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Support Technology of Ultra-high Roadway in Thick Coal Seam

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Abstract: Based on the ultra-high roadway appeared in the process of excavation in a Shanxi mine. Surrounding rock mass plastic zone of roadway between height 3.5-7.5 m is simulated: Surrounding rock mass shear and tensile plastic zone is in direct proportion to the roadway height. That roadside surrounding rock mass is the key part of ultra-high roadway is clarified as well as the scientificity to strengthen the roadside based on the theory anchorage wall. Timely support technology is used, high strength, high bond force, high pre-tightening force and high reliability. The maximum of relative nearer speed after excavation of roadway is 7 mm day^{-1} and becomes stable below 1.5 mm day^{-1} after 15 days. Relative convergence of the roadside is 125 mm after 120 days. The guiding ideology of this type of ultra-high roadway supporting and scientificity of support is verified to provide reference for the similar condition on ultra-high roadway support.

Key word: Ultra-high, roadside, stability, support

PREAMBLE

Excavated roadway is mostly in the shape of horizontal rectangle; however, it turns into the shape of vertical rectangle with ultra height arising from ultra excavation, cutting of geological structure or other factors. In addition, the weak physio-mechanical properties of coal have increased risks of roadway sloughing, endangering safety and security of production (Chen, 2009; Li, 2011; Yang, 2008).

During the excavation on 4105 working face of a mine in Shanxi, caving mining method has to be adopted due to cutting of geological structure. As a result, an ultra high roadway has been produced with approximately 15 m, 5 and 7.5 in length, width and height, respectively.

In this research, support of ultra high roadway here above has been selected as the research object to analyze difficulties in the control of surrounding rock of ultra high roadway.

GEOLOGICAL CONDITIONS OF THE PROJECT

The roadway section is designed to be 5 and 3.5 m in width and height, respectively and the ultra high section be 5, 7.5 and 15 m in width, height and length, respectively. The roadway is excavated along the bottom of coal stratum with embedded depth of being approximately 250 m and f coefficient of coal seam being approximately 1.5. The coal seam belongs to half dark coal composed of bright coal and dull coal, having ladder shaped section and weak glass luster. The geological conditions are illustrated in Table 1.

Table 1: Information of geological conditions

Name of roof and floor	Name of rock	Thickness (m)	Rock properties
Hard roof	Medium and coarse sandstone	5~8	Off white in color, hard and having sound bonding capacity
Immediate roof	Sandymudstone	1.5	Charcoal grey in color, unevenly bonded, having uneven sand
Coal seam	No. 4 coal seam	8	Black in color, composed of bright and dull coal, ladder shaped in section, having weak glass luster and falling into category of half dark coal
Immediate floor	Sandy mudstone	2.00	Charcoal grey in color and rich in zoolite and phytolite

RELATION BETWEEN SURROUNDING ROCK MASS PLASTIC ZONE AND ROADWAY HEIGHT

With excavation of roadway, the surrounding rock mass bears triaxial stress rather than biaxial stress, resulting in unloading failure. As a result, shallow surrounding rock falls into plastic state. Meanwhile, the height of road becomes major factor to control the plastic zone due to ultra height of roadway.

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Table 2: Elements of model

Name of software	FLAC3D
Model specifications	L×W×Hadiga: 60×60×60 m
Average density of overburden	2755 kg m^{-3}
g	9.8 m sec^{-2}
Vertical stress	6.51 MPa
Stress gradient	0.02755 MPa
Pressure coefficient	1.1
Constitutive relation	Strain softening

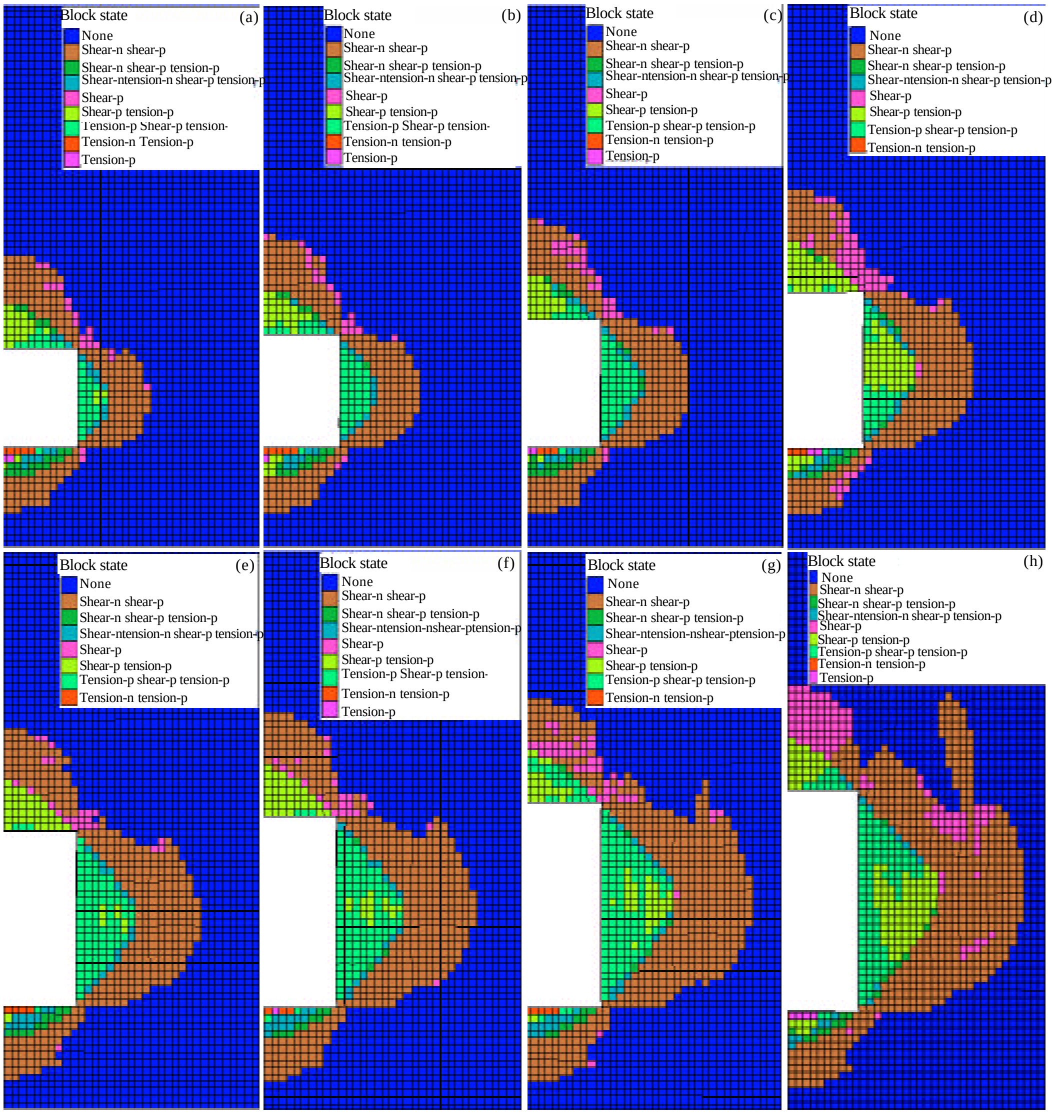

Fig. 1(a-h): Distribution properties of plastic zone, (a) Roadway height of 3.5 m, (b) Roadway height of 4 m, (c) Roadway height of 4.5 m, (d) Roadway height of 5 m, (e) Roadway height of 5.5 m, (f) Roadway height of 6 m, (g) Roadway height of 6.5 m and (h) Roadway height of 7 m

Numerical model: Flac3D values are simulated to investigate the effects of roadway height on the surrounding rock mass plastic zone.

Parameters for numerical value model are detailed in Table 2.

Distribution properties of plastic zone: Single factor analytic method is employed to fix the the roadway width at 5 m and roadways from 3.5-7.5 m are simulated to investigate distributions of the surrounding mass plastic zone at 0.5 m intervals. The results are detailed in Fig. 1.

As illustrated in Fig. 1, distributions of plastic zone with different roadway heights show similar characteristic, all half circle in shape. In addition, distributions of shear and tensile plastic zone are almost identical and the maximum depth of plastic zone is located at the belt line of the surrounding rock mass. It could be learnt that the depth and area of the surrounding rock mass shear and tensile zones grow with the height of roadway in this model and the biggest increase occurs near belt line. Hence, it could be learnt that with other conditions unchanged, height of surrounding rock mass is major factor to control the distribution properties of surrounding rock mass plastic zone.

Analysis of maximum depth of surrounding rock mass shear and tensile plastic zones: As shown in Fig. 2, depths of surrounding rock mass shear and tensile plastic zones differ with different height of the roadway. When the roadway height is 3.5 m, depths of surrounding rock mass shear and tensile plastic zones are 2.5 and 1 m, respectively. Depths of surrounding rock mass shear and tensile plastic zones grow gradually as height of the roadway rises. When the roadway height is 7.5 m, depths of surrounding rock mass shear and tensile plastic zones are 6 and 2.75 m, respectively. Hence, it could be seen that depths of surrounding rock mass shear and tensile plastic zones are in direct proportion to height of the roadway. Depths of surrounding rock mass shear and tensile plastic zones of roadway at depth of 7.5 m are 2.4 and 2.75 times, respectively as large as those at the depth of 3.5 m. Hence, it is apparent that the roadway height has more significant effects on depth of the tensile plastic zone than on depth of the shear plastic zone. Generally speaking, depth of surrounding rock mass plastic zones grows with height of the roadway and the roadway height has more significant effects on depth of the tensile plastic zone than on depth of the shear plastic zone.

Development trends of surrounding rock mass shear and tensile plastic zones: According to the analysis here above, it could be learnt that increase in roadway height has apparent effects on depths of surrounding rock mass shear and tensile plastic zones. In order to illustrate the relation between the two, comparison and contrast have been made between depth of the shear plastic zone and that of the shear plastic zone with the same height of the roadway, which is defined as shear tensile coefficient. As shown in Fig. 3, shear tensile coefficient drops significantly when roadway height stays between 3.5 to 5 m, the former rises a little as the latter is between 5 to 5.5 m and the former goes down again as the latter rises between 5.5 to 7.5 m. Hence, it could be learnt that in the large percentage of the depth of entire plastic zone and the surrounding rock mass mainly bears destructive force. And in the declining section (5.5-7.5 m) of shear tensile ratio, depth of the tensile plastic zone accounts for increasingly small percentage of the depth of entire plastic zone. Based on the above analysis, as the roadway height goes up, more weight of rocks will be born by the surrounding rock mass which demonstrates apparent shear plasticity deep inside. Meanwhile, depth of the shear plastic zone is increased considerable and the shear failure is major force deep inside the surrounding rock mass which has the trend of shear slip.

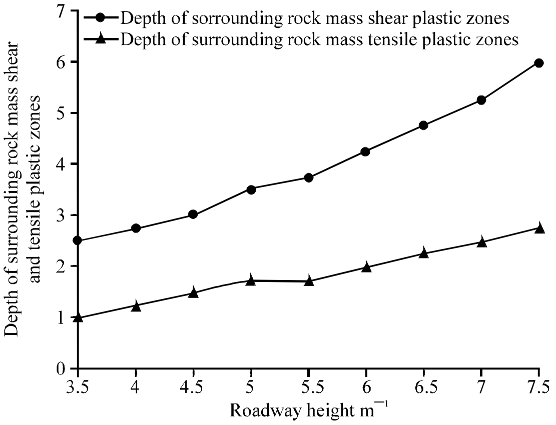

Fig. 2: Relation between roadway height and depth of surrounding rock mass shear and tensile plastic zones

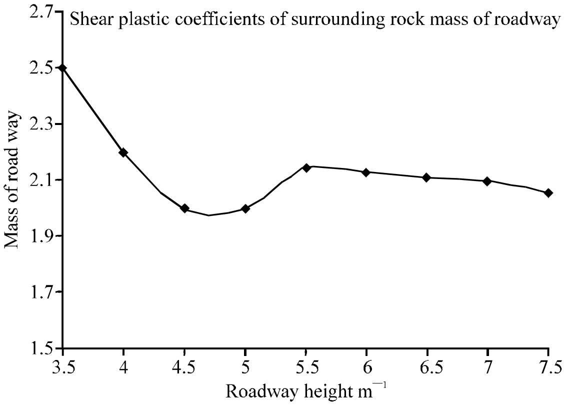

Fig. 3: Relation between roadway height and shear and tensile coefficients of surrounding rock mass of roadway

KEY CONTROL POSITION OF THE SURROUNDING ROCK MASS

After the disclosure of coal in roadway, the surrounding rock has unloading effects and projection deformation under the effects of ground stress. According to Protodyakonov's theory, the surrounding rock mass has horizontal arch shaped sloughing under the pressure of the support. As shown in Fig. 5, the maximum depth of the sloughing could be calculated by $\Delta a = h/2f$ where h and f refer to roadway height and Protodyakonov's coefficient (Hou and Ma, 1989), respectively.

As the above formula Fig. 4 has shown, the higher the roadway is, the deeper the sloughing will be; depth of the roadway sloughing is in direct proportion to the roadway height. The coal pressure properties of the surrounding rock of roadway are mainly determined by deformation and destruction state of the surrounding rock. In the case of bad roadway control, the surrounding rock mass could be easily deformed and sloughed, causing enlargement of span of the roadway roof. In this circumstance, the deformation of the roof could be aggravated which leads to further destruction to the surrounding rock mass.

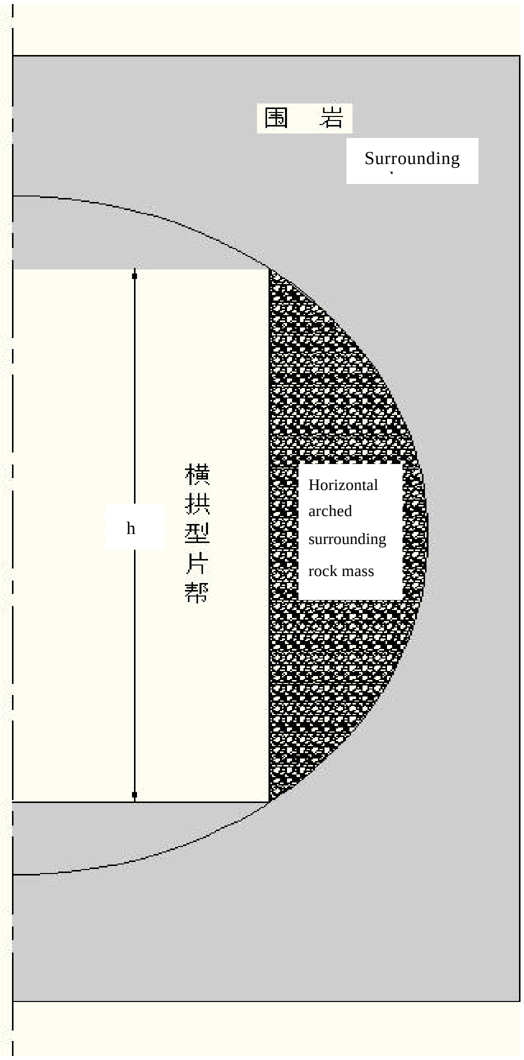

Fig. 4: Model of horizontal arched surrounding rock mass

Hence, the surrounding rock mass of ultra high roadway is the key position to stabilize the bearing structure of the roadway of the category. Control of the surrounding rock mass has significant effects on stabilization of roadway roof, whose key lies in whether or not the malignant circulation of plastic zone and destruction zone of the surrounding rock mass could be effected kept under control.

CONTROL PRINCIPLES OF THE SURROUNDING ROCK

In the case of ultra high roadway, the legs of the metal support, if applied, could be considered according to compression bar stability principle. The higher the roadway, the longer the support legs, where, according to compression bar stability principle, the stability of support legs could be easily lost and could be worse when the surrounding rock mass is deformed under pressure.

Anchorage bolt support technology is ripe at the present and timely support technology of high strength, high bond force, high pre-tightening force and high reliability is employed to practise effective control of the surrounding rock mass with ultra large plastic zone. The mechanic principles are illustrated in Fig. 5a. With the "Four High (Zhang *et al*., 1999; Kang, 2000; Xu *et al*., 2011)". Anchorage bolt technology, broken surrounding rock could be reinforced. The anchorage support technology adopted in the mine of the research includes the uses of high strength anchorage or net and high pre-tightening force so that the surrounding rock has certain bearing capacity to press against the anchorage wall. The reinforcement effects of the roadway illustrated in Fig. 5 could be realized with reasonable determination of support coefficient.

α: Influence angle of anchorage force, β: Bolt interval, l: Effective thickness of anchorage wall.

Anchorage structure could help improve the bearing capacity of the surrounding rock, reinforce its adaptability to deformation so that the surrounding could sustain bearing capacity with deformation in considerably large area. In addition to maintain self stability, the anchorage could restrain deformation deep inside the rock, prevent

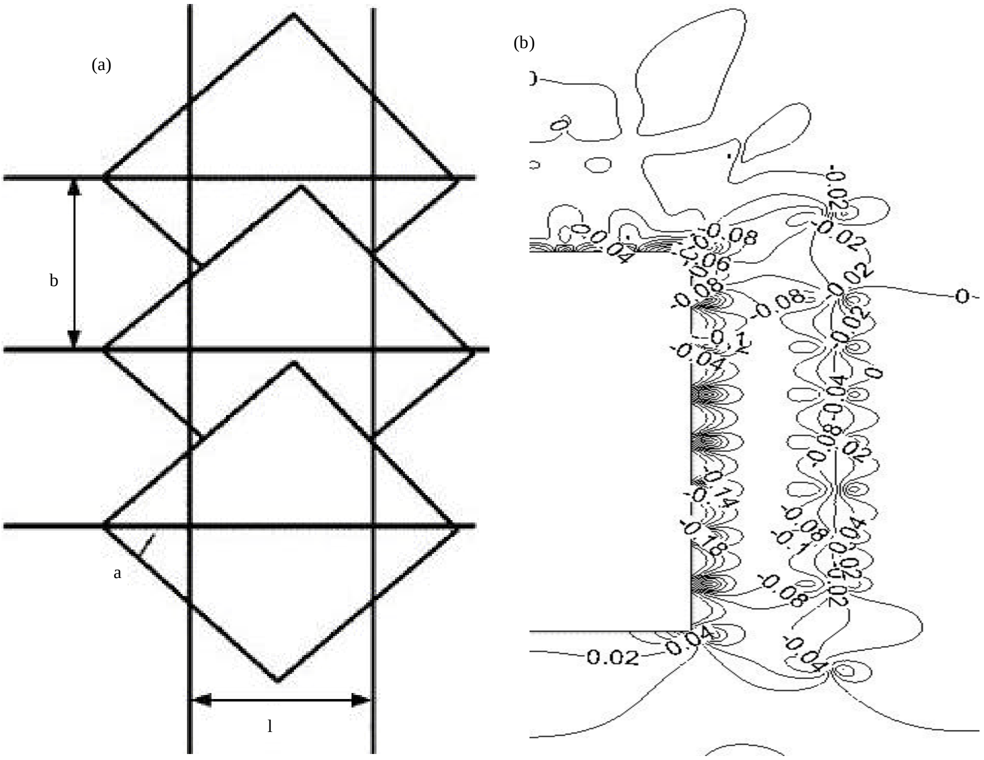

Fig. 5: Mechanical model of stability of roadway, (a) Mechanical model of anchorage wall and (b) Simulated figure of anchorage effects

deformation of the rock and interrupt the extension of the deformation to the deeper side of the rock (Gou and Hou, 2000).

SUPPORT AND STABILIZATION TECHNOLOGY OF ULTRA HIGH ROADWAY

Support coefficient will be finalized as below with help of theoretical analysis and engineering analogy after taking into consideration actual geological conditions:

- For surrounding rock mass of ultra high roadway: The anchorage bolt is left screw high strength anchorage bolt of screw steel without longitudinal ribs (2400 and Φ20 mm in length and diameter). Each anchorage bolt is reinforced and prolonged with help of Z2360 resin anchorage agent. Roof anchorage bolts are placed in 1000×1000 mm intervals and the anchorage force is ≮100KN per bolt
- Screw steel anchorage tray is of specification 150×150×10 mm, whose central aperture is 1-2 mm, slightly larger than diameter of the anchorage bolt. The nut torque is no less than 200 N·m
- Rhombus mesh of 1200×5000 mm dimension is laid horizontally on the surrounding rock mass of roadway. The mesh is made of 8# wires with 200 mm overlapping and the rhombus is 50×50 mm in dimension. The wire is connected with use of double 14# wires in spacing no more than 200 mm. The mesh on the roof and on the side shall be connected tightly

ANALYSIS OF EFFECTS OF THE PROJECT

After the support of the roadway, the mine company is concerned about the stability of the roadway due to its ultra height, which might result in sloughing. Hence, pressure of the roadway has been observed in the long term and the observation results are given in Fig. 6:

- The maximum of relative nearer speed after excavation of roadway is 7 mm day^{-1}
- The relative nearer speed becomes stable after approximately 15 days
- The relative nearer speed declines to 1.5 mm day^{-1} after 15 days
- Relative convergence of the roadside is 125 mm after 120 days

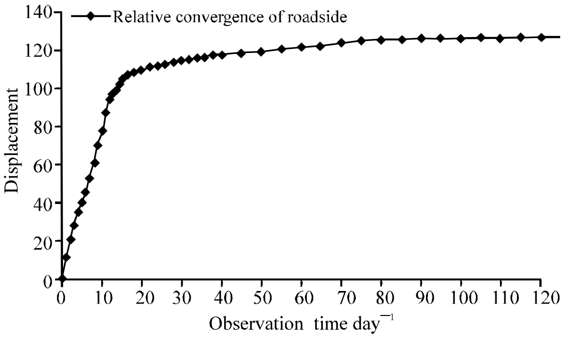

Fig. 6: Deformation and deforming speed of the surrounding rock

After 120 days of mine pressure observation, the guiding ideology of this type of ultra-high roadway supporting and scientificity of support is verified to provide reference for the similar condition on ultra-high roadway support.

CONCLUSION

The research has taken geological conditions of a mine in Shanxi as research object and the following conclusions could be obtained with practical work of support for ultra high roadway:

- Roadway height has apparent effects on development of plastic zone in the surrounding rock mass; the higher the former, the deeper the shear and tensile plastic zone would be. Depth of shear and tensile plastic zone of the surrounding rock mass is in direct proportion to the roadway height
- The surrounding rock mass is the key position to support ultra high roadway, which influences the overall stability of the roadway
- Anchorage structure of roadway could help stabilize the roadway and prevent the deformation deep inside the surrounding rock
- The support coefficient of road is suitable for geological conditions in the project area

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