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An Experimental Study of Skew Footings Resting On Cohesionless Soil

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ABSTRACT

Provision of skew footing in the design of foundation of a bridge becomes very essential whenever it crosses to a railway line, canal or river with a skew angle more than 60 degree. For the purpose of design to a skew footing, different parameters are required. In this study, the author had attempted to investigate the behavior of such footings experimentally. In the present study, an effort has been made for the stability and settlement behavior of the skew model footings of width, B = 60 mm, 80 mm and 120 mm each having skew angles of 10^o, 15^o and 25^o resting on bed of Sandy soil. For bridges on straight alignments with support skews exceeding 60 degrees, the designer should select to use a skew footing while designing a bridge foundation to more accurately capture true load distribution on sub-soil base. For the superstructure, it was assumed that support skew does not affect the distribution of loading response across the section with the exception of shear. In a skewed bridge, loads tend to distribute to the supports in a direction normal to the supports.

In the present experimental work, three small model footings tests were conducted on Sandy soil having different sizes of 60 mm, 80 mm and 120 mm. Each skew footing having skew angle of 10^0, 15^0 and 25^0. The ultimate bearing capacity of skew footings has been determined by double tangent method. The settlement aspects have also been analyzed for the prediction of settlement of prototype.

1. INTRODUCTION

Sometimes foundations of bridges, aqueducts and culverts etc. need skew footings. For foundation shapes other than strip footings, analytical solutions of ultimate bearing capacity problem is considerably difficult. Based on some published (Golder, 1941-42, and skempton, 1942) and unpublished test results, Terzaghi (1943) gave semi empirical formulae for ultimate bearing capacity of circular and square footings. De Beer and Vesic (1975) have also suggested shape factor for rectangular, circular and square footings, based on extensive experiments. To the knowledge of the author, neither any analytical or empirical formula for ascertaining the ultimate bearing capacity nor shape factor has so far been given by any one for the skew footings. Experimentally also, no investigation seems to have yet been carried out for studying the behavior of skew footings. The author, therefore, has attempted to investigate the behavior of such footings experimentally. The design of bridges on straight alignments with support skews between 0 and 60 degrees.

For bridges on straight alignments with support skews exceeding 60 degrees, the designer should use a skew footing to more accurately capture true load distribution. For the superstructure, it was assumed that support skew does not affect the distribution of loading response across the section with the exception of shear. In a skewed bridge, loads tend to distribute to the supports in a direction normal to the supports. This causes a greater proportion of the load to concentrate at the obtuse corners of the span and less at the acute Corners. Depending on the contract, the centerlines of construction, structure, and roadway may be the same line or three different lines. For example, a two-lane bridge with no shoulders or with shoulders of equal widths would probably have one line for all three references. In most cases, however, one or more centerlines is different from the other centerlines. Centerlines of bearing are transverse lines that bisect the bridge seats or bearing areas on abutments and piers and intersect the longitudinal centerlines. Generally, if the centerlines of bearing intersect the longitudinal centerlines at an oblique angle (an angle other than a right angle), the bridge is said to be skewed or built on a skew. If the centerlines of bearing intersect the longitudinal centerlines at right angles, there is no skew.

For this study, investigations were carried out by small-scale model footings tests on clay layers, in laboratory. Three sizes of footings, 60 mm, 80 mm and 120 mm, each having skew angles of 10^0, 15^0 and 25^0 were tested. Since the test results of small-scale model tests are quite often looked with suspicion, the dimensional analysis was carried out on the effect of the size, skew angle of the footing and the soil parameters, on the ultimate bearing capacity of skew footings. The soil parameters include the angle of shearing resistance and unit weight of clay layers.

It may be mentioned here that the dimensional analysis helps in providing a simple basis for the possible correlation ship between the results of small-scale model tests and the behaviour of full-scale prototypes. Kondner (1960), had first demonstrated the effectiveness of this technique in the field of soil mechanics. Experimental data has been analysed for shear and settlement criteria. Experimental results have confirmed the findings of the dimensional analysis in so far as the effect of the size is concerned. The observed values have been compared with the theoretical values obtained from „Theoretical Model", based on modification of the bearing capacity formula for square footing, suggested by Terzaghi.

The theoretical and experimental results are found to be in fairly good agreement qualitatively. However, quantitatively, the results are at much variance. This is so, probably because of the conservative values of N_C, N_γ, suggested by Terzaghi. Based on the experimental results, the author has suggested a shape factor for computing the ultimate bearing capacity for skew footings resting on the surface of clay layers. The settlement aspect of the problem has also been analysed and a new approach, incorporating the concept of load intensity and settlement has been suggested, for the prediction of settlement of the prototype, on the basis of small-scale model tests. The value of predicted settlements for skew footings, by proposed method has been found to be much closer to the observed values of settlements.

LITERATURE REVIEW

Dash et al. (2001) conducted a load test for a strip footing on homogeneous dense sand (relative density of 70%) beds, however, indicate that an 8 fold increase in bearing capacity could be achieved with the provision of geocell in the foundation sand. Dash et al.(2001) conducted the model test results on a circular footing supported on a dense sand layer (relative density of 70%) overlying a soft clay bed show about a six-fold increase in bearing capacity with the provision of geocell in the overlying sand layer. The higher performance improvement due to geocell in the sand bed compared with that in the soft clay bed is attributed to the mobilization of higher passive force at the geocell walls and frictional resistance at the geogrid-soil surface.

Mostafa A et al. (2007) tries to investigate the potential benefits of reinforcing a replaced layer of sand constructed on near a slope crest was studied. Model tests were carried out using model footing of 75 mm width and geogrids. Several parameters including the depth of replaced sand layer and the location of footing relative to the slope crest were studied. Particular emphasis is paid on the reinforcement configurations including number of layers, spacing, layer length and depth to ground surface. A series of finite element analyses were performed on a prototype slope using two- dimensional plane strain model using the computer code Plaxis. The soil was represented by non- linear hardening soil model, which is an elasto-plastic hyperbolic stress–strain model while reinforcement was represented by elastic elements. A close agreement between the experimental and numerical results is observed. Test results indicate that the inclusion of geogrid layers in the replaced sand not only significantly improves the footing performance but also leads to great reduction in the depth of reinforced sand layer required to achieve the allowable settlement.

Rethaliya R. P. and Verma A. K. (2009) investigated the foundation on soft clay can be improved by placing a layer of compacted sand or gravel. The results shows that, while placing of sand over the soft clay sub grade leads to an increase in the load carrying capacity and also the reinforcement layer at the sand clay interface has resulted in the additional increase in bearing capacity and decrease in the settlement of the footing. The optimum width of reinforcement for sand layer overlying soft clay was found 5B for strip footing and 3B for rectangular, square and circular footing.

S. M. Nawghare et al. (2010) investigated the bearing capacity of eccentrically loaded footing. Footings of different size and shape are used for testing. Testing for bearing capacity of centrally loaded footing and then for eccentrically loaded footing with different „e/B" ratio is carried out. For every footing bearing capacity and settlement has been found out for central as well as eccentric loading. These results of central and eccentric loading are compared with each other for same footing.

Jignesh N. Lad et al. (2011) investigated the potential benefits of using the reinforced soil foundation to improve the bearing capacity and reduce the settlement of strip footing on sand bed with thin soft lens. It is found that the soft lens below strip footing influence not only the bearing capacity but also the settlement of the footing. It is found that when the soft lens is within a zone of 1.5 times width of footing, the bearing capacity and settlement are affected. After 1.5B, the soft lens has no effect on the performance of strip footing.

Sai K. Vanapalli et al. (2013) studied the influence of three parameters; namely, (i) matric suction, (ii) overburden stress, and (iii) dilation, on the bearing capacity and settlement behaviour of surface and embedded model footings in unsaturated sands. The results show that the bearing capacity and settlement behaviour of unsaturated sands are significantly influenced by all the three parameters. In addition, comparisons are provided between the predicted and measured bearing capacity and estimated and measured settlement values using the proposed modified Terzaghi‟s equation and modified Schmertmann‟s CPT-based method, respectively. There is a good comparison between the predicted/estimated and measured bearing capacity and settlement values for the laboratory and field tests using the proposed modified methods.

Ravi Gupta et al. (2014) presented the results of laboratory model tests on the influence of three dimensional confinement of dense sand on the behaviour of a model circular footing resting on dense sand (Relative Density 70%). To confine the soil three dimensionally, skirts of different height and diameter with a layer of geogrid below it used. The load bearing capacity of a circular footing supported on a three-dimensional confined sand bed was studied. The studied parameters include the confinement height and confinement diameter. Initially, the response of an unconfined case was determined and then compared with that of confined soil. The results were then analysed to study the effect of each parameter. The results indicate that the bearing capacity of circular footing can be appreciably increased by soil confinement. It was concluded that such type of confinement (skirt with geogrid) restricts the lateral and longitudinal displacement of sand leading to a significant improvement in the response of the footing. For small confinement diameters, the three dimensional Confinement–sand-footing system behaves as one unit (deep foundation), while this pattern of behaviour was no longer observed with large cell diameters.
Hemantkumar Ronad (2014) tries to investigate the bearing capacity of the square study the bearing capacity of square footing on sand reinforced bed. The effect of different parameter like the depth of the upper most layer of reinforcement from the base of the model footing (u), for different densities of the sand (γ = 1.55, 1.65, and 1.75 gm/cc) the test has been carried out. The test results showed that the beneficial use of geo-grid reinforcement in terms of increasing in the bearing capacity and minimizing the settlement, at an optimum depth of reinforcement, however for the higher density of the soil gives maximum bearing capacity. Therefore, for effective utilization of geo-grid reinforcement, the optimum depth should be (u= 0.33B) which is found to be good agreement with the past researchers, and the foundation soil should be in higher density.

MATERIAL AND METHOD

Properties of soil

Liquid limit, W_L = 32 %, Plastic limit, W_P = 22 %, Plasticity index, I_P = 10 %, natural moisture content w = 3.5 %, type of soil = CL, maximum dry density = 18.8 kN/m^3, optimum moisture content = 17.6 % and bulk density = 21.9 kN/m^3.

Methodology

The optimum moisture content (OMC) and maximum dry density (MDD) of clayey soil was determined by standard Proctor's compaction tests (Fig. 2). The tests on the soil have been carried out in the experimental tank of dimensions 500 mm x 500 mm x 750 mm and was made up with 25mm thick sita-ply and 12.5 mm aluminum angles. Aluminum stiffeners were provided at all vertical sides of the tank to avoid bulging of walls.

Oven dried clayey soil was mixed at OMC and deposited in three equal layers in experimental tank. Each layer was tamped by a circular hammer of diameter 50mm and weight of 4.5 kg having a free fall of 300mm and required maximum dry density (18.8 kN/ m^3) was achieved in four trials as given in the following table.

No. of Blows	30	60	90	120
MDD (kN/m^3)	14.1	16.5	18.8	20.4

Three sizes of skew footing of 60 mm, 80 mm and 120 mm having skew angles of 10^0, 15^0 and 25^0 are taken for present experimental study. Each footing was kept at the center of the bed of compacted clayey soil to avoid the wall effect on pressure bulb. The whole assembly was placed under loading machine and the point load was applied axially through a wall which rested in the groove on the footing. Two dial gauges of 0.01mm sensitivity were used to measure settlement of footing placed diagonally to each other and the corresponding loads were recorded from the proving ring as shown in Table 2.

DIMENSIONAL ANALYSIS

According to Buckingham π-theorem, the independent dimensions parameters π-terms are the arrangement of semi homogeneous function F.

$$F = (\pi_1, \pi_2, \pi_3, \pi_4 \ldots\ldots\ldots\ldots\ldots\ \pi_{n-m}) = 0 \qquad (1)$$

n = variables (physical quantities), m = fundamental units

n-m = independent dimensionless parameters (π-terms)

There are 8 physical quantities, 2 fundamental units and 6 independent non dimensional parameter as shown in Table 1.

Table1: Physical quantities and dimensionless parameters		
Physical Quantities	Symbol	Dimensional Formula
Ultimate load	Q_f	F
Size of footing	B	L
Area of footing	A	L^2
Angle of skew	α	$F^0L^0T^0$
Moisture content	ω	$F^0L^0T^0$
Unit cohesion	C	FL^{-2}
Unit weight	γ	FL^{-3}
Time	T	T

In the present study, the functional relationship between the physical quantities given as

$$\frac{Q_f}{CB^2} = F\left(\frac{A}{B^2}, \alpha, \gamma, C, \omega\right) \qquad (2)$$

For skew footing of size ‘B’ and skew angle ‘α’.

$$\frac{Q_f}{CB^2} = F\left(\frac{B^2 \cos\alpha}{B^2}, \alpha, \gamma, C, \omega\right) \quad (3)$$

γ, C and ω can regarded as constant for all tests conducted under same conditions

$$\frac{Q_f}{CB^2} = F(\cos\alpha, \alpha) = F(\alpha) \quad (4)$$

ANALYTICAL METHOD FOR ULTIMATE BEARING CAPACITY

Terzaghi has been suggested the following formula for ultimate bearing capacity for square footing

$$q_f = CN_c + \gamma DN_q + 0.4\gamma BN_\gamma \quad (5)$$

In the present study, the soil is cohesive having $Ø = 12^0 \approx 0^0$ and the footings are resting on the surface of soil therefore D = 0 and the equation (5) reduces to

$$\frac{Q_f}{A} = \frac{2}{3} CN_c \quad (6)$$

For skew footing of size B and angle α,

$$\frac{Q_f}{B^2 \cos\alpha} = \frac{2}{3} CN_c \quad (7)$$

$$\frac{Q_f}{CB^2} = \frac{2}{3} N_c \cos\alpha \quad (8)$$

This is in dimensionless form

Empirical equation for shape factor

$$S_r = 1.36\left[1 - 6.125 \times 10^{-5}\left(\alpha^2 - 35\alpha\right)\right] \quad (9)$$

Equation for non dimensional parameter

$$\frac{Q_f}{CB^2} = 7.23\left[1 - 9.22 \times 10^{-5}\left(\alpha^2 - 34\alpha\right)\right] \quad (10)$$

RESULT AND DISCUSSION

The liquid limit of the clayey soil was determined by Casagrande liquid limit apparatus was found as 32% and plastic limit as 22%. The value of shear strength parameter was obtained by using Triaxial Shear Strength Test. The values of angle of shearing resistance and cohesion were found as 12^o and 45 kN/m^2. The specific gravity of soil was obtained by density bottle as 2.71 at 27^oC. The optimum moisture content (OMC) and maximum dry density (MDD) were obtained by Standard Proctor Compaction Test. The values of OMC and MDD were obtained as 17.6 % and 18.8 kN/m^3 respectively as shown in Fig. 2.

The value of the settlement and bearing capacity increases with the increase of skew angle for the same intensity of load and the same size of footing, Figs. 4, 5 and 6.

It was also observed that the value of settlement increases with the increase of skew angle $\alpha = 10^0$ to 25^0 but decreases with the increase of size of footing B = 60 mm to 80 mm.

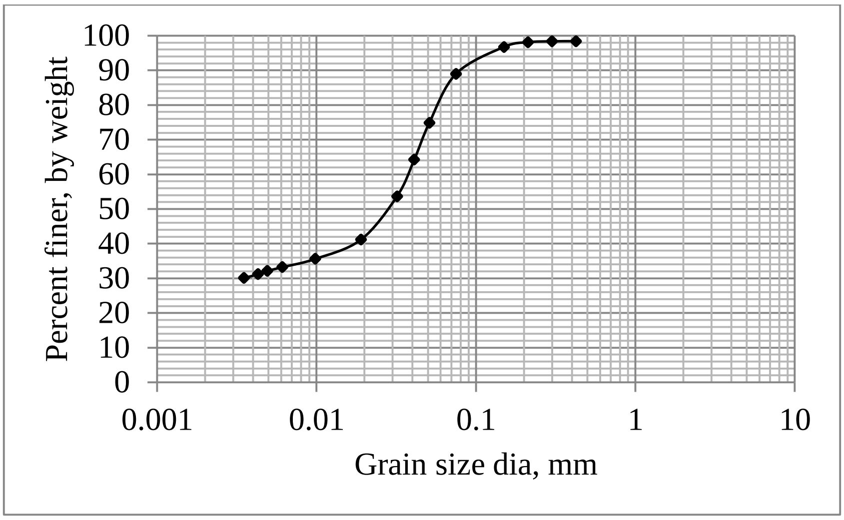

Fig. 1: Particle Size Distribution Curve for Clayey Soil

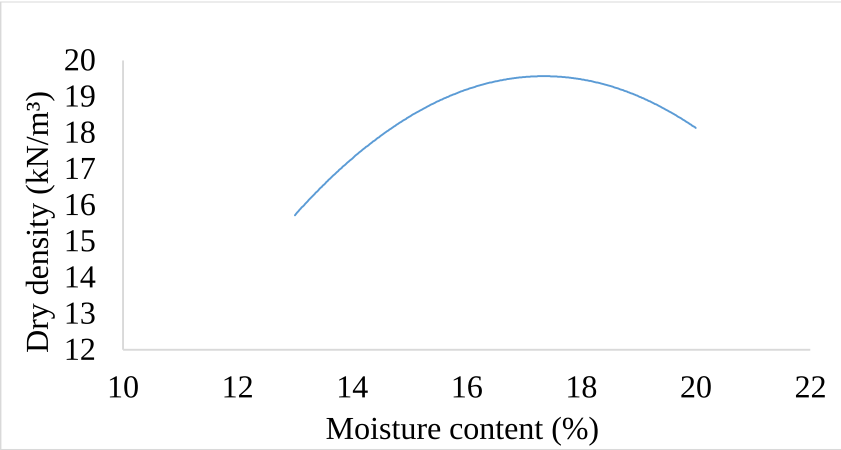

Fig. 2: Compaction Curve for Clayey Soil

Table:2 Load (P) and Settlement (S) Values of Skew Footings with different Skew Angle (α)

Load P (N)	Width of Footing = 60 mm			Width of Footing = 80 mm			Width of Footing = 120 mm		
	α = 10°	α = 15°	α = 25°	α = 10°	α = 15°	α = 25°	α = 10°	α = 15°	α = 25°
	S (mm)	S (mm)	S (mm)	S (mm)	S (mm)	S (mm)	S (mm)	S (mm)	S (mm)
0	0	0	0	0	0	0	0	0	0
300	0.29	0.51	0.3	0.35	0.21	0.29	0.18	0.2	0.18
600	0.71	0.96	0.7	0.85	0.5	0.7	0.49	0.47	0.45
900	1.2	1.52	1.19	1.1	0.96	1.1	0.75	0.73	0.71
1200	1.87	2.3	1.68	1.6	1.24	1.5	1.09	1.01	0.9
1500	2.3	2.98	2.2	2.2	1.49	1.96	1.3	1.28	1.2
1800	2.84	3.78	2.8	2.89	1.82	2.36	1.58	1.6	1.49
2100	3.2	4.2	3.29	3.4	2.09	2.82	2.1	1.93	1.8
2400	3.87	4.91	3.88	3.99	2.38	3.44	2.32	2.18	2.2

2700	4.42	5.7	4.4	4.44	2.61	3.98	2.71	2.45	2.49
3000	5.41	6.19	4.99	4.89	2.99	4.55	2.91	2.75	2.76
3300	-	6.95	5.79	5.34	3.29	5.2	3.24	3.02	2.96
3600	-	7.9	6.5	5.9	3.62	5.8	3.45	3.34	3.29
3900	-	-	7.5	6.3	3.99	6.5	3.69	3.6	3.61
4200	-	-	8.5	6.89	4.72	7.49	4.08	3.92	3.91
4500	-	-	-	7.39	5.36	-	4.4	4.28	4.19
4800	-	-	-	-	6	-	4.75	4.63	4.45
5100	-	-	-	-	6.66	-	5.1	4.77	4.81
5400	-	-	-	-	-	-	5.36	5	5.13
5700	-	-	-	-	-	-	5.7	5.3	5.4
6000	-	-	-	-	-	-	6.1	5.6	5.7
6300	-	-	-	-	-	-	6.58	5.96	5.97
6600	-	-	-	-	-	-	7	6.3	6.33

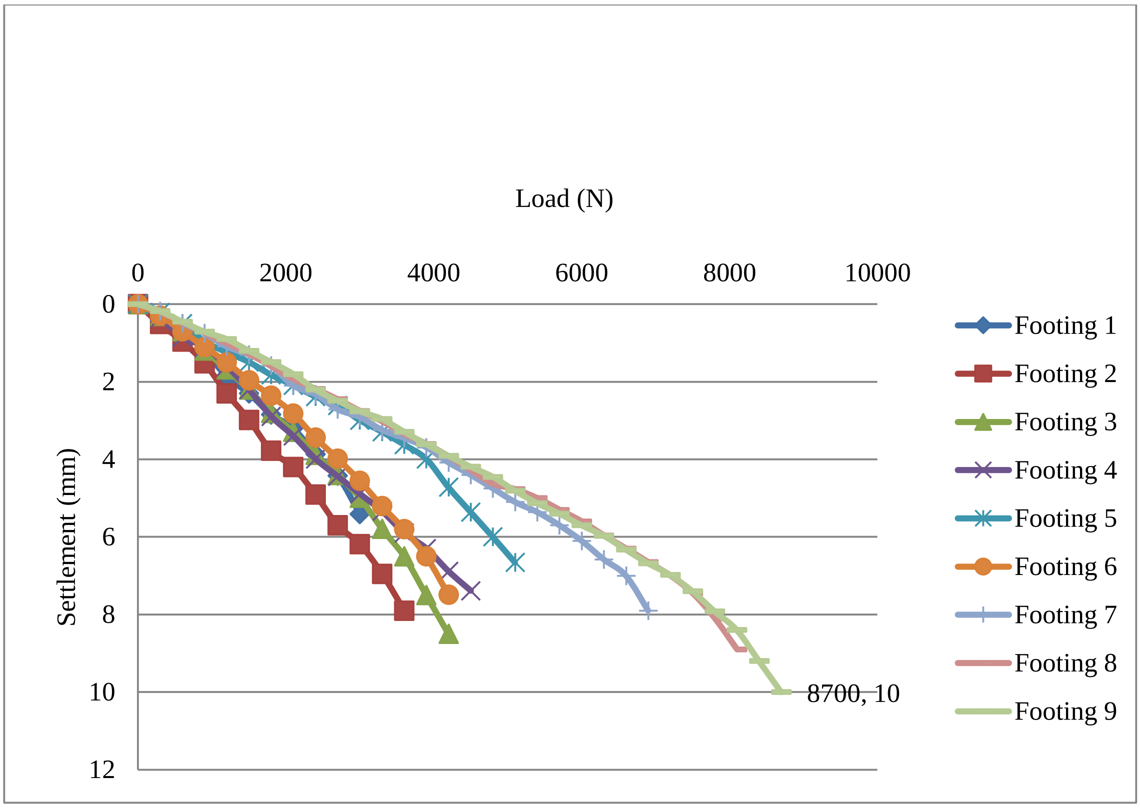

Fig. 3: Load v/s settlement curves of different size of skew footings resting on bed of clayey soil

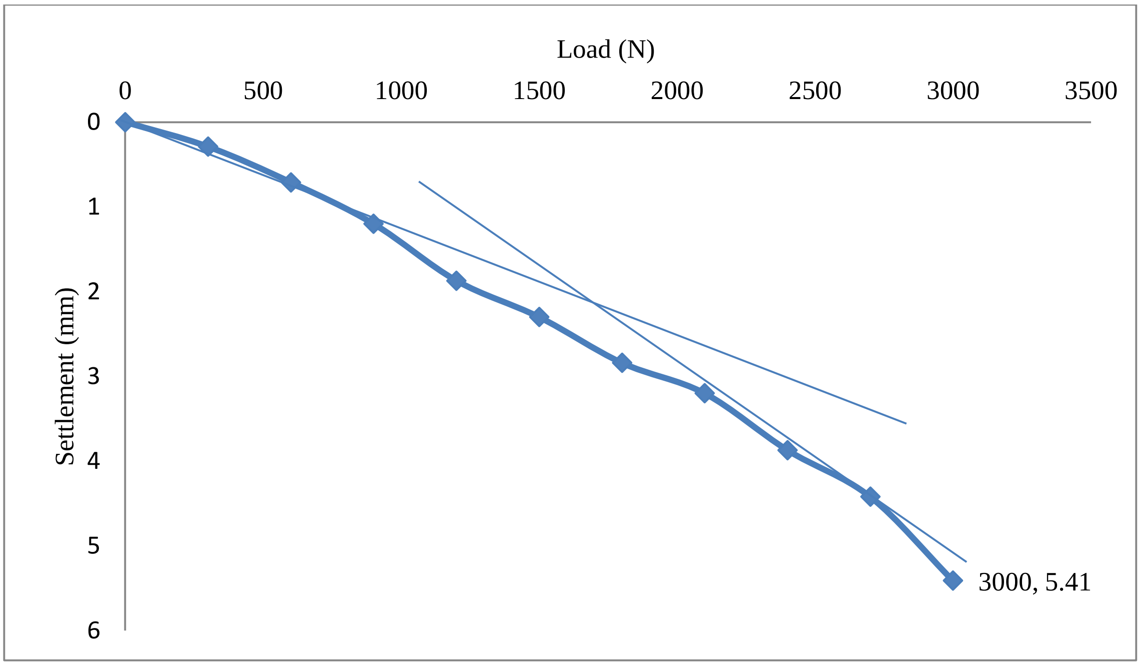

Fig. 4: Load v/s settlement curve of footing No: 1 (B = 60 mm, Skew Angle = 10 Degree

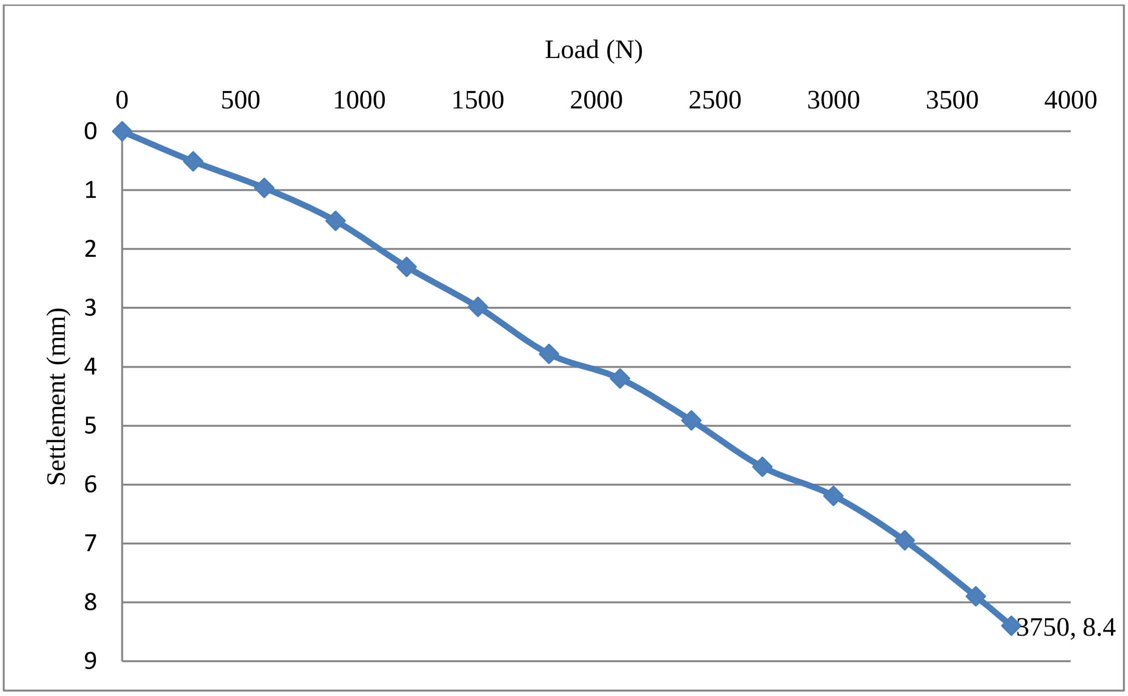

Fig. 5: Load v/s settlement curve of footing No: 2 (B = 60 mm, Skew Angle = 15 Degree)

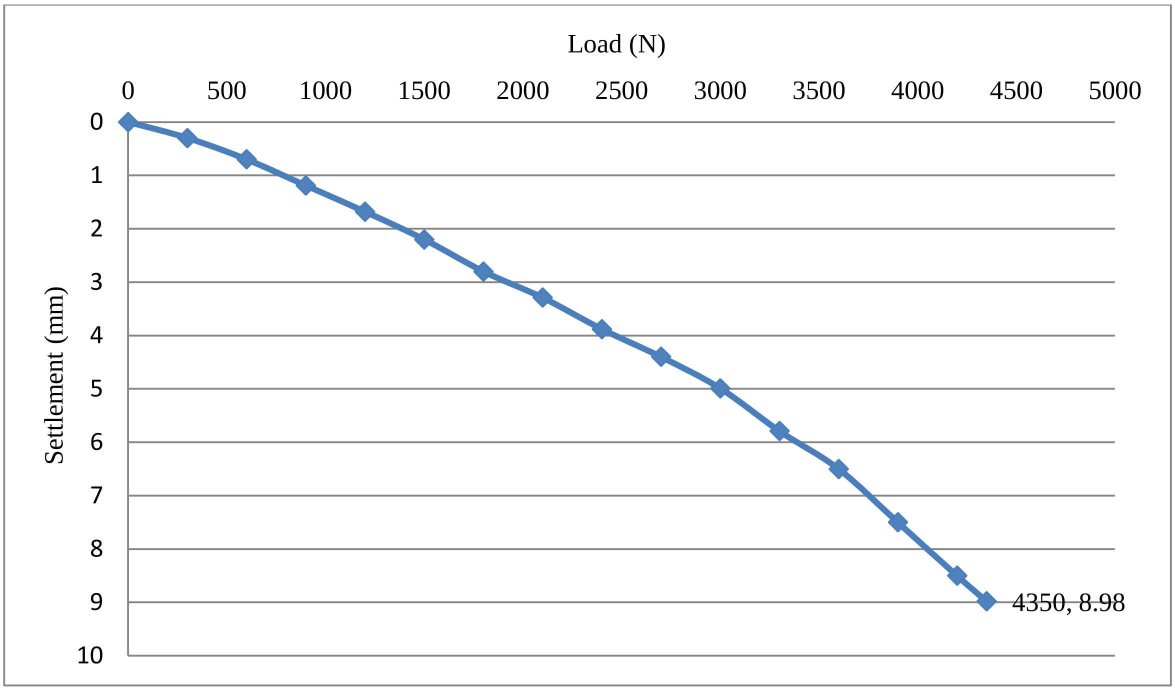

Fig. 6: Load v/s settlement curve of footing No: 3 (B = 60 mm, Skew angle = 25 Degree)

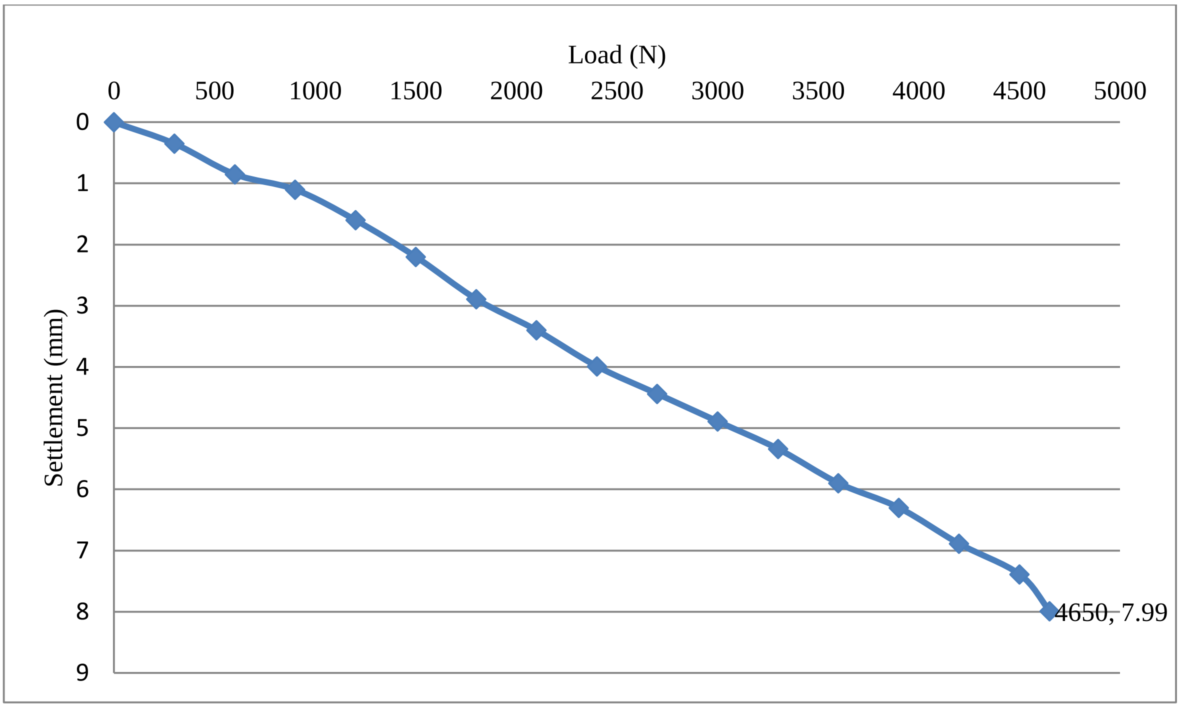

Fig. 7: Load v/s settlement curve of footing No: 4 (B = 80 mm, Skew Angle 10 Degree)

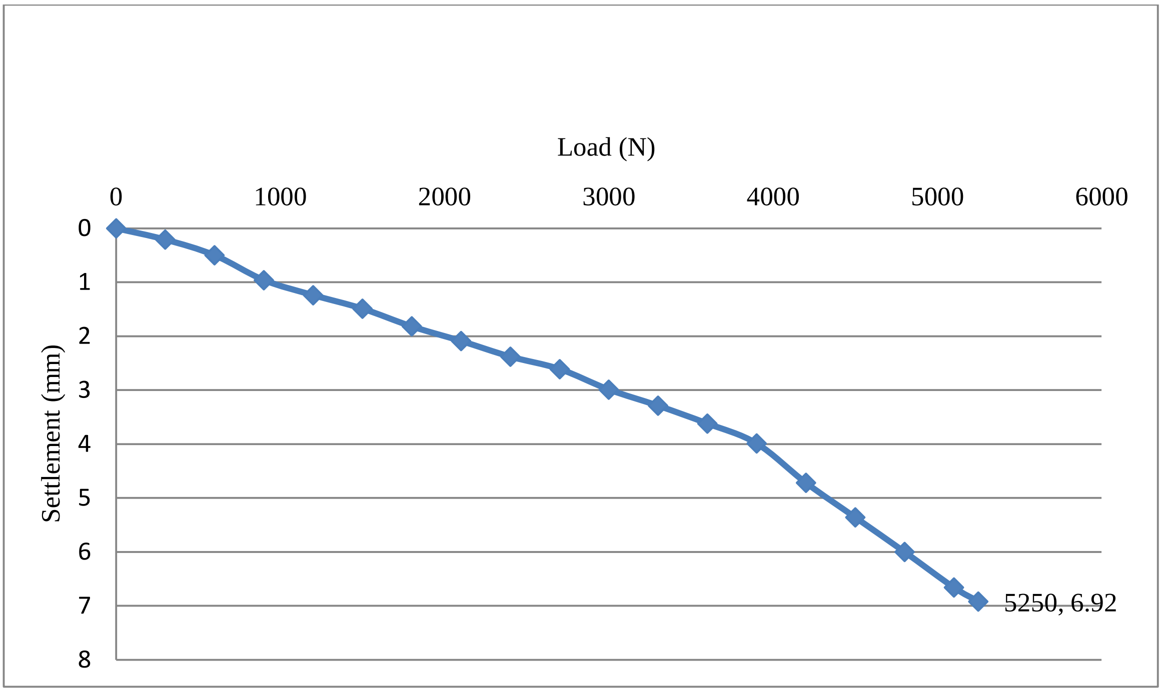

Fig. 8: Load v/s Settlement of footing No: 5 (B = 80 mm, Skew Angle = 15 Degree)

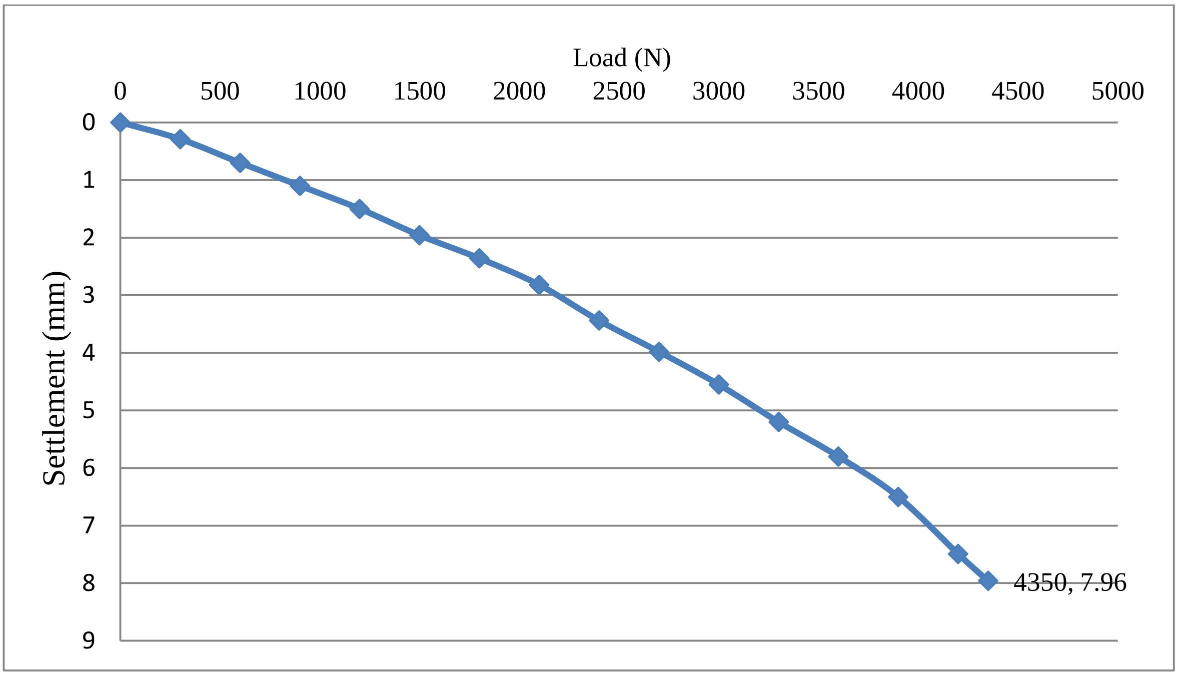

Fig. 9: Load v/s settlement curve of footing No: 6 (B = 80 mm, Skew Angle = 25 Degree)

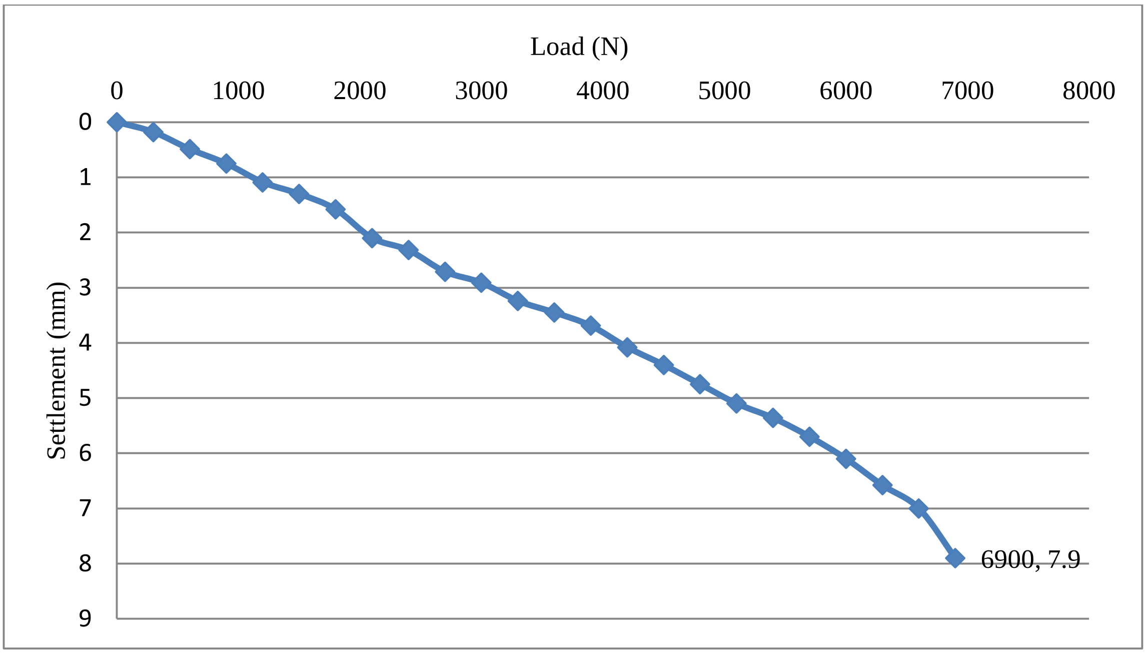

Fig. 10: Load v/s settlement curve of footing No: 7 (B = 120 mm, Skew Angle = 10 Degree)

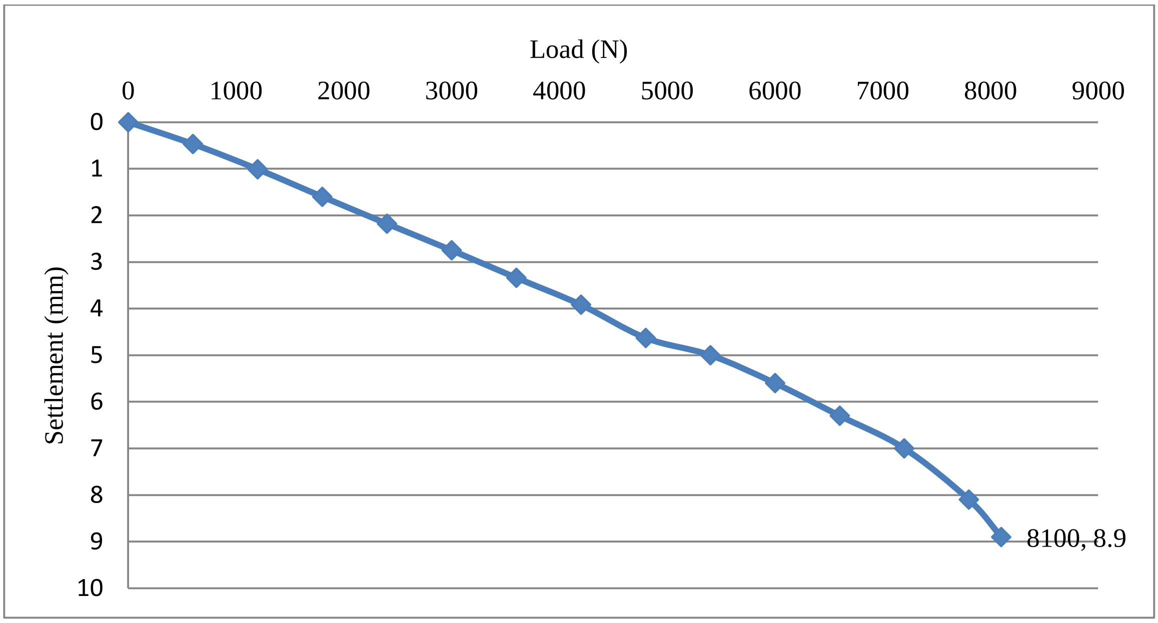

Fig. 11: Load v/s settlement curve of footing No: 8 (B = 120 mm, Skew Angle 15 Degree)

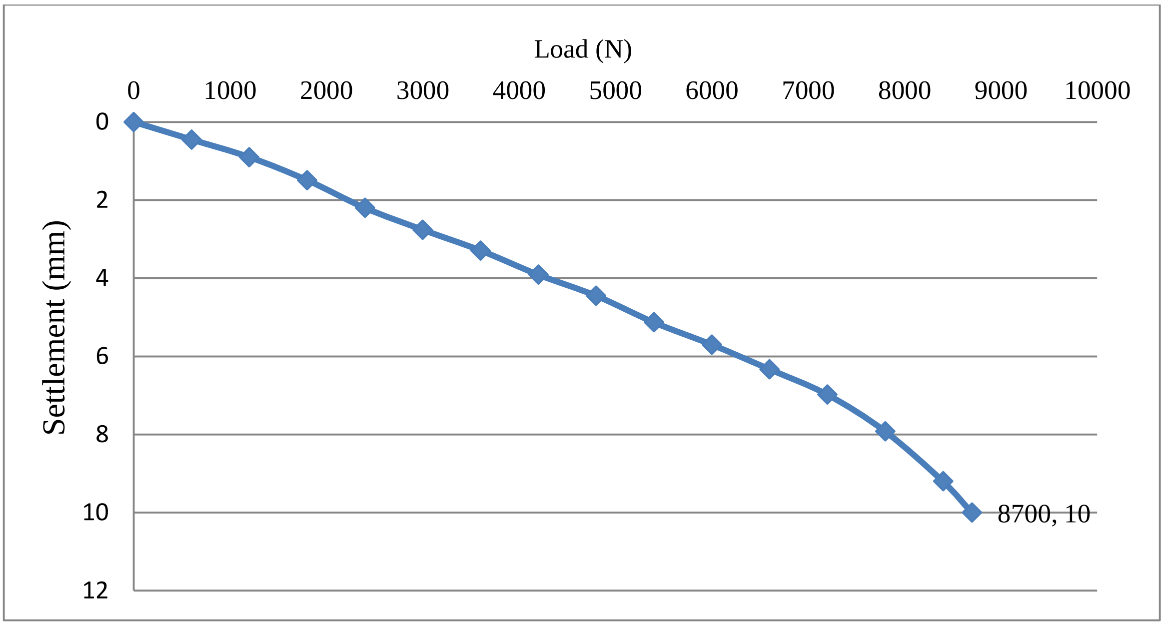

Fig. 12: Load v/s settlement curve of footing No: 9 (B = 120 mm, Skew Angle 25 Degree)

Table 3: Ultimate Bearing Capacity of Skew Footings resting on Bed of Clayey Soil						
Width of Footing (B)	Skew Angle	Area	Major Diagonal	Minor Diagonal	Ultimate Load	Ultimate B. C. of Soil
	(α)	cm²	cm	cm	(N)	kN/m²
B = 60 mm	10°	32.5	10	6.5	1700	523.08
B = 60 mm	15°	35.5	9.6	7.4	2500	704.23
B = 60 mm	25°	36.7	9.4	7.8	2900	790.19
B = 80 mm	10°	58.5	13.6	8.6	3800	649.57
B = 80 mm	15°	62.9	12.7	9.9	3300	524.64
B = 80 mm	25°	65.7	12.4	10.6	3000	456.62
B = 120 mm	10°	119.7	19	12.6	5800	484.54
B = 120 mm	15°	139	19.3	14.4	6800	489.21
B = 120 mm	25°	143.4	18.5	15.5	6200	432.36

Conclusion:

- For the same soil and same size of skew footing, skew angle plays dominating role for the increase of soil resistance and bearing capacity with the decrease of skew angle.
- For skew footing as for as the area is concern with the increase in skew angle, the area of the footing decreases and therefore the settlement increases.
- The soil develops the shear failure due to reduction in area. On increasing the skew angle of footing, the ultimate bearing capacity increases.
- It has also been proved theoretically that in case of clay there is no effect of width of footing on the bearing capacity of soil.

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