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Technical Note

Model Tests on Ring Footings on Reinforced Sand

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Introduction

Ring foundations are usually provided for tall circular structures like smoke stacks, cement silos, water towers, etc. These foundations generally are subjected to vertical loads due to the superstructure and the horizontal loads due to wind pressures acting on the structure.

Ring foundations have not attracted much attention of research investigators. In the past, attempts to develop analytical solution for estimating settlements, using elastic theory (Egorov, 1965; Brodocheva, 1968) and finite element technique (Milovic, 1973; Bowles, 1975), have been made. However, these studies pertain to foundations under axial vertical loads only. Experimental studies under both axial and eccentric vertical loads have also been reported (Saha, 1978; Haroon, 1980; Chaturvedi, 1982; Kakroo, 1985). Dimensional analysis approach has generally been adopted to analyse the experimental results (Kakroo, 1985). Attempts to measure contact pressure distribution below the base of ring footings have also been made by conducting model tests on instrumented foundations (Kakroo, 1985). However, there is no study reported in the literature where studies on ring footings subjected to a combination of axi-symmetrical vertical and lateral loading have been carried out. This is the problem of great practical relevance, because the tall structures for which such foundations are provided, are also subjected to large lateral load due to wind. Thus, in addition to the vertical load, the base of these foundations is subjected to large moment and horizontal load. In other words, the ring foundations are in general subjected to eccentric-inclined load.

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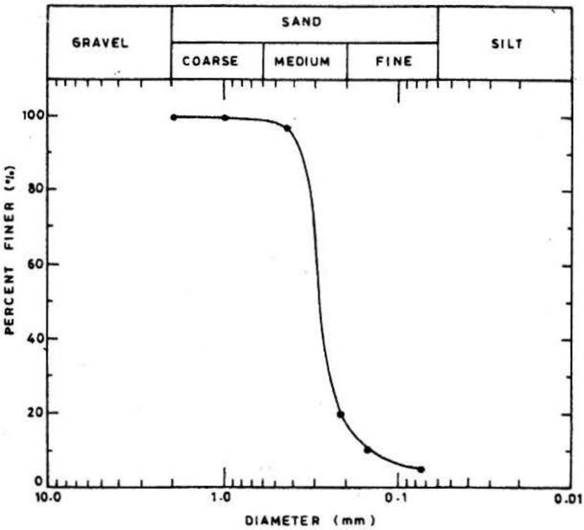


FIGURE 1 : Grain Size Distribution Curve for Amanatgarh Sand

In this note, results and conclusions derived from a number of carefully conducted tests on model ring footings subjected to eccentric-inclined load and resting on unreinforced and reinforced sand have been reported.

Model Tests

The tests were performed on dry Amanat Garh sand (Fig.1) at relative density of 70%. Amanatgarh Sand (D_{10} = 0.15, C_u = 2.0, C_c = 1.39, G_s = 2.66) has angle of shearing resistance and unit weight as 38° and 16.2 kN/m^3, respectively, at relative density of 70%.

Tensar SS 20 Geogrid (Fig.2) was used to reinforce the sand throughout

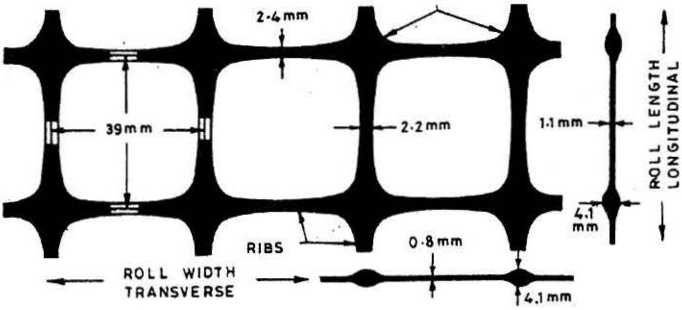


FIGURE 2 : Typical Dimensions of TENSAR SS20 Geogrid

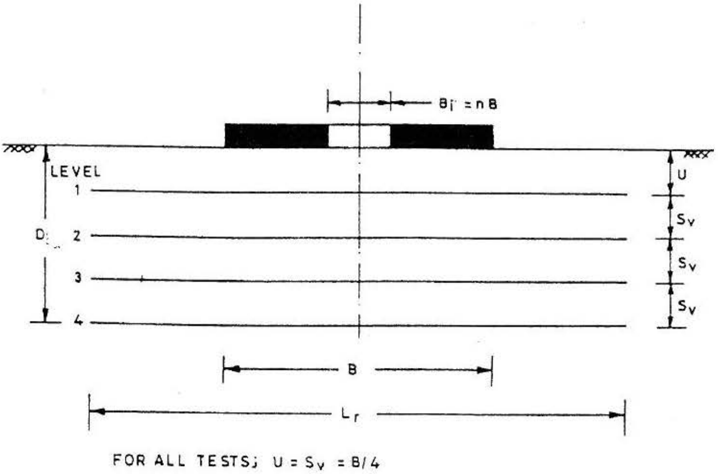


FIGURE 3 : Diagram Showing a Footing on Reinforced Soil

the test program. The tie-soil interface friction angle (ϕ_f) and breaking strength were found as 22° and 17.5 kN/m respectively.

A typical layout of reinforcement placement in sand with footing resting on it is shown in Fig.3.

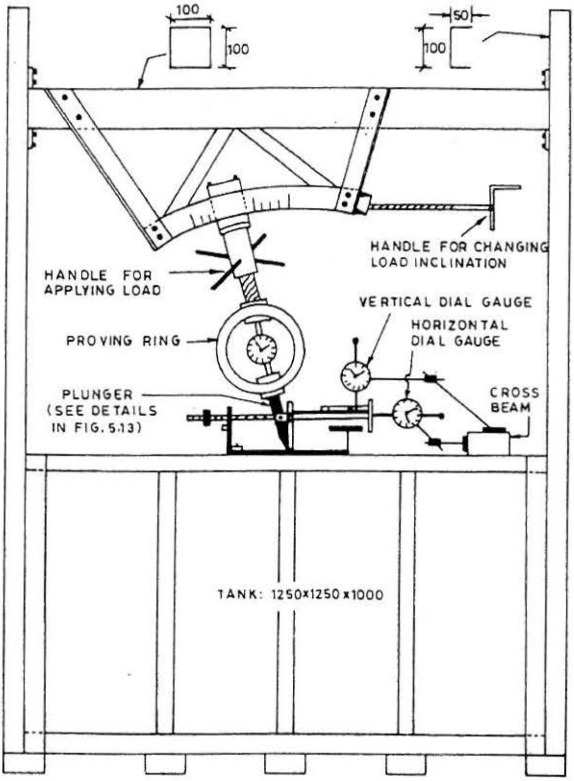
Model ring footings of external diameter (B) equal to 200 mm with different annular ratios (n = internal diameter/external diameter, Fig.3) were used for testing. The bottom sides of the footings were knurled, in order to simulate the roughness of actual foundations.

The tests were conducted in a tank of size 1250 mm × 1250 mm × 1000 mm deep. It was build of wood, and angle iron stiffeners were provided at bottom, top and at all corners for added strength.

The eccentric-inclined loads were applied by specially designed and fabricated device (Murty, 1967). The set-up arrangement for model tests is shown in Fig.4.

In all 98 tests were performed. The amount of eccentricity is expressed in terms of e/B ratio. Through these tests, effect of n, α, e/B, N and L_r/B ratio were studied on the response of ring footings subjected to eccentric-inclined loads. Values of these parameters for which tests were performed are given below:

Annular ratio, n = 0, 0.4, 0.6



— ALL DIMENSIONS ARE IN mm,(NOT TO SCALE)

FIGURE 4 : Setup Arrangement for Model Tests

Load inclination, α = 0°, 10°, 20°
e/B ratio = 0, 0.1, 0.2
Number of reinforcing layers, N = 2, 3, 4
Size of reinforcement (L_r/B ratio) = 2, 3

Following observations were taken during every test

Load : The load on the footing was applied by means of screw jack and recorded through a proving ring (Fig.4). Loads were applied in increments, and the next increment was applied when the settlement becomes sensibly constant (change in settlement was less than 0.2 mm in 10 minutes).

Vertical Settlement (S_e) and Horizontal Displacement (H_D) : Vertical settlement and horizontal displacement of the point of load application were measured through a specially designed devices (Figs.5 and 6). This device consists of

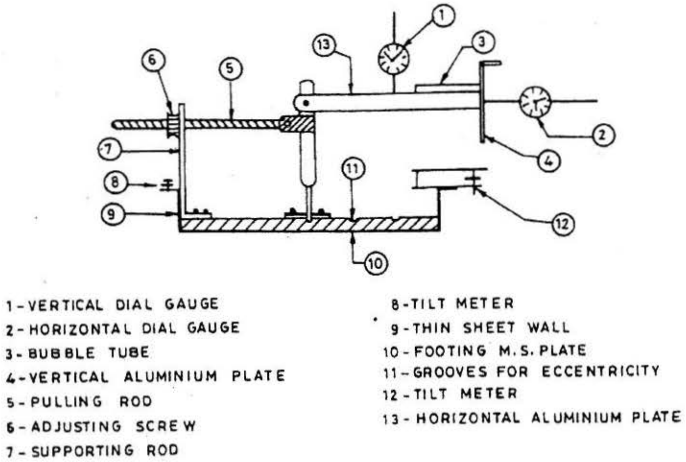


FIGURE 5 : Device for Measuring Vertical Settlement and Horizontal Displacement of Footing

mild steel base plate (50 mm × 25 mm × 12.5 mm) having a socket of diameter 3 mm on one end of the base plate. A vertical mild steel rod of diameter 12.5 mm and length 150 mm, with one end fabricated in the form of a ball whose diameter was slightly less than 3 mm, so that it just fitted into the socket. On the other end of the vertical rod, an aluminium plate measuring 150 mm × 30 mm × 5 mm was fixed at right angle with screws. A bubble tube of sensitivity 20 seconds was fixed on the top side of the aluminium plate. Another aluminium plate of size 60 mm × 30 mm × 5 mm was fixed at right angle to the far end of the horizontal aluminium plate. A horizontal rod (pulling rod) was attached to the vertical rod, on the opposite side of the aluminium plate. The other end of the pulling rod had a thread in which screw was fitted. The pulling rod passed through a slot cut in plate which was fixed to the footing. Grooves were made in the footing in line parallel to the grooves made for applying loads at different eccentricity ratios.

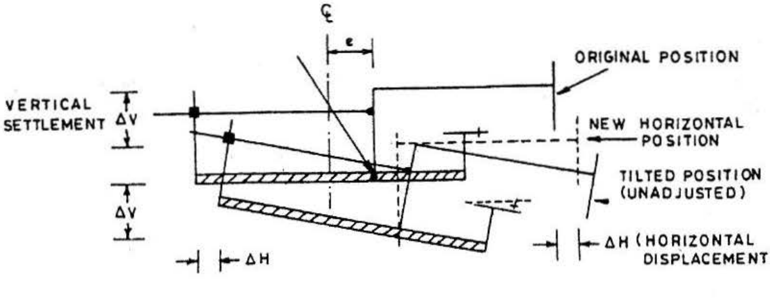


FIGURE 6 : Diagram Showing Mechanism of Measuring Vertical Settlement and Horizontal Displacement of Footing

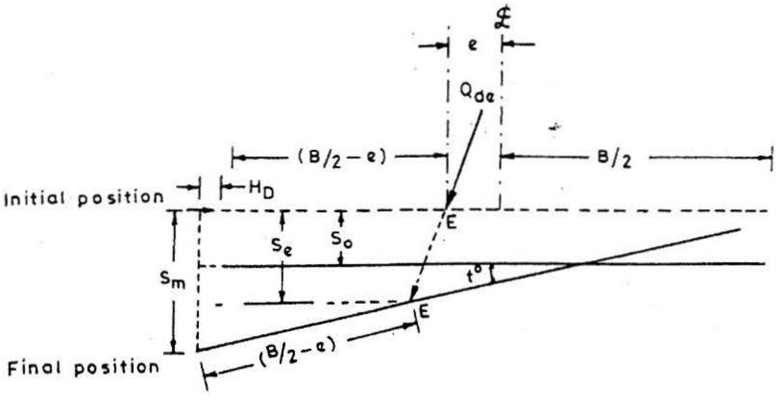


FIGURE 7 : Settlement and Tilt of a Eccentrically-Obliquely Loaded Footing

The base plate was tightened to the footing by screws, after ensuring that the ball of the vertical rod was seated in the desired groove. Backward or forward movement of the assembly was achieved by loosening or tightening of the screw of the pulling rod. Side movement of the assembly was restricted by means of slots. Vertical settlement and horizontal displacement were measured by using sensitive dial gauges of least count 0.005 mm. A dial gauge was mounted on the horizontal plate for measuring the vertical settlement, while the other was placed on the vertical plate for measuring the horizontal displacement.

Tilt : Specially designed tiltmeters were used to measure the tilts of the footing. Each tiltmeter was provided with a micrometer screw, with which tilts upto an accuracy of 10 seconds could be achieved. Two tiltmeters were mounted on each footing. One tiltmeter was fixed along a line parallel to the central axis containing grooves for applying loads, to measure the tilt of the footing, whereas, the other tiltmeter was fixed on a line perpendicular to the line of the load application to check lateral tilt of the footing, as shown in Figs.5 and 6.

The maximum settlement (S_m) of the footing as shown in Fig.7 can be obtained from the following equation:

$$S_m = S_e + \left[\left(\frac{B}{2}\right) - e\right] \sin t \qquad (1)$$

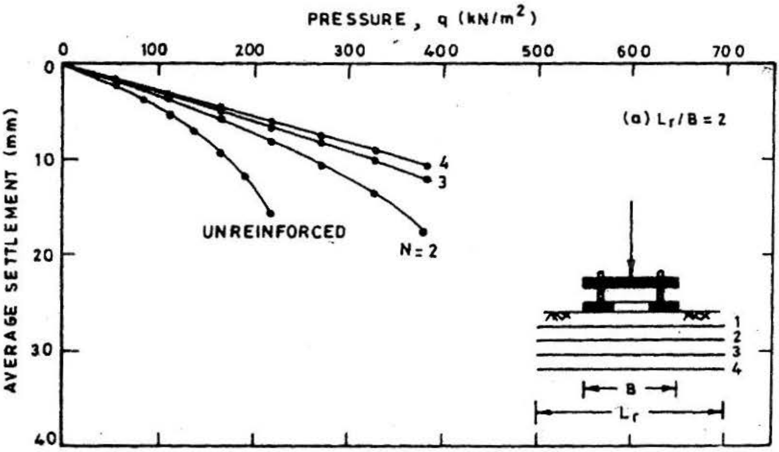
where S_e = Settlement of the point of load application

B = External diameter of footing

t = Tilt of footing

e = Eccentricity of applied load

Finally for each test, pressure (load/footing base area) versus settlement (S_e), pressure versus tilt (t), and pressure versus horizontal displacement curves were drawn. Typical curves so obtained are shown in Figs.8 to 13. Similar other curves for all the 98 tests are given elsewhere (Al-Smadi, 1998).



n = 0·4

α = 0°

e/B = 0.0

B = 200 mm

R_D = 70 %

u = S_v = 0·25 B

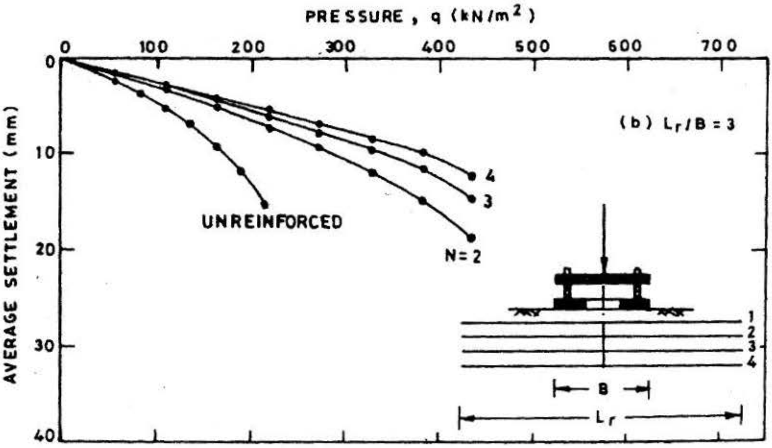


FIGURE 8 : Pressure Versus Vertical Settlement Curves for Ring Footing on Sand Reinforced with TENSAR SS20 Geogrid

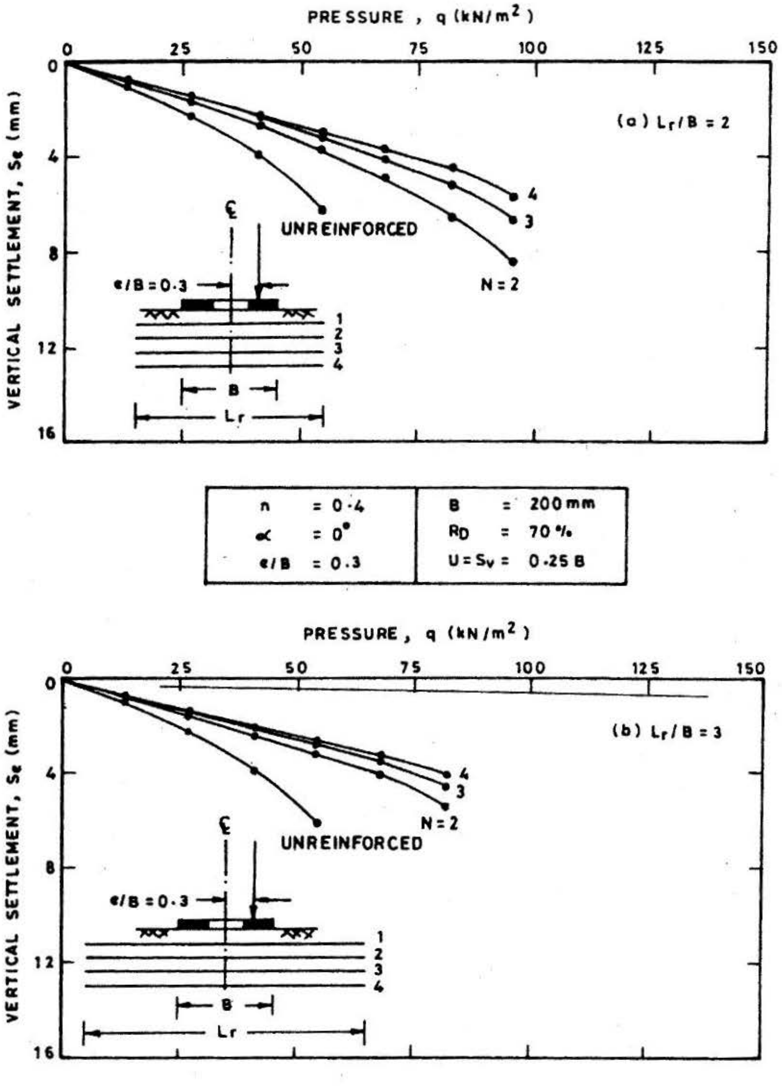


FIGURE 9 : Pressure Versus Vertical Settlement Curves for Ring Footing on Sand Reinforced with TENSAR SS20 Geogrid

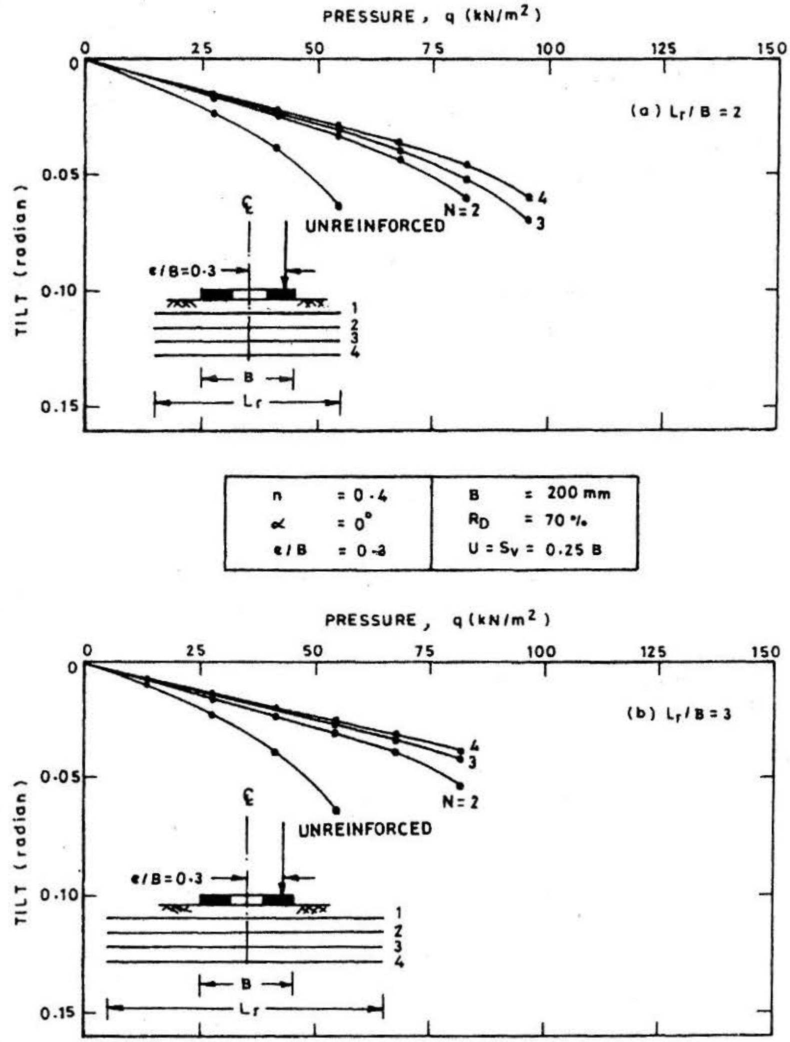


FIGURE 10 : Pressure Versus Tilt Curves for Ring Footing on Sand Reinforced with TENSAR SS20 Geogrid

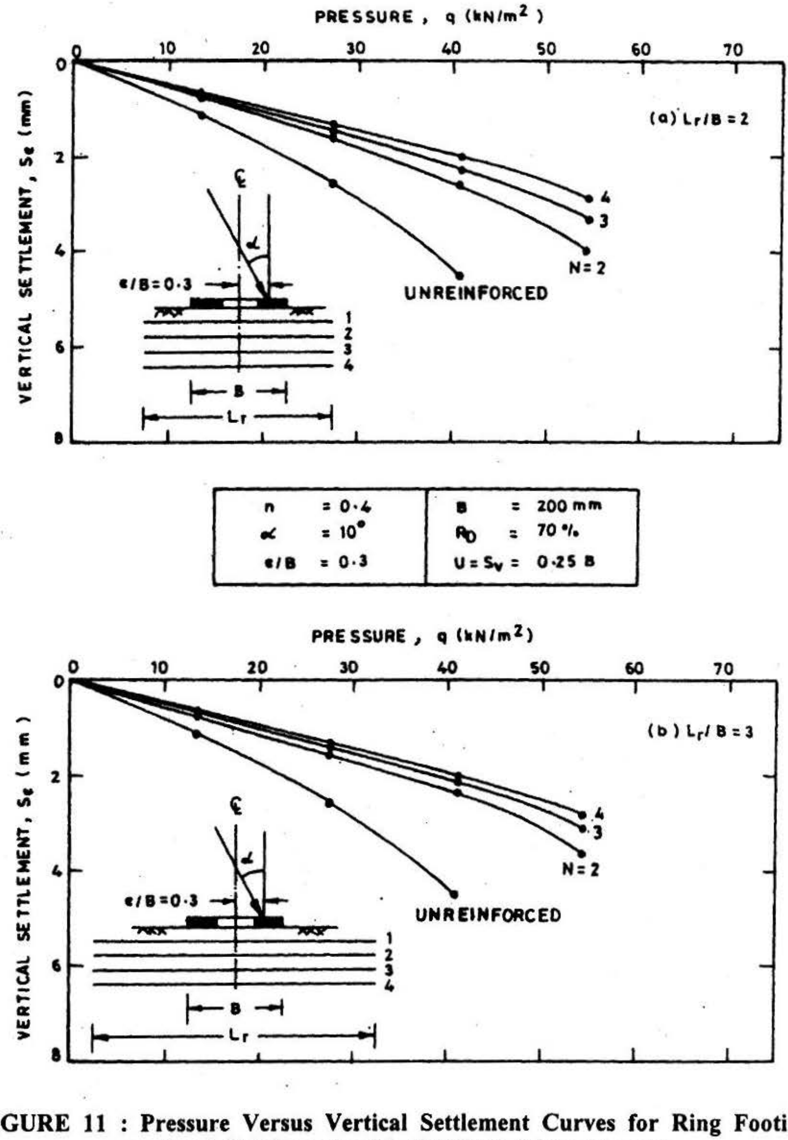


FIGURE 11 : Pressure Versus Vertical Settlement Curves for Ring Footing on Sand Reinforced with TENSAR SS20 Geogrid

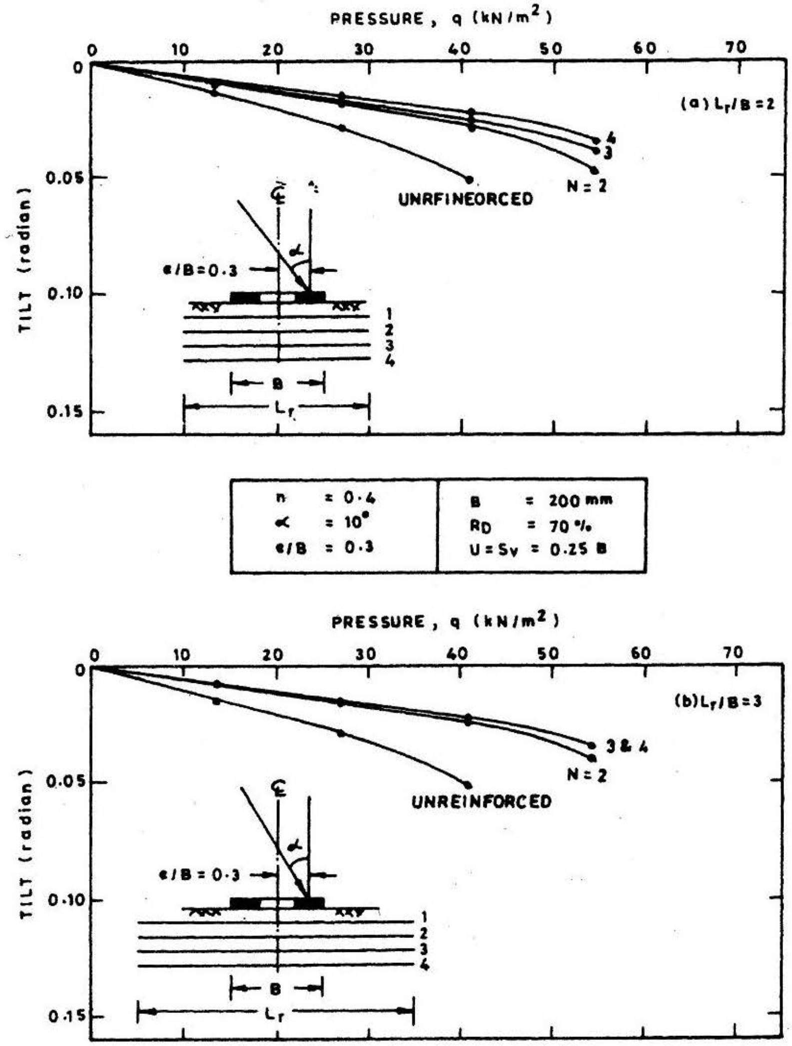
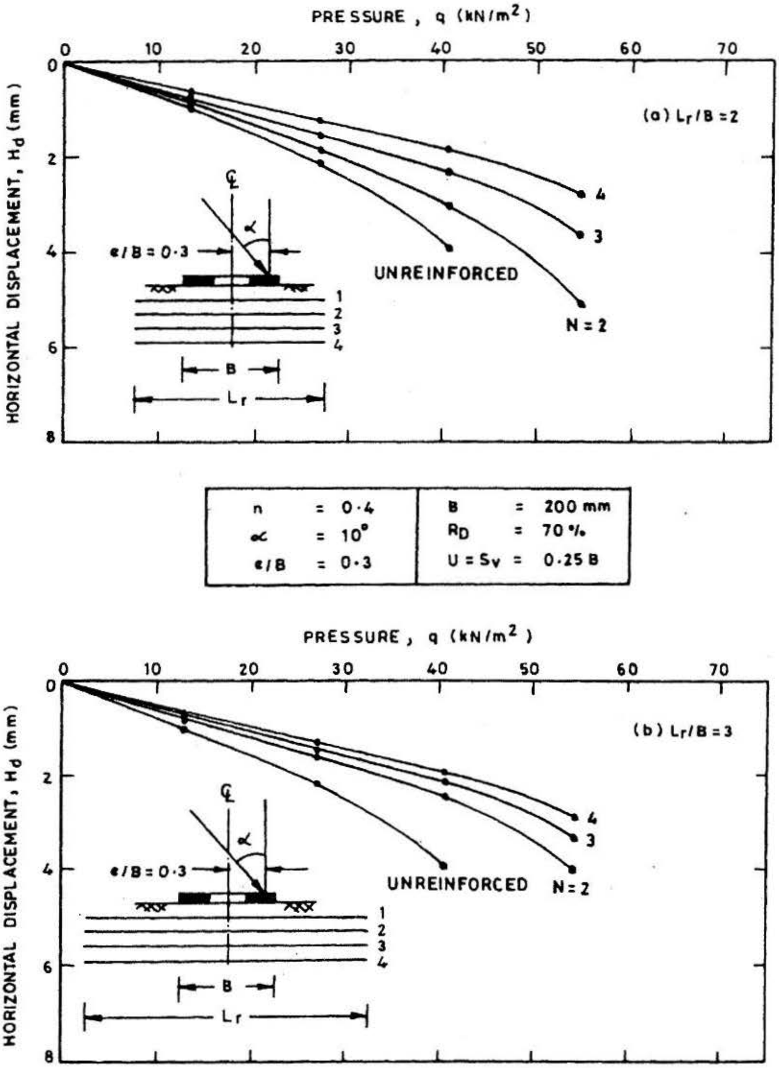


FIGURE 12 : Pressure Versus Tilt Curves for Ring Footing on Sand Reinforced with TENSAR SS20 Geogrid



n = 0·4		B = 200 mm	
α = 10°		R_D = 70 %	
e/B = 0·3		U = S_v = 0·25 B	

FIGURE 13 : Pressure Versus Horizontal Displacement Curves for Ring Footing on Sand Reinforced with TENSAR SS20 Geogrid

Discussions and Concluding Remarks

Figure 8a shows the pressure-settlement curves for a ring footing ($n = 0.4$) subjected to central vertical load (i.e. $e/B = 0$, $\alpha = 0°$) for $L_r/B = 2$ and for different number of reinforcing layers (N). It is evident from this figure that pressure settlement curves shift upwards with the increase in N. It means that for a given pressure intensity, settlement decreases with the increase of N. However the decrease in settlement with the increase in N becomes lesser for N values more than 3. Figure 8b shows similar curves for L_r/B ratio equal to 3. Exactly same trend is evident as described above. On comparing the corresponding values of settlement in Figs.8a and 8b, it can be seen that the settlement decreases with the increase in L_r/B ratio.

Figures 9a and 9b show the pressure versus settlement curves for ring footings subjected to eccentric vertical load ($\alpha = 0$, $e/B = 0.3$) for respectively $L_r/B = 2$ and 3. In this case also settlement of the footing decreases with the increase in number of reinforcing layers (N) and L_r/B ratio. On comparing the corresponding curves of Fig.8 and 9, it is evident that the settlement for the same pressure intensity is very large in ring footing subjected to eccentric vertical load. In this case, pressure versus tilt curves are shown in Figs.10a and 10b. It can be observed from the curves shown in these figures that tilt decreases with the increase in N and L_r/B ratio.

In the case of ring footings subjected to eccentric-inclined load ($\alpha = 10°$, $e/B = 0.3$), pressure versus settlement, pressure versus tilt and pressure versus horizontal displacement curves were obtained for different values of N and L_r/B ratios. The observations are shown in Figs.11 to 13. It can be seen from these figures that values of settlement, tilt and horizontal displacement decrease with the increase in N and L_r/B ratio. Maximum influence is observed for $N = 2$. For higher values of N, the decrease is by much lesser amount.

On comparing the data of Figs.9 and 11, and Figs.10 and 12, it was observed that both the settlement and tilt increase if the load becomes eccentric-inclined.

In general it can be concluded that in ring footings subjected to eccentric-inclined load, settlement, tilt and horizontal displacement decrease with the increase in number of reinforcing layers (N) and length of reinforcement. Substantial decrease is observed for $N = 2$ and $L_r/B = 2$. Further increase in N and L_r/B ratio did not decrease S_e, t and H_D with the same rate.

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