Review and interpretation of intersection stability in deep underground based on numerical analysis

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ABSTRACT: This paper conducted a preliminary study on the stability of roadway intersection in deep underground conditions on the basis of the underground observations and numerical modeling. Firstly, according to the intersections used in current coal mines, five different geometrical shapes of two-dimensional intersections are selected and modeled under deep ground condition. It is noted that the cross-intersection is the most unstable two dimensional intersection currently used in coal mines. Also, the depth of cover is one of important factors for this investigation, which clearly indicated that the stability of the intersection is threatened seriously when the depth of cover reached at 1000 m or more below the surface. In addition, the construction sequence and direction for the cross-intersection is studied. It is believed that the construction sequence and direction are sensitive factors for the stability of two dimensional cross-intersection. It is suggested that the formation of the cross-intersection should be conducted one side by another individually, even this kind of construction sequence will cause twice stress concentration and redistribution, it is still less influence on the stability of intersection comparing with other construction methods selected.

1 INTRODUCTION

From the statistical data, it is noted that the roof failure mainly occurred around the large span of underground opening, and the situation is getting worth, when the complex geometrical structures and deep mining conditions are encountered. This paper is describes the stability and failure characteristics of intersection on the basis of literature review and study of the stability and failure behaviour of different geometrical structure of intersection, which commonly used in underground of coal mine in China, associated with various depths of cover using numerical simulation.

It is noted that the geometrical shapes used in China coal mining industry is much complex, comparing with major coal mining countries in overseas, such as Australia and USA. With increasing the depth of cover, it is susceptible to ground control problems due to the complex geometries of underground structure.

2 PREVIOUS INVESTIGATION ON UNDERGROUND INTERSECTION IN COAL MINES

Stability of underground intersection had been paid attention previously, even in the shallow condition. The investigations had been conducted to study the structural characteristics, stability and failure behaviour in the shallow condition by former US Bureau of Mine (Hanna, 1991).

In 1976, Balachandra studied the stability of intersection using underground monitoring and computer simulation.

The department of mining engineering from West Virginia University studied the stability of three-way intersection with different geometrical parameters, and it found that the tensile stress is the main reason to cause the failure of the intersection. Comparatively, the three-way intersection is more likely having shear failure than the cross intersection. It is concluded that the tensile and shear failure on the roof strata increased with the reducing of angle between two roadways (Peng, 1978).

The department of mining engineering from University of Wollongong also studied the stability of the T-intersection (Singh, 2001). Based on the numerical modeling and underground monitoring, it indicated that the depth of cover, horizontal stress and geometrical parameter are three major factors which significantly influence the stability of T-intersection. It also indicated that the stresses induced during intersection formation may result in high incidence of roof and rib failures.
In China, the depth of cover in coal mine is increasing 8–12 m annually, and there are many collieries going to face deep mining situation, with depth of cover around 1000–1500 m. With increasing of the depth of cover, the stress regime and deformation characteristics of roadway is changed significantly, it resulted in failure and difficult to ground control. Also, construction condition is getting worse than shallow conditions (Jin and Sun, 2001). Under such situation, the stability of intersection is facing more serious problem during the deep mining.

The depth of cover is a sensitive factor to the ground control. For example, the ground problem was occurred when the depth of cover was changed from 550 m to over 600 m below the surface in Xiezhuang colliery, Shandong. Previously, the stability of intersection can be maintained by using steel frame when the depth of cover less than 600 m, but when the depth of cover reached over 800 m, ground control around intersection became a major problem, due to: 1) the soft rock characteristics of surrounding rock mass was encountered and the mechanical properties was getting worse; 2) the capacity of reinforcing element was reduced significantly; 3) the plastic zone around intersection increased significantly, 4) roof separation was formed significantly and it is considered as a major factor to cause the stability of intersection (Wang, 2001).

The further study on two way intersection indicated that, in deep underground (700–900 m), the angle of intersection is not a major factor to influence the plastic zone around intersection, but when the angle is less than 35 degree, the reinforcing area is increased significantly with decreasing of the angle. It is, therefore, suggested that the angle between two roadways should not be less than 35 degree for the designation of intersection (Zhu and Cao, 2005).

On the other hand, many ground control problem related to intersection are not affected by single factor, but combination phenomenon, which involved roof stress, physical properties of mudstone, reinforcement technique and parameters used are not suitable for such underground environment (He, et al, 2005).

3 MODELING OF INTERSECTION STABILITY

The modeling was conducted by using FLAC3D with three dimensional and non-linear simulations. The numerical model used for the analysis is presented in Figure 1, hard rock to soft rock, the mechanical properties are given in Table 1.

3.1 Effect of geometries on stability of intersection

There are large number of roadway intersections are constructed annually in China coal mines industry with various geometries, including three-way intersection, four-way intersection, two dimensional roadway intersection (Figure 2a,b,c) and three dimensional roadway intersection (Figure 2d,e) and geological conditions, e.g. strong rock mass and soft rock mass. With increasing of the mining depth, the stability of these roadway intersections is susceptible to ground control problems due to inherently wide roof spans and complicated intersection geometry used.

The study conducted in this section is to clarify the effect of the geometrical shapes on the stability of intersection. To do so, the depth of cover is determined as 800 m, and the two dimensional intersections with five different geometrical shapes, plus one normal single roadway are compared as:
- Cross intersection, with 90° angle between two roadways;
- X – intersection, similar with cross, but with 45° angle between two roadways;
- T – intersection;
- L – intersection;
- Y – intersection;
- Single roadway

The modeling was conducted to evaluate the stability behaviour of the intersection in terms of the roof and rib deformation and the failure depth into the rock mass with different shapes, on the basis of mechanical properties given in Table 1. The deformation and failure of the intersection have been compared with the normal single roadway, it is indicated that the simpler the geometry, the more stable the underground structures. The results also shown that the most unstable two-dimensional intersection is the cross-intersection (Figures 3 and 4).
Table 1. Mechanical parameters of rock mass.

<table>
<thead>
<tr>
<th>No</th>
<th>E (GPa)</th>
<th>µ</th>
<th>Modular of volume (GPa)</th>
<th>Modular of share (GPa)</th>
<th>Density (kg/m³)</th>
<th>Cohesion (MPa)</th>
<th>Angle of inter-friction (°)</th>
<th>Tensile Strength (MPa)</th>
<th>Residual Cohesion (MPa)</th>
<th>Residual angle of inter-friction(°)</th>
</tr>
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<tbody>
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<td>1</td>
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<td>2500</td>
<td>3.7</td>
<td>26</td>
<td>1.4</td>
<td>0</td>
<td>22</td>
</tr>
</tbody>
</table>

Figure 2. Main intersections used in Chinese coal industry.

Figure 3. Comparison of roof/rib deformation with different geometrical shapes.

Figure 4. Comparison of roof/rib failure with different geometrical shapes.

3.2 Effect of excavation sequence on the stability of intersection

Stresses induced during the intersection formation may result in high incidence of roof and rib failure (Singh, 2001), thus the construction sequence (procedure) may be another sensitive factor that influences the stability of intersection. As the indicated above, the cross-intersection is the most unstable two dimensional intersection, thus, the effect of the excavation sequence on stability of cross-intersection is studied accordingly.

Figure 5 shows the construction sequences of the cross-intersection, the sequences are designed as five different types of a, b, c, d, and e, which represent the sequences and directions of the construction. According to the modeling results, the minimum vertical stress and deformation have been found from the excavation sequence Nos. 1 and 2, and both represented similar construction sequence, that is, the roadways formed the intersection are developed at different time. It is indicated that even the stress state around opening are interrupted twice by using these developing sequences, but the each interruption is considered to be smaller comparing with other construction sequence proposed.

The developing direction is also sensitive to the stability of intersection. If the excavation is toward the existing opening (Figure 5e and Figures 6a&b), the significant affect on the stability of intersection is detached, and if the excavation direction is moving away from intersection (Figure 5b and Figures 6a&b), the affect is comparatively small (Figure 6).
Figure 6. Effect of construction sequences on stability of intersection.

Figure 7. Effect of depth of cover on stability of intersection.

4 SUMMARIES AND CONCLUSIONS

Due to inherently wide roof spans used, the stability of the roadway intersection was always paid attention by the researchers and engineers. Now, with continual increasing of the mining depth of cover, more and more serious stability problems, particularly related to the roadway intersection, will be faced in Chinese coal mines.

The study confirmed that the stability of the intersection could be maintained in the shallow condition, but when the depth of cover reached a certain level, such as over 1000 m below the surface, the stability of intersection is under the threat.

The geometry of the intersection is concerned, as comparatively the geometrical shapes used in China coal mining industry are relatively complicated, which results in much more wide roof span than normal heading roof. Comparing with six different types of the underground opening, it is noted that, under the similar conditions, the normal roadway has minimum displacement and failure than other intersections. It implies that the large roof span will cause more stability problem than small roof span. Also, comparing different geometrical shapes of the two-dimensional intersections, the most unstable one is the cross-intersection, which is the most comment intersection used in coal mines.

The construction sequences also influence the stability of the intersection during the excavation. To minimize the stress interruption to existing roadway during the intersection development, particularly for the cross-intersection, it is suggested that all the additional roadway construction should always move away from rather than forward to the intersection. In addition, the construction for additional roadway around the intersection should be conducted one side by another individually (Figure 5b), even this kind of construction sequence will cause twice stress concentration and redistribution, but it still is the less influence on the stability of intersection comparing other methods of the construction.

The depth of cover is recognized as the most important factor for the stability of underground openings. According to the modeling results, the stability of the intersection is not linearly related to the depth of cover, the significant effect only occurred when the depth of cover reached to 1000 m under typical surrounding rock mass conditions selected.

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REFERENCES


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