STRUCTURE OF THE ROOF AT THE END OF LONGWALL FACE AND ITS SUPPORT

By
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ABSTRACT

Two ends of a longwall face are not only concentrated locations of equipment, but also provide ventilation and access. The roof strata stability here has an important influence on mining coal and safety. Based on field observations in the gateways at Zaozhuang Colliery (Shandong Province) and model tests, the author developed a structural model of the overlying strata at the ends of the longwall face — the arc triangular cantilever plate — to which the elastic theory of plates can be applied. Factors influencing the stability of the cantilever plate and its breaking characteristics are discussed. Requirements and design parameters for supports at face ends are proposed, based on these factors.

INTRODUCTION

Control of stresses associated with, and induced by longwall mining, has been a main subject studied by mining researchers and engineers. These studies include exploring the behaviour of overlying strata, finding out the factors influencing stability of the immediate roof and determining the support principle and methods. These studies were required to assist in establishing guidelines for the design and manufacture of face supports. In China some excellent achievements concerning these aspects have been made, for example, an interlocked blockbeam structure model of overlying strata of the longwall face (Ming Gao, 1982), and the calculation and prediction of the roof weighting (Song Yang et al, 1984). The load deformation behaviour of roof strata at the ends of a longwall face has rarely been discussed. It is noted, however, that at these areas roof strata are normally characterised by irregular features as a result of special boundary conditions and support practice. For these reasons it is necessary to explore the roof structure and stability at the face ends through field investigations where typical roof conditions prevail.

GEOLGICAL AND MINING CONDITIONS

Observations were made in seams No. 14, No. 16 and No. 18 at Zaozhuang Colliery. The representative geological sections in the vicinity of the coal seams are shown in Figure 1. Limestone No. 8, No. 10 and limenudstone are the main roof strata at the face. The mechanical properties of these strata are listed in Table 1.

Fig. 1.

TABLE 1

<table>
<thead>
<tr>
<th>Strata</th>
<th>Density 10^3 kN/m^3</th>
<th>Compressive strength 10^8 kN/m^2</th>
<th>Tensile strength 10^7 kN/m^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>limestone No. 8</td>
<td>2.73</td>
<td>874</td>
<td>32.6</td>
</tr>
<tr>
<td>limestone No. 10</td>
<td>2.69</td>
<td>587</td>
<td>28.2</td>
</tr>
<tr>
<td>limenudstone</td>
<td>2.36</td>
<td>352</td>
<td>24.5</td>
</tr>
<tr>
<td>Immediate roof of seam No. 14</td>
<td>2.32</td>
<td>101</td>
<td>6.9</td>
</tr>
</tbody>
</table>

The investigations were conducted at the faces No. 4232 in the coal seams No. 14, No. 6205 in No. 16 seam and No. 8118 in No. 18 seam, all of which were mined with the longwall retreatting method. The gateways were maintained in the retreated goaf and during the whole period of maintenance of these gateways, the roof-to-floor convergence was measured. Convergence noted was the result of roof sagging.

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ANALYSIS OF ROOF CONVERGENCE IN GATEWAYS

Fig. 2. Convergence rates measured in gateway No. 6205.

In Fig. 2 roof convergence is plotted in relation to distance from the active longwall face. The convergence rate curve shows regular variation with a peak area occurring outbye in advance of the working face. The peak convergence rates and their locations were measured at each observation point and are shown in Figure 3. From this, the following conclusions can be derived:

1. The statistical distribution of peak roof sagging rates in a gateway is normal. For example, distribution of the peak rates observed in gateway No. 6205 is

\[
f(v) = \frac{1}{2 \pi \sigma} e^{-\frac{(v-\mu)^2}{2\sigma^2}}
\]

where \( v = \) peak rates, mm/day

\( \sigma = 7.35 \)

2. Different roof conditions produce a different set of results (as shown in Table 2).

TABLE 2

<table>
<thead>
<tr>
<th>Gateway</th>
<th>No. 6205</th>
<th>No. 4232</th>
<th>No. 8118</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak rate</td>
<td>12.66</td>
<td>9.94</td>
<td>12.01</td>
</tr>
<tr>
<td>±</td>
<td>±5.36</td>
<td>±3.54</td>
<td>±4.20</td>
</tr>
<tr>
<td>Peak rate location</td>
<td>17.15</td>
<td>12.89</td>
<td>10.20</td>
</tr>
<tr>
<td>Observed behind face (m)</td>
<td>±10.65</td>
<td>±8.59</td>
<td>±31.73</td>
</tr>
<tr>
<td>Span limit calculated from face (m)</td>
<td>1st 8.30-11.30</td>
<td>8.29</td>
<td></td>
</tr>
<tr>
<td>2nd 17.70-19.50</td>
<td>31.80</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The author considers that the peak roof sagging rates are caused by roof breaking at this location. Thus the roof breaking pattern and its probable structure at the ends of longwall face can be derived by analysing these peak rates.

ARC TRIANGULAR CANTILEVER PLATE STRUCTURE

Figure 4 shows the roof situation at the ends of the longwall face, which were observed at Zhangji Colliery (Shanxi coal mine). The figure indicates the formation of an arc triangular cantilever plate in the roof strata at the end of longwall face.

Fig. 4. Roof situation observed in Zhangji Colliery.

Figure 5 shows the test model which confirms the existence of the roof structure as mentioned above.

The cantilever plate phenomenon develops in the following way:

1. On the basis of elastic theory of plates we can calculate the maximum bending moments in rectangular roof beams under given boundary conditions, as shown in Table 3.

2. If the roof strata is broken by stretching,
the maximum bending moment is
\[ M_{\text{max}} = \frac{5}{6}H^2 \]
where \( H \) = tensile strength (kN/m²)
and \( H \) = thickness of the roof strata (m).

Fig. 5. A result of model tests.

1. Based on the equations in Table 3 and formula (1) the span limits of the roof beam are also given in Table 3.

According to Table 3 it can be deduced that the roof breaking during longwall mining involves the following process:

1. When the span between the set-up entry (CD) and the face line (AB) is equal to \( L_{\text{max}} \) roof strata breaks at the centre of AB and that of CD, followed by an expansion of the breaks. With the expanding of the cracks the boundary conditions of the beam is changed from a. to b., Table 3, and therefore other breaks form at the centre of the plate or at the centre of the fixed ends (AD, BC) and expand outward, Figure 6.

3. Owing to the angular effect which results from the perpendicular clamped sides, the breaking finally takes the shape as shown in Figure 7 and the arc triangular cantilever plate at the face end is thereby formed.

Fig. 6. The broken plate

Fig. 7. Arc triangular cantilever plate

4. With the face advancing, the cantilever plate breaks at two locations E and D, Table 3c; where the bending moments are at the maximum.

Table 3

<table>
<thead>
<tr>
<th>Boundary Condition</th>
<th>Maximum Bending</th>
<th>Span Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b &gt; 5L_1 )</td>
<td>( M_{\text{max}} = 0.0833Kr - H_{-}L_1^2 )</td>
<td>( L_{\text{max}} = \sqrt{H/S_{0.5} - Kr} )</td>
</tr>
<tr>
<td>( b &gt; 5L_2 )</td>
<td>( M_{2\text{max}} = 0.125Kr - H_{-}L_2^2 )</td>
<td>( L_{2\text{max}} = \sqrt{H/S_{0.75} - Kr} )</td>
</tr>
<tr>
<td>( b = L_3 )</td>
<td>( M_{3\text{max}} = 0.252Kr + H_{+}L_3^2 )</td>
<td>( L_{3\text{max}} = \sqrt{H/S_{1.15} + Kr} )</td>
</tr>
</tbody>
</table>

The symbols are:
- \( r \): density, \( \text{kn/m}^3 \)
- \( H \): thickness, \( \text{m} \)
- \( S \): tensile strength, \( \text{kn/m}^2 \)
- \( K \): load coefficient

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then the breaks expand along the principal arc stress line of the plate, causing the plate to move forward.

EXAMPLE CALCULATIONS

Using the above analysis, the locations of the roof strata breaks above the seams No. 14, No. 16 and No. 18 at Zaozhuang Colliery can be calculated, for example:

From the field observations it is noted that limestone No. 10 above the seam No. 16 falls in slices, the first falling slice is 1-2m in thickness, the second is 4.5-5.5m, thus the calculation must be performed separately for each slice.

From Tables 1 and 3 we have:

\[ L_1 \max = \sqrt{H_k / 0.55} \cdot K \cdot r \]
\[ = (14.5-20.5) / \sqrt{K} \text{ (m)} \]
\[ L_1 \max = (30.4-34.0) / \sqrt{K} \text{ (m)} \]

where \( H' \) = the first falling thickness, \( m \)
\( H \) = the second falling thickness, \( m \)
\( r \) = density, \( \text{KN/m}^3 \)
\( K \) = load coefficient, \( K > 1 \)

and \( L_3 \max = \sqrt{H'' / 1.51} \cdot K \cdot r \)
\[ = (8.33-11.8) / \sqrt{K} \text{ (m)} \]
\[ L_3 \max = (17.3-19.5) / \sqrt{K} \text{ (m)} \]

where \( K = 1 \)

\[ L_1 \max = 14.5-20.5 \text{ m} \]
\[ L_1 \max = 30.7-34.0 \text{ m} \]
\[ L_3 \max = 8.33-11.8 \text{ m} \]
\[ L_3 \max = 17.3-19.5 \text{ m} \]

From these results it can be seen that the span of the first fall (\( L_1 \max \)) of the roof strata over seam No. 16 is 14.5-20.5 and the first weighting interval (\( L_1 \max ) is 30.7-34.0m.

These values are close to those observed at face No. 6205, which were about 12.3 and 26.7m.

The span of the first break of the arc triangular cantilever plate is 8.33-11.8m behind the face line, and the second one is some 17.3-19.5m inbye the face line. The peak rate area observed in the gateway No. 6205 was located at 17.15m from the face. This proved that the peak sagging rate was caused by roof strata breaking, and under such condition the second break has stronger effect than that of the first one.

The values calculated and the results observed in the gateways No. 4232 and No. 8118 are shown in Table 3 and a similar conclusion to that as above can be derived.

CONDITIONS FORMING THE ARC TRIANGULAR CANTILEVER PLATE AND FACTORS INFLUENCING STABILITY

1. Conditions

When the roof at the face end is fixed-ended on the two adjacent sides, the arc cantilever plate may be formed with suitable stratified thickness having tensile strength. If \( L_3 \max =5\text{m} \) is taken as a standard, the following conditions must be satisfied:

\[ S \cdot H > 37.75 \cdot r \cdot k \]

where \( K = 1 \)
\[ r = 25\text{KN/m}^3 \]
\[ S \cdot H > 946 \text{KN/m}^3 \]

Under normal conditions the immediate roof can not form the cantilever plates, but the main roof can. This can be confirmed by using the data of the immediate roof and main roof (limestone No. 8) of seam No. 14.

**immediate roof**

\[ S \cdot H = 759 > 946 \text{KN/m}^3 \]

**main roof**

\[ S \cdot H = 6520 > 946 \text{KN/m}^3 \]

Where there is only one fixed side, the longwall end roof breaks along the fixed side and a cantilever plate is not easy to form there. This boundary condition usually exists when the chain pillar is small. For example, (Figure 8) the peak rate area of the tail entry which was protected by a small pillar is larger than that of the main entry protected by large pillar.

Fig. 8. Subsidence rates measured in gateway No. 12112 at Pingdingshan Colliery No. 10.

2. Factors influencing the stability of the cantilever plate:

(a) Thickness and tensile strength.

The thicker the slice and the higher the tensile strength, the more stable the cantilever plate becomes. For example, the limestone No. 10 showed a greater variation in thickness than limestone No. 8, thus the area affected by the maximum rate of roof deformation is larger in the gateway No. 6205 (622) than that in the gateway No. 4232 (352).

(b) Boundary conditions.

When the boundary conditions of a cantilever plate change, such as from fixed to simple supported edges, the cantilever plate may fail. Therefore the strength and stability of the pillar in the abutment zone are important factors influencing face end stability.

In addition, a cantilever of higher horizon can be supported by goaf and its stability is
increased.
(c) Roof weighting at the face.
The peak rates and distances measured in the excavation during the period of roof weighting at the face No. 6205 are shown in Table 4. The mean values are: 18mm/day and 18.5m from the face line as compared with values in Table 3. It can be seen that the roof weighting has very little influence on the stability of the cantilever plate.

**TABLE 4**

<table>
<thead>
<tr>
<th>the day of</th>
<th>peak rate</th>
<th>location from face m</th>
</tr>
</thead>
<tbody>
<tr>
<td>23-25/4</td>
<td>10.07</td>
<td>10.5</td>
</tr>
<tr>
<td>3-5/5</td>
<td>12.3</td>
<td>22</td>
</tr>
<tr>
<td>15-17/5</td>
<td>12.05</td>
<td>23</td>
</tr>
<tr>
<td>mean value</td>
<td>18.14</td>
<td>18.5</td>
</tr>
</tbody>
</table>

(d) Supports at the face end.

At Tangshuang Colliery, the support resistance at the end of the face No. 611 was measured by the author. It is found that when the resistance increased from 2600kN/m² to 4000kN/m², the peak rate decreased from 58mm/day to 27mm/day, and the peak location moved from 13m to 25m inbye the face line indicating that, by increasing the period of roof weighting, a better control of strata behaviour can be achieved. (Zhu De Ren, 1982).
(e) Inherent cracks in the roof.

The inherent and mining induced cracks in the roof, such as fissures and cleats, can change the breaking location and direction of the cantilever plate. For example, at a position more than 32m from the set-up entry a cantilever strip was formed in the roof due to the presence of the original fissures (Figure 4). The most important thing is that the cantilever plate may suddenly fall by the initiation of these breaks. This fissured structure of the roof cantilever plate can be a cause of sudden and hazardous roof failure.

**ROOF PRESSURE BEHAVIOUR AND SUPPORT AT THE FACE END**

1. Roof behaviour

The breaking pattern of the arc triangular cantilever plate at the end of the longwall face is different from that of the roof beam at the longwall centre. The beam breaking is a periodical instability rebalance process which causes periodic weighting, whereas the breaking of cantilever plate starts at both ends of the arc shape and a beam expands along the principal arc stress line. This makes the cantilever plate move forward continuously with new periodic weightings occurring at the end. Under the protection of the cantilever plate stability at the face end is better than that at the centre, but the portion of the gateway inbye the face is difficult to maintain.

In addition, when the cantilever plate can not be formed or is destroyed, the roof fall at the end may occur immediately.

2. Face end support

The face end support is expected to satisfy the following requirements:
(i) Support the roof strata which can not form the cantilever plate structure;
(ii) Give certain resistance to the roof strata which can form the structure;
(iii) Provide bearing capacity against the load and dynamic pressure of the roof strata which can form the structure but are not stable.

For this reason, the parameters of the roof end support should be:
(a) Support resistance

\[ P = \gamma \cdot H^k \cdot k \cdot r \cdot H \]

where \( r \), \( H \) are the density and thickness of the cantilever plates, \( r' \), \( H' \) are those of the strata under the plates, \( k \) is a coefficient, 2-4. For example, the end support resistance of No. 4232 is

\[ P = 23.2 \cdot 2.5 + 3.2 \cdot 3.3 = 308 \text{ kN/m}^2 \]

(b) Stability and yieldability

When the cantilever plate suddenly falls in an uncontrollable fashion, the end support may collapse and seriously deform, thus a higher capacity for the end supports is required.

(c) Setting resistance and resistance increasing properties are important factors in ensuring roof stability at the ends of the longwall face.

**CONCLUSION**

Based on the observations and model tests the author developed a roof structure model - the arc triangular cantilever plate.

As the longwall face advances, the cantilever plate breaks regularly and moves forward to the wash. With the self supporting ability of this structure, roof stability at the face end is moderate and differs from that at the centre. Where the cantilever roof strata condition can not be achieved, premature failure can occur and roof caving in the face will be unpredictable and difficult to control with subsequent maintenance problems in the gate roads.

Face end supports must be able to sustain the detached neither roof which separates from the main roof rock mass and the dynamic impact load caused by the failure of the unstable cantilever plate. Therefore higher setting resistance and design factors to enhance resistance are needed to ensure roof support strength and stability at the face end. For this reason, special hydraulic supports must be required at the end of the longwall face.

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