Numerical Simulation of Force Mechanism of Nanping Tunnel

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Abstract: Based on the landslide of Nanping tunnel, the causes of landslide in Nanping tunnel are obtained by using the research method of numerical simulation, and the stress mechanism of tunnel under the action of landslide thrust and the stress change process of tunnel in the process of disease treatment are simulated and studied after the formation of landslide surface, which verifies that the treatment effect of the current treatment measures is good. The results provide a basis for similar projects.

1. Introduction

When the slope through the tunnel appears landslide phenomenon, it is bound to cause the tunnel in the slope to have different degrees of diseases, such as the overall movement of the tunnel, the serious deformation of the lining, cracking, spalling, falling blocks and even the collapse of the tunnel, which may interrupt the normal operation of the line. Therefore, it is a very necessary and urgent work to study the deformation of tunnel in landslide area.

Previous scholars have done a lot of research on tunnel-landslide related problems. Ma Huimin[1] Yes Since the 1980s, the examples of tunnel deformation caused by slope disease on some railway trunk lines have been summarized and analyzed, five typical geological structure models have been summarized, and the corresponding technical measures for prevention and control have been put forward. Tao Zhiping et al.[2-4] also used the method of indoor model test to analyze the deformation mechanism of the tunnel in the landslide section, and studied the variation law of the surrounding rock of the tunnel and the lining pressure of the tunnel, as well as the deformation characteristics of the landslide and the tunnel, in which the interaction mechanism between the landslide and the tunnel was studied and analyzed. Mao Qiang et al.[5] use contact surface to simulate sliding surface The finite element algorithm is used to analyze the interaction mechanism between landslide and tunnel and the stress and deformation law of tunnel. Wu Honggang, Ma Huimin et al.[6-8] took the typical tunnel-landslide of Wuzhou Expressway as the key object of investigation, and preliminarily established the concept of "tunnel-landslide system". From the aspects of "slope structure, disaster inducing factors and spatial combination relationship between tunnel and landslide", a relatively...
complete stress and deformation model with parallel system, orthogonal system and skew system as the core was established.

Nanping tunnel landslide is loess-mudstone bedding landslide, the main slip section is located in mudstone dip angle is only about 10 degrees, and the landslide shear exit is under the inverted arch of the tunnel and the right side of the tunnel is a natural mountain bag, generally speaking, no landslide will occur. Therefore, the study of the cause of landslide formation and the stress mechanism of Nanping tunnel has certain supplementary significance both in theory and in practical engineering.

2. Geological profile
Nanping Tunnel is located in Quager Banner at the junction of Loess Plateau and Ordos Plateau. The surface of Nanping Tunnel is covered with Quaternary aeolian sand and loess layer in a large area, which is a typical hilly and gully region. The geological stratification of the field area is relatively simple. The first layer is the Upper Pleistocene alluvial Aeolian (Q3a eol) new loess. It is widely divided on the natural slope of the field area, with macropores and vertical joints, and loess joints are more developed. The second layer is Permian Upper (P2) sandstone, mudstone. It is a clastic sedimentary rock, which is composed of mudstone, argillaceous sandstone, sandstone and so on, most of which are interbedded with mudstone. The distribution of strata is detailed in figure 1. The landslide is mainly Quaternary loess and its whole. Weathered sand and mudstone slips along the soft and weak surface of strong weathered mudstone to produce slicing (near bedding). The steeper dip angle of the back of the landslide is controlled by the vertical joint characteristic inclination angle of loess about 60°, and that of the middle part is about 10° controlled by mudstone weak zone, and the reverse warping angle of the lower part of the inverted arch of the tunnel is about 48°. The material of sliding zone is mudstone, the water content of nearby rock and soil is high, the rock mass is mostly soft plastic, some boreholes find smooth mirror or scratch.

![Fig.1 Geological section of V-V section](image)

3. Original edge stability simulation
The model selects the V-V section geological profile as the prototype, the size is the same as the prototype. The slope body is stratified according to the prototype and the corresponding properties are given to different strata, as shown in figure 2. The red part of figure 2 is the position of the slip zone, which is divided into two sections. The upward development process of the softening zone is simulated by setting the parameters of the slip zone in different positions, and the stress and strain characteristics of the slope body are observed.

According to the survey report, the material parameters are obtained by indoor test and landslide stability calculation, as shown in Table 1.

![Fig.2 Stratigraphic division of model](image)
Table 1 Material parameter values

| lamination                      | γ/kN⋅m⁻³ | Ep/MPa | υ  | ψ° | C/kPa |
|---------------------------------|---------|-------|----|----|-------|
| banket                          | 18      | 100   | 0.35 | 23 | 13    |
| loess                           | 19      | 100   | 0.35 | 25 | 15    |
| Slip belt                       | 18      | 80    | 0.35 | 11.42 | 10 |
| Fully weathered sand mudstone   | 20      | 200   | 0.32 | 13 | 30    |
| Strong weathered sand mudstone  | 20      | 600   | 0.28 | 13 | 52.5  |
| Medium weathered sand mudstone  | 21      | 800   | 0.24 | 15 | 200   |

The standard red part of fig.3 (a) is set as the sliding zone, and fig. 3 (b) is the corresponding strain cloud map. It can be seen from the two diagrams that the plastic strain occurred in the slip zone, and then the strain zone suddenly steeped up along the loess layer, and the strain zone basically corresponds to the slip zone of the previous landslide with actual tension (the position of the red line in the figure).

It can be verified by numerical simulation that the main reason for the formation of landslide is the continuous upward development of the sliding zone. Under the action of the weight of the slope body, the loess layer is pulled out and the sliding body slips along the sliding zone.

![Slide position](image1)

![Slope strain](image2)

Fig.3 Set a section for the sliding belt

4. Characteristics of stress deformation during tunnel disease treatment

4.1 Establishment of the Model

In order to facilitate modeling and calculation, the slope model is divided into three parts, namely, sliding bed, sliding body and sliding belt. The geometric distribution of slope shape, geometric size and slip zone position is set according to the geological profile of V-V section. The thickness of slope model is 5 m, and the grid size is 4 m. In order to study the stress state of the soil around the tunnel in detail, the tunnel filling is established separately. In order to obtain more detailed stress characteristics, the grid size is 2 m. The geometric size and shape of the tunnel are consistent with the prototype. The stress and strain characteristics of the tunnel under landslide extrusion are obtained in this simulation. The size of the tunnel grid is set to 1 m, and the specific grid division is shown in figure4.

The material parameters are selected according to Table 2. Among them, the internal friction angle of sliding zone soil is 11°, and then 9°. 11°is the real parameter of sliding zone soil, 9°is the internal friction angle of sliding zone soil after completely saturated, the cohesion of saturated soil decreases less, and the cohesion has little effect on the anti-skid ability of sliding zone, so it can be considered to be unchanged. The comparison of 9° is to further predict the development of landslide and the changing trend of stress, strain and deformation of tunnel under the action of further increasing landslide thrust, and it is hoped that the final failure form of tunnel can be obtained.
Table 2 Material parameters

| Stratification   | γ/kN·m⁻³ | Ep/MPa | v  | ψ⁰/ºC/kPa | C/kPa |
|------------------|----------|--------|----|-----------|-------|
| slide bed        | 21       | 800    | 0.24 | 15        | 200   |
| Slip belt        | 18       | 80     | 0.35 | 11 (9)    | 10    |
| slip mass        | 19       | 100    | 0.3  | 25        | 15    |
| Tunnel filling   | 18       | 100    | 0.35 | 23        | 13    |
| tunnel           | 25       | 25000  | 0.2  | -         | -     |

4.2 Mechanical characteristics of tunnel after slope

After load reduction, the stress of the tunnel changes obviously (Fig. 5 ≤ 6): the concentrated force at the connection between the left side wall and the inverted arch basically covers the 3 ≤ 4 of the left side wall, the stress value is about $1.7 \times 10^3$ kPa–$6.8 \times 10^3$ kPa, and the stress value is still very large, but at this time, most of the left side wall of the tunnel becomes compressed on the inside and pulled on the outside. The stress of the left side wall moves upward to the left side of the arch roof above the arch waist. Compared with the bending moment figure 6, it can be seen that the bending moment near the left side wall is obviously reduced from $6.2 \times 10^3$ kN·m to $1.1 \times 10^3$ kN·m, and the bending moment near the arch waist is directly above the arch waist. The bending moment produced by landslide thrust is also greatly reduced, and the arch roof bending moment moves to the right and decreases obviously, from $4 \times 10^3$ kN·m to $0.62 \times 10^3$ kN·m. It can be seen that the load reduction of slope cutting has obvious benign influence on the stress of tunnel.

The stress cloud diagram of the uncut slope shows that the stress distribution of the tunnel moves counterclockwise after slope cutting, which indicates that the landslide thrust on the left side of the tunnel is decreasing, and the resultant force center of landslide thrust and fill gravity moves to the arch roof, that is, the movement from the arch waist position to the arch shoulder position can also be confirmed by the stress distribution of the fill soil. There is also obvious stress concentration in the middle of the inverted arch, which indicates that the partial pressure of the tunnel moves from the left side wall to the arch roof. The center of the resultant force is moved from the arch waist position to the arch shoulder position, which is a directly compressed position, The pressure on the inside side of the tunnel leads to the change of the stress mode in other positions of the tunnel. The left and right sides of the side wall are pulled from the inside, the outer side is compressed to the outside, and the inner side is compressed.

The maximum stress is still located on the left side of the inverted arch, the compression stress value on the inside is about $1.14 \times 10^{-4}$ kPa, the tensile stress on the outside is about $8.6 \times 10^3$ kPa, and the pressure on the left side of the inverted arch is mainly on the inside. This is the place where the geometry of the tunnel changes the most, so it is the easiest part of the stress concentration, as long as the tunnel is slightly biased, the position where the stress concentration is the largest is
always here. Therefore, in tunnel design, we should try our best to avoid the sudden change of geometric shape, to ensure excessive smoothness, and to avoid excessive concentration of stress in a certain position.

4.3 Stress distribution of tunnel after adding anti-slide pile

Fig.7 shows the cloud picture of the stress distribution of the tunnel after the application of anti-slide pile. Compared with the direct compression area of the tunnel after sloping, the tunnel is no longer subjected to the stress mode of the landslide thrust tunnel from the left to the left, which is completely changed into the compression on the outside of the arch roof, the compression on the inside of the left and right sides, the tension on the outside of the side wall, and the stress on the left side wall and the right side wall. 1) it shows that the stress is dispersed on the tunnel. It is beneficial to reduce the stress concentration; 2) it shows that the direct compression area of the tunnel moves to the center of the arch roof. The stress is mainly concentrated on the inside of the left and right side wall and the outside of the arch roof, and the maximum stress value is no longer concentrated on the left side of the inverted arch. Spread to the left side of the wall. Combined with the bending moment figure 6 after slope cutting and the bending moment figure 5 after adding anti-slide pile, it can be seen that the tunnel is basically only subjected to the filling pressure of the arch roof at this time, and the bending moment distribution of the left and right side walls is more uniform, and the maximum bending moment at the arch foot accords with the best stress mode.

4.4 Stress characteristics of tunnel after external arch

After the excavation, a ring of outer arch is applied to improve the strength of the tunnel. It can be seen from figure 9 that the stress value of the side wall of the tunnel is obviously reduced after the outer arch is applied, indicating that the outer arch shares part of the pressure, and the outer side wall and arch roof of the tunnel which have been cracked and destroyed are not designed to bear the lateral landslide thrust, but are only used to protect the side wall of the tunnel and the outside of the arch roof from being damaged by vertical earth pressure. Tunnel cracking is serious, there is a large area of leakage phenomenon, the application of jacket arch will also control the tunnel leakage phenomenon.

5. Comprehensive comparison of tunnel stress modes under several conditions

Fig. 11 shows the summary of tunnel stress cloud diagram under several working conditions. The tunnel stress modes can be divided into three types: (1) large bias mode, (2) small bias mode, (3) ideal compression mode.

1) Large bias mode

The main feature of large bias mode is that the side wall of the tunnel is directly under pressure, and the stress characteristic is that the outer side of the side wall is under compression and the inside of the arch and inverted arch is subject to the compression outside. This kind of stress mode is most
unfavorable, the side wall has poor bending, easy to crack and deformation, and the tunnel is easy to converge horizontally, and the side wall seriously deforms into the gauge, endangers the train operation safety.

(2) Small bias mode

The main characteristics of the small bias mode are that the arch roof is subjected to eccentric pressure, and the force is characterized by the compression on the outside of the arch roof and the tension on the outer side of the side wall. The stress distribution mode after slope cutting is a typical small bias mode. Although the bias pressure is still large at this time, the stress mode of the tunnel has changed, which greatly improves the stress state of the tunnel and reduces the lateral convergence of the tunnel.

(3) Ideal Pressure Mode

When filling alone, it is an ideal compression mode, which is characterized by uniform distribution of tunnel pressure in arch roof, symmetry between left and right, and stress characteristic of tunnel side wall and outer side of arch roof.

![Figure 11 Tunnel stress cloud map under different operating conditions](image)

Comprehensive comparison of figure 11 shows that the treatment of landslide can obviously improve the stress mode of tunnel, change the situation of tunnel subjected to landslide thrust bias, prevent the further development of tunnel disease, and fundamentally control the landslide and tunnel disease.

Fig.12 shows the change process of tunnel bending moment in the process of tunnel treatment. It can be seen from the figure that the bending moment decreases obviously in the process of tunnel treatment, especially the unfavorable stress mode of the left side wall of the tunnel after adding anti-slide pile has been completely changed, and the maximum bending moment is concentrated at the foot of the wall, where the corresponding stress value of the thickest position of the tunnel is not large.
6. Conclusion

Based on the method of numerical simulation, the following conclusions are obtained.

(1) By using the research method of numerical simulation, it is concluded that the causes of landslide in Nanping tunnel can be divided into the following points: (1) In the process of large excavation, the slope is disturbed, which leads to the failure of mudstone structure to provide conditions for moonstone to soften; (2) Characteristics of moonstone softened rapidly after first losing water and then absorbing water.

(2) After slope cutting for landslide, it has two effects on tunnel: (1) The thrust of the landslide is reduced and the force acting on the tunnel is directly reduced; (2) The stress mode of the tunnel is changed, and the joint force shifts to the center of the arch roof. The left side of the tunnel is directly subjected to pressure and the inside of the side wall becomes compressed. Although this stress mode is not the most ideal mode, the left side wall is no longer directly subjected to pressure, which greatly enhances the ability of the tunnel to resist deformation.

(3) After the application of anti-slide pile, the stress mode of the tunnel is completely changed, the inner side wall is completely compressed, and the tunnel as a whole is basically subjected to the vertical pressure of filling. The application of anti-slide pile is the key step to control landslide and tunnel diseases.

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