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Review Confirmation Method of Foundation Bearing Capacity

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Abstract: The calculation of bearing capacity of foundations is a fundamental topic in soil mechanics and an indispensable basic data in practical engineering. Some calculation methods and different improvement measures of foundation bearing capacity are summarized by reading relevant Chinese literature, standardizing and combining with the contents of textbooks, and the mechanism of foundation bearing capacity is strengthened.

Keywords: Bearing Capacity of Foundation; Terzaghi Formula; Empirical Formula.

1. Introduction

The bearing capacity of the foundation is the application of the theory of shear strength of the foundation in engineering. It is the maximum (limit) capacity of the unit area to bear the load under the premise of allowable deformation and maintaining stability. The bearing capacity of the foundation is closely related to the deformation conditions and stable state of the foundation. The foundation has different bearing capacity levels, such as the critical plastic bearing capacity and the ultimate bearing capacity. There are many methods for determining the bearing capacity of the foundation, all of which are based on the theory of shear strength of soil. Studying the bearing capacity of the foundation is to design the foundation and its basis reasonably, determine the total area of the foundation reasonably, etc., so that the bearing capacity does not exceed the prescribed allowable value to ensure the safety and stability of the foundation.

From the above analysis, it can be seen that the fundamental reason for the inaccurate calculation of foundation bearing capacity at present is that superposition calculation is adopted for the plastic mechanics problem of ultimate load calculation, that is, the three non-independent parts of the foundation bearing capacity calculation formula are calculated independently of each other. In recent years, some researchers have paid attention to this, and adopted different ideas to study the calculation of coefficient N_γ, considering the influence of multiple parameters on $N\gamma$. This aspect was studied earlier in literature[1]. On the basis of summarizing previous studies, literature [2] adopted numerical slip line method to calculate and fit the approximate calculation formula of N_γ.

This paper will start from the mechanism research of the bearing capacity of the foundation, introduce several commonly used methods for confirming the bearing capacity of the foundation and the preface research on the methods for confirming the bearing capacity of the foundation.

2. Theory of Bearing Capacity of Foundation

2.1. Foundation Deformation and Stability

The stability of the foundation means that the foundation can maintain the original existing state under the change of environmental conditions and force field conditions, otherwise, it is called instability. In the field of geotechnical engineering, the failure of shear strength is often called instability for the underground engineering of structure foundation and tunnel slope engineering. The basic forms of foundation strength failure, also known as instability, can be divided into overall shear failure, local shear failure and punching failure, as shown in Fig.1. Fig.1(a) shows the overall shear failure, that is, with the increase of foundation load, the p-s curve first presents a linear elastic relationship, and the inflection point of the straight line means that a plastic zone begins to appear in the foundation. According to the stress theory in soil and the shear strength theory of soil, the end point of the foundation is the singular point of the solution, and the stress at this point is multi-valued, so the appearance of the plastic zone in the foundation always starts from here. With the expansion and development of the plastic zone in the foundation, the p-s curve shows obvious curve characteristics. Finally, when the curve tends to the vertical section, the foundation is in a critical failure state or a state of invasion failure, and an obvious slip surface appears in the foundation, as shown in Fig.1(a). Taking strip foundation as an example, two sets of continuous and complete sliding surfaces with left and right symmetry are formed. This kind of sliding occurred on the gully side foundation of a soft soil foundation in Lianyungang project, which caused the ground uplift on both sides and small settlement under the foundation. In this case, the impact of the depth of burial is greater. For the foundation soil with relatively small compressibility, such as the dense sand soil and the hardness of the clay above medium, the overall shear failure will generally occur. The *p-s* curve is shown by curve I in Fig.1(d).

Fig.1(b) shows local shear failure. When the foundation is in a critical state of failure, two sets of symmetric sliding surfaces tend to form from the two ends of the foundation, but they are discontinuous and incomplete. When the foundation is pushed out from both sides, it is difficult to expand to the left and right sides, and the sliding surface cannot be completely formed, as shown by the dashed line in the figure. Therefore, it is called local shear failure. There is settlement under the foundation, and the uplift on both sides of the foundation is not obvious. Curve *p-s* Curve II in Fig.1(d). Fig.1(c) shows punching failure. Due to factors such as the depth of foundation burial and load conditions, the foundation is cut down into the soil along the perimeter, with significant settlement as the prominent feature. There are only signs of sliding surface under the end point of the foundation and just below the foundation, and no ground uplift can be seen on both sides of the foundation, and the features of depression will also appear around the foundation. Its *p-s* curve also belongs to the II curve in Fig.1(d).

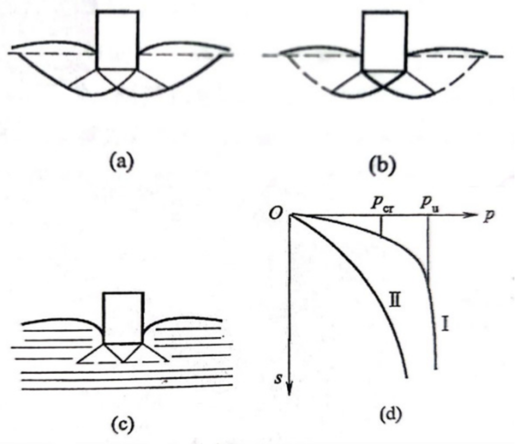

Fig 1. Foundation failure pattern

The p_{cr} in Fig.1(d) is called the plastic-plastic load, that is, the end of the straight segment on the p-s curve and the beginning of the curve segment. p_u refers to the limit load, that is, the end of the curve section on the *p-s* curve and the beginning of the steep drop section. In engineering, if the goal is to be able to use, the limit load is the maximum load, and if the strength failure is the reference standard, the limit load is the minimum load.

2.2. Prandtl Foundation Ultimate Bearing Capacity

In 1920, according to the plastic theory, Prandtl studied the pressing of a rigid punch into a massless semi-infinite rigid plastic medium, he also studied the plastic deformation of a foundation equivalent to a strip foundation, and derived the sliding surface shape and the ultimate pressure formula when the medium reached failure[3]. His solution has been applied to the study of ultimate bearing capacity of foundation. At that time, his research work assumed homogeneous soil foundation, no weight, integral shear failure, strip foundation with no buried depth, central load and smooth foundation, so that when the load reaches the limit value, the foundation will have integral shear failure, and the sliding plane of the basement and the maximum principal stress (p_u) surface will be α=45°+φ/2, see Fig.2 (buried depth in the figure). Prandte divided five regions between the two sets of continuous and complete sliding plane and the base plane when the whole shear failure occurred under the strip foundation. The microelement is taken in each cell, and the shear stress of the surface is ignored. Directly below the base is zone I, where the soil mass is compressed to reach the active limit equilibrium state (σ_1>σ_3). Zone I pushes against zone III on both sides through zone II to form two continuous and complete sliding surfaces, and zone III reaches the passive limit equilibrium state (σ_1<σ_3). To sum up, zone I is called the active zone, which is both the active zone of foundation deformation and the active limit state. The boundaries of zone I are all straight lines and the whole is an isosceles triangle, and the Angle α=45°+φ/2 between the sliding surface *aO*, *a'O* and the surface of maximum principal stress. Zone II is the transition zone between Zone I and Zone III. The boundary lines of zone II are *aO*, *ac*, *Oc*, and *a'O*, *a'c'*, and *Oc'*, where *aO* and *ac* are straight line boundaries, while *Oc* is a curve boundary and a logarithmic spiral($\gamma=\gamma_o e^{\theta\tan\varphi}$). When θ=0°, $\gamma=\gamma_0$. As can be seen from Fig.2, the value range of θ is 0°~π/2. It is both a passive region of foundation deformation and a passive limit equilibrium region. The boundaries of region III are *ac*, *af*, *cf* and *a'c'*, *a'f'* and *c'f'*. The Angle between the slip plane of region III and the surface of the minimum principal stress (σ_1)is 45°-φ/2, and region III is also an isosceles triangle

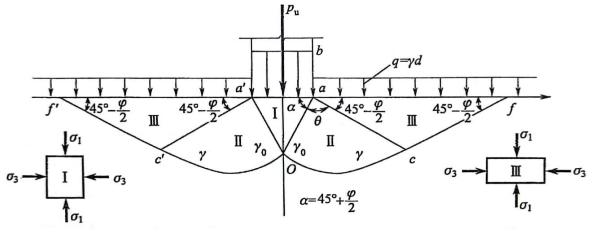

Fig 2. Prandtl foundation sliding model

Since Prandtl did not consider the buried depth of the foundation and did not calculate the soil body weight within the sliding range of the foundation when studying the problem, the ultimate bearing capacity of the foundation was obtained:

$$p_u = c \cdot N_c \tag{1}$$

$$N_c = \cot\phi\left[e^{\pi\tan\phi}\tan^2\left(45° + \frac{\phi}{2}\right) - 1 \right] \tag{2}$$

In 1924, Reissner adopted Prandtl's assumption and physical model, and considered the buried depth of the foundation, but only converted the soil mass within the buried depth into a vertical equivalent load acting on the horizontal plane of the foundation. Therefore, the ultimate bearing capacity of shallow foundation is obtained as follows:

$$p_u = cN_c + qN_q \tag{3}$$

$$N_q = e^{\pi\tan\phi}\tan^2\left(45° + \frac{\phi}{2}\right) \tag{4}$$

$$N_c = \cot\phi\left(N_q - 1\right) \tag{5}$$

Now it is necessary to consider the influence of the soil weight within the sliding range on the ultimate bearing capacity of the foundation. Many scholars' research results have adopted the following general expression:

$$p_u = cN_c + qN_q + \frac{1}{2}\gamma bN_\gamma \tag{6}$$

Caquot and Kerisel proposed an empirical approximation formula in 1953:

$$N_\gamma = 2\left(N_q + 1\right)\tan\phi \tag{7}$$

In 1955, Meyerhof proposed the formula as follows:

$$N_\gamma = \left(N_q - 1\right)\tan\left(1.4\phi\right) \tag{8}$$

The formula proposed by Hansen from 1961 to 1970 is:

$$N_\gamma = \left(1.5 \sim 1.8\right)\left(N_q - 1\right)\tan\phi \tag{9}$$

All these achievements are complements and improvements based on Prandtl's assumptions and models.

When φ<35º, the results obtained in Eq.8 and Eq.9 (where the coefficient is taken as 1.5) are very close.

The famous scholar Vesic1973 suggested that the ultimate bearing capacity of the foundation be calculated using Eq.6.

$$N_c = \cot\phi\left(N_q - 1\right) \tag{10}$$

$$N_q = \mathrm{e}^{\pi\tan\phi}\tan^2\left(45° + \frac{\phi}{2}\right) \tag{11}$$

$$N_\gamma = 2\left(N_q + 1\right)\tan\phi \tag{12}$$

2.3. Terzaghi's Ultimate Bearing Capacity of Foundation

Terzaghi[4] published the German version of Soil Mechanics in 1925 and Theoretical Soil Mechanics in 1943, which recorded his research results on the ultimate bearing capacity of foundations. Terzaghi's research assumes and foundation model conditions are homogeneous soil foundation, strip foundation, shallow buried foundation, subject to the central vertical load, the foundation belongs to the overall shear failure and considers the influence of soil self-weight on the ultimate bearing capacity. The main difference between Terzaghi foundation model and Prandtl foundation model is that the foundation ground in Terzaghi model is rough and not smooth. As shown in Fig.2, at this time, the base friction has a great effect, and the base I region cannot reach the limit equilibrium state. Therefore, $\alpha=\varphi$ under the base in the Terzaghi figure, the I region is still in the elastic working state, which is called the elastic compaction nucleus. Region II is the transition region where region I is pushed to region III on both sides. In this case, there is $\gamma=\gamma_0 e^{\theta\tan\varphi}$. When θ=0º, $\gamma=\gamma_0$ is *aO* or *a'O* in the figure. Region III can still reach the passive limit equilibrium ($\sigma_1<\sigma_3$), which is the same as the Prandtl model, which is also an isoscellous triangle.

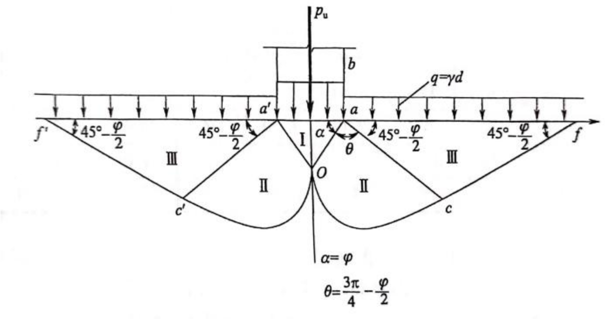

Fig 3. Terzaghi foundation sliding model

Based on the above assumptions and physical model, Terzaghi deduced the ultimate bearing capacity formula of the foundation as follows:

$$p_\mathrm{u} = cN_c + qN_q + \frac{1}{2}\gamma bN_\gamma \tag{13}$$

$$N_q = \frac{1}{2}\frac{\mathrm{e}^{\left(\frac{3\pi}{2}-\phi\right)\tan\phi}}{\cos^2\left(45° + \frac{\phi}{2}\right)} \tag{14}$$

$$N_c = \cot\phi\left(N_q - 1\right) \tag{15}$$

If the overall shear failure of the foundation does not occur, but local shear failure or punching failure occurs, Terzaghi empirically changed Eq.13 to:

$$p_\mathrm{u} = \frac{2}{3}cN_c^{'} + qN_q^{'} + \frac{1}{2}\gamma bN_\gamma^{'} \tag{16}$$

If it is not a bar foundation, but a rectangular, square or circular foundation, Terzaghi is also the formula for calculating the ultimate bearing capacity of the foundation recommended by experience.

For square foundation:

$$p_\mathrm{u} = 1.2cN_c + qN_q + 0.4\gamma bN_\gamma \tag{17}$$

For circular foundations:

$$p_\mathrm{u} = 1.2cN_c + qN_q + 0.3\gamma bN_\gamma \tag{18}$$

3. Conclusion

The bearing capacity of foundation is a fundamental problem in soil mechanics and foundation engineering. There are a lot of researches on the bearing capacity of foundation both in theory and experiment.

The confirmation of the bearing capacity of the foundation needs to consider the mechanical indexes of the foundation soil, the buried depth of the building structure and other factors, and in the engineering practice, it should be determined comprehensively by combining the engineering experience, the test results and the numerical simulation analysis.

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