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Numerical Study of Cyclic Behavior of Shallow Foundations on Sand Reinforced with Geogrid and Grid-Anchor

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***Abstract*—**When the foundations of structures under cyclic loading with amplitudes less than their permissible load, the concern exists often for the amount of uniform and non-uniform settlement of such structures. Storage tank foundations with numerous filling and discharging and railways ballast course under repeating transportation loads are examples of such conditions. This paper deals with the effects of using the new generation of reinforcements, *Grid-Anchor*, for the purpose of reducing the permanent settlement of these foundations under the influence of different proportions of the ultimate load. Other items such as the type and the number of reinforcements as well as the number of loading cycles are studied numerically. Numerical models were made using the Plaxis3D Tunnel finite element code. The results show that by using grid-anchor and increasing the number of their layers in the same proportion as that of the cyclic load being applied, the amount of permanent settlement decreases up to 42% relative to unreinforced condition depends on the number of reinforcement layers and percent of applied load and the number of loading cycles to reach a constant value of dimensionless settlement decreases up to 20% relative to unreinforced condition.

***Keywords*—**Shallow foundation, Reinforced soil, Cyclic loading, Grid-Anchor, Numerical analysis.

I. INTRODUCTION

BEHAVIOR of foundations on reinforced sand beds is one of the most interesting topics in geotechnical engineering.

The type and the quality of reinforcements have been changed a lot. The use of polymeric reinforcements such as geotextiles, geogrids and geonets has been increasingly expanding.

Up to now, many experimental and numerical studies have been made to determine the bearing capacity of shallow foundations on different soils reinforced by different elements such as metal strips, metal rods, tire shreds and geosynthetics [1]-[4]. Fig. 1 shows the classical scheme of a system of reinforced soil for a square foundation with $B\times B$ dimensions and N reinforcement layers. The dimensions of reinforcements are $b\times b$ and the distance between their first layer and the foundation bottom is denoted by u. the depth of the reinforcement area can be found using equation 1.

$$d = u + (N - 1)h \tag{1}$$

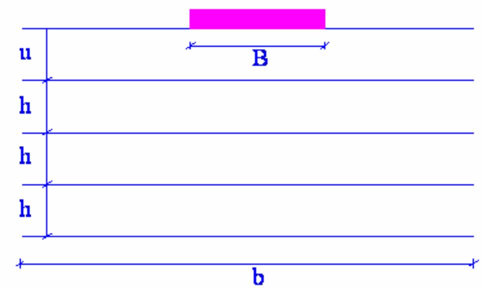

Fig. 1 Shallow square foundation supported by geogrid-reinforced sand

Previous studies have given different optimal values for the ratios *u/B*, *b/B* and *h/B* for optimizing the bearing capacity of shallow foundations [1]-[5]. Binquet and Lee (1975) and Guido *et al.* (1986) showed that the ratio *u/B* for the most suitable state possible of the influence of the use of the reinforcement must be chosen as less than 0.67 [1], [4]. They provided also the values of $(b/B)_{cr}$ and $(d/B)_{cr}$ for a square foundation on the sandy soil reinforced by the geogrid to be 2 to 3 and 1.25 respectively.

Yetimuglu et al. (1994) found that the critical value of *u/B*, *h/B* and *b/B* were equal to 0.25, 0.2 and 4.5 respectively [6]. Adams and Collin (1997) also conducted a comprehensive study on geogrid and geocell reinforced foundations on 34 large-scale models [7]. Bearing capacity ratio $(BCR=q_r/q_{ur})$ which is defined as the ratio of the bearing capacity of the reinforced soil (q_r) to that of the unreinforced soil (q_{ur}), was reported to be 2.63 for the geogrid reinforced foundations while BCR = 1.27 for the geocell-reinforced foundations. Das *et al.* (1994) investigated the behavior of strip footing on geogrid reinforced sand [8]. They found that full depth geogrid reinforcement may reduce the permanent settlement of a foundation by about 20% to 30% compared to one without reinforcement. Unikrishnan *et al.* (2002) conducted laboratory triaxial tests to investigate the behavior of reinforced clay under monotonic and cyclic loading. They found that due to provision of sand layers on either side of the reinforcement (sandwich technique) within reinforced clay soils, the response of reinforced clay soil by way of enhanced interfacial bond was improved [9]. Boushehrian and Hataf

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(2003) studied experimentally and numerically the effect of depth to first layer of reinforcement *(u)*, spacing between reinforcements *(z)*, and reinforcement stiffness *(EA)* on the bearing capacity of circular and ring foundations on sand [10].

Chang and Cascante (2006) have shown that a critical zone between 0.3B and 0.5B is identified for maximizing the benefits of soil reinforcement [11]. They found that if the reinforcements placed within one footing width *(B)* below the foundation, *BCR* and the low strain stiffness of reinforced system is increased by transferring the foundation load to deeper soil layers and thus reducing the stresses and strains underneath the foundation.

Mosallanezhad *et al*. (2007) deal with the influence of new generation of reinforcement (named by them grid-anchor) on the increase of bearing capacity of square foundation [12]. They found that the critical value of *u/B*, *h/B* and *b/B* were equal to 0.25, 0.25 and 4.5 respectively. They also showed that *BCR* for this system was greater than ordinary geogrid and equal to 3.0. Table I shows the result of their research

TABLE I
SUMMARY OF EXPERIMENTAL RESULTS MOSALLANEZHAD *ET AL.* (2007)

Characteristic	**Value**
h/B	0.25
u/B	0.25
b/B	5.0
c/B	4.0
N	4

Shin et al. (2008) showed that for the same maximum depth of reinforcement under cyclic loading test, the shear modulus increases with the number of layers in depth [13].

As revealed by the previous studies, few researches have been performed to obtain the cyclic behavior of shallow footings on reinforced soils [14]-[16]. Most of the studies have been done on reinforced soil under static loads.

In this study the effect of various factors such as the amplitude of the cyclic load applied, type and the number of reinforcements on the amount of permanent settlement of square foundations and the number of cycles required to achieve such amount of settlement computed numerically.

II. NUMERICAL MODELING

Numerical models were made using finite element software. PLAXIS 3D Tunnel which is a 3-dimensional finite element code for soil and rock analysis enhanced with abilities to model reinforced soils was employed for the analyses. The code is able to model geogrid sheets and connected anchors as a geo-anchor reinforced soil. Among other features of the software one can mention its ability to simulate the testing process, such as application of two groups of load, one in static form (load system *A*) and the other in cyclic form (Load system *B*) and specifying the number of load cycles by staged construction modeling. Fig. 3 shows one of the models being made using this software.

For all the models analyzed, the values of $u/B = (h/B)_{cr}$,$(b/B)_{cr}$ and $(d/B)_{cr}$ were taken as 0.25, 5.0 and 1.25, respectively.

The bearing capacity of the foundation on the reinforced soil by the tangent method (Fig. 3) was found to be 220 kPa.

The procedure of the analysis was as follows:

The first step: at first the initial fixed load in the form of static distributed load with a load per area unit of 4kN/m^2 that represents the weight of the structure and its accessories was applied to the foundation *(qs)*.

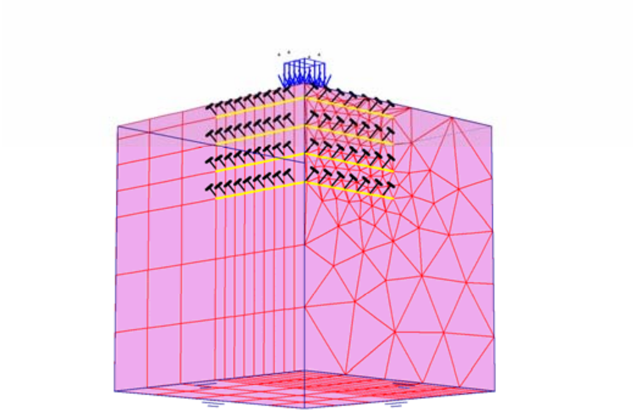

Fig. 2 3D modeling created with Plaxis3DT

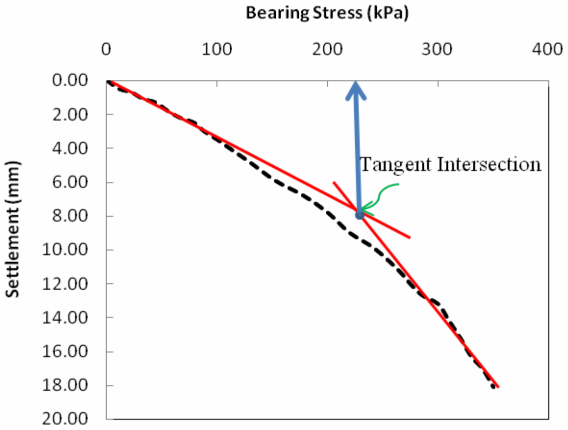

Fig. 3 Load settlement curve for unreinforced soil

The second step: in this step, the cyclic load in the form of a percentage of the ultimate load on the foundation was being added to the previous fixed load (q_d).

The two-above mentioned steps were repeated for both reinforcement types with different number of layers. Table II shows the details of analysis being analyzed with numerical models. The selected percentages are 6, 20 and 33 percent (with respect to allowable bearing capacity), respectively.

The hypotheses being used in the numerical modeling are given in Table III.

III. RESULTS AND DISCUSSIONS

In analysis results the final settlement due to the cyclic load is denoted by $(S_d)_f$. This is the permanent settlement due to the sum of fixed and cyclic loads.

TABLE II DETAILS OF NUMERICAL ANALYSIS

Analysis Series	Reinforcement	Percent of Applied Load(q_d/q_{ur})	N
A-1 to A-3	Unreinforced	6,20,33	-
B-1 to B-3	Geogrid	6,20,33	1
B-4 to B-6	Geogrid	6,20,33	2
B-7 to B-9	Geogrid	6,20,33	3
B-10 to B-12	Geogrid	6,20,33	4
C-1 to C-3	Grid-Anchor	6,20,33	1
C-4 to C-6	Grid-Anchor	6,20,33	2
C-7 to C-9	Grid-Anchor	6,20,33	3
C-10 to C-12	Grid-Anchor	6,20,33	4

N: number of reinforcement layers

TABLE III MATERIAL SET AND PARAMETERS USED IN THE NUMERICAL MODELING

Characteristic	Value
Friction Angle (Degree)	43
Cohesion (kPa)	10
Material Model	Hardening Soil Model
Material Type	Drained
E_{50}^{ref}	10e3 (kN/m^2)
E_{ur}^{ref}	30e3 (kN/m^2)
E_{ode}^{ref}	7000 (kN/m^2)
ν_{ur}	0.2
Power	0.5

E_{50}^{ref} : Reference secant stiffness modulus for mobilization of 50% of the maximum shear strength

E_{ur}^{ref} : Unloading-reloading modulus of elasticity

E_{ode}^{ref} : Oedometric modulus of elasticity

Fig. 4 provides variations of (S_d/B) with the number of cycles for series *A* (Unreinforced soil) analysis in different load percentages.

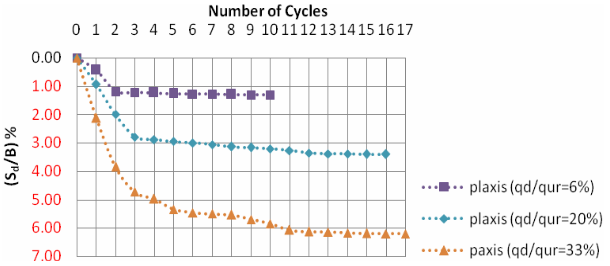

Fig. 4 Variation of (S_d/B) with number of load cycles for series A

Figs. 5 and 6 show the same items for soils reinforced by common geogrids with different numbers of layers and grid-anchors with 4 reinforcement layers, respectively.

A careful examination of the figures reveals that by increasing loading cycles, due to the soil beneath the foundation getting more compact, and, consequently, more engagement of soil grains with the reinforcements, the rate of settlement reduction is decreased. Increase in loading cycles more than a given number denoted by n_{cr} will have no effect on reducing the settlement. Figs. 7 and 8 show variations in the settlement ratio with the number of geogrid reinforcement and grid-anchor layers, respectively.

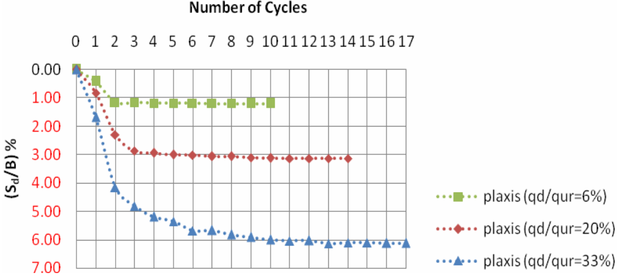

Fig. 5 .Variation of (S_d/B) with number of load cycles for Series B1-B3

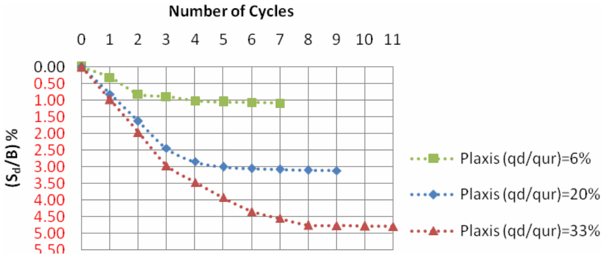

Fig. 6 .Variation of (S_d/B) with number of load cycles for series C10-C12

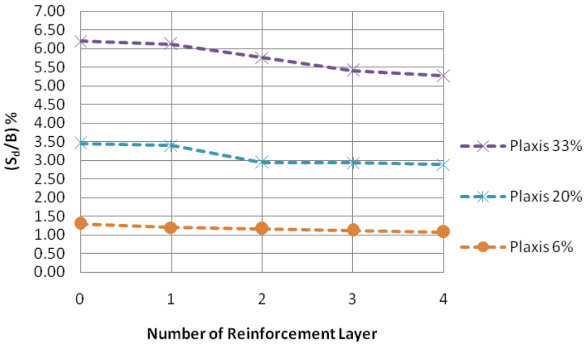

Fig. 7 Variation of (S_d/B) with number of reinforcement layers with geogrid

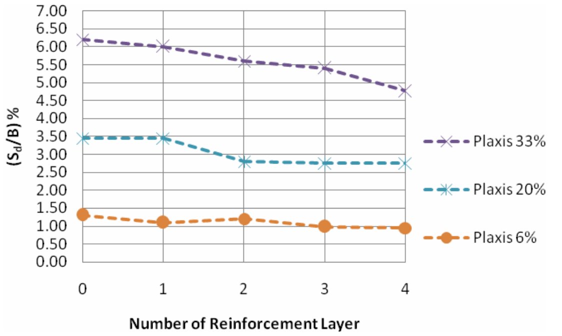

Fig. 8 Variation of (S_d/B) with number of reinforcement layers with grid-anchor

Figs. 9 and 10 indicate variation of number of load cycles with number of reinforcement layers for common reinforcements and the grid-anchor system respectively. Comparing the findings provided in these figures, one can conclude the higher ability of the grid-anchor system in reducing the settlement. This effect is more noticeable for higher values of cyclic load. The reason is more engagement of this 3D system with the soil and their more involvement against pull out of reinforcement layers.

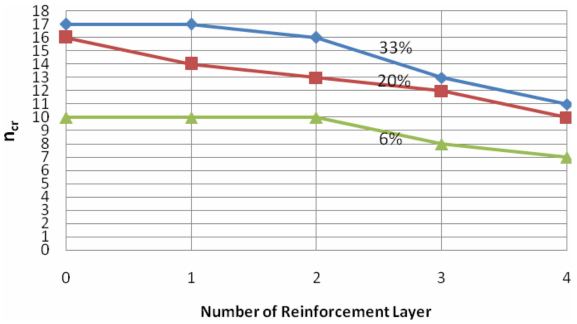

Fig. 9 Variation of number of load cycles with number of reinforcement layers (geogrid)

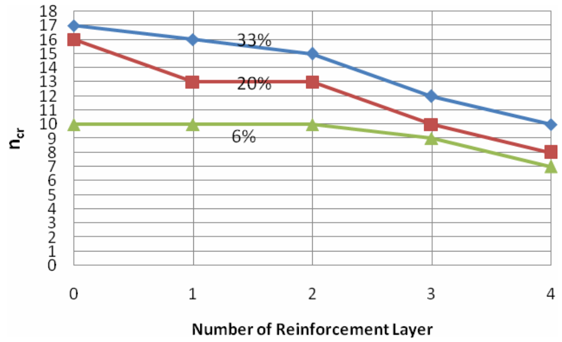

Fig. 10 Variation of number of load cycles with number of reinforcement layers (G-A)

The optimal number found from Mosallanezhad *et al.* (2007). Analysis were limited to 4 layers. They found that if more than 4 reinforcement layers were used, no improvement in the BCR ratio would follow.

As revealed by figures, by increasing the number of reinforcements, due to the soil stiffness getting higher, the number of loading cycles needed to achieve a constant permanent settlement is reduced.

IV. CONCLUSIONS

According to the numerical analysis, the following results were obtained:

For a given initial fixed load, the dimensionless settlement of the foundation increases with the cyclic load amplitude.

For a given initial fixed load, the number of loading cycles to reach a constant value of dimensionless settlement decreases with increase in the number of reinforcement layers.

By using the grid-anchor system, the amount of dimensionless settlement to reach a constant value of it decreases up to 12% relative to ordinary reinforcements and up to 32% relative to unreinforced condition depends on the number of reinforcement layer and percent of applied load.

Also by using the grid-anchor system, the number of loading cycles to reach a constant value of dimensionless settlement decreases up to 20% relative to ordinary reinforcements and up to 42% relative to unreinforced condition depends on the number of reinforcement layer and percent of applied load.

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