Research on characters of surrounding rock in complex geology conditions and supporting time

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Abstract: The methods combined by test, field monitoring and theoretical analysis were adopted to do the systemic research on the rock mass from micro-structure to macro-deformation, and rheological model of Jinchuan rock mass was established to discuss the reasonable supporting time. Results show that supporting after suitable stress and displacement release can benefit for the long-term stability of surrounding rock.

Key words: complex geological conditions; surrounding rock; characteristic test; supporting time; rheological characteristic

1 Introduction

Rock mass under complex geological conditions is largely affected by ground stress and geological structures, therefore, the excavations works show some instability and creep characteristics. Many issues related to the instable problems have been addressed home and abroad, and a substantial number of tests and theoretical research on such soft rock as coal have been performed. It is commonly believed that rheological characteristic is the major feature of deep-buried rock mass[1-3]. In general, rheological deformation can be divided into stable rheological behavior and unstable rheological behavior, and the latter can lead to the failure of rock mass engineering. So deformation should be controlled in the range of stable rheological behavior when designing supporting. Modern supporting theory believes that it should make full use of the self-supporting ability of rock mass, and supporting should be performed after suitable pressure release of surrounding rock to form the flexible community of surrounding rock and supporting structures. The key problem is how much pressure should be released before supporting. Too much release may cause the lack in time for supporting; while, if the pressure is not resealed enough, the large pressure from the aggregated energy in the rock mass will make the supporting structure deform more, and even fail. Therefore, the supporting time theory was put forward by some scholars[4]. Based on the characteristics of No. Ⅲ Mine District of Jinchuan, test and theoretical analysis are adopted in this paper to do the reasonable supporting theory research on the surrounding rock in complex geological conditions.

2 General situation of engineering and analysis of influencing factors

Major and minor shaft engineering projects of No. Ⅲ Mine District in Jinchuan are located at the head of the brush structure formed by fractures F_1, F_2, F_8, F_3 and F_{58}, and the geological conditions are complex. The survey documents show that the rock layers through the major and minor shaft systems belong to Ⅲ ~ Ⅴ rock mass, the upper rock layer has good properties, which can be controlled by common supporting. But the rock mass below 1 220 m level has weaker properties, which are the unstable surrounding rock. The disclosed rock displays lumpy structure, powdery structure and strong expansibility, which cause the poor integral stability of rock mass.

Due to the occurrence of ore deposit and the target of mining, a crushing cave for the purpose of mining, whose buried depth is 573 m, should be excavated in the instable surrounding rock under the 1 165 m level. According to the monitoring results of exploratory drift, the horizontal deformation of surrounding rock of crushing cave are affected by many factors, including the properties of rock mass, excavation, penetrating of water, supporting type, and so on. They make rock mass generate long-term rheological deformation. As a result, it is necessary to do some research on the horizontal characteristics of surrounding rock to provide some basic materials for support design.

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3 Study of complex surrounding rock characteristics

3.1 Micro-structure and tectonic of ore rock

As seen from the determining result of ore rock in Table 1, mixed rock mass of No. Ⅲ Mine District in Jinchuan mainly includes calcite, chlorite and kaolinite. This type of rock would be expanding and muddy when meeting water, and this phenomenon is common below the level of 1 120 m.

Table 1 Mineral type and content of rock by X-ray diffraction

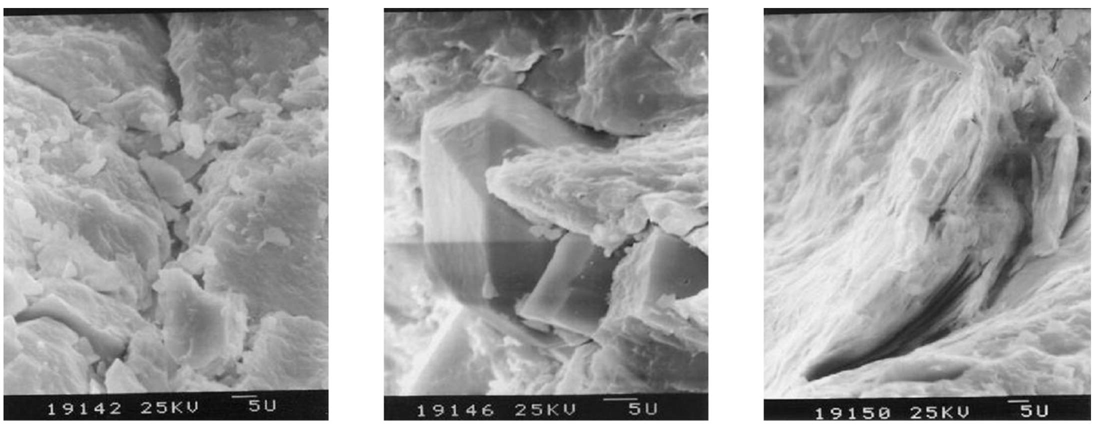
Rock type	Rock sample	Quartz /%	Felds-par/%	Calcite /%	Chlori-te/%	Mica /%	Kaolin-ite/%	Amphi-bole/%	Others /%
Mixed rock	Y-1	39	20	15	10	5	4	2	5
	Y-2	35	33	14	0	7	8	0	3
	Y-3	40	38	10	4	4	2	0	2

In order to analyze the micro-structure and tectonic of ore rock, aim at rock mass of 1 165 m level of main shaft, after 3 h of observation by the electron scan with magnification of 200 ~ 2000. Micro-fracture and minerals are shown in Fig. 1, and the conclusions are as follows:

1) Micro-structure of rock is loosening in the complex geological conditions, which form the crystal structure with many clay minerals. Those clay minerals exhibit accumulating body, which distribute on the surface of unweathered crystals;

2) There is a great deal of pores among every loosening accumulating body, and every pore is connected to each other, which form the good channel for the intrusion of water. This type of soft rocks would absorb water and be softened, expansive, and disintegrative even lost its strength;

3) Due to the action of techonic stress, regular crystal structure is tensioned to be fibrous and to be weak crystal structure. The damaging and weakening phenomenon make the rock mass lose its original strength.



(a) Incompact stuctural surface (b) Feldspar crystals (c) Tensed crystals by tectonic stress

Fig. 1 Micro-fracture of rocks in influence area

3.2 Creep test

In order to study the rheological property, some typical rock samples are gathered, then creep tests of samplings are performed by repeated loading and unloading, after long-time test of single rock in terms of different loading means, creep curve of mixed rock are shown in Fig. 2. As can be seen from the Fig. 2, at the final phase of rheological deformation, as the increasing of pressure, creep curve has the tendency to increase linearly with time and leads to the failure of rock. The creep curve diagram has the following characteristics:

1) There is an original rheological strength at every confined pressure. When the acting force is below the strength, samples will not generate rheological deformation, and when the acting force is greater than the strength, samples will generate rheological deformation.

2) When the acting force is greater than the original rheological strength, there is an obvious damping (the first phase) and a constant rheological deformation phase (the second phase) in the duration curve of samplings.

3) When the acting force approaches to the peak strength of samplings, samplings are short and enter into the accelerating phase quickly (the third phase).

3.3 Field monitoring of roadway

Monitoring work is done on the supported roadway

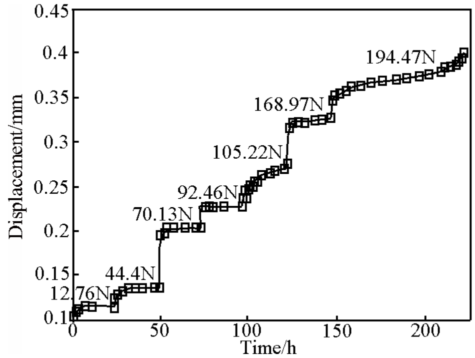


Fig. 2　Creep curve diagram of mixed rock

with the similar surrounding rock, and lasts nearly four months. Laser diastimeter and tape are adopted. According to the field situation, four points are monitored. Two points are fixed on both sides of roadway, whose convergence is measured at fixed time, part of the processed monitoring data are shown in Fig. 3. According to practice of roadway convergence monitoring of Jinchuan Mine and experience of home and abroad, there are three phases in the curve of convergence rate vs. times: sharp deformation, convergence rate $V > 0.25$ mm/d; decelerating deformation phase, convergence rate 0.1 mm/d $\leqslant V \leqslant 0.25$ mm/d; stable phase, convergence rate $V < 0.1$ mm/d, and the final value of it will less than 0.02 mm/d.

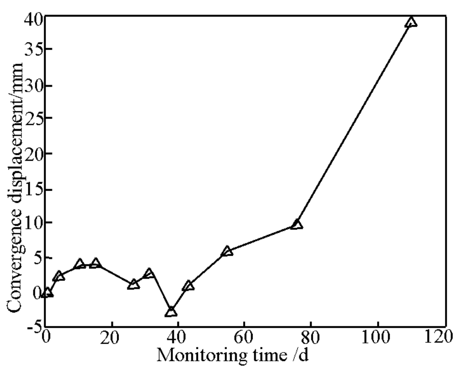


Fig. 3　Convergence displacement curve diagram of monitoring

After four months of monitoring, the convergence rate of the monitoring points are greater than 0.25 mm/d, therefore, the roadway is at the sharp deformation phase with obvious rheological properties, this phase will last for a long time.

4　Supporting time research

4.1 Foundation of rheological model

According to the creep test and the deformation monitoring of roadway, it is concluded that the rheological behaviors of deep soft rock mass in this district are the superposition of transient deformation and stable creep deformation, which will exhibit accelerating rheological deformation and failure under complex tectonic stress. From the view of damaging and fracture mechanics, the failure of rock mass attributes to the combination of external load and the evolution results of internal flaw, which is a progressive process[5,6]. The rheological deformation of rock mass in complex geological conditions is a comprehensive process with multi-deformation, including elasticity, plasticity, visco-elasiticity and visco-plasticity, whose stimulation analysis needs multi-units (linear and nonlinear units).

Before the establishment of rheological model, in order to embody the nonlinear rheological property of soft rock mass in high stress conditions, the viscous coefficients are amended. The relation between improved nonlinear viscous coefficients and time are as follows:

$$\eta' = \eta'_0 \exp\left[-A\left(\frac{\sigma}{\sigma_s} - 1\right)(t - t_0)\right] \qquad (1)$$

where, η'_0 is the viscous coefficient of t_0 or critical stress level σ_s; A is a positive constant , σ is the present stress level of rock mass; σ_s (positive constant) is the critical stress level when accelerating rheological deformation taking place; t_0 is the initial time when rock mass reaches the stress level .

In addition, the widely used viscous-elastic model is adopted, but the viscous coefficient of viscous units in this model is replaced by η', which forms the mended viscous-elastic model, as is shown in Fig. 4.

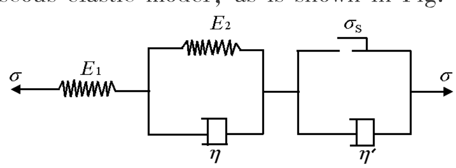


Fig. 4　Viscous-elastic mechanics model

When it is under higher stress level ($\sigma \geqslant \sigma_s$), the rheological deformation includes transient elastic deformation, transient plastic deformation, creep and relaxation. As time increases ($t \to +\infty$), it turns into unstable creep and even damage. Here, the rheological deformation equation is:

$$\varepsilon(t) = \frac{\sigma}{E_1} + \frac{\sigma}{E_2}\left\{1 - \exp\left[(-E_2/\eta)t\right]\right\} + \frac{\sigma - \sigma_s}{\eta'}t \qquad (2)$$

In this rheological model, Kelvin Model still follows the properties of stable rheological deformation, therefore, $\eta = \eta'_0$. In addition, in order to establish the rheological model suitable for practical engineering situation, take the nonlinear viscous coefficients η' into the Eq. (2). Then, the following equation is obtained:

$$\varepsilon(t) = \frac{\sigma}{E_1} + \frac{\sigma}{E_2}\left[1 - \exp\left(-\frac{E_2}{\eta_0'}t\right)\right] + \frac{(\sigma - \sigma_s)t}{\eta_0'}\exp\left[A\left(\frac{\sigma}{\sigma_s} - 1\right)(t - t_0)\right] \quad (3)$$

4.2 Numerical analysis of nonlinear rheologic parameters

According to the deformation characteristics of surrounding rock in 1 165 m level of main shaft and creep test as well as field monitoring data, Matlab is used to obtain the parameters of Eq. (3) in terms of least squares fitting method. Because the limited field data can not reflect the rheologic properties under different stress levels, numerical simulation is adopted to obtain a great deal of data, which are used to get the rheologic parameters of different stress level by curve fitting. $FLAC^{2D}$ is used to do numerical simulation. Numerical model is established according to the actual rock mass mechanical parameters and geological engineering assessment. Calculating parameters are shown in Table 2.

Table 2 Numerical analysis parameters of rock mass in cavern

Rock type	Density γ /(kg· m^3)	Tensile strength R_t/MPa	Cohesive strength C/MPa	Internal friction angle φ/(°)	Elastic ratio E/GPa	Poisson ratio μ	Bulk modulus B/GPa	Shear modulus G/GPa
Mixed rock	2 300	0.33	0.10	37	5.3	0.30	4.81	1.97

Roadway of 1 165 m level looked as calculating target in order to do comparison with monitoring data. The model size is 2.5 m × 2.5 m. In general, the influencing range is 4 ~ 6 times of the cross section. 20 m × 20 m range considering roadway as center is selected, and grids are 50 × 50. The numerical model is given in Fig. 5. Plastic model is adopted in this simulation to get the data suitable for roadway deformation. The horizontal stresses of surrounding rock are calculated by choosing different coefficients of horizontal pressure.

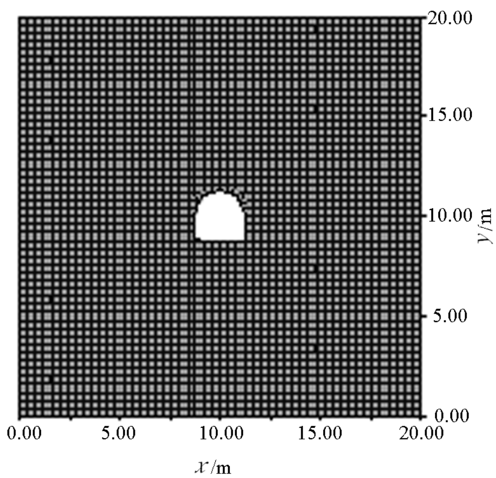


Fig. 5 Numerical model of nonlinear rheologic

Data obtained in above numerical model are fitted according to Eq. (3), when errors reach the minimum value, obtained variable parameters are reduced to get E_1, E_2, η'_0 and A. The fitting results are shown in Table 3, here, σ_s is set to 16 MPa, the average value of rock mass compress strength at crushing cave, Table 3 shows the changing of parameters with different maximum compress. The rheologic curve (Fig. 6) shows that the deformation of roadway arrive at stable under lower stress level (10.2, 13.2, 15.1 MPa), while under higher stress level (17.3, 20.5, 24.2 MPa), the roadway deformation has jump points and develops into unstable rheologic deformation, the deformation regularity under 17.3 MPa stress level approaches the rock deformation of 1 165 m level well, which can reflect the rheologic tendency intuitively. So, deformation characteristics under this stress level are adopted to do the research on reasonable supporting time.

Table 3 Calculation results of rheologic parameters on different stress level

Serial number	Max stress σ_{max}/ MPa	Vertical stress σ_h/MPa	Elastic module E_1/GPa	Elastic module E_2/GPa	Viscid coefficient η'_0/ (GPa· d)	Stress coefficient $A/10^{-3}$
1	10.2	8.30	1.585	3.125	14.377	2.432
2	13.2	10.40	1.342	2.813	14.335	2.122
3	15.1	12.00	1.112	2.524	14.301	1.987
4	17.3	14.07	1.362	2.685	67.868	0.042
5	20.5	16.67	1.552	3.032	68.258	0.033
6	24.2	18.46	1.724	3.874	68.851	0.019

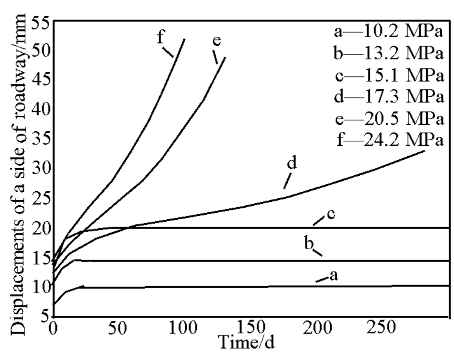


Fig. 6 Rheological curve diagram of rock mass in different stress level

4.3 Discussion of secondary supporting time

Because the rock mass of 1 165 m level of main shaft, No. Ⅲ Mine District in Jinchuan belongs to the state between unstable and stable. In order to assure the safety of construction, primary supporting should be done in short time after excavation and the main supporting types are cable plus mesh spray-layer. The primary support can assure the temporary stability of surrounding rock. But, due to the long-term existence of aging and rheologic properties, as time goes on, fractures in the rock mass expand gradually, which generate mutation and cause failure. Therefore, it is necessary to do reasonable secondary support, but, the key problem is when implementing the secondary support after primary support.

According to the properties of rheologic curve, there is a moderating process before the generation of jumping, therefore, referring to Eq. (3) , when the convergence rate after primary support are controlled in the range of 0.1 mm/d ≤ V ≤ 0.25 mm/d, the secondary support can be done. Taking the parameters under the forth stress level in Table 3 into Eq. (3) can get the rheologic rate curve of surrounding rock in 100 d (Fig. 7). When the rheologic rate reaches near 0.15 mm/d, rheologic deformation enters into moderating process, in addition, the maximum displacement is controlled in the range of 12 ~ 16 cm. Then, secondary support can be done. The best supporting time should be 15 ~ 21 d according to Fig. 7, namely, best secondary supporting time is in the third week after the primary support.

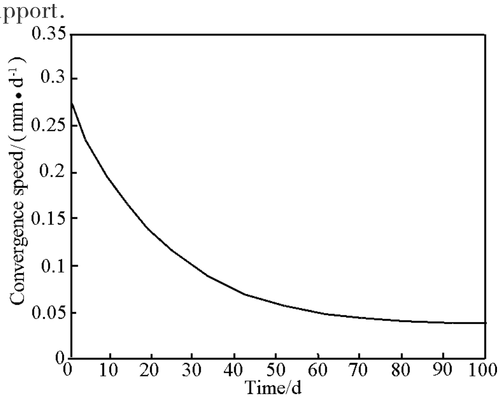


Fig. 7 Rheological speed rate curve diagram of rock mass in 1 165 m level

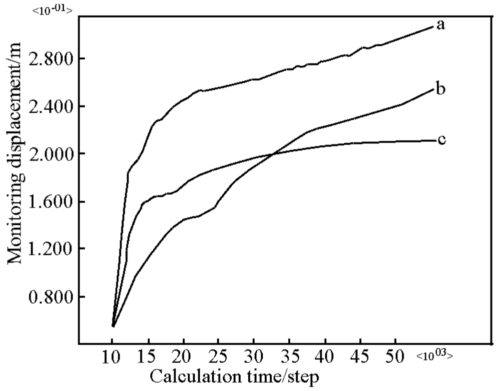
5 Application and verification of numerical analysis

Cave in 1 165 m level is designed. This cave is excavated by three steps, and its supporting project is shown in Table 4. According to the initial design, condition of surrounding rock and related criterions, the idea of suitable displacement release before supporting is brought up.

Table 4 Calculation project of support

Arch crown	Upper sider	Under sider	Secondary support
5 cm spray-up (C30) + 3 m sand pulp bolt (array pitch: 1.1; separation: 0.9)	5 cm spray-up (C30) + 3 m sand pulp bolt (array pitch: 0.9; separation: 0.9)	5 cm spray-up (C30) + 3 m sand pulp bolt (array pitch: 0.9; separation: 0.9)	15 cm pour concrete +8 m cable

In order to get the optimal supporting project with displacement release, nine projects are put forward according to actual construction condition. After comprehensive evaluation of maximum displacement, maximum axial stress bearing in supporting structure and safety factors after secondary support, optimal excavation and supporting project are as such: releasing displacement is 3 cm after excavation of net section, releasing displacement is 5 cm after primary liner, and another releasing displacement is 10 cm after primary support. Fig. 8 shows the comparison of monitoring data with three conditions: support after optimal displacement release, support after unreasonable displacement release and immediate support without displacement release. The curve 2 in Fig. 8 shows: immediate support without displacement release, displacement and convergence rate at earlier stage of excavation is low, convergence rate will kept at certain range in limited time. As time goes by, convergence rate of surrounding rock increases and evolutes to severe deformation even to failure. As can be seen from curve 1: supporting after excessive displacement release, the excessive displacement release leads to the increase of convergence rate of surrounding rock, this tendency can not be changed effectively even after support. At this time, the deformation of supporting structure and rock mass are not coordinate, that is to say, the supporting structure can not play role when the rock mass approach failure, which will cause the failure of the whole roadway. Besides, displacement changing situation of support after suitable displacement release is shown in curve 3, reasonable support after the releasing of rock internal strain energy will good to the stability of surrounding rock, as can be seen from figure, the convergence rate of curve 3 at earlier stage of excavation is less than that of curve 1 and great than that of curve 2, which suggest that definite deformation and deformation rate are permissible after suitable displacement release, but the deformation and deformation rate should not too large. As time goes on, the convergence rate of curve 3 is greater than those of curve 1 and 2 and enters into stable phase, which suggests that after suitable displacement release, the convergence rate of surrounding rock reaches stable state and final displacement is in the control range which is good to the stability of surrounding rock.



a—Support after unreasonable displacement release
b—Immediate support without displacement release
c—Support after optimal displacement release

Fig. 8 Displacement curve diagram of supported roadway after release stress

6 Conclusions

The conclusions are:

1) The rock mass of 1 165 m level of main shaft, No. Ⅲ Mine District in Jinchuan is affected by long term geological structure. Rheologic phenomenon is formed gradually when it excavated, and this rheologic action of the surround rock follow nonlinear characteristic.

2) The best secondary supporting time is in the third week after the primary support and excavating, based on the rheologic model of the rock mass of 1 165 m level in Jinchuan.

3) Supporting after reasonable time can not only benefit the long-term stability of surrounding rock, but also can improve the self-bearing, shear and compressive capacity. Controlling the convergence displacement in limit range can prevent the probability of large deformation.

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