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Modelling for bearing capacity analysis of reinforced sand subgrades

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ABSTRACT: Bearing capacity of sand subgrades is increased when reinforced with galvanised rods placed as vertical instrusions in the subgrade. The improvement is comparable with the results obtained by investigators using horizontal forms of reinforcements. The improvement is a function of the spacing, diameter, roughness and extent of the reinforcing element. The present investigation attempts a modelling for bearing capacity analysis of reinforced sand subgrades.

1 INTRODUCTION

Many investigators such as Akinmusuru and Akinbolade (1981), Binquet and Lee (1975), Fragaszy and Lawton (1984) and others have reported improvement in bearing capacity of sand subgrades under footing foundations when horizontal reinforcements are placed in the subgrade. However, the serious disadvantage with horizontal reinforcements is that it can not be used in in-situ conditions. Re-laying and compaction of the subgrade is essential after placement of the reinforcement. Bassett and Last (1978) investigated the possibility of using non-horizontal reinforcements. Installation of root piles for improving bearing capacity has been advocated by Lizzi (1979). If inclined or vertical reinforcements are established to be effective they can be installed more easily in new constructions and used for strengthening of existing foundations as well. With this objective a laboratory investigation was carried out by the authors to evaluate the efficiency of vertical reinforcing elements in improving sand subgrades, and the results were found to be encouraging and have been reported (1986).

2 TEST ARRANGEMENT

Two dimensional model tests were carried out in a wooden box of size 720 x 400 x 90 mm. A 7mm thick perspex sheet was used in the frontage for observing the failure surface. Special care was taken to make the box as rigid as possible. Model footings of 40 mm thickness were made out of well-seasoned teak wood and their bases were made rough to simulate the rough base of a prototype footing. The cohesiouless test beds were prepared by pouring standard Ennore sand in layers through a funnel held at a constant height of 300 mm above the surface. The uniformity co-efficient and the effective size of the sand were 1.41 and 0.49 mm respectively. The dry density of the sand bed was found to be 1.58 mg/m^3 (R.D. = 71%) for all the tests performed. Galvanized iron rods of required leugth and size were pushed into the sand bed vertically at predetermined spacings (Fig.1). A single layer of sand particles were bonded onto the surface of rods with araldite to simulate a rough surface and were employed iu a few tests. The footing was pushed into the sand bed at a constant speed of 1 mm per minute until failure. The applied load was recorded with the help of a

Table 1. Ultimate bearing capacity ratio for reinforced sand subgrades: Width of footing (B) = 100 mm

Diameter (mm)	Spacing (mm)	Spacing / Diameter	Ultimate Bearing Capacity Ratio					
			R=B		R=2B		R=3B	
			L=B	L=1.5B	L=B	L=1.5B	L=B	L=1.5B
1	2	3	4	5	6	7	8	9
1.7	18	10.59	1.48	1.49	1.67	1.69	1.71	1.76
1.7	15	8.82	-	1.50	-	1.69	-	1.91
1.7	13	7.65	1.70	1.89	1.79	2.31	1.91	2,51
1.7	10	5.88	1.94	2.31	2.08	3.08	2.66	3.20
1.7 (Rough)	13	7.65	2.51	-	2.79	-	3.91	-
2.51	22.5	8.96	-	1.69	-	1.79	-	2.11
2.51	18	7.17	1.79	1.91	2.11	2.31	2.51	2.50
2.51	15	5.98	2.11	2.31	2.51	2.51	2.74	2.69
2.51	13	5.18	-	2.91	-	3.31	-	3.91
2.51 (Rough)	18	7.17	2.50	2.66	2.89	3.91	3.11	-

calibrated proving ring. The settlements of the footing were recorded by two dial gauges fixed with adapters and resting on two extension plates fixed on either side of the footing.

3 TEST RESULTS

The variables of the investigation and bearing capacity ratios at failure are given in Table 1. Since a well defined failure point in the load-settlement curves was not present in most of the cases determination of experimental ultimate loads were done through the method suggested by De Beer (1970) and employed by Vesic (1973). Detailed test results are available elsewhere [Verma (1986)] .

4 MODELLING FOR BEARING CAPACITY ANALYSIS

The experimental results show improvement in bearing capacity of the sand subgrades due to vertical reinforcement of different lengths and of different extents as shown in Table 1.

The following alternative approaches for the evaluation of bearing capacity of reinforced subgrades are examined in this paper.

1. Reinforcements as piles: reinforcement rods are assumed to act as vertical piles and their contribution is added to the bearing capacity of the subgrade.

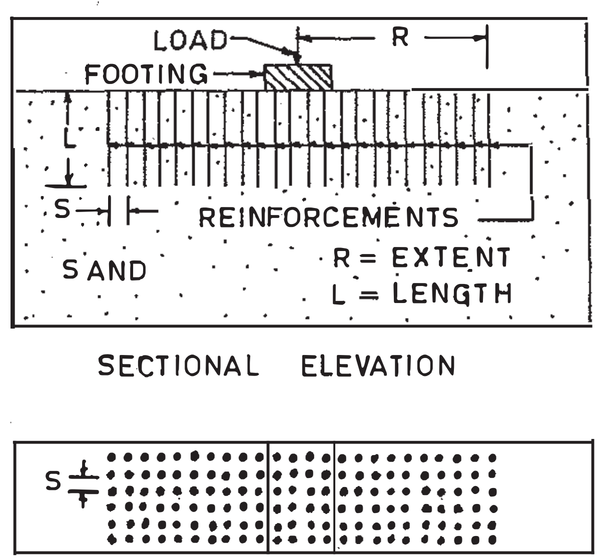

FIG.1 REINFORCEMENT PATTERN

Table 2. Load carrying capacity of reinforcing rods acting as piles: Diameter of rods = 1.7 mm, Length= 1.5B, Width of footing = 100 mm

Test No	Spacing of rods (mm)	Ext. of Reinforcement (R)	A_r/A_s x 10^{-3}	Total No.of rods used	Total pile load for all rods used in kN (Q_{PR})	Capacity of sand+ pile load ($Q_{UR}+Q_{PR}$)	Expt. Load in kN (Q_R)
1	2	3	4	5	6	7	8
10	18	B	6.06	48	0.0215	4.5611	6.645
12	18	2B	6.06	96	0.0429	4.5825	7.543
13	18	3B	5.72	136	0.0608	4.6004	7.793
15	15	B	8.83	70	0.0313	4.5709	6.663
17	15	2B	8.83	140	0.0626	4.6022	7.506
18	15	3B	8.41	200	0.0894	4.6290	8.457
20	13	B	12.11	96	0.0429	4.5825	8.422
22	13	2B	12.11	192	0.0859	4.6255	10.235
23	13	3B	12.11	228	0.1020	4.6416	10.960
25	10	B	22.20	176	0.0787	4.6183	10.234
27	10	2B	21.19	336	0.1503	4.6898	13.679
28	10	3B	20.86	496	0.2218	4.7614	14.212

2. Equivalent surcharge depth: reinforcements are assumed to contribute an equivalent surcharge on the subgrade.

3. Apparent cohesion or shear strength increase: the reinforcements are assumed to impart an apparent cohesion or cause an increase in the frictional resistance or both.

4.1 Reinforcement as piles

Reinforcement rods may be considered as vertical piles whose load capacity can be computed through static formulae. An appreciation of their fundamental functions and a comparison with those of presently considered reinforcement system may clarify the functional difference of the two. Load carrying capacity of the unreinforced subgrade (Q_{UR}) along with the additional contribution of reinforcing rods as piles (Q_{PR}) for a few test results are tabulated in Table 2. Another set of values of all the reinforcing rods contribution as piles (Q_{PR}) are also given in the table . Comparison with the experimental loads (Q_R) on the reinforced sand subgrade for different conditions reveal that Q_R is always much more than (Q_{UR} + Q_{PR}) which suggests that the improvement in bearing capacity may not be due to the reinforcing rods acting simply as piles.

4.2 Equivalent surcharge depth

In this hypothesis, the increase in bearing capacity due to the introduction of reinforcements in the subgrade is assumed to be due to an increase in the effective surcharge pressure (D_{equiv}) at the footing base and consequent increase in the confining pressure [Denver et al (1983)] . Using the bearing capacity equation (1), D_{equiv} can be evaluated as all other terms in the equation are known.

$$q_{ult} = [D_{equiv} + (h_1 + h_2)]\gamma N_q + \tfrac{1}{2}\gamma B N_\gamma \quad \ldots (1)$$

Table 3. Apparent cohesion and equivalent surcharge depth due to reinforcing rods. Dia of rods = 1.7 mm, Length = 1.5B, B = 100 mm

Test No	A_r/A_s x 10^{-3}	Surcharge depth in cm	Calculated UBC in kPa (q_c)	Expt. UBC in kPa (q_{expt})	$q_{expt}-q_c$ (C_F)	App. cohesion= C_F/N_c in kPa (C_a)	$D_{equiv}=\frac{\Delta q x100}{N_q}$ (in cm)
1	2	3	4	5	6	7	8
10	6.06	3.30	517.7	755.1	237.4	1.10	6.57
12	6.06	3.70	544.4	857.1	312.7	1.44	8.54
13	5.72	3.45	533.4	885.6	352.2	1.62	9.63
15	8.83	3.25	517.7	757.1	239.4	1.11	6.61
17	8.83	3.05	524.1	852.0	329.0	1.51	8.94
18	8.41	3.75	553.2	961.0	407.8	1.86	11.05
20	12.11	4.10	559.1	957.0	398.0	1.83	10.86
22	12.11	3.90	560.7	1163.1	602.6	2.75	16.29
23	12.11	4.00	551.7	1245.5	693.9	3.20	19.02
25	22.20	3.87	554.2	1163.0	608.8	2.79	16.55
27	21.19	3.90	584.3	1554.4	970.1	4.31	25.39
28	20.86	3.90	591.9	1615.0	1023.1	4.55	26.77

where

h_1 = height of soil which heaves above the original surface of the subgrade.

h_2 = height of soil above base of the footing.

In Table 3 values of D_{equiv} have been tabulated for a typical series of tests on reinforced sand subgrades. The obtained values are very large and appear to have no useful relation to the length or density of reinforcements. From the results it is seen that equivalent surcharge depth increases with A_r/A_s and is dependent on length and extent of reinforcement. (A_r represents area of reinforcement and A_s area of soil reinforced) .

4.3 Apparent Cohesion

Vidal (1969) and Schlosser and Long (1974) hypothesise that when reinforcement is introduced to a non-cohesive soil, the whole mass exhibits some cohesion arising from the friction of soil grains against the reinforcing elements. This concept has been supported by several investigators such as Gray (1978), Waldron (1977), and Verma and Char (1978). Based on this concept the value of apparent cohesion was evaluated from the experimental results. Since the unreinforced soil was frictional the bearing capacity q_c was calculated by the equation

$$q_c = (h_1+h_2)\gamma N_q + \tfrac{1}{2}\gamma B N_\gamma \qquad ...(2)$$

where h_1 and h_2 are already defined through equation (1). The values of q_c have been tabulated in Table 3. It is noted that experimental ultimate bearing capacities (q_{expt}) of reinforced sand are always larger than values obtained by equation (2) . This difference(q_{expt} - q_c) is assumed to be the contribution due to apparent cohesion due to the introduction of reinforcements in the subgrade. This difference is termed as a cohesion factor (C_F) and the apparent cohesion is evaluated through

$$C_a = \frac{C_F}{N_c} \qquad \dots (3)$$

where

C_a = apparent cohesion

and N_c = Terzaghi's bearing capacity factor for cohesion corresponding to ϕ_p .

The values of C_a for a few test results are tabulated in Table 3. The relation between A_r/A_s and C_a shows that the rate of increase of C_a with A_r/A_s is dependent on the length of the reinforcing bar and the extent of reinforcement and the variation is almost linear, the slope of the curve being a function of the extent of reinforcement.

5 CONCLUSIONS

The study shows the beneficial effect of using vertical reinforcing rods for sand subgrades. The greatest advantage of this method is that relaying of the subgrade is not required as in the oase of horizontal reinforcements. The increase in bearing capacity of sand subgrade may be taken as due to apparent cohesion induced in the soil due to the presence of reinforcement. The apparent cohesion is dependent on the area ratio of reinforcement as well as the length and extent of reinforcement. Tests on bigger models or prototype testing may help in arriving at accurate analytical estimates.

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