The influence of excavation of the dredged foundation of transmission towers on the stability of Yanzi landslide

Zhou Yingbo1, Chen Hang2, Zhou Qiupeng1, Duan Zhiqiang1, Gao Xiaojing1, Gao Lisong3, Zhou Yongqiang4

1 State grid Hubei electric power company limited economic research institute, Wuhan, Hubei, 430071, China
2 Changjiang institute of survey, planning, design and research, Wuhan, Hubei, 430071, China
3 Hubei University of Technology, Wuhan, Hubei, 430071, China
4 State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, Hubei, 430071, China

*Corresponding author’s e-mail: 852538607@qq.com

Abstract: With the construction of the national network project, transmission towers are inevitably erected on the landslide body. Excavation of transmission tower foundation often causes disturbance to the soil of the slope and reduces the stability of the slope. At the same time, the unfavorable stacking of construction spoil is also an unfavorable load to the slope. Under the combination of various unfavorable factors, slope instability accidents are prone to occur, causing losses to the grid operation. In order to reduce the amount of excavation and to minimize the impact of foundation excavation on the landslide, generally, dredged foundation is the selected excavation method of the transmission tower foundation. Therefore, this article takes the Yanzi landslide and 500kV transmission tower as the research object. Firstly, the mechanical parameters of the soil of the Yanzi landslide were analyzed, and then the influence of the excavation of dredged foundation and the spoil pile loading on the stability of the landslide was studied by 2D finite element method. Finally, 3D finite element method was used for verification and supplementation. The results show that the foundation excavation of transmission tower has negligible effect on total landslide stability, but local potential landslides need to be considered.

1. Introduction
The nationwide network will cover China's high-altitude areas. High-voltage transmission towers, which are the components of transmission lines, are important power engineering facilities. They are inevitably erected on the ridges, edges of steep slopes, and river banks. Induced by internal factors and external factors, it is easy to cause landslide disasters in these areas, resulting in power grid accidents such as tilting of power poles, disconnections, and trips [1]. Excavation of transmission tower foundation often causes disturbance to the soil of the slope and reduces the stability of the slope. At the same time, the unfavorable stacking of construction spoil is also an unfavorable load to the slope. Under the combination of various unfavorable factors, slope instability accidents are prone to occur, causing losses to the grid operation [2]. Many related studies on transmission towers and landslides have been carried out. For example, Li et al. analyzed the reasonable position of the transmission towers at loess slopes.
Similarly, According to characteristics of tower foundation on sloping ground, four kinds of solutions are proposed to match up between the base and the tower structure of transmission line by Lu and Cheng [4]. A model of artificial neural network is applied to the calculation of the safety factor of slope of the foundation of electric transmission line towers with cross validation [5]. In addition, many scholars have studied the stability of transmission towers landslides [6,7]. However, the influence of excavation of transmission tower foundations and spoil loading on landslide stability is rarely analyzed. Therefore, this article takes the Yanzi landslide and 500kV transmission tower as the research object. Firstly, the mechanical parameters of the soil of the Yanzi landslide were analyzed, and then the influence of the excavation of dredged foundation and the spoil pile loading on the stability of the landslide was studied by two-dimensional finite element method. Finally, 3D finite element method was used for verification and supplementation.

2. Mechanical parameters of Yanzi landslide

The Yanzi landslide is an old landslide with a long tongue shape on the plane of the landslide area. The topographic slope in the landslide area is steep forward and then gentle backward. The trailing edge slope is 15-25 °, and the leading-edge slope is 25-40 °, and the main sliding direction is 310 °. The landslide body has a length of about 400m, a width of about 150m, an area of about 6.00 × 10^4 m^2, an average thickness of the landslide of about 10m, and a volume of about 60.0 × 10^4 m^3. The soil layer of the Yanzi landslide model consists of 3 layers. The upper layer of the sliding surface is clay intercalated with block soil. The lower layer of the sliding surface is marl, and the sliding surface is calcareous mudstone.

According to the stratum situation of the Yanzi landslide, we went to the site and retrieved the silty clay with crushed stones (sliding soil). A large-scale indoor direct shear test was carried out for landslide soils, mainly analyzing the effect of compactness and moisture on the shear strength of the landslide soil. Figure 1 is the shear displacement diagram of the landslide soil under different compaction conditions and different water contents. Figure 2 is the shear strength parameter change of the landslide soil under different compaction conditions and different water contents. It can be seen from Figure 2 that under normal pressures of 400 and 600kPa, as the compactness increases, the shear strength of the gravel soil changes little. Under normal pressures of 200kPa, the shear strength of gravel soil is linearly related to the compactness. The cohesion of the gravel soil increases linearly with the increase of the compactness, and the internal friction angle has a negative linear relationship with the compactness. Unlike compactness, under different normal pressures, as the moisture content of gravel soil increases, its shear strength decreases, and its cohesion and internal friction angle have a negative linear relationship with the moisture content.

---

**Figure 1** Shear displacement diagram of landslide soil under different compaction and different water content

(a) Density is 1800kg/m^3  
(b) Natural moisture content

---
### 3. 2D finite element calculation

According to the foundation size of the transmission tower, it is assumed that the diameter of the excavated foundation pit is 1m and the buried depth is 8m, and the pitch of the foundation pit is 6m. The excavated soil is piled in the lower part of the foundation pit. Its two-dimensional model is shown in Figure 3.

![Excavation model of the tower foundation](image)

**Figure 3** Excavation model of the tower foundation

Figure 4 is the distribution of the plastic area before and after the excavation of the tower foundation. It can be seen that after the excavation of the foundation pit, the plastic area of the sliding on the upper part of the foundation pit expands along the ancient landslide surface, but does not penetrate the ground.
surface, and the plastic area in the area far from the pit is unchanged.

Figure 5 is the stress distribution before and after the excavation of the tower foundation. The minimum stress before excavation is 14.682 KPa and the maximum stress is 3094.5 KPa. After excavation, the minimum stress of the foundation pit is -57.946 KPa, and the maximum stress is 3092.9 KPa. It can be seen that after the excavation, a negative stress, which is also called a tensile stress, appeared around the foundation pit. However, the overall distribution of stress has remained unchanged.

Figure 6 is the displacement distribution of the tower foundation after excavation. After excavation of the foundation pit, the maximum displacement on both sides of the foundation pit is 0.0473 m. The displacement is mainly concentrated on the upper and lower sides of the foundation pit. The further away from the foundation pit, the smaller the displacement is. Figure 7 shows the landslide stability before and after foundation excavation. The stability coefficient of the overall landslide before the excavation of the foundation pit is 1.378, and the stability coefficient of the local landslide below the foundation pit is 1.042. After the excavation, the overall stability coefficient of the landslide is 1.377, and the stability coefficient of the local landslide below the foundation pit is 0.997. It can be seen that the excavation of the tower foundation has little effect on the overall stability of the landslide. However, the excavation of the foundation caused the loading of spoil and increased the sliding force of the local landslide in the lower part of the foundation pit, making it in an unstable state, and corresponding support measures need to be taken.

4. 3D finite element calculation
In order to analyze the impact of the simultaneous excavation of four transmission tower foundations on local landslides, according to the three-dimensional topographical geological map, a local three-
dimensional geological model and section layout diagram of the Yanzi landslide as shown in Figure 8 was established. In order to analyze the influence of the excavation of the tower foundation on the surrounding soil, sections 1-1 and 2-2 were set up, and the tower foundations were 1 #, 2 #, 3 #, and 4 # in the reverse direction.

![Figure 8 Local 3D geological model and section layout of Yanzi landslide](image)

(a) 1-1 section  
(b) 2-2 section

![Figure 9 Distribution of plastic zone of the tower foundation after excavation](image)

(a) 1-1 section  
(b) 2-2 section

![Figure 10 Displacement distribution of the tower foundation after excavation](image)

(a) 1-1 section  
(b) 2-2 section

Figures 9 and 10 are the plastic zone and displacement distribution of the surrounding soil after excavation. It can be seen from the figures that the plastic area is mainly distributed on both sides of the foundation pit. The 1-1 section has more plastic zones than the 2-2 section, but the plastic zone between the two plastic pits is not continuous. The displacement is also mainly distributed on both sides of the foundation pit. The maximum displacement occurs near the lower right corner of the foundation pit, which is the same as the result of the 2D analysis. Figure 11 shows the landslide shear strain increment and velocity vector distribution before and after foundation excavation. It can be seen that the plastic area is not penetrated, but the velocity vector at the position near the base of the tower is significantly larger than that in other areas. Moreover, after excavation, the velocity vector in this area is significantly greater than that before the excavation. However, excavation does not have much effect on the stability of the landslide, and the safety factor before and after is only 0.01.
5. Conclusion
This article mainly focuses on the Yanzi landslide and transmission tower foundation, using two-dimensional and three-dimensional finite element methods to analyze the influence of transmission tower foundation excavation and spoil pile loading on the landslide during construction, and draws the following conclusions:

1) The cohesion of the landslide soil increases linearly with the increase of the compactness, and the internal friction angle has a negative linear relationship with the compactness. Unlike compactness, the cohesion and internal friction angle of the landslide soil have a negative linear relationship with the water content.

2) Using a 2D calculation model, the results show that the excavation of the tower foundation has little effect on the overall stability of the landslide. However, the excavation of the foundation caused a pile of spoil, which increased the gliding force of the local landslide in the lower part of the foundation pit, making it in an unstable state.

3) Using a 3D calculation model, the plastic area of the tower foundation did not penetrate after the excavation, but the velocity vector near the location of the tower foundation was significantly larger than that of other areas. The influence of the tower excavation on the overall landslide safety factor did not exceed 0.01, which was consistent with the results of 2D calculation model.

Acknowledgements
The authors are grateful for the financial support from the National Key R&D Program of China (2018YFC0809400). The authors are thankful for the support and reviewers for their valuable comments to improve this manuscript.

References
[1] Wang H.H., Luo J.Y., Xu T.S., et al. (2010) Questionnaire Survey and Analysis of Natural Disaster Defense Techniques of Power Grids in China. Automation of Electric Power Systems, 34(23):5-10.
[2] Guo C.S., Kong L.W., Yin L. (2017) Stability Analysis of Spoil Slope of Transmission Line in Mountain Area. Electric Power Survey & Design, 2(1): 6-9.
[3] Li B., Hu Y.R., Cao R.T., et al. (2013) Analysis for Reasonable Location of Transmission Line Towers at Loess Slope. Electric Power Survey & Design, 4(2): 17-20.
[4] Lu X.L., Cheng Y.F. (2011) Study on Technology of Foundation to Match Tower Structure of Transmission Line on Sloping Ground. Electric Power Construction, 32(8):29-33.
[5] Wei L.D., An S.P., Li P.Y., et al. (2013) BP Network Model of Stability Evaluation of Tower Foundation Soil Slope in Transmission Line. Electric Power Survey & Design, 4(2): 17-20.
[6] He Y.X., Xu L., Nie W.P. (2012) Slope Stability Influence Factors Analysis of Slope-side Foundations of Transmission Tower by Strength Reduction Method. Electric Power Construction, 33(7):30-33.
[7] Wang W., Shi Z.R., Wang R. (2015) Slope Disease and Prevention Method of Tower Foundation Caused by Rainfall in Shenzhen Area. Electric Power Survey & Design, 3(s1): 5-10.