The internal force numerical analysis of the tunnel structure affected by landslide-tunnel system

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Abstract. In order to reveal the internal force law of tunnel structure on different positions of landslide tunnel system, the internal force of supporting structure around tunnel on 12 working conditions was compared by numerical simulation method. The results show that the axial force is much greater than the bending moment and shear force. The influence of buried depth on axial force is greater than that of sliding zone. The bending moment and shear force are lower in the whole range of the arch, while the middle and lower parts of the side wall and the two ends of the invert vary greatly. In the design of similar tunnel structure, axial force should be taken as the main control parameter.

1. Introduction
Landslide tunnel in the process of excavation due to the influence of landslide, tunnel support structure stress will show different characteristics with ordinary tunnel, due to the existence of soft sliding zone, there will be support structure deformation, cracking, collapse and other risks.

Based on the results of field investigation, landslide monitoring and laboratory tests, the causes of creep type landslide and the mechanism of tunnel deformation and cracking are analyzed. (Zhang Luxin and Zhou Depei 1999). The interaction mechanism and deformation law between landslide and tunnel are studied by using the finite element method of contact problem.. (Zhou Depei, Mao Jianqiang, Zhang Luxin et al. 2002). Long-term monitoring using a multi-point displacement was used to analyse the deformation characteristics of a rock slope with weak bedding structural planes on the tunnel excavation conditions. (Dangqing, Song , C. Jundong , and C. Jianhua .2018). Therefore, through the numerical analysis method, this paper makes a comparative analysis of the internal force of tunnel structure on 12 different positions in the landslide tunnel system, so as to provide reference for design of the similar tunnel structure.

2. Numerical analysis
In this paper, a total of 12 working conditions are simulated for the relationship between the landslide-tunnel spatial position, of which the reference condition is that the center of the tunnel is located in the slip zone. The tunnel was shifted up, down, left and right by 1.0D, 3.0D and 5.0D, respectively, as the comparison condition. (D is the diameter of tunnel).
In the model, highway tunnel section is adopted for the standard section, the diameter of tunnel is 10m. The support structure only considers the primary support. The landslide is a circular single slide zone with a slip zone thickness 2m. The parameters of all kinds of rock and soil mass are obtained from the tests of rock and soil mass taken by tunnel site and landslide, and the parameters of support structure are obtained from relevant codes and literatures. Plane strain element is used to simulate rock mass. Beam element simulates the composite system of shotcrete and steel frame in initial support. The physical and mechanical parameters of the model are shown in Table 1.

| Material          | Density (kg/m³) | Elastic modulus (MPa) | Poisson's ratio | Cohesive force (kPa) | Cohesive force (°) |
|-------------------|-----------------|-----------------------|-----------------|----------------------|---------------------|
| Sliding body      | 2500            | 400                   | 0.4             | 18                   | 40                  |
| Sliding belt      | 2100            | 50                    | 0.45            | 1                    | 30                  |
| Bedrock           | 2580            | 600                   | 0.35            | 25                   | 40                  |
| Tunnel lining     | 2300            | 28.5                  | 0.22            | —                    | —                   |

The model has a horizontal length of 305m, an uphill height of 155m and a downhill height of 105m. The model grid is shown in Figure 1. The boundary conditions of the model are as follows: the surface is a free surface, the lower boundary is constrained in the vertical direction, and the left and right boundary are constrained in the horizontal direction.

The tunnel is less affected by the tectonic stress, so only the self weight stress is considered in the local stress field. The calculation process is divided into three construction steps. First of all, gravity is applied to balance the initial geostress and the displacement is cleared. Secondly, the sliding zone element is activated to realize the landslide sliding. Finally, the surrounding rock of tunnel excavation is passivated and the initial support structure of tunnel is activated. Finally, the landslide tunnel is simulated.

3. Analysis of numerical results

3.1. Supporting force of tunnel lining structure

Figure 2 shows the axial diagram of tunnel lining structure on three working conditions.

(a) Upper-3D condition   (b) Cross condition   (c) Lower-3D condition

Figure 2. Lining axial diagram (Unit/kN)
It can be seen from Figure 2 that all lining structures are compression structures. The axial force on invert is the smallest, followed by arch and side wall. The axial force at the arch and invert decreases from the middle to both sides, and the axial force distribution on the left and right sides of the lining is basically symmetrical along the center. Fig. 2 (a) as the tunnel is located at the sliding zone, the sliding zone causes the lining axial force to increase.

In order to quantitatively analyze the difference of lining internal force distribution under different working conditions, the lining units are numbered and the rules are the same as node numbers. The number of each unit of tunnel lining is shown in Fig. 3.

![Figure 3. Schematic diagram of tunnel lining unit number](image)

Figure 4 shows the layout of lining axial force under different working conditions.

![Figure 4. Vertical displacement of rock joints around the tunnel](image)

(a) Arch and sidewall areas  
(b) Invert area

It can be seen from Fig. 4 (a): the axial forces at the arch and side wall are distributed symmetrically along the unit 10, and the symmetry increases with the increase of the distance from the tunnel to the landslide. The axial force of arch crown is the smallest and that of side wall is the largest. The curve of axial force is W-shaped, and the influence of buried depth is greater than that of sliding zone. The deeper the buried depth is, the steeper the curve is and the greater the axial force is. It is shown that the axial force under the working conditions of left-1d, left-3d, left-5d, right-1d, right-3d and right-5d are concentrated in the range of 2000kN ~ 4000kN. The axial force of lower-5d working condition is the largest, the side wall is about 6200kN, and the vault is about 3600kN, and the difference between them is 2600kN; the axial force of upper-3d working condition is the smallest, the side wall is about 1600kN, and the vault is about 1000KN, and the difference between them is 600kN.

It can be seen from Fig. 4 (b): the symmetry of axial force distribution of inverted arch is worse than that of arch, and the axial force on the right side is greater than that at the same position on the left side. Similar to the axial force of the side wall of the arch, the axial force of the invert increases with the
increase of the buried depth. Due to the intersection of inverted arch and sliding belt in left-1d condition, the stress of inverted arch is greater than that of other conditions with the same buried depth, reaching the stress level of lower-5d working condition.

3.2. Shear force of supporting structure

Figure 5 shows the shear diagram of tunnel support structure on three working conditions.

![Figure 5. Schematic diagram of shear force of supporting structure](image)

It can be seen from Figure 5 that the lining shear force level in the whole range of arch is low, less than 10kN; the shear force at the middle and lower parts of side wall and both ends of inverted arch changes greatly. Because the tunnel is located in the slip zone, the shear force at the right arch foot, left wall foot and inverted arch in Figure 5 (a) is larger than that in Figure 5 (b).

The shear extremum at the side wall and invert under various working conditions is compared, as shown in Figure 6.

![Figure 6. Comparison of shear force at the side wall and invert](image)
It can be seen from Figure 6 that under all working conditions, the maximum shear force at the foot of side wall and invert is smaller on the left than on the right. Except for the left 1D and lower 5D conditions, the ratio of left and right shear force values is in the range of 85% ~ 95%. In the horizontal direction, the shear forces of left 3D, left 5D, right 1D, right 3D and right 5D are equivalent, the side wall foot is about 250kN, and the invert foot is about 380kN. In the vertical direction, the shear forces of upper 1D and lower 1D are equivalent, and the shear force increases with the increase of buried depth.

3.3. Bending moment of supporting structure

Figure 7 shows the bending moment diagram of tunnel support structure under various working conditions.

Figure 7. Lining bending moment diagram of tunnel sliding zone

It can be seen from Figure 7 that the distribution of bending moment is similar to that of shear force, and the bending moment of lining in the whole range of arch is relatively low; the bending moment of middle and lower parts of side wall and both ends of inverted arch varies greatly. Figure 7 (b) because the tunnel is located in the slip zone, the bending moment at the right arch foot, left wall foot and inverted arch is larger than that in Figure 7 (a) and Figure 7 (b).

Figure 8 shows the distribution of lining bending moment on various working conditions.

Figure 8. Bending moment distribution of lining on various working conditions

In Figure 8 (a), except for 1D condition and 0d condition on the right side, the left side of arch (1D condition) and right side (0d condition) of supporting structure intersect with sliding belt. In Figure 8 (b), due to 1D working condition on the left side, the right side of inverted arch intersects with sliding belt, resulting in different distribution of structural bending moment compared with other working conditions. The bending moment of the arch is low, and the bending moment at the foot of the wall...
changes greatly, and the bending moment value is high. The bending moment at both ends of inverted arch is higher than that in the middle part.

4. Conclusion
In this paper, through the numerical analysis method, the internal force of the tunnel on 12 different spatial positions in the landslide tunnel system is compared and analysed. The conclusion is as follows.

On the whole, the axial force is much more affected by the spatial position of the sliding zone and the tunnel than by the bending moment and shear force.

The sliding of sliding belt leads to the increase of lining axial force. The influence of buried depth on axial force is greater than that of sliding zone. The symmetry of axial force distribution in inverted arch is worse than that in arch.

The distribution of bending moment and shear force is similar, the bending moment level of lining is low in the whole range of arch, and the bending moment of middle and lower parts of side wall and both ends of inverted arch change greatly.

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