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Numerical Simulation Analysis of Loess Slope Stability under the action of Power Tower foundations

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Abstract: Electric energy is the national key energy, and the safety construction of power tower is very important. In this paper, the influence of power tower foundation layout on slope stability in loess slope area is studied. Qingyangning County, Gansu Province is selected as the target area. Based on climate and rainfall data, numerical simulation method is adopted. Firstly, the study area is determined and the data are collected. Then, AUTO CAD and FLAC3 D are used to simulate the slope stability under different rainfall conditions and analyze the influence of rainfall. Then, several tower foundation layout schemes are determined, focusing on the influence of tower foundation on slope settlement under heavy rainstorm conditions, and calculating the slope safety factor and settlement of different schemes. Finally, the optimal tower foundation layout scheme is obtained, which provides reference for designers. This study is of great significance to the safety construction of power tower and the improvement of loess slope stability.

Keywords: Tower Base; Stability of Loess Slope; Rainfall; Layout Location.

1. Introduction

The safe transmission of electric energy relies on power tower construction. This paper studies the safety layout of power tower foundations in loess slope areas, using the ±800 kV UHV DC project from Longdong to Shandong as an example. Data on climate and rainfall were analyzed with AUTO CAD and FLAC3D modeling. The study discusses the impact of rainfall and tower foundation position on slope stability, evaluates safety factors and settlements under various schemes, and determines the optimal layout. Results show that rainfall and foundation position significantly affect slope stability, providing a scientific basis for safe foundation layout in loess slopes. Specific data are implicit in research methods and results.

2. Engineering Background

The selected project in this paper is Longdong-Shandong ± 800 kV UHV DC transmission project (Gansu section). The main construction contents include new sending end converter station, DC transmission line and multiple AC line relocation. The project is through Qingyangning County, which is located in the eastern part of Gansu Province. The geographical location is 107 ° 41 ′ to 108 ° 34 ′ east longitude and 35 ° 15 ′ to 35 ° 52 ′ 57 north latitude [1-6]. The loess slope in Ningxian County belongs to the type of multi-stage rotating loess landslide, which has the characteristics of complex structure and large scale, and has great damage to the surrounding environment. The project is 22.3 km through Ningxian County.

(1)The scope of the study area (2)The reflection of the slope in the study area

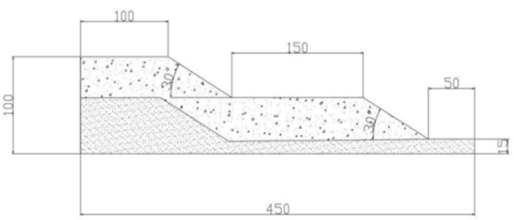
Fig 1. The scene map of the study area

3. The Influence of Different Working Conditions on the Stability of Loess Slope

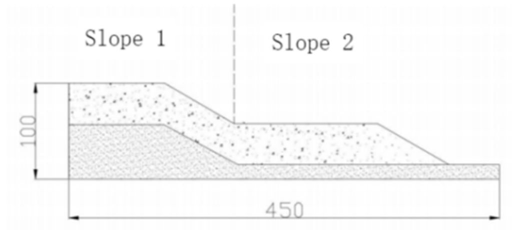
3.1. Model Establishment and Parameter Selection

3.1.1. Model Establishment

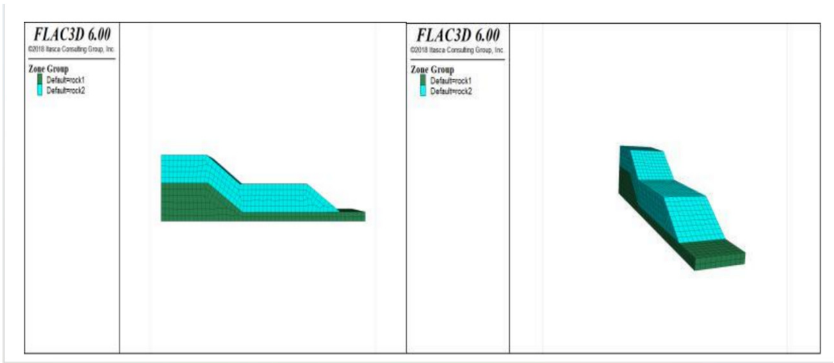
According to the data collected from the loess slope in Ningxian County, a simplified model of the loess longitudinal section slope was established by Auto CAD software, and then imported into FLAC3 D to build a specific model. As shown in Figure 2. The height of the loess slope is 100 meters, the slope angle of the upper part of the slope is 30 °, there is a road in the middle with a width of 150 meters, and the slope angle of the lower slope is 30 ° [7].



(1)Slope size



(2)Slope division



(3) Based on FLAC3D loess slope model

Fig 2. Loess slope model and slope division (unit: m)

3.1.2. Parameter Selection

The main physical and mechanical parameters of each geotechnical soil layer are shown in Table 1 [8].

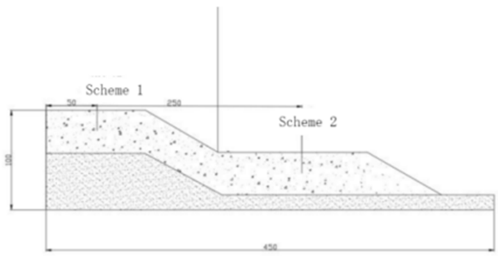
Table 1. The main physical and mechanical parameters of each geotechnical soil layer

Soil type	Elastic modulus (MPa)	Poisson 's ratiov	Tensile strength(kPa)	Dilatancy angle (°)
LoessQ3eol	25	0.35	10	0
LoessQ2eol	30	0.35	10	0

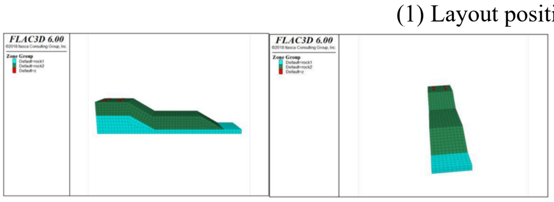
In addition to Poisson 's ratio, tensile strength and shear angle, bulk modulus (K) and shear modulus (G) need to be set when setting constitutive model and material parameters in FLAC3D [9-11]. According to the characteristics of the influence of loess slope settlement on stability, it is determined that the upper surface of the model is a free surface, which only needs to be constrained on both sides of the X and Y directions and below the Z direction.

3.2. The Influence of Tower Foundation Layout on the Stability of Loess Slope

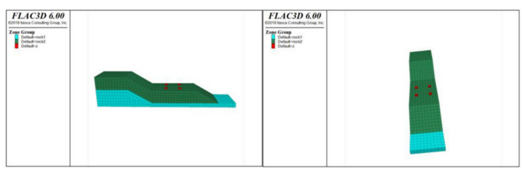
3.2.1. Model Establishment



(1) Layout position (unit : m)



(2) Scheme 1



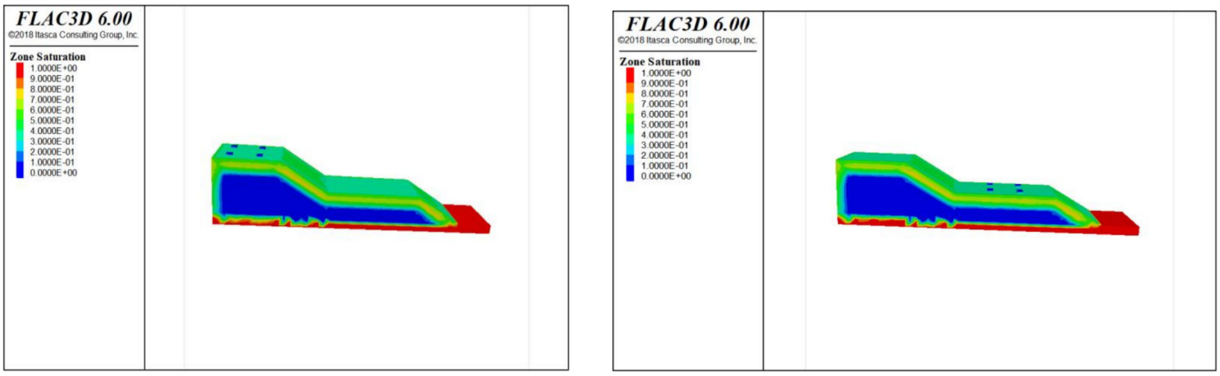
(3)Scheme 2

Fig 3. Layout size and scheme of tower foundation (unit : m)

According to the engineering investigation, the layout model of the power tower foundation on the loess slope is established (see Fig 3). The model analyzes the influence of the tower foundation on the overall and local stability at different slope positions. The pile foundation is deeply buried. The total weight of the tower foundation is 70 t. It is composed of four cube piles with a side length of 2 meters and a height of 15 meters. The pile spacing is 8 meters and the buried depth is 12 meters. The modeling scheme is shown in Fig.3 (2,3). The tower foundation is laid at two positions of the slope, and the displacement, stress cloud diagram and slope safety factor under natural and rainfall conditions are compared, and the monitoring points are set to analyze the settlement.

3.2.2. Rainfall Conditions

Comparing stress and displacement cloud maps, scheme 2 under natural conditions stabilizes the slope more, as the slope is naturally stable and rainfall significantly affects it. Heavy rainstorm impacts loess slope stability more, necessitating detailed comparison of both schemes under these conditions. Since rainfall is continuous, soil water content increases. Figure 4 shows soil water saturation for schemes 1 and 2.



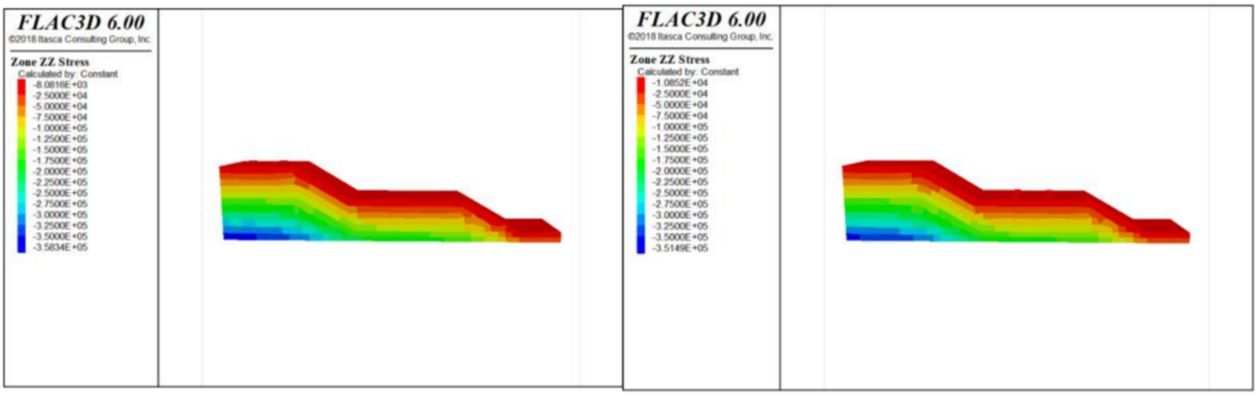
(1)Scheme 1 (2)Scheme 2

Fig 4. Variation of soil water saturation

Through the comparative analysis of the soil water saturation under the two groups of pictures and the non-layout tower foundation, it can be known that the layout of the power tower foundation will not affect the saturation change of the soil water during continuous rainfall.

(1) Stress comparison

According to the model of the two parameters, the parameters are set to simulate the rainfall conditions. Firstly, the stress cloud diagrams of the two schemes are generated and compared. Fig.5 is the stress cloud diagram of scheme 1 and the stress cloud diagram of scheme 2.



(1) Scheme 1 stress cloud diagram (2) Scheme 2 stress cloud diagram

Fig 5. Stress cloud diagram of different schemes under rainfall conditions

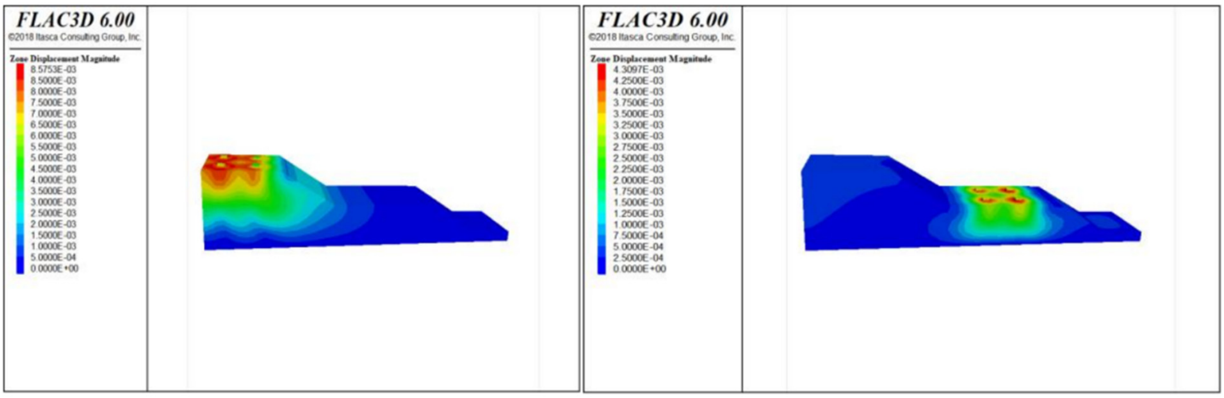
Table 2. Slope stress stability values of different schemes (unit : kN)

Scheme	Slope	Monitoring points	Stress stability value
Scheme 1	Slope1	1	78
		2	92
		3	100
	Slope2	4	60
		5	80
		6	42
Scheme 2	Slope1	1	80
		2	90
		3	94
	Slope2	4	57
		5	82
		6	42

Comparing and analyzing the stress cloud diagram of the two schemes under continuous rainfall, it is found that the change of soil stress caused by the layout of tower foundation in the two schemes becomes smaller after continuous rainfall. Because it is difficult to compare the difference between the two schemes from the stress cloud map, the detection points are set up to analyze the difference between the two schemes. The monitoring points are the same as when the tower foundation is not laid. The stress stability value obtained by the analysis of the stress cloud monitoring point data is shown in the table 2.

(2) Settlement comparison

The displacement cloud images of the two schemes under heavy rainstorm conditions are generated for comparison. Fig 6 is the displacement cloud image of scheme 1 and the displacement cloud image of scheme 2.



(1) Scheme 1 (2) Scheme 2

Fig 6. Displacement nephogram of different schemes

(3) Layout comparison

From the analysis, different layout positions affect loess slope stability. To compare stability with and without a tower foundation, settlement data under various conditions are analyzed. Table 3 shows 80 mm/hr rainfall for different conditions, and Fig. 7 displays settlement stability values of slope observation points. This comparison focuses on slope stability data.

Table 3. Working condition classification

Condition 1	Rainstorm conditions without tower foundation layout
Condition 2	Carry out the rainstorm condition in scheme 1
Condition 3	Carry out the rainstorm condition in scheme 2

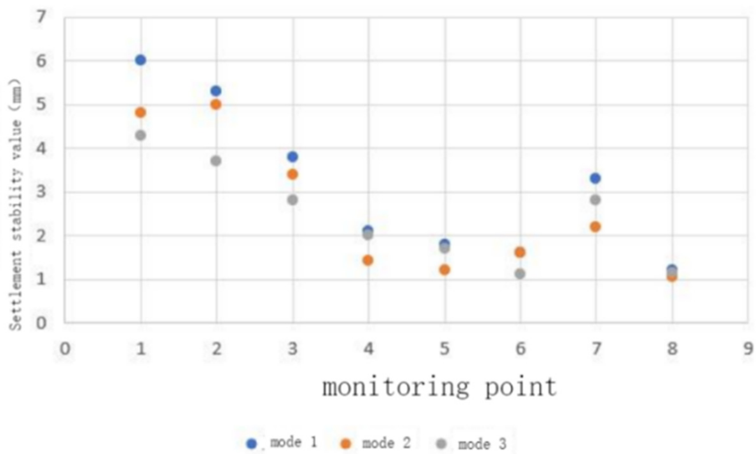


Fig 7. Comparison of settlement curves under different working conditions

According to Figure 7: A, B, C: Working condition two and three settlements are equal, less than condition one.D, E, F, G, H: Settlements of condition two and three are less than condition one.D, E specify condition two settlement as smallest. F, H specify condition three settlement as smallest.G states settlements of condition two and three are equal. D and E (near scheme 2 tower foundation) show different settlements in conditions 2 and 3, but relationship undetermined. Points F, G, H indicate condition three settlement is smallest at some positions.

Scheme 2 settlement near tower foundation may be greater than scheme 1, but overall, lower tower foundation placement reduces loess slope settlement and improves stability.

(4) Slope safety factor

Finally, the slope safety factors of the two schemes under different working conditions are compared by FLAC3D using the strength reduction method, and the optimal scheme is found for the tower foundation layout. Table 4 is the slope safety factor of the two schemes under different working conditions.

Table 4. Slope safety factors under different working conditions

	Rainstorm	Nature
No tower base layout was carried out	1.11	1.31
Scheme 1	1.15	1..26
Scheme 2	1.17	1.28

It can be found from the above table that when the tower foundation is laid, the stability of the loess slope will be reduced under natural conditions, but it is still in the stable area. However, due to the layout of the tower foundation, the stability of the loess slope will be greatly improved under rainfall conditions. At the same time, by comparing the data in the table, it can be found that the tower foundation layout in scheme 2 improves the safety factor of loess slope more obviously.

4. Conclusion

Taking the loess slope of the Loess Plateau in Qingyangning County, Gansu Province as the research object, the characteristics, diseases and stability influencing factors of the loess slope were analyzed by means of network investigation, engineering geological analysis and finite element software numerical simulation. The settlement under rainfall conditions is mainly studied, and the influence of tower foundation layout position on slope stability is evaluated. The main conclusions include:

(1) Unique loess structure affects stability.

(2) Failures include slope deformation and slump (primary form). Three failure types summarized.

(3) Rainfall and freeze-thaw are critical stability factors.

(4) FLAC3D modeled a typical slope under natural and rainfall conditions, finding rainfall crucial, especially in the second slope prone to landslides. Strength reduction analysis showed rainfall types impact slope safety.

(5) Tower foundation placement improves stability under rainfall; optimal position is slope's lower part.

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