Model tests on reinforced soil mattress on soft soil

Essais sur modèle d'un matelas de sol armé sur sol mou

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SYNOPSIS The use of reinforced sand mattress over soft layer has been examined in relation to the results of a simulated model test. A simple method of analysis has been presented which accounts for the variation of geometric parameters. By using the available type of geogrid in India, it has been shown that the improvement in load carrying capacity of the soft layer can be more than three folds.

INTRODUCTION

Design of embankments and footings on soft soil like marshy and reclaimed lands is a difficult task for engineers. Conventional practice in such a condition is to improve the mechanical properties of the soft soil by stabilizing techniques or by adopting pile foundations. These methods are costly and often may not be practicable. Recently, reinforced earth technique has been developed as a method to improve the load carrying capacity in such conditions. However, most of the researchers have considered the reinforcement at the interface between the soft layer and the fill material. In such a condition, it acts more as a separator than as a reinforcement. In this investigation an attempt has been made to examine the behaviour of reinforced sand mattress on soft soil with reinforcements placed within the fill material. Further, a method of analysis has been suggested to predict load-settlement behaviour of such a system.

Improving the load carrying capacity of a soft soil by providing a blanket of sand/gravel on it is a proven technique. However, penetration/ mixing of gravel/sand into soft soil reduces the effectiveness of this technique. But, it can be improved by providing a membrane viz. geotextile, geogrid,...etc at the interface. Milligan and Love (1984), Milligan and Fannin (1986), Jarrett, 1986 and others have shown from model tests that the above technique can perform satisfactorily. In general, these model test results can be used for design of pavements on soft soil. In this study an attempt has been made through model tests to show the improvement in load carrying capacity of a soft soil under structural footings by providing a reforced sand mattress. Further, a possible method of analysis has been proposed.

EXPERIMENTAL PROGRAMME

The model plate load tests were conducted in a steel tank of size 750 x 750 x 600 mm. A circular, rigid, mild steel plate of 50 mm thick and 150 mm diameter was used as model footing. A self straining reaction frame together with a screw jack was used for loading the model footing. The settlement of the footing was measured using two dial gauges placed diametrically opposite. Fig. 1 schematically shows the experimental set up.

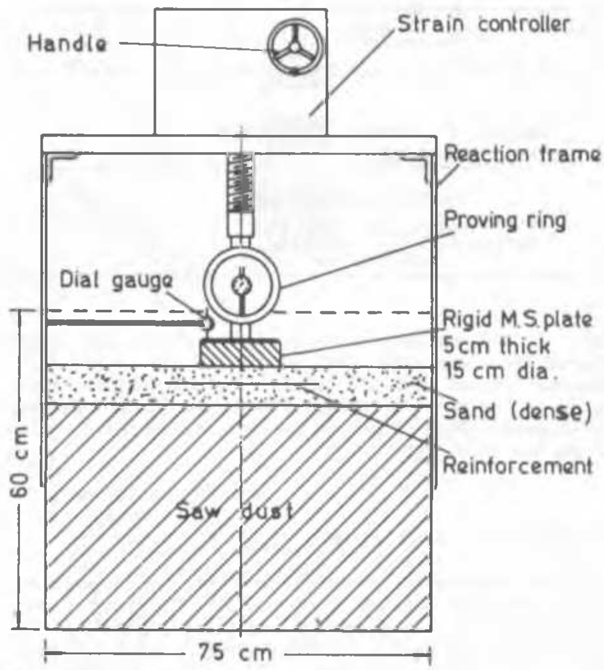


Fig 1 Experimental Setup

The soft soil has been simulated by saw dust with very low shear strength and high compressibility, and uniformly graded sand has been used as a fill material, the properties of which are indicated in Table I.The performance of the reinforced soil mattress has been studied using three types of reinforcements in the form of two varieties of locally available Netlon geogrid meshes and a galvanized iron mesh. Table II indicates the salient properties of reinforcements used. The parameters varied are:

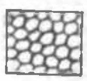
1) thickness of backfill material
2) position of reinforcement and
3) number of layers of reinforcement.

The saw dust was compacted by preloading to an uniform pressure of 15 kPa using a rigid plate of size nearly equal to that of the tank. Sand was placed in a definite

Table I - Characteristics of soft and fill soil

	Sand	Saw dust
Density	1.62 gm/cc	0.39 gm/cc
Relative density. Dr	65%	-
Cohesion, c	0.0	0.0
Friction angle,	41°	13°
Uniformity Coefficient	2	-
Average particle size, D50	0.95mm	-

Table II. Properties of Reinforcement

Sl No	Reinforcement type	Schematic diagram	Tensile str. kN/m	Inter-facial friction angle with sand
1	G I Mesh		90	39°
2	Geogrid I (Netlon CE 131)		6.55	40°
3	Geogrid II (Netlon CE 121)		7.6	41°

manner to the desired thickness. The sand - saw dust combined layer was again preloaded to 60 kPa. By this technique it was possible to achieve reproducible test conditions in all the tests. For reinforced cases, reinforcements were placed at appropriate depths, while placing the sand.

TEST RESULTS AND DISCUSSIONS

Fig. 2 illustrates the effect of thickness of sand layer on soft soil without any reinforcement. It can be seen that the behaviour is changing from strain hardening to strain softening with increase in thickness of sand layer. At smaller settlement levels, load carrying capacity increases with increase in sand thickness. But at larger settlements the trend is reversed. This is because of the strain hardening nature of saw dust in contrast to strain softening nature of sand.

Fig. 3 shows the load - settlement curves with reinforcement in soft soil. The improvement in load carrying capacity is negligible. This is mainly because of the low interfacial friction between saw dust and reinforcement. This indicates that the interfacial friction is essential for the peformance of reinforced earth technique. This necessitates the use of frictional fill material on the soft soil to place the reinforcements.

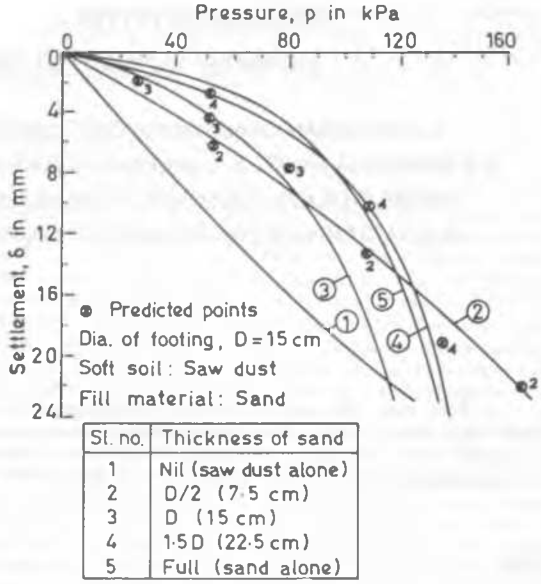


Fig 2 Load - Settlement Behaviour

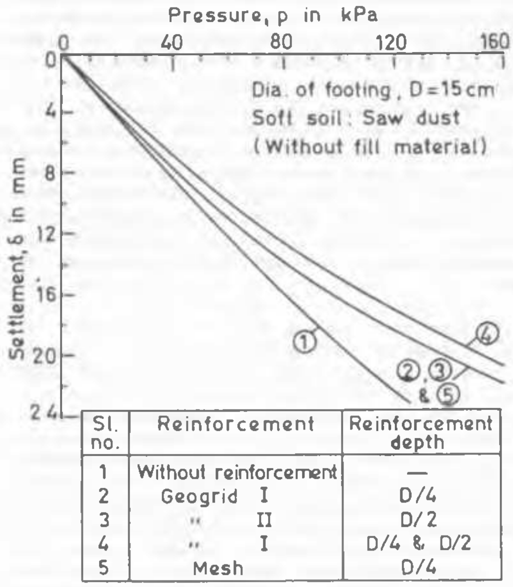


Fig 3 Load - Settlement Behaviour

Fig. 4 presents the load-settlement curves of reinforced condition compared with that of unreinforced condition. It can be seen that the improvement in load carrying capacity is nearly same for the three types of reinforcements used in this study for a given size. This is because of low sliding strain level which mobilize nearly the same ϕ_μ value in all the reinforcements. Fig 5 indicates the effect of position and number of layers of reinforcements. The load carrying capacity increases with the increase in number of layers. The best reinforcement placement position appears to be within a depth range of 0.25D to 0.4D for thickness of sand layer being 0.5D. The improvement in the load carrying capacity of the reinforced mattress with two layers of reinforcements is more than three fold over that of saw dust at comparable settlements.

Analysis

Binquet and Lee (1975) have carried out the analysis for the case of reinforced sand mattress below a rigid strip footing. Srinivasa Murthy et.al (1988) and Hans Raj Singh (1988) have modified the approach given by Binquet and Lee (1975) by overcoming some of the limitations in the analysis and to cover other shapes of footings. The modified method of analysis has been shown to be valid for the fill material being semi-infinite and homogeneous. It is attempted in this section to encompass the analysis for layered systems also. The modified analysis for reinforced sand mattress under circular footing for frictional failure condition results in the equation for bearing capacity ratio of the form:

$$BCR = 1/(1-K')$$

$$K' = K\sum_{i=1}^{n} \rho_i \,(F_N/P)_i \left[1 - \sum_{j=1}^{i-1} (F_N/P)_j \tan\phi_{\mu j}\right] \tan\phi_{\mu j}$$

where : BCR is defined as the ratio of the load carried by the reinforced sand mattress to that by the unreinforced condition at same settlement level.

ρ_i is the linear density ratio of the reinforcement which is equal to unity for grid reinforcements.

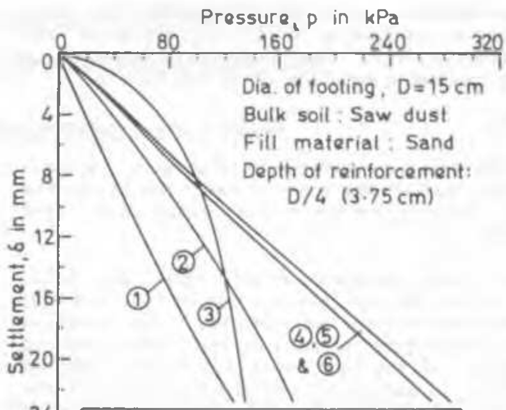
K is the ratio of the interfacial contact area to the plan area of the reinforcement which is equal to unity for grid reinforcements.

(FN/P) is the normal force factor which is the ratio of total normal force on the reinforcement projected beyond the edge of the footing to the applied load. This factor is obtained by integrating the Boussinesq's equation for vertical stress over the reinforcement projection beyond the edge at the level of reinforcement.

ϕ_μ is the angle of interfacial friction and is nearly equal to the value of angle of internal friction of the backfill material for grid reinforcements. The value of ϕ_μ depends on the sliding strain and the normal force in addition to the stiffness of the reinforcing material.

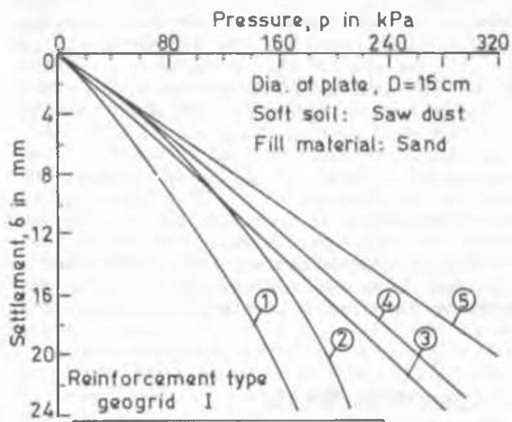
Once the BCR value is obtained for a given reinforcement configuration, by knowing the load carrying capacity of the unreinforced soil system, the component of the load carried by the reinforcement can be computed and used in the design of reinforcement section for tie failure condition. The load carrying capacity of the unreinforced layered soil system at any settlement can be obtained by the classical Burmister theory by knowing the basic properties of the two layers. However a simple method to evaluate the same from the individual load-settlement curves of the two materials is presented later.

Whenever a load is applied on the footing, the soil below the footing moves vertically down and induces lateral flow in the soil adjoining to it. This in turn causes sliding strain on the reinforcement, on which the



Sl. no.	Sand thickness	Reinforcement
1	Nil (saw dust only)	Nil
2	D/2 (7·5 cm)	Nil
3	Full (sand alone)	Nil
4	D/2 (7·5 cm)	Geogrid I
5	" "	" II
6	" "	Mesh

Fig 4 Load - Settlement Behaviour



Sl. no.	Thickness of sand	Reinforcement depth
1	D/2 (7·5cm)	–
2	D (15 cm)	D/2
3	D/2 (7·5 cm)	D/4
4	" "	D/6 & D/3
5	" "	D/4 & 0·4 D

Fig 5 Load - Settlement Behaviour

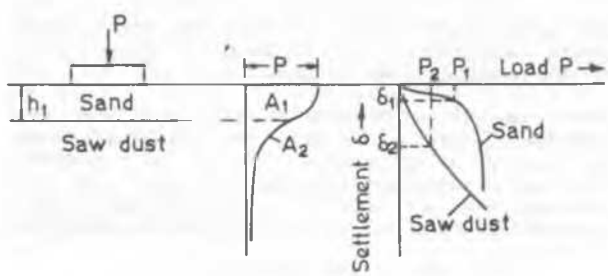


Fig 6 Stress Distribution, for Layered System   Load - Settlement Curves

mobilised ϕ_μ depends. Hans Raj Singh (1988) has proposed a method of evaluating the sliding strain at any level of reinforcement. Considering failure wedge in the soil the governing equation is of the form :

$$\epsilon_s = \delta/4D$$

where δ is the relative vertical displacement along a vertical plane through the edge of the footing at the layer level and D is the depth of that layer from footing bottom.

In reinforced sand mattress on soft soil the total settlement at the footing level is due to the compression of both the soft and sand layers. The relative displacement causing the sliding strain is only due to the compression of the sand layer under the applied loading. This is because of uniform settlement of the soft layer over a larger area. Then the relative displacement can be computed using the Burmister's two layer theory in which solutions can be obtained for both surface and interface settlements. Since these solutions are tedious for a case of rigid footing the following simple alternative method is proposed.

Pressure - settlement curve of layered system

Let S1 and S2 be the settlement-load curves from plate load tests for the semi-infinite condition of the two materials, which can also be obtained theoretically (Janbu,1976) [Figure . 6]. For an applied load P on the layered system it can be assumed that the load causing the compression of each layer will be proportional to the fraction of the area of the Boussinesq's stress intensity curve for semi-infinite condition in that zone. For two layered system, P1, the load causing deformation in the sand layer is equal to P. A1/(A1+A2) and P2 for saw dust, is equal to P.A2 /(A1+A2). Then the total settlement is equal to $\delta = \delta 1 + \delta 2$ which are obtained from Fig. (6), against P1 and P2. The validity of this mode of computation is indicated in Fig. (2) for three thicknesses of sand layer. Now, for any surface settlement of the two layered system, the relative settlement in the sand layer can be computed, which can be used further in the computation of strain and hence the mobilised.

Prediction of Experimental Results

Using the above method of analysis prediction of BCR values were attempted for the experimental results. For this, ϕ_μ has been obtained from the direct (sliding) shearing test results. The predicted values of BCR have been compared with the experimental values in Table III. The close agreement of the values indicates the viability of this approach.

Table III. Predicted BCR values

	Surface deformation (mm)	Strain %	tan ϕ_μ	FN/P	BCR pred	BCR Exptl	BCR w.r.t soft soil Exptl
One layer of reinforcement at B/4	6.5	0.3	0.35	0.32	1.25	1.37	2.47
	9.8	0.9	0.83	0.32	1.43	1.30	2.32
	13.4	1.4	0.95	0.32	1.52	1.46	2.39
	17.2	2.2	1.15	0.32	1.71	1.45	2.25
Two layer of reinforcement at D/4 and 0.4D	6.5	0.3	0.39	0.31	1.40	1.81	3.25
	9.8	0.6	0.60	0.31	1.75	1.82	3.26
	13.4	0.9	0.75	0.31	2.06	1.99	3.22
	17.2	1.4	1.0	0.31	2.20	2.02	2.94

CONCLUDING REMARKS

From the results of the model tests on reinforced sand mattress over soft soil and the analysis thereof, the following conclusions can be made.

1. The load carrying capacity of a soft layer can be improved by about three times, providing a layer or two of an appropriate type of reinforcement.
2. The load vs settlement behaviour of a reinforced sand mattress over soft material is strain hardening when compared to the strain softening nature for unreinforced sand blanket over soft material when blanket thickness is more than half the diameter of the footing.
3. The proposed method of analysis appears to be reasonable and consistently predicts the bearing capacity ratio within the permissible limits of error.
4. The method of analysis can be effectively used to develop a design methodology for the reinforced sand mattress over soft soils.

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