04 Apr 1995, 2:30 pm - 3:30 pm

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Swami Saran
University of Roorkee, Roorkee, India

B. V. K. Lavania
University of Roorkee, Roorkee, India

R. K. Sharma
University of Roorkee, Roorkee, India

Proceedings: Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
April 2-7, 1995; Volume III, St. Louis, Missouri

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Paper No. 2.19

Swami Saran, B.V.K. Lavania and R.K. Sharma
University of Roorkee
Roorkee, India

ABSTRACT: This paper presents a set of results of laboratory scale model footing tests conducted to determine the cyclic load resistance of sand beds reinforced with horizontal sheets of geogrid. The test results indicate that the total settlement decreases and the bearing capacity increases, with the increase in size of reinforcements and number of layers. With the inclusion of reinforcing sheets, the coefficient of elastic uniform compression decreases slightly; but this decreased value is valid upto the increased bearing capacity of the reinforced sand bed. There is significant improvement in the damping capacity upon reinforcing the sand bed as indicated by the comparison of the strain energies under the pressure-settlement curves obtained from cyclic plate load tests.

INTRODUCTION

The inclusion of geogrid reinforcements into the weaker foundation soil to increase its bearing capacity and improve static load-settlement characteristics is an established methodology. The behaviour of footings on sand beds reinforced with various materials subjected to static loadings has been studied by many investigators; e.g. Binquet and Lee, (1975); Basset and Last, (1978); Akinmusuru and Akinbolade, (1981); Saran and Talwar, (1981); Fragaszy and Lawton, (1984); Guido et al., (1986); Sridharan et al., (1988); Huang and Tatsuoka, (1990); Murthy et al., (1993); etc.; indicating an improvement in the load bearing capacity of the reinforced sand beds. Omar et al., (1994); conducted model tests on shallow rectangular foundations supported on sand reinforced with geogrid and concluded that the critical depth of reinforcement for mobilization of maximum possible ultimate bearing capacity decreases with increase in width to length ratio of the foundation.

Cyclic plate load tests on sand beds reinforced with fibre glass woven rovings has been conducted by Patel and Paldas (1982), who reported that the elastic settlements of the footing for both optimally reinforced and unreinforced sand beds are linearly varying with load and have same slope but the range of load for the former is higher than that for the latter. Also, the optimally reinforced sand bed has a higher damping capacity than that of the unreinforced sand bed, at a particular load level.

The cyclic load resistance of sand subgrades vertically reinforced with smooth as well as rough steel bars has been studied by Puri et al, (1991) by conducting laboratory scale model footing tests. They concluded that the coefficient of elastic uniform compression Cu, of vertically reinforced sand subgrades is much larger than that of the unreinforced sand bed; the improvement in Cu value depending upon the length, extent & spacing and surface roughness of reinforcement and also the initial relative density of sand. In this paper, the behaviour of the geogrid reinforced sand beds under cyclic loading conditions has been studied through a series of cyclic plate load tests conducted on two footing sizes at two relative densities, varying the size and number of reinforcing layers.

EXPERIMENTAL PROGRAMME

A series of cyclic plate load tests were conducted on reinforced and unreinforced sand beds prepared afresh. The reinforced soil beds were prepared by depositing sand in layers using rainfall technique and placing the geogrid sheets at a selected vertical spacing.

MATERIALS

The characteristics of the materials used are outlined as under:

Sand

Dry uniformly graded Amanantgarh sand (SP), obtained from the river Ganges was used to prepare the bed. The grain size characteristics, relative density and angle of shearing resistance are indicated in Table 1.

TABLE 1. Characteristics of sand

Sand	D_{60} (mm)	D_{30} (mm)	D_{10} (mm)	U (D_{60}/D_{10})	Relative density (%)	ϕ (degrees)
Amanant-garh	0.284	0.241	0.188	1.51	70	40

Reinforcement

Geogrid NETLON CE-121, possessing the undermentioned physical, chemical and mechanical characteristics was used in reinforcing the sand:

TABLE 2. Characteristics of reinforcement

Reinforcement:	Geogrid NETLON CE-121
Physical:	Colour - Black. Roll Width = 2m, Roll Length = 15m. Mesh aperture = 6mm. Mesh thickness = 3.3mm. (width across) Structural weight - 730 g.s.m. (gram per square metre)
Chemical:	100% high density polyethylene.
Mechanical:	Yield load - Machine direction (1m. width) - 6.40 kN/m. Transverse direction - 3.90 kN/m. Break load - Machine direction (1m. width) - 7.64 kN/m. Transverse direction - 4.45 kN/m.

TEST SET-UP

The test set-up consisted of two rigid steel tanks of sizes 0.90m x 0.90m x 1.0m (height) and 1.5m x 1.5m x 1.0m (height) assembled under a loading frame of capacity 10T. Two square steel plates with roughened bases, having sizes 0.15m x 0.15m and 0.30m x 0.30m and thickness 20mm each were used in the tests. The loading arrangement consisted of a compensating lever arm mechanism alongwith a hydraulic jack. The vertical displacements of the footings were measured by fixing four dial gauges one at each corner of the plate. Two stainers of sizes appropriate to the tanks were used to deposit the sand by rainfall technique in lift of 100mm. each.

TESTS CONDUCTED

Cyclic plate load tests were conducted on unreinforced and reinforced sand beds at 70% relative density, containing 2,3,4,6 and 8 geogrid layers of size varying from 1B to 5B; B, being the size of the square plate. The vertical spacing between the reinforcements and the distance of the top reinforcement layer below footing base was kept 0.25B each. The cyclic plate load tests were conducted by applying a predetermined vertical load increment which was maintained until the increase in the settlement of the footing became negligible. The vertical settlement was measured by averaging out the values observed from four dial gauges and the load value was recorded from the proving ring. The applied load was then reduced to zero and the corresponding elastic rebound of the footing was recorded. This procedure was continued for several cycles until the sand bed showed large settlements. Table 3 indicates the details of the cyclic plate load tests conducted.

TEST RESULTS

Figure 1 shows the pressure-settlement curve obtained from repeated loading and unloading test for the case of 0.15m x 0.15m footing supported on sand bed reinforced with four geogrid layers of size 0.45m x 0.45m. The corresponding curve for the unreinforced case is shown in Figure 2. For any loading intensity, the elastic settlement S_e, may be determined as:

$$S_e = S - S_r$$

where

S = total settlement

and S_r = residual settlement.

Pressure versus total settlement curves are obtained by joining the boundry points as shown in Figures 1 and 2. These are used to calculate the ultimate bearing capacity employing the double tangent method. Settlement ratio is defined as the ratio of the settlement of reinforced sand bed at a particular pressure intensity to the settlement of the unreinforced sand bed at the same pressure intensity.

The damping capacity of the reinforced sand bed has been defined as the ratio of the strain energy required to cause unit vertical displacement in it to the strain energy required to cause unit vertical displacement in the unreinforced sand bed. The test results for 32 tests for various footing sizes and reinforcement configurations are presented in Table 3.

DISCUSSION OF TEST RESULTS

With the inclusion of geogrid reinforcements in the sand bed, the coefficient of elastic uniform compression is slightly decreased as compared to the value of Cu for the unreinforced soil (Figures 3 & 4). However, the pressure-intensity range for the reinforced sand bed, upto which the decreased Cu value is valid; is much higher as compared to the pressure-intensity for the Cu value of the unreinforced sand bed. This decrease in Cu value may perhaps be attributed to somewhat dilating of the sand layers around the reinforcements as well as to the flexibility of the reinforcements. Under cyclic loading conditions as well, there is substantial decrease in the total settlements as well as an improvement in the bearing capacity values as illustrated in Figures 1 & 2; which is further enhanced with increase in the size and number of reinforcement layers (Table 3).

There is an improvement in the damping capacity upon reinforcing the soil which seems to increase with larger sizes and numbers of reinforcement layers. This improvement in damping capacity may be as a result of the dispersion of the load to larger mass of soil by the reinforcements. The scale effects can be studied having data on larger size plates.

TABLE 3. Details of tests conducted and test results

Test No.	Reinforcement		Ultimate bearing capacity (kN/m^2)	Settlement ratio	Coefficient of elastic uniform compression Cu (kN/m^3) x 10^5	Damping capacity
	Size (B_R) (m^2)	Number of layers (N)				
			For footing size 0.15m x 0.15m			
				At pressure intensity of 160 kN/m^2		
1.	Unreinforced	-	160	-	2.69	-
2.	0.15 x 0.15	2	200	0.736	2.22	1.17
3.		3	245	0.656	2.04	1.24
4		4	300	0.648	1.80	1.25
5.		6	320	0.640	1.58	1.27
6.		8	330	0.640	1.45	1.28
7.	0.30 x 0.30	2	275	0.712	2.10	1.19
8.		3	325	0.524	2.28	1.62
9.		4	390	0.456	2.18	1.80
10.		6	425	0.440	2.00	1.82
11.		8	450	0.416	1.91	1.91
12.	0.45 x 0.45	2	310	0.528	2.25	1.55
13.		3	355	0.520	2.10	1.56
14.		4	450	0.504	2.08	1.63
15.		6	485	0.432	2.03	1.88
16.		8	535	0.384	2.02	2.11
17.	0.60 x 0.60	2	320	0.656	2.17	1.55
18.		3	372	0.520	2.17	1.82
19.		4	475	0.448	2.15	1.64
20.		6	510	0.432	2.10	1.79
21.		8	585	0.380	2.08	2.16
22.	0.75 x 0.75	2	330	0.624	2.35	1.31
23.		3	410	0.512	2.32	1.55
24.		4	505	0.440	2.40	1.80
25.		6	560	0.400	2.36	2.06
26.		8	625	0.376	2.16	2.12
			For footing of size 0.30m x 0.30m			
				At pressure intensity of 210 kN/m^2		
27.	Unreinforced	-	210	-	2.29	-
28.	0.30 x 0.30	4	300	0.710	1.95	1.36
29.	0.60 x 0.60	4	350	0.640	1.75	1.48
30.	0.90 x 0.90	4	410	0.623	1.63	1.50
31.	1.20 x 1.20	4	465	0.614	1.57	1.51
32.	1.50 x 1.50	4	490	0.605	1.54	1.52

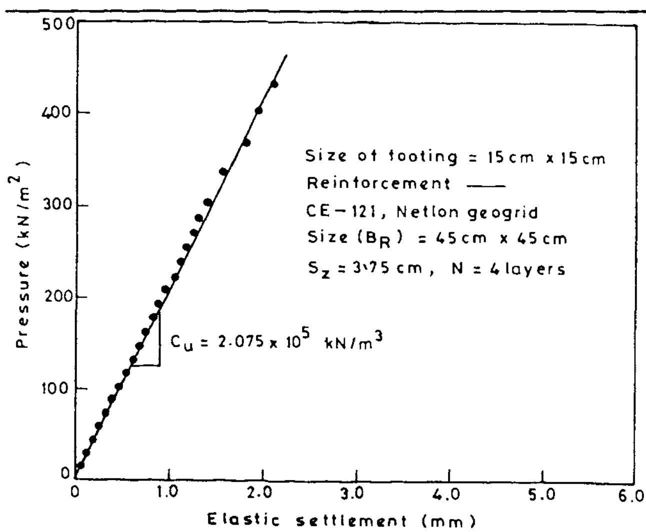

Fig. 3. Pressure vs elastic settlement plot - Reinforced sand.

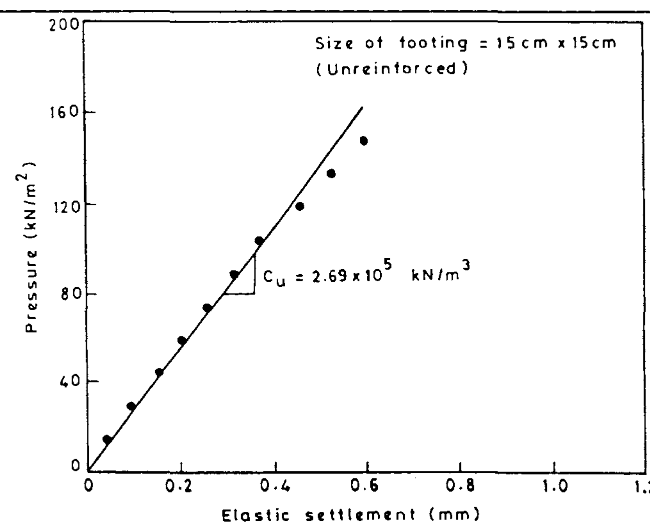

Fig. 4. Pressure vs elastic settlement plot - Unreinforced sand.

CONCLUSIONS

1. Under repeated loading conditions, there is a decrease in the total settlements and improvement in the bearing capacity, upon reinforcing the sand bed. With larger sizes and number of reinforcements, larger decrease in total settlements and greater enhancements in the bearing capacity values are observed.

2. There is a slight decrease in the coefficient of elastic uniform compression with the inclusion of geogrid layers, the decrease being somewhat more for increasing size and number of layers. However, the pressure range for the Cu value for reinforced sand is much higher as compared to that for the unreinforced sand.

3. The damping capacity of the sand bed is improved upon reinforcing with geogrid layers, the improvement being more with more number and larger size of geogrid layers.

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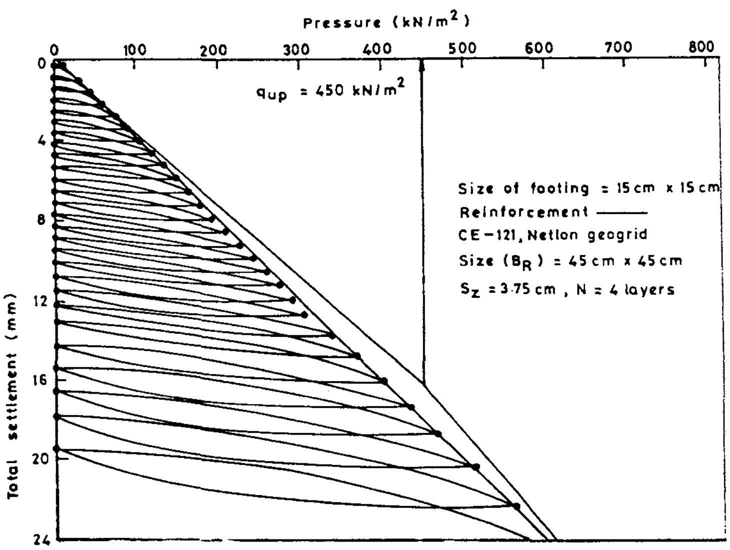

Fig.1. Cyclic Plate Load Test on Reinforced Sand.

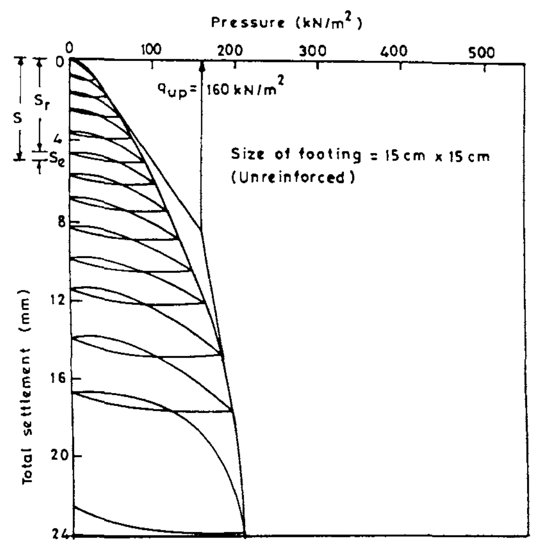

Fig. 2. Cyclic Plate Load Test on Unreinforced Sand.