The influence of excavation of combined foundations of high-voltage transmission towers and spoils loading on landslide stability

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Abstract: With the construction of "West-to-East Power Transmission" and national networked engineering projects, high-voltage transmission towers, which are important components of transmission lines, are important power engineering facilities. They are inevitably erected on the ridges, edges of steep slopes, and river banks. Therefore, 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. This article takes the Yanzi landslide in Badong County and 500kV transmission tower on the landslide as the research object. For the combined foundation excavation form of the tower foundation, the relative positions of different tower foundations and landslides and the loading of spoil are analyzed. The influence of excavation of transmission tower foundation and pile dumping on the stability of the landslide is discussed. The research results show that the effect of the combined foundation excavation on the stability of the landslide is negligible, but it will affect the stability of the local landslide, and the stability of the local landslide is related to the relative position of the tower foundation and the landslide. In addition, the pile loading of spoil will also affect the stability of local landslides, and the degree of impact is related to the size of the spoil pile.

1. Introduction

In recent years, with the construction of "West-to-East Power Transmission" and the nation's networked engineering projects, the realization of water, thermal and power mutual benefit across large regions and river basins, and the optimization of the allocation of power resources on a larger scale have great significance for improving energy utilization. As the carrier of high-load electrical energy transmission, the safe operation of transmission lines has always received great attention from all walks of life. As an important infrastructure of the country, the safe and stable operation of the power system is related to the national economy and people's lives. Once a failure or damage occurs, it will cause huge economic
losses and cause various secondary disasters [1, 2]. The nationwide network will cover China's high-altitude areas. High-voltage transmission towers, which are important 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. For example, the 500kV cross-region power grid Ertan-Zigong transmission line has been in operation for almost ten years since it was put into operation. Almost every year, damage to transmission line equipment caused by landslides causes the line to be shut down for reconstruction. As of 2008, due to natural disasters such as landslides and mudslides, the investment in the reconstruction of the Second Line has exceeded 100 million RMB [3]. There are many types of pole tower foundations to choose from, depending on the terrain and geological conditions of the transmission line, such as rock embedded foundation, excavated foundation, stepped foundation, large slab foundation, combined foundation and composite caisson foundation. The excavation of these foundations will cause disturbance to the rock and soil of the slope and reduce the stability of the slope. The unfavorable stacking of construction spoil is also an unfavorable load on the slope. The slopes where many towers are located have no visible instability phenomenon or trend under natural conditions, and once excavated, the balance of rock and soil itself is destroyed or weakened. Under various combinations of unfavorable factors, slope instability accidents are prone to occur, causing losses to the grid operation [4]. Therefore, in order to study the maximum influence of the tower foundation excavation on the stability of the landslide, this article takes Yanzi landslide as the research object, and selects the tower foundation type as the joint foundation. The influences of the excavation positions of different tower foundations and the pile loading of spoils on the stability of the landslide are analyzed.

2. Yanzi Landslide
The Yanzi landslide is an old landslide with a long tongue shape on the plane of the landslide area. On January 26, 2016, during the slope-cutting construction of the G209 National Highway Bypass Highway in the middle of the landslide, it was found that the 500kV national power grid across the river tower base in the middle and rear of the landslide was deformed. The deformation and expansion of the original surface cracks intensified, posing a threat to the safety of the river crossing tower, and the surface cracks extended along the north side, which caused serious deformation of the three-family houses on the northern side of the landslide, posing a threat to the life and property of the three families. 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. Based on the Yanzi landslide profile, a geological generalization model of the Yanzi landslide is established as shown in Figure 1.

![Figure 1 Geological generalization of Yanzi landslide](image1)

![Figure 2 Distribution of excavation locations](image2)

3. Influence of different excavation positions on landslide stability
According to the foundation size of the tower, assuming that the ground width of the tower foundation is 10m, and the buried depth of the foundation is 10m, three different locations on the Yanzi landslide...
body were selected for excavation, namely position 1, position 2 and position 3. The excavation diagram is shown in Figure 2.

Figure 3 is the displacement distribution diagram at different excavation positions. It can be seen from the figure that the place with the largest displacement after excavation in different positions is mainly the upper edges of the two sides of the foundation pit. The maximum displacement of the soil around the foundation pit after excavation at position 1 is 0.021m. The displacement of the soil mass after excavation at location 2 is mainly concentrated on the upper slope of the foundation pit, and the lower slide has no significant displacement. The maximum displacement of the upper soil is 0.126m. The maximum displacement of the soil around the foundation pit after excavation at position 3 is 0.019m. Therefore, the displacement of the soil at excavation position 2 is significantly larger than that at other positions.

![Excavation at position 1](image1)

![Excavation at position 2](image2)

![Excavation at position 3](image3)

Figure 3 Displacement distribution at different excavation positions of the tower foundation

The boundary of the soil layer in the model is the ancient landslide zone, which is the specified slip surface in the model. The slip-in and slip-out method is selected to search for the potential slip surface after excavation. Figure 4 shows the safety factor and plastic area distribution of landslides at different excavation positions of the tower foundation. When the foundation is excavated at position 1, the safety factor for the designated slip surface is 1.381 and the stability factor for the potential slip surface is 1.179. When the foundation is excavated at position 2, the safety factor for the designated slip surface is 1.401, and the stability factor for the potential slip surface is 0.745. When the foundation is excavated at position 3, the safety factor for the designated slip surface is 1.379, and the stability factor for the potential slip surface is 1.139. After excavation at positions 1 and 3, a small area of plastic area appeared around the foundation pit. The plastic area is basically the same as the plastic area distribution in situ. However, a large area of plastic area appears on the upper side of the foundation pit after excavation at location 2. Although the overall plastic area is not penetrated, there will be no overall instability. The plastic area above the excavation position is penetrated, which is prone to local instability, and is also consistent with the low safety factor of the potential sliding surface. The designated slip surface is stable when excavated at different positions, but the lower the tower base position, the greater the possibility of local potential landslides at the upper part of the excavation position is, especially at position 2. Therefore, when selecting the base position of the pole tower, the scope of the landslide body needs to be determined during the early geological survey. Due to the constraints of the terrain, it is inevitable that the landslide body should be built on the landslide body. It should be selected as far as possible in the middle and upper part of the landslide. And avoid building it at steeper locations.
4. Effect of spoil pile loading on landslide stability

Selecting excavation position 1, the width of the fixed excavation pit is 10m, and the excavation depths are 8m and 14m, respectively. The excavated soil is piled at a certain distance below the foundation pit. As shown in Figure 5, the volume of soil piled is the same as that of the excavated foundation pit.

Figure 5 shows the plastic distribution with or without spoil pile loading after the excavation depths are 8m and 14m at position 1, respectively. When the excavation depth is 8m, the plastic distribution of no spoil loading is almost the same as that of the loaded with spoil, and no new plastic zone appears.
locally. When the excavation depth is 14m, a new plastic zone appears when the loaded with spoil. The plastic zone appeared at the bottom of the spoil, but the plastic zone did not penetrate. Figure 6 is comparison chart of the safety factor of the landslide with or without spoil pile loading at the excavation position 1. When the excavation depth is 8m, the safety factor with the loading condition is 1.362 and the safety factor with the unloading condition is 1.377. When the excavation depth is 14m, the safety factor under load conditions is 1.316, and the safety factor under no load conditions is 1.332. Under two different excavation depths, the pile loading of spoil will reduce the stability of the slope, but the effect will not exceed 0.02. This shows that the effect of spoil dumping on landslides is not significant.

5. Conclusion
This article focuses on the Yanzi landslide, and analyzes the influence of the pole tower foundation on the landslide under different excavation positions and spoil loading conditions during construction. The following conclusions are obtained:

(1) When excavating at different positions, the designated sliding surface is stable and the safety factor is not much different, but the lower the tower base position, the greater the possibility of local potential landslides at the upper part of the excavation position, especially at position 2.

(2) when selecting the base position of the pole tower, the scope of the landslide body needs to be determined during the early geological survey. Due to the constraints of the terrain, it is inevitable that the landslide body should be built on the landslide body. It should be selected as far as possible in the middle and upper part of the landslide. And avoid building under steeper locations.

(3) Under two different excavation depths, the pile loading of spoil will reduce the stability of the slope, but the impact will not exceed 0.02. This shows that the impact of spoil dumping on landslides is not significant.

![Figure 6](attachment:image6.png)

(a) Excavation depth with 8m
(b) Excavation depth with 14m

Figure 6 Safety factor at the excavation position 1 with or without spoil pile loading

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] Zhang Y.Y. (2014) Study on vulnerability evaluation model of transmission powers to landslides. Chongqing University, Chongqing.

[3] Zhang X.H., Jia Z.J. (2016) Challenges of Construction, Operation and Maintenance in Sichuan Grid and Countermeasures. High Voltage Engineering, 42(4):1091-1099.

[4] Guo C.S., Kong L.W., Yin L. (2017) Stability Analysis of Spoil Slope of Transmission Line in Mountain Area. Electric Power Survey & Design, (1): 6-9.