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Research Article

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Deformation analysis and simulation on soft rock roadway of Jianxin mine

Yongsheng Liu*, Xingyu Dong and Wang Liu

School of Civil Engineering and Architecture, East China Jiaotong University, Nanchang, China

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ABSTRACT

According to the roadway deformation of Jianxin Mine of Jiangxi Fengcheng Mining Bureau. Based on the basic theory of elastic-plastic mechanics, the Mechanical principle of soft rock roadway deformation was analyzed; the calculating formula of surrounding rock and plastic zone radius and the radius of rupture zone were gained. Then the numerical simulations of the soft rock roadway deformation were conducted by ANSYS software. The roadway deformation graph and the strain and stress nephogram were gained. The simulation results are agree with the measured deformation of the roadway.

Key words: elastic-plastic mechanics; soft rock roadway; deformation; mechanical mechanism; numerical simulation.

INTRODUCTION

In recent years, the pressure control and supporting problem of Soft rock mine roadway is more and more brought to the attention of the experts with the increasing of mining depth [1-4]. In our country, many mines have great difficulty in soft rock roadway supporting and become the main factors that influence the mine development and the economic benefit. The buckling deformation of soft rock roadway excavation happens easily, and it shows as floor heave and two roadsides crowded and folded, roof causes layer off the top or roof fall and so on by fracture and abscission. When using the traditional supporting of soft rock roadways, it results in roadway maintenance difficulties, disrepair seriously, high maintenance costs for many times, low mine production efficiency. The depth of Jiangxi Jianxin Mine is -1000m at present, thereby the pressure is high, the litho logy is poor and the roadway had several large deformations [5-6]. Combined with the actual situation of Jianxin Mine, this paper describes support technology of deep soft rock roadway briefly, provides support and references for mining for deep coal rock roadway excavation safety.

2. ENGINEERING SURVEY

2.1 STRUCTURE OF MINING AREA

Jianxin Mine is located in the north of Qujing syncline in Xianguling Mine. The tectonic of the mine is monoclinic, the north-east and east-west trend, south and south-east dip and the inclination angle is 8 °-10 °. The mine develops a structural anticline—Xiufangshan anticline, it is located in the secondary level West Wing mining area, axial is between N40 °-60 °E, the inclination angle is 0 °- 8 °,the local rises, south west inclines, exposes in the western mountain and Xiufangshan line, east wing rock strata dips and the dip angle is small, the west wing steepens and dip is 12 °-25 °.

There are F3, F4 and F5 faults in the mine area. The F3 fault is located in east of Longmen Shan, at the junction of Pinghu Mine and Jianxin Mine territories, with Miling Cun and Tangxia Cun, is the field boundary fault of two mine (Pinghu Mine and Jianxin Mine), towards the N10 °W, trends southwest, and it is angle of 67 °, fall of 10 to 26 m. But according to the based on the actual mining fold two mine coal seam floor elevation to analysis, to deep F3 fault became smaller gradually. F4 fault group sets in shallow mining field outcrop area, north-central of Longmen Shan, nun 1 ridge north, north of the Xianguling and the Xiufangshan, south of the Mabianshan to Sue Keng village. the fault strike changes from west to east by S40 °-60 °E to N60 °- 80 °, the gap is between 10-80 m. the group is composed of three main faults and fault fracture zone width of fault combination for 60-220m.F5 fault strike is 60 -80 °, tends to the south-east, and it is angle of 25 -35 °, fall of 124 to 180 m. Jianxin Mine roadway is not through the fault F5, the fault is a stepped fault groups from the Jianxin secondary minefield exposed situation.

The minefield develops two group small fault showed “X”. In the east wing, the fault of the North-East strata and the North-West and South-east dip direction is primary. In the west wing, the fault of the west-north strata and the North-east and South-west dip direction is primary. The fault dip angle is 45 °-60 °, the plots between the west of Xiufangshan and F5 fault develop many tension mainly, the torsional extensional faults of short extension and wide fracture zone toward the N20 °-50 °E, angle is above 60°, falls ranging from 1-10m.

2.2 COAL SEAM AND ROOF- FLOOR CONDITIONS

To the minefield of Jianxin Mine, a coal measure strata is the Leping Upper Permian Longtan coal series, including coal seam of Guanshan layer, Laoshan layer and Wangpan layer. From bottom to top, Guanshan layer contains A coal group, Laoshan layer contains B coal group and Wangpan inner layer contains C coal group. Coal seam named step by step from bottom to top in turn partial number 1, 2, 3,...26. A coal group contains two layers as the A1, A2, which the layers are instability in the region as the second line and not be produced. B coal group contains four layers as B3, B4, B5, B6, but only B4 is recoverable. C coal group contains 20 layers as C7, C8,...C27, and C8, C18, C23 layers are local recoverable--mining coal seam is the place of little well.

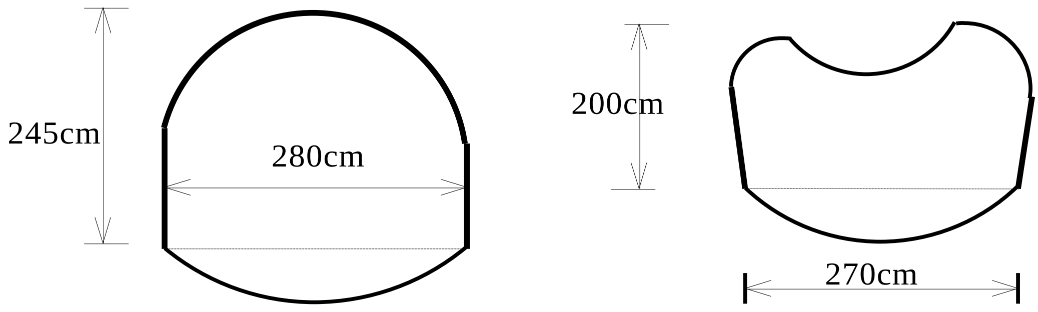
B4 layer is an average thickness of 2.4m, 8 °-12 °dip. The roof and floor can be expressed as follows: the false roof for carbonaceous siltstone or carbonaceous shale along with mining colony, generally thickness of 0-0.4m; the direct roof is dark grey carbonaceous sandy siltstone, sometimes lower for carbonaceous shale, middle-lower of sandy shale with fine sandstone of about 3m thin bedding, thickness of 6 -8 m; the old roof is grey or light grey fine quartz sandstone, thickness between 3 to 5 m, plats hardness of 5-8 m. To sum up, B4 seam roof is Ⅲ class. The false bottom is dark grey clay shale rock or clay, thickness of 0-0.3 m, an average of 0.1 m, west thin and east thick, uneven distribution; the direct bottom is light grey, taupe clay shale rock or clay, downward transition to siltstone and fine sandstone, thickness of about 2.5-3.6m, treat water swelling, prone to deformation of the bass drum because of the influence of the surrounding rock pressure.

3. DEFORMATION OF ROADWAY

3.1 DEFORMATION TEST

Due to deep mining and poor geological conditions, many roadways deform in Jianxin Mine. The typical is the 7# in the central panel of the wind roadway, the deformation of the roadway is shown as Fig.1(a). And the roadway original design and the transverse section size after deformation are as shown as Fig.1(b) and Fig.1 (c) .

(a) The live deformation of the roadway diagram



(b).The design of the roadway diagram **(c).The deformation of the roadway diagram**

Fig.1 deformation graph of roadway

3.2 DEFORMATION MECHANICS MECHANISM

Taking the circular roadway as an example, the research object is the roadway cross section, the roadway radius is R_0, the original rock stress is p_0, isotropic. When the buried depth $H \geq 20R_0$, ignore 3-5 times of the R_0 scope of the rock weight, if the roadway is infinite and the properties of surrounding rock are basically the same, it can be as ideal elastic-plastic body, and use calculation method of plane strain problem. It is as shown as Fig.2 [7-10].

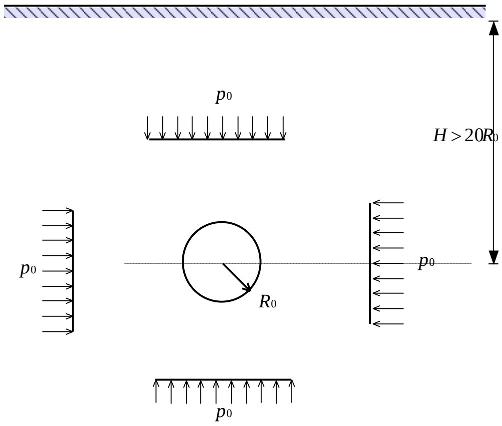


Fig.2 A simplified mechanical model of roadway pressure

After the roadway excavation, the stress redistribution of surrounding rock occurs, and the roadway surrounding rock forms fracture zone, plastic zone and elastic zone along the peripheral to the depth successively, as shown as Fig.3.

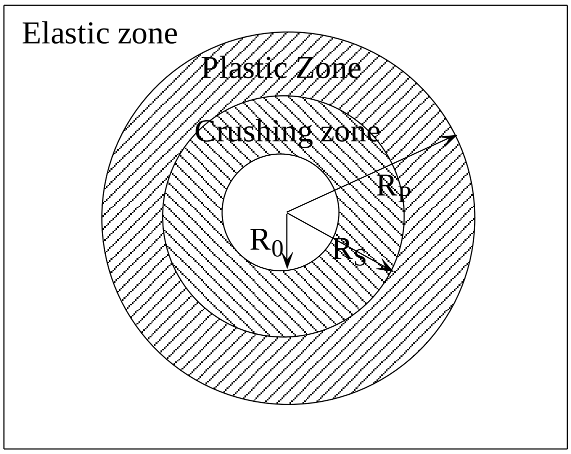


Fig.3 The partition map of deformation of roadway

The basic equations of force and application conditions of the roadway deformation:

Equilibrium equation:

$$\frac{d\sigma_r}{dr} + \frac{\sigma_r - \sigma_\theta}{r} = 0 \tag{1}$$

Geometric equation:

$$\varepsilon_r = \frac{du}{dr}, \varepsilon_\theta = \frac{u}{r} \tag{2}$$

Constitutive equation:

$$\varepsilon_r = \frac{1-\upsilon^2}{E}(\sigma_r - \frac{\upsilon}{1-\upsilon}\sigma_\theta) \tag{3}$$

$$\varepsilon_\theta = \frac{1-\upsilon^2}{E}(\sigma_\theta - \frac{\upsilon}{1-\upsilon}\sigma_r) \tag{4}$$

In the above formula: σ --stress, ε -- strain, σ_r -- radial stress, σ_θ -- tangential stress, u -- radial displacement, υ -- Poisson ratio, E -- modulus of elasticity of surrounding rock, r, θ --radial and tangential coordinates.

In the elastic rang to meet the following conditions:

Outer boundary: $r \to \infty$, $\sigma_r = \sigma_\theta = p_0$

Inner boundary: $r = R_P$

$$\sigma_r^e = A + \frac{B}{R_p^2} \tag{5}$$

$$\sigma_\theta^e = A - \frac{B}{R_P^2} \tag{6}$$

In the above formula: $\sigma_r^e, \sigma_\theta^e$ -- radial elastic zone boundary stress and tangential stress respectively, A、B-- the material parameters.

At the plastic zone, only the following conditions are satisfied:

Outer boundary (interface with elastic zone): $r = R_p$

$$\begin{cases} \sigma_r^p = \sigma_r^e \\ \sigma_\theta^P = \sigma_\theta^e \\ \varepsilon_r^P + \varepsilon_\theta^P = 0 \end{cases} \tag{7}$$

Inner boundary (surrounding): $r = R_0$, in no supporting conditions, $\sigma_r = 0$. in supporting conditions, if the support force is P_1, then $\sigma_r = P_1$.

After roadway excavation, surrounding rock redistributes and forms plastic zone and elastic zone, fracture zone. The radial and tangential stress of circular roadway surrounding rock elastic zone can be represented as:

$$\begin{aligned} \sigma_r &= p_0 + \tfrac{R_p^2}{r^2}(\sigma_{R_0} - p_0) \\ \sigma_\theta &= p_0 - \tfrac{R_p^2}{r^2}(\sigma_{R_0} - p_0) \end{aligned} \tag{8}$$

In the above formula: σ_{R_0} can be expressed as： $\sigma_{R_p} = \frac{2p_0 - \sigma_c}{1+k_p}$ ， σ_c --uniaxial compressive strength of rock mass(MPa), $\sigma_c = \frac{2c\cos\varphi}{1-\sin\varphi}$, k_p --coefficient， $k_p = \frac{1+\sin\varphi}{1-\sin\varphi}$.

The radial deformation and strain can be expressed as:

$$\begin{aligned} u &= \tfrac{1+\lambda}{E} \times \tfrac{R_p^2}{r}(p_0 - \sigma_{R_p}) \\ \varepsilon_\theta &= -\varepsilon_r = \tfrac{1+\lambda}{E} \times \tfrac{R_p^2}{r^2}(p_0 - \sigma_{R_p}) \end{aligned} \tag{9}$$

Plastic radial strain ε_r^p and tangential strain ε_θ^p can be shown as:

$$\begin{aligned} \varepsilon_r^p &= (\varepsilon_r^e)_{r=R_p} + \Delta\varepsilon_r^p \\ \varepsilon_\theta^p &= (\varepsilon_\theta^e)_{r=R_p} + \Delta\varepsilon_\theta^p \\ \Delta\varepsilon_r^p &+ \eta_1 \Delta\varepsilon_\theta^p = 0 \end{aligned} \tag{10}$$

In the above formula: $\Delta\varepsilon_r^p$ --radial strain increment of plastic zone of surrounding rock, $\Delta\varepsilon_\theta^p$ --tangential strain increment of plastic zone of surrounding rock, η_1 -- the parameter considered rock dilatancy of the plastic zone $\eta_1 = k_p = \frac{1+\sin\varphi}{1-\sin\varphi}$.

The deformation of plastic area should meet the deformation geometry equations:

$$\varepsilon_r = \frac{d_u}{d_r} \quad \varepsilon_\theta = \frac{u}{r} \quad \varepsilon_z = 0 \tag{11}$$

By formula (9), (10), (11) get the deformation of plastic zone:

$$u^p = k_4 r^{-\eta_1} \tag{12}$$

By elastic-plastic deformation boundary same conditions can be available:

$$u = \frac{pr}{E}\left\{1 + \frac{2}{1+\eta_1}[(\frac{R_p}{r})^{1+\eta_1} - 1]\right\} \tag{13}$$

In the formula: $p = (1+\lambda)[2p_0\sin\varphi + (1-\sin\varphi)\sigma_c]/2$

Strain in the plastic ring can be shown as:

$$\varepsilon_r^p = -\frac{p}{E}\left\{\eta_1 + \frac{2\eta_1}{1+\eta_1}[\left(\frac{R_p}{r}\right)^{1+\eta_1} - 1]\right\} \quad \varepsilon_\theta^p = \frac{p}{E}\left\{1 + \frac{2}{1+\eta_1}[\left(\frac{R_p}{r}\right)^{1+\eta_1} - 1]\right\} \tag{14}$$

Radial strain ε_r^b and tangential strain ε_θ^b of rupture zone can be shown as:

$$\varepsilon_r^b = (\varepsilon_r^p)_{r=R_b} + \Delta\varepsilon_r^b \quad \varepsilon_\theta^b = (\varepsilon_\theta^p)_{r=R_b} + \Delta\varepsilon_\theta^b \quad \Delta\varepsilon_r^b + \eta_2\Delta\varepsilon_\theta^b = 0 \tag{15}$$

In the formula: $\Delta\varepsilon_r^b$ --radial strain increment of rupture zone of surrounding rock, $\Delta\varepsilon_\theta^b$ --tangential strain increment of rupture zone of surrounding rock, η_2 --the parameter considered rock dilatancy of the plastic zone, $\eta_2 = 1.3 \sim 1.5$.

By formula (12), (13), (14) combined with the deformation geometric equation can get any point deformation of rupture zone:

$$u^b = \frac{2pr}{E}\left\{\left\{\frac{1}{1+\eta_1} + \frac{1}{1+\eta_2}[\left(\frac{R_b}{r}\right)^{1+\eta_2} - 1]\right\}\left(\frac{R_p}{R_b}\right)^{1+\eta_1} + \frac{\eta_1 - 1}{2(1+\eta_1)}\right\} \tag{16}$$

Surface deformation of surrounding rock is:

$$u^b = \frac{2pr_0}{E}\left\{\left\{\frac{1}{1+\eta_1} + \frac{1}{1+\eta_2}[\left(\frac{R_b}{r}\right)^{1+\eta_2} - 1]\right\}\left(\frac{R_p}{R_b}\right)^{1+\eta_1} + \frac{\eta_1 - 1}{2(1+\eta_1)}\right\} \tag{17}$$

According to the elastic-plastic boundary, plastic zone and fracture zone boundary stress equal, support for the rupture zone boundary is p_i, and considers the softening of the plastic zone intensity (mainly cohesion).

The radius of plastic can be expressed as:

$$\frac{2}{1+k_p}[p_0 + \frac{\sigma_c}{k_p - 1} + \frac{(k_p+1)k_5 p}{(k_p-1)(k_p+\eta_1)}](\frac{r_0}{R_p})^{k_p - 1} + \frac{2k_5 p}{1+\eta_1}[\frac{1}{k_p+\eta_1}(\frac{R_p}{r_0})^{1+\eta_1} - \frac{1}{k_p - 1}] - \frac{\sigma_c}{k_p - 1} - p_i = 0 \tag{18}$$

In the formula: p_i -- support force (MPa), k_5 --coefficient, $k_5 = \frac{M_c}{E}$, M_c --rock softening modulus（MPa）.

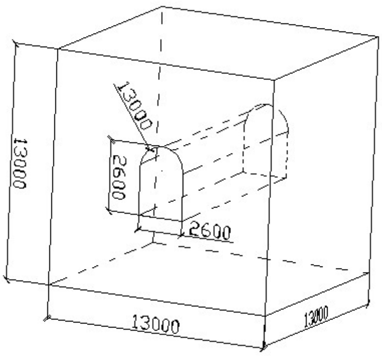
Then the rupture radius can be expressed as:

$$R_b = R_0\left\{\left\{\frac{2}{1+k_p}\left[p_0+\frac{\sigma_c}{k_p-1}+\frac{(k_p+1)k_5 p}{(k_p-1)(k_p+\eta_1)}\right]\left[\frac{2k_5 p}{2k_5 p+(1+\eta_1)(\sigma_c-\sigma_c^*)}\right]^{\frac{k_p-1}{1+\eta_1}}-\frac{2k_5 p+(1+\eta_1)(\sigma_c-\sigma_c^*)}{(k_p-1)(k_p+\eta_1)}\right\}/\left(p_i+\frac{\sigma_c^*}{k_p-1}\right)\right\}^{\frac{1}{k_p-1}} \tag{19}$$

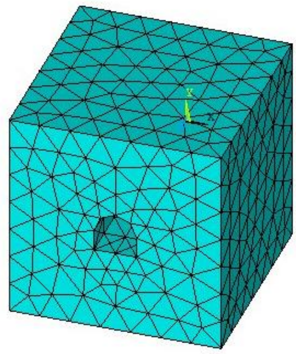
According to the surrounding rock properties and roadway cross-section size, in-situ stress size, plastic coefficient of expansion, rock softening modulus, supporting reaction force can determine the surface displacement of surrounding rock and radius of plastic and rupture zone.

4. NUMERICAL SIMULATION

Generally, the surrounding rock of roadway rock around that outside of larger 3 times than the hole is disturbed zone [11-12], so this paper calculate the range for 3 times length of the roadway span. In this paper, the calculation of the geometric model and finite element model is shown as Fig.4.



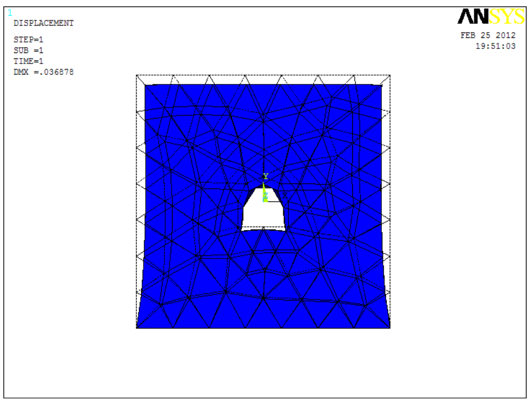
（a）The simplified model figure



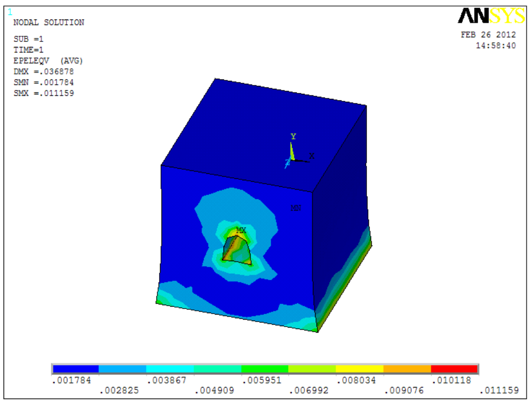
(b) finite element model figure

Fig.4 Calculation model figure

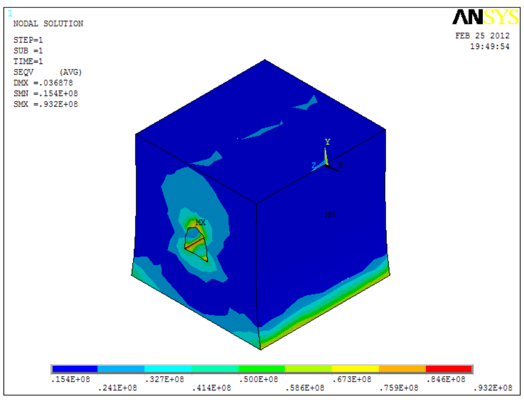
The roadway deformation figure, strain contour and stress nephogram using simulation calculation are shown as Fig.5.



（a）The deformation figure（natural state）



（b）Strain contour figure



（c）Stress contour figure

Fig. 5 The calculation results

The simulation results show that: the model the maximum stress appears at the top position in the roadway, which is consistent with the reality of the situation. The natural state of the sandstone roadway, the stress maximum for the top position is 9.32E8Pa; the datum read from the above displacement figure, the maximum displacement is 0.37m in the natural state. Maximum strain of the simulation of natural state is 0.11159.

CONCLUSION

Deformation of soft rock roadway and supporting technology is the important work of deep underground engineering, especially in the poor condition called "three high and one disturbance" after the deep mines transfer. And the stability of surrounding rock of roadway is the important premise of the mine economic benefits and the security situation. Therefore, it is necessary to study the deformation mechanism of deep soft rock roadway excavation and determine the reasonable way of supporting technology, and then the specific support measures. Under the condition of deformation mechanism of soft rock roadway excavation in the specific analysis, Jianxin Mine gets the ideal supporting effect with the supporting technology combined a variety of techniques. The roadway deformation and its mechanism, the calculation formulas for calculating the deformation of roadways, the radius of plastic zone and fracture zone radius were gained by theoretical analysis. And the numerical simulations for the roadway deformation were conducted. The simulation results show that the maximum stress appears at the top of the roadway, and its value 9.32E8Pa; the maximum displacement is 0.37m; the largest strain is 0.11159. All this are consistent with the reality of the situation.

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