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The Comprehensive Treatment of the Ancient Landslide Deformable Body in the Giant Deep Rock Bedding based on the FLAC Analysis Model

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ABSTRACT

In previous studies, most of the studies are based on the failure mechanism of the landslide deformable body on tunnel and the safety monitoring and early warning after the completion of the tunnel, while there is less research on tunnel construction. In order to study the comprehensive treatment of the deformable body of the ancient landslide in the giant deep rock bedding better, the treatment of JM tunnel landslide deformable body was selected to carry on the empirical study. After a detailed analysis of the geological characteristics of JM tunnel engineering landslide, the stability analysis of the landslide and the deformation body and the calculation of the thrust value based on the FLAC model were carried out on the basis of the monitoring data. After the construction of the model, the intensity parameters of the slip mass deformation and the sliding zone were obtained from the back analysis. On the basis of the above, the comprehensive treatment scheme for the rear side of the old landslide deformation body was determined, including earthwork cleanup, grading supporting, and the back pressure by abandoning the cleaned earthwork at the leading edge. The study is of great significance to the design of the construction of undercrossing tunnel of landslide under the complicated geological conditions.

Tratamiento integral del deslizamiento de un cuerpo deformable antiguo en un gigante lecho rocoso profundo con base en el modelo FLAC

RESUMEN

Estudios anteriores suelen basarse en el mecanismo de falla de un cuerpo deformable por deslizamiento de tierra en un túnel y en el monitoreo de seguridad y alerta temprana después de la finalización del túnel, mientras que hay menos investigación sobre la construcción del túnel. Para estudiar mejor el tratamiento integral del cuerpo deformable de un antiguo deslizamiento de tierra en un lecho de roca profunda gigante, se seleccionó el tratamiento del cuerpo deformable de deslizamiento de túnel del túnel JM para llevar a cabo el estudio empírico. Después de un análisis detallado de las consideraciones de deslizamiento por las características geológicas del túnel JM, se realizaron el análisis de estabilidad del deslizamiento de tierra y el cuerpo de deformación y el cálculo del valor de empuje basado en el modelo FLAC y en el monitoreo de información. Después de la construcción del modelo, los parámetros de intensidad de la deformación de la masa de deslizamiento y la zona de deslizamiento se obtuvieron del análisis posterior. Después de esto, se determinó el esquema de tratamiento integral para la parte posterior del antiguo cuerpo de deformación por deslizamiento de tierra, incluida la limpieza del movimiento de tierras, el soporte de nivelación y la contrapresión al abandonar el movimiento de tierra limpio en el borde delantero. El estudio es de gran importancia para el diseño de la construcción del túnel de deslizamiento de tierra bajo condiciones geológicas complicadas.

Introduction

The excavation of the tunnel may lead to the deformation of the original mountain, coupled with the original landslide geological conditions, the comprehensive consideration of all kinds of complex factors is necessary in the corresponding reinforcement construction (Chen, Xiao, Sun, & Fang, 2014). There are many studies on the investigation and support design of slope landslide in China, while there are few studies on the existing landslide with complicated construction conditions (Liu & Qian, 2014). The traditional analysis methods of slope stability are mainly qualitative analysis and quantitative analysis of the two, in which, the qualitative analysis includes the geological analysis method, the engineering analogy method and the graphic method, while the quantitative analysis method includes the limit equilibrium method, the numerical analysis method and so on (Shuan-Cheng, Wang, Wang, & He, 2015). These methods can be used to analyze and predict the process of slope landslide, but the parameters needed are many, and the calculation is large (Ming-Zhu, Kong, & Zheng 2011). To this end, the empirical study on the comprehensive treatment of the JM tunnel landslide deformable body was carries out, the relevant parameters of the landslide deformable body were calculated on the basis of the construction of the FLAC two-dimensional numerical analysis model and the uniform design test method (Sun, Wong, Shang, Shen, & Lü, 2010). The study has certain reference significance to the construction of the modern expressway in China and the reinforcement supporting engineering of slope under the complicated geological conditions, which is helpful to promote the application of neural network model in engineering design.

Description of the problem

JM tunnel from XY to GL expressway is divided into two tunnels, on the left and right; the tunnel passes through the landslide two times, the left hole body is 103m, the entrance section is 347m and the right hole section is 204m. The JM landslide belongs to the old landslide of the giant bedding rock, therefore, it has the characteristics of multi-sliding, which is influenced by tunnel excavation; the large sliding deformation of landslide deformable body causes significant surface cracks and tunnel cracks, as shown in figure 1. The main treatment difficulties include: (1) the geological condition is very complex, the JM landslide belongs to the multi-level sliding deformation, the landslide areas are many, and the stress change is complex; (2) the duration of construction is tight, the entire expressway from XY to GL must be opened to traffic in 2016; (3) the project cost is needed to control. Therefore, it is necessary to make a comprehensive analysis of the JM expressway landslide deformable body, so as to provide the basis for the selection of the treatment plan. For the supporting scheme of landslide deformation, it is necessary to analyze the sliding surface and the sliding bed characteristics of the landslide and deformable body, and calculate the stability and the thrust value of the landslide and the deformation body, so as to provide data basis for the choice of treatment plan.

China is vast in territory, and the geological conditions are complicated (Xiao & Huang, 2013). Affected by natural factors, the main threat to road safety in mountainous areas is the landslide (Zhou, Zeng, & Zhu, 2012). In the engineering construction of several decades, affected by the landslide, there have been many traffic disruption and engineering accidents caused by landslide disaster in China, which has caused serious economic losses to our country; this is not conducive to the construction of infrastructure in our country (Zhenyu, Chen, & Wan, 2014). But whether it is expressway construction or railway construction will face the situation through the landslide mountain areas (Song-Yue, Cao, Hong, & Zhou, 2009). In the process of slope excavation and tunnel construction, there are serious security problems because of the landslide (Deng, 2014). Especially in the southwest, heavy rain may further lead to instability of the slope in the rainy season, and exacerbate landslide deformation (Jiang, 2010). The use of tunnel construction is to avoid the disturbance caused by the slope excavation; however, affected by natural factors and human impact of construction, it is difficult to carry on the supporting work of the slope (Lin, 2011).

Figure 1. Deformation and cracks of tunnel landslide in Jimei

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Based on the analysis of the geological conditions of each partition, it can be seen that the whole JM landslide initially slid from the soft stratum of bedrock, and gradually disintegrated under the influence of external stress after a long period of time, which was characterized by multi-zone, multi-layer and multi-period sliding (Shi, 2012). Among them, there was an extrusion affected zone at the junction between the southeast of Ⅰ$_3$ and the zone Ⅱ, the bedrock occurrence of the landslide was 14-55°∠33-15°, while the bedrock occurrence of slide bed in zone Ⅰ$_3$ was 14-31°∠33-35°, and the angle between the deformation direction of deformable body was 19-36°. The sliding surface slope of bedding landslide and the direction of the maximum sliding force were bedding tendency, namely 14-31°. In which, the direction of the maximum slip force was the northwest direction. The traction, extrusion and rub occurred in the east side of zone Ⅰ because of the influence of sliding body, thus forming a lateral impact area, as shown in figure 2. As a result, the surface topography in the affected area was messy, and the secondary landslide was developed.
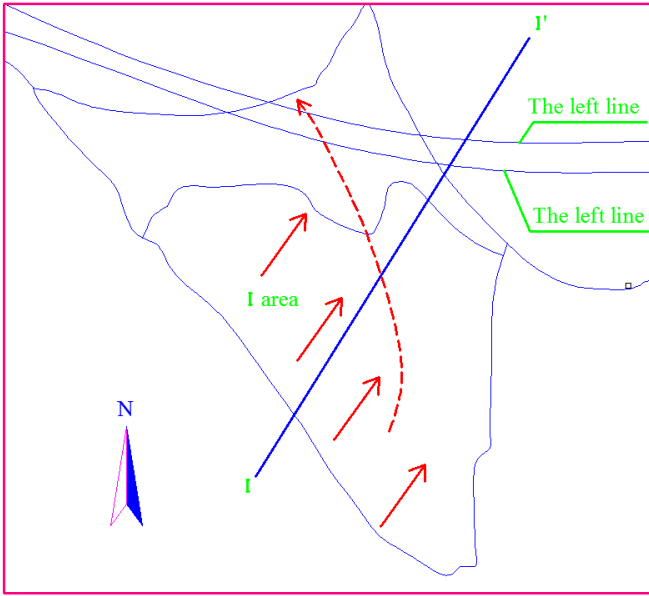

Figure 2. Deformation force and deformation direction of deformable body

Methodology

In order to put forward the feasible measures for the treatment of JM tunnel landslide, it is necessary to analyze and calculate the displacement deformation value of the deformable body and tunnel, so as to ensure the safety of the whole project, and provide data support for the optimization of the scheme (Xueyong, Cai, Zhao, & Zhu, 2013). Taking into account the actual situation of the project, the calculation results of special numerical analysis which are widely used in the analysis and calculation of slope and landslide of hydropower system at present were used as the main basis, at the same time, the monitoring data of the deformable body and tunnel deformation was adjusted and perfected to realize informatization construction and dynamic design (Mei, Peng, & Xiao-Hong, 2008). Based on this, the FLAC model was used to carry on the specific analysis and research:

FLAC finite difference mesh was used to carry on the calculation, which was divided into quadrilateral elements, each quadrilateral was made up of 2 triangular elements with constant strain. The weighted average values of all variables in a triangular element were taken as the element variable value of the quadrilateral. Assuming that the integrals of the closed surface boundary and surface area of were $\int_S$, $\int_A$. The unit normal vector of the surface s was n_i, and the increment ar length was ds. The Lagrange's method and the Gauss's theorem were used for the calculation:

$$\int_A \frac{\partial f}{\partial x} dA = \int_s fn_i\ ds \tag{1}$$

Furthermore, assuming that the velocity component of node was u_i, then the constant strain triangular element was obtained on the basis of the Gauss's theorem:

$$\frac{\partial v}{\partial x_i} = \frac{1}{A}\sum_s u_i\ n_i\ \Delta s \tag{2}$$

The nodal velocity was used to calculate the strain increment of a time step unit:

$$\Delta e_{ij} = \frac{1}{2}\left|\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right|\Delta t \tag{3}$$

The total stress was calculated by the constitutive relation function. Assuming that the stress tensor was σ_{ij}, so there was:

$$\Delta\sigma_{ij} = f\left(\Delta e_{ij,......}\right) \tag{4}$$

Assuming that the unbalanced component of node in i direction was $F_i(t)$ at t time, so that the motion equation of node was expressed as:

$$\frac{\partial u_i}{\partial t} = \frac{F_i(t)}{m} \tag{5}$$

Based on the principle of virtual work and the formula (5), formula (6) was obtained:

$$u_i^{\left(t+\frac{\Delta t}{2}\right)} = u_i^{\left(t-\frac{\Delta t}{2}\right)} + \sum F_i^{(t)}\frac{\Delta t}{m} \tag{6}$$

Firstly, the inverse analysis of parameters of slip soil was carried out under the natural working condition, the 6-6' section plane in the zone Ⅰ was used as the main sliding profile, and the FLAC two-bit numerical analysis model was established by means of the generalized engineering geological profile. At the same time, the homogeneous design test method was used to establish the computational scheme table of numerical analysis experiment homogeneous design of sliding deformation parameters and sliding zone intensive parameters (Yan, Guan, & Xie, 2006). According to the homogeneous design test plan, the experimental parameters were substituted into the FLAC model, thus, the displacement values of the same position of the model and field monitoring were calculated (Wang, Kang, & Wang, 2011). The coefficient reduction was used to obtain the parameters of the new rock and soil to carry out the cycle computing, so as to make the stability judgment. Assuming that the reduction coefficient was F, the shear strength indexes were c^t, φ^t after the reduction, so there was:

$$c^t = c/F \tag{7}$$

$$\varphi^t = \arctan\left(\tan\varphi/F\right) \tag{8}$$

The stability limit of the slope was determined by the Mohr Kulun yield criterion. The ratio of the maximum shear strength of slope and the actual shear stress of slope was expressed as:

$$F = \frac{\int\left(C^t + \sigma_n^t\tan\varphi^t\right)dt}{\int\tau dll} \tag{9}$$

Combined with the strength factor reduction method, there was:

$$1 = \frac{\int\left(\dfrac{c}{F} + \sigma_n\dfrac{\tan\sigma}{F}\right)}{\int\tau dll} = \frac{\int\left(c^t + \sigma_n\tan\varphi^t\right)dll}{\int\tau dll} \tag{10}$$

Then the deformation displacement was used as the input variable, and the sliding deformation parameters and sliding zone intensive parameters were taken as output variables, so that the neural network RBF model was established (Shuanping, 2010). The calculation model of 6-6' profile is shown in figure 3. The homogeneous design test analytical data sample was used to train the grid, so that a neural network model was established to accurately reflect the nonlinear relationship among the deformation parameters of the sliding body, the sliding zone intensive parameters and the displacement value of the monitoring points, then the intensive parameters of slip deformation and slip zone were obtained by substituting the measured displacement values into the model.
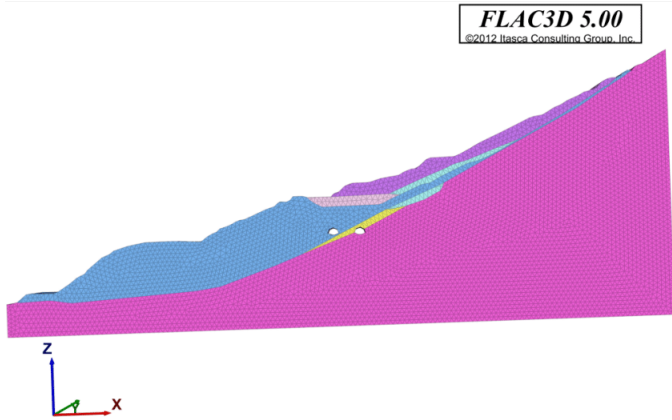

Figure 3. Calculation Model of section 6-6 'section

The anti-slide pile was used in the treatment scheme, and the pile element was used to simulate the anti-slide pile in the latter part of the calculation, so that the solid element was used to simulate the soil of sliding zone (Liu, 2012). The shear force was generated between the constitutional unit of anti-slide pile and the surrounding rock mesh because of the slippage. Assuming that the axial displacement of the pile was u_p, and the axial displacement of the rock and soil surface was u_m, and the length of the unit was L, so there was:

$$\frac{F_s}{L} = CS_{sstiff}\left(u_p - u_m\right) \qquad (11)$$

The maximum shear force of unit length pile was:

$$\frac{F_s^{\max}}{L} = CS_{scoh} + \sigma_c^t \times \tan\left(CS_{sfric}\right) \times perimeter \qquad (12)$$

The calculated results of the back analysis of parameters are shown in table 1.

Table 1. Back analysis of parameters

Elastic modulus of sliding body E/ (Pa)	Poisson's ratio μ	Elastic model of slip zone E/(Pa)	Poisson's ratio μ	Slip band cohesion C/(kPa)	Internal friction angle of sliding belt phi(°)
7.00E+07	0.33	4.00E+07	0.35	33.2	18.6

Secondly, the numerical analysis of the deformable body and tunnel was carried out, so that the rationality of the subsequent program was verified to guide the later supporting design. In this paper, the 6-6' profile was selected to carry out the stress-deformation analysis of typical profile, and four kinds of working conditions were fully taken into account in the calculation: (1) natural + tunnel excavation + earthwork non-cleanup; (2) natural + tunnel excavation + earthwork cleanup; (3) rainstorm + tunnel excavation + earthwork cleanup; (4) rainstorm + tunnel excavation + earthwork cleanup + supporting structure. Among them, for the third working condition, the strength of slip soil was reduced by 1.15 under the condition of rainstorm; for the fourth working

condition, a row of anti-slide piles was arranged at the right side of the left and right tunnel hole of 10m, respectively. The calculated parameters of the model are shown in table 2:

Table 2. Model parameter table

Lithology	Elastic modulus E/Pa	Poisson ratio μ	Cohesive force C/ Pa	Internal friction angle /°	Bulk density KN/m³	
					Natural	Saturated
Slip zone	4.00E+07	0.35	30	19	2350	2400
Sliding body	7.00E+07	0.33	36	28	2350	2400
Bedrock	5.00E+09	0.26	6000	42	2640	
Primary support	9.00E+08	0.24	500	38	2500	
Two support	9.00E+09	0.2	6000	40	2500	

Results analysis

Through the analysis of the different working conditions of the 6-6' profile after the tunnel excavation, the deformation of the landslide was understood, and the equivalent nephogram of landslide deformation was obtained, as shown in figure 4. As can be seen from the figure, under the condition of the natural state of tunnel excavation, the maximum deformation of slope was 57cm, the deformation mainly was concentrated in the upper part of the deformable body, the lower part would not happen (Yang, Peng, Gong, & Wu, 2012). Under the condition of rainstorm + earthwork cleanup, the deformation of the slope was only about 2.3cm, and the deformation around the tunnel was very small.
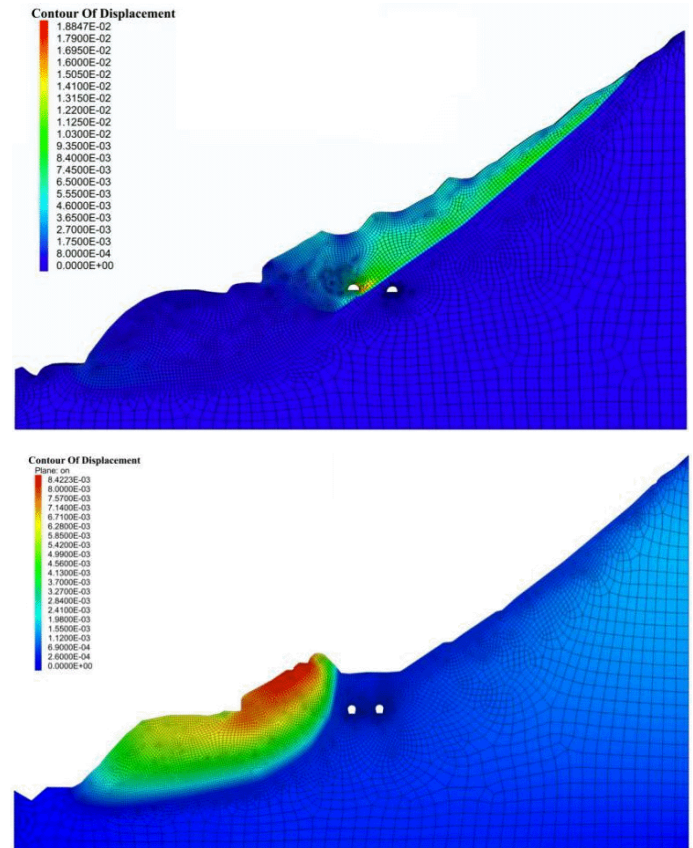

Figure 4. Equivalent nephogram of landslide deformation

The maximum shear stress equivalent nephogram of the landslide is shown in figure 5. As can be seen from the figure, the maximum shear stress was mainly concentrated around the tunnel; the maximum shear stress value

was about 5.4Mpa under the working condition of the natural + earthwork non-cleanup, while the maximum shear stress value was about 2.5Mpa under the working condition of rainstorm + earthwork cleanup.
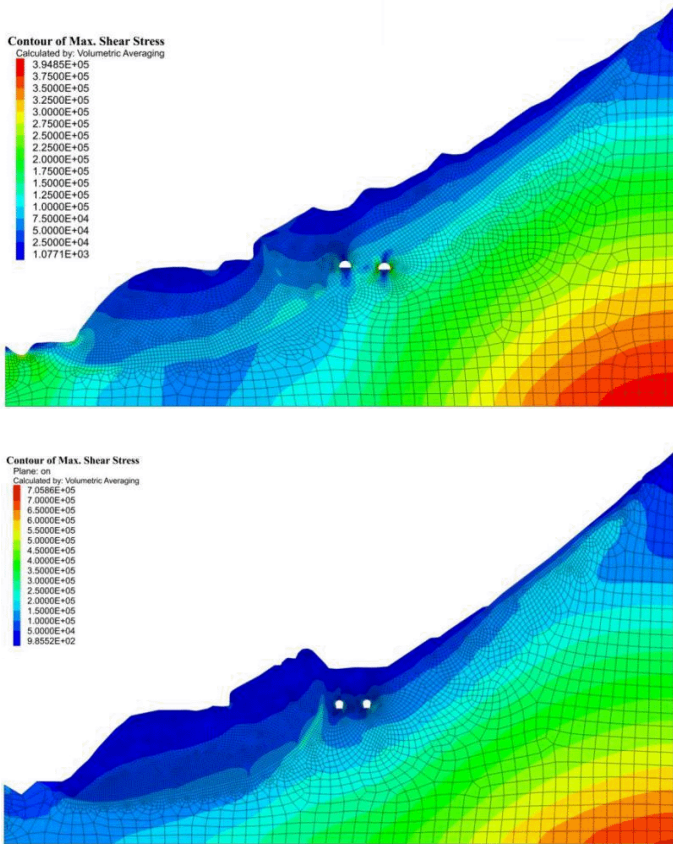

Figure 5. The maximum shear stress equivalent nephogram of landslide

Figure 6. Distribution of plastic zone of landslide body

decreased with the decrease of sliding soil cohesion, but which was still greater than the requirements of the safety factor.

Table 3. The slope safety coefficient of different sliding soil cohesion of the landslide

Sliding soil cohesion (Kpa)	26.09	22	18
Safety factor	1.38	1.35	1.3

Through further analysis, the plastic zone distribution map of the deformation was obtained, as shown in figure 6. As can be seen from the figure, there was a shear stress strain increment zone in the upper part of landslide under natural conditions, but there was no in the lower part. It can be found that the whole slope was stable and there might be local sliding. Under the working condition of rainstorm + earthwork cleanup, the strength of slip soil was reduced by 1.15 times, and the shear stress strain increment zone mainly appeared in the lower part of the landslide.

Thirdly, as can be seen from the analysis of the deformation and stress distribution law of tunnel, under the condition of rainstorm, the maximum shear stress around the tunnel was about 2.45Mpa after the earthwork cleanup of deformable body, and the displacement value was about 5.7mm. When the anti-slide pile was applied to the periphery, the stress and displacement value of the tunnel were not changed greatly.

In the previous calculations, under the condition of rainstorm, soil cohesion was reduced by 26.09kPa according to the natural condition, and the friction angle was also reduced by 16.6°. According to the previous calculation method, the 6-6' profile was calculated. Under the condition of rainstorm + earthwork cleanup, the deformation range of the landslide increased with the decrease of the cohesion of the sliding body, the corresponding displacement values of the sliding body also increased, the deformation of the left line tunnel was obvious, while the deformation of the right line tunnel was relatively small. When the soil cohesion values of sliding zone were 26.09Kpa, 22.0Kpa and 18.0Kpa, respectively, the maximum displacement values of the corresponding slope were 2.13cm, 2.55cm and 5.38cm. The maximum shear stress increment of the landslide concentration gradually increased with the decrease of sliding soil cohesion, and enhanced with smooth consistency. It can be concluded that under the working condition of rainstorm + earthwork cleanup, the slope safety coefficient of different sliding soil cohesion of the landslide was taken, as shown in table 3. As can be seen from the table, the slope safety coefficient
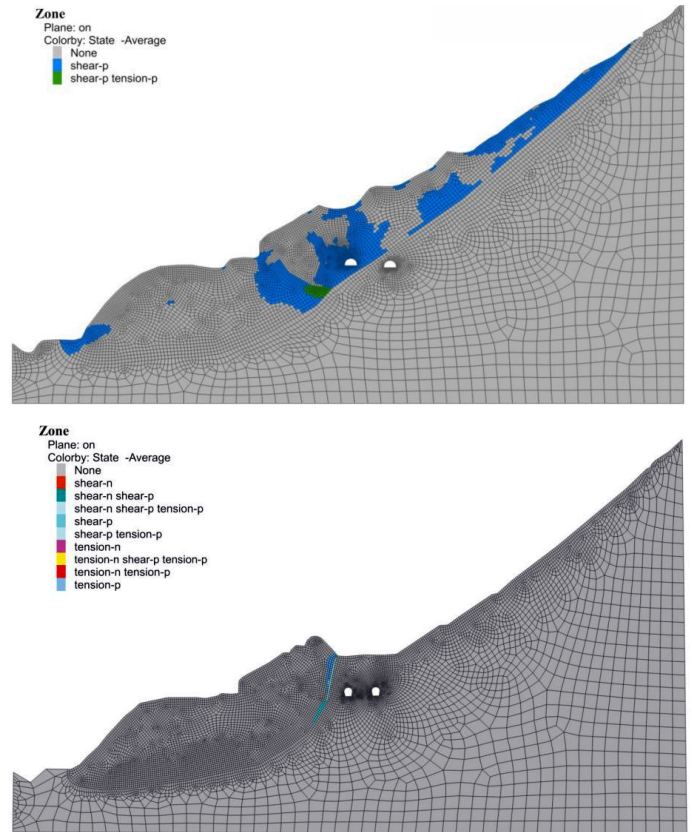
The results were calculated by using the neural network RBF model, and the inverse analysis was used to obtain the sliding soil cohesion value and the internal friction angle value under the natural working condition. According to the actual situation of the landslide, the slip soil cohesion value of zone Ⅰ was 30.0Kpa under the natural working condition, and the internal friction angle was 19°. Under the working condition of natural + tunnel excavation, each section of the landslide body underwent significant deformation; and the deformation was concentrated in the middle and upper part of the deformable body, while the deformation of the lower part was not obvious. On the whole, JM landslide was in a relatively stable state. Based on the comparison and analysis of the scheme of earthwork cleanup, the measures of earthwork cleanup for the rear part of the deformed body were determined; at the same time, taking into account the rainstorm condition, the sliding soil strength was reduced by 1.15 times, so that the overall sliding surface was not formed, which shows that the deformation induced by JM landslide and tunnel excavation was in a stable state. A row of anti-slide piles was arranged at the right side of the left and right tunnel hole of 10m, which had no effect on the deformation of the tunnel, therefore, the implementation of the anti-slide pile supporting engineering of two holes was not considered. Through the comprehensive analysis, the in-situ treatment was determined, and the anti-slide pile was given priority.

Because the protective range of anti-slide piles on the tunnel and the top was greater than 5m, the Pile top and above sliding body could be transferred to the leading edge slide to offset the sliding thrust, so that the sliding thrust of the tunnel range was considered. The residual sliding thrust values of the right side of Left and right hole were calculated as 13674KN/m, 11653KN/m. Therefore, multi rows of anti-slide pile needed to be set up in the upper deformation.

Conclusions

Because the excavation construction of JM tunnel may cause the old landslide which originally belongs to the giant bedding rock have further large sliding deformation, the cracks appeared in the tunnel and the ground surface need to be treated. In order to put forward the feasible measures for the treatment of JM landslide, it is necessary to analyze and calculate the displacement deformation value of the deformable body and tunnel, so as to ensure the security implementation of the whole treatment project and provide data support for the optimization of the scheme. The 6-6' profile was taken as the research object, and the FLAC two-dimensional numerical analysis model was constructed; combined with the analytic results of uniform design test and actual monitoring displacement value, the intensity parameters of the slip mass deformation and the sliding zone were obtained by forward and reverse analysis. At the same time, under four different working conditions, the maximum displacement value of the slope obtained from different sliding soil cohesion was considered, it can be seen that the safety coefficient of slope decreased with the decrease of sliding soil cohesion, but which was still greater than the requirements of the safety coefficient. On the basis of the above analysis, the comprehensive treatment scheme of the JM tunnel landslide deformation body was proposed, including earthwork cleanup, grading supporting, and the back pressure by abandoning the cleaned earthwork at the leading edge. This study is based on the reinforcement supporting of landslide deformation as the main research object, although the mechanism of the tunnel and landslide deformation has been studied, the reinforcement supporting of the tunnel has not been studied in depth.

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