Influence of transmission tower load under extreme conditions during operation period on the stability of landslide and tower foundation

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Abstract: Taking Yanzi landslide and 500 kV transmission tower foundations on the landslide as the research object, this paper presents a study of the influence of transmission tower on the stability of landslide and tower foundation under extreme conditions during operation period. Firstly, the ultimate loads of transmission tower foundation under different operating conditions are determined. Secondly, based on the limit load of transmission tower, the overall and local stability of Yanzi landslide is analyzed. Finally, the disturbance of tower foundation load state on soil around the tower foundation and the change of tower foundation displacement are studied. The results show that, with the increase of wind speed, the tower foundation load In addition, under the action of wind load, the soil around the adjacent tower foundation basically does not affect each other, the maximum displacement of tower foundation does not exceed 0.5 mm, and the maximum inclination rate of tower foundation meets the requirements of cod.

1. Introduction

The national electricity grid will cover high altitude areas in China. As an important part of transmission lines, high-voltage transmission towers are important power engineering facilities. Inevitably, they will be erected on the ridge, the edge of steep slope and the river. The slopes in these areas are easy to cause landslide disasters induced by internal and external factors, leading to power grid accidents such as tower tilt, line break and trip. On July 21, 2007, heavy rain caused a landslide in the tower foundation, the most important power supply line in Nan'an District of Chongqing. 60% of the main power supply lines in the South Bank of Chongqing stopped working, and 400000 people were affected by the power failure [1].

In the complex geological conditions, in addition to its own self weight load, tower often bears the instantaneous or cyclic action of large wind load and snow load, which also brings great threat to the stability of side landslide. In view of how external factors affect the stability of tower foundation landslide, such as rainfall, excavation and earthquake, Guo et al. [2] took a tower site in the Wuning-Zhuyun 220 kV transmission line project as the research object, analyzed the stability and displacement field before and after the pile up of the excavation spoil at the tower site, and studied the deformation and failure mechanism of the landslide induced by the excavation waste soil of the tower foundation. Based on the rock slope engineering of a new transmission line tower, Zhao et al. [3] analyzed the
influence of excavation steep slope on the stability of rock slope of new tower. Fan et al. [4] and Hu et al. [5] analyzed the stability of transmission tower foundation landslide under rainstorm, earthquake and their combination. However, there are few studies on the influence of tower foundation load on landslide and its own stability, and even less on the influence of ultimate load conditions on landslide stability.

Yanzi landslide is an old landslide with a long tongue shape on the plane, an armchair like terrain at the back edge, and a terrace shape on the profile. On January 26, 2016, during the process of cutting the slope of the South Bank of Badong Yangtze River Bridge on G209 National Highway in the middle of the landslide, it was found that the tower foundation of the first circuit of Panlong of State Grid in the middle and rear part of the landslide was deformed. The existing surface cracks became more and more extensive, posing a threat to the safety of the tower crossing the river. In addition, the surface cracks extended along the north side, causing serious deformation of the three-family houses on the north side of the landslide and posing a threat to the safety of life and property of the three houses.

Therefore, based on the Yanzi landslide and 500 kV transmission tower foundation on the landslide as the research object, the influence of transmission tower ultimate load state on the stability of landslide and tower foundation during operation period are studied in this present study.

2. The load of the tower foundation
The slope of Yanzi landslide area is steep in the front and gentle in the back, and the gradient of the back edge is 15-25° and most of the residents transform the gentle slope into cultivated land, the front edge is slightly steep, the slope is 25-40° and the main sliding direction is 310°. The landslide mass is about 400 m in length, 150 m in width and 6.00×10^4 m^2 in area. The average thickness of the landslide mass is about 10m and the volume is about 60.0×10^4 m^3. The 500 kV Panlong first circuit 200 kV tower is a large crossing-river tower in Badong County. The 200 kV tower is located in the Yanzi landslide of xiroangpo community, Xinling Town, Badong County. Figure 1 shows the site map of Yanzi landslide and the 200# transmission tower.

![Yanzi landslide and 200 # transmission tower](image)

Taking the 200# transmission tower on Yanzi landslide as the object, according to the local meteorological conditions, the load of transmission tower foundation under normal operation conditions (including maximum wind speed, icing) and line break is analyzed. It can be found that when the wind speed is greater than 20 m/s, the maximum wind speed is determined as the maximum load condition of the tower foundation. The relationship between load size of the tower foundation and wind speed is also calculated, as shown in Figure 2. It can be seen that the vertical load and horizontal load of tower foundation are approximately linear with wind speed.
3. Influence of tower foundation load on landslide stability

It has been concluded that the maximum wind speed under normal operation is the most extreme weather condition of tower foundation load. Meanwhile, the stability of tower foundation under different wind speed conditions is preliminarily analyzed. According to the research results and the actual buried depth of the 500 kV Transmission Tower of Panlong primary circuit on Yanzi landslide, it can be determined that the foundation stability meets the requirements of uplift, overturning and foundation bearing capacity. Therefore, on this basis, the influence of tower foundation load on the safety and stability of landslide under different wind speeds is studied.

Figure 3 shows the safety factors of the whole landslide and local landslide under different wind speeds. It can be seen from the figure that with the increase of wind speed, the safety of the overall landslide remains unchanged, while for the local landslide, the safety factor decreases to a certain extent, but it does not exceed 0.003. It indicates that the tower foundation load has no impact on the overall landslide, although it has a certain impact on the local landslide, the impact is small and can be ignored.

4. Influence of tower foundation load on tower foundation and surrounding soil

4.1 The numerical model

According to the 3D topographic and geological map, the local 3D geological model and section layout of Yanzi tower foundation landslide are established, as shown in Figure 4. In order to analyze the influence of tower foundation load on surrounding soil through tower foundation, the vertical sections 1-1 and 2-2 are set up. The tower foundations are marked as 1#, 2#, 3# and 4# in counterclockwise. For the load, the wind speed is assumed to be in the positive x-direction. Therefore, the tower foundations, 1# and 4#, are being pulled up, while the tower foundations, 2# and 3# are subjected to down force.
4.2 Result analysis

4.2.1 Displacement

The total displacement of tower foundation under different wind speeds is analyzed, as shown in Figure 5. It can be found that with the increase of wind speed, the tower foundation displacement also increases, but the maximum value is less than 0.5 mm, and the increase amplitude is basically consistent with the increase of wind speed.

In order to analyze whether the foundation deformation of the tower foundation meets the requirements, the displacement of the top and bottom of each tower foundation in z-direction are recorded, as shown in Figure 6. It can be seen that under different wind speeds, the positive displacement in z-direction of 4# foundation is the largest, while the subsidence displacement of 3# tower leg is basically the largest.

Therefore, according to the section 1-1, i.e. 3# and 4#, the maximum inclination rate of tower foundation under different wind speeds is analyzed, as shown in Figure 7. It can be found that the maximum inclination rate of tower foundation is not greater than 0.00012. According to the specification requirements (Table 1), it can be seen that the foundation deformation of tower meets the requirements.

Figure 5 Displacement of the tower foundation at different wind speeds

Figure 6 Variation of the displacement of the tower foundation in the z direction with the wind speed
Figure 7 Variation of the maximum inclination of the tower foundation with wind speed

Table 1 Allowable values of foundation deformation

| Total height of tower (m) | (0,50) | (50,100) | (100,150) | (150,200) | (200,250) | (250,300) |
|---------------------------|--------|----------|-----------|-----------|-----------|-----------|
| Maximum inclination       | 0.006  | 0.005    | 0.004     | 0.003     | 0.002     | 0.0015    |

Note: the ratio of the settlement difference between the two ends of the foundation inclined direction and its distance.

4.2.2 Analysis on the plastic zone

Figure 8 shows the distribution of plastic zone of tower foundation and surrounding soil under different wind speeds.

It can be seen from the figure that for section 1-1, the plastic zone is mainly concentrated in the soil around the tower near the ground. With the increase of wind speed, the plastic zone of soil around the tower foundation increases. When the wind speed reaches 35 m/s, the plastic area of soil around the tower foundation increases significantly, compared to other wind speed cases. In addition, plastic zone of soil around the 3# tower foundation is always greater than that of 3# tower foundation. In general, the influence of tower load on the plastic zone of soil around the tower is small, thus, the influence of adjacent tower foundation can be ignored.
5. Conclusions
In this paper, the stability of Yanzi landslide and the response of corresponding tower foundation are analyzed under extreme load conditions during operation period. The following conclusions are obtained:

(1) With the increase of wind speed, the safety of the overall landslide remains unchanged, while for the local landslide, the safety factor has a certain reduction, but not more than 0.003.

(2) The maximum displacement of the tower foundation is concentrated on the top of the tower foundation, and the maximum value is not more than 0.5 mm. The adjacent tower foundation basically does not affect each other.

(3) With the increase of wind speed, the displacement of tower foundation is also increasing, and the increase amplitude is basically consistent with the increase range of wind speed. The maximum inclination rate of tower foundation is not greater than 0.0001 2. According to the specification requirements, the foundation deformation of tower foundation can meet the requirements.

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