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SYNOPSIS: This paper presents the results of laboratory scale model footing tests which were conducted for determining the cyclic load resistance of sand subgrades reinforced with semi-flexible vertical elements. The tests were conducted in a sandbox having a length of 91.5 cm, width 15.25 cm, and height of 61.0 cm. Steel bars 1.58 mm in diameter were used as reinforcing elements. Tests were also conducted by using rough reinforcing elements. The test results indicate that the value of coefficient of elastic uniform compression of the footing on sand increases with the provision of vertical reinforcement in the sand subgrade. Rough Reinforcing elements were found to be more effective in improving the value of C_u as compared to plain reinforcing elements. The improvement in the value of C_u as a result of provision of vertical reinforcement was observed to depend on initial relative density of sand and, also on parameters such as the length, extent and spacing of reinforcing elements.

INTRODUCTION

The improvement in soil properties by reinforcing it with tension resisting elements has been accepted as a versatile and economical means for construction of earth structures and foundations. Materials such as sheets, strips, metal nets, woven or resin fibers, polymers and plastics have been used for this purpose. Most of the studies on soil reinforcement deal with the use of horizontal reinforcing elements and static loading conditions only.

Binquet and Lee (1975) conducted model footing tests on reinforced earth slabs to study the effect of number of layers of horizontal reinforcement, spacing between the reinforcement layers, and the distance of the first layer of reinforcement measured from the bottom of the foundation. Marked improvement in bearing capacity was observed as a result of soil reinforcement. Akinmusuru and Akinbolade (1981) investigated the effect of flat strips of rope fiber embedded horizontally in granular soil on the bearing capacity of square footings. They observed an increase in bearing capacity with increase in number of layers of reinforcement below the footing. The optimum results were obtained with three layers of reinforcement when the horizontal spacing of fibers in the layers was 0.5B (B = width of the footing) and the vertical distance between the layers was 0.5B.

The effect of soil density and length of reinforcing strips on the improvement in bearing capacity of horizontally reinforced sand subgrades was studied by Fragaszy and Lawton (1984). Guido et al (1985, 1986), and Kinney (1982), studied the beneficial effects of geotextiles placed at the interface of a finely crushed gravel layer underlain by soft clay by conducting model footing tests on circular footings. The behavior of a footing supported on a horizontally reinforced clayey soil was evaluated by Ingold and Miller (1982). Milligan and Love (1984) studied the behavior of a strip footing resting on an aggregate layer overlying soft ground with horizontal geogrid reinforcement.

The possibility of using non-horizontal reinforcements in soil was explored by Basset and Last (1978), and Gray and Al-Refai (1986). Hence it appears possible to use semi-flexible non-horizontal reinforcement in soil to increase its load bearing capacity. In some situations, it may be much easier to install vertical reinforcement provided its beneficial effects are established. A preliminary study on improvement in bearing capacity of sand reinforced with vertical elements was reported by Verma and Char (1986). Puri and Das (1989) conducted model footing tests to study the effect of parameters such as length of vertical reinforcing elements, lateral extent of reinforcing elements, and the horizontal spacing between the reinforcing elements, on the improvement in the ultimate and allowable bearing capacity of sand. No studies have been reported on the effect of vertical reinforcement in soil on its cyclic load resistance.

This paper deals with the evaluation of beneficial effects of vertical reinforcement in sand on its cyclic load resistance. A laboratory investigation consisting of model footing tests was conducted to study the effect of important parameters such as geometry of the footing, density or relative density of sand, length, spacing, extent and roughness of vertical reinforcement in improving the ultimate bearing capacity under static loads, and the cyclic load resistance of sand subgrades. The terms relating to vertical reinforcement namely the length 'L', spacing 'S' and extent 'R' are

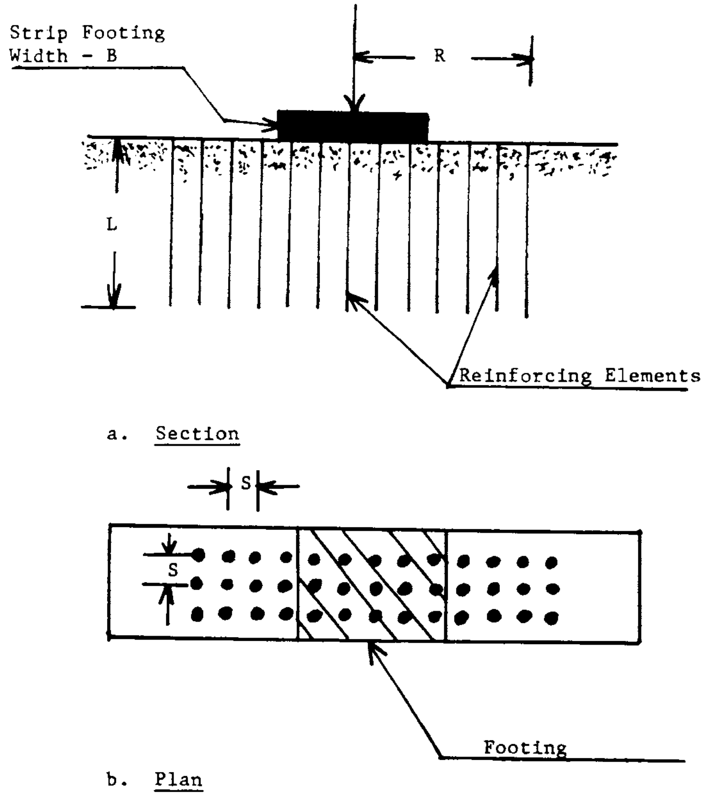

Fig. 1 Geometry of Reinforcement in the Soil Box

defined in Figure 1. The results of the study pertaining to load-settlement characteristics and ultimate bearing capacity under static loads are discussed elsewhere, (Chae (1988)). The results of static loading tests indicated that for a given footing size and relative density of sand, the maximum improvement in ultimate bearing capacity was observed when the combination of reinforcement parameters given in Table 1 was used. This information was used in planning the cyclic loading tests which are discussed here in detail. The cyclic load resistance was measured in terms of the coefficient of elastic uniform compression 'C_u' which is commonly used in design of rigid block type foundations for reciprocating machines (Barkan (1962), Prakash and Puri (1988)). The details of the model footing tests conducted and the results obtained during this study will now be presented.

TEST SETUP

Model footing tests under plane strain conditions were conducted in a sandbox measuring 914.4 mm x 52.4 mm x 609.6 mm (length x width x height). The longer side of the box was made of thick plexiglass to observe the deposition of sand in the box during sample preparation and the development of the failure surface in the sand under the foundation during the model tests. The smooth surface of the plexiglass also helped to minimize the effects of side resistance on the rupture surface in the soil. The walls of the box were also restrained against lateral deformation by stiffening them with angle irons.

TABLE 1 - Combination of Reinforced Parameters for Best Improvement in Ultimate Bearing Capacity Based on Model Test Results.

Reinforcement Parameter	Value
Length, L	1.5B* - 2.0B
Spacing, S	0.15B - 0.2B
Extent, R	2B

*B = Width of Footing.

The load on the model footing was applied with the help of hand-operated screw jack and measured with a proving ring. The vertical settlement of the footing was observed with a pair of dial gauges fixed to extension links on either side of the model footing.

TEST PARAMETERS

The model footings used in this study were 50.8 mm (width) x 152.4 mm (length) x 50.8 mm (thickness) and 101.6 mm (width) x 152.4 mm (length) x 50.8 mm (thickness) and were cut from hard wood. The base of the footings was made rough by gluing sand particles to the base. The soil used for this study was medium silica sand with a Unified soil classification of SP. The effective size of the sand and its uniformity coefficient were 0.398 mm and 1.2, respectively. The tests were conducted by depositing sand at initial relative densities of 45, 60, and 70 percent.

TABLE 2 - Test Parameters

Parameters	Range	
Footing Size (mm)	50.8 x 152.4	101.6 x 152.4
Initial Relative Density, D_r (%)	45, 60, 70	45, 60, 70
Length of Reinforcement, L	B, 1.5B, 2B	B, 1.5B, 2B
Spacing of Reinforcement S	0.2B, 0.3B 0.4B	0.1B, 0.15B, 0.2B
Extent of Reinforcement R	B, 2B	B, 2B

Cyclic loading tests were performed on Unreinforced and reinforced sand. Two types of reinforcement elements were used in this investigation, (a) plain reinforcement that consisted of 1.58 mm diameter steel rods, and (b) rough or (ribbed) reinforcement which consisted of steel rods with a single grain layer of very fine sand bonded onto their surfaces using epoxy glue. The effective diameter of ribbed reinforcement was also kept as 1.58 mm. Several combinations of length (L), spacing (S) and extent of the reinforcement (R) were used for the tests. These combinations are listed in Table 2 which also summarizes other test parameters.

TEST PROCEDURE

The sand test beds were prepared by depositing sand in layers through a long-stemmed funnel. The height of free fall of sand to ensure a deposit of uniform density was decided by conducting trial tests. The uniformity of layers was also checked by placing small containers before depositing the particular layer and taking out and weighing these samples after the layer was deposited. After proper preparation of the sand bed, the vertical reinforcing elements were pushed into it at predetermined spacings. The sand bed was again leveled at the end of placement of the reinforcement and before placing the model footing on it.

The cyclic loading tests were performed by applying a predetermined vertical load increment which was maintained until the vertical settlement of the model footing became constant. The applied load and the corresponding settlement were recorded. The static load was then released and the new equilibrium value of the settlement was noted. The above process was repeated for several predetermined values of load increments for each test.

MODEL TEST RESULTS AND DISCUSSION

The data obtained from the model footing tests was used to make settlement versus pressure plots under conditions of cyclic loading (repeated loading and unloading). A typical settlement versus pressure plot for the case of cyclic loading test on 50.8 mm x 152.4 mm model footing resting on unreinforced sand at an initial relative density (D_r) of 60% is shown in Fig. 2. From a plot of this type, the elastic settlement corresponding to a given load intensity may be obtained as follows (Fig 2):

$$S_e = S_t - S_r \tag{1}$$

where, S_e = elastic settlement,
S_t = total settlement,
and S_r = residual settlement.

A typical plot of settlement versus pressure from a cyclic loading test on 50.8 mm x 152.4 mm footing resting on sand placed at an initial relative density of 60% and reinforced with plain elements (L = 1.5B, S = 0.2B and R = 2B) is shown in Fig. 3. A comparison of Figs. 2 and 3 shows that for any given value of applied pressure within the range of experimental

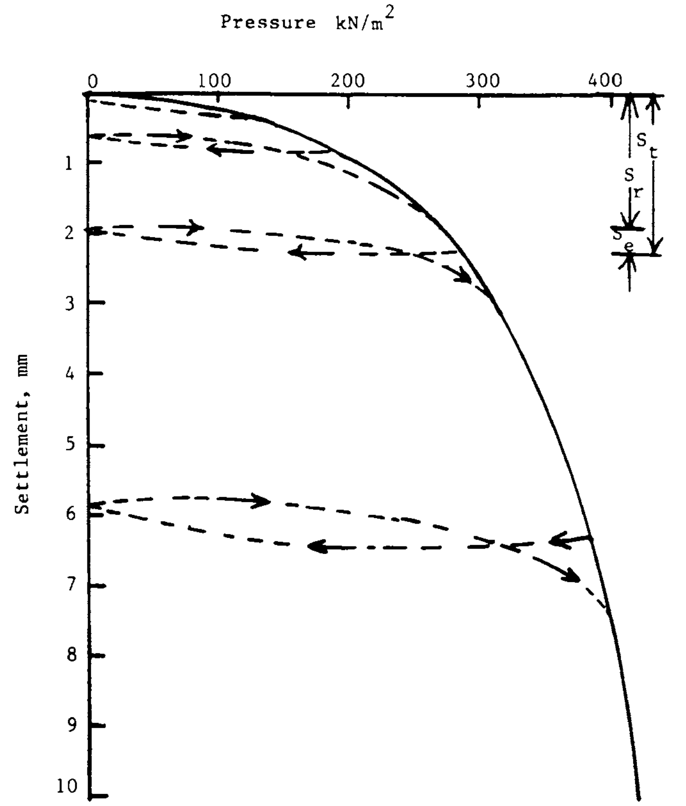

Fig. 2. Typical settlement Versus Pressure Plot From Cyclic Loading Test, Footing size 50.8 mm x 152.4 mm, Unreinforced Sand D_r = 60°/°

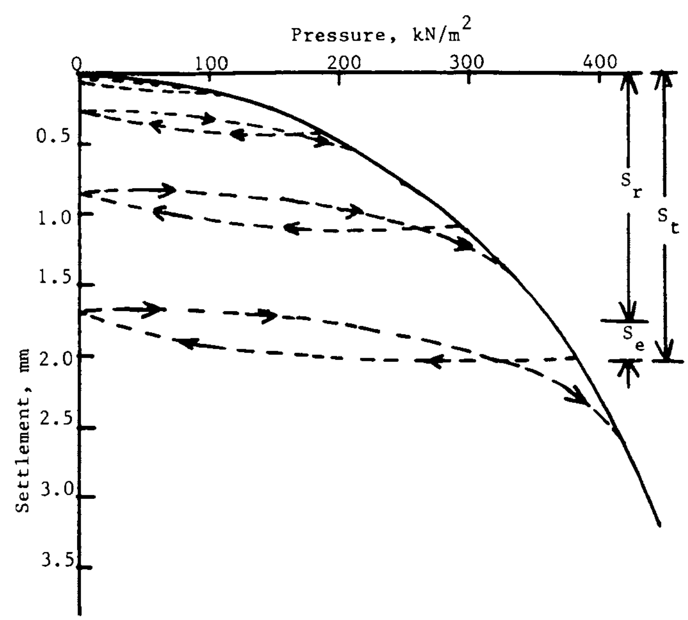

Fig. 3. Typical Settlement Versus Pressure Plot From Cyclic Loading Test, Footing Size, 50.8 mm x 152.4 mm, Reinforced Sand, L = 1·5B, R = 2B, S = 0·2B, D_r = 60°/°

values, both the total settlement, and the elastic settlement are smaller for the case of model footing resting on reinforced sand as compared to the case of model footing resting on unreinforced sand, all other conditions remaining the same. Sand reinforced with plain vertical elements is thus seen to exhibit a higher resistance to cyclic loading compared to the case of unreinforced sand placed at the same initial relative density. Similar trends of results was observed for tests conducted on sand at other relative densities and using different combinations of reinforcement parameters. The cyclic loading resistance was found to increase further when the plain reinforcing elements were replaced by ribbed (or rough) reinforcing elements.

From plots similar to those shown in Figs. 2 and 3, the values elastic settlement were obtained for different values of applied pressure used in each test. This information was used to make elastic settlement versus pressure plots for each of the cyclic loading tests. Figure 4 shows typical plots of elastic

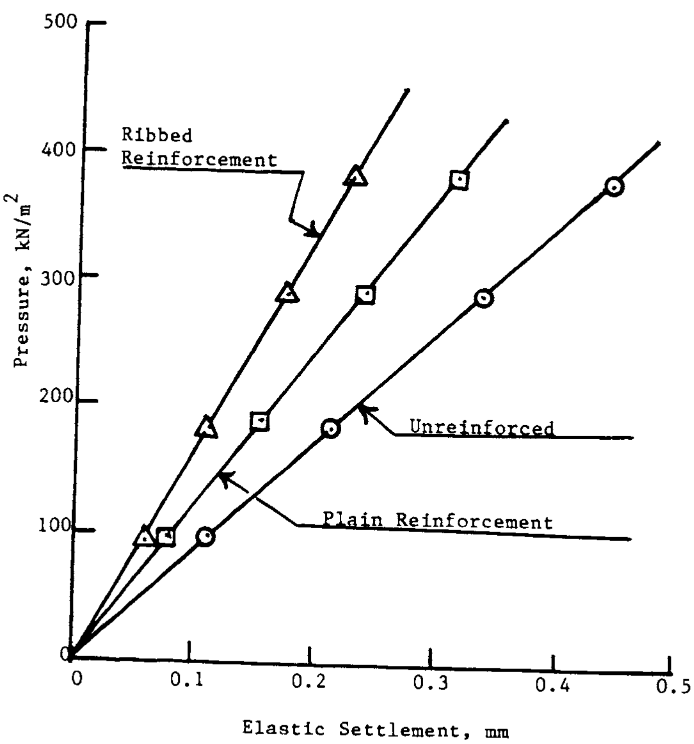

Fig. 4. Pressure Versus Elastic Settlement Plot for 50.8 mm x 152.4 mm Footing, D_r = 60%, for Tests with Reinforcement, L = 1·5B, R = 2B, S = 0·2B

settlement versus pressure for 50.8 mm x 152.4 mm footing on sand placed at an initial relative density of 60%, for the cases of unreinforced sand and for sand reinforced with plain and ribbed elements (L = 1.5B, S = 0.2B and R = 2B). From the elastic settlement-pressure plots, the value of coefficient of elastic uniform compression C_u may be calculated as follows:

$$C_u = \frac{p}{S_e} \qquad (2)$$

where p = applied pressure.

The value of C_u was then used for comparing the test results, and evaluating the beneficial effects of vertical reinforcement in sand in increasing its value compared to unreinforced sand.

It was also observed during the analysis of the test data that for any given model footing size and initial relative density of sand, the value of C_u for the case of sand reinforced with plain elements was always more than its value for the case of unreinforced sand. For a given footing size and initial relative density of sand, the value of C_u was found to be more for the case of sand reinforced with rough elements compared to its value for the case of sand reinforced with plain elements.

For the case of reinforced sand, the value of 'C_u' was observed to vary with the variation in reinforcement parameters. The value of C_u was observed to increase with increase in length (L) of the reinforcement elements, and attained a maximum value when L was about 1.5 to 2.0B. Similarly, the values spacing (S) and extent (R) that yielded the maximum values of C_u for a given footing size and initial density of sand, were observed to be about 0.2B and 2B respectively. The values of reinforcement parameters that give optimum improvement in values of C_u are thus in the same range as the values of these parameters for best improvement in ultimate bearing capacity (Table 1). The average values of C_u for the model footings used in this study for the case of unreinforced sand, and sand reinforced with plain and ribbed elements using optimum combination of reinforcing elements are given in Table 3. In order to evaluate the effect of initial density of sand on the improvement in value 'C_u' resulting from use of vertical reinforcement, an improvement index 'I' was defined as follows:

$$I = \frac{(C_u)_r}{(C_u)_u} \qquad \textbf{(3)}$$

where, $(C_u)_r$ = Value of C_u for the reinforced sand

and, $(C_u)_u$ = Value of C_u for sand without any reinforcement

The calculated values of 'I' are given in Table 3. Plots were then made of I versus the initial relative density of sand for the footing of width B = 50.8mm and 101.6 mm for the case of plain and ribbed reinforcement and are shown in Figs. 5 and 6 respectively. It is observed from these two figures that the values of 'I' for all initial relative densities of soil used in these tests are more than one. The beneficial effects of vertical reinforced (plain as well ribbed) in improving the value of C_u therefore occurred at all placement densities used in this study. The magnitude of I is however a function of the initial relative density of sand. The value I (Figs. 5 and 6) is seen to increase with increase in relative density 'D_r' up to a certain maximum value and becomes practically constant thereafter. This may be due to the fact that when the vertical reinforcing elements are installed in sand at

TABLE 3 - Values of C_u and I

Model Footing Size	Initial Relative Density D_r %	Unreinforced Sand	Sand with Plain Reinforcement		Sand with Ribbed Reinforcement	
		C_u kN/m^3 x 10^5	C_u kN/m^3 x 10^5	I	C_u kN/m^3 x 10^5	I
50.8 mm x 152.4 mm	45	5.510	6.890	1.25	9.095	1.65
	60	8.75	12.680	1.59	16.80	2.14
	70	11.025	17.690	1.60	30.870	2.80
101.6 mm x 152.4 mm	45	3.885	4.960	1.27	6.420	1.56
	60	5.790	9.095	1.57	12.200	2.10
	70	7.800	11.025	1.57	19.290	2.47

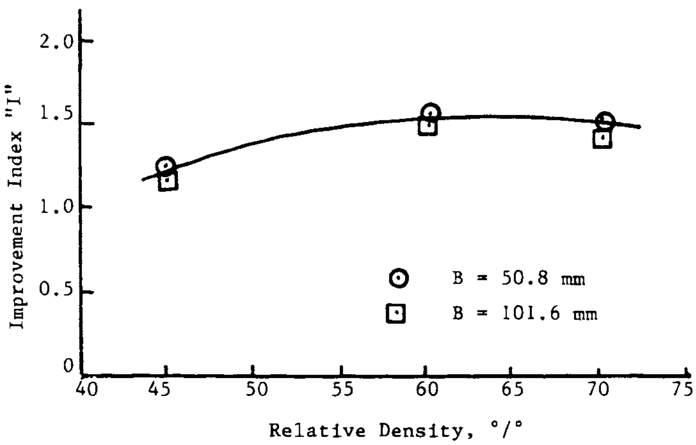

Fig. 5. Improvement Index Versus Relative Density, Plain Reinforcement

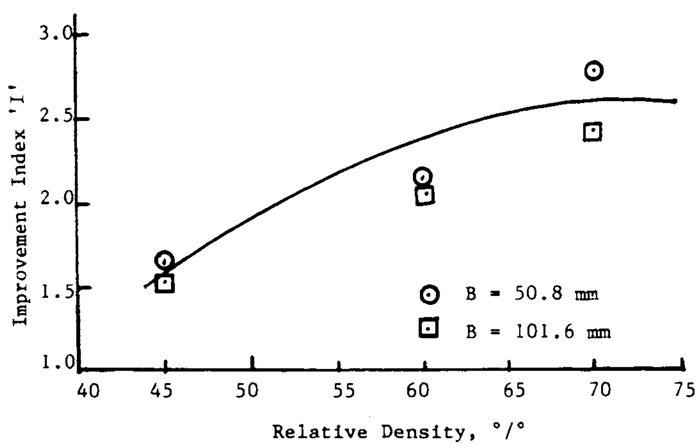

Fig. 6. Improvement Index Versus Relative Density, Ribbed Reinforcement

a relatively lower density, it becomes somewhat compacted, and the combined effect of this increase in density and the presence of reinforcing elements results in an increase in the value of C_u. When the reinforcing elements are installed in a relatively dense sand, the upper sand layers get somewhat loosened and the combined effect of this loosening in sand and the presence of reinforcing elements tends to make the value I more or less constant or may even make it to decrease somewhat.

CONCLUSIONS

1. The beneficial effects of using vertical reinforcing elements in improving the values of coefficient of elastic uniform compression of sand subgrades have been demonstrated through a series of model footing tests conducted in the laboratory.

2. The improvement in values of C_u resulting from the use of flexible vertical reinforcing elements depends on the length, extent and spacing of the reinforcing elements. The optimum improvement in values of C_u can be obtained by using combination of reinforcing parameters suggested in Table 1.

3. Rough reinforcement was found to be more effective in improving the value of C_u as compared plain reinforcement, all other factors remaining the same.

4. The beneficial effects of using the vertical reinforcement for improving the values of C_u were observed at all densities of sand used in the tests. The improvement index 'I' tends to increase with increase in initial relative density of sand and tends to become constant as relative density becomes about 70%.

REFERENCES

Akinmusuru, J. O. and Akinbolade, J. A. (1981) "Stability of Loaded Footings on Reinforced Soil," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT6, pp. 819-827.

Bassett, R. H. and Last, N. C. (1978) "Reinforcing Earth Below Footings and Embankments," Proceedings, Symposium on Earth Reinforcement, ASCE Annual Convention, Pittsburgh, PA.

Barkan, D. D. (1962) "Dynamics of Bases and Foundations," McGraw Hill Book Co., NY.

Binquet, J. and Lee, K. L. (1975) "Bearing Capacity Tests on Reinforced Earth Slabs," Journal of the Geotechnical Engineering Division, ASCE, Vol. 101, No. GT12, pp. 1241-1255.

Chae, A. (1988) "Static and Cyclic Load Resistance of Vertically Reinforced Sand Subgrades," M.S. Thesis, Department of Civil Engineering and Mechanics, Southern Illinois University, Carbondale, IL.

Fragaszy, R. H. and Lawton, E. (1984) "Bearing Capacity of Reinforced Sand Subgrades," Journal of the Geotechnical Engineering Division, ASCE, Vol. 110, No. GT10, pp. 1500-1507.

Gray, D. H. and Al-Refeai, T. (1986) "Behavior of Fabric Versus Fibre Reinforced Sand," Journal of the Geotechnical Engineering Division, ASCE, Vol. 112, No. GT8, pp. 804-820.

Guido, V. A., Biesiadecki, G. L. and Sullivan, M. J. (1985) "Bearing Capacity of a Geotextile Reinforced Foundation," Proceedings, XI International Conference on Soil Mechanics and Foundation Engineering, pp. 1777-1780.

Guido, V. A., Chang, D. K. and Sweeny, M. A. (1986) "Comparison of Geogrid and Geotextile Reinforced Earth Slabs," Canadian Geotechnical Journal, Vol. 23, No. 4, pp. 435-440.

Ingold, T. S. and Miller, K. S. (1982) "Analytical and Laboratory Investigations of Reinforced Clay," Proceedings, II International Conference on Geotextiles, pp. 587-592.

Kinney, T. (1982) "Small Scale Load Tests on a Soil-Geotextile Aggregate System," Proceedings, II International Conference on Geotextiles, pp. 405-409.

Milligan, G. W. E. and Love, J. P. (1984) "Model Testing of Geogrids Under an Aggregate Layer of Soft Ground," Proceedings, Symposium on Polymer Grid Reinforcements in Civil Engineering, Institution of Civil Engineers, London, Paper No. 4.2.

Prakash, S. and Puri, V. K. (1988) "Foundation for Machines: Analysis and Design," John Wiley and Sons, New York.

Puri, V. K. and Das, B. M. (1989) "Model Tests for Bearing Capacity of Vertically Reinforced Foundations in Sand," Foundation Engineering: Current Principles and Practices, ASCE, Vol. I, pp. 474-484.