Stability Control of Surrounding Rock in Large-Section Weak- and Thick-Coal Open-cutting Roadway in Deep Mine

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Abstract: In view of the supporting problems in the large-section weak- and thick-coal open-cutting roadway in the deep coal mines, this paper adopts numerical simulation, theoretical analysis, and field measurement to study the deformation and failure law of the surrounding rock and explore corresponding control measures. The results show that: 1) The surrounding rock of open-cutting roadways is divided into a fracture-through zone, a fracture development zone, and a micro-fracture zone. When the width of the roadway is 12 m, the maximum height of the fracture-through zone is 2.6 m, and the two-side fracture zone is 1.1 m, and the height of fracture-through zone of the top plate is 1.5 m. 2) Considering the actual geological production conditions, this paper proposes the control measures combining high-strength bolt support, large-diameter anchor cable support, and single column reinforcement, and expounds its control mechanism. In addition, on-site industrial test verifies the rationality of the supporting plan.

1. Introduction
In recent years, with the large-scale promotion of full-height techniques, the large-section thick-coal open-cutting project has been more widely spread [1], with the width of the open-cut gradually increasing from 6 m to 8~10 m, even to 12~14 m. Abundant studies have shown that the large section and the weak and thick coal roof of the large-mining-height cutting roadway will inevitably make roadway support more difficult [2, 3]. First, poor physical and mechanical properties of the thick coal top make it easy to be affected by mining, leading to a wide range of primary cracks. Secondly, the increase of roadway width makes the plastic zone in the roof plate expand rapidly to the deep, and its stability is also greatly reduced [4]. Therefore, it is significant to conduct stability analysis of surrounding rocks of the large-section mining roadway and propose scientific and reasonable control measures for ensuring the safe production of coal mines. Domestic and foreign scholars have done a lot of research on the stability and control measures in this regard [5-7], providing a good reference for the stability control of surrounding rock in large-section open-cutting roadway. However, due to the fact that geological production conditions in coal mines are complicated and different in different coal mines, the corresponding evolution and control measures of stress and displacement of roadway are also significantly different [8].

This paper analyzes the evolution law of crack field in the large-section thick roadway, and designs scientific and reasonable support plans to be applied on site, by taking the large-section open-cutting roadway of 3301 working face of Guotun Mine, Heze, Linyi, Shandong Energy Mining Group as the
material (width×height = 11.9 m×4.3 m, arranged along the bottom), using theoretical analysis, field measurement, and numerical simulation. This paper delivers significant effect of surrounding rock control, making it of referential value in similar projects.

2. Numerical Simulation of Fracture Expansion of Large-Section Thick-Coal Roadway

2.1 Numerical model
Located in Heze City, Shandong Province, the 3301 working face of Guotun Coal Mine is about 1200 m, with the length of tendency of about 188 m and the down-hole elevation of 650m. It also adopts one-time full-height mining technique. In order to facilitate the transportation and installation of the equipment in the working face, this paper sets the open-cut to be 11 m wide, 4.3 m high and 47.3 m² in cross section, which belongs to the large-section roadway.

Influenced by excavation and unloading, the cracks in the surrounding rock continue to develop to the deep, which eventually leads to instability of the surrounding rock of the roadway. This paper adopts UDEC numerical simulation to simulate the evolution law of internal cracks in the surrounding rock. Based on the production geological conditions of the open-cutting roadway in the 3301 working face of Guotun Coal Mine, a numerical model is established as shown in Figure 1. The model is 60 m × 55 m (width × height), and the coal seam and the top and bottom plates are divided into 0.5 m × 0.5 m blocks. The bottom boundary of the model is fixed in the vertical direction, while the left and right boundaries are fixed in the horizontal direction. As for the material constitutive models, the strain softening model is adopted for the coal seam and the top and bottom plates, while the Mohr-Coulomb model with a lateral pressure coefficient of 1.0 is adopted in the rest. The simulation plan is to establish 7 numerical models of open-cut widths of 6 m, 7 m, 8 m, 9 m, 10 m, 11 m and 12 m with the fixed height of 4.3m.

![Fig.1 Model diagram](image)

2.2 Fracture field distribution
The UDEC numerical software can be used to determine the shape of the fracture based on the shear stress and the normal stress between the fractures. Based on that, different widths can be used to show the internal fracture network of the surrounding rock. The final fissure development state is as follows: a). The developmental state of the fissures of the surrounding rock of the open-cutting roadway can be divided into three zones: the fracture-through zone, the fracture development zone, and the micro-fracture zone; the primary fractures in the micro-fracture zone begin to expand, the single crack in the fracture development begins to expand sufficiently, and the single crack in the fractured-through
zone begins to cut, slip, and penetrate to form a larger one. b). The fractures in the top and bottom plate and the two sides are in the semi-elliptical shape. The fracture area in the top plate fissure is the largest, that in the bottom plate the second, and that in the two sides the smallest. c). When the roadway is 12 m wide, the top plate has the largest fracture density and crack opening volume, with the maximum height of the penetration zone of 2.6 m, the gap between the two fractures of 1.1 m, and the height of the roof fracture zone of 1.5m.

2.3 Deformation law of the surrounding rock
The surface displacement deformation of the roadway with different open-cut widths, which indicates:
 a. As the cut-off width increases, the deformation of the roof and the two sides increases proportionally. As it increases from 7 m to 12 m, the amount of roof subsidence increases from 94 mm to 380 mm, an increase of 3.04 times. The amount of deformation of the two sides increases from 83 mm to 198 mm, an increase of 1.39 times. b). As the cut-off width increases, the amount of deformation of the bottom plate is maintained between 76 mm and 84 mm. c). When the coal pillar width is fixed, the deformation of the roof is the largest, that of the two sides is the second, and that of the bottom plate the smallest. Therefore, support design should emphasize on the support of the roof.

3. Control strategies and key technologies
Based on the existing roadway supporting theories and technologies, it is necessary to increase the strength of the roof and the two sides using bolts, limit the development of the fracture-through zone, so as to improve its overall carrying capacity. It is also necessary to link the fracture-through zone, the fracture development zone, and the micro-fracture zone by using a large-diameter high-strength anchor cable, so as to ensure the integrity of the roof structure and improve the stability and shear resistance of the thick coal roof. In addition, the single column should be used to support the thick coal roof so as to reduce the roof span in disguise, thus reducing the difficulty of support. Only by taking the above measures can the stability control of the open-cutting roadway be achieved [9]. Therefore, this paper adopts the supporting measures combining high-strength bolt support, large-diameter anchor cable support, and single-column reinforcement.

3.1. High-strength anchors limit the development of shallow fractures
The shallow coal body of the deep mine with large section and thick coal will inevitably rupture, so it is important to use the high-strength bolt and apply the high preload in time to improve the mechanical properties of the shallow coal body, inhibit the development of cracks, and maintain the integrity of the coal body [10]. Considering the strength limitations of traditional round steel anchors and FRP anchors and the unreliability and low preload of anchoring, the top plate and both sides adopt high-strength threaded steel anchors of φ20 mm×2400 mm with a spacing of 900 mm × 900 mm and the preload lower than 200N-m, based on the existing economic and technical conditions and engineering experience of the mine. One roll of Z2360 and one roll of CK2335 are used for anchoring, and the Φ14 steel ladder beam connection is adopted in the same row so as to ensure the integrity of the supporting structure.

3.2. Large-diameter high-strength anchor cable enhances the integrity of the roof structure
It can be seen from the numerical simulation results that when the open-cut width is 12 m, the maximum height of the open-cutting fracture-through zone is 2.6 m, and the crack has developed to 6.6 m high. In this situation, the stability of the roof coal cannot be guaranteed by the anchor alone. Therefore, in addition to the high-strength bolt support, the top plate must be reinforced with high-strength anchor cables in order to form a large-scale anchor bearing structure connecting the shallow anchor with the deep one. [11]. Based on the actual engineering, this paper uses theφ21.8 mm×8300 mm anchor plate for roof reinforcement, with the spacing of 1800 mm×1800 mm and the preload of no less than 120 KN. One roll of Z2360 and one volume of CK2335 are used for anchoring, which are connected by theφ16mm steel ladder beam.
4. Industrial test

Based on fissures and deformation characteristics of the surrounding rock of the large-section open-cutting thick coal roof in the deep mine and the above control measures and specific geological production conditions, and uses it in the 3301 open-cutting tunnel.

During excavation, the surface displacement of the roadway is measured on site. The results show that the deformation of the top and bottom plates and the two sides gradually become stable after 35 days of excavation with the maximum deformation of 35 mm and 31 mm. After 60 days of excavation, the deformation of the coal pillars gradually becomes stable with the maximum deformation of 64 mm. Although the time for stabilization is long, the deformation amount is small, which satisfies the requirements of the roadway section.

5. Conclusion

1) The fractures in the surrounding rock of the open-cutting roadway can be divided into the fracture-through zone, the fracture development zone, and the micro-fracture zone. When the roadway is 12 m wide, the density and the opening of the crack are the largest in the middle of the roof. The maximum height of the fracture-through zone is 2.6 m, with the area of the fracture development zone of 1.1 m.

2) The large section, the high mining stress, and the low strength of coal body are the main factors influencing the stability of the large-section and thick roadway in the deep coal mine, among which the large section of roadway is the main one.

3) Engineering practice shows that the control measures combining high-strength bolt support, large-diameter anchor cable support, and single-column reinforcement can effectively control the deformation and damage of the surrounding rock.

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