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Analysis of Ring Footings using Field Test Results

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ABSTRACT: The ring footings are suitable and economical for symmetrical structures such as silos, cooling towers, smoke-stacks, transmission towers, radar stations, TV antennae, chimneys, bridge piers, underground stops, water towers, mine and liquid storage tanks. When compared with the other geometrical shapes of the footings, such as (strip, rectangular, square and circular footings) a few studies directly related to ring footings have been reported in the literature. This study presents a series of field tests on ring footings. The field tests were conducted on natural clay soils. Seven different model rigid footings (20mm thick and 200mm in outer diameter) were used in the field tests. The first of the model footings were circular; the others were ring footings. The diameters of the inner boundaries of the ring foundations for the tests were 20.0, 40.0, 60.0, 80.0, 100.0 and 120.0mm. The experimental studies indicate that the bearing capacity of the ring footings depends directly on the ratio of the inside to outside radii, i.e. radius ratio.

1 INTRODUCTION

In recent years, the use of the ring footings has increased considerably for axi-symmetric structures such as silos, cooling towers, smoke-stacks, transmission towers, radar stations, TV antennae, chimneys, bridge piers, underground stops, water towers, mine and liquid storage tanks. The ring footings enable decreasing the amount of material used and cost of construction.

The bearing capacity and settlement behavior for strip, square, rectangular and circular footings has already been one of the most highly interesting areas in geotechnical engineering for researchers and practical engineers. When compared with the other geometrical shapes of the footings, a few studies directly related to ring footings have been reported in the literature. Fisher (1957) and Egorov (1965) were the first researchers to study the ring footing behavior in geotechnical engineering. Fisher (1957) proposed a method to calculate the settlement of ring footings on a semi-infinite elastic media. Then, Egorov (1965) presented some relations to calculate the bearing pressure under the ring footing and its settlement. Ismael (1996) investigated the behavior of ring foundations on very dense cemented sands by using plate loading tests. The load–settlement curves and ultimate bearing capacities for solid and ring plates were compared. Ismael (1996) found that the ultimate bearing capacity of ring plates is close to that of the solid plates, and proposed that ring foundations can be used with different ratios of the inside to outside radii (r_i/r_e) up to 75% in practical applications. Ohri et al. (1997) performed a series of laboratory tests on model ring footings and found that, for a ratio of internal to external diameter of the ring (d/D) equal to 0.38, the bearing capacity reaches its maximum for dune sand. Hataf and Razavi (2003) found that the value of d/D for the maximum bearing capacity of sand is not unique, but is in the range 0.2–0.4. Boushehrian and Hataf (2003) performed tests to investigate the bearing capacity of circular and ring footings on reinforced sand by conducting laboratory model tests together with numerical analysis. The effects of the depth of the first layer of reinforcement, vertical spacing and the number of reinforcement layers on the bearing capacity of the footings were investigated. In the numerical analysis, they found that the radius ratio is 0.40 for ring foundations. Laman and Yildiz (2003) performed some experimental analysis and investigated the bearing capacity of ring foundations supported by sand beds with and without geogrid reinforcement; they showed that the optimum ring width ratio (r/R) is 0.30. This means that the maximum performance in the bearing capacity is obtained at the ratio of 0.30. They found that a ring foundation with optimum width gives similar performance to that of a full circular foundation with the same outer diameter. Mehrjardi (2008) reviewed the behavior of ring footing compared with circular footing and presented the design method of these structures algorithmically.

This study presents a series of field tests on ring footings. The field tests were conducted on natural clay soils. Seven different model rigid footings (20 mm thick and 200 mm in outer diameter) were used in the field tests. The first of the model footings were circular; the others were ring footings. The diameters of the inner boundaries of the ring foundations for the tests were 20.0, 40.0, 60.0, 80.0, 100.0 and 120.0 mm. The experimental studies indicate that the bearing capacity of the ring footings is depend directly on the ratio of the inside to outside radii, i.e. radius ratio.

2 FIELD TESTS

A total of seven field tests were conducted in the Adana Metropolitan Municipality’s (AMM) Water Treatment Facility Center (WTFC) located in the western part of Adana, Turkey. The soil conditions at the experimental test site (WTFC) were determined from a geotechnical site investigation comprising both field and laboratory tests. Two test pit excavations (TP1 and TP2) and four borehole drillings (BH1, BH2, BH3 and BH4) were performed in the WTFC test area (Figure 1). The test area had dimensions of 30 m (length) by 11.6 m (width). Test pits of 2.50 m were excavated and boreholes were drilled with diameters of 0.10 m and depths of 13 m. The borehole drilled on the south side was 20 m. The ground water level was observed as being 2.20 m from the borehole drillings. The saturation ratio of the clay layer, where the tests were conducted, was about 80%. Three subsoil layers were clearly identified by visual inspection and by the Unified Soil Classification System (USCS). The first layer, 0.80 m in depth, was observed as topsoil and was removed before the tests. The intermediate layer, between the depths of 0.80 m and 7.0 m, exhibited a silty clay stratum with high plasticity (CH). A silty clay layer, with the intrusion of sand (CL), was observed in the bottom layer to a depth of 10.0 m.

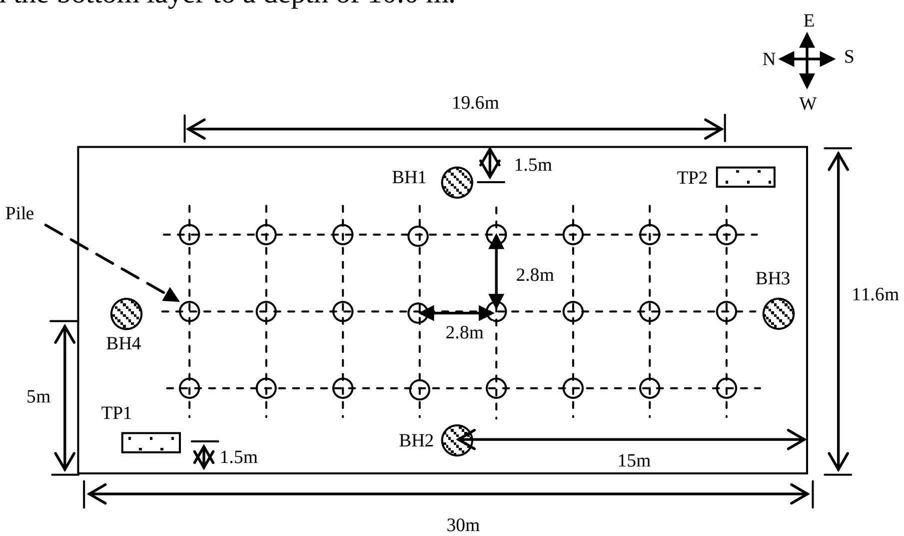


Figure 1. Plan view showing piles, borings and test pits

Standard Penetration Test (SPT) was carried out during the drilling of each borehole and the distribution of SPT values with depth is shown in Figure 2. These values infer that the tested soil was classified as medium stiff clay. Conventional laboratory tests, such as sieve analysis, moisture content, Atterberg limit, specific gravity, standard proctor, unconfined compression, laboratory vane, triaxial and consolidation tests were performed in the Geotechnical Laboratory of the Civil Engineering Department at Cukurova University, Adana, Turkey. The clay content of the soil layers varied from 60% to 70%. The upper homogeneous layer, where all the loading tests were carried out, was classified as high plasticity clay (CH) according to USCS. The water content of the stratified soil layers varied between 20% and 25%, depending on depth, which was almost the same as or greater than the plastic limit. The specific gravities of the soil layers (G_s) varied from 2.60 to 2.65 along the depths. The values of the undrained shear strengths, c_u, were determined by unconfined compression tests in the range of 60–80kPa. The average value of undrained shear strength from the triaxial tests was obtained as 65kPa. The soil layers were classified as a slightly overconsolidated soil (OCR=1–2.65) from odometer tests. The clay content, the water content, the unconfined strength and the pre-consolidation pressure distributions of the natural clay deposits along the depths are presented in Figure 3. Triaxial compression, consolidation and unconfined compression tests were conducted on undisturbed soil samples derived from the field. All of these conventional experimental facilities were performed to determine the soil characteristics of the test field.

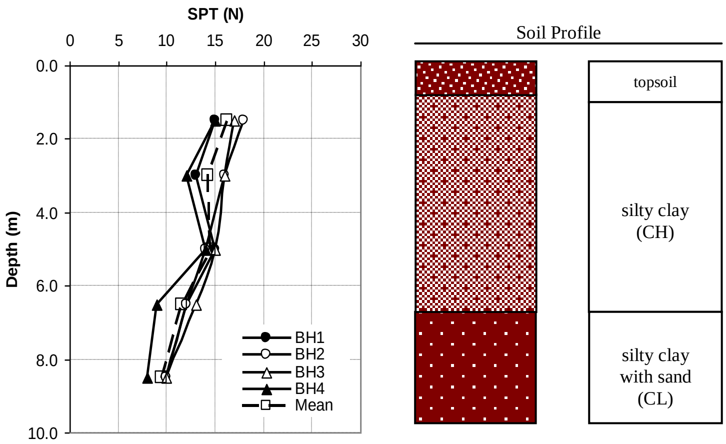
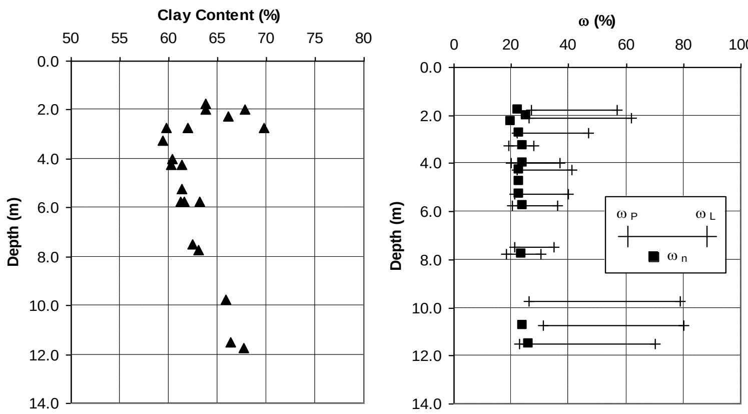
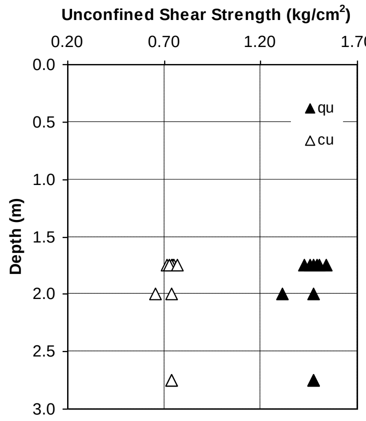


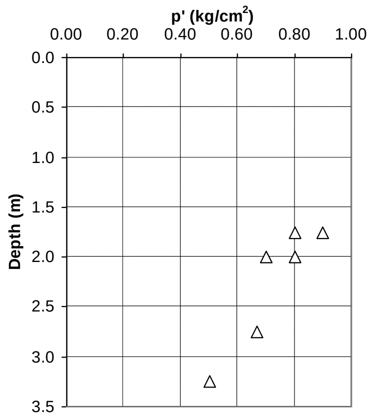
Figure 2. SPT(N) values measured from boreholes



(a) Clay Content (b) Water Content



(c) Shear Strength



(d) Pre-consolidation Pressure

Figure 3. Distribution of typical soil characteristics of natural clay soil

After obtaining the soil properties of the WTFC test area, 24 piles were constructed. The topsoil was removed before the tests. Then, reaction piles were connected with a steel beam. The top surface of the test area was leveled, and the footing was placed on a predefined alignment such that the loads from the hydraulic jack and the loading frame would be transferred concentrically to the footing. A hydraulic jack against the steel beam provided downward load. The hydraulic jack and the two linear variable displacement transducers (LVDT) were connected to a data logger unit and the data logger unit was connected to a computer. Load was applied with a hydraulic jack and maintained manually with a hand pump. The load and the corresponding footing settlement were measured with a calibrated pressure gauge and two LVDTs, respectively. The testing procedure was performed according to ASTM D 1196-93 (ASTM, 1997), where the load increments were applied and maintained until the rate of the settlement was less than 0.03 mm/min over three consecutive minutes. Some tests were repeated twice to verify the repeatability and the consistency of the test data. The same pattern for the load–settlement relationship, with a difference in ultimate load values of less than 2.0%, was obtained. The difference was considered to be small, and thus, ignored. The tests were continued until the applied vertical load was clearly reduced or a considerable settlement of the footing was obtained from a relatively small increase in vertical load. Detailed information on the testing procedure can be found by Laman et al. (2009), Ornek (2009), Demir (2011), Laman et al. (2012) and Ornek et al. (2012). The general layout of the test set-up is given in Figure 4.

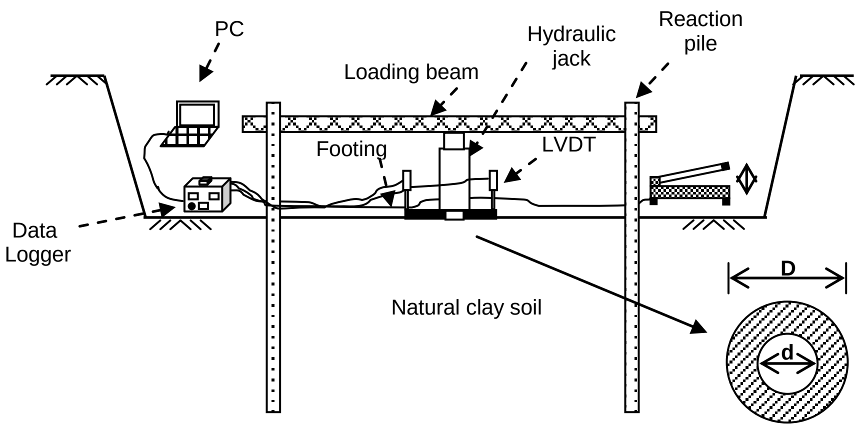
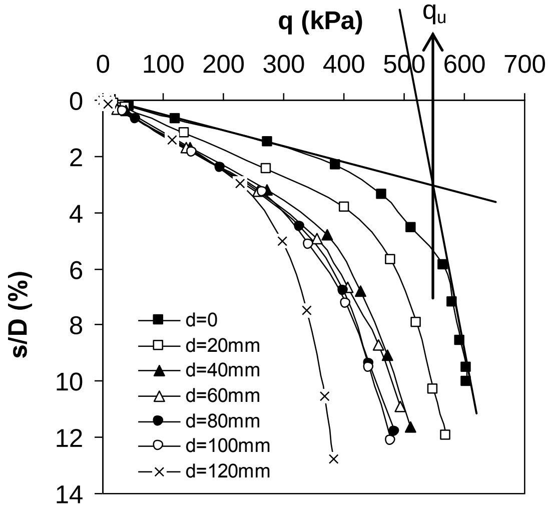
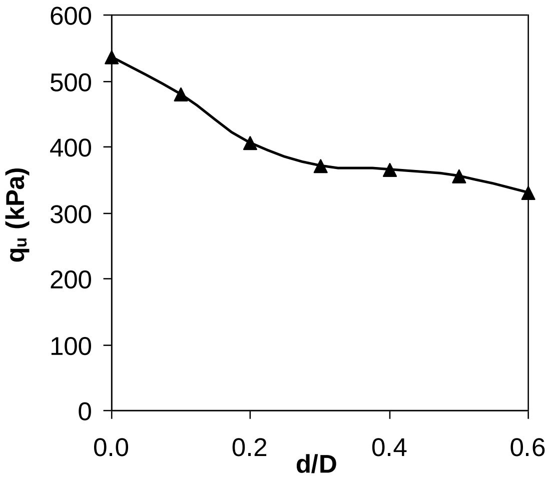


Figure 4. Schematic view of test setup, loading, reaction system and typical layout of instrumentation

3 FIELD TEST RESULTS

The field tests were conducted using different ring diameter ratios (d/D) on natural clay. The relations of vertical loading pressures to settlement ratios (q–s/D) and the relations of ring diameter ratio, d/D, to the ultimate bearing capacity for sand are presented in Figure 5. In this type of loading conditions, the plot of q against s/D takes almost a linear shape, and a peak value (ultimate bearing capacity) cannot be obtained directly. This type of failure in natural clay soil is called 'plunging shear failure' (Das, 1999). The ultimate bearing capacity in this case was defined as the tangent intersection between the initial, stiff, straighter portion of the loading pressure–settlement curve and the steeper, straight portion of the curve (Adams and Collin 1997). It can be seen from Figure 5 that q_u decreases rapidly when d/D changes from 0.0 to 0.3 and then it decreases at a slower rate when d/D changes from 0.3 to 0.6. An optimum value of d/D may visually be estimated from the curve as approximately 0.30.





(a) Load-settlement curves for natural clay (b) Relation of q_u to d/D

Figure 5. Test results for natural clay

In the literature, the ratio of inside to outside diameter (d/D) is generally recommended to be in the range 0.2–0.4 for ring footings. Ohri et al. (1997) found that for a ratio of internal to external diameter of the ring equal to 0.38 the bearing capacity reaches its maximum for dune sand. Hataf and Razavi (2003) found that the value of n for maximum bearing capacity of sand is not unique but is in the range 0.2–0.4. The values of the ultimate bearing capacity, q_u, were calculated for each experiment. These values are given in Table 1. As seen from the table that the same outer diameter (D=200mm) are used in the field tests.

Table 1. Field test results of natural clay soil for different ring diameter

D (mm)	d (mm)	d / D	q_u (kPa)
200	0	0.0	535
200	20	0.1	490
200	40	0.2	390
200	60	0.3	376
200	80	0.4	366
200	100	0.5	344
200	120	0.6	339

6 CONCLUSIONS

This study presents a series of field tests on ring footings. Before conducting the field tests, conventional laboratory tests were performed to determine the soil properties of the tested area. The field tests were conducted on natural clay soils. Based on the field observations, the following main conclusions can be drawn:

- For the natural clay soils, the ultimate bearing capacity decreases rapidly when d/D changes from 0.0 to 0.3 and then then it decreases at a slower rate when d/D changes from 0.3 to 0.6. An optimum value of d/D may visually be estimated from the curve as approximately 0.30.
- The measured ultimate bearing capacities for d/D=0.0 and d/D=0.6 are 535 kPa and 339 kPa, respectively.
- A ring footing with the optimum width shows approximately similar performance to that of a full circular footing with the same outer diameter as the ring footings. This option can provide an economical solution in practical applications.
- Nevertheless, the investigation is considered to have provided a useful basis for further research leading to an increased understanding of the ring footing applications.

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