A comparative Study on the Analysis of Elastic Plastic and Viscoelastic Constitutive Model in Soft Rock large Deformation Tunnel

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Abstract. With the construction of large highway engineering, large section soft rock highway tunnel is more and more. In the process of excavation, large section highway tunnel, soft surrounding rock and complex stress, during the excavation process prone to large deformation. Reasonable determination of the deformation of the large section soft rock highway tunnel is particularly important. According to the geological conditions and the mechanical characteristics of surrounding rock, using elastic-plastic and visco elastic constitutive model for deformation of the same level under different embedding rock by numerical analysis, the same rock using different constitutive relations, area difference, measured data through the laying on the site to provide the comparative analysis by the viscoelastic constitutive relation constitutive model is closer to the actual site, which is due to the large section soft rock tunnel has obvious time effect in the process of excavation, therefore in the process of excavation for large deformation of soft rock tunnel is more close to the actual rheological constitutive model considering the effect of amount.

1. Introduction

Highway construction has entered a new period of development with the development of economic construction and continued investment in national infrastructure construction, and combined with the national strategy to The Belt and Road, transportation network in the southwest hub will be gradually formed. In the process of highway construction in the southwest mountain area, tunnel is widely used to ensure the safety of operation, avoid damage to the ecological environment and to shorten the mileage and so on. So far, in the world of highway tunnel size and ownership, China has jumped to the first [1]. Chinese railway tunnel re-entered a period of rapid development with The Belt and Road national strategic and has built a large number of railway tunnels [2,3], such as Wushaoling tunnel. However, shallow depth and poor conditions of surrounding rock is the most commonly encountered situation in the construction of tunnel project.

Among the many problems encountered in the actual construction of the tunnel, the most difficult problem is the large deformation caused by the excavation of the tunnel in the soft surrounding rock. Large deformation of the tunnel is easy to cause instability of surrounding rock, many problems encountered in the process of excavation will lead to design changes, and thus affect the progress of

the construction so that the final investment can not be estimated [4,6]. Numerical simulation has been widely used in engineering, which has the characteristics of intuition, quick, low cost and so on. Deformation of rock excavation in soft rock tunnel, the excavation of soft rock deformation has long-time effect, using different numerical simulation methods result the large deviation, how to find a reasonable and feasible numerical simulation method become a problem to be solved on soft rock large deformation in engineering [7,10]. In this paper, we try to use different constitutive models to simulate the deformation of large section tunnels in soft rock, and through the monitoring measurement to verify the analysis, and strive to find a more suitable solution.

2. Engineering survey

Lanchuan Road is the main road New of Haidong Town in Dali City where the ZhongheCun tunnel is located in, which design level is the first classd and design speed is 60 kilometres per hour. The starting and ending pile number is YK0+755 ~ YK1+755, and the length of the dividing line is 1020m; the whole tunnel is located in a straight line; the longitudinal slope of the section of the tunnel is -1.181%; the maximum buried depth of the tunnel is about 122m, and the surrounding rock of the tunnel site is mainly based on the V level, the surrounding rocks are dominated by sandy mudstone, and the weathering degree of rock mass is high and mainly to strong weathering, which joint fracture is developed, with a small amount of bedrock fissure water, poor integrity of the surrounding rock, poor stability, weak cohesion, easy to produce after excavation deformation, and deformation time is longer. The tunnel span is 16m and the height is 8m, which belongs to typical large section soft rock tunnel.

3. Design of numerical simulation for tunnel

MIDAS / GTS NX is a versatile finite element analysis software developed for the geotechnical field. It is widely used in the accurate modelling and analysis of metro, tunnel, slope, foundation pit, pile foundation, hydraulic engineering, mine engineering and other various accurate modelling and analysis of practical engineering. Through the “segmentation, boolean operation” provide by software to model; and with the help of "construction stage" function to simulate the process of tunnel excavation support and surrounding rock deformation; finally, the results of the analysis using the "form, the results mark, profile, contour" and other ways to deal with and output. To achieve the whole process analysis of the entire tunnel construction and the numerical simulation results , which provides a reliable basis for the value of tunnel deformation reserve.

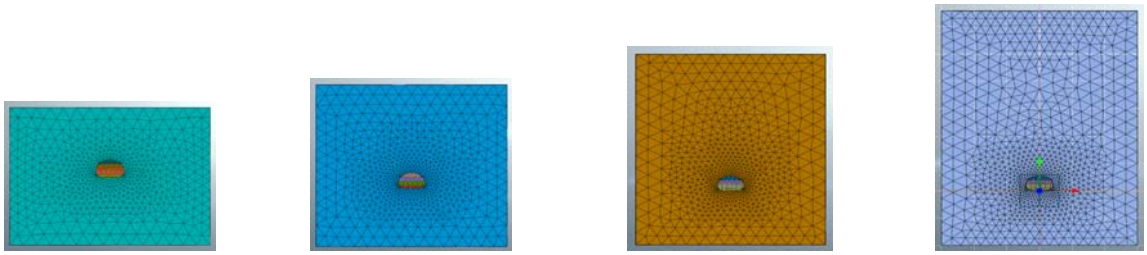
In this paper, the simulation and analysis of shallow buried soft large deformation tunnel with surrounding rock level and different buried depth, which is based on the following basic assumptions:

(1) The deformation characteristic of surrounding rock is isotropic, so the nature of surrounding rock will not change with the change of direction;(2) The surrounding rock is homogeneous and continuous, which the material properties of the same area are the same, and the selected medium is filled with no voids in the model volume.(3) Don't consider the existence of tectonic stress in the formation and no external load, under the condition of gravity stress field is only considered the deformation characteristics of surrounding rock;(4) In the process of tunnel excavation, the I-section ring support of the tunnel in the initial support is replaced by the increase of the shotcrete thickness;(5) In the process of site monitoring, the creep characteristics of tunnel surrounding rock are found. The model assumes that the elastic-plastic model is adopted during excavation, and the creep model is applied after excavation.

ZhongheCun tunnel is located in the hilly areas of Haidong, where the area is mostly lowland hills and the mountain is relatively slow. Zhonghecun tunnel entrance view as showed in Fig. 1. The full length of Zhonghecun tunnel is 1020m and the maximum depth is 122m, according to the research in this paper that the simulation of the deformation of surrounding rock in tunnel excavation is carried out. In this paper, a separate tunnel is used as a simulation object.

Figure 1. Contour and surface top view

In order to simplify the calculation and consider the effect of boundary effect on the model calculation, single tunnel model around the border since the centre line of the tunnel is not less than 5 times of tunnel radius, tunnel span 16m, the model horizontal direction width take 120m, the distance from the bottom boundary of the model to the bottom of the inverted arch tunnel is not less than 3 times of the tunnel height, the tunnel height 8m, the bottom boundary take 40m distance from the bottom of the inverted arch, the model longitudinal length is 60m, and this paper is proposed to simulate the tunnel embedment depth of 30 m ,60 m, 90 m and 120 m. The tunnel entrance section and the maximum depth section of the tunnel are covered, and the same height gradient is added to simulate the deformation of the surrounding rock at different embedment depths in the tunnel construction process. The D-P criterion is used to calculate the constitutive relationship of the grade IV rock, and the combination of D-P creep coupling model for V grade surrounding rock shows the deformation law of large deformation tunnel in soft rock. During the excavation, the surrounding rock is in the stage of elastic-plastic deformation, and the surrounding rock after excavation and support is in the creep deformation stage. Model size diagram and simplified calculation model shown in Fig. 2:



30m buried depth 60m buried dept 90m buried depth 120m buried depth

Figure 2. Different depth models

Referring to the engineering design and the exploration data, combined with the range of rock physical and mechanical parameters provided by the highway tunnel design code, which the initial support and anchor bolts belongs to the structure. The physical and mechanical parameters of the materials involved in the calculation of the model are shown in table 1:

Table 1. Physical and mechanical parameters of materials

material	Elastic modulus E (Mpa)	Poisson's ratio μ	Cohesion C (Mpa)	internal friction angle φ ($^\circ$)	Severe γ (KN/m^3)
V(Strong weathered mudstone)	100	0.35	0.30	23	22
Initial support	20000	0.20	—	—	25
anchor	200000	0.30	—	—	—

Three steps excavation method is used for the ZhongheCun tunnel construction. Due to the difference of the surrounding rock weathering degree and the nature of the surrounding rock, the middle part of the mountain where the tunnel is located in is better in nature, the shallow buried section of the tunnel is the whole reinforced wind mudstone sandstone, which is broken in the rock mass. Therefore, by simulating the variation of surrounding rock deformation caused by tunnel excavation under the condition of grade V, the variation is relevant with the buried depth of the tunnel (30m, 60m, 90m, 120m), we can obtain surrounding rock's deformation and deformation law under same level rock and different buried depth condition in the process of the tunnel excavation , so as to provide the basis and support for determining the reasonable deformation of tunnel.

According to the actual construction sequence of the tunnel, the excavation is carried out with the construction schedule of one cycle of 2m/s. The step parameters are optimized according to Zhang Quanquan's optimization of the three-step excavation of the shallow-buried large-section tunnel. So we can carried the excavation simulation of the model according to the construction parameters, such as step height: 3m on the step, 3m on the middle, 3m on the step and 2m on the height of the arch; Step length: 6m on the step, 6m on the middle, 6m on the step, inverted arch from the next step 4m.

When the constitutive relation is selected, the DP constitutive relation is elastic-plastic. According to the theory of elastic-plastic mechanics, the stress and deformation of surrounding rock in the tunnel after excavation are released in an instant, and the time effect is not considered. During the actual monitoring of the tunnel, it is found that the deformation of tunnel surrounding rock is a process of continuous deformation with time extending, which cannot be explained by the elastoplastic theory. So in the simulation, the DP-creep coupled constitutive model is used to simulate the deformation of the rock mass in the V level, that is, the DP model is used to instantaneously release part of the stress and deformation during tunnel excavation. After the excavation of the tunnel section, the constitutive relation of surrounding rock is modified to make the surrounding rock continuously deformed to simulate the deformation process of the actual surrounding rock. In order to further clarify the relationship between the two methods, taking the V grade surrounding rock as an example. Numerical simulation and comparative analysis are carried out for the elastic-plasticity and viscoelastic-plasticity, the simulation data are shown in Table 2, and the graph is shown in Fig. 3.

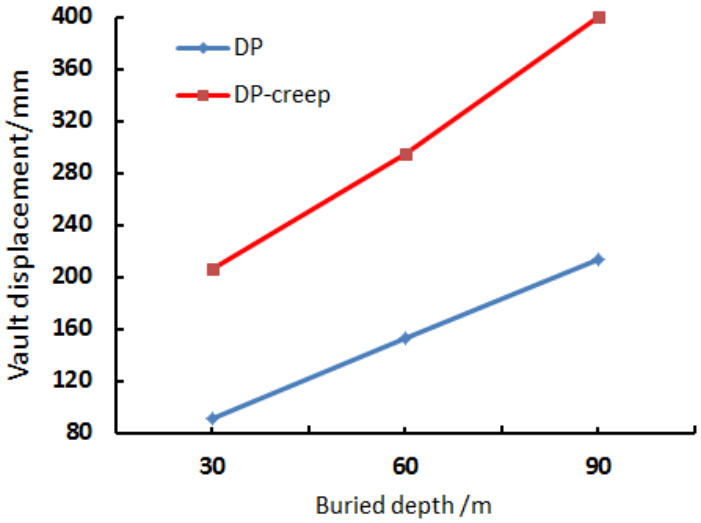


Figure 3. Displacement of different constitutive relations - depth curve

It can be seen from Fig. 3 that considering the elastic-plasticity and the viscoelastic-plasticity of the surrounding rock, the vault displacement increases with the increase of the buried depth. The deformation of the vaults of the surrounding rock considering the rheological process is obviously larger than that of the rock mass under the elastic-plastic state.

Table 2. Displacement data of vaults in different constitutive relations

Buried depth /m	Displacement of V grade surrounding rock vault /mm		
	DP	DP-creep	difference/mm
30	91	206	115
60	153	295	142
90	214	400	186

The data in Table 2 shows that the displacement of the vault creep condition is about 1.8~2.2 times the deformation of surrounding rock in elastoplastic state, when buried depth are 30m, 60m, 90m under the conditions of considering and not considering the creep deformation, the difference were 115mm, 142mm, 186mm, that is to say with the increase of buried depth, the deformation difference is also increasing. The physical and mechanical parameters of surrounding rock are the same, the main reason of deformation difference is the use of the creep constitutive model take the time factor into account, the time effect of tunnel surrounding rock after excavation deformation is very obvious.

Sort out the tunnel monitoring data and drawing vault displacement mileage figure, it can be seen from Fig. 4 that the tunnel surrounding rock deformation law in general agreement with the numerical simulation results, which the deformation of the surrounding rock under the condition of the same-quality increases with the buried depth increase. The field test data of grade V surrounding rock are close to those simulated by DP-creep constitutive model. The deformation of the surrounding rock is obviously jumped by complex factors, and the numerical simulation results are smooth.

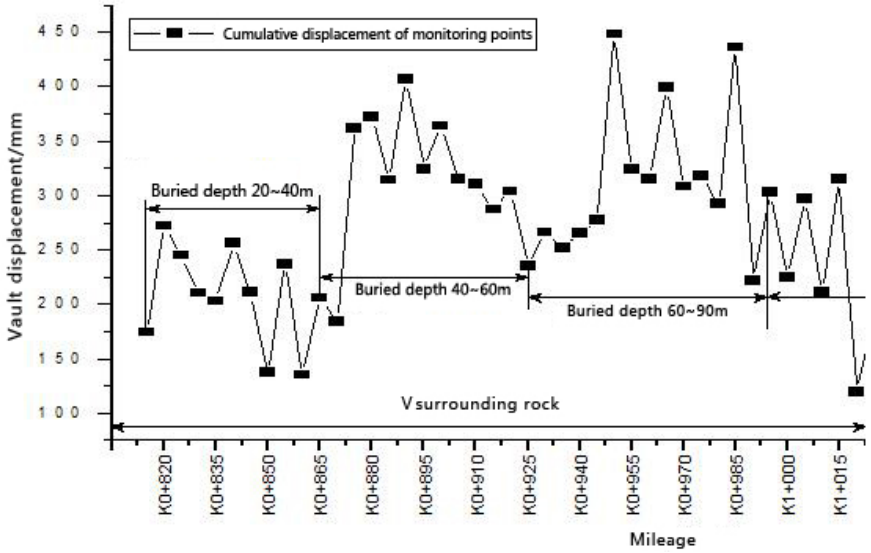


Figure 4. Longitudinal arch displacement of tunnel

4. Conclusion

This paper takes Zhonghe Cun tunnel as the object, through the simulation in 30m, 60m, 90m, 120m depth V rock DP- creep coupling model under different conditions. To study the spatial and temporal laws of the vertical and horizontal deformation of surrounding rock in tunnel, and to deduce the deformation of surrounding rock based on the numerical simulation. The following conclusions are obtained:

(1) Under the condition of the same surrounding rock, when the tunnel excavates the deformation of surrounding rock increases with the increase of the depth of the tunnel, the fitting formula of the vault displacement and the surrounding displacement of the surrounding rock tunnel is obtained.

(2) According to the simulation results of DP model under IV surrounding rock tunnel excavation, the surrounding rock displacement time effect is not obvious. In the course of the excavation time, the surrounding rock of the tunnel is obviously deformed, which tends to converge after the tunnel excavation, and the time effect of the deformation of the surrounding rock is obvious under the condition of the V grade surrounding rock creep model.

(3) From the simulation results obtained with the working face excavation process of the vault displacement, vault monitoring step the greatest impact by excavation disturbance, so in the actual construction process do a good job of supporting the excavation steps. The influence range of the tunnel face is about 2.5m in the front of the tunnel. Outside this range, the influence of perturbation on the surrounding rock is less. When the monitoring points ahead of the tunnel face outside the 15m range, with the working face advancing, monitoring position ahead of deformation had no obvious buried depth effect.

(4) Under the same surrounding rock condition, the gap is obvious which between the elastic-plastic constitutive model and the viscoelastic model, the deformation of the tunnel in the viscoelastic model is about 1.8 to 2.2 times of the tunneling deformation of the elasto-plastic model.

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References

[1] China is the world's largest developing and the fastest highway tunnel - Chinese Highway Tunnel Engineering Association Branch Jiang Shuping in the 2013 national highway tunnel academic conference opening speech [J]. tunnel construction, 2013,10:808.
[2] Yao Yongqin, Yang Xinan, Yu Yu. Railway tunnel [M]. Beijing: China Railway Publishing House, 2004
[3] Wang Mengshu. Construction technology of tunnel and underground engineering in China [M]. Beijing: China Communications Press, 2010
[4] Guan Baoshu, Zhao Yong. Construction technology of soft surrounding rock tunnel [M]. Beijing: People's communication press, 2011
[5] Xiao Tonggang. Analysis and evaluation of the safety of weak surrounding rock and support system in tunnel and its engineering application [D]. Tongji University, 2007.
[6] The first survey and Design Institute of railway, Shijiazhuang Railway Institute, LanZhou JiaoTong University, etc. Deformation control technology of the complex stress condition in the ridge section of the tunnel of the Wuqiaoling tunnel[R] Lanzhou: first survey and Design Institute of Railway, 2004.
[7] Kidybinski. Strata Control in Deep Mines [M]. A. A. Balkema Press, 2013.
[8] Franclss. F. O. Weak Rock Tunneling [M]. A. A Balkema Press, 2011.
[9] YUYi.Mechanism and determination method of large deformation of supporting large deformation of surrounding rock [J]. World tunnel, 1998, 01: 46-51.
[10] ZHAO YONG.Study on deformation mechanism and control technology of soft surrounding rock in tunnel [D] Beijing Jiaotong University,2012.