

Numerical Simulation Analysis of Optimization of Peripheral Rock Section in Large Inclination Angle “Three Soft” Roadway

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Abstract: In order to solve the problem of asymmetric deformation and damage of the surrounding rock in the transport road of Yiluo Mine 35050, the paper adopts the numerical simulation method of FLAC 3D, and establishes the numerical simulation models of four kinds of large inclination angle “three soft” coal seams with different cross-section shapes (straight-wall arch, rectangle, pentagonal heteromorphism, and right-angled trapezium), and investigates the mechanism of deformation and damage of the four kinds of roadways under the mining of the “three soft” seams with large inclination angle through numerical simulation. Through numerical simulation, we studied the deformation and damage mechanism of the four kinds of cross-section shapes of the roadway under the mining of “three soft” coal seam. By comparing and contrasting the four different support sections under the same stress field and unsupported condition of excavation, the distribution law of stress, displacement and plastic zone of the roadway perimeter rock was studied, and the optimal support section was obtained. The study further reveals the asymmetric stress distribution characteristics and deformation damage law of the roadway surrounding rock in the large inclination angle “three soft” coal seam, and analyzes the dynamic evolution of its progressive asymmetric deformation damage.

Keywords: Large inclination; Roadway section optimization; Numerical simulation; Soft rock roadway.

1. Introduction

Due to the special geological conditions of “three soft” coal beds with large inclination angle, the local stress distribution is uneven, which leads to deformation and even destabilization of the surrounding rock in the local area, and the conventional section design is often unable to adequately adapt to this change, thus affecting the safety and construction progress of the overall roadway. This phenomenon of local stress concentration usually leads to the collapse, rupture and deformation of the rock surrounding the roadway, which brings great risks to the construction and operation. Based on the characteristics and geological features of “three soft” coal seams with large inclination angle, the roadway section design should be optimized to change the self-supporting capacity of surrounding rocks. Therefore, according to the specific geological conditions, it is necessary to adopt a more refined and targeted section design, in order to solve the problem that it is difficult to control the stability of the surrounding rock in the face of the local stress concentration of the ordinary section shape. By improving the shape of the roadway section, the local stress concentration of the surrounding rock can be reduced to a certain extent in the roadway of “three soft” coal bed with large inclination angle. In this chapter, numerical simulation software is used to establish four kinds of section shapes (right-angle trapezoidal, rectangular, straight wall arch, and pentagonal heteromorphism) which are more common in the engineering of large inclination angle “three soft” coal seams, and simulate the distribution of stress, deformation characteristics, and distribution of plastic zone of the roadway peripheral rock under the action of geostress when the roadway is unsupported after excavation to make a comprehensive comparison of advantages and disadvantages of the various sections, and then arrive at the optimal support section. In order to arrive at the optimal support section, many scholars

have optimized and changed the roadway section by means of optimization.

Numerous scholars have optimized and changed the shape of the roadway section to transfer and weaken the degree of local stress concentration in the surrounding rock, so as to achieve the deformation and damage control of the surrounding rock in the roadway.[1-6].

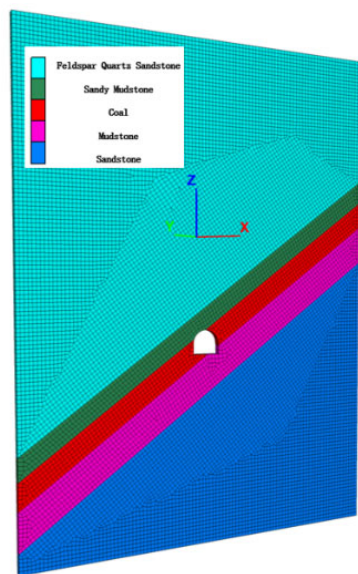
2. Computational Modeling

In this chapter, according to the geological profile of the roadway on the working face of Yiluo coal mine 35050, it is appropriately simplified, and FLAC 3D numerical simulation software is used to establish four kinds of models, and the numerical calculation model is shown in Fig. 1. Where the z-axis is the vertical direction, specified upward as positive, the top surface of the calculation model is the free boundary, the x-axis is the front face of the excavation of the roadway, and the y-axis is the direction of the excavation of the roadway, the side of the model adopts directional support to restrain its horizontal displacement, and the bottom of the model adopts fixed support to restrain its horizontal and vertical displacements, and the top surface of the model is the no-displacement constraint condition, and the loads are applied to it to simulate the gravity of the overburden rock layer. In the calculation process, the engineering geological conditions of the Yiluo mine area are simplified, and the coal rock layer is assumed to be a continuous medium and isotropic. An ideal elastic-plastic intrinsic model was chosen to describe the plastic behavior of the coal rock layer, and the Mohr-Coulomb criterion was adopted as the damage criterion of the coal rock body. Based on this model, the calculation and analysis of the stress, deformation and plastic zone of the surrounding rock of the roadway were carried out.

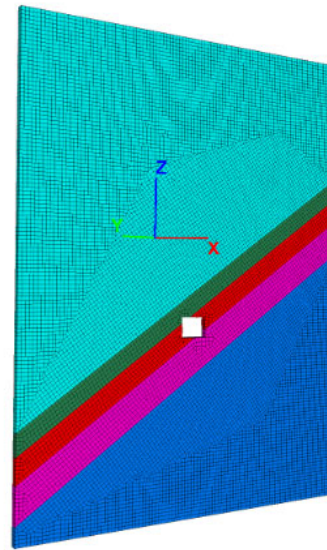
Because the length of the roadway is relatively long, it can be solved as a plane strain problem, according to the plane strain model of elastic mechanics, the axial depth of the

roadway is taken as 2 m. According to the principle of St. Venant of elastic mechanics, the width of the model is taken as 60 m. The height is 80 m, the thickness of the coal seam is 3.5 m. The origin of coordinates is located in the center of the roadway, and the roadway is dug along the bottom. According

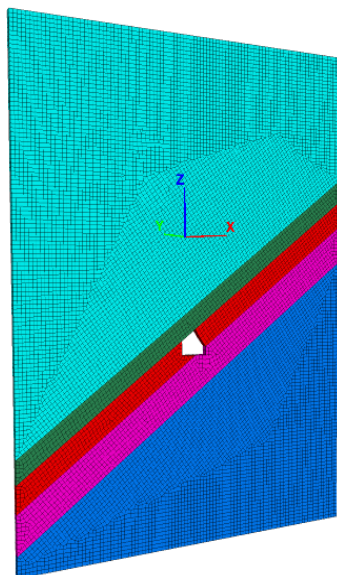
to the ground stress measurement of Yiluo coal mine, the initial horizontal stress of 12 MPa and vertical stress of 10 MPa were applied to the model, and the lateral pressure coefficient was 1.2.



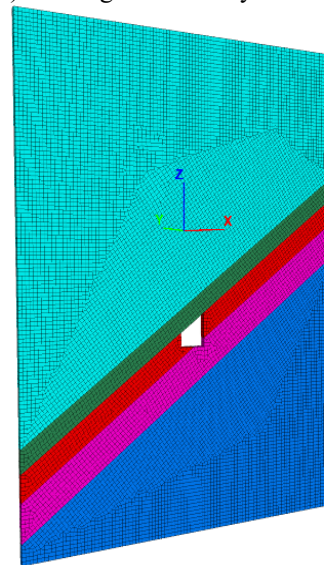
(a) Straight wall arch roadway section



(b) Rectangular roadway section



(c) Pentagonal shaped roadway section



(d) Right angle trapezoidal roadway section

Figure 1. Numerical modeling diagram for different inclination sections

FLAC 3D (Fast Lagrangian Analysis of Continua in 3 Dimensions) is a 3D numerical simulation software based on finite difference method, based on the finite difference method, with the ability of 3D modeling and dynamic simulation, which can be used to perform large deformation and nonlinear analysis. It is mainly used to analyze the behavior of geological and structural bodies in terms of statics, dynamics and thermodynamics. It has a wide range of applications in geology, mining, engineering and other fields, especially in the coal mining process, it is suitable for complex coal mining process, accurate simulation of roadway stability, mine disasters, etc. It is able to deal with complex geotechnical problems, such as rock body rupture, contact problems and nonlinear behavior.

3. Evolutionary Analysis of Asymmetric Deformation and Damage of Roadway with Different Section Faces

3.1. Stress distribution and deformation damage law of surrounding rock in different section roadway

(1) Characteristics of vertical stress distribution

As shown in Figure 2, the vertical stresses in different section shapes of inclined coal beds are distributed asymmetrically, and the stresses are distributed along the coal

bed direction, and the vertical stresses are mainly concentrated in the two gangs of the roadway, and the stress peaks in the left gang of the roadway are generally higher than those in the right gang. When the section shape of the roadway is straight wall arch, rectangle, pentagonal heteromorphism, right-angle trapezoid, the peak stress in the left gang is 15.59 MPa, 16.18 MPa, 16.63 MPa, 17.07 MPa, and that in the right gang is 14.57 MPa, 15.07 MPa, 15.03 MPa, 15.61 MPa, and the difference in the peak stress between right and left gang is 1.02 MPa, respectively. The difference between the vertical stress peaks of the right and left gangs is 1.02 MPa, 1.11 MPa, 1.60 MPa, 1.46 MPa respectively, and the stress peaks of the arch section of the straight wall are lower, and the asymmetric rows are better.

The distance from the peak stress of the left gang to the

gang side of the roadway is 3.67 m, 4.08 m, 4.12 m, 4.71 m, and the distance from the peak stress of the right gang to the gang side of the roadway is 3.94 m, 4.40 m, 4.52 m, 5.38 m. The difference between the peak stress of the left and right gangs of the roadway and the distance from the gang side of the roadway is 0.27 m, 0.32 m, 0.42 m, and 0.59 m respectively. The stress peak and stress concentration area of the roadway perimeter rock of the straight wall arch roadway is the smallest, and the asymmetric distribution characteristics are not the most obvious, followed by rectangular roadway, pentagonal heteromorphic shape, and right-angled trapezoidal shape. Thus, it is concluded that the straight wall arch roadway has the best control of stress, and the asymmetric characteristics are the least obvious compared with the other three roadways.

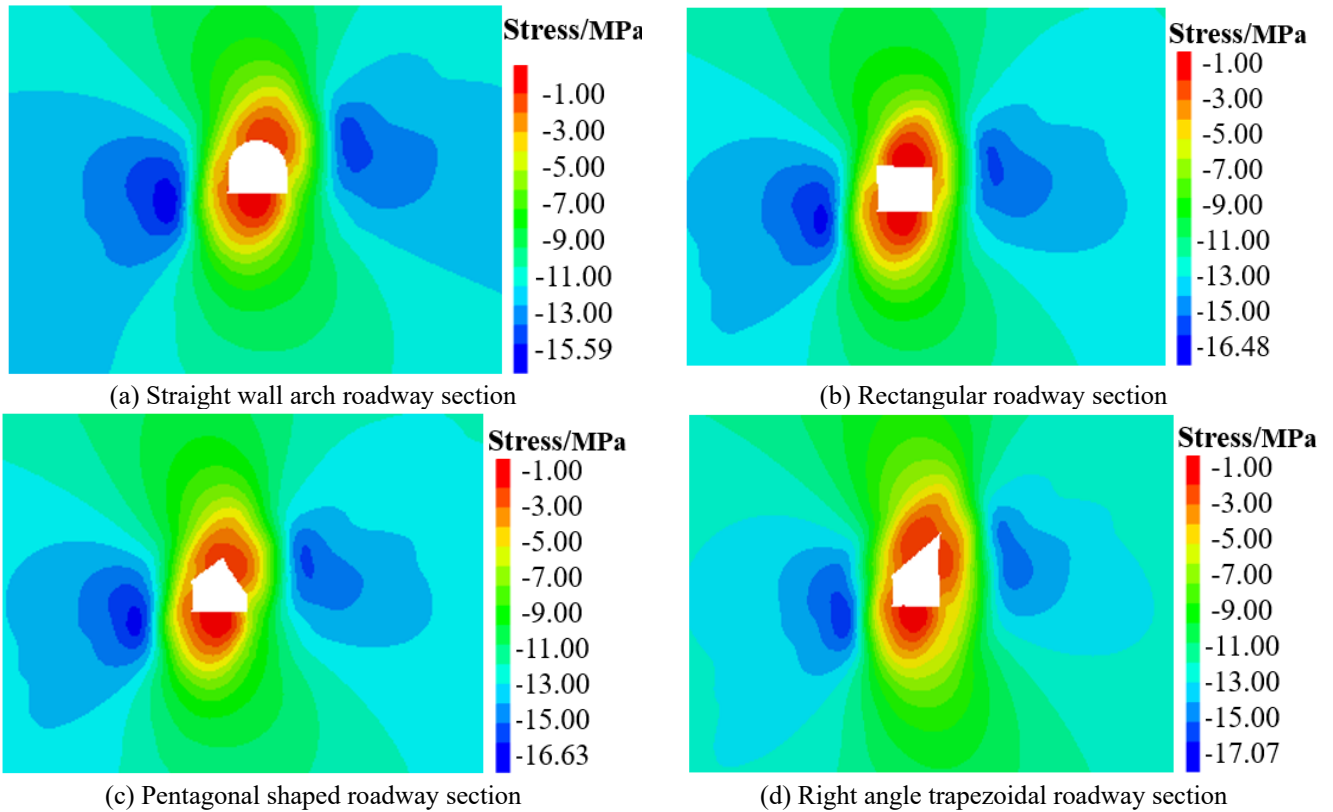


Figure 2. Numerical model of vertical stress in different sections

(2) Shear stress distribution characteristics

Figure 3 shows the cloud diagram of shear stress of the surrounding rock of the roadway with different cross-section shapes of large inclination coal bed. From the figure, it can be observed that the shear stress of the surrounding rock of the roadway is mainly concentrated in the four sharp corners, and the whole shows asymmetric “butterfly” distribution characteristics. Meanwhile, it can be observed that the stress peak and stress concentration area at the left sharp corner of the roadway is obviously larger than that at the right side. When the section shape is straight wall arch, rectangle,

pentagonal heteromorphism, right angle trapezium, the peak stresses at the top corners of the left gangway are 5.01 MPa, 5.35 MPa, 5.19 MPa, 5.80 MPa, the peak stresses at the top corners of the right gangway are 3.93 MPa, 4.17 MPa, 4.22 MPa, 4.28 MPa, and the peak stresses at the bottom corners of the left gangway are 4.31 MPa, 4.22 MPa and 4.28 MPa, respectively. 4.31 MPa, 4.57 MPa, 4.51 MPa, 4.79 MPa, and the peak stress at the bottom corner of the right gangway is 4.21 MPa, 4.55 MPa, 4.39 MPa, 4.51 MPa, respectively. Overall, the peak stress in the straight-wall archway is the smallest.

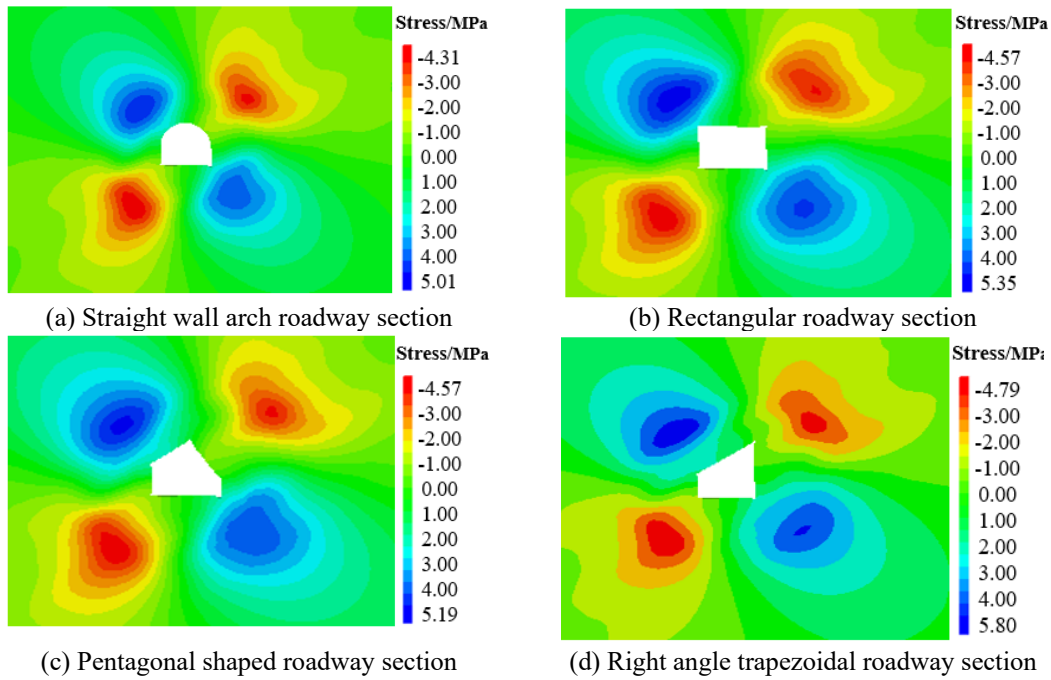


Figure 3. Numerical model diagram of shear stress in different sections

3.2. Displacement distribution and deformation damage law of peripheral rock in different roadway sections

(1) Horizontal distribution characteristics

The numerical model cloud diagrams of horizontal displacement of four different sections are shown in Figures 4, the deformation of two gangs shows obvious asymmetry, and the displacement of the left gang of the roadway is generally larger than that of the right gang, which indicates that the surrounding rock here is more significantly extruded to the inner side of the roadway, and the overall displacement is roughly distributed along the direction of the coal seam approximately. The overall maximum horizontal displacement of straight wall arch, rectangular, pentagonal and right-angle trapezoidal left gang is 118.3 mm, 118.6 mm, 117.5 mm, 128.3 mm, respectively, and the convergence of right gang is 103.7 mm, 117.2 mm, 112.6 mm, 143.9 mm, respectively, and the overall right-angle trapezoidal roadway, the stability is the poorest, and the horizontal displacement of the left and right gangs are far more than that of other sections. The absolute values of the left and right gang horizontal displacements are far more than those of other sections, except that the horizontal displacements of the left gang in the straight wall arch, rectangular and pentagonal sections are similar, with little difference; while the absolute values of the right gang horizontal displacements are significantly better in the straight wall arch than in the rectangular and pentagonal sections. In summary, it can be seen that the deformation size of the surrounding rock of the two gangs of the roadway presents: right angle trapezoidal roadway > rectangular roadway > pentagonal roadway > straight wall arch roadway.

117.5 mm, 128.3 mm, and the convergence of right gang is 103.7 mm, 117.2 mm, 112.6 mm, 143.9 mm, respectively, and the overall right-angle trapezoidal roadway, the stability is the poorest, and the horizontal displacement of the left and right gangs are far more than that of other sections. The absolute values of the left and right gang horizontal displacements are far more than those of other sections, except that the horizontal displacements of the left gang in the straight wall arch, rectangular and pentagonal sections are similar, with little difference; while the absolute values of the right gang horizontal displacements are significantly better in the straight wall arch than in the rectangular and pentagonal sections. In summary, it can be seen that the deformation size of the surrounding rock of the two gangs of the roadway presents: right angle trapezoidal roadway > rectangular roadway > pentagonal roadway > straight wall arch roadway.

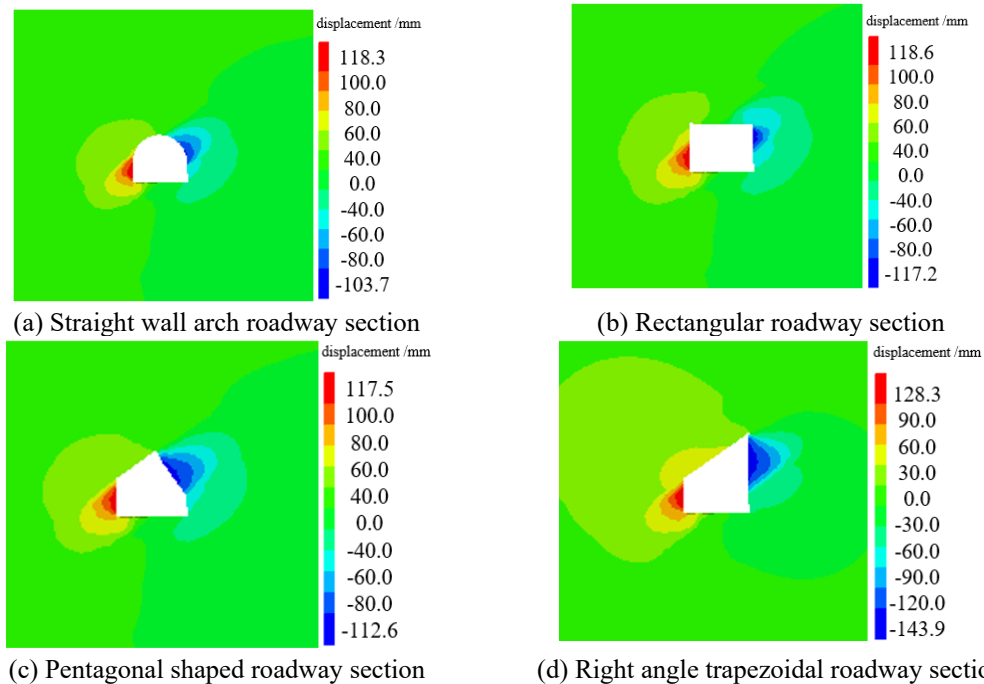


Figure 4. Numerical model of horizontal displacement of different sections

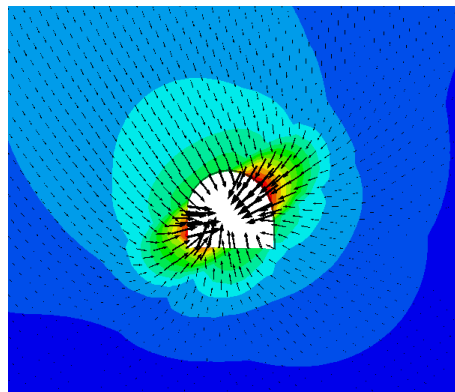
(2) and displacement vector distribution characteristics

Figure 5 shows the cloud diagram of numerical modeling of different sections and displacement vectors, the arrow direction indicates and displacement direction, and the length of the arrow indicates the displacement size. Overall, the four kinds of sections converge to the center of the roadway, all pointing to the direction of the roadway surface normal, and the center of the roadway shows a certain degree of contraction. The deformation of straight wall arch roadway and rectangular roadway is obviously due to the pentagonal roadway and right-angle trapezoidal roadway, and the displacements at the junction of the bottom plate and two gangs of the four different cross-sections are all pointing to the geometrical center of the roadway, and the rock body at the junction of the left gang and the bottom plate is seriously extruded inward, which is easy to trigger shear damage. And the right gang displacement of d is perpendicular to the roadway surface, not pointing to the center of the roadway. Specifically each roadway section to analyze can be seen:

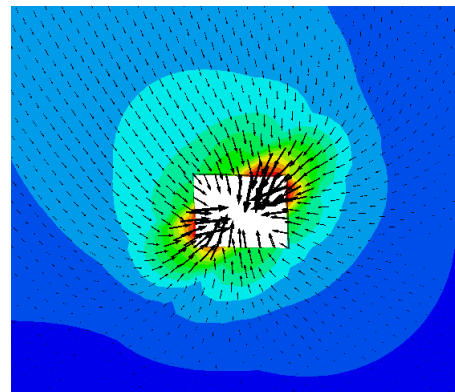
Straight wall arch roadway vault area arrows radiate inward uniformly, the length is shorter, indicating that the arch structure effectively disperses the roof pressure and avoids local stress concentration. The junction of straight wall and bottom plate: here the arrow direction is deflected to the inside of the roadway, and the length is increased, reflecting that there is a risk of shear slip at the junction of straight wall and bottom plate, which needs to pay attention to the shear-

resisting performance of the support; the length of the arrow at the junction of the top plate of the rectangle roadway and the bottom plate and the side gangs is increased suddenly and the direction is changed suddenly, pointing to the inside of the roadway, which shows that the right-angle structure triggers the concentration of local stresses, which may lead to the cracking of bottom drums or the side gangs; the five-corner heteromorphic roadway is a special type of roadway in the inclined coal bed due to the special characteristics of the section. special characteristics in the inclined coal seam caused by the asymmetric stress field, showing more obvious asymmetry, the left gang angle and the right top plate asymmetric extrusion, the right top plate deformation is more obvious, this is due to the top plate is perpendicular to the coal seam, can't effectively dispersal of the coal seam deformation; right angle trapezoidal roadway left gang and the first three are similar to the right gang roadway surface displacement along the distribution of the normal direction and the displacement is larger, this is due to the right gang is higher in height, it's more likely to produce deformation damage.

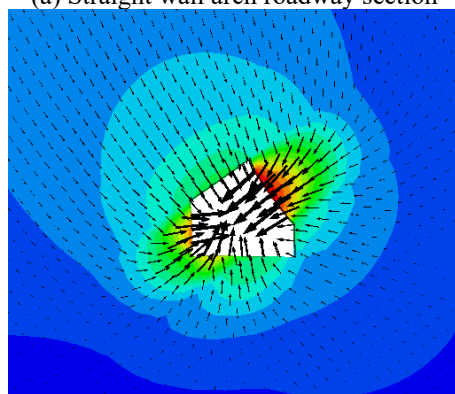
Comprehensive analysis shows that the displacement arrow of straight wall arch roadway is uniformly radiating to the center of the circle, the length is short and the direction is the same, and the arch structure effectively disperses the stress, significantly reduces the risk of roofing, etc., and the stability is optimal, so it is the first choice for the optimal cross-section.



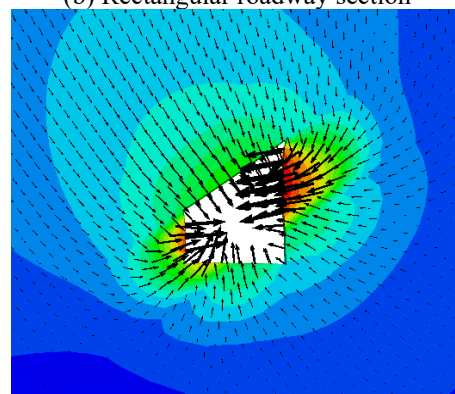
(a) Straight wall arch roadway section



(b) Rectangular roadway section



(c) Pentagonal shaped roadway section



(d) Right angle trapezoidal roadway section

Figure 5. Numerical modeling diagram for different sections and displacement vectors

3.3. Distribution of plastic zone and deformation damage law of surrounding rock in different section roadway

Figure 6 shows the numerical model of plastic zone in different sections. From the viewpoint of plastic zone broken

ring area: overall, so the section under 35° inclination angle, the plastic zone presents asymmetric deformation damage characteristics, the plastic zone damage area is distributed symmetrically along the direction of the coal seam, the plastic zone damage area near the two gangs of the roadway is more concentrated, and the plastic zone damage area of the top of

the arch of the section is more concentrated in a straight-wall arch.

From the viewpoint of the plastic zone destruction form: the shallow and deep destruction modes of the roadway in all sections are dominated by shear destruction, and a small amount of tensile destruction exists on the surface of the roadway. Specifically, a straight wall section surface tensile damage mainly occurred in the past, and now no tensile

damage, while b, c, d section of the roadway surface there are sporadic tensile damage is occurring, b, c, d surface there are tensile, shear damage superposition area, the form of damage is more complex, more detrimental to the stability of the roadway, indicating that the arch structure can effectively dispersal of the roof pressure, the overall stability of the roadway is better.

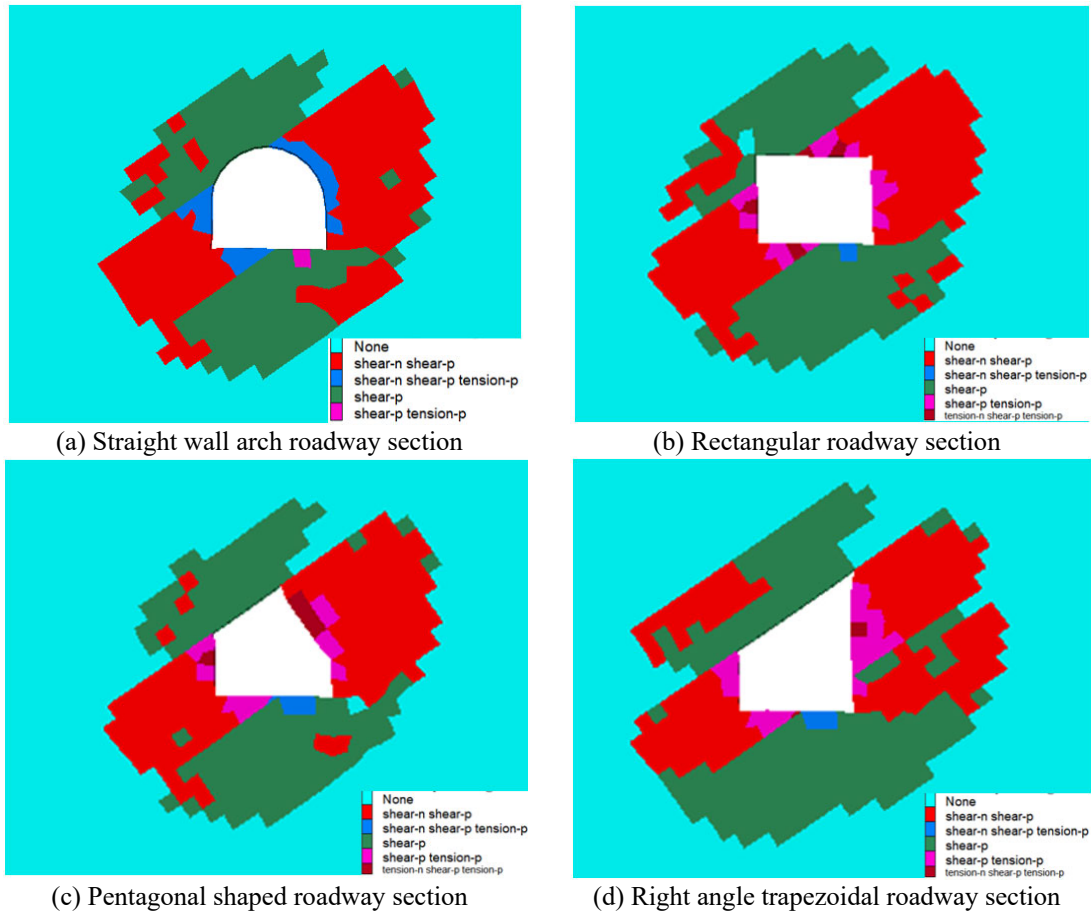


Figure 6. Numerical model of plastic zone in different sections

Fig. 7 shows the plastic zone volume of different sections, the volume of different sections of straight wall arch, rectangle, pentagonal heteromorphism, and right angle trapezium is calculated geometrically to be: 16.95 m³, 17.28 m³, 18.91 m³, and 14.57 m³, respectively. The command flow of the plastic zone is written using the Fish language in FLAC 3D, and the volume of plastic zone of different sections is extracted to be: 102.058 m³, 106.774 m³, 125.785 m³, 97.737 m³. Normally, the larger the volume of the section, the larger its plastic zone volume. Due to the different volume of different sections, there is a certain influence on the plastic zone volume, in order to eliminate the section volume as an influencing factor, a dimensionless unit $a = \text{vertical coordinate plastic zone volume} / \text{section volume}$ is introduced. Through the analysis of plastic zone volume/section volume ratio, it is concluded that the stability ranking straight wall arch roadway > rectangular roadway > pentagonal heterogeneous roadway > right-angle trapezoidal roadway, so the straight wall semicircular arch roadway should be preferred for section support.

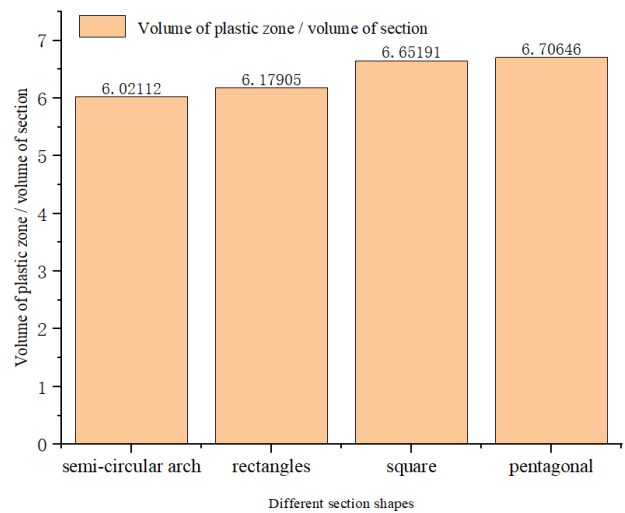


Figure 7. Volume map of plastic zone for different sections

4. Conclusion

Comprehensive consideration, the use of straight wall semi-circular arch roadway support section: help to improve the stress state of the roadway surrounding rock, reduce the

deformation of the surrounding rock, stress concentration is low, the two gangs of the force is reasonable, reduce the size of the peak around the roadway and the area, reduce the damage range of the surrounding rock plastic zone, bearing capacity. By improving the roadway section shape, adjusting the support parameters and other methods, it can reduce the degree of local stress concentration of the surrounding rock in the roadway of large inclination coal seam to a certain extent, which is conducive to the long-term stability of the deep large inclination “three soft” roadway.

Specific analysis: straight wall semi-circular vault will convert vertical stress into tangential pressure, uniformly transferred to both sides of the straight wall, significantly reduce the local stress concentration of the roof plate, straight wall arched roadway roof displacement arrows to the center of the circle uniformly radial, shorter length, and the direction is the same, the vault structure effectively disperses stress, significantly reduce the risk of roofing, the overall asymmetrical deformation characteristics are less obvious, the most conducive to the roadway support, the overall analysis Consider establishing the straight wall arch section as the optimal support section.

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