Discussion on Determination of Foundation Bearing Capacity by Load Test and Case Study

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Abstract. Based on the basic principle of soil mechanics, this paper gives some suggestions on the naming rules of foundation bearing capacity. In addition, the test principle and specific application of determining foundation bearing capacity by load test are analyzed and discussed in combination with relevant cases. It is suggested that the naming of foundation bearing capacity should include the name of in-situ test, test depth and subject. To determine the characteristic value of building foundation bearing capacity by load test, two influencing factors should be considered: i) the size difference between the bearing plate and the foundation, and ii) the lateral stress difference of the soil layer within the depth of influence of stress under the bearing plate and the foundation. For homogeneous soil layer, the characteristic value of foundation bearing capacity determined by shallow plate load test is a constant in theory, the characteristic value of foundation bearing capacity determined by deep plate load test is a function of test depth, and the gradient of foundation bearing capacity determined by deep plate load test of homogeneous soil layer is $\eta_d\gamma_m$ along depth in theory.

1. Naming and Definition of Foundation Bearing Capacity
The design code for building foundation named the results of load tests or other in-situ tests as the characteristic value of foundation bearing capacity, and the characteristic value of foundation bearing capacity determined by in-situ tests as the modified characteristic value of foundation bearing capacity after the foundation width and embedding depth are modified[1]. The naming of the foundation bearing capacity in the code for design of building foundation is relatively simple. Based on daily use experience, the following suggestions are made for the naming of the foundation bearing capacity.

The name of foundation bearing capacity shall include the name of in-situ test. Article 5.2 of the Code for Design of Building Foundation stipulates that the foundation bearing capacity characteristic value determined by the deep plate load test does not need to be corrected by the foundation embedding depth, but the foundation width and the foundation embedding depth shall be corrected for the foundation bearing capacity characteristic value determined by other in-situ tests, empirical values and other methods[1]. If the name of the in-situ test is not clear, it is easy to cause error correction. For example, in the examination of registered geotechnical engineers, it is often assumed that the characteristic value $f_{ak}$ of the foundation bearing capacity of a certain soil layer is a known condition[2], but the known condition does not specify the name of the in-situ test, so it is difficult to
define whether the characteristic value $f_{ak}$ of the foundation bearing capacity needs to be corrected by the embedded depth of the foundation.

The naming of foundation bearing capacity shall include the test depth. The shallow plate load test requires that the width of the test foundation pit should not be less than 3 times the width or diameter of the bearing plate. Assuming that the lateral stress of the soil layer within the depth of influence of stress under the bearing plate is the same during each test, the characteristic value of foundation bearing capacity determined by the shallow plate load test of homogeneous soil layer is theoretically a constant. The bearing plate of the deep flat load test is close to the surrounding soil layer, and the lateral stress of the soil layer within the stress influence depth range under the bearing plate is proportional to the test depth, so the characteristic value of foundation bearing capacity determined by the deep flat load test of homogeneous soil layer is a function of the test depth. It is necessary to explain the test depth when naming the foundation bearing capacity. It is meaningless to talk about the foundation bearing capacity of homogeneous soil layer without the test depth and in-situ test types.

The naming of foundation bearing capacity should include the subject, that is, whose bearing capacity. The revised foundation bearing capacity is the maximum vertical load acting on the structural stress system composed of foundation and foundation to meet the requirements of deformation and bearing capacity. The maximum vertical load comes from the dead weight of the superstructure of the building and other external active loads that may act on the structural stress system. However, the foundation bearing capacity determined by in-situ load test is the maximum vertical load acting on the structural stress system composed of soil layers within the stress influence depth under the bearing plate and bearing plate, which meets the requirements of deformation and bearing capacity. The main body of foundation bearing capacity is different.

2. Test Principle of Determining Foundation Bearing Capacity by Load Test
Assuming that the load test is carried out at the design elevation of the building foundation, the structural stress system composed of the bearing plate and the soil layer within the stress depth influence range under the bearing plate is relatively consistent with the structural stress system composed of the building foundation and the foundation, both of which can reflect the actual stress and deformation of the foundation soil layer within the stress influence depth range under the foundation bottom surface, and the characteristic value of the bearing capacity of the building foundation can be calculated by modifying the in-situ load test results based on engineering experience. The foundation here refers to single foundations such as independent foundation, rectangular foundation, strip foundation, box foundation and raft foundation. For pile composite foundation, the load test is difficult to simulate the complex stress distribution of the soil layer below the foundation bottom surface, which requires additional demonstration [3-4].

There are two obvious differences in using bearing plate load test to simulate the behaviour of structural system composed of building foundation and foundation under upper load. The first difference is the size difference between the bearing plate and the bottom surface of the foundation. The second difference is that there is no soil around the bearing plate in the shallow plate load test, and the lateral pressure load can be regarded as 0 kPa. However, there is a certain buried depth of soil layer around the building foundation, and the lateral pressures acting on the soil layer under the bearing plate and the soil layer under the foundation are inconsistent, which makes the foundation bearing capacity determined by the shallow plate load test smaller than the true value[5].

When revising the foundation bearing capacity determined by the bearing plate load test, the code for design of building foundation stipulates that the foundation width shall be revised for the first difference and the foundation embedding depth shall be revised for the second difference.

3. Comparative Analysis of Shallow Plate Load Test and Deep Plate Load Test
According to the buried depth of the building foundation, the shallow slab load test and the deep slab load test have different applications, as shown in Table 1.
Table 1. Comparison of Elements between Shallow Plate Load Test and Deep Plate Load Test [1].

| Name of test | Shallow plate load test | Deep plate load test |
|--------------|-------------------------|----------------------|
| Applicable object | Shallow foundation soil layer. | Deep foundation soil layer and large diameter pile end soil layer. |
| Test conditions | Generally, the bearing plate area shall not be less than 0.25m$^2$, and when the test soil layer is soft soil, the bearing plate area shall not be less than 0.5m$^2$. The width of the test foundation pit shall not be less than 3 times of the width or diameter of the bearing plate. | The bearing plate adopts a circular rigid plate with a diameter of 0.8m, and the soil layer close to the outer side around the bearing plate shall be not less than 80cm in height. |
| Criterion of settlement stability after loading | Within 2 consecutive hours, the settlement rate is less than 0.1mm/h, and the next level of load can be applied. | Within 2 consecutive hours, the settlement rate is less than 0.1mm/h, and the next level of load can be applied. |
| Judgment standard for terminating loading | 1) The soil layer around the bearing plate is obviously extruded laterally. 2) the $p$-$s$ curve appears steep drop section. 3) Under a certain level of load, the settlement rate does not reach the stability standard within 24 hours. 4) $s/b \geq 0.06$. | 1) the $p$-$s$ curve has a steep drop and $s > 0.04d$. 2) Under a certain level of load, the settlement rate does not reach the stability standard within 24 hours. 3) The settlement of this stage is more than 5 times of the settlement of the previous Stage. 4) The soil layer of the bearing stratum is hard, the settlement is very small, and the maximum load is not less than 2 times of the design requirements. |

Determination of unmodified foundation bearing capacity $f_{ak}$

| 1) When the $p$-$s$ curve has a proportional limit, take the load corresponding to the proportional limit as $f_{ak}$. 2) When one of the above three termination loading conditions is satisfied and the corresponding load of the previous stage is less than 2 times of the load corresponding to the proportional limit, 1/2 of the load of the previous stage is taken as $f_{ak}$. 3) When the area of bearing plate is 0.25m$^2$-$0.5m^2$ and cannot be determined according to the requirements of the above two paragraphs, the load corresponding to $s=0.01-0.015d$ shall be $f_{ak}$, which shall not be greater than 1/2 of the maximum load. |

| 1) When the $p$-$s$ curve has a proportional limit, take the load corresponding to the proportional limit as $f_{ak}$. 2) When one of the above three termination loading conditions is satisfied and the corresponding load of the previous stage is less than 2 times of the load corresponding to the proportional limit, 1/2 of the load of the previous stage is taken as $f_{ak}$. 3) When it cannot be determined according to the requirements of the above two paragraphs, the load corresponding to $s=0.01-0.015d$ shall be taken as $f_{ak}$, and $f_{ak}$ shall not be greater than 1/2 of the maximum load. |

In the table 1, $p$ is the load, $s$ is the accumulated settlement, $b$ is the width or diameter of the bearing plate, $d$ is the diameter of the bearing plate, $f_{ak}$ is the characteristic value of the bearing capacity of the foundation soil layer measured by the in-situ load test, and $h$ is the unit time hour.

From Table 1, it can be seen that the main difference between shallow plate load test and deep plate load test is the test object and test conditions, and other test elements are similar.

When the shallow flat load test is used to determine the characteristic value of the bearing capacity of the building foundation, the first difference and the second difference exist. The code for design of
building foundation stipulates that both the foundation width and the foundation embedment depth shall be revised, and the calculation formula is as follows:

\[ f_a = f_{ak} + \eta_b \gamma(b - 3) + \eta_d \gamma_m(d - 0.5) \]  

(1)

Where \( f_a \) is the corrected characteristic value of foundation bearing capacity, \( f_{ak} \) is the characteristic value of foundation soil bearing capacity determined according to load test, \( \eta_b \) and \( \eta_d \) are foundation bearing capacity correction coefficients of foundation width and foundation embedment depth respectively, \( \gamma \) is the effective weight of soil below foundation bottom surface, \( \gamma_m \) is the weighted average effective weight of soil above foundation bottom surface, \( b \) is the foundation bottom surface width, \( b = 3 \text{m} \) when \( b < 3 \text{m} \), \( b = 6 \text{m} \) when \( b > 6 \text{m} \), and \( d \) is the foundation embedment depth.

When the characteristic value of the bearing capacity of building foundation is determined by using the deep plate load test, there is only the first difference. The code for design of building foundation stipulates that only the width of foundation shall be modified. The calculation formula is as follows:

\[ f_a = f_{ak} + \eta_b \gamma(b - 3) \]  

(2)

4. Case analysis: special case of determining bearing capacity of building foundation by applying load test results.

For a brick-concrete residential strip foundation, the stratum is homogeneous silty soil with clay content less than 10%, the weight is 20kN/m\(^3\), the width of the foundation bottom surface is 4m, and the embedded depth of the foundation is 4 m. It is known that the vertical force transmitted from the upper structure to the top surface of the foundation is 200kN/m, the average weight of the soil on the foundation and steps is 20kN/m\(^3\), and the unmodified characteristic value \( f'_{ak} \) of the foundation bearing capacity determined by the deep plate load test at the foundation elevation before construction is 400kPa. Now there is an engineering change, the embedded depth of the foundation is increased by 1m, and the original ground elevation is unchanged. Try to calculate the modified characteristic value \( f_a \) of foundation bearing capacity after engineering change.

The essence of the problem raised in this calculation case is to obtain the gradient of the measured value along the depth from the load test on the deep flat plate of homogeneous soil foundation. From the foregoing discussion, it can be seen that the characteristic value of foundation bearing capacity determined by shallow plate load test for homogeneous soil foundation is a constant, while the characteristic value of foundation bearing capacity determined by deep plate load test is a function of test depth.

Assuming that the shallow plate load test and the deep plate load test are respectively carried out at the elevation of the foundation bottom surface, uncorrected foundation bearing capacity characteristic values \( f_{ak1} \) and \( f_{ak2} \) are obtained. The revised foundation bearing capacity \( f_{a1} \) and \( f_{a2} \) can be obtained by formula (1) and formula (2), which are theoretically equal.

\[ f_{a1} = f_{ak1} + \eta_b \gamma(b - 3) + \eta_d \gamma_m(d - 0.5) \]  

(3)

\[ f_{a2} = f_{ak2} + \eta_b \gamma(b - 3) \]  

(4)

Both sides of the equal sign of equation (3) and equation (4) simultaneously calculate partial derivatives for \( d \), which shows that

\[ \frac{\partial f_{ak2}}{\partial d} = \frac{\partial f_{a2}}{\partial d} = \frac{\partial f_{a1}}{\partial d} = \eta_d \gamma_m \]  

(5)

According to formula (5), the gradient of the measured value along the depth from the load test of the deep flat plate of homogeneous soil foundation is \( \eta_d \gamma_m \).

The derivation of the above formula must meet the preconditions for the use of formula (1), i.e. the foundation width is greater than 3m or the embedding depth is greater than 0.5m, and a foundation meeting the preconditions can be simulated during specific application, then the above derivation conclusion is not limited by the preconditions for the use of formula (1).
In the above case, the uncorrected characteristic value $f_{ak}$ of foundation bearing capacity determined by the deep plate load test at the base elevation after engineering change is:

$$f_{ak} = f_{ak}' + \frac{\partial f_{ak}'}{\partial d} \times (d_1 - d_2) = 400 + 2 \times 20 \times 1 = 440 \text{kPa}$$

(6)

The revised characteristic value $f_a$ of foundation bearing capacity after engineering change is:

$$f_a = f_{ak} + \eta_b \gamma (b - 3) = 440 + 0.5 \times 20 \times 1 = 450 \text{kPa}$$

(7)

5. Conclusion

Based on the basic principle of soil mechanics, this paper gives some suggestions on the naming rules of foundation bearing capacity. In addition, the test principle and specific application of determining foundation bearing capacity by load test are analysed and discussed in combination with relevant cases, and the following conclusions are obtained:

(1) The naming of foundation bearing capacity should include the name of in-situ test, test depth and subject. It is meaningless to talk about foundation bearing capacity without data source and test depth.

(2) To determine the characteristic value of building foundation bearing capacity by load test, two influencing factors should be considered: i) the size difference between the bearing plate and the foundation, and ii) the lateral stress difference of the soil layer within the depth of influence of stress under the bearing plate and the foundation. When calculating the characteristic value of building foundation bearing capacity by shallow plate load test, the above two influencing factors are corrected. When calculating the characteristic value of building foundation bearing capacity by deep plate load test, only the first influencing factor is considered to be corrected.

(3) For homogeneous soil layer, the characteristic value of foundation bearing capacity determined by shallow plate load test is a constant in theory, the characteristic value of foundation bearing capacity determined by deep plate load test is a function of test depth, and the gradient of foundation bearing capacity determined by deep plate load test of homogeneous soil layer is $\eta d \gamma_m$ along depth in theory.

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To ask the water in the pond, why is it so clear? Because there is an inexhaustible source of constant flow of living water for it. I would like to express my sincere thanks to those who have given me help and care.

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