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STUDY OF BEHAVIOUR OF SQUARE AND RECTANGULAR FOOTINGS RESTING ON COHESIVE SOILS BASED ON MODEL TESTS

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ABSTRACT

The estimation of a reliable value of bearing Capacity of soil is the most important step in the foundation design work. Number of theoretical approaches and in-situ tests for the estimation of bearing capacity of footing are available. The reliability of any theory can be demonstrated by comparing the experimental test results on field footings with theoretical predictions. One of the reliable methods is the load test on full sized footing. However, this test as covered under IS 1888-1982 is too expensive and time consuming. Model tests can be conducted on footings of various sizes. The surface characteristics for different loading conditions can provide information on qualitative and quantitative contribution of such parameters on bearing of footings in absence of field test results. It is revealed that research work (Sawant et al (2000), Rajgopal et al (2000), Sawaf et al (2005), Mohmoud et al (1989), Harikrishna et al(2000), Sahu et al (1970) etc.)has been carried out for load tests on model footings resting on sand as foundation medium. However no work has been reported so far on c – Φ soil.

In this present study a laboratory model with loading frame has been developed in Geotechnical Engineering Laboratory of College of Engineering, Pune to conduct small scale load tests, to determine Bearing capacity characteristics of footings resting on c-Φ soil. Load tests were conducted on two square, two circular and five rectangular footings resting on c – Φ soil in the laboratory model. The bearing capacity, time – settlement relationship, pressure settlement relationship of footing resting on c – Φ soil and effect of various parameters such as L/B ratio, shape and size of footing on bearing capacity of footing were studied. Comparison is made between bearing capacity of footings estimated by the conventional methods such as Vesic's, Tezaghi's method and that estimated by Model Test Results. The model tests provide qualitative information on parameters influencing bearing capacity of footings. These tests can be used to check the bearing capacity estimated by analytical method.

INTRODUCTION

The most important step in foundation design is to arrive at a reliable value of Bearing Capacity. Bearing capacity may be defined as the largest intensity of pressure which may be applied by a structure or a structural member to the soil which it supports without causing excessive settlement or failure. There are three approaches for the estimation of allowable bearing pressure

(1) Conventional Methods depending on Theoretical Soil Mechanics approach,
(2) In situ Tests,
(3) Laboratory Model tests.

In the Conventional Methods the bearing capacity can be calculated by means of the theory of elasticity, classical earth pressure theory and the theory of plasticity.

There are four types of In situ tests which are generally used for estimating bearing pressures; mainly Standard Penetration Test (SPT), Static cone Penetration Test (SCPT), Pressuremeter Test (PMT) and Plate Load Tests.

Number of theories such as Rankine's theory (1885), Bell's theory (1915), Terzaghi's theory (1943), Meyerhof's theory(1951, 63), Hansen's Approach(1970), Vesic's approach (1973-75) and Skempton's approach (1951) regarding estimation of bearing capacity have been developed over the years. The reliability of these theories can be demonstrated only by comparison of experimental results on model or field footings with theoretical predictions. Load Tests on field footings are too expensive and time consuming. Model tests, however can be conducted on footings of various sizes and surface characteristics for different loading conditions. The foundation medium can be prepared under controlled conditions with dependable values of its engineering properties. Properly conducted laboratory tests, with known variation of parameters affecting the soil foundation system under compressive loads, will provide information on qualitative and quantitative contribution of such parameters on bearing of footings.

Extensive theoretical and experimental investigations on estimation of bearing capacity of footing resting on sand are available (Sawant et al (2000), Rajgopal et al (2000), Sawaf et al (2005), Mohmoud et al (1989), Harikrishna et al(2000), Sahu et al (1970) etc.). At present there is scant information available on experimental results on footings resting on c – Φ soil. Load testing on full size footing is generally expensive and difficult to perform. Therefore in this present work a laboratory model with loading frame has been developed in Geotechnical Engineering Laboratory of College of Engineering, Pune to conduct small scale load tests to determine bearing capacity of footing resting on c-Φ soil.

The aim of present study is to develop a laboratory model to facilitate small scale load tests on footings resting on c- Φ soil and to determine bearing capacity of footing resting on c – Φ soil using model test results and compare this experimental data with theoretical work. To achieve this objective, load tests on two square, two circular and five rectangular footings resting on c– Φ soil in the laboratory model were conducted as detailed in table1.

LITERATURE REVIEW

It is revealed from the research work carried out by many authors such as A. S. Sawant et. al. (2000), K Rajgopal et. al. (2000), M. E. I. Sawaf and A Nazer (2005), M .A. Mahmoud & F. M. Abdrabbo (1989) P Harikrishna et.al. (2000), Basudev Sahoo &V.N.S. Murthy (1970) etc.), that the tests were conducted on sand as foundation medium. Little Research work so far has been done on load tests on footings resting on c– Φ soil.

EXPERIMENTAL INVESTIGATION

In this present study a laboratory model has been developed with loading frame to conduct small scale load tests on model footings to determine bearing carrying capacity of c–Φ soil.

Test Programme

Total nine tests were conducted on square, circular and rectangular model footings of different sizes placed on the surface of foundation medium, prepared under controlled engineering parameters. The properties of soil used as foundation medium were kept constant for each test. Details of the test programme are listed in table 1. The model footings were placed on clayey sand of unit weight - 18.49 kN/m^3, +cohesion - 4 kN/m^2, angle of internal friction - 34^0 and water content - 12.56%.

Table 1: Model Test Programme

Sr. No.	Shape of Footing	Footing Designation	Size of footing (mm x mm)	L/B ratio
1	Square	S1	101.6 x 101.6	1
2	Square	S2	203.2 x 203.2	1
3	Rectangular	R1	50.8 x 152.4	3
4	Rectangular	R2	50.8 x 203.2	4
5	Rectangular	R3	101.6 x 203.2	2
6	Rectangular	R4	101.6 x 304.8	3
7	Rectangular	R5	101.6 x 406.4	4
8	Circular	C1	114.3 mm dia.	-
9	Circular	C2	228.6 mm dia.	-

Experimental Set up

The experimental set up consists of foundation medium, model footings, Model Testing Tank, Loading arrangement for the application of load, Rammer for compacting soil to the required density, Dial gauges and dial gauge fixtures to measure settlement.

Foundation Medium. Before starting the test programme, soil was tested to determine preliminary properties as listed in table 2

Model Footings. Steel plates of 22 mm thickness, with a groove at its top centre and with single surface characteristics were used as model footings. A rough base condition was achieved by spot welding in grid pattern as shown in plate 1. A load is transferred through a ball bearing which was kept between the footing and extensible rod of hydraulic jack. Such an arrangement produces a hinge, which allows the footing to rotate freely as it approaches failure and eliminates any potential moment transfer from loading fixture.

Model Testing Tank. Model steel tank of size 1200 mm x 1200 mm in plan and 1000 mm deep was designed and fabricated in geotechnical engineering laboratory of College of Engineering Pune, shown in plate 2.
To determine the size of testing tank the previous research work of many researchers (Basudev sahho and V.N.S. Murthy (1968), A. S. Sawant (2000), K Rajgopal et. al. (2000), P Harikrishna et.al. (2000), M. E. I. Sawaf and A Nazer (2005)

and M .A. Mahmoud & F. M. Abdrabbo (1989) etc.) were reviewed.

The size of tank 1200 mm x 1200 mm in plan and 1000 mm in depth is fixed in such a manner that at least four footings of 100 mm can be tested on the same foundation medium, at the same time. The care was taken that influencing area of failure surfaces of any footing should not overlap each other nor should it interact with the walls of the tank. The tank walls were constructed using 1200 x 1200 mm x 5 mm thick plates, stiffened by providing angles of size 50 x 50 x 5mm along the perimeter of plates and centrally along the length and width, to safely carry pressure exerted by the soil compacted in the tank. The hinge is provided below the front wall so that it can be opened to extract the compacted soil in the tank after completion of test.

Table 2: Soil Properties

Sr. No.	Name of test	Name of property	I. S. Code No.
1	Sieve analysis	Gravel: 0 %	2720 - IV
		Sand : 56.99 %	
		Silt: 25.25 %	
		Clay content : 17.76 %	
		Soil classification : CL	
2	Standard proctor test	MDD: 1.764 g/cc	2720 - VII
		OMC : 15 %	
3	Direct shear Test	C : 4 kN/m^2 , Φ : 34^0	2720 - XIII
4	Consistency limits	Liquid limit : 34.20 %	2720 – V
		Plastic limit: 22.67 %	
		Plasticity index : 11.53 %	

Loading Arrangement. Load was applied to the footing by hydraulic jack of capacity 20 kN, mounted on the loading frame anchored to the two channels at the two ends. The capacity of hydraulic jack was selected considering minimum and maximum possible expected load on various sizes of footing considered. The two channels were fixed to the concrete bed by anchor bolts. A 40 kN capacity loading frame as shown in Plate 2 was designed in such a way that it can develop suitable reaction against hydraulic jack. Moreover it can be moved along the length of the tank and can be fixed at any position along the length where load has to be applied. Loading frame was fabricated in three parts i,e Beam and two columns for the convenience of handling, which can be bolted at the testing place. Beam and columns were made of 2 ISLC 100 welded together to form the box section. Pressure gauge was attached to the hydraulic pump, to measure the load applied to the footing.

Rammer

Rammer consists of a 2.9 kg weight and the base plate connected to the rod over which weight falls. The weight was made to fall through height of 30 cm over 100mm x 100 mm base plate and 30 number of blows were given at a time at a place, to achieve the same energy produced as that in standard proctor test.

Dial gauges and dial gauge fixtures to measure settlement.
Two mechanical dial gauges of sensitivity 0.02 mm were used to measure settlements.

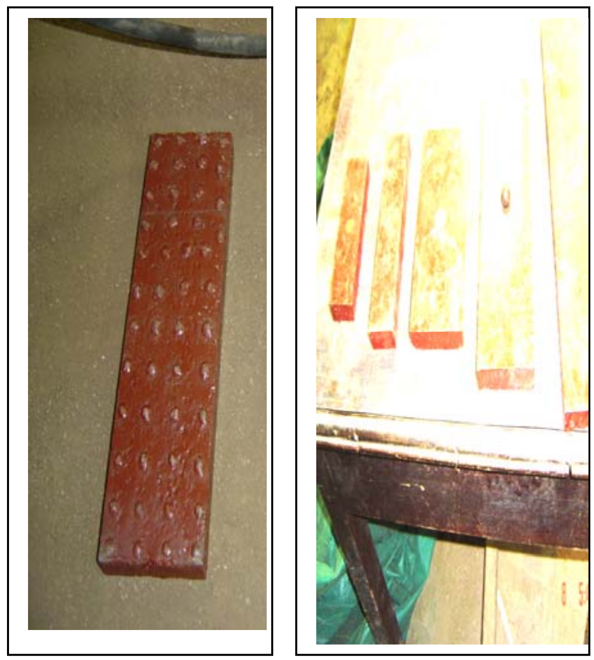

Plate1: Model Footing – surface conditions

1: Loading Frame 2: Hydraulic Jack
3: Hydraulic Pump 4: Model Testing Tank

Plate 2: Experimental Set up

Plate3: Dial gauge arrangement

Experimental Test Procedure

The experimental Test procedure for footing load test consists of following steps, which are described in details as below

Preparation of Foundation Bed. The moisture content present in the soil was determined. Soil weighing 10 kg was taken in a large pan. Then measured amount of water was added uniformly to the soil in the pan to achieve the predetermined amount of water content. After adding the water, soil was thoroughly mixed with water. Then the moist soil was kept so as to allow moisture movement to take place say for about 3 hrs. To prepare foundation bed, the moist soil was poured in the testing tank in layers. The soil was then gently levelled and compacted by rammer in 50 mm layers till the desired height was reached to achieve design density. Each layer was compacted uniformly so as to achieve uniform density. Total 30 blows, with height of fall 300 mm were given at each location of rammer.

Load Application and Observation. After the foundation bed was set up, the footing was placed in position, and the load was applied on it by using hydraulic jack. The load was applied in small cumulative increments of minimum 1/5th of estimated bearing capacity until the failure was reached. Each load increment was maintained constant until the footing settlement had stabilized or until 32 min have elapsed, whichever occurs first. The settlement observations were recorded at 1, 2, 4, 8, 12, 16, 20, 24, 28 and 32 minutes. The test is continued until one of the following states is attained:

a) The settlement becomes definitely progressive.
b) The rate of settlement or load has increased beyond the capacity of the test apparatus.
c) Total settlement of 25 mm is reached.
d) The applied pressure exceeds three times the allowable pressure

The load applied to the footing is removed after the completion of test

DISCUSSION ON TEST RESULTS

Time - Settlement Relationship

The settlement readings were recorded at 1, 2, 4, 8, 12, 16, 20, 24, 28 and 32 min for each load increment. Fig. 1 shows time – settlement relationship for footings S1, S2, C1, C2, R2, and R5 for applied load of 2.46 kN. Settlements observed at 1 min after load application were 0.57 mm, 0.91mm, 1.47mm, 1.6mm for footing S2, R5, S1,C1 respectively. It is observed that settlement rate is high up to 3 min for all load applications for all types of footing.. The settlement rate becomes negligible after 16 to 20 minutes.

Pressure - Settlement Relationship

The observed Pressure settlement curves for footings S1, S2, C1, C2, R1, R2, R3, R4 and R5 were obtained by plotting pressure settlement readings to arithmetic scale (Fig. 2, 3, and 4). It is observed that pressure settlement curve is linear in the earlier stage of loading but flattens out at later stage. There was no clear point of failure. The ultimate bearing capacity was obtained as the pressure corresponding to the point of intersection of two tangents drawn to the curve. It is clear that for pressures greater than ultimate pressure, settlement occurs at increasing rate. The ultimate bearing capacity for each footing obtained from model test results and using conventional methods namely Vesic's and Terzaghi's theory are listed in Table3.

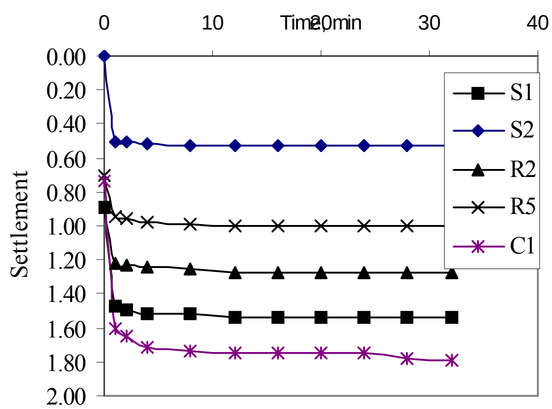

Fig.1. Time settlement crve for footings under the load application of 2.46 kN

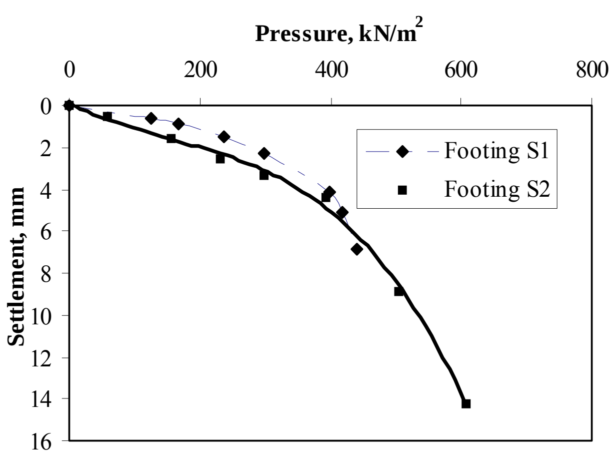

Fig. 2. Pressure - settlement behaviour for square footing

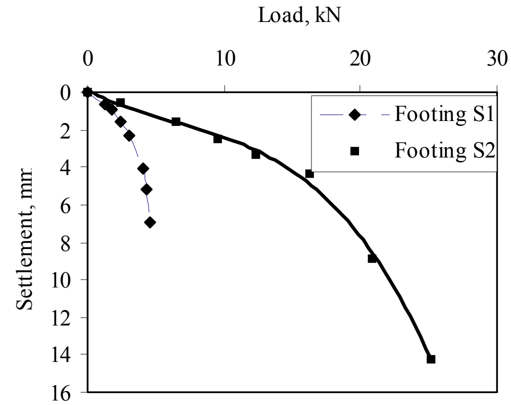

Fig. 2 A. Load - settlement behaviour for square footing

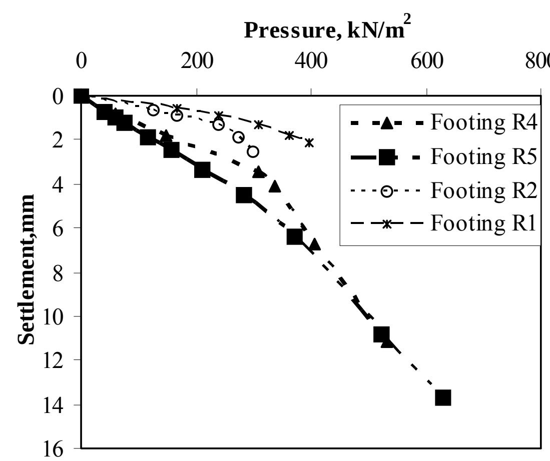

Fig. 3. Pressure Settlement behavior for Rectangular footing

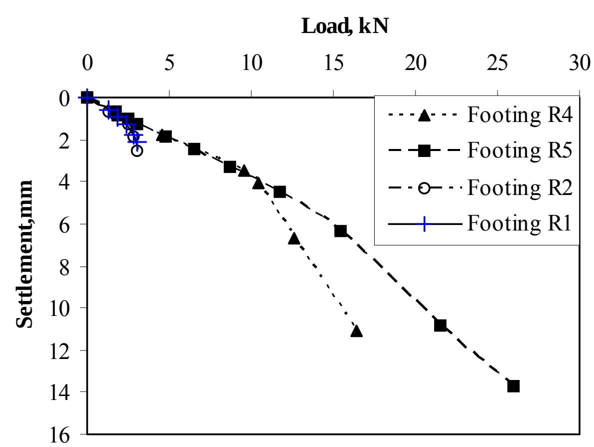

Fig. 3A. Load - Settlement behaviour of Rectangular footing

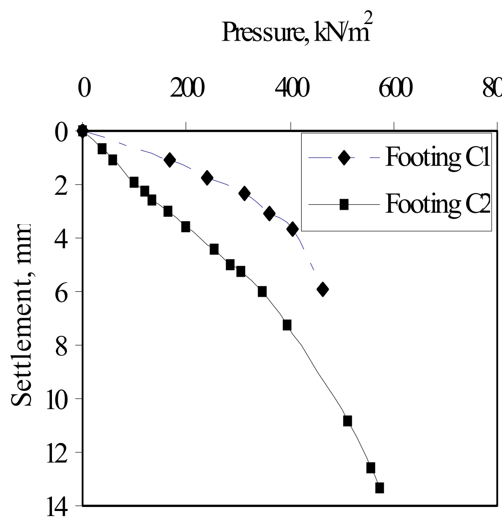

Fig. 4. Pressure - settlement behaviour for Circular footing

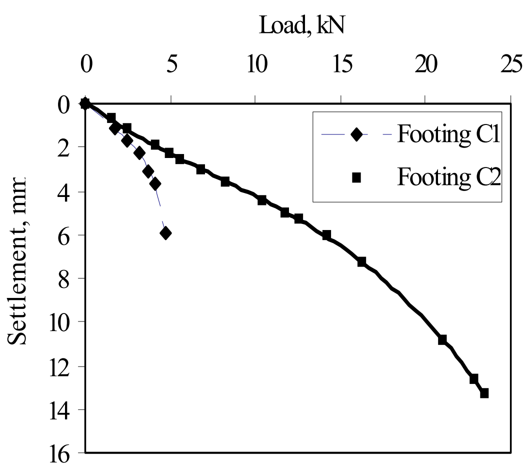

Fig.4 A: Load - settlement behaviour for Circular footing

Table 3.: Ultimate Bearing Capacity (UBC) for footings

Footing No.	Footing Size Mm	L/B Ratio	Measured UBC, kN/m^2	UBC by Vesic's approach, kN/m^2	UBC by Terzaghi's approach, kN/m^2
S1	101.6 x 101.6	1	377.81	308.88	299.98
S2	203.2 x 203.2	1	406.87	331.35	326.24
R1	508 x 152.4	3	271.25	224.13	246.92
R2	50.8 x 203.2	4	244.13	214.94	241.93
R3	101.6 x 203.2	2	324.43	257.49	271.68
R4	101.6 x 304.8	3	321.3	240.36	262.24
R5	101.6 x 406.8	4	319.68	231.79	257.53
C1	114.3 Dia.	-	372.28	311.69	295.87
C2	228.6 Dia.	-	404.81	336.96	318.03

Effect of various parameters on bearing capacity*-

Effect of size on bearing capacity

The size of the footing has an important effect on bearing capacity. For the investigation of the effect of size of footing, a comparison is made between the data which was obtained from two loading tests, one on small area and other on a larger area for square circular and rectangular footing.

Effect of size on square footing. n attempt has been made to compare test results, which are obtained from the load tests on square footing of sizes 101.6 x 101.6 mm (footing S1) and 203.2 mm x 202.3 mm (footing S2). It is observed from the fig. 2 that the settlement under footing S2 is more than that under footing S1, when both are subjected to the same load intensity. The ultimate bearing capacities estimated for footings S1 and S2 are 377.81 kN/m^2 and 406.87 kN/m^2 respectively. It is clear that the ultimate bearing capacity for footing S2 is 7.69 % more than that of footing S1 which is having area one fourth of that of footing S2.Fig.2A shows load settlement behaviour for footings S1 and S2. The ultimate loads estimated are 3.90 kN and 16.80 kN for footing S1 and S2 respectively. The ultimate load for footing S2 is 4.30 times more than that of footing S1

Effect of size on rectangular footing. A comparison is made between the test results which are obtained from model tests on two footings of different sizes keeping L/B ratio same. Fig. 3 shows comparison between footing size of 50.8 mm x 154.8

mm (Footing R1) & 101.6 mm x 304.8 mm (footing R4) and footing size of 50.8 mm x 203.2 mm (footing R2) and 101.6 mm x 406.4 mm (footing R5). It is observed from the fig. 3 that the settlement under footing R4 & R5 is more than that under footing R1 & R2 respectively when both are subjected to same pressure intensity. The ultimate bearing capacities estimated for footings R1 and R4 are 271.25 kN/m^2 and 321.3 kN/m^2 respectively. The ultimate bearing capacities estimated for footings R2 and R5 are 244.13 kN/m^2 and 319.68 kN/m^2 respectively. It is clear that for L/B ratio = 3 if the area of footing is increased by four times, the ultimate bearing capacity of footing increases by 18.45%. Similarly for L/B ratio = 4 if the area of footing is increased by four times, the ultimate bearing capacity of footing increases by 30.94%. Fig.3A shows load settlement behaviour for footings R1 & R4 and R2 & R5. The ultimate loads estimated are 2.10 kN and 9.95 kN for footing R1 and R4 respectively. The ultimate loads estimated are 2.52 kN and 13.20 kN for footing R2 and R5 respectively. It is clear that for L/B ratio = 3 and 4, if the area of footing is increased by four times, the ultimate load on footing increases by 4.73 and 5.24 times respectively.

Effect of size on circular footing. A comparison has been made between test results, which are obtained from the load tests on circular footings of diameter 114.3 mm (footing C1) and 228.6 mm (footing C2). It is observed from the fig. 4 that the settlement under footing C2 is more than that under footing C1, when both subjected to the same load intensity. The ultimate bearing capacities estimated for footings C1 and C2 are 372.28 kN/m^2 and 404.81 kN/m^2 respectively. It is clear that the ultimate bearing capacity for footing C2 is 9.27 % more than that of footing C1 which is having area one fourth of that of footing C2.

The ultimate loads estimated from fig. 4A are 3.82 kN and 16.7 kN for footing C1 and C2 respectively. The ultimate load for footing C2 is 4.37 times more than that of footing C1.

Effect of (L/B) ratio on bearing capacity

In order to investigate the effect of size of the footing on bearing capacity, a comparison is made between the data obtained from the tests on footings 50.8 mm x 152.4 mm (footing R1, L/B = 3) & 50.8 mm x 203.2 mm (footing R2 L/B = 4) and 101.6 mm x 203.2 mm (footing R3 L/B = 2), 101.6 mm x 304.8 mm (footing R4, L/B = 3) & 101.6 mm x 406.4 mm (footing R4, L/B = 4). Figure 3 shows the variation of pressure - settlement curve for different L/ B ratios and footing widths. From Fig. 3, ultimate bearing capacity for footings R1 and R2 are 271.25 kN/ m^2 and 244.13 kN/m^2 respectively. Ultimate bearing capacities estimated from test results are 324.33 kN/ m^2 and 321.3 kN/m^2 and 319.68 kN/m^2 for footings R3, R4 and R5 respectively. It is observed that the settlement under the footing R5 (L/B = 4) is more than that of footing R4 (L/B = 3) and R3 (L/B = 2). It is clear from the results that ultimate bearing capacity values of footings with same width decrease with increase in L/B ratio of footing. For footing R1 and R4 which has same L/B ratio but different sizes ultimate bearing capacities estimated are 271.25 kN/m^2 and 321.3 kN/m^2 respectively Similarly for footings R2 and R5 with same L/B ratio but different areas, ultimate bearing capacities estimated are 244.13 kN/m^2 and 319.68 kN/m^2 respectively Further it is clear that for the same L/B ratio, bearing capacity increases with increase in footing size.

Effect of shape on bearing capacity

For the investigation of the effect of shape of footing a comparison is made between the data which was obtained from loading tests on footings with same area but of different shapes such as square, circular and rectangular.

An attempt has been made to compare test results, which are obtained from the load tests on square footing S1, rectangular footing R2 and circular footing C1. It is observed from the fig. 8. that the ultimate bearing capacities estimated for footings S1, R2 and C1 are 377.81 kN/m^2, 244.13 kN/m^2, and 372.28 kN/m^2 respectively. It is clear that the ultimate bearing capacity for footing S1 is 1.5 % more than that of footing C1and 54.75 % more than that of Footing R2.

The ultimate bearing capacities estimated for footings S2, R5 and C2 are 406.87 kN/m^2, 404.81kN/m^2, and 319.68 kN/m^2 respectively. It is clear that the ultimate bearing capacity for footing S2 is 0.51 % more than that of footing C2 and 27.27 % more than that of footing R5.

Comparison between UBC obtained from model test and that by conventional methods mentioned earlier

An attempt has been made to compare ultimate bearing capacities obtained by model tests with that by Tezaghi's and Vesic's method. For square footings Terzaghi's theory and vesic's method underestimate the ultimate bearing capacity by 19.82 % to 20.60 % with that obtained by Double tangent method respectively. Similarly for rectangular footings the ultimate bearing capacity estimated by Terzaghi's theory show 0.90 % to 19.44 % variation with that obtained by Model test results. For circular footings the ultimate bearing capacity estimated by Terzaghi's theory show 26 % to 27.12 % variation with that obtained by Model test results. This clearly indicates that Terzaghi's theory is always conservative. For rectangular footings the ultimate bearing capacity values estimated by Terzaghi's theory are closer to that by Model load tests.

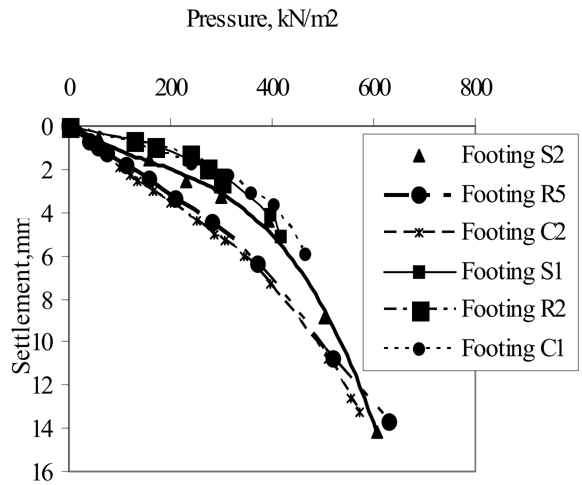

Fig. 5. Effect of Shape on Bearing capacity of footing

CONCLUSIONS

From the load tests on square, circular and rectangular footings in the laboratory model, following conclusions are drawn

- It is observed from Time – settlement relationship of square and rectangular footings of different sizes that settlement rate is high up to 3 min for all load applications. The settlement rate becomes negligible after 16 min for pressure intensities equal to ½ to 1/3rd of ultimate bearing capacity. For corresponding footing load intensity equal to or greater than the ultimate bearing capacity, the settlement becomes negligible after 28 to 30 min of load application.
- Pressure - settlement curve drawn to arithmetical scale for square, circular and rectangular footing is linear in the earlier stage of loading but becomes non linear at later stage of loading. Further no clear point of failure is observed in c-φ soil. It is observed that for pressures greater than ultimate pressure, settlement occurs at increasing rate.
- Footings fail by tilting indicating that rupture surface development is not guaranteed in cohesive soil.
- The size of the footing has an important effect on bearing capacity. The ultimate bearing capacity/load increases with increase in size of the footing. However, this experimental investigation on c-φ soil has indicated that size effects are minimal for square and circular footings whereas they are pronounced in rectangular footings.
- The ultimate bearing capacity values of footings with same width decrease with increase in L/B ratio of footing. For the same L/B ratio, bearing capacity increases with increase in footing size.
- Bearing capacity for square footing is more than that of circular and rectangular footing having same area as that of square footing.
- Both Vesic's and Terzaghi's methods underestimate the bearing capacity of both square as well as rectangular footings.

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