

# Accurate Numerical Simulation Study on Bearing Capacity and Sliding Surface of Slope Foundation

**JIAN Chao**

Jiujiang Geological Engineering Exploration Institute, Tonggang west road, west port area, Jiujiang, Jiangxi, 332000

Email: 295568062@qq.com

**Abstract.** The bearing capacity of slope foundation is an important condition for the stability of mountain transmission line. At present, the methods for studying the bearing capacity of slope foundation are mainly as follows, such as the Limit Analysis Method, Slip-Line Field Method and Numerical Simulation Method. In this paper, the numerical simulation method with high accuracy is used to study the bearing capacity changes of slope foundation under different slope ratios, slope border margin and foundation conditions with the help of the finite difference software FLAC3D. Based on the correlations obtained from above, the reasons and laws for the changes of the ultimate foundation bearing capacity can be found, which can provide some guidance for related engineering design.

## 1. Introduction

China has a vast territory, and there are many hilly areas in mountainous areas. At the same time, Transmission Lines in Mountainous Area accounts for a considerable proportion in transmission projects. This requires that the slope foundation conditions must be fully considered in the design process of the transmission line. It is necessary to meet the requirements of the foundation for the bearing capacity of the slope foundation and the stability of the slope.

At present, there are three main methods for studying the bearing capacity of slope foundations:

- Limit Analysis Method
- Slip-line field Method.
- Numerical Simulation Method.

The Finite Analytic Method is a method of considering the stress-strain relationship of soil in an ideal way, and based on this, the limit theorem of limit analysis is established to solve the ultimate load. It's simple and widely used. For example, Yan Xueyong<sup>[1,2]</sup>, Zhao Lianheng<sup>[3]</sup>, Wang Zhibin<sup>[4]</sup> used the limit analysis method to study the bearing capacity of slope foundations.

Based on the properties of the slip-line and boundary conditions, the slip line field method can acquire the distribution of stress, displacement and velocity in plastic zone, and the ultimate load is obtained thereby. Generally speaking, it can only satisfy the equilibrium equation and the yield condition, but the stress and deformation of the elastic zone cannot be determined. Therefore, it still belongs to an approximate solution.

Based on the theory of Continuum Mechanics, the numerical simulation can calculate the internal stress-strain relationship of the model, which is an effective calculation method. Wang Xiaomou<sup>[7]</sup>, Deng Chujian<sup>[8]</sup>, and Kong Tingxue<sup>[9]</sup> used ANSYS/FLAC3D to study the bearing capacity of foundations and obtained some valuable conclusions.



This paper starts with the numerical simulation method, then uses the finite difference software FLAC3D to study the numerical simulation calculation method of the ultimate bearing capacity of the foundation under slope conditions, and analyze the factors affecting the ultimate bearing capacity of the slope foundation.

## 2. Numerical simulation schemes for slope foundation

### 2.1 Calculation model

The model is established as follows: a simulation is performed on a plane of 0.5 m thickness perpendicular to the ground in the actual slope body. The length of the slope from the inner side of the foundation to model edge is fix times of the foundation width. The foundation is buried at a height of 15m. The specific geometric model is shown in Figure 1. The actual calculation model is built on the base of the geometric model.

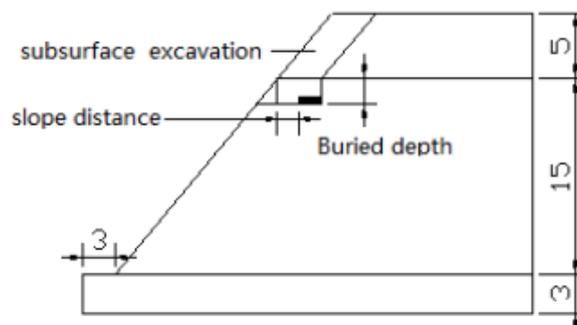


Figure 1. The calculation model

### 2.2 Calculation parameters

The calculation results are based on three different foundation conditions which are soil, soft rock and general rock. The mechanical parameters are selected with reference to the Engineering Geology Manual and practical experience. According to the trial calculation, the calculation parameters selected are shown in Table 1.

Table 1. Numerical simulation parameter table

| material parameter         | Soil | Soft rock | General rock |
|----------------------------|------|-----------|--------------|
| Elastic Modulus /Mpa       | 60   | 1200      | 15000        |
| Poisson ratio              | 0.35 | 0.3       | 0.25         |
| Cohesion force /kPa        | 35   | 38        | 45           |
| Internal friction angle /° | 25   | 30        | 40           |

### 2.3 Calculation conditions

In order to study the bearing capacity as well as the stress and deformation of the slope foundation under different working conditions, the five different factors have been taken into consideration according to the slope ratio, slope border margin, buried depth, plate width as well as the rock and soil conditions. And then the results are comparing analysed. The specific working conditions are shown in Table 2.

Table 2. Numerical Simulation Conditions of Vertical Bearing Characteristics

## of Slope Foundation

| scheme | Investigation factor | Foundation condition              | Foundation width B(m) | Foundation depth | Slope distance | Gradient of slope      | Number of test groups |
|--------|----------------------|-----------------------------------|-----------------------|------------------|----------------|------------------------|-----------------------|
| 1      | Gradient of slope    | soil                              | 2                     | B                | B              | 1:1,1:1.75<br>,1:2,1:3 | 4                     |
| 2      | Slope border margin  | soil                              | 2                     | B                | 0.5B,2B,3B,4B  | B                      | 4                     |
| 3      | Foundation condition | rock<br>soft rock<br>general rock | 2                     | B                |                | B                      | 3                     |

### 3. Analysis of ultimate bearing capacity of slope foundation

#### 3.1 Influence of slope ratio condition on ultimate bearing capacity.

In order to comprehensively investigate the influence of slope ratio on the bearing capacity of the slope tower foundation, the bearing capacity under different slope conditions were studied by changing the ratio of the slope. Figure 2 shows the calculation results of the ultimate bearing capacity of the slope foundation under different slope ratios.

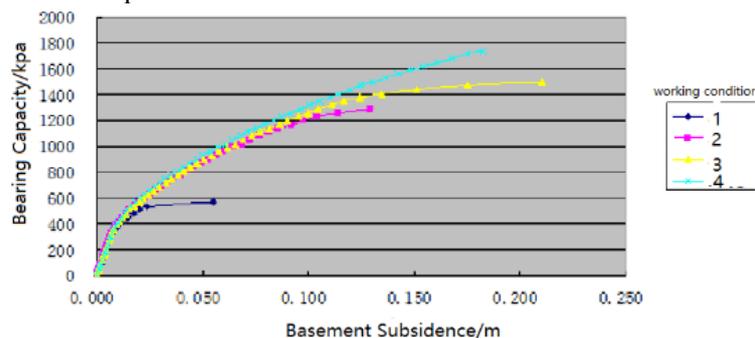


Figure 2. The linear relationship Comparison of P-S under different working conditions and slope ratios

It can be seen from Figure 3 that the slope ratio is inversely proportional to the ultimate bearing capacity. As the slope ratio decreases, the ultimate bearing capacity increases gradually. This inverse relationship is similar to a straight line.

The most obvious reason is that as the slope ratio increases, the distance from the slope of the base to the slope increases, and the area of the rock and soil mass that can bear the load increases, as is shown in Figure 4(a) and Figure 4(b). It can be seen from them that when the slope is relatively large at 1:1, the area of the soil that can bear the load in the direction of the basic slope is smaller than the slope at 1:2. In the process of sliding development, it always slides in the direction of free face. Compared with the slope ratio at 1:2, when the slope ratio is 1:1 and the plastic zone extends to the area near the slope surface, there is no soil that can bear the load near the slope, so the sliding surface will extend to the area near the corner. As for the slope ratio at 1:2, the sliding surface is obviously not as deep as the ratio at 1:1, which indicates that the more rock and soil mass that can bear the load exist in the direction of area near the slope, the more load that the foundation could bear, and also the shallower depth of the sliding surface in the vertical direction.

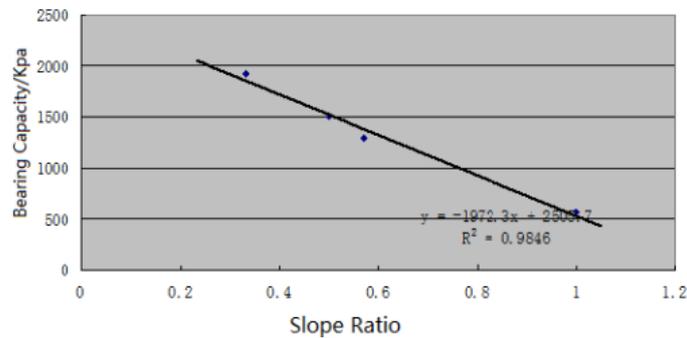
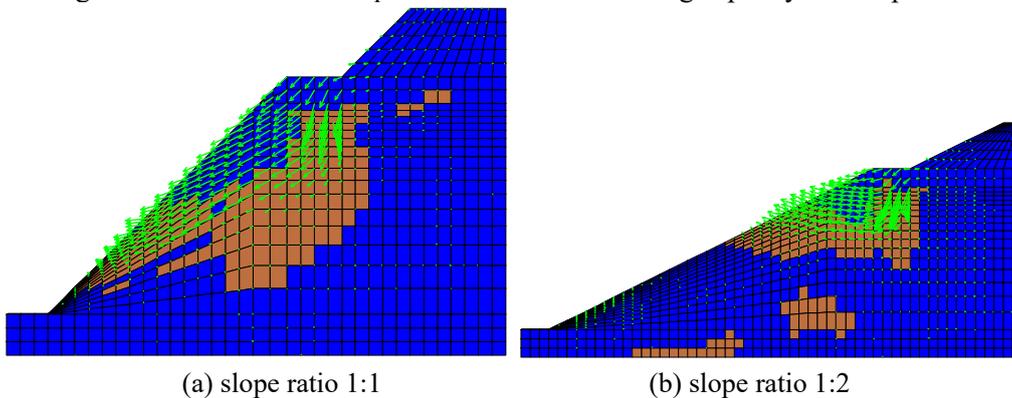


Figure 3. Linear relationship between ultimate bearing capacity and slope ratio



(a) slope ratio 1:1 (b) slope ratio 1:2  
Figure 4. Plastic zone and potential slip surface under different slope ratio

3.2 Influence of slope condition on ultimate bearing capacity characteristics

Figure 5 shows the bearing capacity curves of slopes under different slope conditions.

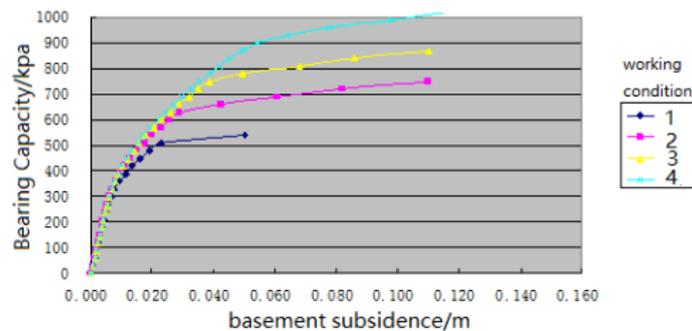


Figure 5. Comparison of ultimate bearing capacity under different conditions

It can be seen from Fig. 5 that the ultimate bearing capacity is proportional to the slope border margin. As the slope border margin increases, the ultimate bearing capacity also increases. It's nearly the linear relationship, as is shown in the Figure 6. The increase of the slope border margin also increases the volume of rock and soil mass under the foundation, and thus the ultimate bearing capacity increases, as shown in Figures 7.

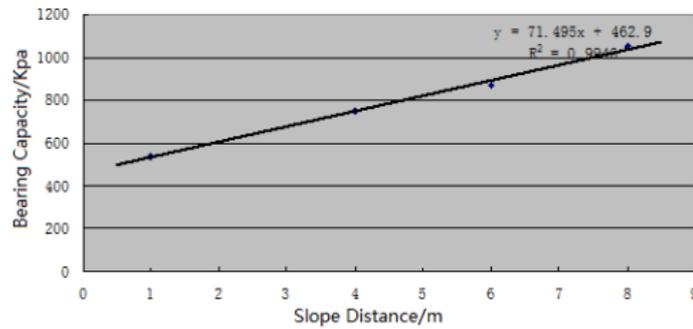


Figure 6. Proportion of slope border margin and ultimate bearing capacity

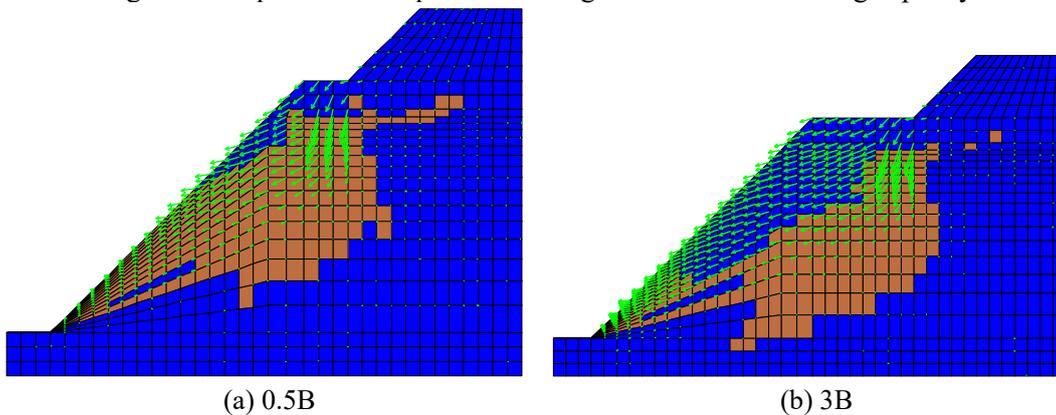


Figure 7. Potential sliding surface and plastic zone when different slope border margin

### 3.3 Influence of foundation conditions on ultimate bearing capacity characteristics

This group of experiments was conducted under three different rock and soil mass conditions. During the process, other conditions are the same among the experiments. The study on the influence that rock and soil mass make to the bearing capacity is based on analyzing the difference of the ultimate bearing capacity. The calculation results are shown in the figure 8.

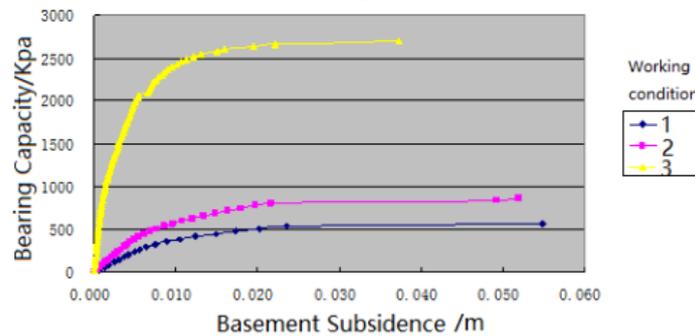


Figure 8. Comparison of bearing capacity of different rock and soil mass

It can be seen from Fig. 8 that as the mechanical parameters of rock and soil increase, the ultimate bearing capacity of the foundation increases continuously, but it is difficult to be described by a linear relationship. The reason as follows, the ultimate bearing capacity of the foundation is the limit load of the rock and soil mass when it is ruptured, which is controlled by the cohesive force  $c$  and internal friction angle  $\Phi$ . According to the theory of elastoplastic mechanics, as the cohesion and internal friction angles increase, the slope of the molar strength envelope increases, so that the rock and soil can withstand large stresses, and therefore, the ultimate bearing capacity increases.

#### 4. Conclusion

In this paper, the study on the calculation and the influential factors of the slope foundations are based on the numerical simulation technology.

The main conclusions are as follows:

- The numerical simulation method calculates the ultimate bearing capacity of the slope foundation, which could overcome the shortcomings of too much assumptions of the traditional method and take the stress-strain relationship of the material into consideration. The method can calculate the ultimate bearing capacity of the slope foundation under various working conditions and can reflect the actual deformation and process of the foundation.

- The ultimate bearing capacity is linearly proportional to the slope border margin and foundation conditions. In brief, the greater the slope border margin, the better the foundation condition and the higher the ultimate bearing capacity. In addition, the slope ratio is inversely proportional to the ultimate bearing capacity, and the smaller the slope ratio, the greater the ultimate bearing capacity.

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