Study the behavior of square footing in clayey soil subjected to vertical loading

Mohanned Q Waheed*1, Awf A Khalid2 and Falah H Rahil3

1 Lecturer, Civil Eng. Department, University of Technology, Baghdad, Iraq
2 Assist Prof., Civil Eng. Department, University of Technology, Baghdad, Iraq.
3 Assist Prof., Civil Eng. Department, University of Technology, Baghdad, Iraq.

E mail: 40094@uotechnology.edu.iq

Abstract. Foundation is a part of the structure that transmits the load applied from the super structure to the soil below. Estimation of the bearing capacity of foundation is one of the most complicated problems in geotechnical engineering, therefore it provides a number of theories to estimate the bearing capacity. The purpose of this paper to study the behavior of model square footing in clayey soil subjected to vertical axial loading. The tests are conducted at three grades of undrained shear strength (Cu) of clayey soil which are (20 or 40 or 60 kPa). It is found that, in general, the load settlement curves of raft tests are non-linear hyperbolic shape without a well-defined peak load and the mode of failure is local shear failure in this type of soil, i.e. the behavior of this type of soil is strain hardening. Moreover, the bearing capacity factor (Nc) is equal to (2.8) where this value is not within the acceptable range of the bearing capacity factor (Nc) which ranges from (4 to 6.18) for saturated clay at (ϕ = 0). The ultimate load may occur at settlement more than (10%) of the width of the foundation which leads to make the settlement criterion control the allowable bearing capacity in design of shallow foundation in this type of soils.

1. Introduction

Foundation is a part of the structure which is a transition element between the super structure and soil. It is in direct contact with soil and transmits the load applied from the super structure to the soil below. Shallow foundation is the first option where near surface soil has sufficient bearing strength to carry the load from the superstructure without any unacceptable total and differential settlements to prevent damage of infrastructure and superstructure.

Bearing capacity failure of foundation occurs as the soil supporting the foundation fails in shear, which may involve either a general, local or punching shear failure mechanism. The conventional method of design of footing requires sufficient safety against failure and the settlement must be kept within the allowable limit. These requirements are dependent on the type of soil, its behavior and bearing capacity, thus, estimation of the bearing capacity of foundation is one of the most complicated problems in geotechnical engineering. There are number of theoretical approaches available to find out the bearing capacity of footing, consequently, the reliability of any approach can be demonstrated by comparing them with the experimental results.

The purpose of this paper to study the behavior of model square footing in clayey soil under vertical axial loading. It used a small-scale model which is relatively inexpensive and can be performed under controlled soil conditions, and can provide an appropriate boundary condition for...
investigation. The tests are conducted at three grades of undrained shear strength (cu) of clayey soil which are (20 or 40 or 60 kPa) which simulates the clayey soil formation encountered in a large part of the central and southern areas of Iraq.

2. Apparatus, Materials, and Testing Techniques

2.1. Testing Box
A steel box is used to contain the clayey soil that supports the raft models. The internal dimensions of the box are (600 mm x 600 mm) in plan and (650 mm) depth. The box size is chosen to be large enough to keep its sides and bottom away from the influence zone of the stress bulb induced due to loading the raft during the tests.

2.2. Loading system
The loading system used represents a type of load-controlled system that imposes a vertical concentrated load on the raft. The loading system consists of a loading frame with a lever arm ratio of (1:3). It is possible to apply a large load using this frame in a safe and easy manner. The load is transferred to the footing system using a weight hanger attached to the lever arm with a pin connection at the free end. The load is applied by placing slotted dead weights on the cradle. The steel frame and the loading system are shown in Plate (1).

Plate 1. The loading system.

2.3. The Soil
Soil used in this study was taken from the area of Al Taji, north of Baghdad city. Standard tests were performed to determine the physical properties of the soil. The physical properties of the soil used are shown in Table (1).

2.4. Footing model
Two sizes of square raft were used in this study which were of (150mm X 150 mm) and (210 mm X 210 mm) in dimension. The thickness of footing was equal to (5mm) to simulate a rigid footing case.
Table 1. Physical properties of clay soil used.

| Property                  | Value Index | Specification                  |
|---------------------------|-------------|--------------------------------|
| Liquid limit (L.L)        | 48          | ASTM-D4318-2010- [1]           |
| Plastic limit (P.L)       | 25          | ASTM-D4318-2010- [1]           |
| Plasticity index (P.I)    | 23          | ASTM-D4318-2010- [1]           |
| Specific gravity (Gs)     | 2.69        | ASTM-D854-2010- [2]            |
| Gravel (larger than 4.75 mm) | 0 %      | ASTM-D422-2010- [3]            |
| Sand (4.75mm to 0.075mm)  | 4 %         | ASTM-D422-2010- [3]            |
| Silt (0.075 mm to 0.005mm) | 45 %       | ASTM-D422-2010- [3]            |
| Clay (less than 0.005 mm) | 51 %        | ASTM-D422-2010- [3]            |
| Soil Classification       | CL          | USCS                           |

2.5. Test Preparation
The clay soil is mechanically ground in the laboratory and then the water content is adjusted as per the required undrained shear strength. A mechanical blender is used to mix the wet clay. The wet clay obtained is spread in layers inside the testing box and tamped in an aim to get rid any entrapped air with the soil. The top surface of each layer is scratched to ensure good interface binding with the next top layer.

After completion of the final layer, the surface is scraped and leveled and then covered with polyethylene sheet to avoid moisture loss from the prepared clay soil mass. After that a seating load of (5 kPa) was applied on top of the installed steel plate for a period of (24 hours) to ensure homogeneity of the soil mass.

2.6. Test Procedure
The load is applied in controlled steps, with each step being about one-tenth of the estimated maximum load capacity of the raft. The test is continued until the settlement was more than (10 %) of raft width. A settlement equal to (10%) of pile diameter or raft width is often considered to define the ultimate load capacity in foundation design as suggested by many researchers such as (Cooke (1986), Lee and Salgado (1999), Lee and Chung (2005). This criterion is used in this study, which represents the “measured raft load capacity”.

3. Results and Discussions
In this study six tests were carried out using two sizes of square raft (B) which are (150 mm) and (210 mm), where each one was conducted in three levels of clay strength \((C_u = 20, 40 \text{ and } 60 \text{ kPa})\). The load settlement curves of tests are shown in figure (1).

It can be seen from figure (1) that in general, the load settlement curves of raft tests are non-linear hyperbolic shape without a well-defined peak load, i.e. strain hardening as the supporting material is remolded clay. It is clearly seen from the trend of curves that the mode of failure of raft model test is of the local type, which is distinguished by the significant compression of soil below the footing during loading tests and no bulging of the soil adjacent to the footing.
Figure 1. The load settlement curves of footing tests.

In order to analyze the results of all raft tests regarding the applied stress and the corresponding settlement, the results have been presented on the basis of the relationship between the bearing pressure (q) and the settlement ratio (ratio of settlement to footing width) for the six tests performed, as shown in Figure (2). Figure (3) illustrates the relation between bearing ratio (q/Cu) against settlement ratio (S/B), where the bearing ratio represent the ratio of applied stress to undrained cohesion of clay.

It can be seen from Figure (2) that the ultimate bearing capacity corresponding to the settlement ratio of (10%) being (67, 94 and 168 kPa) as an average for the soil with undrained shear strength (20, 40 and 60 kPa) respectively. This average value represents the average for the two sizes of raft used in each clay type. Moreover the average bearing ratios of the six raft tests performed is (2.8), as shown in Figure (3), where this value is not within the acceptable range of the bearing capacity factor (Nc) which ranges from (4 to 6.18) for saturated clay at (φ = 0) [7]. This may be attributed to the mode of failure of model test which is local shear failure as observed from tests that were previously mentioned. In general, it was observed by some researchers that for foundations at a shallow depth, the ultimate load may occur at a foundation settlement of (4-10%) of the width of the foundation (B), when general shear failure in soil occurs; however, in the case where local or punching shear failure is encountered (as observed in cases of this study), the ultimate load may occur at settlement of about (15-25%) of the width of the foundation (B).

It can be concluded that the ultimate load may occur at settlement more than (10%) of the width of the foundation (B), which leads to make the settlement criterion to control the allowable bearing capacity in design of shallow foundation in this type of soils.
Figure 2. Relationship between bearing pressure & settlement ratio for footing tests.

Figure 3. Relationship between bearing ratio & settlement ratio for raft tests.
The summary of the tests results in addition to calculated raft capacity are listed in Table (2), where the values of the calculated load capacity of raft is according to local shear failure with a reduction factor ($C' = 0.67 C$) as suggested by Terzaghi ,1943 [8]. It is found that the calculated bearing capacity for these tests is over estimation.

| Test No. | Footing width (mm) | Cu (kPa) | Measured raft capacity (N) | Calculated raft capacity (N) |
|----------|--------------------|----------|----------------------------|-----------------------------|
| 1        | 150 mm             | 20       | 1700                       | 1851                        |
| 2        | 150 mm             | 40       | 2000                       | 3702                        |
| 3        | 150 mm             | 60       | 4500                       | 5554                        |
| 4        | 210 mm             | 20       | 2300                       | 3628                        |
| 5        | 210 mm             | 40       | 4100                       | 7257                        |
| 6        | 210 mm             | 60       | 6000                       | 10885                       |

4. Conclusions

From the experimental investigations conducted in this study, it can be concluded that:

1. In general, the load settlement curves of raft tests are non-linear hyperbolic shape without a well-defined of a peak load, i.e. the behavior of this type of soil is strain hardening.
2. The calculated bearing capacity for these tests is over estimation and the bearing capacity factor ($N_c$) is equal to (2.8) where this value is not within the acceptable range of the bearing capacity factor ($N_c$), which ranges from (4 to 6.28) for saturated clay at ($\phi = 0$), which may be attributed to having the mode of failure as local shear failure.
3. In case of local or punching shear failure is encountered (as observed in cases of this study), the ultimate load may occur at settlement more than (10%) of the width of the foundation which leads to make the settlement criterion to control the allowable bearing capacity in design of shallow foundation in this type of soils.

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