Load Effect and Sensitivity Analysis of Tunnels in Landslide Area Method

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Abstract. In this paper, the mechanical model of tunnel in landslide area is established, the boundary and load conditions are determined, the internal force distribution of tunnel under landslide load is analyzed, and the influence of the scope of landslide area, load characteristics and stiffness of support structure on the internal force of tunnel structure is analyzed by using finite element software, and the sensitivity of each influencing factor is divided. Analysis. It is proposed that the support of tunnel in landslide area should be combined with increasing the thickness of secondary lining and the length of bolt, and verified by finite element method. By comparing the internal force of reinforced lining with that of unreinforced lining, it is concluded that the new support method is feasible.

1. Introduction
In the construction of highway and water conservancy projects in mountainous areas, tunnels often pass through landslide areas. This paper establishes a geomechanical model, calculates the internal forces acting on the supporting structure of tunnels by using structural mechanics theory, and uses finite element software ANSYS to analyze the factors affecting the internal forces of the supporting structure and obtains the different effects of landslides. In the range, the change of internal force of support structure under different load characteristics and different secondary lining factors. In this paper, the method of supporting tunnel in landslide area by increasing the thickness of secondary lining and anchoring depth of anchor bolt is proposed. The finite element software is used to analyze the stability of landslide before and after reinforcement, the displacement of landslide and the simulation results of lining. The conclusion that is suitable for engineering practice is drawn.

2. Load Effect of Landslide Area on Tunnel Supporting Structure
Relaxation and extrusion bias tunnel is a common form. The lateral relaxation and extrusion pressure P1 of tunnel subjected to ground pressure slope P and landslide sliding decreases with the increase of tunnel burial depth. The calculation models are shown in Fig. 1 and Fig. 2.
Before calculation, the following simplifications are made: relaxation pressure $P$ is decomposed into vertical and horizontal directions without considering the anti-sliding effect of non-eccentric compression and fracture, so that the structural calculation is relatively conservative, ignoring the axial force and shear force of side walls and vaults, and ignoring the friction force between support structure and rock mass, the calculation model is simplified to a graph Fig. 3:

\[
\begin{align*}
X_1\delta_{11} + X_2\delta_{12} + X_3\delta_{13} + \Delta_{1p} &= 0 \\
X_1\delta_{21} + X_2\delta_{22} + X_3\delta_{23} + \Delta_{2p} &= 0 \\
X_1\delta_{31} + X_2\delta_{32} + X_3\delta_{33} + \Delta_{3p} &= 0
\end{align*}
\]

(1)

The coefficients of the equation are calculated as follows.

\[
\delta_{11} = \frac{2l_1^3}{3EI} + \left( \frac{R(2\theta l_1^2 + 4l_1R\sin\theta - \cos\theta) + R^2\theta(1 + \cos^2\theta) - 3R^2\sin2\theta/2}{EI} \right)
\]
\[\delta_{22} = \frac{l_1^3}{EI} + \frac{R^2 (2\theta l_1 \sin^2 \theta + \theta - \sin 2\theta / 2)}{EI}\]
\[\delta_{33} = \frac{2R(R\theta + l_1)}{EI}\]
\[\delta_{12} = \frac{R^2 (2\theta l_1 \sin \theta + 2R \sin^2 \theta - R\theta \sin 2\theta)}{3EI}\]
\[\delta_{31} = \frac{l_1^2}{EI} + \frac{2R(l_1 \theta + R \sin \theta - R\theta \cos \theta)}{EI}\]
\[\delta_{23} = \frac{l_1 l_2}{EI} + \frac{2R\theta \sin \theta}{EI}\]

\[\Delta_{p,1} = \frac{1}{EI}\begin{cases}
\left[\frac{p_l^2 + pl_1 R(1 - \cos \theta) + p_l R^2(1 - \cos^2 \theta)}{2} + \frac{(p_3 - p_1) R^2(1 - \cos^2 \theta)}{6}\right]
\int_{-\theta}^{\theta} \frac{2p_l R^2(1 - \cos^2 \theta)}{2} d\phi - \frac{p_3 R^2(1 - \cos^2 \theta)}{6} \int_{-\theta}^{\theta} 2(1 - \cos^2 \theta) d\phi
\end{cases}\]

\[\Delta_{p,1} = \frac{1}{EI}\begin{cases}
\left[\frac{p_l^2 + p_1 R(1 - \cos \theta) + p_1 R^2(1 - \cos^2 \theta)}{2} - \frac{p_3 R^2(1 - \cos^2 \theta)}{6}\right]
\int_{-\theta}^{\theta} \frac{2p_l R^2(1 - \cos^2 \theta)}{2} d\phi - \frac{p_3 R^2(1 - \cos^2 \theta)}{6} \int_{-\theta}^{\theta} 2(1 - \cos^2 \theta) d\phi
\end{cases}\]

\[\Delta_{p,1} = \frac{1}{EI}\begin{cases}
\left[\frac{p_l^2 + p_1 R(1 - \cos \theta) + p_1 R^2(1 - \cos^2 \theta)}{2} - \frac{p_3 R^2(1 - \cos^2 \theta)}{6}\right]
\int_{-\theta}^{\theta} \frac{2p_l R^2(1 - \cos^2 \theta)}{2} d\phi - \frac{p_3 R^2(1 - \cos^2 \theta)}{6} \int_{-\theta}^{\theta} 2(1 - \cos^2 \theta) d\phi
\end{cases}\]

The coefficients are brought into the equation and solved, and Fig. 5, Fig. 6, Fig. 7 results are obtained.

Figure 5. X1=1 M diagram  
Figure 6. X2=1 M diagram  
Figure 7. X3=1 M diagram

The internal force diagram of the basic structure is used to obtain the moment diagram under external loads according to the graph multiplication, as shown in Fig. 8.
On the basis of the above analysis, the finite element software ANSYS is used to simulate the load characteristics and the sensitivity of the secondary lining stiffness to the internal force of the structure. The two-dimensional beam element is used to simulate the tunnel lining. The following monitoring points are selected to fit the numerical analysis results.

3. Effect of Load Characteristics on Structural Internal Force
Assuming that the vertical relaxation pressure remains unchanged, the horizontal relaxation pressure is increased by 50KN steps. Fig. 10, Fig. 11 and Fig. 12 are obtained, respectively. Displacement and bending moment versus horizontal relaxation stress are plotted.

Figure 8. Moment Diagram of Fig. 8 Basic Structures under External Loading

Figure 9. Layout of Monitoring Points

Figure 10. Change of displacement of monitoring point with relaxation stress
Assuming that the horizontal relaxation pressure remains unchanged, the horizontal relaxation pressure is increased according to 5KN steps to obtain Fig. 13, Fig. 14 and Fig. 15, respectively, which show the variation of displacement and bending moment with the vertical relaxation stress.

**Figure 11.** Change Diagram of Bending Moment of Monitoring Point with Relaxation Stress

**Figure 12.** Diagram of Shear Force Change with Relaxation Stress at Monitoring Point
Figure 13. Change of displacement of monitoring point with relaxation stress

Figure 14. Change Diagram of Bending Moment of Monitoring Point with Relaxation Stress

Figure 15. Diagram of Shear Force Change with Relaxation Stress at Monitoring Point
4. Effect of Secondary Lining Thickness Variation on Internal Force of Structures
The calculation process assumes that the vertical and horizontal relaxation pressures remain unchanged, and only changes the thickness of secondary lining to analyze the structural internal force changes as shown in Figures 16, 17 and 18.

*Figure 16. Diagram of Displacement of Monitoring Point with Lining Thickness*

*Figure 17. Change Diagram of Bending Moment of Monitoring Point with Lining Thickness*

*Figure 18. Diagram of Shear Force at Monitoring Points Depending on Lining Thickness*
5. Effect of Landslide Range on Tunnel Structure

At present, three-dimensional landslide thrust calculation can be based on two-dimensional platform method, and there are many methods that can be applied. In this paper, the following calculation diagrams are used.

Figure 19. Sketch of calculation of space sliding force

In the calculation process, the most dangerous sliding surface, i.e. the main sliding section of the figure above, is found through calculation according to the lateral distribution of the spatial downsling force. The sliding force perpendicular to any section of the main sliding surface is a function of the distance between the section and the main sliding surface, which is defined as \( P(y) \). If the sliding force of any slider on the main sliding surface is \( P_0 \), the sliding force of \( Y \) distance from the main sliding surface is as follows Figure 19:

\[
R(y) = P_0 \lambda(y)
\]  

(2)

As \( \lambda(y) \) a distribution function, the transfer coefficient method is used to calculate the sliding force of each block on the main sliding surface, and the formula is used to calculate the sliding thrust of any section at \( Y \) distance from the main sliding surface. Because of many forms, there are many differences in the sliding force calculated in different forms, but it is not very different from the actual engineering, so the accuracy can be guaranteed. The distribution function has the following forms:

\[
\lambda(y) = 1
\]  

(3)

\[
\begin{align*}
\lambda(y) &= \frac{y_{p_{\text{min}}} - y}{y_{p_{\text{min}}}^2} & & \text{if } y_{p_{\text{min}}} \leq y \leq 0 \\
\lambda(y) &= \frac{y_{p_{\text{max}}} - y}{y_{p_{\text{max}}}^2} & & \text{if } 0 \leq y \leq y_{p_{\text{max}}}
\end{align*}
\]  

(4)

\[
\begin{align*}
\lambda(y) &= \frac{y_{p_{\text{min}}}^2 - y^2}{y_{p_{\text{min}}}^2} & & \text{if } y_{p_{\text{min}}} \leq y \leq 0 \\
\lambda(y) &= \frac{y_{p_{\text{max}}}^2 - y^2}{y_{p_{\text{max}}}^2} & & \text{if } 0 \leq y \leq y_{p_{\text{max}}}
\end{align*}
\]  

(5)
In the formula: \( y_{p_{max}} \) Pmax is the maximum distance between the plane parallel to the main sliding surface and the main sliding surface.

\( y_{p_{min}} \) Pmin is the maximum distance between the plane parallel to the main sliding surface and the main sliding surface.

The above distribution functions are shown in the following figures:

Figure 20. Common Distribution Form Map of 19

6. Conclusion

The relaxation pressure of tunnel is directly related to the buried depth of tunnel. When the distance between tunnel and sliding surface is large, the relaxation pressure can be neglected. When the distance between tunnel and sliding surface is close, the relaxation pressure can be simplified as a uniform force P acting on lining structure. Because the sliding of landslide will disturb the rock and soil in a certain range of sliding bed, but by the sliding of landslide, the relaxation pressure can be neglected. At present, there is no more accurate method for calculating the range of sliding bed rock and soil disturbed by landslide, and it can only be estimated by experience.

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