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Optimization and Application of Coal Pillar in Fully Mechanized Mining Face based on Energy Analysis

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Abstract: Based on the theory of energy dissipation, a numerical model of goaf excavation was established by FLAC3D based on the backflow channel of Heilong Coal Industry 2202. The dissipative energy distribution characteristics of coal pillars with different widths were studied, and the dissipative energy evolution law of surrounding rock of goaf roadway was analyzed. With the increase of the width of coal pillar, the width of elastic core zone is positively correlated with the bearing capacity. The peak value of dissipated energy density decreases with the increase of the width of coal pillar, and the concentration degree and region of dissipated energy density on the side of coal pillar are greater than that on the side of solid coal pillar. The project is applied to Heilong 2201 working face, and the optimum width of coal pillar and its supporting scheme are given. The practice results show that when the width of coal pillar is 5m, the deformation of surrounding rock can be effectively controlled and the demand for safe and efficient production can be met.

Keywords: Roadway Excavation; Coal Pillar Width; Energy Dissipation; Size Optimization.

1. Introduction

Gob-side entry driving (GSED) is a mining roadway that leaves a certain width of coal pillars along the goaf of the upper section to drive the lower section. GSED has the advantages of improving recovery rate and improving roadway maintenance. It has been widely used in major mining areas. The key to the success of GSED is to select a reasonable coal pillar width [1-3]. The width of coal pillar is an important factor affecting the maintenance of roadway and the stability of coal pillar [4-6]. The width of coal pillar is too large, which will lead to the reduction of recovery rate and easy to waste coal resources. On the contrary, affected by the lateral pressure of the goaf, the coal pillar is prone to collapse, and the whole is in a plastic state, resulting in difficult roadway maintenance.

Hou Chaojiong studied the limit equilibrium width of coal pillar based on the limit equilibrium theory by establishing the mechanical model of coal pillar roadway under load [8]. Bai Jianbiao et al.studied the surrounding rock control mechanism of gob-side entry driving by analyzing the stress field of fully mechanized caving face, and analyzed it with 4m coal pillar as an example [8]. Wang Hongsheng established the mechanical model of surrounding rock structure of gob-side entry driving, and determined the reasonable width of coal pillar by the position of the fracture line of the main roof [9]. Based on the limit equilibrium theory, Qi Fangkun studied the distribution characteristics of abutment pressure on the goaf side of coal pillar, and determined the upper and lower limit analytical expressions of the width of coal pillar [10]. Aiming at the problem of retaining small coal pillars in gob-side entry driving, Tong studied the plastic zone and stress distribution characteristics of coal pillars through theoretical calculation and numerical simulation [11].

However, the above research uses limit equilibrium theory and numerical simulation to study the equilibrium zone, stress and displacement of coal pillars in gob-side entry. There is energy dissipation in the deformation and failure of coal rock during roadway excavation. Based on the theory of energy conservation, Gao deduced the energy criterion of roadway surrounding rock instability under dynamic pressure [12]. By studying the internal relationship between energy dissipation and rock mass strength in the process of rock mass deformation and failure, Xie Heping established the strength loss criterion and the overall failure criterion [13]. Cao established a roadway excavation model with discrete element software, studied the energy dissipation law in the process of rock mass deformation and failure, and revealed the evolution mechanism of surrounding rock energy [14]. Zhao Zhonghu studied the problem of rock failure from the perspective of energy, and put forward the criterion of quantifying rock failure with energy [15]. Therefore, this paper takes the 2202 working face of Heilong Coal Industry as the engineering background. Based on the energy dissipation theory, numerical simulation combined with on-site monitoring and other methods are used to optimize the width of coal pillars in gob-side entry driving, which provides a scientific basis for gob-side entry driving under similar conditions.

2. Engineering Situations

The 2202 fully mechanized caving face of Heilong Coal Industry is located in the 22 mining area. The working face is mining 9+10+11 coal, with an average buried depth of 267 m. The north side of the working face is the mining boundary, the south side is the excavated +1023 horizontal track roadway, the +1023 horizontal transportation roadway, and the west side is the solid coal. According to the Fig.1, the adjacent borehole (ZK605) in the working face, the thickness of the coal seam is stable, the average thickness of 9 coal is 0.75 m, the average thickness of 10 + 11 coal is 5.3 m, and there is a layer of mudstone between 9 coal and 10 + 11 coal. The direct roof of the coal seam is limestone with a thickness of 11.2 m ~ 16.2 m. Pseudo-roof is 0.4 m thick mudstone ; the direct bottom is carbonaceous mudstone with a thickness of 1.67 m. The old bottom is siltstone with a thickness of 2.45m

~ 4.4m, and the lithology of the roof and floor is shown in Table 1.

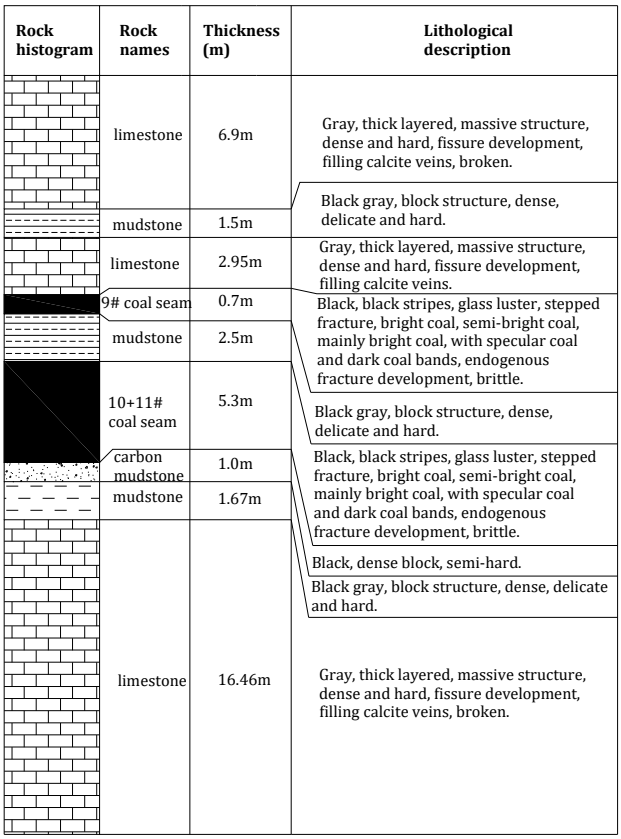


Fig 1. Rock stratum histogram

Table 1. Lithological characteristics of roof and floor of working face

lithologic	thickness/m	lithological description
limestone	6.9	Gray, thick layered, massive structure, dense and hard, fissure development, filling calcite veins, broken.
mudstone	1.5	Black gray, block structure, dense, delicate and hard.
limestone	2.95	Gray, thick layered, massive structure, dense and hard, fissure development, filling calcite veins.
9# coal seam	0.75	Black, black stripes, glass luster, stepped fracture, bright coal, semi-bright coal, mainly bright coal, with specular coal and dark coal bands, endogenous fracture development, brittle.
mudstone	2.5	Black gray, block structure, dense, delicate and hard.
10+11# coal seam	5.3	Black, black stripes, glass luster, stepped fracture, bright coal, semi-bright coal, mainly bright coal, with specular coal and dark coal bands, endogenous fracture development, brittle.
carbon mudstone	1.0	Black, dense block, semi-hard.

3. Numerical Model Establishment of Gob-Side Entry Driving

The numerical simulation software chooses FLAC^{3D} software. The buried depth is 267 m, the roof is mudstone, the floor is sandy mudstone, the roadway is rectangular roadway, the size (W × H) is 5 m × 3 m, and the numerical calculation model of (L× W × H) 160 m × 100 m × 83 m is established. The displacement of the side and bottom of the model is fixed, and the vertical stress boundary is applied to the upper boundary. The model profile is shown in Fig 2. The constitutive model of coal seam adopts Softening model, the constitutive model of goaf adopts Double-yield constitutive model, and the rest adopts Mohr-Coulomb. The numerical calculation model is shown in Fig.3.

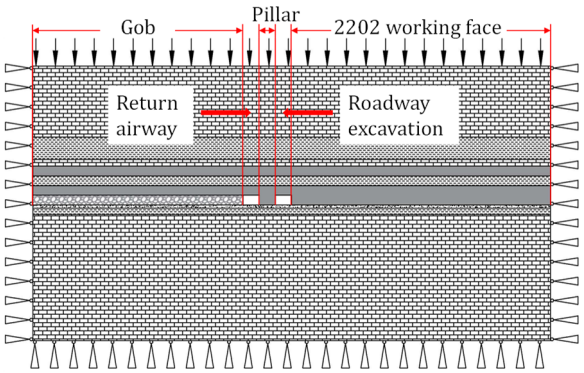


Fig 2. Numerical calculation model profile

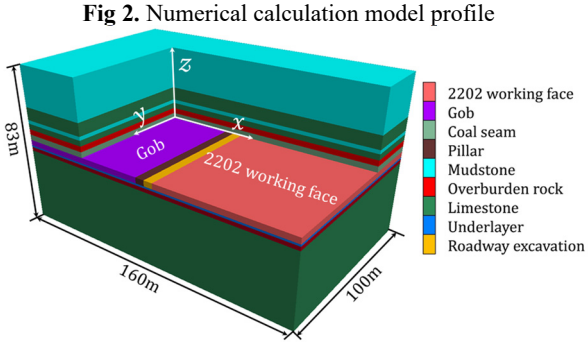


Fig 3. Numerical calculation model diagram

4. Engineering Situations

Coal pillars need to be retained in the excavation process of gob-side entry. After excavation, the stress field of surrounding rock is destroyed and the stress is redistributed. Due to the influence of overlying strata load and dynamic pressure, plastic failure zones appear on both sides of coal pillars within a certain range. If the width of the remaining coal pillar is small, it will lead to large deformation of the coal pillar, reduce the bearing capacity, and cannot maintain its own stability. On the contrary, the bearing capacity is enhanced, resulting in the waste of coal resources. Therefore, the width of coal pillar should not only meet the stability of roadway surrounding rock, but also avoid the waste of coal resources.

4.1. Dissipative Energy Distribution Characteristics of Wide Coal Pillar

The distribution of dissipated energy density of coal pillars with a width of 10 ~ 30 m is shown in Fig.4. It can be seen from Fig.4 that in the process of coal pillar width reduction, the peak value of dissipated energy density of roadway surrounding rock and coal pillar becomes larger, and the elastic area inside coal pillar gradually shrinks. When the width of coal pillar is reduced to 30 m, 25 m and 20 m, the peak value of dissipation energy density of coal pillar has no obvious change, and the width of elastic area is about 28 m, 23 m and 18 m. The concentration degree and area of dissipation energy density of roadway surrounding rock become larger, and the overall integrity of coal pillar area is

better.

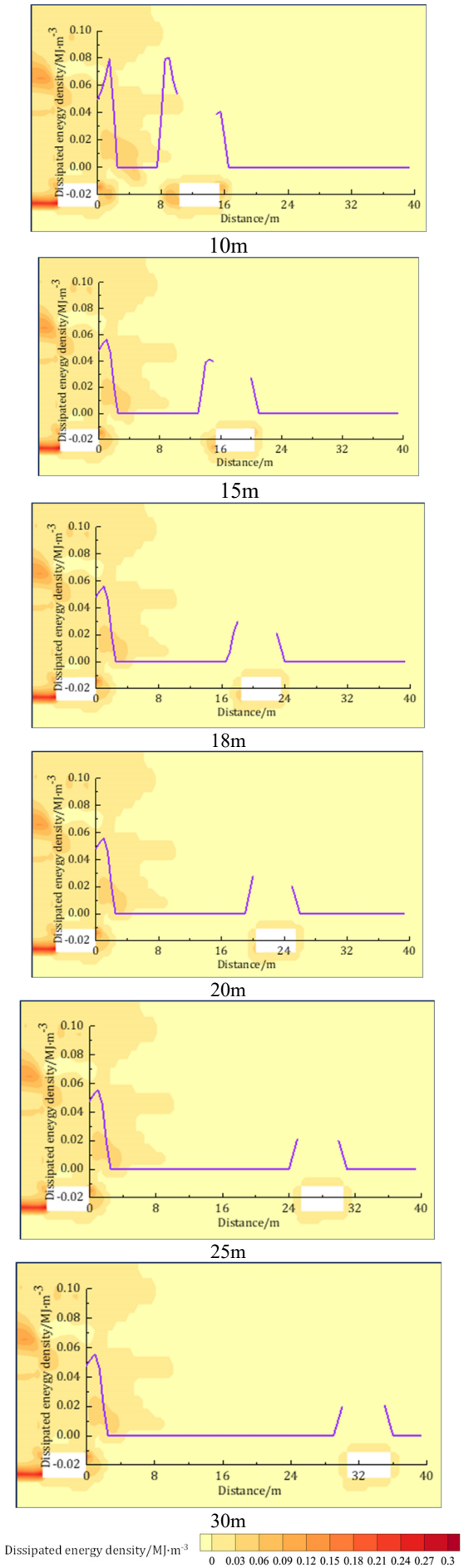


Fig 4. 10~30m width of coal pillar dissipation energy density nephogram

When the width of the coal pillar is reduced to 18m, the peak value of the dissipated energy density of the coal pillar is about 0.057 MJ/m^{-3}, and the width of the elastic area of the coal pillar is about 14.5 m. The concentration of the dissipated energy of the surrounding rock of the roadway is reduced, and the dissipated energy density of the solid coal side has no obvious change, while the peak value and concentration area of the dissipated energy density of the coal pillar side are reduced. When the width of coal pillar is 15 m, the peak value of dissipated energy density of coal pillar decreases to 0.057 MJ/m^{-3}, the width of elastic zone is about 9.5 m and the bearing capacity becomes stronger, and the distribution area and peak value of dissipated energy density of roadway surrounding rock decrease. When the width of coal pillar is 10 m, the peak value of dissipated energy density is about 0.08 MJ/m^{-3}, and the width of elastic zone is about 5.5 m. The dissipated energy density and area of roadway coal pillar side are larger than that of solid coal side.

4.2. Dissipative Energy Distribution Characteristics of Narrow Coal Pillar

The distribution of dissipated energy density of coal pillars with a width of 3 ~ 8 m is shown in Fig.5. It can be seen from Fig.5 that in the process of coal pillar width reduction, the elastic area of coal pillar gradually decreases and the plastic area becomes larger, and the stability of coal pillar gradually decreases. When the width of coal pillar is 7 m and 8 m, the peak value of dissipation energy density of coal pillar is about 0.12 MJ/m^{-3} and 0.15 MJ/m^{-3}. The concentration degree and area of dissipation energy of coal pillar side are larger than those of goaf side and solid coal side. The distribution form of dissipation energy density is bimodal curve, and the width of elastic area of coal pillar is about 1.8 m and 2.5 m respectively. When the width of the coal pillar is 6 m, the width of the elastic area of the coal pillar is about 0.8 m, and the dissipated energy density is mainly concentrated on the coal pillar. The dissipated energy density of the two sides of the roadway is more concentrated than that of the roof and floor, and the bearing capacity is lower than that of the width of 7 m and 8 m coal pillars. When the width of the coal pillar is 5 m, the elastic area of the coal pillar decreases sharply, the concentrated area of the dissipated energy of the surrounding rock of the roadway becomes larger, the dissipated energy density of the two sides is almost the same in value, and the dissipated energy density of the roof and floor is less than that of the two sides. At this time, the coal pillar still has a certain strength bearing capacity. When the width of the coal pillar is 4 m, the distribution of the dissipated energy density of the coal pillar is a single peak curve, and the peak value of the dissipated energy density is about 0.33 MJ/m^{-3}. The coal pillar has a plastic zone but no elastic zone. At this time, the coal pillar has no bearing capacity. When the width of the coal pillar is 3 m, the dissipation energy density is concentrated in the coal pillar, the peak value and concentration area of the dissipation energy density of the roof and floor increase, the coal pillar is in the plastic zone and the coal pillar has no bearing capacity.

4.3. Determination of Coal Pillar Width

When the width of the coal pillar decreases from 30 m to 10 m, the width of the elastic zone inside the coal pillar gradually decreases, and the concentrated area of the dissipated energy density gradually increases. When the width of the coal pillar is 10 m, the coal pillar still has a strong

bearing capacity. When the width of the coal pillar is in the range of 3 ~ 8 m, with the decrease of the width of the coal pillar, the elastic core area decreases until it disappears. The form of the dissipated energy density curve changes from a bimodal curve to a single-peak curve, and the peak value of the dissipated energy density gradually increases until the coal pillar is in a plastic state and loses its bearing capacity. There is an elastic core area inside the coal pillar with a width of 5 m, which has a certain bearing capacity. Therefore, considering the saving of coal resources and safe production, the optimal width of the coal pillar is determined to be 5 m.

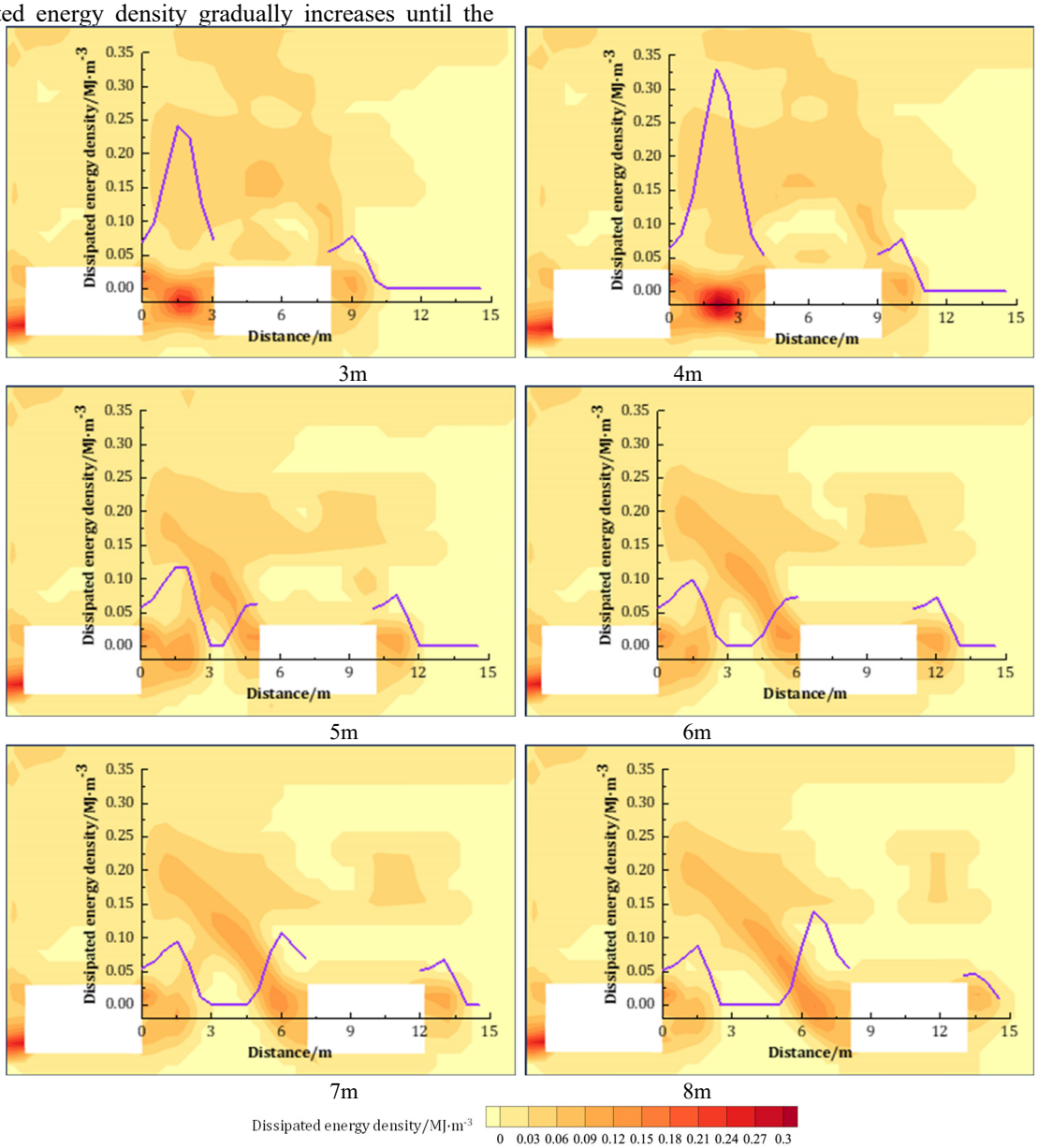


Fig 5. 3 ~ 8m width of coal pillar dissipation energy density nephogram

5. Filed Application

5.1. Support Technology Scheme

Because the field conditions of 2202 working face and 2201 working face are roughly the same, according to the simulation results, the optimum width of the coal pillar left in the transportation gateway of 2201 working face is 5 m and the support scheme is determined. The roof and two sides of the roadway adopt Φ20 mm-L2400 mm model BHRB335 left-handed non-longitudinal reinforced rebar equal-strength bolts. The bolt tray uses a 150 mm × 150 mm × 10 mm dish tray. The row spacing between bolts is 800 mm × 800 mm. The roof adopts Φ18.9 mm-L6300 mm anchor cable. The coal pillar side adopts Φ18.9 mm-L4300 mm anchor cable. The row spacing between roof anchor cables is 2200 mm × 1600 mm, which is in the form of ' 202 '. The row spacing between the anchor cables of the coal pillar is 1600 mm × 1600 mm, and the specific scheme is shown in Fig 6.

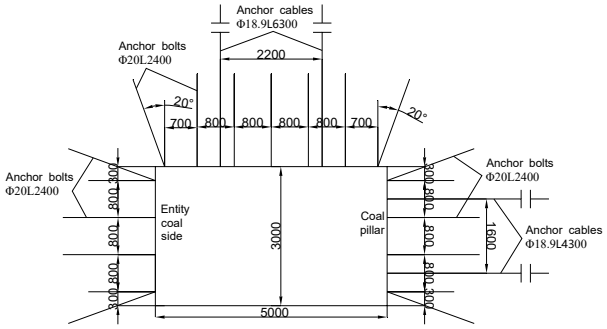


Fig 6. Roadway support section diagram

5.2. Analysis of Surrounding Rock Control Effect

In order to verify the rationality of the width of the coal pillar of the 5m roadway, the monitoring points are arranged during the excavation of the 2201 working face, and the cross method is used for manual measurement. The surface deformation results of the surrounding rock of the gob-side entry are shown in Fig 7. It can be seen from Fig.7 that the deformation of surrounding rock is large within 30 days before roadway excavation, and the convergence of roof and floor and two sides is about 124 mm and 92 mm respectively. After about 50 days, the deformation of surrounding rock tends to be stable, and the deformation of roadway can be effectively controlled. It can be seen from this that the rationality of leaving 5 m coal pillar in gob-side entry driving is verified.

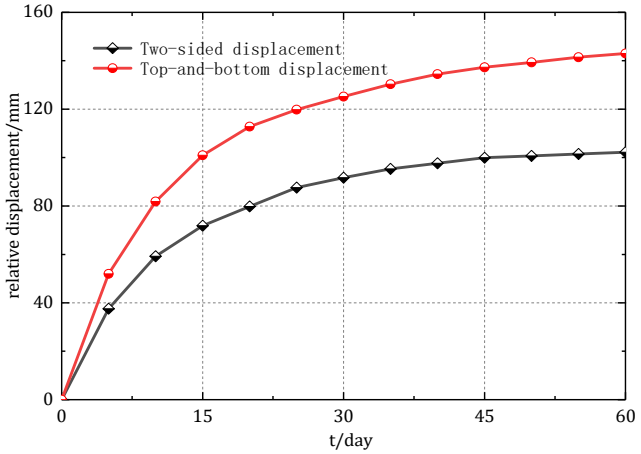


Fig 7. Surrounding rock deformation curve of roadway

6. Conclusion

(1) From the perspective of dissipative energy, the distribution characteristics of dissipative energy and elastic zone of roadway and coal pillar under wide coal pillar and narrow coal pillar are studied by FLAC^{3D} numerical simulation software. It is concluded that when the optimal width of coal pillar is 5 m, it has certain bearing capacity.

(2) Based on the simulation results and the actual conditions of the site, the roadway support scheme is designed. The application results show that the deformation of the surrounding rock of the roadway is controlled when the 5m wide coal pillar is retained, which ensures the safe and efficient production of the working face.

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