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Study on Failure Mechanism and Support Design of Tunnel Surrounding Rock

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Abstract: Taking a tunnel as the engineering background, this paper focuses on the mechanism of large deformation of soft rock, the design and optimization of supporting technology, aiming at the problem of large deformation of tunnel surrounding rock. By means of numerical simulation, the failure mechanism of structural large deformation of layered surrounding rock is deeply analyzed and studied. The tunnel is simulated with different support parameters to find more reasonable support parameters and optimize the existing support. The results show that the displacement of surrounding rock increases with the increase of upper load. When the roof load is less than 0.7 MPa, the vertical displacement of the sensitive block tends to be stable after a certain period of time; When the top plate load is 0.7 MPa, the vertical displacement of the roof sensitive block cannot converge, so some reinforcement measures must be taken at this time. When the tunnel is supported by bolts, the longer the length of bolts, the better the effect will be. 3m anchor length should be selected for support, and other support methods should be added to control tunnel deformation.

Keywords: Tunnel, Surrounding rock, Support.

1. Introduction

The complexity of tunnel geological conditions and the progress of construction technology put forward newer requirements and higher challenges to engineering geology, rock mechanics and geophysics. If the surrounding rock grade of the tunnel is not high, with the advance of the tunnel face, the surrounding rock of the tunnel will be gradually destroyed due to the stress redistribution of the surrounding rock and the strain softening of the rock mass after the tunnel excavation. When the tunnel support is not timely or the support parameters are not reasonably selected, the deformation pressure and expansion pressure formed by the formation pressure can cause the surrounding rock to be destroyed, and the resulting loose pressure will cause the surrounding rock to be unstable. The design specification for the large deformation of the tunnel is basically blank, and the existing design and construction methods have not yet established a set of mature and reliable methods. There are still many places to be explored and studied in this respect [1-3]. Taking a tunnel as the engineering background, this paper focuses on the mechanism of large deformation of soft rock, the design and optimization of supporting technology, aiming at the problem of large deformation of tunnel surrounding rock. By means of numerical simulation, the failure mechanism of structural large deformation of layered surrounding rock is deeply analyzed and studied. The tunnel is simulated with different support parameters to find more reasonable support parameters and optimize the existing support.

2. Failure Mechanism Analysis of Tunnel Surrounding Rock

At present, there are many soft rock tunnel projects in China. Because of the different lithology, occurrence, in-situ stress and groundwater, soft rock tunnels show different engineering problems, among which the most obvious ones are the large deformation of surrounding rock, over-excavation of tunnels, collapse and falling blocks. Large deformation of surrounding rock can be divided into the following situations: influenced by rock properties, surrounding rock structure and excavation behavior [4]. Because of the different engineering geological conditions of tunnels, the tunnel is buried deeper and deeper, and the support methods are diversified, the practicability of many previous research results is also limited. On the one hand, the surrounding rocks of deep-buried tunnel projects are subjected to the existing geostress, on the other hand, the stress concentration and redistribution caused by excavation lead to deformation and failure of some surrounding rocks, resulting in loose circles.

It is an important premise and foundation for effective deformation control of soft rock tunnel to find out the deformation characteristics, development and evolution law of soft rock tunnel. The deformation law and duration around the tunnel determine the excavation scheme and support technology. The development form of deformation and the ability of surrounding rock to bear deformation provide the basis for dynamic management of construction. Among them, the deformation of hard rock mainly occurs elastic and plastic deformation; The soft rock mainly undergoes creep and plastic deformation [5-6].

If the tunnel construction is supported by general support, and then under the action of high ground stress, the previous support produces a certain displacement U, and the radius of the tunnel is expressed by r, then once U/r exceeds 3%, it is judged that the surrounding rock deformation is large at this time.

In this study, the relative quantity D_b of absolute deformation value to the radius of the upper tunnel is used to describe the large deformation of surrounding rock, namely:

$$D_b = \frac{U_a}{R_0} \tag{1}$$

Where U_a, R_0 is the maximum normal deformation displacement of the tunnel side wall and the radius of the circumscribed circle of the tunnel excavation clearance respectively.

If the soft rock is severely cut by bedding and joints or is affected by the broken zone of prayer layer, the rock mass will be loose and there is no obvious bedding direction and crack propagation law. If it is assumed that the rock before tunnel excavation has reached a relatively stable state under the action of in-situ stress for a long time, then the stress concentration gauge of surrounding rock around the tunnel at the moment of tunnel excavation conforms to the elastic mechanical solution [7].

If it is assumed that the tunnel is under the action of uniform stress σ_0 before excavation, the stress state at the edge of the tunnel will change immediately after excavation, and according to the third strength theory, the rock mass is in an unyielding state when it meets the following formula:

$$\sigma_1 - \sigma_3 \leq [\sigma] \tag{2}$$

According to the traditional mechanical theory of plastic parts, the stress state around the tunnel can be expressed by the following formula:

$$\left.\begin{aligned} \delta_{\rho p} &= \frac{R_b}{\xi - 1}\left[\left(\frac{\rho}{a}\right)^{\xi-1} - 1\right] \\ \delta_{\varphi p} &= \frac{R_b}{\xi - 1}\left[\left(\frac{\rho}{a}\right)^{\xi-1}\xi - 1\right] \end{aligned}\right\} \tag{3}$$

Where $\delta_{\rho p}, \delta_{\varphi p}$ is radial stress and non-directional stress respectively, R_b is uniaxial expansion strength of surrounding rock, a is tunnel radius, and $\xi = \dfrac{1+\sin\varphi}{1-\sin\varphi}$ and φ are internal friction angles.

The surrounding rock of the tunnel is simplified as a geological model whose strike is parallel to the tunnel axis and the inclination angle changes randomly in the plane. Among them, the structural plane of surrounding rock considers two aspects: thin sheet characteristics and calculation efficiency, and its spacing is uniformly 0.1 m. The numerical calculation of displacement field after excavation is carried out by using 3DEC discrete element numerical analysis software [8]. Vertical and horizontal stresses are applied according to the in-situ stress measured data in Table 1.

Table 1. Simulation parameters of surrounding rock and layered structural plane

parameter	density/(kg/m^3)	modulus of elasticity /GPa	Poisson's ratio	cohesive strength /MPa	internal friction angle/ (°)	tensile strength/MPa
surrounding rock	2200	14	0.23	1.5	40	12
structural surface	-	-	-	0.3	2.7	26

The numerical results show that under the same occurrence condition, the deformation displacement of layered rock tunnel increases with the increase of lateral pressure coefficient K, that is, the horizontal tectonic stress where the tunnel is located, and the range of excavation disturbance (plastic circle) continues to expand, but the concentrated part of deformation will not change.

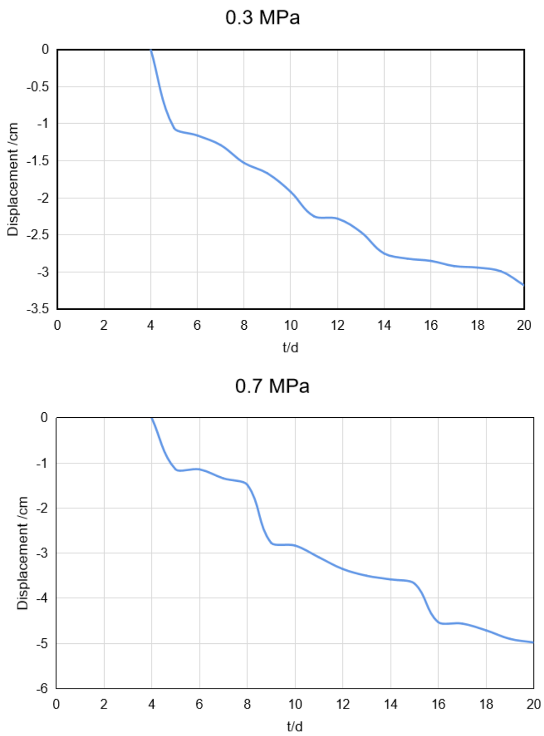

Figure 1. Vertical displacement of sensitive block

When the tunnel roof is pebble bed, the physical and mechanical parameters of the model are the same as those when the roof is mudstone, but there is no load above the top slab. The numerical simulation results show that the vertical deformation of the tunnel is the largest at the axis of the arch in all cases. In order to understand more clearly the changes of stress and strain in the process of cavern failure, the vertical maximum deformation block, namely sensitive block [9-10], is tracked and simulated in the calculation, and its change curve is shown in Figure 1.

The simulation results show that the displacement of surrounding rock increases with the increase of upper load. When the roof load is less than 0.7 MPa, the vertical displacement of the sensitive block tends to be stable after a certain period of time; When the top plate load is 0.7 MPa, the vertical displacement of the roof sensitive block cannot converge, so some reinforcement measures must be taken at this time.

3. Support Design of Tunnel Surrounding Rock

Tunnel supporting structure system is the basic requirement to ensure the stability of tunnel surrounding rock. Based on the understanding of surrounding rock structure and load effect, many scholars at home and abroad have interpreted the essential function of supporting structure, thus forming various tunnel design theories and methods. In the current tunnel design code, the scheme and parameters of advance support, anchor support and initial support are determined mainly by engineering experience. As far as its function is concerned, the essential function of support is to mobilize and assist the surrounding rock to bear the load. Obviously, the surrounding rock is not only the source of load, but also the main bearer of load, and its mechanical behavior will inevitably affect the stability of the whole system.

When building a tunnel in soft rock, the choice of supporting measures is very important to control large deformation, and the supporting scheme suitable for geological conditions should be selected. Whether the scheme is correct or not will directly affect the construction safety, progress and economic benefits. The commonly used supporting schemes in tunnel construction include: anchor rod, shotcrete, steel arch, advanced support and grouting.

In order to establish numerical models of different support schemes for engineering tunnels, including support schemes with different anchor lengths and different anchor cable lengths, anchor lengths are 2.4m, 2.6m, 2.8m and 3m for simulation, and anchor cable lengths are 5.5m, 6.5m and 7.5m for simulation. At the same time, the shotcrete support methods are simulated under the existing anchor support, and the thickness of shotcrete is 10cm, 20cm and 30cm respectively. It is analyzed by FLAC numerical simulation.

FLAC numerical simulation results show that when the anchor length is 2.4m, it can reach 1.508m, but the maximum displacement of the vault is 1.5068m after the anchor length is lengthened to 3.0m m. It can be seen that changing the anchor length has poor control effect on the vault displacement, and other supporting methods should be used to assist the anchor to support the tunnel. The horizontal displacement is mainly concentrated in the two sides, and the displacement in the middle is the largest. After deformation, the surrounding rock on the surface of the two sides presents an arc shape. Among them, in the range of surrounding rock with deformation of more than 50mm, the length of anchor rod is 2.4m more than 3.0m, no matter in the extension range or depth of two sides. When the tunnel is supported by anchor rod, the longer the anchor rod length, the better the effect will be, but the effect can not meet the requirements. According to the condition that the surrounding rock of the engineering tunnel is soft rock, the anchor rod length of 3m should be selected for support, and other support methods should be added to control the deformation of the tunnel.

In order to ensure the long-term safety of the tunnel, the supporting structure system should have a certain safety reserve coefficient. According to the relevant engineering experience, C30 reinforced concrete is used for the secondary lining, which is analyzed according to plain concrete during calculation, and the safety coefficient of the secondary lining under the supporting timing and thickness is compared respectively, as shown in Figure 2:

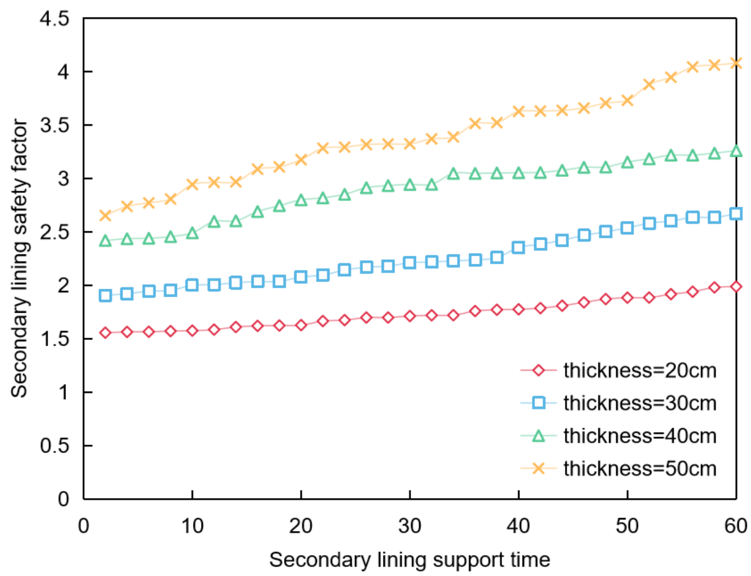

Figure 2. Relationship between safety factor of secondary lining and supporting opportunity under different stiffness

It can be seen that when the secondary lining is close to the tunnel face, the secondary lining with conventional thickness can no longer meet the requirement that the safety factor is not less than 2.0 in the service life of the tunnel. At this time, it is necessary to thicken the secondary lining, which means that the overbreak of the tunnel is greatly increased, thus increasing the support cost. In fact, as long as the plain concrete of 30~40cm can meet its functional requirements as a safety reserve, the construction timing should mainly consider the requirements of the construction organization and adapt to the deformation process of surrounding rock.

4. Conclusions

Taking a tunnel as the engineering background, this paper focuses on the mechanism of large deformation of soft rock, the design and optimization of supporting technology, aiming at the problem of large deformation of tunnel surrounding rock. The results show that the displacement of surrounding rock increases with the increase of upper load. When the roof load is less than 0.7 MPa, the vertical displacement of the sensitive block tends to be stable after a certain period of time; When the top plate load is 0.7 MPa, the vertical displacement of the roof sensitive block cannot converge, so some reinforcement measures must be taken at this time. When the tunnel is supported by anchor rod, the longer the anchor rod length, the better the effect will be, but the effect can not meet the requirements. According to the condition that the surrounding rock of the engineering tunnel is soft rock, the anchor rod length of 3m should be selected for support, and other support methods should be added to control the deformation of the tunnel. As long as 30~40cm plain concrete can meet its functional requirements as a safety reserve, the timing of construction should mainly consider the requirements of construction organization and adapt to the deformation process of surrounding rock.

References

[1] Hao Z, E-Chuan Y. Surrounding rock deformation and failure mechanism of Wudang group schist tunnel: A case study of Tongsheng tunnel[J]. Electronic Journal of Geotechnical Engineering, 2015, 20(11):4457-4478.

[2] He F, Xu X, Qin B, et al. Study on deformation mechanism and control technology of surrounding rock during reuse of gob side entry retaining by roof pre-splitting[J]. Engineering failure analysis, 2022(137):137.

[3] Huo B, Tai Y, Meng X, et al. Deformation and failure mechanism of full seam chamber with extra-large section and its control technology[J]. Open Geosciences, 2020, 12(1):390-405.

[4] Yu Y, Wang X, Bai J, et al. Deformation Mechanism and Stability Control of Roadway Surrounding Rock with Compound Roof: Research and Applications[J]. Energies, 2020, 13(6):1350.

[5] Luo G F, Zhang H. Mechanical behavior and damage mechanism of loaded coal and rock[J]. Military operations research, 2017, 14(3):200-207.

[6] Wu Y, Chen J, Jiao J, et al. Damage and failure mechanism of anchored surrounding rock with impact loading[J]. Meitan Xuebao/Journal of the China Coal Society, 2018, 43(9):2389-2397.

[7] He P, Li S C, Li L P, et al. Discontinuous deformation of surrounding rock for small-space tunnel with super-large section in jointed rock mass[J]. Yantu Gongcheng Xuebao/Chinese Journal of Geotechnical Engineering, 2018, 40(10):1889-1896.

[8] Song Z, Yuan C B, Du Y B, et al. The Characteristics and Formation Mechanism of Rock-burst for a Long and Deep Tunnel of Chengdu-Lanzhou Railway[J]. Journal of Railway Engineering Society, 2017, 34(10):66-72.

[9] Wang Q, Dong Z, Li P, et al. Collapse Mechanism and Treatment Measure Assessment for Deep Tunnel with Large Cross Section in Soil-Stone Composite Strata[J]. Zhongguo Tiedao Kexue/China Railway Science, 2018, 39(1):59-65.

[10] Xiao M Q, Wang S F, Chen L B, et al. Research on the Design Method of Primary Support of Tunnel Based on the Load-structure Method[J]. Journal of Railway Engineering Society, 2018, 35(4):60-64.