PARAMETERS AFFECTING THE SHIELD SUPPORT EFFICIENCY IN LONGWALL MINING

By

S.S. Peng, S.M. Haung, and Y.M. Jiang

ABSTRACT

The orientation and location of the hydraulic legs are two very important parameters for the design of shield supports in longwall mining. Studies have shown that leg orientations and locations of a support determine the magnitude, orientation and location of the resultant support resistance which in turn affects the efficiency of the support and the ability to prevent premature roof falls in the face area. Therefore, there is a need to determine the best combination of orientation and location of the hydraulic legs for each type of shield support under various geological conditions.

This paper attempts to evaluate, first, the individual role of each parameter (orientation or location) and then to determine their integrating functions in terms of ground control employing finite element analysis. Three types of shield support (2-leg and 4-leg shields and 4-leg chock shield) with various combination of the parameters are simulated and their effects are discussed. The optimum design for each parameter for each support type under various geological conditions is also discussed and recommended.

INTRODUCTION

The orientation and location of and resistance distribution in the front and rear legs of the 4-leg shields are important parameters in the design of shield supports in longwall mining. Studies (1-4) have shown that leg orientation and location of a support determine the magnitude, orientation and location of the resultant support resistance which in turn affect the efficiency of the support. In particular, they are very important parameters in weak roof condition, in which premature roof falls in the unsupported roof between canopy tip and faceline occur easily due to nature of rock or the existence of many weak planes, (i.e., fractures or joints) or both. Therefore, in selecting the support for weak immediate roof it is necessary to study the best combination of the orientation of and load distribution in the front and rear legs of the shield supports.

In this paper, each parameter for each type of support is simulated and its role is evaluated using finite element method. The optimum design for each parameter under the weak immediate roof condition is discussed and recommended.

FINITE ELEMENT MODELING

Fig. 1 shows a typical two-dimensional finite element mesh layout employed for this research. The model simulated a weak immediate roof condition after the first caving. A weak immediate roof is defined as those that cave immediately following support advancing.

The geological condition simulated was the Redstone seam with an overburden depth of 120 ft. Isoparametric quadrilateral membrane elements were used to simulate rock strata and the canopy and base plate of the shield support. Gap elements were used in the contact planes between the roof or floor and the supports. Because of the symmetry in the third dimension, only half of the support was simulated. The thickness in the third dimension was 2.5 ft. The legs, gob shield and lenticulate bars were simulated by bar elements. The location of the lenticulate bars and legs of the support both in the simulated plane and in the third dimension was accurately simulated according to the special features of the bar element provided by the MSC/NASTRAN (5). The end points of the bar elements were assumed to be hinge-jointed and only axial loading was allowed to be transmitted. The stiffness of the bar elements that simulated the hydraulic legs was approximated by calculating the ratio of the support load increment, which is the difference between the maximum support load attained in a mining cycle and the setting load, to the corresponding leg closure. The setting load was simulated by externally applying a force at each end point of the bar elements that
Fig. 1 Finite element mesh layout.
Fig. 1 Finite element mesh layout - Inset AA
represented the legs. The direction of the force coincided with the axial direction of the elements and pointed outward. The setting load for each leg of the 4-leg chock shield or the 4-leg shield was 100 tons and that for the 2-leg shield was 200 tons so that a total of 400 tons was applied. The mechanical properties of the rocks used in the model are listed in Table 1.

TYPES OF SHIELD SUPPORTS

Currently the following three types of memiscate shield supports are most commonly employed in the U.S. (Fig. 2) (4).

1. 4-leg chock-shield. All 4 legs are connected from the base plate to the canopy and mostly form a truncated V-shape.

2. 4-leg shield. The front 2 legs are connected from the base plate to the canopy while the rear 2 legs to the gob shield and form a truncated V-shape.

3. 2-leg shield. The legs are connected from the base plate to the canopy.

These three types of shield supports are analysed in this paper.

RESULTS AND DISCUSSIONS

Roof falls in unsupported areas are mainly due to tensile failure. Normally, the weak roof cannot sustain a tensile stress. Therefore, an important function that supports should provide in order to secure a better or a more stable roof condition is to prevent possible roof falls at the face. In order to prevent roof falls in the unsupported roof between the canopy tip and the faceline it requires the complete elimination of tensile horizontal stress in the area. To achieve this, the supports selected should have the ability to provide, when necessary, a horizontal resistance directed toward the face. If the supports do not provide such a resistance when needed, fractures along the faceline will initiate and enlarge continuously and may eventually lead to roof falls. For friable immediate roofs with numerous intrinsic fractures or joints, the optimum design of the parameters of the supports that are capable of providing a horizontal force is extremely important. The parameters include: (a) the relative magnitude of pressure in the rear and front legs, (b) the orientation of the hydraulic legs, and (c) type of powered support. These parameters affecting the supporting efficiency and effects of the shield will be discussed in detail in the following sections.

THE EFFECTS OF LOAD DISTRIBUTION IN THE REAR AND FRONT LEGS

In order to study the effects of load distribution in the rear and front legs, three cases are discussed for the 4-leg shield. Different loads were applied in the rear and front legs, but the total load of the support remained the same for all three cases, i.e. 400 tons. The load distributions in the hydraulic legs for the three cases are listed in Table 2.

Fig. 3 shows the vertical stress distribution on the canopy of the support for different load ratios of the rear to front legs. Curves 1, 2 and 3 represent the load ratios of 0.33, 1.0 and 3.0, respectively, with the load of the front leg being 300, 200 and 100 tons, respectively. It can be seen that the vertical stress distribution on the canopy is somewhat different for different load ratios. Analysis of Curve 1 shows that when the ratio is 0.33, the vertical stress distribution on the front portion of the canopy is the largest, and the horizontal force acts toward the face. As a result, there is no tensile stress in the immediate roof in unsupported area between the canopy tip and faceline and consequently the roof will be stable. Conversely, when the load in the front leg is smaller, the vertical stress distribution in the front portion of the support is also smaller (Curve 3), while the horizontal force acts toward the gob, resulting in tensile stress being developed in the roof of unsupported areas. This is the main reason for roof falls in unsupported areas.

Fig. 4 shows the change of the horizontal stress for the unsupported roof area with respect to the load ratio of the rear to front legs. When the load ratio increases, the stress in the unsupported area will change from compressive to tensile stress. In other words, the stress in the unsupported area will change from compression to tension when the front leg load continues to decrease. When the ratio is 1.0, that is, the magnitude of the front and rear leg loads is the same, there is only a small compressive stress in the unsupported roof area. After that, as the ratio decreases further, the stress will become tensile and the unsupported roof area is unstable. This situation must be prevented in designing the parameters of the powered support under the weak roof condition. Therefore, a smaller load ratio, i.e., the rated load of the front leg is larger than that of the rear leg, is preferred for the weak roof condition. From Fig. 4, it can be seen that it is preferable to design the load ratio of the rear to front leg from 0 to 1.0 under weak roof condition. If a stronger immediate roof exists, a larger load ratio could be used. Because roof falls in unsupported area is no longer the main problem for design consideration. It must be noted that if the rear leg load is much smaller than the front
Table 1. Rock Properties Used in the Finite Element Modeling

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Young's Modulus x 10⁴ MN/m²</th>
<th>Poisson's Ratio</th>
<th>Unit Weight (KN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray (red) Shale</td>
<td>0.76</td>
<td>0.19</td>
<td>24.6</td>
</tr>
<tr>
<td>Dark Shale</td>
<td>0.48</td>
<td>0.14</td>
<td>24.6</td>
</tr>
<tr>
<td>Coal</td>
<td>0.82</td>
<td>0.44</td>
<td>12.3</td>
</tr>
<tr>
<td>Sandyshale (roof)</td>
<td>4.66</td>
<td>0.29</td>
<td>24.6</td>
</tr>
<tr>
<td>Sandyshale (floor)</td>
<td>4.66</td>
<td>0.34</td>
<td>24.6</td>
</tr>
<tr>
<td>Sandstone</td>
<td>1.78</td>
<td>0.20</td>
<td>24.6</td>
</tr>
<tr>
<td>Soil</td>
<td>2.07</td>
<td>0.43</td>
<td>24.6</td>
</tr>
</tbody>
</table>

Fig. 2 Three types of shield supports simulated in the finite element modeling.
Table 2. Load Distribution in the Hydraulic Legs for the Three Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Load (tons)</th>
<th>Load Ratio$^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rear Leg</td>
<td>Front Leg</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>100</td>
</tr>
</tbody>
</table>

$^*$Ratio of the rear- to front-leg loads

Fig. 3 Vertical stress distributions due to various load ratios of rear to front legs.

The AusIMM Illawarra Branch, 21st Century Higher Production Coal Mining Systems—Their Implications, Wollongong, NSW, April 1988

127.
Fig. 4 Magnitude and type of horizontal stress.
Fig. 5 Comparison of stress distributions on canopy between 4-leg shield and 4-leg chock shield supports.

Fig. 6 Comparison of the supporting effects for different orientations of the front legs of the 4-leg chock shield. Load Ratio, R = 1.
Fig. 7(a) Horizontal stress contour in the roof when $\alpha = 90^\circ$ and $R = 1$.

Fig. 7(b) Horizontal stress contour in the roof when $\alpha = 51.3^\circ$ and $R = 1$.

The AusIMM Illawarra Branch, 21st Century Higher Production Coal Mining Systems—Their Implications, Wollongong, NSW, April 1988

131.
S.S. Peng, S.M. Hsiung and Y.M. Jiang

Fig. 8 Horizontal stress in unsupported area changes with the orientation of the front legs when setting load is 400 tons.

Fig. 9 Graph for determining the maximum allowable orientation of the front legs.
THE EFFECTS OF THE REAR HYDRAULIC LEGS

Under a thick weak immediate roof, the roof above the rear edge of the shield is often broken and caves prematurely (Fig. 10). Once the rear legs are set the rear edge of the canopy can not maintain a full contact with the roof. Under this condition, the setting of the rear legs will affect the supporting effects of the front portion of the support.

Fig. 11 shows the stress distribution of the canopy under three roof conditions, each of which shows a different width of roof caving above the rear portion of the canopy. The caving width (L) in Fig. 10 of the three conditions are 0, 1.5 and 3.0 ft respectively. When the roof caving width at the rear edge is very large, the stress distribution on the front portion of the canopy is very small. Sometimes, the front portion of the canopy can not maintain contact with the roof because the rear edge of the canopy is tilled up while the front edge down. Consequently, the unsupported roof span will increase, resulting in large tensile stress in the unsupported roof areas. The remedial measure is to select proper support type that will prevent its occurrence.

Curve 2 in Fig. 12 shows the stress distribution on the canopy of the 2-leg shields. A large stress distribution occurs at the rear portion of the canopy. There is no tensile stress but a larger compressive stress zone in the unsupported roof area. As discussed previously, if the roof caving at the rear edge is large, it will greatly affect the stress distribution on the front portion of the canopy for the 4-leg shock shields. However, the situation will be quite different for the 2-leg shield supports. Curve 2 in Fig. 12 shows the stress distribution on the canopy when a large roof caving width occurs at the rear edge of the 2-leg shield. Comparing Curves 1 and 2, it can be seen that there is no large difference in the stress distribution under the two conditions when the 2-leg shields are used. Therefore, when roof fall or roof caving is very severe at the rear edge of the canopy, it is better to select the 2-leg shield.

CONCLUSION

1. The orientation of the hydraulic legs and load distribution in the rear and front legs are two very important parameters for the design of shield support in longwall mining. These parameters directly affect the roof stability in unsupported area between the canopy tip and face. Under a weak immediate roof condition, the major purpose for designing support parameters and selecting support type is to eliminate the tensile stress zone in unsupported area.

2. The orientation of the hydraulic legs directly affect the roof stability in unsupported area, especially, the orientation of the front legs. When the angle of leg inclination from the horizontal decreases to smaller angles the tensile stress in unsupported roof area will be reduced and eventually eliminated, but the supporting efficiency will decrease with decrease in the leg inclination. Based on this consideration, the orientation of the hydraulic legs should be designed from 60° to 85° under a weak immediate roof. The optimum angle of leg inclination must also consider the setting load and load ratio.

3. Under a weak roof condition, the front leg load should be larger than the rear leg load. This way there will be no tensile stress zone in the unsupported roof area. In general, the load ratio of the rear leg to the front leg must be in the range of 0-1.0. If roof caving above the rear edge of the canopy is very severe, the 2-leg shields should be used rather than the 4-leg shields or shock shields.

REFERENCES


The Aust/IMM Illawarra Branch, 21st Century Higher Production Coal Mining Systems—Their Implications, Wollongong, NSW, April 1990
Fig. 10 The supporting effects for the 4-leg shield support under weak roof condition.

Fig. 11 Comparison of the supporting effects for different roof caving widths at the rear edge of the support when employing 4-leg shield supports

The AusIMM Illawarra Branch, 21st Century Higher Production Coal Mining Systems—Their Implications, Wollongong, NSW, April 1988

134.
Fig. 12 Comparison of the supporting effects for different roof caving widths at the rear edge of the support when employing Z-leg shields.