

# Discussion of the Method to Determine the Ultimate Bearing Capacity of Soil Foundation

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**Abstract.** Combining literature examples, this paper has carried out Contrastive analysis of the theoretical formula method and finite element method about the ultimate bearing capacity of foundation, To verify rationality and superiority of the incremental load method in finite element ABAQUS in solving the bearing capacity of foundation soil. The study can provide certain reference for practical engineering calculation and analysis of foundation bearing capacity.

## 1. Introduction

The problem of bearing capacity of soil foundation is one of the three research topics of classical soil mechanics, which has been widely concerned by researchers<sup>[1-2]</sup>. Typically, the foundation bearing capacity is determined by in-situ load testing based on its nature of projects and numerical calculation, in which numerical calculation includes theoretical formula and finite element method. However, there are still some limitations that the traditional testing method waste more strength, time and money and the theoretical formula method has its own conditions in calculation, and it is difficult to apply to the complicated foundation form. Therefore, the focus on the suitability of finite element method for determining the ultimate bearing capacity is carried out.

## 2. limit equilibrium method

The limit equilibrium method is a theoretical system formed by extending the Coulomb and Rankine earth pressure theories to the analysis of slope stability and ultimate bearing capacity of the foundation<sup>[3]</sup>. For solving the problem of ultimate bearing capacity of the foundation, it is necessary to presuppose the shape and range of the sliding surface when the soil reaches the damage, and then solve the problem according to the static equilibrium condition of the sliding body. The theoretical formula for the earliest ultimate bearing capacity of the foundation was proposed by Rankine in 1857. He calculated the ultimate bearing capacity of the soil by assuming the earth pressure balance at the sliding surface and the base side. Then Terzaghi, Meyerhof, Hansen and many other scholars have improved this theory, and finally get the approximate solution as shown in formula 1<sup>[4]</sup>:

$$q_u = cN_c + \gamma DN_q + 0.5\gamma BN_\gamma \quad (1)$$

In the formula,  $N_q$  and  $N_c$  are obtained as formula 2 and 3.

$$N_q = \exp(\pi \tan \phi) \tan^2(45^\circ + \phi/2) \quad (2)$$

$$N_c = (N_q - 1) \cot \phi \quad (3)$$

$N_\gamma$  is a semi-empirical formula which is determined by different method as summarized in table 1.



**Table 1.** Common formula sheets of  $N_\gamma$ 

Formulator	$N_\gamma$
Chen,W.F	$N_\gamma=2 (1+N_q) \operatorname{tg}\phi \operatorname{tg}(\pi/4+\phi/5)$
Terzaghi	$N_\gamma=1.8 (N_q-1) \operatorname{tg}\phi$
Meyerhof	$N_\gamma= (N_q-1) \operatorname{tg}1.4\phi$
Vesic	$N_\gamma=2 (1+N_q) \operatorname{tg}\phi$

### 3. Finite Element Method

#### 3.1 The Basic Theory of Finite Element Method

Finite Element Method (FEM) is a very strict numerical analysis method of theoretical system, which converts ideally the continuum into a discrete structure which composed of a finite number of units, and then analyzes the stress and deformation of each unit. Compared with the theoretical method, it is more comprehensive considering the constitutive relation, strain compatibility condition and static equilibrium between stress and strain, and it has the advantages of solving various complex boundary conditions, heterogeneous and nonlinear geotechnical problems.

#### 3.2 Basic Theory of Ultimate Bearing Capacity of Foundation

In the actual engineering, the rock and soil damage process is often progressive. At first, the soil is in the linear elastic state due to the small load, and then the soil internal changes including deformation and shear stress increase with the increase of the load. When the soil shear stress in a certain area reaches the shear strength, it will form a local plastic zone. If the external load continues to increase, the local plastic zone will develop into a continuous sliding surface, and the soil structure loses stability. Then the external load the soil bears is the ultimate bearing capacity. More precisely, the critical state of the destruction of the soil structure is that the soil will slide along the sliding surface as a whole and not slip out. At this time, the external load acting on the foundation surface is the ultimate bearing capacity of the soil<sup>[5]</sup>.

Finite element software to solve the ultimate bearing capacity of the foundation generally uses incremental loading method, that is, the incremental load is applied step by step until the soil structure is in the ultimate state of failure. Then the sum of the incremental loads is the ultimate bearing capacity.

#### 3.3 Standard of Bearing Capacity of Foundation

The key of finite element method to solve the ultimate bearing capacity is how to determine whether the foundation reaches the ultimate destructive state based on the results of finite element calculation, but At present, there is no unified understanding . There are several types of soil instability criteria as follows:

① According to the finite element calculation, the convergence is the standard for the failure of the foundation, and And the load corresponding to the non-convergence is taken as the ultimate bearing capacity of the foundation. When the foundation is unstable, the displacement and plastic strain can mutate and the numerical calculation will not converge.

② Take the plastic area through the ground as a sign of damage and take the corresponding load when the sliding surface of the soil is just through as the ultimate bearing capacity of the foundation. Therefore, the researchers attempted to map the distribution of generalized plastic strain in the soil using graphical visualization techniques, and If a particular value of the generalized plastic strain region interconnects, the soil is considered to be destroyed.

③ The load corresponding to the inflection point on the displacement (s) and load (p) curve of the characteristic site is the ultimate load. The displacement and load curve of the finite element method are the most intuitive reaction of the foundation instability. According to the calculation, the p-s curve of a certain part is drawn, and the inflection point on the curve is used as the criterion of critical

damage state. Or draw 1gp-s curve whose the first half is curve, and the latter part is obvious straight line segment, and the starting point of the straight line can be set as the ultimate load point.

At present, many scholars tend to choose the third. But in author's opinion, it is unreasonable to judge whether the foundation reaches ultimate destructive state by the single factor, and the development of the stress, strain and displacement of the finite element method and the penetration of the plastic zone, the plastic displacement and the deformation mutation of the soil are all influence factors.

#### 4. Example: bearing capacity of homogeneous soil

The bearing capacity of homogeneous sandy soil is calculated by using the model <sup>[6]</sup>. Soil thickness is 5m, it is deep and hard rock layer under sand layer, and  $\mu=0.3$  the base width is 2m. The material parameters are as follows:  $E = 13000 \text{ kPa}$ ,  $\mu=0.3$ , the internal friction angle is  $31^\circ$ , and the cohesion is  $1 \text{ kPa}$ .

##### 4.1 Theoretical Formula Method

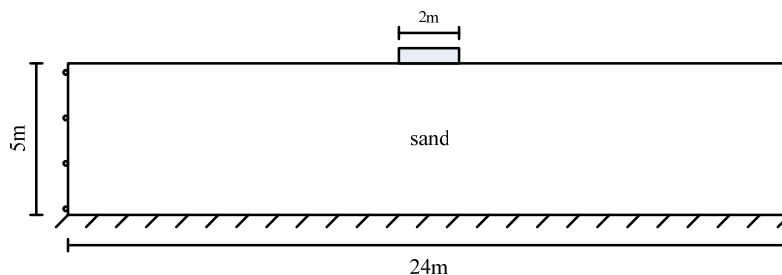
According to the traditional formula of foundation bearing capacity, the results in table 2 are obtained.

**Table 2.** Theoretical formula method calculation value

	$N_q$	$N_c$	$N_r$	$Q_u \text{ (kPa)}$
Terzaghi	20.6	32.7	21.2	393.6
Chen,W.F	20.6	32.7	32.3	582.3
Meyerhof	20.6	32.7	18.6	348.3
Vesic	20.6	32.7	23.6	433.7

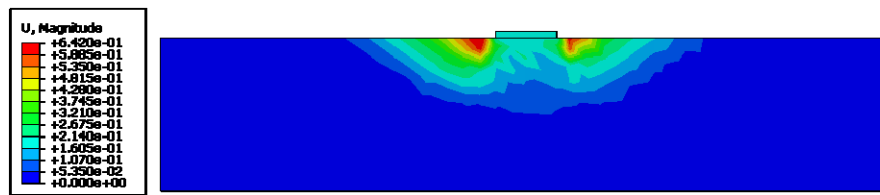
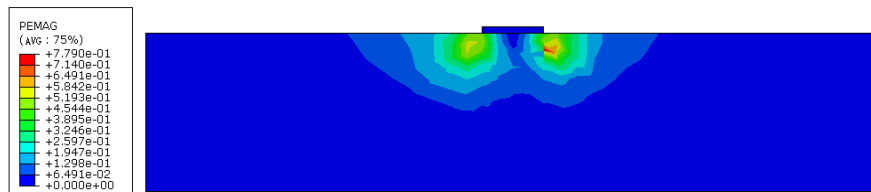
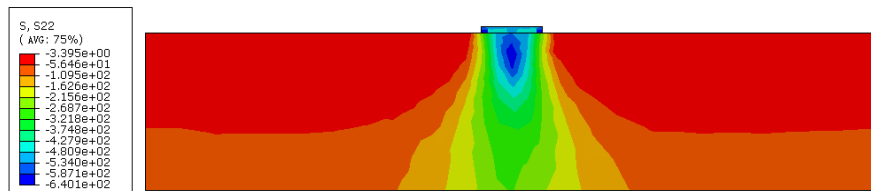
##### 4.2 The Finite Element Method(Incremental loading method)

Based on the finite element software ABAQUS to establish calculation model (figure 1), Model does not contain lithosphere, the both sides of the soil adopt water level constraints, and the bottom of model adopts fixed constraint. According to the sliding surface of prandtl formula hypothesis, in order to avoid the size effect, foundation model extended to 11 meters in horizontal direction.

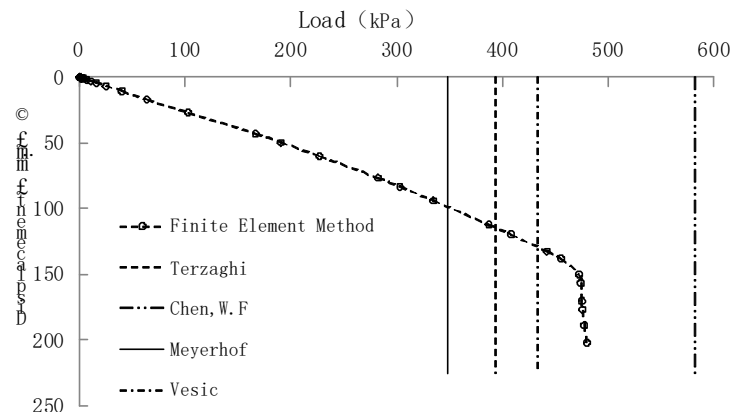


**Figure 1.** Model Size

Compared with the theoretical formula method, when solving the ultimate bearing capacity of soil, the finite element method can not only find out the development of the strain and stress in the soil, but also can analyze the development of the damage surface of the soil. The following figure 2-4 is the calculated displacement, stress and strain cloud of the soil. It can be seen from the figure that under the influence of the external load the influence range of soil is much smaller than the model size, which effectively avoids the error caused by the size effect.

**Figure 2.** Displacement (Magnitude) Cloud**Figure 3.** Plastic Strain (PEMAG) Cloud**Figure 4.** Stress (S22) Cloud

Draw the load-displacement curve, and use the traditional formula to calculate the bearing capacity of the foundation drawn in the same coordinate system, as shown in Figure 5. The inflection point value ( $P_u=455.2\text{kPa}$ ) of the p-s curve is clearly within the range of the traditional formula and is close to the value ( $P_u=433.7\text{kPa}$ ) of the Vesic formula. Considering the development of the displacement, plastic strain and stress, the author thinks that the finite element method is in good agreement with the traditional calculation formula.

**Figure 5.** Load-displacement curve

## 5. Conclusion

Numerical calculation is an effective method to study the bearing capacity of foundation, Compared with the theoretical formula method, the finite element method can not only find out the development process of strain and stress , but also can analyze the development process of the damage surface of the soil. In this paper, the traditional bearing capacity calculation formula is used to calculate the ultimate bearing capacity of the foundation, and then the finite element software ABAQUS is used to model and calculate. Finally, the plastic strain, displacement cloud and load-displacement diagram are

obtained. It is verified that the incremental loading method is used to solve the rationality of the foundation bearing in finite element ABAQUS.

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