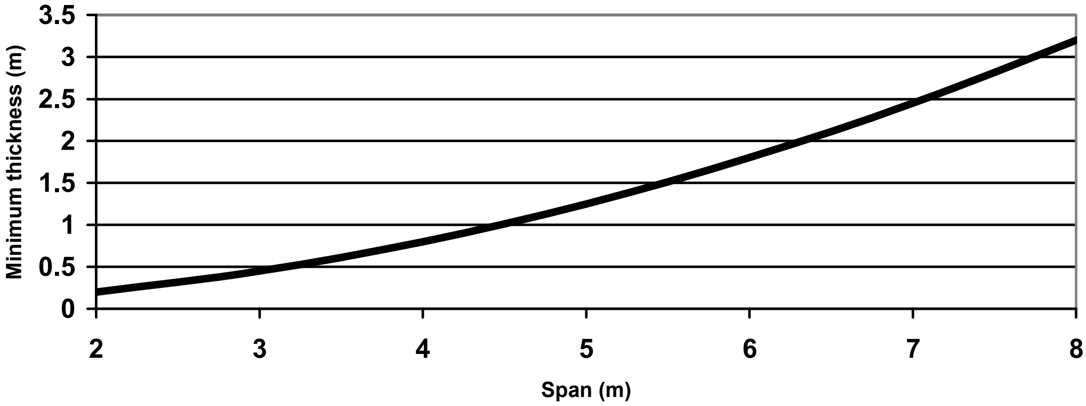


FIG. 4 - Analysis of cantilever failure

ROOF SUPPORT

A roof support strategy was developed in response to the intersection falls. The original layout of the mine recognised the importance of aligning the roadways so as not to be parallel to the major joint sets. The ability of the Fletcher bolter to install only vertical bolts meant that reinforcement of the vertical joints is not possible. The use of standing support is not compatible with the place-change operation.

The immediate response was to use 4m long cables installed using hand held drill rigs. Whilst this apparently stabilized the roof the collar assemblies and cable tails proved to be a substantial workplace hazard in the low seam height.

Finite element analyses were conducted to estimate the bedding parallel shear forces that may develop in cantilevers that are not thick enough to span across an intersection. An installed capacity of 42 tonnes/metre was found to be adequate to resist the onset of shear. This was implemented using 2.5m long mechanical anchored header bolts installed vertically. The support has been successful in controlling cantilever failures.
Control of block falls (Figure 3b) is only currently possible with standing support.

ONSET OF ZERO CONFINEMENT IN THE ROOF

A key requirement for the application of the proposed failure mechanism is a stress field that results in zero horizontal stress acting across the roof line. The block and cantilever failures will not develop if there are compressive stress acting across the joints. The elastic solution of stresses about an elliptical hole aligned so that axes are parallel to the principal stresses can be used to give an indication of the field stresses needed to induce tensile stresses in the crown of an excavation. If the vertical stress is a principal stress, and the horizontal stress is equal to K times the vertical, then tensile stresses will be induced when

$$1 - K + 2 K H / W = 0,$$

where W is width of roadway and H = height.

For the case of Gibsons Colliery (W=5.2, H=1.5), tensile stresses are induced if $K \leq 0.65$, which means that the vertical stress needs to be greater than the horizontal stress.

Of course, in the mine the principal stresses are not aligned parallel to the axes of the opening – nor is a coal mine roadway an ellipse. Finite element modeling has been used to determine the roof stresses induced in the roof of a rectangular excavation in an inclined stress field. The models assumed a major principal stress of 5 MPa imposed on a 5.2m by 1.4m roadway driven in a 1.2m coal seam, and the minor principal stress was varied along with the orientation of the stress field. The roof and floor of the coal seam were modeled with joints, and the roof, coal, and floor material were assumed to be elastic. The two dimensional finite element code (Phase2) was used and a typical output is shown in Figure 5.

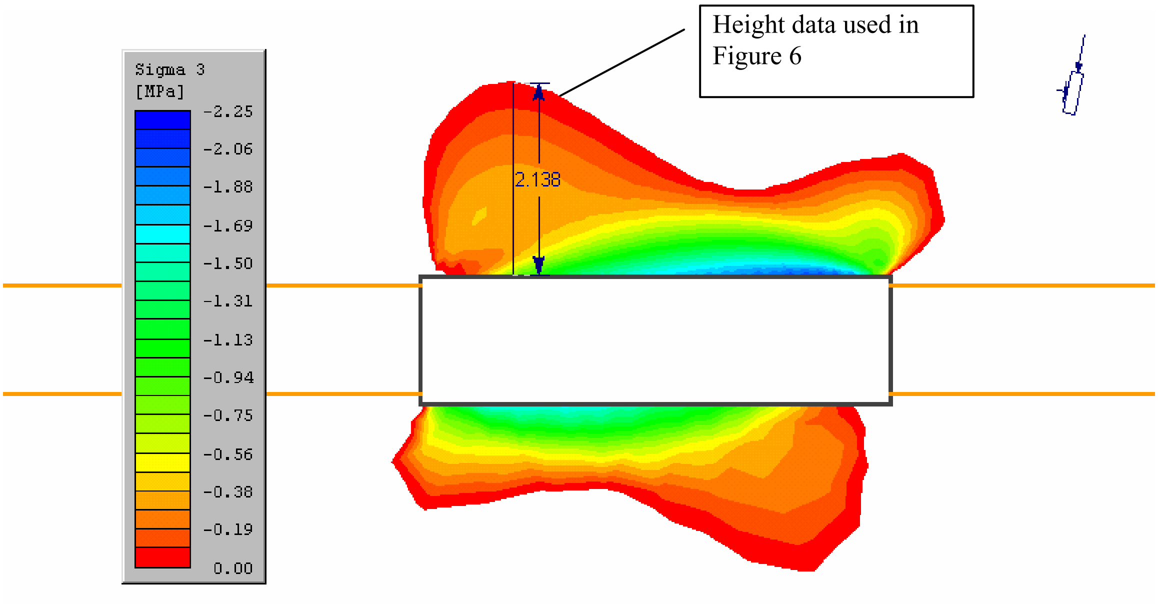


FIG. 5 - The zone of negative values of the minor principal stress developed around a rectangular opening exposed to an inclined stress field.

Figure 6 presents the height of the zone of negative minor principal stress in the roof of the roadways as a function of the ratio of the principal stresses and the alignment with respect to the vertical. There are no tensile zones developed if the major principal stress is aligned flatter than 50° from the vertical, and for steeper orientations the size of the tensile zone increases with increasing values of the stress ratio.

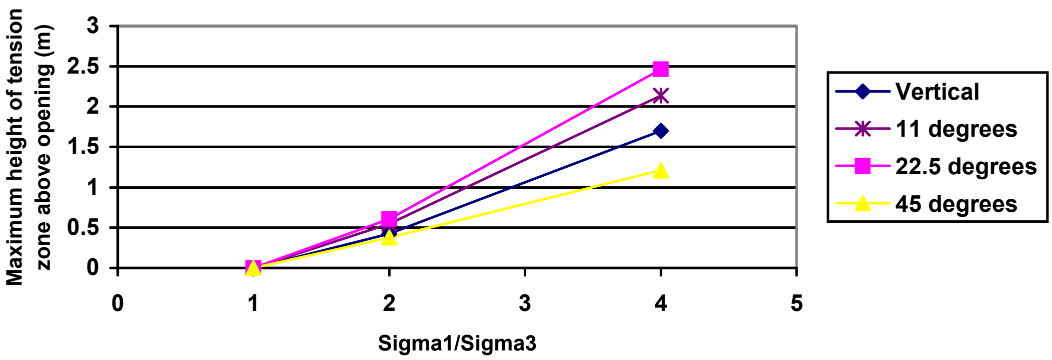


FIG. 6 - Results of finite element analysis of the height of negative minor principal stress as a function of stress ratio and inclination

Additional finite element modeling was conducted to identify where adverse stress field could develop in a layout similar to that used at Gibsons Colliery. The key requirements were found to be a low insitu horizontal stress field and elevated vertical stresses which can be expected in the vicinity of pillars. The low insitu horizontal stress is considered to be related to the proximity to the escarpment. An interesting result was obtained when the horizontal stress is 4MPa compared to a vertical stress of 5 MPa. Tensile zones develop under the goaf edge and extend up to the Bulli Seam. This is what is observed and also provides an explanation of water in the Balgownie seam workings. It is known that the Bulli workings are not submerged, but it is anticipated that water is present in the destressed floor of the goaf adjacent to the pillars (See Figure 2). When the Balgownie workings are formed, it is suggested that a low permeability connection via joints is made to the Bulli goaf floor.

FIG. 7 - Development of tensile conditions above a roadway located adjacent to the goaf edge

IMPLICATIONS TO MULTIPLE SEAM LONGWALLS

There is an extensive body of literature on multiple seam mining, particularly in the USA. Hsuing and Peng (1987) provide a useful summary of the mine design issues, although like much of the literature there is little reported on roof support implications. Hsiung and Peng refer to fracture zones (Zone H, Figure 8) that are present below goaf edges. It is not clear how such fracture zones would be developed in areas where there are increases in both vertical and horizontal stresses such that the deviatoric stress is relatively low – an alternative explanation has been developed. It is speculated that the reported fracture zones are areas of elevated high vertical abutment stress such that when a mine opening is made there are induced tensile zones in the roof. In Figure 9, the results of a finite element analysis are presented. In this model, a chain pillar is simulated as a traction applied to a rigid footing with a load equivalent to 20 MPa stress. Field stresses of 7.5 MPa vertical and 10 MPa horizontal were imposed on the model. The model is therefore representative of a standard longwall geometry at about 250 to 300m under typical Australian stress conditions.

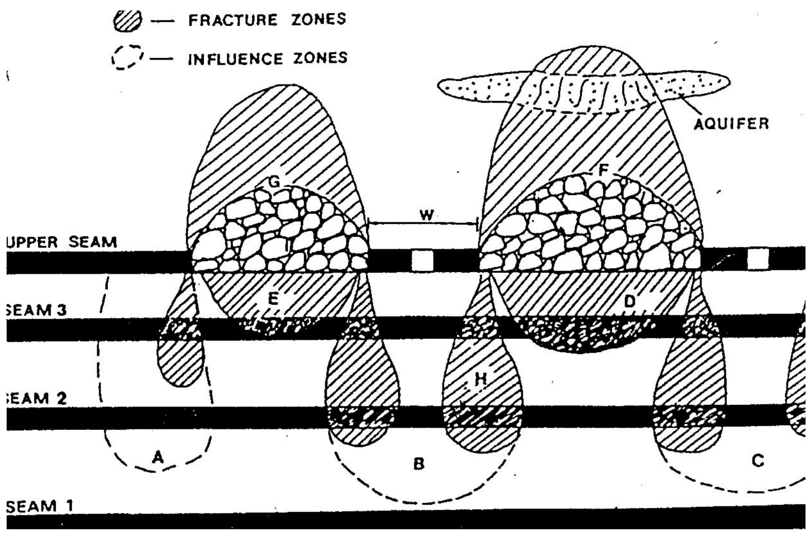
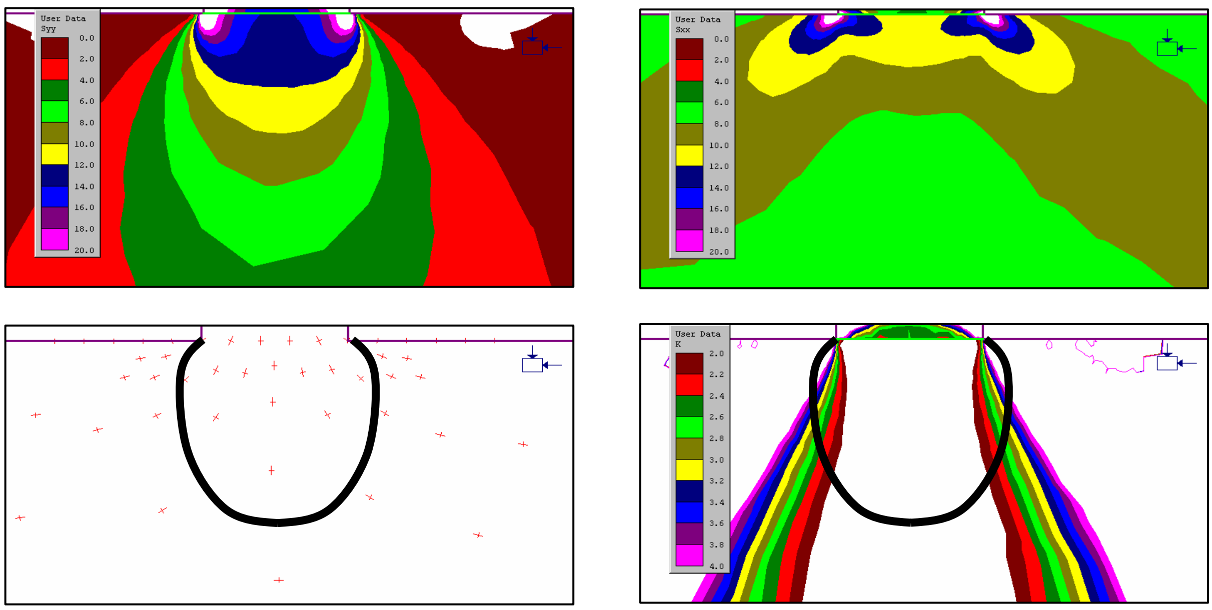


FIG. 8 - Interaction effects caused by longwall mining in the upper seam (Hsiung and Peng, 1987)

Figure 9a shows the distribution of vertical stresses where it can be seen that there is a concentration of stresses at the pillar edges, as is well known. In Figure 9b, there is a similar concentration of horizontal stresses at the pillar edges and zones of elevated stress oriented at about 40° to the horizontal. At an horizon located at ½ pillar width below the pillar, the maximum horizontal stress is in the order of 10 MPa, or an increase of 33%. Figure 9c presents the orientation of the major principal and minor principal stresses, with the black line enclosing the area in which the major stress is aligned at steeper than 45°. The line is also presented in Figure 9d which shows the distribution of K – the ratio of the major to minor principal stress. When Figure 9d is compared to Figure 6, it follows that the contoured areas inside the black line present the area where tensile stress conditions could develop around rectangular roadways with a width to height ratio of 3.7/1. Different zones would apply for different shaped roadways and for different imposed horizontal stresses. Note that there is a good correspondence between the zones in Figure 9d and Zone H in Figure 8.

9a **9b**



9c **9d**

FIG. 9 - Finite element analysis of stresses developed below a chain pillar

It is suggested that roof support in roadways in proximity to overlying chain pillars needs to consider both the possibility of the onset of elevated horizontal stresses and also the onset of tensile stresses. The horizontal stress increases are relatively low compared to typical rock strength so the support design can be based on resisting shear along bedding – vertical bolts would be appropriate. The onset of tensile stress conditions in the roof would lead to failure involving shear on vertical joints. Vertical bolts would not be appropriate in this case and a support regime based on 'slinging' the roof from ground above the ribs would be preferred as a massive sandstone roof with widely spaced joints as at Gibsons may not be present.

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REFERENCES

Hsiung SM and Peng SS 1987 Design Guidelines for Multiple-Seam Mining, Part II. Coal Mining, October, pp 48-50.