Scale effect of rectangular and square footing of shallow foundation resting on cohesive soil

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Abstract. This experimental research work was performed to evaluate settlement and bearing capacity in cohesive soil. The predominant objective of this study is to develop the existing state of the knowledge about the present simulation processes to estimate its settlement and load carrying capacity. From the past literature study, the semi-empirical procedures were studied to estimate the settlement and bearing capacity parameters. The investigation was done into three parts, based on the past literature studies. The index and laboratory experimental investigations were done in the first stage. In the second part, the experimental procedure was elaborated to determine the settlement and load carrying capacity of small-scale model tests on cohesive soil. This research works presents, the effect of small-scale laboratory tests on the load carrying and settlement of model footings. The experiments were carried out with three types of model footing such as square, rectangular, and circular shapes were chosen to study the scale effect. For the circular footing, the diameters of 30, 40, and 50 mm sizes of plates were used and for square and rectangular model footings dimensions were used as 30mm × 30 mm, 40mm × 40 mm, and 50mm × 50 mm and 50mm × 33 mm, 40mm × 28 mm, and 30mm × 20 mm respectively. A steel tank of size 330×220×300 mm was fabricated and used for conducting model tests. The width of the plates ranged from 50mm to 100mm for modeling plane strain and axisymmetric problems and care taken to avoid the wall friction when the load is applied. The size effects on settlement and bearing capacity was studied under different moisture conditions such as optimum moisture and plastic limit of the soil.

1. Introduction
Foundation plays a vital role in the stability of building and it possesses the structure load to sub soil strata in to the deeper layer or on rock [1]. The parameters of load geometry, properties of soil, shape, width, and depth of footing plays a major role in the estimation of settlement and bearing capacity of soil under foundations [2, 3, 4]. Commonly the foundations are categorized as shallow and deep, and in the shallow
foundations types are generally transfer the super structures load in to relatively small depth below the soil [5, 6].

Generally the shallow foundations with different shapes are commonly used on the construction site, such that rectangular, square, strip, and circular shape [7, 8, 9]. The shape of the footing and size of the footing has to be selected based on the structural load, bearing capacity of the soil, and site condition by the horizontal cross section. The depth or thicknesses of the footing in the vertical cross sections are basically same. It creates their way of collaboration with the base of the soil trunk-wise (vertically) basically the same [10]. The load settlement curve is basically used to study the foundation interaction below the footing.

In the literatures, the shape of the footing was considered predominantly. The collaboration of these shapes of footings with the base of soil is such that the soil above their bases impart to the reaction of the loads from structure by surcharge load of soil below the base of the foundation [3]. Since the investigation of other shapes of shallow foundation (particularly vertical cross-sectional shapes), which can together partway mete out/counterattack structural loads vertically along their trunks and bases, is presented.

The shapes of footings are used to study the pattern of load-settlement correlation of soil below the foundation [1]. This investigation was fastened on the circumstance that, in the design of footing the settlement criteria has been used mostly commonly than the load carrying capacity [11]. Commonly the strip / pad footings are limited to 25 mm settlement in the shallow foundation [5].

Most experimental and analytical methods were presented based on the available field, large and small scale experimental study, and numerical study. The analytical methods involve limit equilibrium; slip line analysis, numerical approaches [12]. It is reported that the relative density of sand is influenced by the grain size of particle and free fall height and the scale effect (size and shape of footing) is also more important for the dense sand [13,14]. Loukidis & Salgado, (2011) investigated the failure mechanism in the two layered sandy soil and performed the finite element analysis to study the scale effect with varying sand density and size of footing [15]. The significant influence was observed in the load carrying capacity of soil by varying density of soil [16, 17]. The load carrying capacity and settlement of foundation was investigated by Nareeman (2012), the load carrying capacity of square and rectangular footing is greater than the shape of circular footing with same diameter [18].

2. Materials and methodology
The clay soil was selected as foundation medium. The clay soil has swelling and shrinking character when it contact with water. The energy of compaction plays an important role to prepare the foundation bed. The light compaction method was adopted to carry over the experiments. The energy of compaction is determined by using the following equation (3.1).

\[
\text{Energy of compaction} = \frac{\text{Weight of hammer} \times \text{height of free fall} \times \text{no.of layer} \times \text{no.of blow}}{\text{Volume of the soil sample}} \quad \ldots (3.1)
\]

The water content is selected as optimal water content and plastic limit of the sample was adopted to carry over the experiments. The maximum dry unit weight of the soil sample was measured during the load settlement analysis. A core cutter of 60 mm x 60 mm x 30 mm was used to measure the density of soil in the model test tank. To attain the light compaction density, the no of blows were calculated based on the volume of model tank, height of free fall of hammer (300 mm) and no of layers (3).

2.1 Properties of Soil
The cohesive soil sample was collected at Salem, Tamilnadu, India and the laboratory tests were performed and found the index and strength properties. Naturally clay soil has expansive character when it contact with water and which is very stiff when it is in dry condition. The swelling and shrinking character
cause foundation problems on structures. Precautions should be made before construction on clay soil. Table 1 shows the index and strength properties of clay soil.

Table 1. Soil Properties

| Properties                      | Values     |
|---------------------------------|------------|
| Moisture Content (Wc)           | 9.30       |
| Specific Gravity (G)            | 2.60       |
| Percentage of Gravel            | 0.2        |
| Percentage of Sand              | 23.7       |
| Percentage of Silt & Clay       | 76.1       |
| Liquid Limit                    | 43         |
| Plastic Limit                   | 27         |
| Plasticity Index                | 16         |
| Max Dry Unit weight             | 1.904      |
| Optimum Moisture Content        | 14         |
| Unconfined Compression Strength | 3.165 kg/cm² |
| Cohesion                        | 1.805 kg/cm² |
| Soil Classification             |            |

3. Experimental setup

3.1 Model Plate
Model plates were designed according to the foundation model requirements and this has made up of mild steel plates with the selected dimensions. The rectangular plates are assumed in the ratio of L/b = 1.5. The circular and square plates are assigned based on the loading frame width due to pressure bulb distribution (Figure 1). The plates used in the tests are stainless steel plate with the thickness of 2mm and the dimensions of the model plates are shown in Table 2.

Table 2. Model Plate Dimensions

| Shape     | Dimensions in mm |
|-----------|------------------|
| Rectangular | 30x20  40x28  50x33 |
| Square    | 30x30  40x40  50x50 |
| Circular  | 30     40     50    |
3.2 Model Tank
The model tank was fabricated based on the pressure bulb of footing plates and load frame width. Generally the tank width has assumed 4 times the plate size and depth and length has 6 times the breadth of plate [1]. According to the Indian Standard Specification1888:1972 for clay soil the boundary effect is 2.5 times the breadth / diameter of footing is recommended, so the boundary condition requirements fulfilled in the design of model tank [19]. The thickness of model tank is 2 mm and shown in Figure 2.

![Figure 2. Model Tank](image)

3.3 Experimental Test (Plate Load Test)
The prototype footings are not realistic able in the assessment of the field loading requirement and in the field test, it consumes time and cost, in the absent of full scale test, a small scale plate load test is commonly preferred for the determination of load carrying capacity and settlement [4]. It is a test where load is applied on the surface of the steel plate. This is a semi-direct method since the modifications in dimension between the trial and the structure are to be accurately accounted for in attaining at significant interpretation of the results [11]. The test basically comprises in loading a inflexible plate at the footing base level, cumulative the load in subjective additions, and estimating the settlements conforming to each load increment after the settlement is approximately finished every stage a load increment is applied. The prototype foundation size and plate size of model is varied. Since the results do not straightly replicate the load carrying capacity [9, 20]. Consolidation process take long time in clay soils and the small scale test are performed with short time, since the settlements in cohesive soils was not predictable under the in-situ test, which may take years, thus, the load test do not have considerable importance in the estimation of bearing pressure based on settlement criterion [1]. The load assessment effects replicate the characteristics of the soil situated only within a depth of about twice the breadth of plate. The influence zone in the
situation of a prototype footing will be greatly higher and unless the soil is basically similar for such a depth and more, the results could be very ambiguous [21].

3.4 Procedure of Plate Load Test on Soil
The plate bearing investigation was conducted in a model tank of 330 x 220 x 300 mm. The size of the tank is generally 4 times the plate size and the depth of the model tank was also 4 times the plate size. So, it is satisfied the boundary conditions [4, 22]. The dimension of the plate sizes were 30 mm, 40 mm, and 50 mm for circular shape and for square and rectangular shape dimensions of plates were 30mm x 30mm, 40mm x 40mm, 50mm x 50mm, 30mm x 20mm, 40mm x 28mm, 50mm x 33mm with 2mm thickness respectively. The clay soil had to be filled in the model tank as a three layers with a compaction of 540 blows for each layer. Pre-calibrated proving rings were kept to quantity the load transmitted to the footing. Small increments of load were preferred to conduct the tests. The load increment of each load was retained constant until the footing settlement was stabilized. The dial gauges were used to measure the footing settlements.

3.5 Shape Effect of Footing on Bearing Capacity and Settlement
The model plate influence of the footing was investigated with shape and cross section area of the foundation. Comparisons between groups of footings were made to analysis the influence of the shape and size, such as rectangular, square and circular group. It could be said that for each group, three types of footing with same shapes are drawn with different area to illustrate solely effect of the shape of the footing on the settlement and load carrying capacity. Table 3 shows the load with corresponding settlements for rectangular, square and circular shapes. The graphs (Figures 3 to 8) are shown the load versus settlement curves for 14% and 27% of moisture content.

4. Result and discussion
The footing shapes with different areas are considered to investigate the influence of load carrying capacity and settlement on clay soil. Table 3 shows the experimental results for circle, rectangle and square shape with 14% and 27% of water content. The Figures 3 to 8 show the comparison of different length to width or diameter ratios. The curves show that the failure envelope initially nonlinear and there after it becomes nonlinear. The failure load was taken as when it attains maximum load in the curve.

| Shape of Footing | Water content | Size of Ultimate Failure Load (N) | Settlement (mm) | Ultimate Load (N/m²) | SBC (N/m²) |
|------------------|---------------|----------------------------------|-----------------|----------------------|------------|
| Square           | 14%           | 50 50 - 2687.5                   | 13              | 1075.00              | 358.33     |
|                  | 14%           | 40 40 - 2125                     | 12              | 1328.13              | 442.71     |
|                  | 14%           | 30 30 - 1562.5                   | 8               | 1736.11              | 578.70     |
|                  | 14%           | 50 50 - 750                      | 13              | 300.00               | 100.00     |
|                  | 14%           | 40 40 - 468.75                   | 11.5            | 292.97               | 97.66      |
|                  | 27%           | 30 30 - 281.25                   | 9               | 312.50               | 104.17     |
|                  | 27%           | 50 33 - 2750                     | 10.5            | 1666.67              | 555.56     |
| Rectangular      | 14%           | 40 28 - 1875                     | 5.5             | 1674.11              | 558.04     |
|                  | 14%           | 30 20 - 1000                     | 10.5            | 1666.67              | 555.56     |
|                  | 27%           | 50 33 - 2750                     | 10.5            | 1666.67              | 555.56     |
|                  | 27%           | 40 28 - 375                      | 8               | 334.82               | 111.61     |
|        | Length | Width   | Load  | Settlement | Load  | Settlement |
|--------|--------|---------|-------|------------|-------|------------|
| Circular | 50     | 30      | 218.75| 12.5       | 1210.19 | 589.76     |
| 14%    | 50     | 40      | 2375  | 10.5       | 1393.31 | 111.46     |
|        | 30     | 1250    | 656.25| 8          | 334.39  | 10.5       |
| 27%    | 50     | 312.5   | 6.5   |            | 248.81  | 6.5        |
|        | 40     | 250     | 12    |            | 353.86  | 12         |

**Figure 3.** Load-settlement curve for rectangular plates-14%

**Figure 4.** Load-settlement curve for rectangular plates-27%

**Figure 5.** Load-settlement curve

**Figure 6.** Load-settlement curve
Figure 7. Load-settlement curve for square plates-14%

Figure 8. Load-settlement curve for square plates-27%

Figure 9 and 10 show that the comparison of square, rectangle and circle plates. It clearly shows that the load carrying capacity increases with increase in footing size and also it clearly indicates that the water content increases, the load carrying capacity decreases rapidly. The settlement of the plates has attained 8 to 13 mm for 14% of water content (OMC) and 9 to 14 mm for 27% of water content. The voids are increasing with increase in water content in soils, which leads reduction in bearing capacity of soil rapidly.

Figure 9. Model Plate size vs Ultimate load for 14% of OMC

Figure 10. Model Plate size vs Ultimate load for 27% of Water content (Plastic Limit)

5. Conclusion
From the experimental test results the following conclusions were drawn;
The load carrying capacity increases with increase in footing size. The load settlement curve behaves linear in the initial stage and thereafter becomes non linear. The load carrying capacity is maximum at optimum moisture content when compared with higher moisture contents. The bearing capacity of the soil decreases 4 to 5 times with increase in water content from OMC to PL. The decrease in load carrying capacity due to increase of voids in between the soil solids. The settlement range of the footing 8 mm to 13 mm for 14% of water content (OMC) and 9 mm to 14 mm for 27% of water content (Plastic Limit). The settlement of the footing is linearly increases when the water content increases beyond the optimum.

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