Research on Secondary Support Time of Soft Rock Roadway

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***Abstract* – In order to determine accurately secondary support time, the adjustment process of surrounding rock stress and strength in the course of supporting is analyzed based on the support principle of soft rock roadway. Based on the rheological model of soft rock roadway and the corresponding relationship between the mechanics behaviors of elastic zone, plastic zone and fractured zone and rock complete stress-strain process, the theoretical formula of secondary support time is proposed. Then the influential factors and rules of secondary support time are analyzed. To validate the study, the secondary support time theory is applied to engineering practice. Results show the roadway maintains a good stability according to the proposed secondary support time.**

Keywords – soft rock roadway; secondary support time; rheological model Introduction

I. INTRODUCTION

Many tunnels in China need to be excavated in soft surrounding rock, especially in the construction of underground coal mine. Due to the rheological characteristics of soft rock, roadway after excavation gradually deformed, which could cause new cracks in rock, propagation of cracks reduces the strength of the rock, thus easily lead to roadway surrounding rock instability and failure, and due to the generation of cracks, soft rock roadway will be porous and permeable phenomenon occurred, increasing the difficulty of support of soft rock roadway.

Due to rock with rheological properties in the soft rock roadway, using a branch support is still not up to the requirements of the stability and secondary support method is usually adopted. Release of massive plastic properties in the surrounding rock after primary support, and then the second supporting is adopted [1-5]. But engineering practice shows that the secondary support in time and strength is difficult to maintain coordination with the surrounding rock deformation, if secondary support time is more earlier after the initial support, great of soft rock plastic strain cannot be fully released, the strength of secondary support is difficult to resist the huge plastic deformation and damage of surrounding rock. If secondary support late, although plastic strain free, surrounding rock carrying capacity decreases. Therefore, it is necessary to solve the coupling problem between the secondary support in time and strength and the characteristics of surrounding rock, and choose the best time of secondary support time of soft rock roadway. In this paper, based on the relationship between the mechanical behavior of surrounding rock and the stress-strain of rock, using the rheological model of soft rock roadway, the theoretical formula of the best time of the secondary support is determined finally.

II. DETERMINATION OF SECONDARY SUPPORT TIME OF SOFT ROCK ROADWAY

The secondary support is different from the initial support, especially in the choice of the timing of support. The secondary support usually occurs after the deformation of the soft rock, it is best time to support. But on the other hand, in order to maintain the stability of the roadway, the bearing capacity of the rock must be able to guarantee the stability of the rock.

A. *The soft rock roadway engineering support principle*

Assuming after the roadway excavation surrounding rock force P_T in the rock moving to the area of the excavated, the resultant force including gravity, water force, expansion force, tectonic and engineering partial stress, According to the literature [5], the principle of roadway supporting is expressed by the following formula:

$$P_T = P_D + P_R + P_S \tag{3}$$

Where, P_T is join forces after excavation of surrounding rock; P_D is a deformation of the form of transformation of the engineering force; P_R is the bearing capacity of surrounding rock; P_S is the support force of surrounding rock engineering.

The formula (1) is analyzed: the resultant force P_T of surrounding rock mass contains three parts after the tunnel excavation: P_D P_R and P_S. In order to ensure the stability of the roadway to meet the conditions: $(P_R+P_S)>(P_T-P_D)$.

B. *Determination of the best supporting time*

According to the definition of literature [5-6], the best time to support Ts is (P_R+P_D) - t curve corresponding to the peak point of the time. Taking into account the engineering practice, it is difficult to determine the specific time points, and put forward the best supporting time. As shown in Figure 1, T_{s1} ~ T_{s2} time period is the best time period.

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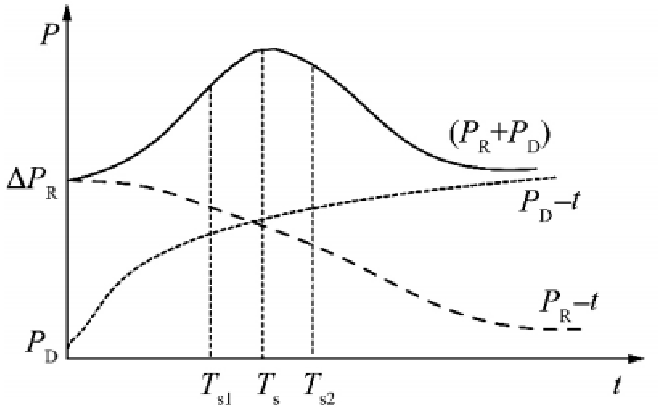

Fig.1.Optimal support time and the optimal support time interval

According to the above analysis, the best supporting time can be obtained when the (P_R+P_D) - t curve peak value is known. In engineering practice, however, due to the influence of many factors is hard to find out the concrete relationship of P_R and P_D, so the method of reference [5] is more difficult to accurately quantify the best supporting time.

According to the surrounding rock loose circle theory, the mechanical behavior of elastic zone, plastic zone and fracture zone of surrounding rock is corresponding to the corresponding section of the whole stress-strain curve of the rock[10-11]. As shown in Figure 2, the yield limit of the rock entering the plastic phase is about 2/3, which is about the peak strength, when the stress of the rock is further expanded until it is greater than or equal to the peak strength, the rock is loose and damaged. According to the analysis of the best supporting time, it is needed to ensure that the surrounding rock can enter the plastic zone to the maximum extent, but it cannot be broken. Therefore, the best supporting time can be expressed by the formula:

$$\frac{2}{3}\sigma_{\theta rct} \le \sigma_t \le \sigma_{\theta rct} \tag{2}$$

Where, $\sigma_{\theta rct}$ is the stress limit of the three axis of the surrounding rock of roadway; σ_t is the stress of surrounding rock in t time.

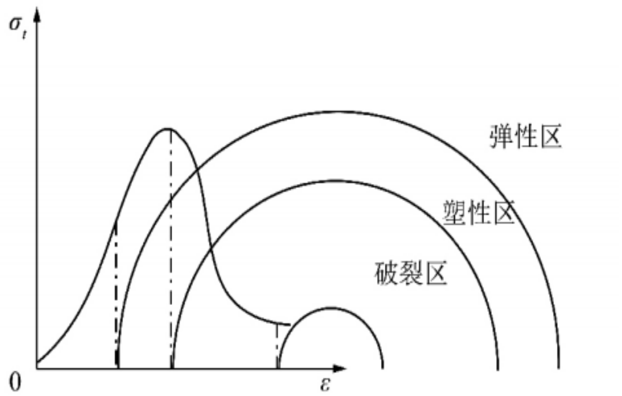

Fig.2.Zone of road way surrounding rock

III. RHEOLOGICAL MATHEMATICAL MECHANICAL MODEL OF SOFT ROCK ROADWAY

According to the above analysis, determination of the best supporting time needs to study the characteristics of surrounding rock long-term strength and stress distribution of surrounding rock[12-16]. Through the reasonable establishment of the soft rock roadway rheological mathematical mechanical model to master the relationship between the strength and the stress distribution of the surrounding rock under the rheological conditions of the soft rock roadway, and scientifically and reasonably determine the timing of the secondary support.

A. *Long term attenuation characteristics of rock*

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

In general, there are two main types of rock failure: 1The load of rock is greater than the instantaneous strength, and the rock will soon be destroyed;2Under the influence of the rheological action, the long-term strength of the rock will be decreased with the increase of the time of the external load.

According to the literature [14-15], the long-term strength of rock is attenuated with time (Fig. 3), and the long-term strength formula of the rock is as follows:

$$\sigma_{ct'} = \sigma_{c0}\exp\left(\frac{-at}{b+t}\right) \tag{3}$$

Where, σ_{c0} is the instantaneous compressive strength of rock; $\sigma_{c\infty}$ is the long-term compressive strength of rock; $\sigma_{ct'}$ is the rock compressive strength of t' at any time; a b are undetermined constants.

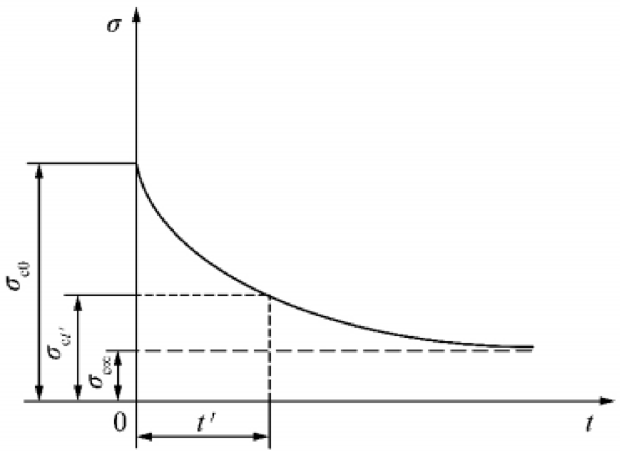

Fig.3.Long-term strength curve of rock

B. *Nonlinear rheological model of roadway*

The following assumptions are made to the roadway of soft surrounding rock in underground space: 1The surrounding rock of roadway is a continuous, homogeneous and isotropic ideal elastic and plastic body;②In the length of the long tunnel, the properties of surrounding rock are consistent;③The buried depth is at least 20 times greater than the tunnel radius, and the level of the original rock stress can be simplified as the uniform distribution of stress. The problem to be studied in this paper is simplified as a plane strain circular hole problem with axial symmetry, and its mechanical model is shown in Figure 4.

Taking into account the actual excavation process, the surrounding rock is subjected to the radial stress of the section σ_r, tangential stress σ_θ and the role of the roadway axial stress σ_z , which are equivalent to the minimum principal stress σ_3, the maximum principal stress σ_1, the intermediate principal stress σ_2:

$$\sigma_r < \sigma_z < \sigma_\theta \tag{4}$$

Applying Mohr-Coulomb criteria, the analytical solution formula of the radial stress σ_r and tangential stress σ_θ in the plastic zone of roadway section to the distance from the axis of the tunnel to the tunnel axis is as follows

$$\sigma_r = (p_i + c\cot\varphi)(\frac{r}{r_a})^{\frac{2\sin\varphi}{1-\sin\varphi}} - c\cot\varphi \tag{5}$$

$$\sigma_\theta = (p_i + c\cot\varphi)\frac{1+\sin\varphi}{1-\sin\varphi}(\frac{r}{r_a})^{\frac{2\sin\varphi}{1-\sin\varphi}} - c\cot\varphi \tag{6}$$

Where, c is the material of cohesion; φ is the angle of internal friction material; r_a is the tunnel section radius; p_i is the initial support resistance.

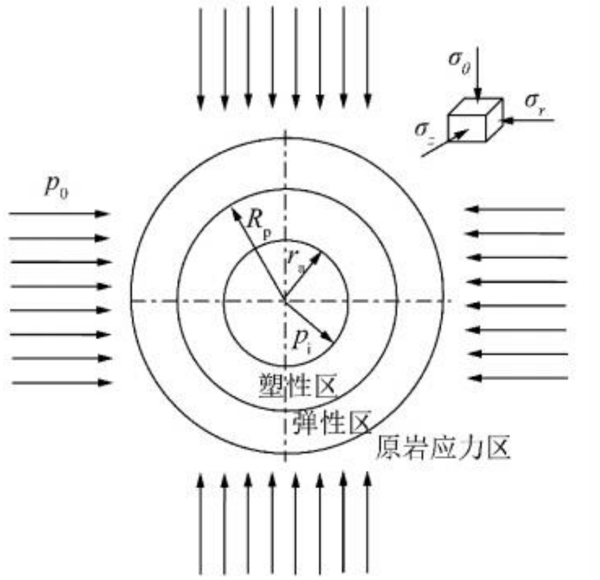

Fig.4.Surrounding rock of roadway model diagram

According to the practice of literature [14,16], the stress of the tunnel confining pressure can be expressed by the radial stress and tangential stress, the formula is as follows:

$$\sigma_t = \sigma_\theta - \sigma_r = \frac{2\sin\varphi}{1-\sin\varphi}(p_i + c\cot\varphi)(\frac{r}{r_a})^{\frac{2\sin\varphi}{1-\sin\varphi}} \tag{7}$$

C. The transformation of uniaxial stress limit and three-axis stress limit of rock

The transformation of uniaxial stress limit to three axis stress limit of rock can be realized by using the Mohr 'stress circle, and the Mohr 'stress circle is shown in Figure 5.

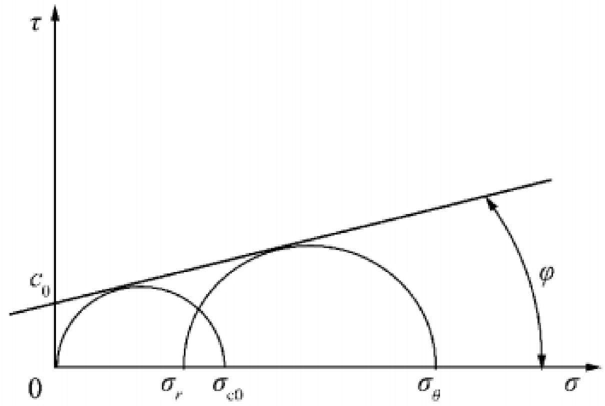

Fig.5.Schematic diagram of linear Mohr strength theory

According to the relationship between the maximum principal stress and the minimum principal stress in the three axial stress state of rock, the formula of three axial stress ultimate strength of rock can be found as follows:

$$\sigma_{\theta rc0} = \frac{2c\cos\varphi}{1-\sin\varphi} + \frac{2\sigma_r\sin\varphi}{1-\sin\varphi}, \sigma_{c0} = \frac{2c\cos\varphi}{1-\sin\varphi}$$

The nature of surrounding rock will change in the process of rock rheology, so the instantaneous strength of rock is considered, make c as the initial cohesion c_0; φ equal to the initial internal friction angle $\varphi 0$, When σ_{c0} is seen as $\sigma_{\theta rc0}$, then the previous formula is changed to the following formula:

$$\sigma_{\theta rc0} = \sigma_{c0} + \frac{2\sigma_r\sin\varphi_0}{1-\sin\varphi_0} \tag{8}$$

Simultaneous formula (3), (8), the long-term strength formula of rock under three axial stress condition is obtained.

$$\sigma_{\theta rct} = \sigma_{\theta rc0}\exp(\frac{-at}{b+t}) = (\sigma_{c0} + \frac{2\sigma_r\sin\varphi}{1-\sin\varphi})\exp(\frac{-at}{b+t}) \tag{9}$$

D. Determination of the best supporting time

According to the formula (2), soft rock roadway surrounding rock stress should be satisfied: $\frac{2}{3}\sigma_{\theta rct} \le \sigma_t \le \sigma_{\theta rct}$, and simultaneous formula(7), (9)

$$\frac{2}{3}(\sigma_{c0}+\frac{2\sigma_r\sin\varphi}{1-\sin\varphi})e^{\frac{-at}{b+t}} \le \frac{2\sin\varphi}{1-\sin\varphi}(p_i+c\cot\varphi)(\frac{r}{r_a})^{\frac{2\sin\varphi}{1-\sin\varphi}} \le (\sigma_{c0}+\frac{2\sigma_r\sin\varphi}{1-\sin\varphi})e^{\frac{-at}{b+t}}$$

(10)

The maximum value of the surrounding rock stress occurs at the junction of the plastic zone and the radius of elastic region R, and at this time R satisfies the following formula.

$$\frac{R}{r_a}=\left[\frac{(p_0+c\cot\varphi)(1-\sin\varphi)}{(p_i+c\cot\varphi)}\right]^{\frac{1-\sin\varphi}{2\sin\varphi}} \quad (11)$$

Let the r=R in the formula (10), then put it to formula (11).

$$\frac{3(p_0\sin\varphi+c\cos\varphi)}{\sigma_{c0}+2p_0\sin\varphi-(c\cos\varphi+p_i)\frac{\sin 2\varphi}{1-\sin\varphi}} \quad (12)$$

As the soft rock tunnel excavation process, the surrounding rock stress redistribution, the surrounding rock crack generated expansion, the mechanical properties of surrounding rock is deteriorating[17-18]. The rock strength parameters c and φ are satisfied: $c=mc_0$, $\varphi=n\varphi_0$.

$$A=\frac{p_0\sin\varphi+c\cos\varphi}{\sigma_{c0}+2p_0\sin\varphi-(c\cos\varphi+p_i)\frac{\sin 2\varphi}{1-\sin\varphi}} \quad (13)$$

Where, m is the ratio of long-term cohesion and instantaneous cohesion; n is the ratio of the internal friction angle and the instantaneous internal friction angle in the long term; put the A into (12), best supporting time can be expressed as:

$$T_{s1}=\frac{-b\ln(3A)}{\ln(3A)+a} \le T_{s2}=\frac{-b\ln(2A)}{\ln(2A)+a}$$

(14)

IV. Engineering Application

Through the formula (13), (14) analysis can be seen that the influence of the secondary supporting time factors: original rock stress p_0, initial support resistance p_i, instantaneous compressive strength of surrounding rock mass σ_{c0}, cohesion c and internal friction angle of rock mass φ. Considering from the roadway excavation roadway in the whole process of supporting, rock cohesion c and internal friction angle φ constantly changing, which is the key factor to determine the stability of surrounding rock and the time of the secondary support.

A. Engineering background

The wind tunnel wall in Jiulong mine of Fengfeng Group is pedestrian semi-circular arched tunnel, The surrounding rock is mainly soft rock, the initial stress is self weight stress, and the horizontal tectonic stress is 1.3 times of the vertical stress. The original branch support using bolting and shotcreting with wire mesh combined support, but as the roadway deformation is too large, so decided to use secondary support. According to the theoretical formula of the best supporting time, by field observation and experimental research, the parameters are as follows: p_0=13MPa,p_i=0.5MPa,c_0=2.5MPa,φ_0=30°,m=0.35,n=0.60,a=0.5,b=100. Taking these parameters into the formula (13), (14), the best supporting time is obtained : 0≤Ts≤14.2003d, However, taking into account the actual supporting process to make the surrounding rock fully deformed and released the huge plastic performance, the time of the secondary support should be close to the theoretical value of the upper limit but not more than the upper limit value. Therefore, the theoretical results were further modified to determine the best time for the secondary support 13-14d, the actual 14d after a support, using combined support with anchor cable and wire mesh for the secondary support.

B. Site monitoring

The roadway surface displacement with and without secondary support was observed, the results of observation as shown in Figure 6, 7. From Figure 6 we can see that both sides convergence of roadway increases rapidly after the initial support of roadway. After the initial support is completed, and then wait for 14 days to carry out the secondary support. After the secondary support, the deformation speed of the roadway has been greatly reduced through observation, which is basically in a stable state; at the same time, both sides convergence of roadway without the secondary support is still a substantial increase, both sides convergence of roadway began to slow down until about 35d,but there is a trend of increase after 50d.

The convergence of roadway with and without secondary support are shown in Figure 6, 7

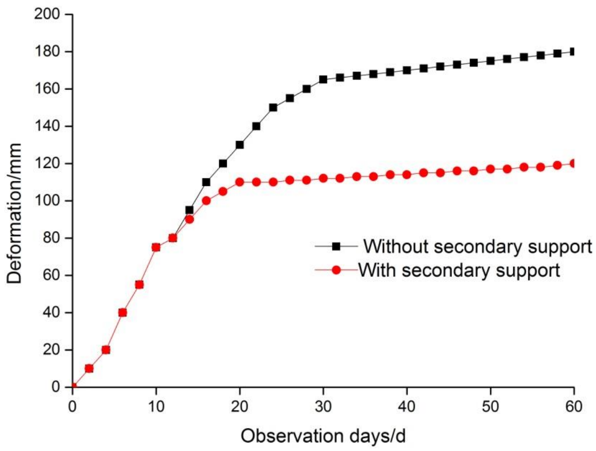

Fig.6.Both sides convergence of roadway with and without secondary support

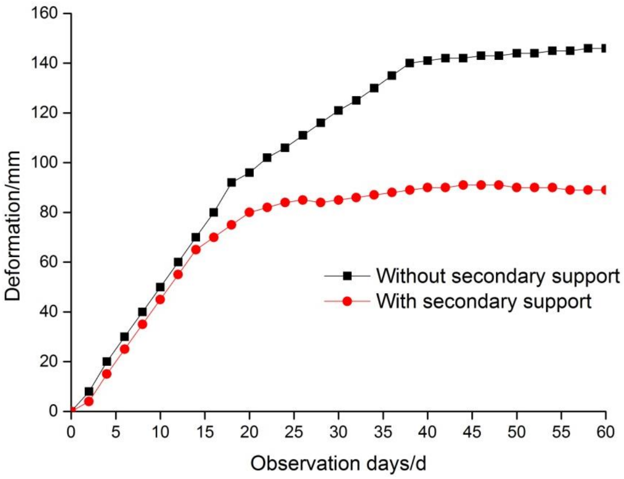

Fig.7.Roof to floor convergence of roadway with and without secondary support

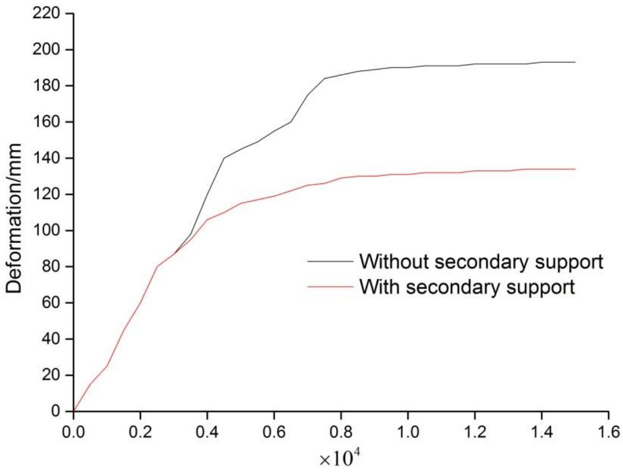

Fig.9.Numerical simulation of both sides convergence of roadway with and without secondary support

C. *Numerical simulation*

FLAC3D numerical simulation software was used to test the effect of the secondary support, in the three-dimensional numerical model, the parameters are as follows: Bolt's elastic modulus 45GPa. Maximum tensile strength is 310KN, the cohesive force of the cement slurry is 108N/m, the elastic modulus of the anchor shotcrete layer is 6GPa and the density is 2200kg/m^3. In the model, the vertical stress of 19.68MPa is applied to simulate the weight of overlying strata, Applying Mohr-Coulomb criterion in the three-dimensional numerical model, Three dimensional numerical model is shown in Figure 8.

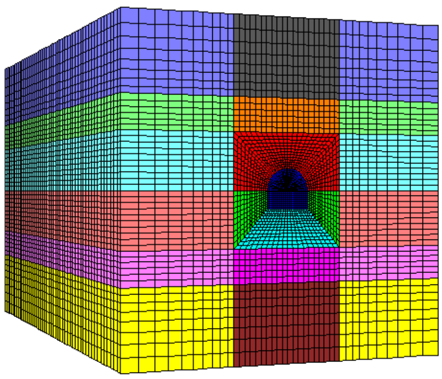

Fig.8.Three-dimensional numerical model

In order to simulate secondary support and protects the opportunity, this paper sets the maximum unbalanced force and typical internal force of the ratio R, through the adjustment of R simulation the time of the secondary support, numerical simulation results are shown in Figure 9 and 10.

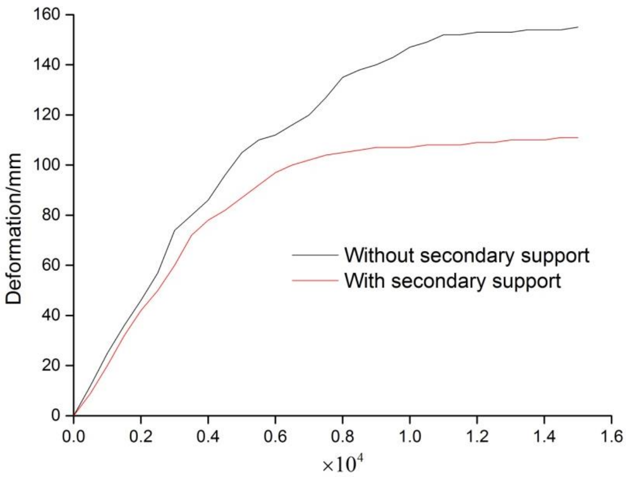

Fig.10.Numerical simulation of roof to floor convergence of roadway with and without secondary support

D. *Result analysis*

Through on-site monitoring data shows that time variation curve of displacement of roadway roof and floor is similar both sides, Roof to floor convergence of roadway with secondary support is 95mm, Both sides convergence of roadway with secondary support is 120mm. The deformation speed of the both sides and the roof and floor of the roadway are greatly reduced after the secondary support, and the deformation speed of surrounding rock is less than 0.32mm/d after 30d, at this time can be considered to maintain the basic stability of the roadway. Through the observation of the surface displacement of roadway show that the theoretical formula of quadratic optimal supporting time is reasonable, scientific and rational choice of supporting time is to realize the secondary support between the time and the intensity and characteristics of surrounding rock coupling of an important condition. This conclusion is also confirmed by FLAC3D numerical simulation analysis.

V. CONCLUSION

(1) Based on the principle of soft rock roadway engineering support, combined with the rheological model of soft rock roadway, the theoretical formula of the best time of the secondary support is determined finally.

(2) Through the study of the best time of the secondary support, the strength parameters of surrounding rock have important influence on the time of the secondary support: the greater the instantaneous strength parameters of rock, the more the strength parameters decrease when the rock is damaged, the time of the secondary support is correspondingly larger.

(3) Applying the theory to practical engineering, and determining the best time of the secondary support is 13- 14d, Through the analysis of the tunnel surface displacement observation and the FLAC3D numerical simulation software, it shows that the theoretical formula is reasonable.

REFERENCES

[1] Bai Jianbiao,Wang Xiangyu,Yao Zhe. Study of coupling support in soft rock roadway under high stress[J]. Journal of China University of Mining & Technology,2007,36(4):421-425.

[2] Li Dawei, Hou Chaojiong, Bai Jianbiao. Control mechanism and application of doubly supported roadways with large rigidity and high strength[J].Chinese Journal of Geotechnical Engineering,2008,30 (7):1072-1078.

[3] Chang Qingliang,Zhou Huaqiang,Li Dawei. Stability principle of extremely rigid secondary support for soft and broken rock roadway[J]. Journal of Mining & Safety Engineering, 2007, 24 (2):169 -172.

[4] Fang xinqiu,Zhao Junjie,Hong Muyin. Failure mechanism and control measure of roadway deformation with fractured surrounding rock in deep mine[J].Journal of Mining & Safety Engineering,2012,29 (1):1-7.

[5] He Manchao, Sun Xiaoming. Design and construction of support & protection engineering of coal mine in China[M]. Beijing:SciencePress,2004.

[6] Zhao Zenghui,Wang Weiming,Wang lei. Response models of weakly consolidated soft rock roadway under different interior pressures considering dilatancy effect[J].Journal of Central South University,2013,20(12): 3736-3744.

[7] Zhang Zhouping,Yu Weijian,Gao Qian. Study on time and parameter design for engineering support of wall rock at depth in Jinchuan Mine[J].Metal Mine,2008,2(5):40- 44.

[8] Chen Weizhong,Tan Xianjun,Lü Senpeng,et al. Research on largescale triaxial compressive rheological test of soft rock in depth and its constitutive model[J]. Chinese Journal of Rock Mechanics and Engineering,2009,28(9):1735-1744.

[9] Wang Yonggang, Ren Weizhong. Creep damage characteristics and decision of optimum support time for weak surrounding rock creep damage characteristics and decision of optimum support time for weak surrounding rock[J]. China Railway Science,2007,28(1):50-55.

[10] Cai Meifeng,He Manchao,Liu Dongyan. Rock mechanics and engineering[M]. Beijing: Science Press,2002.

[11] He Manchao,Yuan Hesheng,Liu Dongyan. Bolt support theory and practice of China coal mine[M].Beijing:Science Press,2004.

[12] He Yongnian, Han Lijun,Wang Yansen.Brief course of rock and soil mechanics[M]. Xuzhou: China University of Mining Science and Technology Press,2010.

[13] Jiang Binsong,Zhang Qiang,He Yongnian.Research on large-scale triaxial compressive rheological test of soft rock in depth and its constitutive model[J]. Chinese Journal of Rock Mechanics and Engineering,2007,26(5):982 -986.

[14] Wan Zhijun,Zhou Chuliang,Ma Wending,et al. Nonlinear rheological mathematical-mechanical of surrounding rock deformation of roadways or tunnels and its preliminary application[J].Chinese Journal of Rock Mechanics and Engineering,2005,24(5):762-767.

[15] Wan Zhijun,Zhou Chuliang, Luo Bingquan. A non-linear rheologic mathematical mechanical model of roadway' s surrounding rock in weak rock[J]. Journal of China University of Mining & Technology,2004,33(4):468-472.

[16] Chen Yanguang,Lu Shiliang. Tunnel surrounding rock control of China coal mine[M]. Xuzhou: China University of Mining Science and Technology Press,1994.

[17] Pen Suping,Wang Xiliang,Liu Xianwei.Research on rhelogical characteristics of rock in the weak coal-bearing strata[J]. Journal of China Coal Society,2001,26(2):149-152.

[18] Lu Yinlong,Wang Lianguo,Zhang Bei,et al.Optimization of bolt-grouting time for soft rock roadway[J]. Rock and Soil Mechanics,2012,5(33):1395-1401.