THE BEHAVIOUR OF SETTLEMENT AND ELASTIC MODULUS OF A CIRCULAR FOUNDATION RESTED ON GEOGRID REINFORCED SAND

Abdulazim Yildiz[1], Mustafa Laman[2], Murat Ornek[3] & Ahmet Demir[4]

[1] *Cukurova University. (e-mail: azim@cukurova.edu.tr)*
[2] *Cukurova University. (e-mail: mlaman@cukurova.edu.tr)*
[3] *Cukurova University. (e-mail: mornek@cukurova.edu.tr)*
[4] *Cukurova University. (e-mail: ahmetdemir@cukurova.edu.tr)*

Abstract: Construction in loose or soft subsurface soil conditions may not sometimes be possible without using a suitable soil improvement technique. Shallow foundations, when built on weak subgrade soils, have low load-bearing capacity and undergo large settlements. So, reinforced soil is one of the soil improvement techniques that the ultimate bearing capacity of a shallow foundation can be improved considerably. However, the design of most shallow foundations is controlled by the allowable level of settlement rather than the ultimate bearing capacity.

This paper investigates the behaviour of settlement and elastic modulus of a circular foundation rested on geogrid-reinforced sand. Laboratory model tests were carried out to determine the variables effecting the settlement behaviour and elastic modulus of circular foundations resting on a geogrid-reinforced soil. The location of the first layer of reinforcement, the number of reinforcement layers, the vertical spacing between reinforcement layers and the length of each reinforcement layer are considered in this investigation as variables effecting these parameters.

Experimental results show that settlement behaviour of soils can be improved by using geogrid reinforcement significantly. Improvement depends on the arrangement and the amount of reinforcement layers. It is also found that elastic modulus of the reinforced soil increases about 3.5-4.0 times than that of the unreinforced case and a decrease occurs in settlements approximately 80%.

Keywords: geogrid, geogrid reinforcement, sand, settlement

INTRODUCTION

The use of reinforcement to improve the engineering performance of soil has gained great attention in recent decades. Reinforced soil is a construction technique that consists of strengthening soil by tensile elements such as metal strips, geotextiles, or geogrids. Several laboratory model test results are currently available in the literature, related to improvement in the load-bearing capacity of shallow foundations supported by sand reinforced with various materials, such as metal strips, metal bars, rope fibers, geotextiles and geogrid. Binquet and Lee (1975) concluded that the bearing capacity of sand increases as much as three times, sometimes even more, with a moderate amount of reinforcement in the form of aluminium strips. Akinmusura and Akinbolade (1981) studied the bearing capacity of square footing supported by sand that was reinforced by natural fibers like iko. Fragaszy and Lawton (1984) investigated reinforced earth slabs with a strip footing on sand reinforced by aluminium foil placed in several layers. A detailed analysis was made paying individual attention to soil, reinforcement and the interface between the soil and reinforcement by Kurian *et al.* (1997). Haeri *et al.* (2000) studied the effect of geotextile reinforcement on the mechanical behaviour of sand. Other studies on geogrid reinforced sand were carried out by Guido 1986; Omar *et al.* 1993; Yetimoglu *et al.* 1994; Adams and Collin 1997; Das 1999; Laman and Yildiz 2003. Gabr and Hart (2000) performed an experimental study to evaluate the elastic modulus of sand reinforced with polymeric geogrids using plate load tests.

Most of the aforementioned studies deal with the aspect of bearing capacity, whereas in the majority of cases, the design of shallow foundations in sand is governed by settlement rather than bearing capacity (Kurian *et al.* 1992). Only very limited information is available in the literature (e.g. Nagoa *et al.* (1988) and Gens *et al.* (1989)) on the settlement of reinforced sand beds. Al-Sanad *et al.* (1993) conducted plate load tests to evaluate the settlement of circular and ring plates in very calcareous sands. Alawaji (2001) evaluated settlement and bearing capacity of geogrid reinforced sand over collapsible soil. Abdel-Baki and Raymond (1994) showed the reduction of settlements using soil reinforcement including eccentric and inclined loadings.

This paper describes a series of laboratory model tests designed to determine the influence of some variables on the settlement behaviour and elastic modulus of circular foundations resting on a geogrid-reinforced soil. The location of the first layer of reinforcement, the number of reinforcement layers, the vertical spacing between reinforcement layers and the length of each reinforcement layer are considered to be the variables in this investigation.

For comparison of test results, Settlement Ratio (SR) and Percentage Reduction in Settlement (PRS) were used as previously described by Mandal and Sah (1992) and others;

$$SR = S / D \qquad PRS = (S_0 - S_r) / S_0 = 1 - (S_r / S_0) \qquad (1)$$

Where S_0 and S_r are the settlements for the unreinforced and reinforced sands respectively; S is the footing settlement and D is the footing diameter.

For calculation of the soil modulus E, the linear portions of load-settlement curves were considered. The soil modulus E was calculated from the theory of elasticity as

$$E = [(q\ D\ (1 - \nu^2)) / S]\ I_s \qquad (2)$$

Where q is the intensity of contact pressure; D is the diameter of plate; S is the settlement; ν is the Poisson's Ratio and I_s is the influence factor, which depends on the shape of the plate and its rigidity.

For a rigid circular plate resting on a homogeneous elastic half-space, I_s is equal to ($\pi / 4 = 0.786$) as presented by Timoshenko and Goodier (1970). Poisson's Ratio was calculated from (Jaky, 1948)

$$\nu = K_0 / (1+K_0) \qquad K_0 = 1 - \sin \phi' \qquad (3)$$

The angle of shearing resistance of the sand at a dry unit weight of 17.1kN/m^3 and for normal pressures of 50, 100 and 200 kPa was determined by direct-shear test. The measured average peak friction angle was 41°. Using this value in (3) yields $K_0 = 0.344$ and $\nu = 0.26$.

Substituting the aforementioned values for ν and I_s in (2) and employing the incremental pressure Δq = (q – 250kPa) and Δs yields;

$$E = 0.715\ [\Delta q / (\Delta s / D)] \qquad (4)$$

The data points representing Δq versus (Δs / D) were plotted, and straight lines were fitted through these points. From the slope of these lines, the E modulus was obtained (Al-Sanad *et al.* (1993)).

The term Elastic Modulus Improvement Factor (EMIF) is used to express the improvement in stiffness of reinforced sand and is defined as follows:

$$EMIF = E_R / E_0 \qquad (5)$$

Where, E_R and E_0 are elastic modules of reinforced and unreinforced sand, respectively.

EXPERIMENTAL PROGRAMME AND MATERIALS

Test Tank

Tests were conducted in a steel tank with dimensions 700 mm (length) x 700 mm (width) x 700 mm (depth). Static vertical loads were applied to the model foundations by hand operated mechanical jack attached to a loading frame located above the tank. Then, load and displacement measurements were made by a dial gauge and a proving ring installed between the jack and the model foundation (Figure 1).

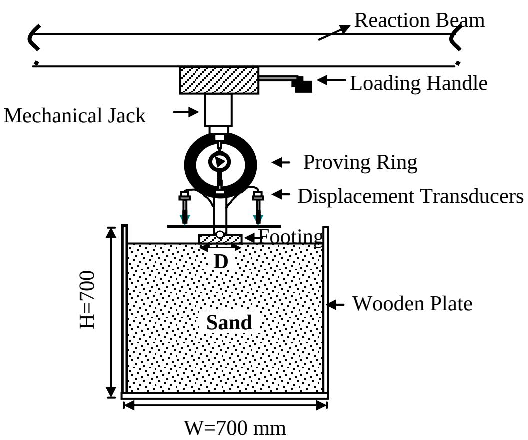

Figure 1. General layout of apparatus for model test

Model Foundation and Soil Property

Loading tests were carried out on a model circular foundation fabricated from mild steel. Circular plate had thickness of 20mm and diameter of 85mm.

Uniform, clean, fine sand obtained from the Seyhan river bed used for the model tests. The properties are summarized in Table 1. The angle of shearing resistance of the sand at dry unit weight of 17.10kN/m^3 and for normal pressures of 50, 100, and 200kPa was determined by direct-shear test. The measured average peak friction angle was 41°.

Table 1. Properties of sand bed

Parameters	Values
Coarse / Medium / Fine Sand Fractions	0.00 / 34 % / 66 %
D_{10} / D_{30} / D_{60}	0.26mm / 0.30mm / 0.40mm
C_u / C_c	1.53 / 0.87
Classification (USCS)	SP
Max. / Min. Dry Unit Weights	1.78t/m^3 / 1.59t/m^3
Specific Gravity	2.68

Details of Geogrid Reinforcement

Terragrid GS1000 type of biaxial geogrid manufactured by the VATEKS Company in Turkey, was used as reinforcement. The physical and mechanical properties of the geogrid are given in Table 2.

Table 2. Engineering properties of geogrid

Parameter	Value
Type of reinforcement	Terragrid GS 1000
Bar length / width / thickness	min 50m - max 70m / 1.0m / 0.95mm
Aperture size	30mm x 30mm
Weight per unit area	0.5 (± 0.1) kg/m^2
Tensile Strength	28.60 kN/m
Raw material	polypropylene
Elongation at yield	11.6 %
Temperature	betw. -50 and +60 °C

Model Tests

Laboratory model tests were conducted on sand bed with unit weight of 17.1kN/m^2. To maintain the consistency of the density throughout the test pit, the same compactive effort was applied on each layer. The model foundation was placed on the surface of the sand bed at predetermined locations in the test pit. Vertical compressive load was applied in small increments to the model foundation by means of a mechanical jack supported against a reaction beam. Constant load increment was maintained until the foundation settlement has stabilised. The tests were continued until the applied vertical load clearly reduced or a considerable settlement of the foundation resulted from a relatively small increase under vertical load.

The location of the first layer of reinforcement (u), the number of reinforcement layers (N), the vertical spacing in the reinforcement layers (h) and the length of each reinforcement layer (B_R) are chosen as variables in the experimental study (Figure 2).

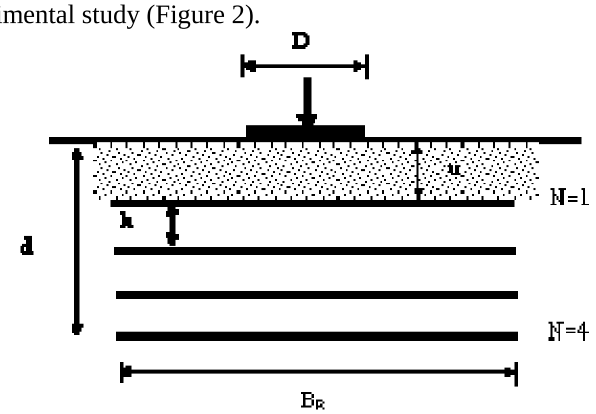

Figure 2. Geometric parameters of model test

Effect of Depth to First Reinforcement Level (u/D)

The tests in this series were conducted to determine the effect of depth ratio, u/D on the settlement behaviour and elastic modulus. For the tests, the values of N, h/D, and B_R/D were kept constant as 4, 0.30, and 5, respectively. The u/D ratios were varied from 0.30 to 1.20. The relations of the loading pressure (q) with foundation settlement (s/D) for various values of u/D obtained from the laboratory model tests are presented in Figure 3 along with the results of unreinforced sand. Figure 4 shows the relation of EMIF with u/D obtained from Figure 3 by using Equation 5. It can be seen from Figure 3 and Figure 4 that the distance between the foundation and the first reinforcement layer affected the settlement quantity and elastic modulus values significantly. EMIF values increase with the decrease in the ratio of u/D. It can be determined that the amount of increase in elastic modulus of reinforced soil was obtained as 370% for u/D ratio of 0.30. For the value of u/D greater than 1, the EMIF values remain practically constant.

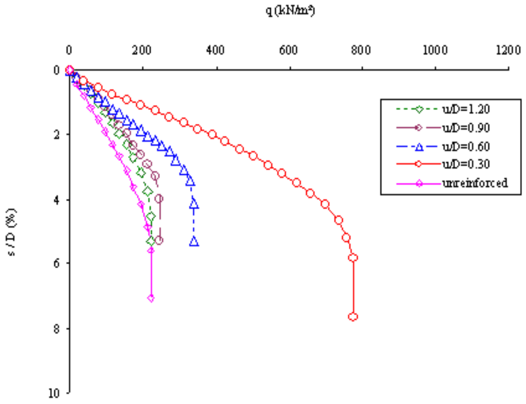

Figure 3. Curves of settlement ratio against loading pressure for different (u/D) ratios

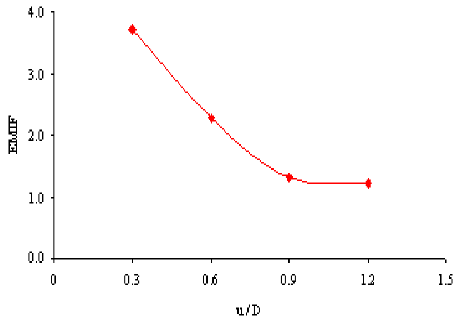

Figure 4. Relation of EMIF to u/D

Figure 5 shows the values of PRS in different u/D ratios for loading pressures of q =50, 100, 150 and 200kN/m² obtained from Figure 3. It can be seen that the PRS values increase generally with decreasing depth of the first reinforcement layer. The PRS is calculated as 75% for u/D=0.30 and q=200 kN/m².

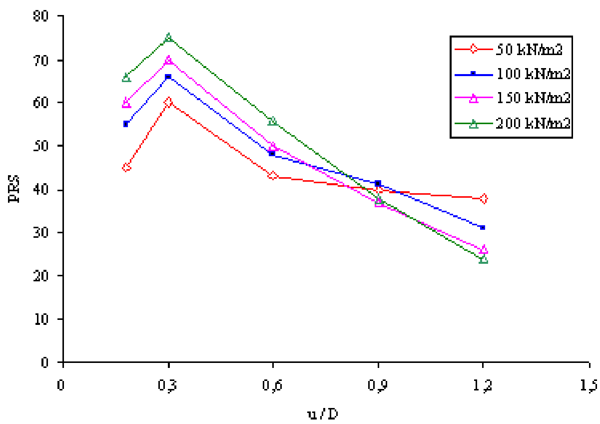

Figure 5. PRS values in different u/D ratios for various loading pressure

Effect of number of reinforcement layer (N)

A second group of test were conducted to investigate the influence of the number of reinforcement layer (N) was examined on the settlement behaviour and elastic modulus at this stage of the tests. For the tests, the values of u/D, h/D, and B_R/D were kept constant as 0.30, 0.30, and 5, respectively. The N values were varied from 1 to 5. The relations of the loading pressure (q) with foundation settlement (s/D) for various values of N obtained from the laboratory model tests are presented in Figure 6 along with the results of unreinforced sand. The relation of EMIF with N values obtained from Figure 6 by using Equation 5 is shown in Figure 7. A significant increase was obtained with increasing number of reinforcement layers. The modulus of elasticity (if N=5) in reinforced case is 4 times greater than that of unreinforced one. Figure 8 shows the values of PRS in different N values for loading pressures of q =50, 100, 150 and 200 kN/m² obtained from Figure 6. It can be seen that the PRS values increase with increasing number of the reinforcement layer. For N=5, the settlement occurred in reinforced case decreases about 75% when comparing with unreinforced case.

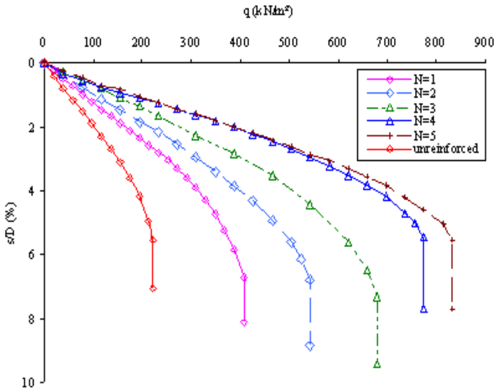

Figure 6. Curves of settlement ratio against loading pressure for different N values

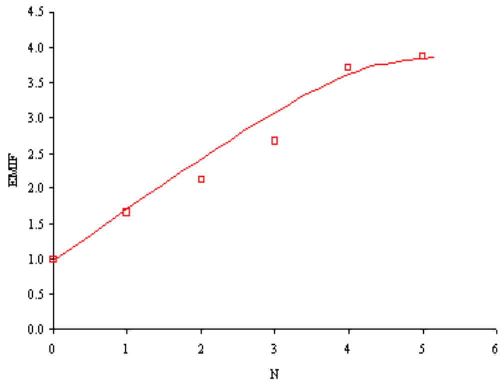

Figure 7. Relation of EMIF to N

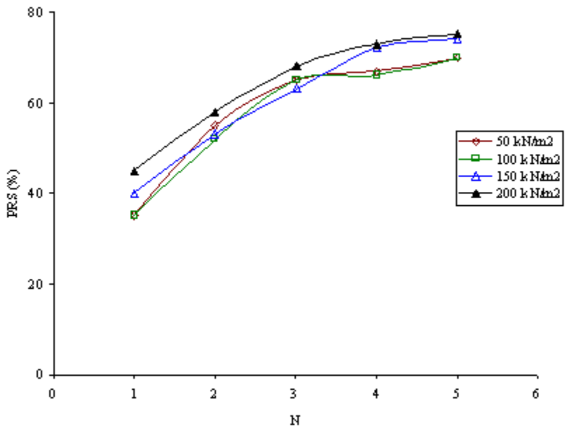

Figure 8. PRS values in different N numbers for various loading pressure

Effect of vertical spacing between reinforcement layers (h/D)

The relationships of (h/D) - (s/D) and (h/D) - EMIF are shown in Figure 9 and Figure 10, respectively. As the (h/D) ratios 0.12, 0.20, 0.30 and 0.40 were chosen to determine loading pressure (q) - foundation settlement (s/D) behaviour in this tests. While there were obtained very close results in EMIF values for h/D values 0.12, 0.20 and 0.30, there was a decrease in the condition of h/D>0.30. PRS values in different h/D ratios for loading pressure, q = 200 kN/m² obtained from Figure 9 is shown in Figure 11. It can be seen from the figure that there is a decrease of %80 in settlement when h/D equals 0.20.

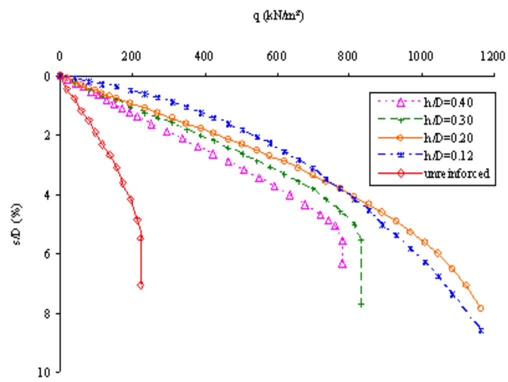

Figure 9. Curves of settlement ratio against loading pressure for different h values

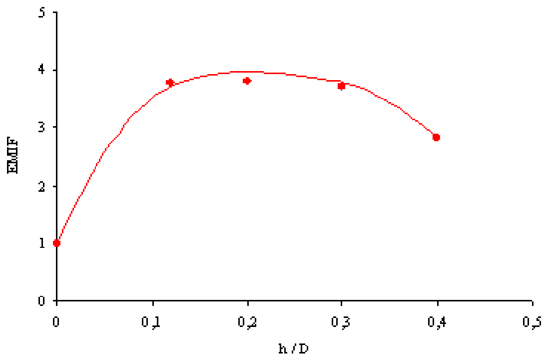

Figure 10. Relation of EMIF to h/D

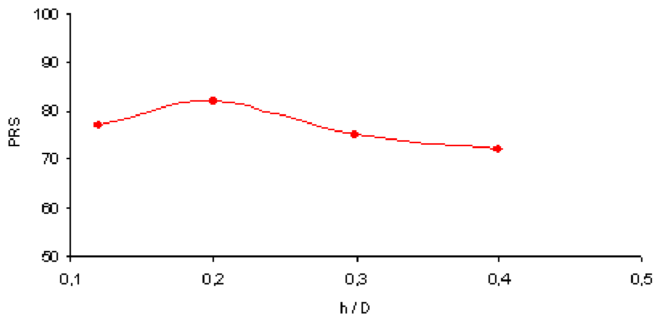

Figure 11. PRS values in different h/D ratios

Effect of length of reinforcement layer (B_R/D)

The influence of the length of reinforcement layer (B_R/D) was examined on the settlement behaviour and elastic modulus here. The relations of the loading pressure (q) with foundation settlement (s/D) for various (B_R/D) ratios obtained from the laboratory model tests are presented in Figure 12 along with the results of unreinforced sand. The relation of EMIF with (B_R/D) ratios obtained from Figure 12 by using Equation 5 is shown in Figure 13. From these figures it is seen that EMIF values are constant after (B_R/D) ≥ 3. Figure 14 shows PRS values in different B_R/D ratios for loading pressure, q = 200 kN/m² obtained from Figure 12. It was obtained that PRS changes between %65-%75 while B_R/D ratios change from 1 to 5.

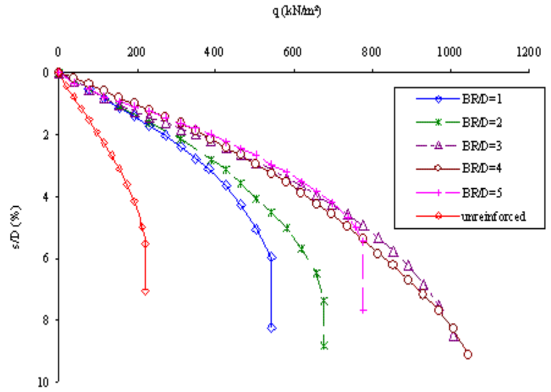

Figure 12. Curves of settlement ratio against loading pressure for different B_R/D ratios

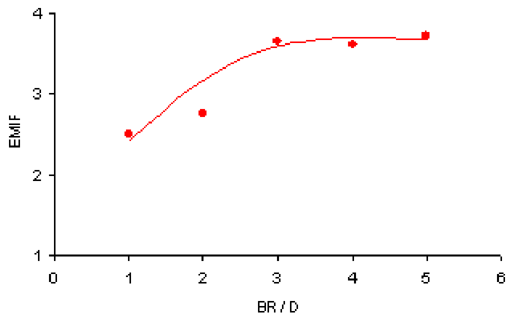

Figure 13. Relation of EMIF to B_R/D

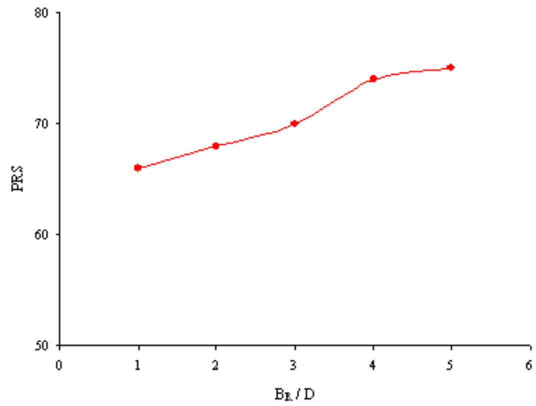

Figure 14. PRS values in different B_R/D ratios

CONCLUSIONS

After the analysis of the load settlement response and elastic modulus of circular model load tests on reinforced and unreinforced sand, the following conclusions can be drawn:

- A significant improvement in foundation performance can be obtained by using geogrid reinforcements, as the transfer of foundation loads to greater depths through the geogrid layers and interlock between the geogrid and the sand reduce lateral and vertical displacements below the foundation.
- The depth to first reinforcement level has a significant effect on foundation settlement. The optimum location of the first geogrid layer to obtain maximum benefit from the reinforcement is about 0.30D below the bottom of the circular foundation.
- The elastic modulus of reinforced sand increases with an increase in the number of reinforcement layers. The optimum number of layers of reinforcement is found to be four. The addition of more layers of reinforcement after the fourth did not contribute much to the elastic modulus improvement.
- Geogrid efficiency increases with the decreased vertical spacing between reinforcement layers. The optimum vertical spacing between reinforcement layers is about 0.20D.
- The optimum length of reinforcement layers that contribute to the significant increase of elastic modulus is found to be 3D. When the length of reinforcement layers is greater than 3D, the elastic modulus remains relatively constant.

- The elastic modulus of reinforced sand can be improved up to 400% and the settlement amount of circular foundations can be reduced up to 80% depending on the reinforcement geogrid arrangement.
- The size and scale effects of model foundations have not been investigated here. Nevertheless the investigations are considered to have provided a useful basis for further research leading to an increased understanding of the application of soil reinforcement to bearing capacity problems

Corresponding author: Prof Mustafa Laman, Cukurova University, Civil Engineering Department, Adana, Yuregir, 01330, Turkey. Tel: +90 322 338 70 50. Email: mlaman@cukurova.edu.tr.

REFERENCES

Abdel-Baki M. S. & Raymond G. P. 1994. Reduction of settlements using soil reinforcement. Proceedings of Settlement 94, ASCE, Geotechnical Special Publication (40), 525-537.

Adams M. T. & Collin J. G. 1997. Large model spread footing load tests on geosynthetic reinforced soil foundation. ASCE Journal of Geotechnical and Geoenvironmental Engineering, 123(1), 66-72.

Akinmusuru J.O. & Akinbolade J.A. 1981. Stability of loaded footings on reinforced soil. ASCE Journal of Geotechnical Engineering, 107(6), 819-827.

Al-Sanad H. A., Ismael N. F. & Brenner R. P. 1993. Settlement of circular and ring plates in very dense calcareous sands. ASCE Journal of Geotechnical Engineering, 119(4), 622-638.

Alawaji H. A. 2001. Settlement and bearing capacity of geogrid reinforced sand over collapsible soil. Geotextile and Geomembranes, 19, 75-88.

Binquet J. & Lee K. L. 1975a. Bearing capacity tests on reinforced earth slabs. ASCE Journal of Geotechnical Engineering, 101(12), 1241-1255.

Das, B. M. 1999. Shallow foundation: bearing capacity and settlement. CRC Press.

Fragaszy R. J. & Lawton E. C. 1984. Bearing capacity of reinforced sand subgrades. Journal of Geotechnical Engineering, 110, 1500-1507.

Gabr M. A. & Hart J. H. 2000. Elastic modulus of geogrid reinforced sand using plate load tests. Geotechnical Testing Journal, 23(2), 245-250.

Gens A., Carol I. & Alonso E. E. 1989. An interface element formulation for the analysis of soil-reinforcement interaction. Computers and Geotechnics, 7(1-2), 133-151.

Guido V. A., Chang D. K. & Sweeny M. A. 1986. Comparison of geogrid and geotextile reinforced slabs. Canadian Journal of Geotechnical Engineering, 23, 435-440.

Haeri S. M., Noorzad R. & Oskoorouchi A. M. 2000. Effect of geotextile reinforcement on the mechanical behavior of sand. Geotextile and Geomembranes, 18, 385-402.

Jaky J. 1948. Earth pressure in silos. Proceedings 2nd International Conference on Soil Mechanics and Foundation Engineering, ICSMFE, Rotterdam, 1,103-107.

Kurian P. N., Beena K. S. & Kumar K. 1997. Settlement of reinforced sand in foundations. ASCE Journal of Geotechnical and Geoenvironmental Engineering , 123(9), 818-827.

Laman M. & Yildiz A. 2003. Model studies of ring foundations on geogrid reinforced sand. Geosynthetics International, 10(5), 142-152.

Mandal J. N. & Sah H. S. 1992. Bearing capacity tests on geogrid reinforced clay. Technical Note on Geotextile and Geomembranes, 11, 327-333.

Nagoa A., Kitamura T. & Mizutani J. 1988. Field experiment on reinforced earth and its evaluation using FEM analysis. Proceedings of the International Geotechnical Symposium on Theory and Practice of Earth Reinforcement, 329–334.

Omar M. T., Das B. M., Puri V. K. & Yen S. C. 1993b. Ultimate bearing capacity of shallow foundations on sand with geogrid reinforcement. Canadian Journal of Geotechnical Engineering, 30(3), 545-549.

Timoshenko S. P. & Goodier J. N. 1970. Theory of elasticity. 3rd Ed, McGraw-Hill, New York.

Yetimoglu T., Wu J. T. H. & Saglamer A. 1994. Bearing capacity of rectangular footings on geogrid-reinforced sand. ASCE Journal of Geotechnical Engineering, 120(12), 2083-2099.