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Seismic dynamic stability analysis of landslide based on unbalanced thrust method

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Abstract: The unbalanced thrust method is one of the main research methods for the stability evaluation of the geological hazard of the landslide caused by the earthquake. When the traditional unbalanced thrust method is used to calculate the safety factor of the seismic downhill slope, all the soil strips use the same seismic acceleration. This treatment does not consider the propagation process of seismic waves in the landslide body. In this paper, the peak acceleration of the seismic center of each soil strip is obtained by numerical simulation, considering the temporal and spatial variation of seismic waves in soil strip, forming an imbalance considering multi-point seismic action thrust method. Based on this, taking the landslide formed by the K92 roadbed excavation of a highway in Yunnan as an example, the unbalanced thrust and safety factor under different seismic intensities are analyzed, and the engineering reinforcement effect is studied. Analysis shows that: sliding surface has obvious sliding section and anti-slip section, and the sliding section is distributed in the soil block with large inclination angle at the trailing edge of the landslide,and the anti-slip section is distributed in the lower part of the landslide; the landslide is in an unstable state after excavation, which is consistent with the scene.After comprehensive measures such as slope reduction, anti-slide pile reinforcement and prestressed anchor cable reinforcement, the landslide meets the requirements of earthquake resistance against IX. The research results provide an effective method for the evaluation of dynamic stability of landslides caused by earthquakes.

1. Introduction

Landslide is a common geological disaster phenomenon, and earthquake is one of the main factors inducing landslide [1]. For example, the Sichuan Wenchuan earthquake induced more than 15,000 landslides and more than 10,000 hidden points [2-3]. Therefore, the evaluation of dynamic stability of landslides caused by earthquakes is a key issue in geotechnical engineering.

The limit equilibrium method and numerical simulation method are usually adopted for analyzing the seismic dynamic stability of a landslide, and the limit equilibrium method is the most widely used in engineering design. Lam[4] proposed a general limit equilibrium formulation for three-dimensional slope stability analysis. J.M[5] discussed the limit equilibrium analysis method of the slope and the conditions of the finite element analysis method, and some suggestions for slope stability analysis are given. Yu et al. [6] proposed a simple method to estimate the permanent displacement of seismic dynamics based on the idea of residual thrust method and the Newmark finite sliding displacement method. Wu et al. [7] proposed a method suitable for nonlinear analysis of rock mass slope safety factor on the basis of static analysis. Gao et al. [8] deduced the limit equilibrium differential equation of the general slip method for slope stability under multi-point and multi-directional earthquakes with arbitrary shape slip surfaces.

Unbalanced thrust method is a kind of limit equilibrium method, which is simple and can provides design thrust forces for landslide prevention, and it is the stability analysis method recommended in many industry specifications [9]. Scholars have done a lot of research on the unbalanced thrust method, but the existing research involves less seismic stability analysis. At present, the unbalanced thrust method uses the quasi-static method for calculating earthquake action. That is, all the slips use a single peak seismic acceleration, which is converted into the horizontal seismic inertial force applied to the center of gravity of each soil strip. We called it the single value input method. However, when the seismic wave propagation in the rock and soil, due to the reflections and refractions, the peak acceleration of each position may be different. To solve this problem, this paper obtains the peak seismic acceleration of each slip by numerical simulation, and combines it with the unbalanced thrust method to propose a modified unbalanced thrust method considering multi-point seismic action. Using the modified method, the unbalanced thrust and safety factor of the landslide under different seismic intensities were calculated for the K92 landslide along an expressway in Yunnan Province, and the dynamic stability of the landslide was analyzed and the reinforcement effects were studied.

2. Unbalanced thrust method considering multi-point seismic action

Unbalanced thrust method is proposed for the line-shaped sliding surface. It divides the sliding body vertically into several slips, and assumes that the residual sliding forces between the slips is parallel to the direction of the bottom slip surface of the upper slip, and acts on the center of gravity of the slip. The force diagram is shown in Figure 1. The failure of the sliding surface obeys the Mohr-Coulomb failure criterion. The sliding force acts on the sliding surface with the shear stress parallel to the sliding surface and the normal stress perpendicular to the sliding surface. The unbalanced thrust and safety factor of the landslide are calculated according to formula (1). As shown in Figure 1, the unbalanced thrust method uses the idea of quasi-static method when studying seismic problems. This is the constant A that treats the seismic load as a single value at the center of gravity of each soil strip of the landslide.

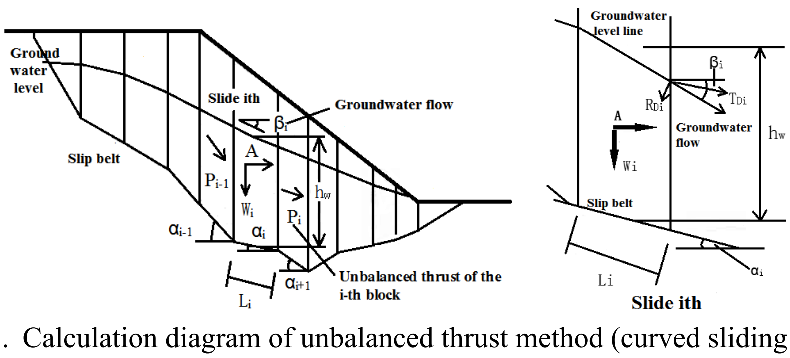

Figure 1. Calculation diagram of unbalanced thrust method (curved sliding surface)

$$K_f = \frac{\sum_{i=1}^{n-1}(R_i \prod_{j=i}^{n-1}\psi_j) + R_n}{\sum_{i=1}^{n-1}(T_i \prod_{j=i}^{n-1}\psi_j) + T_n} \quad (1)$$

Where $R_i = ((W_i((1-r_\upsilon)\cos\alpha_i - A\sin\alpha_i) - R_{Di})\tan\varphi_i + C_i L_i)$, $T_i = (W_i(\sin\alpha_i + A\cos\alpha_i) + T_{Di})$, W_i—Weight of the i-th block, C_i—Cohesion of the i-th block, φ_i—Internal friction angle of the i-th block, L_i—The length of the i-th block slip surface, α_i—The i-th block slip surface inclination, ψ_j—Transfer coefficient ($j=i$) when the remaining sliding force of the i-th block is transmitted to the i+1 block, A—Seismic acceleration, T_{Di}、R_{Di}—The ith block osmotic pressure parallel sliding surface component and the ith block osmotic pressure parallel sliding surface component.

To solve the shortage of the single-value seismic input for the traditional unbalanced thrust method, a modified unbalanced thrust method considering multi-point seismic action is proposed. The specific processing steps are as follows: (1) As shown in Figure 2, a numerical model of the landslide is established, the ground motion is input from the bottom of the model, and the seismic dynamic response of landslide is calculated using finite element method or finite difference method; (2) For the sliding body, the slips are divided for the unbalanced thrust analysis, and peak seismic acceleration of the centre of each slip is obtained by the numerical simulation results; (3) The peak seismic acceleration of the centre of each slip is transformed into the inertial force superimposed on the landslide force system. Finally, the stability analysis of the landslide is carried out by the unbalanced thrust method.

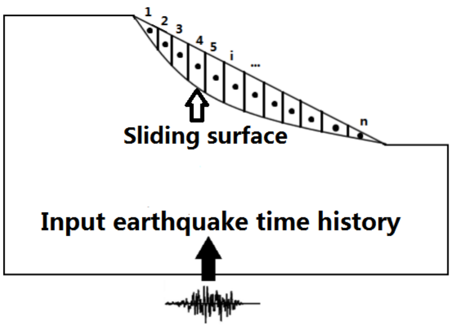

Figure 2. Multi-point input of ground motion

3. Project Overview

The K92 landslide is located in the K92+200～K92+600 section of an expressway in Yunnan. It is a structurally eroded Zhongshan Gorge landform and belongs to the national landslide key prevention zone. The area belongs to the fault block area of the Qinghai-Tibet Plateau, and its geological structure is complex. It is pushed by the north of the Indian plate and the south-south eastward extrusion of the Qinghai-Tibet Plateau. The neotectonic movement is very strong. The area is covered with Quaternary collapsed rock (gravel soil), residual slope (gravel silty clay), and underlying bedrock is Triassic lower slate (full ~ strong weathering), slate Clip limestone (middle weathering).

The geological data shows that there is a potential sliding surface in the K92 landslide area. During the excavation construction of the expressway project, some of the sliding bodies may be partially unstable along the potential sliding surface and the engineering slope. Figure 3 shows the topography and landslide boundary of the K92 landslide. A-A' is selected as the typical section. For the landslide formed by expressway excavation to the design elevation (Fig. 4), 9 slips are divided and the modified unbalanced thrust method is used to analyse the dynamic stability of landslides under different seismic intensities.

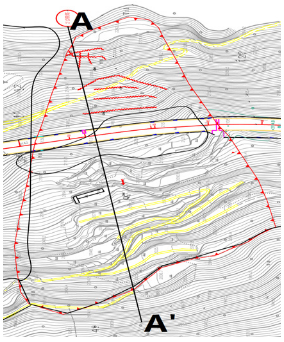

Fig3. K92 landslide terrain and boundary

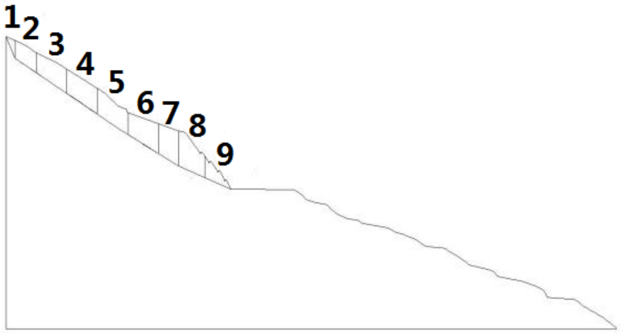

Fig4. Calculation model of the landslide

4. Dynamic stability analysis

Figure 5 shows the sliding angle of each slip and the residual thrust under different seismic intensities. The results show that: (1) There are obvious sliding domain and anti-sliding domain. The sliding domain is distributed at the trailing edge of the landslide, including 1-7 blocks. Due to the large inclination of the slip surface of this part, the sliding surface is relatively steep, so its sliding force is greater than the anti-sliding force, and it has a downward sliding effect on the landslide and the residual sliding force is increasing.The anti-sliding domain is distributed in the lower part of the landslide, among them, the sliding angle of the 8th and 9th blocks are about 23°, and the residual thrust is reduced. It has a certain anti-sliding effect. (2) The maximum residual thrust increases with the increase of seismic intensity. In the absence of seismic load, the final residual thrust is 670.54KN, which shows that the landslide is unstable after excavation.

Figure 6 shows the safety factors of the landslide under different seismic intensity. Taking the control safety factor of 1.10, the results show that the landslide after excavation is in an unstable state, which is consistent with the residual thrust results. Figure 7 shows the filed investigation that the leading edge shearing outlet of the landslide after the excavation of the expressway, which show that the field situation is consistent with the stability analysis results.

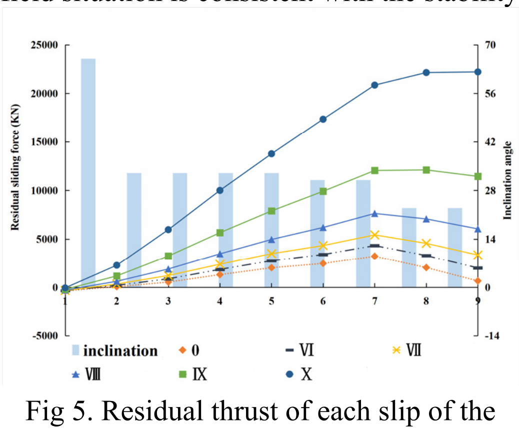

Fig 5. Residual thrust of each slip of the landslide under various intensities

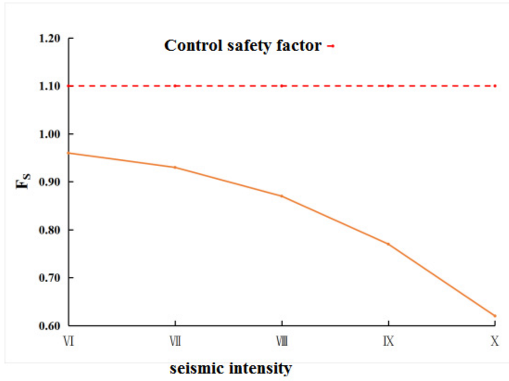

Fig 6. Safety Factor of landslide under various intensities

Fig 7. Filed investigation of the landslide excavation

5. Evaluation of reinforcement measures

The reinforcement measures for landslides include slope cutting, anti-slidling pile and anchor cable, as shown in Figure 8. After using engineering reinforcement measures, the safety factors of landslides under the VIII and IX degrees are 1.85 and 1.55 respectively, which are 0.98 and 0.78 higher than the unsupported conditions. It shows that the reinforcement measures meets the standard control standard under the IX degree earthquake.

Figure 9 is the residual thrust distribution of the IX degree earthquake sloping slope under the condition of no reinforcement and reinforcement. The results show that the residual thrust is significantly reduced in the position of anti-slide piles and cables.The remaining thrust of the landslide is the most obvious before and after the 8th slip support, the difference is 18022.43KN, and the final residual thrust is -5976.03KN.

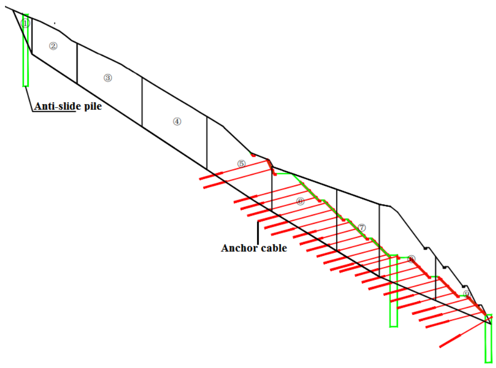

Fig 8. Reinforcement measures

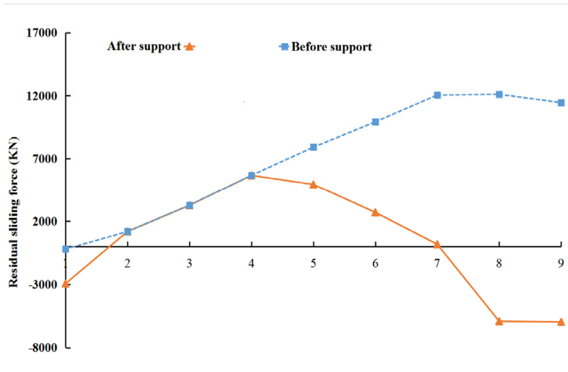

Fig 9. Residual sliding forces of the slices before and after the support under the earthquake

6. Conclusion

In the traditional unbalanced thrust method, the seismic wave propagation is not considered and the single-value input is adopted. A modified unbalanced thrust method considering multi-point seismic action is proposed. And it is used to analysis the stability of the K92 landslide of an expressway in Yunnan under different seismic intensity. The main conclusions are as follows:

- Based on the traditional unbalanced thrust method and the seismic wave propagation law, the peak seismic acceleration of the center of each slip is transformed into the inertial force superimposed on the landslide force system, and the unbalanced thrust method with multi-point seismic action is formed.
- By analysing the residual thrust and safety factor of the landslides under different seismic intensity, the landslide is in an unstable state after excavation, which is consistent with the scene.

- The reinforcement measures are the slope cutting, anti-slidling pile and anchor cable, and the safety factor of the landslide is 1.55 under the earthquake IX degree, which meets the normative control standards.

Acknowledgments
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References
[1] Keefer, D.K. (1989). Landslides caused by earthquake. Bulletin of Geological Society of America, (95):406-421.
[2] Qi, S.W., Xu, Q., Lan, H.X., Zhang, B., Liu, J.Y. (2010). Spatial Distribution Analysis of Landslides Triggered by 2008.5.12 Wenchuan Earthquake, China. Engineering Geology 116, 95–108.
[3] Huang, R., Li, W. (2009). Analysis of the geo-hazards triggered by the 12 May 2008 Wenchuan Earthquake, China. Bulletin of Engineering Geology and the Environment 68, 363–371.
[4] Lam, L., Fredlund, D.G. (1993). A general limit equilibrium model for three-dimensional slope stability analysis. Canadian Geotechnical Journal, 30(6):905-919.
[5] Duncan J.M. (1996). State of the Art: Limit Equilibrium and Finite-Element Analysis of Slopes. Journal of Geotechnical Engineering, 123(9):577-596.
[6] Qi S.L., Qi S.W., Wu F.Q., Liu C. L. (2004). On permanent displacement of earthquake induced slide based on residual pushing force method. Journal of Engineering Geology, 12(02):63-68.
[7] Wu Z.Y.,Bo J.S.,Liu H.S., Ding R. J., Qi W. H., Liu D. D. (2004). A method for evaluating safety factor rock slope seismic stability analysis. Journal of Disaster Prevention and Mitigation Engineering, 24(3):237-241.
[8] Gao Y.F., Fan Z.P. (2010). Generalized slice method for stability analysis of slope with non-circular slide face under multipoint and multidirection seismic ground motions. Rock and Soil Mechanics, 31(12): 3816-3822.
[9] China Geological Survey. DZ/T 0219-2006. Specification of design and construction for Landslide stabilization. Beijing: China Standard Press, 2006.