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Effect of Different Shape of Footing on its Load-Settlement Behaviour (Circular, Square and Rectangular)

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Abstract **-** An experimental investigation is carried out to study the effect of shape of footing on its bearing pressure, when rested on granular soil under centric loading condition. The model footing used in this study are circular, square and rectangle. Rectangular footing used here is a special case of the square footing having L/B ratio of 1.5 and 2 times the width of the square footing. Plate load test is carried out on the dry river sand with two different relative densities (60% and 80%) to obtain the relation between load-settlement and L/B ratio. From this relationship, the bearing pressure of the footing is determined; it has been observed that the bearing pressure varies in increasing order as Solid Circular, Square, and Rectangle. It is found that the bearing pressure varies as the L/B ratio increases in the case of the square footing. The square footing had higher bearing pressure than the circular footing, this may be due to the more confining effect in the case of square footing because for the same lateral dimension, area of square(width=15cm) is higher than the circle(diameter = 15cm). The experimental results are compared with the established bearing pressure theories and it found that the values are comparable and identical.The results revealed that the shape of the footing has a significant effect on its bearing pressure and the settlement characteristics.

Keywords**:** Effect of shape, Load v/s settlement, Bearing pressure, L/B ratio, Confining effect.

1. Introduction

Design and construction of a proper foundation is a prerequisite step in before establishment of any superstructure as it connects the building structure with the ground. Footings serve to distribute the building load to the soil. Foundations are designed in consideration with the soil strength and their various properties. Footings design is specific for each respective building site, depending upon the structural plan and the orientation of the columns in superstructure. It can be designed and oriented in various shapes e.g. circular, square, rectangle etc.

Different types of footing having its own merits and de-merits. For example, in case of square and rectangular footing, both are special in ease of constructability, reinforcement placement and placing of concrete. Furthermore, circular type footings are specially used in structures that are circular in plan and the load transfers takes place from external walls to the footings before it gets transferred into the ground. For the calculating the bearing capacity of the footings and analysis of the behaviour of soil, load tests are carried out on field, one such test is PLT(plate load test) which is used to determine the bearing and settlement of the foundation under the load for clayey and sandy soils. But these are costly and also take too much time. Therefore these tests are conducted on model footings of various sizes and surface characteristics for different loading conditions in a laboratory using Plate Load Test apparatus. Based on the values of the engineering properties of soil the foundation can be designed. The tests performed in laboratory should be in a proper way so that the results obtained are accurate and in range of permissible variation which affects the foundation system under compressive loading conditions.

2. Literature Review

There are numerous methods for increasing the ultimate bearing capacity of the footing and decreasing the soil settlement reduction of the footing. However, large no. of observation has been carried out for development of the footing behavior. The behaviour of square and rectangular footings resting on cohesive soils were also studied by some of the researchers like S. R. Pathak[1], S. N. Kamat[1] and D. R. Phatak[1]. From the series of laboratory tests [1] they concluded that for the same width of footing the ultimate bearing capacity of footings decreases with increases in Length to Breadth ratio (L/B) of the footing. The bearing capacity value of square footing was found out to be more than that of rectangular and circular footings stated that they have same area as that of the square footing. Also as the size of the footing increases the bearing capacity increases, keeping L/B ratio same. Krishna [2], Viswanath[2] Keshav[2] also studied the performance of square footing resting on laterally confined sand. Later, Meyerhof [3] gave the corrections in the form of different N values, based on depth and shape of the footing (in addition to the strength ratio of the layers). Factors are directly related to the distance between adjacent footings. Most prior studies have focused on the ultimate bearing capacity of interfering strip footings on unreinforced soil (Wang and Zhao [4], Kumar and Ghosh[5]). They incorporated the stress characteristics method to obtain the bearing capacity factor Nc for ring footings (both rigid and smooth). Pavan H.M Prof. Aruna. T [6] studied load-settlement characteristics of square footing resting on sand with and without confinement. After conducting a number of experiments, from the load-settlement characteristics they stated that the load carrying capacity of the footing resting on the confining cell that is placed at depth equal to footing width is comparable to the load that was carried by footing in the uncased case. Going through the literature and the works of the previous researchers it was necessary to study the effect of the shape of the footings on its bearing capacity.

3. The experiment procedure

For the designing of any shallow foundation, it is obligatory to have experimental data related to finding bearing capacity of the soil at the suitable depth. For this plate load test is carried out on the site at desired depth. This test is performed on the field to examine ultimate bearing capacity of the soil at any suitable depth, the experimental details from the plate load test is helpful to confirm the design assumptions made from soil test.

For performing the experiment, we have specially designed footings with different shapes; strip, circular, square, rectangular (dimensions of the footings are displayed in below table). All the tests were carried out on dry river sand (which is compacted layer by layer at relative density of the 60% & 80% respectively). A vibration motor of 0.5 hP having a flat solid plate at bottom was used to achieve the required compaction and the relative unit weight of soil, for a specific amount of time. After placing the footings on sand layer load is applied through hydraulic jack gradually and the settlement for each increment of load is recorded through Dial gauges and LVDT (Linear Variable Deformation Transducer). The experiment program consists of the carrying out load bearing test on footing, solid circular footing, square and rectangular footings. The data obtained from the model tests were used to establish relationship between load, settlement and footing pressure.

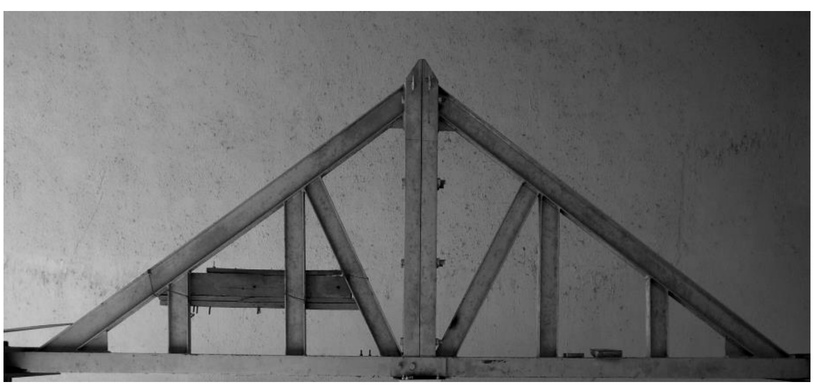

Fig. 1: Reaction Truss.

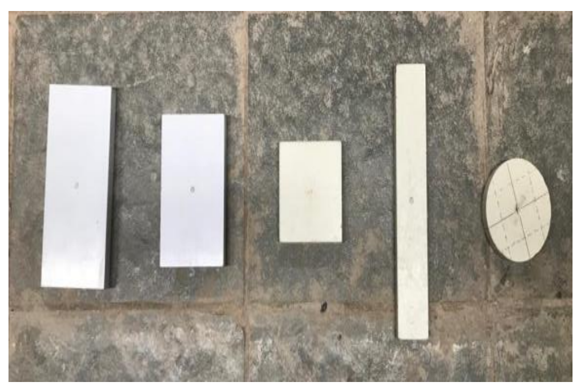

Fig. 2: Footings.

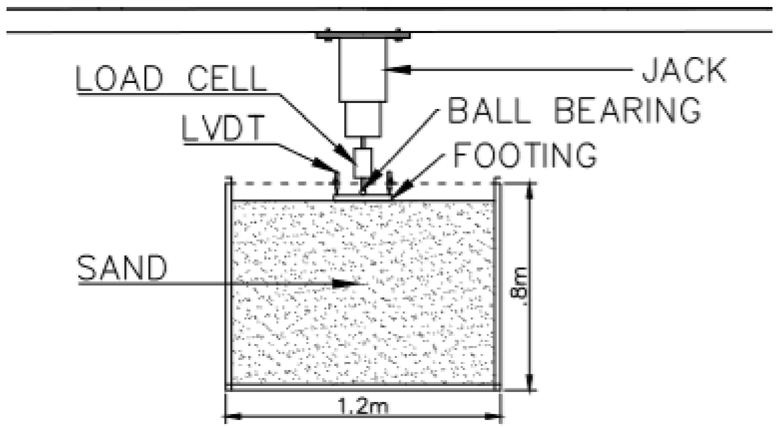

Fig. 3: Experimental Setup.

3.1. Test Apparatus

Table 1: Apparatus Description.

Equipment Name	**Specifications**
Reaction Truss	Howe type
Square Tank	1.2m x 1.2m x 0.8m
Loading Columns supporting the truss	1.15m x 0.3m
Length of reaction truss	6 m
Hydraulic jack & pump	Range-5000 kg
Dial Gauges/LVDT	Accuracy-0.02 mm, Range-52 mm
Solid Square Footing	15cm x 15cm x 3cm
Rectangular Footing	1: 15cm x 22.5cm x 3cm 2: 15cm x 30cm x 3cm
Solid Circle	Diameter = 15cm

3.2. Materials

For preparing the sample, dried river sand was used, which was kept in an airtight container. A sieve analysis was carried out in laboratory to find out the D_{10}, D_{30}, D_{60}, coefficient of uniformity and coefficient of curvature. The test revealed the following data:

Table 2: Properties of the sample.

Properties	**Sand**
D_{10}	0.17
D_{30}	0.22
D_{60}	0.3
C_u	1.764706
C_c	0.94902

4. Results and Discussion

4.1. Footing Pressure and settlement relationship at 60% and 80% relative density

A graph between footing pressure versus settlement is plotted for both the relative densities as shown in Fig. 4 & can be seen that pressure-settlement curve is linear up to a certain stage of loading but after reaching the ultimate the behavior is unfixed; indicating a clear point of failure of the footing. The failure of the footings occurred in order of circular, square, rectangular (case 2) and rectangular (case 1). The circular footing failed before the square footing, it may be due to more confining effect in case of square footing. The maximum footing pressure is of rectangle 1 i.e. a square footing with L/B ratio 1.5 is higher than that of rectangle 2 (square footing with L/B ratio 2). Performance of all the footings in 80% relative density is higher than that in 60% relative density, which is obvious.

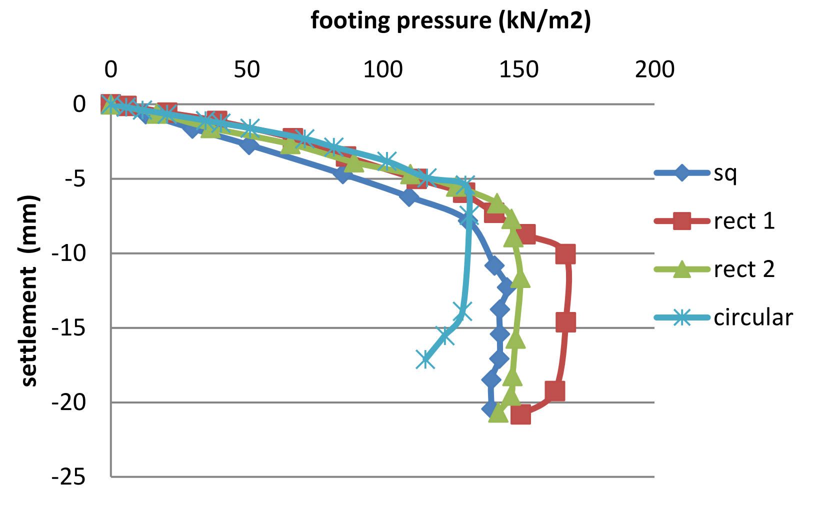

Fig. 4: 60% Relative Density.

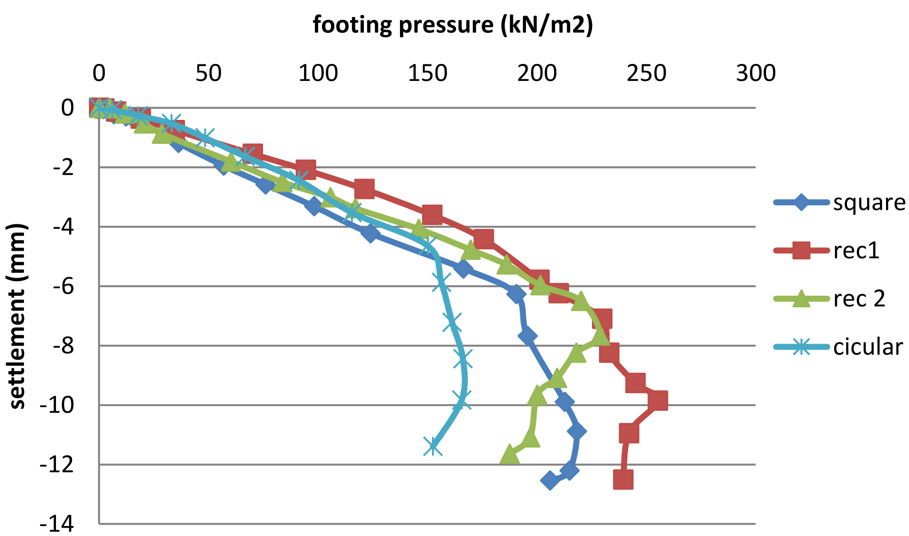

Fig. 5: 80% Relative Density.

4.2. Ultimate Pressure versus L/B ratio (In case of Square Footing)

A plot of ultimate pressure versus L/B ratio of square footing is generated for both the relative densities (60% and 80%) and shown in Fig. 6. It can be seen that the for L/B ratio 1.5 the ultimate pressure is maximum after that it decreases decreases as seen from the graph for both the relative densities.

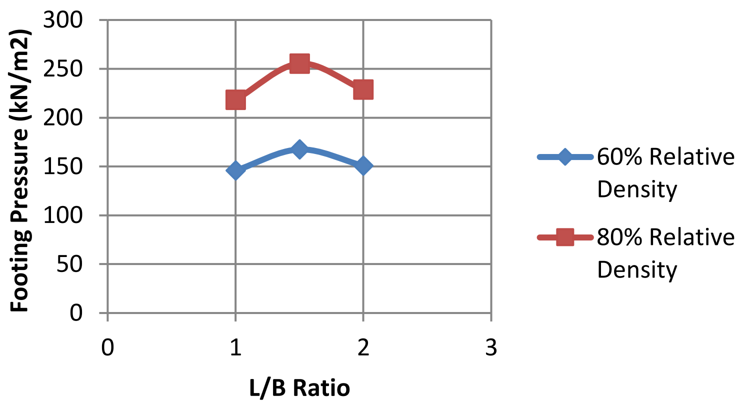

Fig. 6: Ultimate Pressure v/s L/B ratio.

4.3. Efficiency Factor versus L/B ratio (In case of Square Footing)

A factor is develop termed as Efficiency Factor described as the ratio of the footing pressure at ultimate shear failure of the square footing with various L/B ratios (i.e. 1, 1.5 and 2) to the footing pressure at ultimate shear failure of the square footing with L/B = 1. The graph between the efficiency factor and L/B ratio is plotted for both the relative densities (60% and 80%) and shown in Fig. 7. It is clearly observed that the Efficiency of the Square footing with L/B Ratio = 1.5 is maximum.

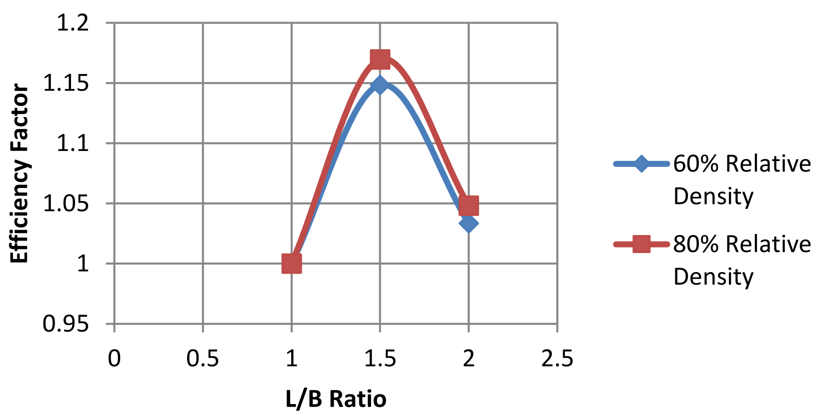

Fig. 7: Efficiency Factor v/s L/B ratio.

4.4. Comparison of the Bearing Capacities of all the footings with the available theories

It is necessary to compare the experimental data with some existing trusted theories. From the Pressure v/s Settlement curve (Fig. 4 & 5), the bearing capacity of all the footings is determined and noted. From the “Theory of Bearing Capacity” by Terzhagi, (1943)[7]; Qult. Values are calculated using equation (1) - (3) values of the bearing capacity are calculated.

These equations are differentiated from each other through the shape factor. Both these values are compared and shown in Table 3.

Equations used for computing the theoretical value of bearing capacity for footing:

Circular Footing
$$Q_{ult.} = 1.3cN_c + \gamma DN_q + 0.3\gamma BN_\gamma \quad (1)$$
Square Footing
$$Q_{ult.} = 1.3cN_c + \gamma DN_q + 0.4\gamma BN_\gamma \quad (2)$$
Rectangle Footing
$$Q_{ult.} = 1.3c(1 + \frac{0.3B}{L})N_c + \gamma DN_q + 0.5\gamma B(1 - \frac{0.2B}{L})N_\gamma \quad (3)$$

where Qult = ultimate soil bearing pressure, c = cohesion of soil (kN/m^2), q = effective over burden pressure at the base level of the foundation i.e. γ*Df (kN/m^2), Df = depth to base of footing from ground surface (m), γ = effective unit weight (kN/m^3), B = width of the footing (or diameter of circular footing) (m), L= length of the footing (m), Sc, Sq, Sγ = shape factors (functions of the soil friction angle, φ) and Nc, Nq, Nγ = bearing capacity factors (functions of the soil friction angle, φ).

Table 3: Comparison of Bearing Capacity (60% Relative Density).

Footing	Experimental Bearing Capacity	Theoretical Bearing Capacity Terzhagi
Circular	132 kN/m^2	95 kN/m^2
Square	146 kN/m^2	132 kN/m^2
Rectangle 1	167 kN/m^2	143 kN/m^2
Rectangle 2	151 kN/m^2	149 kN/m^2

Table 4: Comparison of Bearing Capacity (80% Relative Density).

Footing	Experimental Bearing Capacity	Theoretical Bearing Capacity Terzhagi
Circular	166 kN/m^2	155.5 kN/m^2
Square	218 kN/m^2	207 kN/m^2
Rectangle 1	255 kN/m^2	224.5 kN/m^2
Rectangle 2	228 kN/m^2	233 kN/m^2

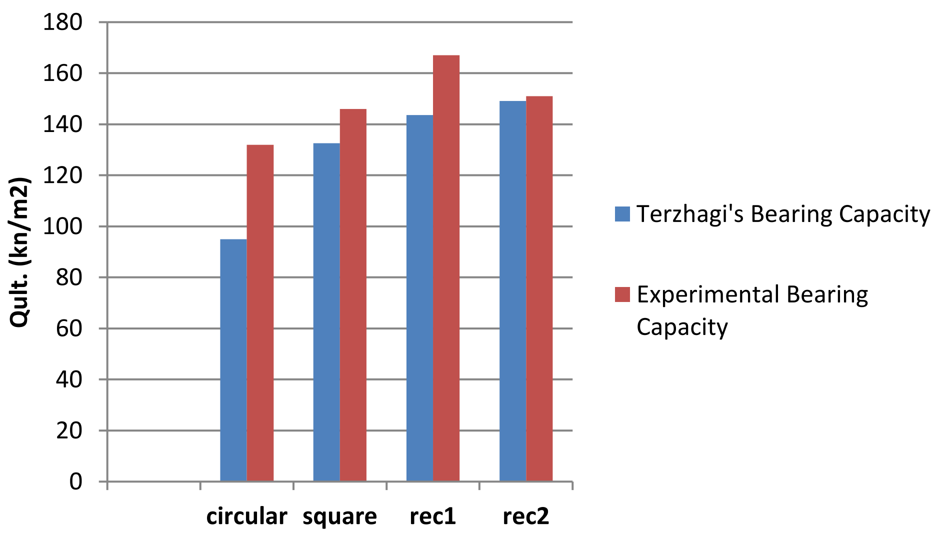

Fig. 8: 60 % Relative Density.

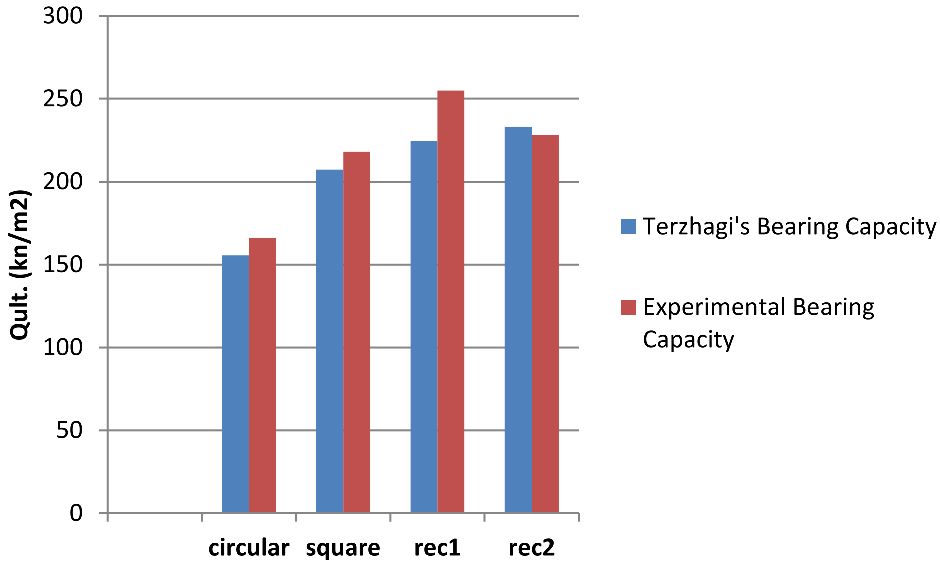

Fig. 9: 80% Relative Density.

5. Conclusion

The result obtained from the model test performed on the different footings to study the effect of shape of footing on the bearing pressure and settlement is quite acceptable. It is observed that the ultimate bearing capacity of the footing increases in order circular, square and rectangle, relative density being 80%. Similar trend is observed for 60% relative density. It is observed that the bearing pressure increases with increase in area of the footing. In case of rectangle footing designed as L=1.5B and 2B of the square footing, result obtained is fascinating; the bearing pressure increases and reaches maximum for the footing having L=1.5B, after that it decreases for L=2B. Bearing pressure for the square footing having width 15cm is higher than that of circular footing having diameter of 15cm. This is due to more confining effect in case of square footing than circular footing because for the given lateral dimension, the area of square is higher than that of the solid circle. The experimental bearing capacities determined from the footing pressure v/s settlement curve (Fig. 5-6) are compared with the calculated bearing capacity from the established theory (Terzhagi [7], Eq.1-4)). From Fig. 8-9, it can be concluded that the experimental values are identical with the theoretical values for all the types of footings used in this study.

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