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EXPERIMENTAL INVESTIGATION OF DYNAMIC BEHAVIOR OF SHALLOW FOUNDATION RESTING ON THE REINFORCED SAND WITH EMBEDDED PIPES

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ABSTRACT
One of the major concerns is to do with the foundations, such as compressors, railroads, roads and so forth, which are under the influence of the static and dynamic loads. These foundations which have been affected by the traffic loads are regarded as uniform and differential settlements. Sometimes a number of pipes are laid under these foundations, thereby influencing the related settlements. In this study, it has been shown that an increase in the dynamic load when both the initial static load and the pipe depth are constant leads to an increase in the settlement. As compared to the ordinary condition, the amount of settlement is greater. Also, it was revealed that the amount of soil settlement is reduced by 54%, as compared with the unreinforced soil, considering that the initial static load and the pipe depth are constant, and that the dynamic load has been applied, and that the grid-anchor system has been used. This research has focused mainly on introducing an appropriate and unified strategy to improve soil behavior using the reinforcements, which reduce the soil settlement in these shallow foundations. In addition, this paper presents the equations for both reinforced and unreinforced soil under dynamic loading to prevent such complicated calculation involved in deformation analysis. According to these equations, calculation of the permanent settlement for each foundation with a given size on the grid-anchor reinforced sand with and without embedded pipe is feasible.

Keywords: Dynamic loads, Grid-anchor, Embedded pipe, Settlement, Shallow foundation, Reinforced sand.

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1. INTRODUCTION

For almost half a century now, the soil reinforcements have been utilized to improve the soil mechanical properties. Hence, attempts have recently been made to improve the type and quality of the soil reinforcements remarkably, leading to using polymer reinforcements. These reinforcements are currently being produced in various types and utilized in industry, civil projects and agriculture. The massive oil and gas pipes located in different directions and the shallow foundations being influenced by considerable dynamic and static loads (large oil tankers, railroads, roads and so on) may result in an excessive settlement in these Foundations. In order to reduce the potential damages to these foundations and pave the way for passing these pipes below these foundations, numerous methods can be taken into consideration. One of the most economical and simplest executive methods is to improve the soil mechanical soil properties through the polymer reinforcements. The majority of the previously conducted investigations were concerned with the use of the reinforcement to increase the bearing capacity related to the foundation deployed on the reinforced soils. However, this study aims at investigating the effect of the reinforcements for the purpose of reducing the foundation settlement influenced by the dynamic loads.

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In the recent years many researchers have done experimental and numerical on reinforced soil due to static loading. They have investigated the reinforcement effect on the ultimate bearing capacity of various types of foundations, for example strip, square, ring, circular and shell foundations Chakraborty and Kumar (2014); Madhavi *et al.* (2013); Boushehrian and Hataf (2003); Boushehrian and Hataf (2008); Smaili and Hataf (2013).

Yeo *et al.* (1993) performed a number of experiments concerning the shallow square foundation settlement on the cyclic load reinforced sand. They showed that by increasing cyclic load amplitude, during constant static load and number of load cycles, the foundation settlement increases (Yeo *et al.*, 1993). Gobel *et al.* (1994) following the unification of Germany, it is highly essential to increase the bearing capacity of the current railway routes in east Germany to take into consideration the increasing volume and speed of traffic. As a rule, this can be attained by a subgrade protective layer (SPL) spread between the subgrade and crushed-stone bed. In a fatigue loading test with 5 million load cycles, it was realized that the SPL bearing capacity could be increased with geogrid reinforcement. The reinforced SPL revealed an increase of 70% in the bearing capacity, as compared with the unreinforced SPL. In addition, the settlements were smaller, along with a flatter settlement curve (Gobel *et al.*, 1994).

Das and Shin (1996) showed that the laboratory model test results have been presented for the cyclic load-induced settlement of a strip foundation supported by a saturated clay soil. According to the model test results, the relationships for the foundation settlement and intensities of the static and cyclic loads were presented (Das and Shin, 1996). Das and Shin (1999) revealed that the laboratory model tests for the settlement of a surface square foundation are supported by a medium dense sand and subjected to the cyclic loading of low frequency (1 cps), and the transient loading was presented. In accordance with the present test results, it seems that the geogrid reinforcement could function as a settlement reducer for the dynamic loading conditions on the foundations (Das and Shin, 1999).

Ling and Liu (2001) focused on an investigation depicting the performance of the geosynthetic-reinforced asphalt pavements under various loading circumstances(Ling and Liu, 2001).

Shin *et al.* (2002) revealed the results of the large-scale laboratory model experiments done to specify the permanent settlement due to the cyclic load of the railroad bed for a proposed high-speed train route extending from Seoul to Pusan in South Korea the settlement of the subbase layer were explored. According to the present model test results, it seems that practically all the permanent settlement due to the cyclic load was accomplished after employing 105 load cycles (Shin *et al.*, 2002).

Nazzal *et al.* (2007) demonstrated that a set of triaxial compression and cyclic triaxial experiments are carried out on the unreinforced and geogrid reinforced crushed limestone specimens to examine the influences of the geogrid type, location, and number of layers on the strength, stiffness, and cyclic deformability of these specimens. The results of these analyses revealed that the geogrid inclusion within the crushed limestone specimens increases their elastic modulus and ultimate shear strength remarkably, whereas it lowers their permanent deformation (Nazzal *et al.*, 2007).

Hataf and Sadr (2009) carried out empirical tests on the two reinforcements, namely the hexagonal Netlon CE131 geogrid and the geogrid-anchor made from this geogrid in the overload strains of 8 and 18 kP and in the SW sand soil. They have specified that grid-anchor has more pull-out (Hataf and Sadr, 2009).

Arjomand *et al.* (2009) showed the large-size direct shear tests (i.e.300 x 300mm) are performed to launch an investigation into the interaction between the clay reinforced by the geogrids embedded in the thin sand layers. Test results showed that the provision of thin layers of the high-strength sand on both sides of the geogrids is highly effective in the improvement of the strength and deformation behavior of the reinforced clay under UU loading circumstances (Arjomand *et al.*, 2009). Hataf *et al.* (2010) showed experimental and numerical behavior of sallow foundations on sand reinforced with geomesh and grid-anchor under cyclic loading. Their experimental program was performed in the field in the form of full scale tests (Boushehrian *et al.*, 2011). Moghaddas and Dawson (2010) portrayed a collection of the laboratory model tests conducted on the strip footings supported on the 3D and planar geotextile-reinforced sand beds under a set of static and repeated loads. The results disclosed that the maximum footing settlement owing to the repeated loading can be compared for either planar- or 3D-reinforced sand and highly ameliorated over the settlement of the unreinforced sand(Moghaddas and Dawson, 2010). Hataf *et al.* (2010) compared the shallow foundations behavior on the reinforced sand soil influenced by the cyclic loading in the laboratory using the Plaxis 3D Tunnel software program (PLAXIS2D Tunnel Scientific Manual, 2001); (PLAXIS3D Tunnel Scientific Manual, 2001; Hataf *et al.*, 2010). Moghaddas and Dawson (2012) presented the results of the laboratory-model tests on the strip footings supported on the unreinforced and geocell-reinforced sand beds under the combination of static and repeated loads. They showed that the reinforcement decreases the magnitude of the final settlement, functions as a settlement reducer, allows for higher loads, or increases cycling(Moghaddas and Dawson, 2012). Boushehrian et al. conducted an investigation entitled numerical investigation of machine foundations on fiber concrete tunnel in reinforced sand by using Plaxis 2D software and found out that the total soil settlement increases by increasing the number of loading cycles PLAXIS2D Tunnel Scientific Manual (2001). They showed that to reduce this settlement, the geogrid reinforcement must be used with 1 to 4 layers. With the 4 layers geogrid, the value of settlement was decreased to 12%, as compared with the non-reinforcement situation (PLAXIS2D Tunnel Scientific Manual, 2001; Bushehrian *et al.*, 2012).

The paper's primary contribution is finding the effect of different factors affecting the amount of foundation settlement over reinforced sand with embedded pipe under dynamic loading. This study originates new formula for reinforced soil under dynamic loading to predict the permanent settlement of various pipe depths and load ratio.

2. EXPERIMENTATION

2.1. Introduction

A type of equipment with the following specifications has been designed and patented in Shiraz Islamic Azad University advanced soil mechanic laboratory. This equipment has been used in this study for the first time. It has the capability for extracting the dynamic and static loads on the soil separately and simultaneously at a given volume through the foundation of the model with various dimensions.

2.2. The Equipment Components

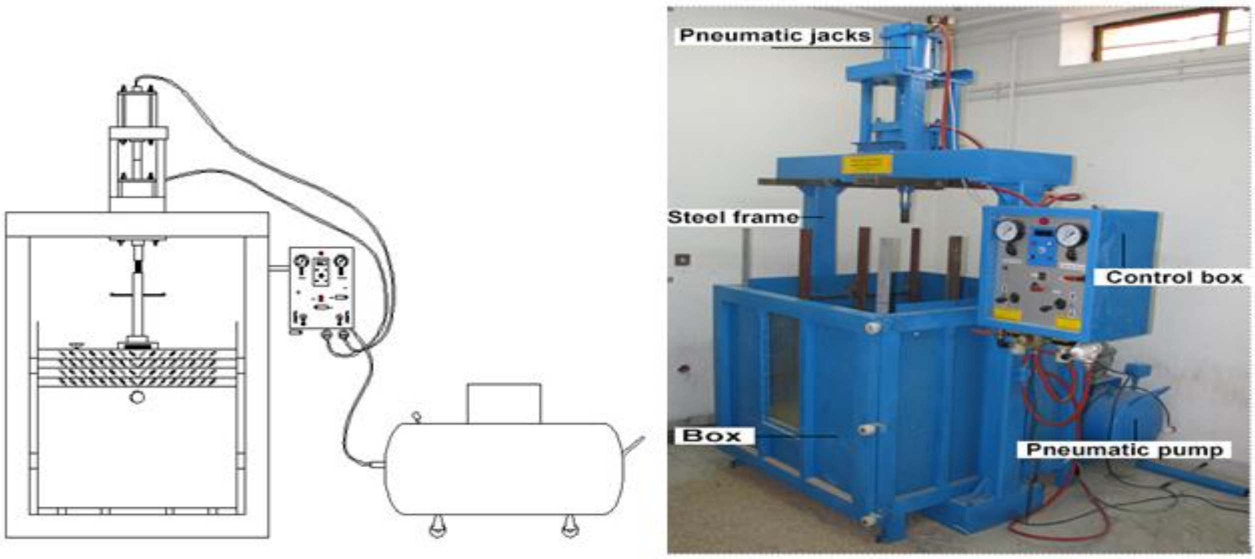

Fig-1. The experiment Apparatus

1. Steel frame has been used to maintain the box, jacks, control box and belongings.

2. The box is 1*1*1 cube meters.

3. The bottom pneumatic jack has been used to apply the static loads.

4. The top pneumatic jack has been utilized to apply the dynamic loads.

5. The control box has been used to control the force rate, to select the force type, and to begin the operation.

6. The pneumatic pump apparatus provides the amount of compressed air required for the jacks.

7. The precision tools (LVDT) measure the modeled foundation settlement with the precision of 0.01 cm.

8. The data logger system obtains the LVDT information shows it and records it.

2.3. The Materials Specifications

1. The following curve has to do with the sand graveling and is of SW type in accordance with the unified classification system.

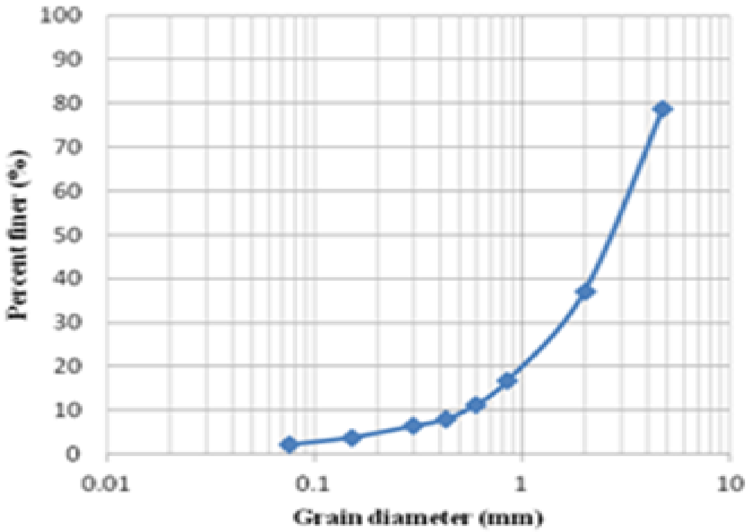

Fig-2. The soil grain size distribution curve

2. The reinforcement used in this test is of geomesh type (Netlon-CE131) and has a hexagonal grid with the technical specifications written in Table 1.

Table-1. The technical specifications of the geomesh (Netlon-CE131)

Parameter	Unit	Value
Elastic axial stiffness	KN/m	7.80
Geomesh opening size	mm	27*27
The average thickness	mm	2.2

3. The anchors utilized in this test are of plastictype and their specifications have been recorded in Table 2.

Table-2. Technical specifications of the anchors use in the grid-anchor

Parameter	Unit	Value
Axial stiffness of anchors	KN	0.18
Length of anchors	mm	50
Thickness of anchors	mm	1.1
Width of anchors	mm	4

4. The cubes used in the anchors have a dimension of 10*10 mm and are made of plastic.

5. A stone glue has been utilized to attach the cubes to the anchors.

6. The pipe used in this test has a size of 63mm and is the PVC pipe.
7. A steel sheet with a dimension of 20*20 has been utilized to model the foundation.

The grid-anchor, which is a new generation of the reinforcements, has been made as a 3D reinforcement in accordance with Mosallanezhad's instructions (Fig. 3) and specifications in tables 1 and 2 (Mosallanezhad *et al.*, 2007).

Fig-3. The method of placing the anchor on the geome

A rapper with a base of 30*30 cm and a height of 20 cm was designed and made. Its net weight was 7.5 kg. In order to increase its weight to 10 kg, 2.8 kg of sand was poured into it. A frame of sheet and profile was made to increase the hammer release height to 20 cm. After compacting the soil three times using this rapper, the soil density reached 1.81±0.1 gr/cm3. After the direct shear teston the soil with the same laboratory water content and relative density, c=0.1 kg/cm^2 and $\varphi = 32^\circ$ were obtained (ASTM D3080 / D3080M-11, 2011). The soil allowable bearing capacity was obtained using the Meyerhof relation to achieve the dynamic and static loads needed for the experiment (Bowels, 1997). The static load was considered 145 kg and the exerted dynamic loads were equal to 33%, 50% and 66% of the allowable load.

2.4. Test Procedure

The prepared sand with the natural water content of 2% was poured into the box, balanced at the thickness of 5cm and compacted by the rapper from the height of 20 cm to reach the required density. This process was continued until the box was filled completely. The model foundation was laid under the force applied bar. After that a static force equal to 133 kg, along with the model foundation weight of 12 kg was applied (the total weight of both the foundation and the static force employed by the apparatus is 145 kg.).Then the dynamic load of 33% of the allowable load was selected and applied to the foundation utilizing 30 blows per minute. This process was carried out for the dynamic load application of 50% and 66% of the allowable load. After that the data was obtained using LVDT and Data logger. After taking the sand from the box located at the depth of 3*B, the soil was re-compacted at the layers of 5cm. After compacting the soil and laying the pipes at the depths of 7.5, 15 and 25 cm, the static and dynamic loads were applied to the model foundation and the settlement amounts were derived. At this stage, the soil was loaded by the dynamic forces of 33%, 50% and 66%, and the settlement-recording was conducted based upon Table 3. In all the test series, the static load was constant and equal to 145 kg and the load frequency was 0.5 Hz. In the reinforced conditions, reinforcement layer were placed in their optimize situations based on the values obtained from the studies of Mosallanezhad *et al.* (2007) on the same soil with fully similar characteristics.

Table-3. The number of and the specifications of the performed experiments

Test Series	Reinforced Condition	Embedded Pipe Depth (cm)	Dynamic Load (kg)	Reinforcement Depth (cm)	Number of Reinforcement
A1	Unreinforced	-	-	-	-
A2 to A4	Unreinforced	-	280, 424, 560	-	-
A5	Unreinforced	7.5	560	-	-
A6	Unreinforced	15	560	-	-
A7 to A9	Unreinforced	25	280, 424, 560	-	-
B1	Reinforced with Geomesh	25	560	5	1
C1 to C4	Reinforced with Grid-Anchor	25	560	5, 10, 15, 20	1
C5 to C7	Reinforced with Grid-Anchor	25	280, 424, 560	5, 10	2
C8 to C10	Reinforced with Grid-Anchor	25	280, 424, 560	5, 10, 15	3
C11 to C13	Reinforced with Grid-Anchor	25	280, 424, 560	5, 10, 15, 20	4

Fig.4. shows the schematic design of a soil reinforcement system for a square foundation with the dimension of B*B and a reinforcement layer. The dimensions of the reinforcements and anchors are b*b and c*c, respectively. U, D and R represent the distance concerning the grid-anchor layer depth, the pipe depth under the foundation, and the pipe diameter, respectively. In all tests R was considered as a constant value equal to 63 mm. For all tests, the values of u/B = (h/B), (b/B) and (d/B) were taken as 0.25, 0.5 and 1.25, respectively.

As can be seen in Fig.4, the pipe is located exactly below the foundation and in the middle of the grid-anchor. Also, the anchors have been considered at the angle of 45 degree and toward the geomesh outside.

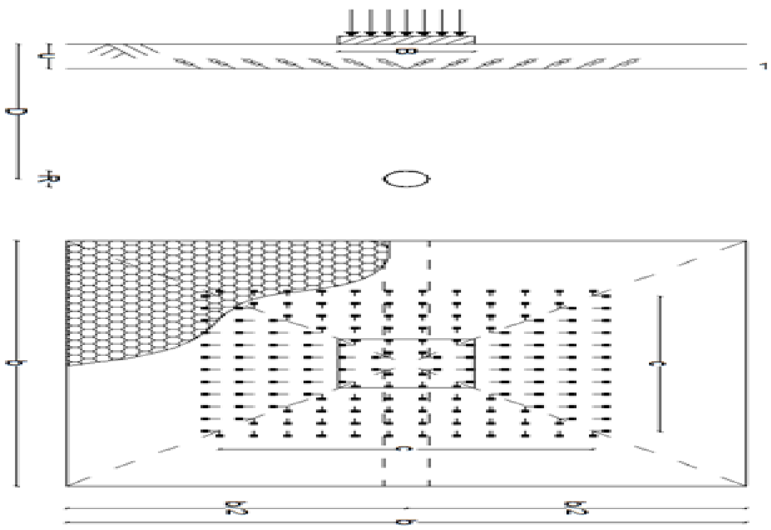

Fig-4. The method of laying the grid-anchor, the pipe and the anchors

3. RESULTS AND DISCUSSION

Fig.5. showing the effect of pipe embedded depth on the dimensionless settlement ratio when the dynamic load amplitude and frequency were constant on the unreinforced soil. In these cases the dynamic load was equal to 560 kg.

The following relation has been obtained from Figure 5:

$$(S/b)\% = -0.503*(D/B)^2 + 0.627(D/B) + 0.819 \quad (3\text{-}1)$$

Where S is the settlement below the foundation. As can be observed in Fig.5, by placing the pipes and applying the constant static and dynamic force, the soil settlement is decreased by increasingthe D/B ratio.

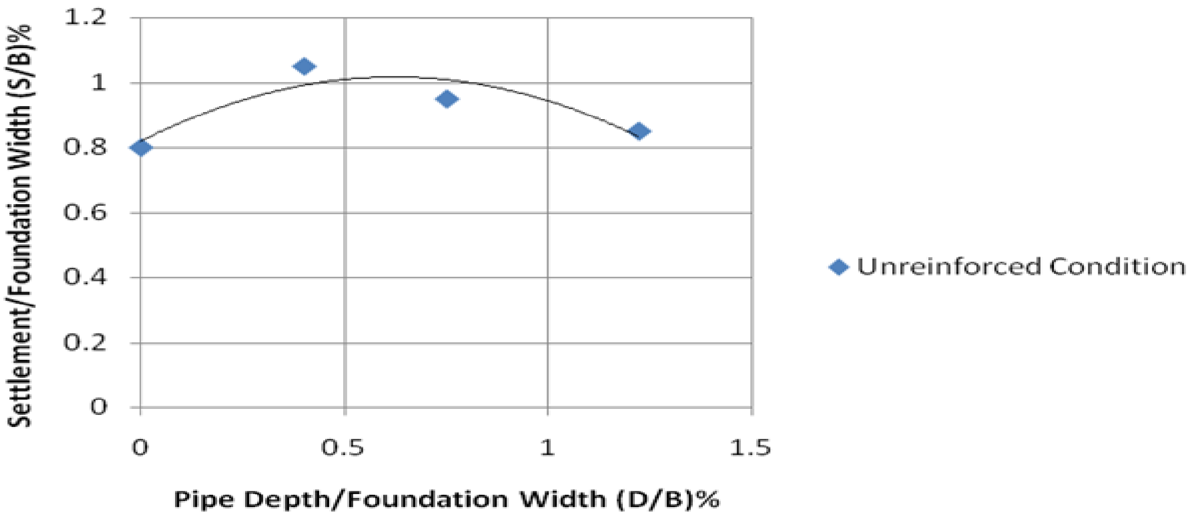

Fig-5. The variations of the dimensionless settlement for the unreinforced soil through constant loads

Fig-6 comparing the effect of load ratio on the ratio of the dimensionless settlement for the unreinforced soil. Load ratio, is defined as the ratio between dynamic load amplitude to static load. The constant static force is equal to 17% of the allowable load and the dynamic forces are 33%, 50% and 66% of the allowable load. As can be seen, considering that the dynamic loads are equal, in the soil with pipes there occurs less settlement than in the soil without pipe.

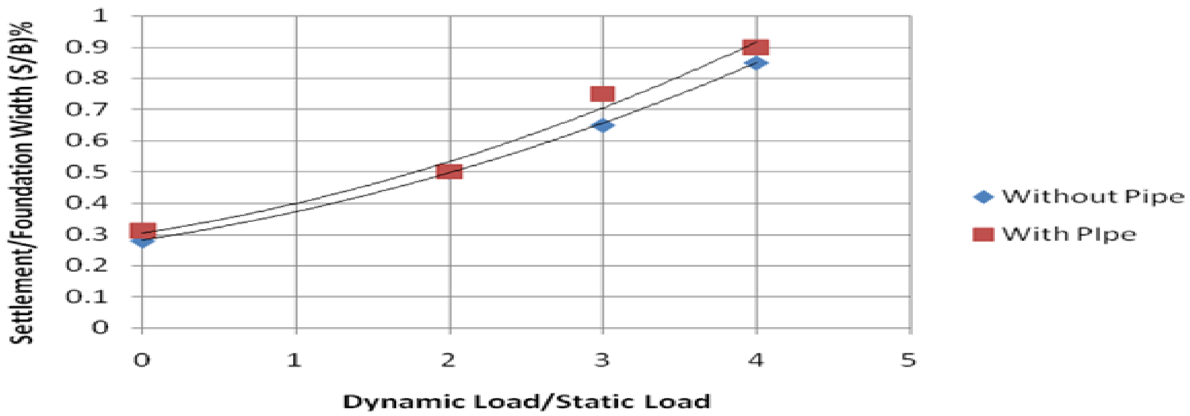

Fig-6. The variations of the dimensionless settlement for the unreinforced soils with and without pipes through applying loads

Fig. 6 reveals that the amount of settlement regarding the unreinforced soil without embedded pipe is less than that of unreinforced soil with the pipe. Fig. 6 demonstrates the effect of the ratio of the dimensionless grid-anchor depth and that of the dynamic load to the static one.

After taking the soil at 3*B and compacting the soil with a thickness of 5 cm at D/B=1.25 below the foundation, a grid-anchor layer was placed on the soil at U/B=0.25 below the foundation. After pouring and compacting the soil, placing the foundation on the soil with a constant static load of 17% of the allowable load, and applying the dynamic load of 66% of the allowable load, the amount of soil settlement was obtained by LVDT. The same process was performed for the grid-anchor layer in the layers of U/B=0.5 and U/B=0.75. This data can be observed in Fig.7. The following relation has been obtained from Fig .7:

(S/B)%=0.057*(U/B)² +0.01(U/B)+0.581 (3-2) As can be seen, the amount of U/B is increased by increasing (S/B) %.

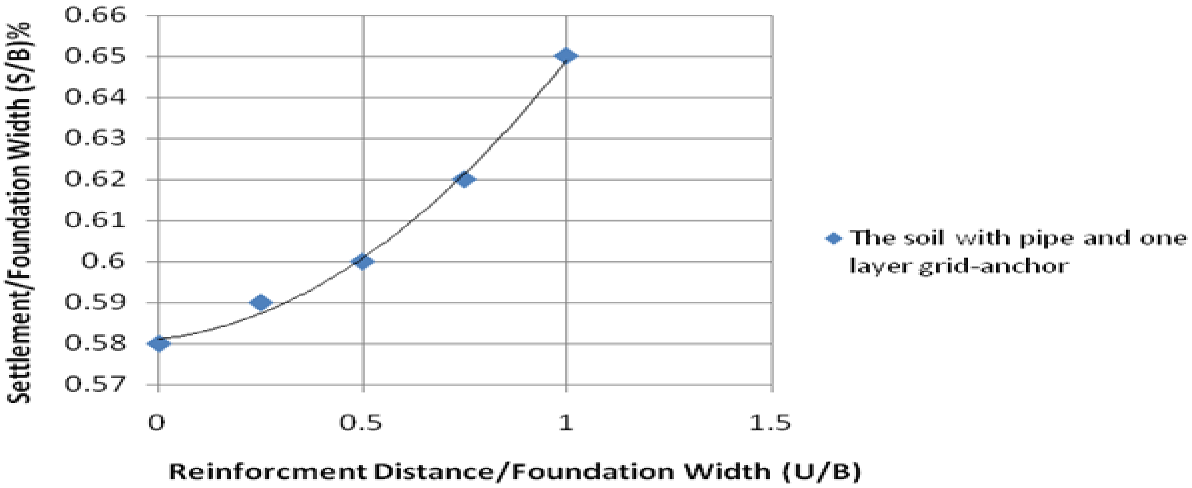

Fig-7. The variations of the dimensionless ratio of the grid- anchor reinforced soil settlement with a pipe verses the dimensionless ratio of the grid-anchor depth to the foundation width

Fig. 8 compares the effect of the settlement dimension ratio and the load ratio for the unreinforced soil and the soil with two grid-anchor layers.

The following relation has been obtained from these experiments:

(S/B)%=0.0774*(qd/qs) +0.1917 (3-3)

Where qd and qs are dynamic and static load parameters, respectively. As can be seen, the qd/qs values increased by increasing the soil settlement. The S/B is reduced by 37%, as compared with the unreinforced soil when the soil with two grid-anchor layers is reinforced.

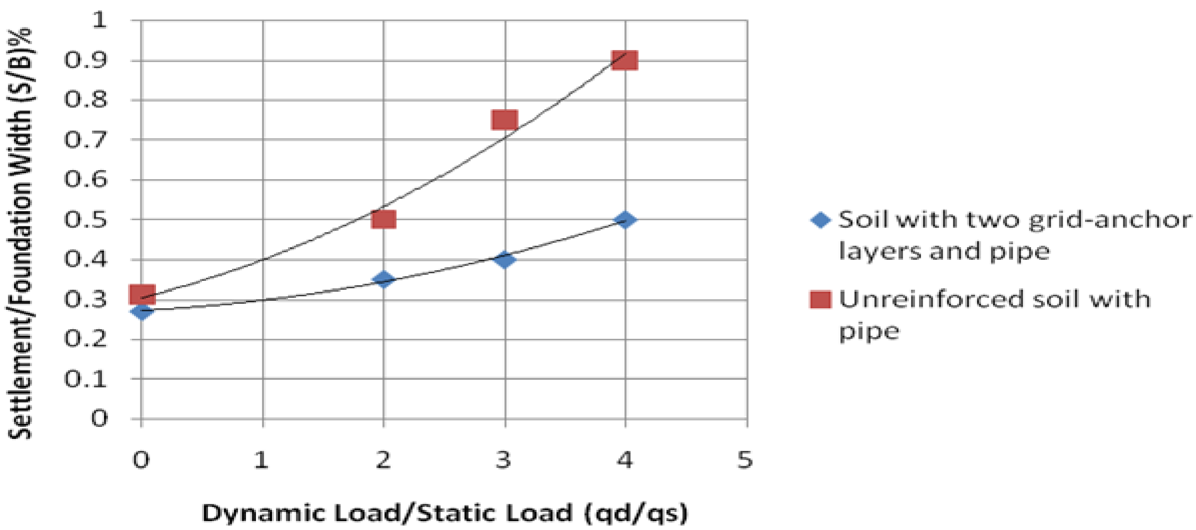

Fig-8. The variations of the dimensionless settlement of the unreinforced soil in comparison to the soil with the two number of grid-anchor layers verses the load ratio

Fig.9. compares the effect of the settlement dimension ratio and the load ratio for the unreinforced soil and the soil with three grid-anchor layers.

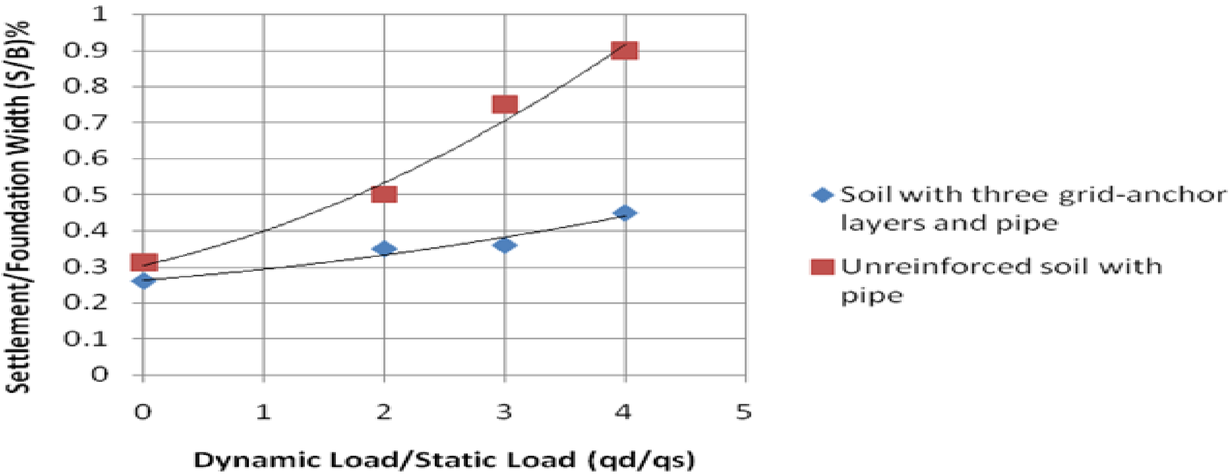

Fig-9. The variations of the dimensionless settlement of the unreinforced soil in comparison to the soil with the three number of grid-anchor layers verses the load ratio

As can be seen, an increase in the number of geomesh layers up to three layers leads to a decrease in the soil settlement, thereby reducing the compaction energy and therefore the cost of construction.

Fig.9 is to do with the data derived from the experiments (A7 to A9) conducted on the unreinforced soil and the tests (C8 to C10) done on the soil with three reinforced grid-anchor layers as can be obtained from Fig.9.

(S/B)%=0.0513*(qd/qs) +0.2343 (3-4)

As can be seen in this relation, the amount of qd/qs increasing the amount of settlement. The proportion of S/B is also reduced by 41 percent, as compared with the unreinforced soil.

Fig. 10 compares the effect of the settlement dimension ratio and the load ratio for the unreinforced soil and the soil with four grid-anchor layers.

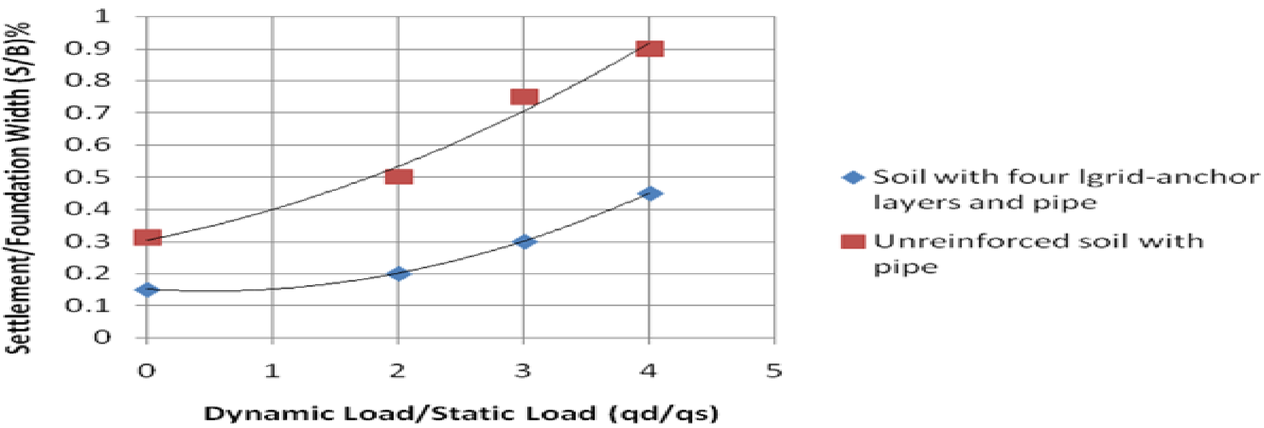

Fig-10. The variations of the dimensionless settlement of the unreinforced soil in comparison to the soil with the four number of grid-anchor layers verses the load ratio

Fig 10 shows the effect of the number of grid-anchor layers on the soil settlement. As can be seen, an increase in the number of grid-anchor layers up to 4 layers leads to a decrease in the soil settlement, thereby reducing the density energy and therefore the cost of implementation.

Fig.10 is to do with the data derived from the experiments (A7 to A9) conducted on the unreinforced soil and the tests (C11 to C13) done on the soil with four reinforced grid-anchor layers as can be obtained from Fig.10.

(S/B)%=0.1292*(qd/qs) -0.0587 (3-5)

As can be seen in this relation, the amount of qd/qs increasing the amount of settlement. The proportion of S/B is also reduced by 54 percent, as compared with the unreinforced soil.

Fig.11 shows the effects of the number of grid-anchor layers on this soil. As can be seen, in the case of the dynamic force equal to 66% of allowable foundation capacity in unreinforced condition in regard to using two grid-anchor layers, there is no indication of changes in the amount of settlement. According, it can be concluded that the use of the grid-anchor paves the way for utilizing the soils with less compaction energy to achieve a desired settlement, thereby reducing the implementation and construction costs.

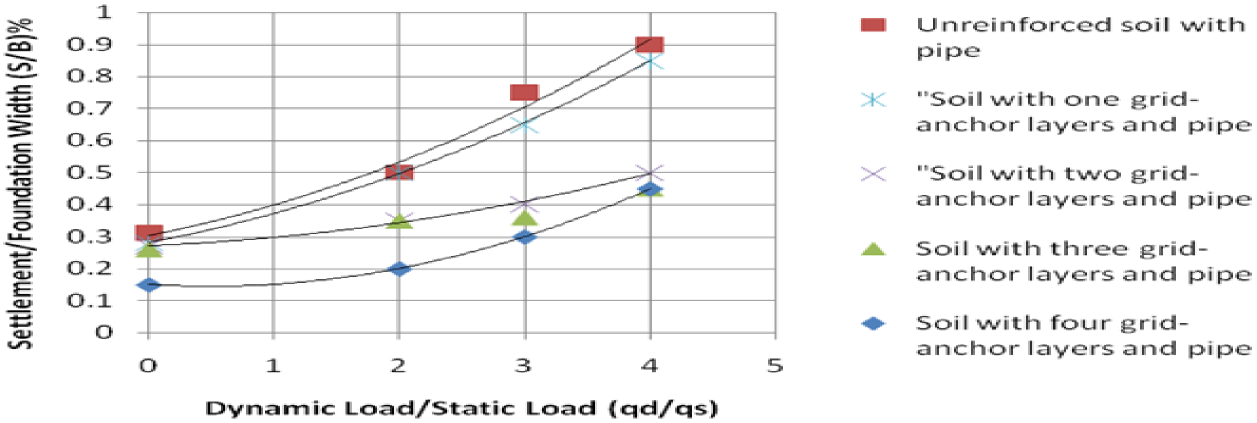

Fig-11. The variations of the dimensionless settlement of the unreinforced soil in comparison to the soil with the various number of grid-anchor layers versus the load ratio

Fig 10 shows the variations of the number of grid-anchor layers on the soil settlement in different load ratios. As can be seen, an increase in the number of grid-anchor layers up to 4 layers leads to a decrease in the soil settlement in all load ratios. In these tests, pipe embedded at constant depth equal to 25 cm.

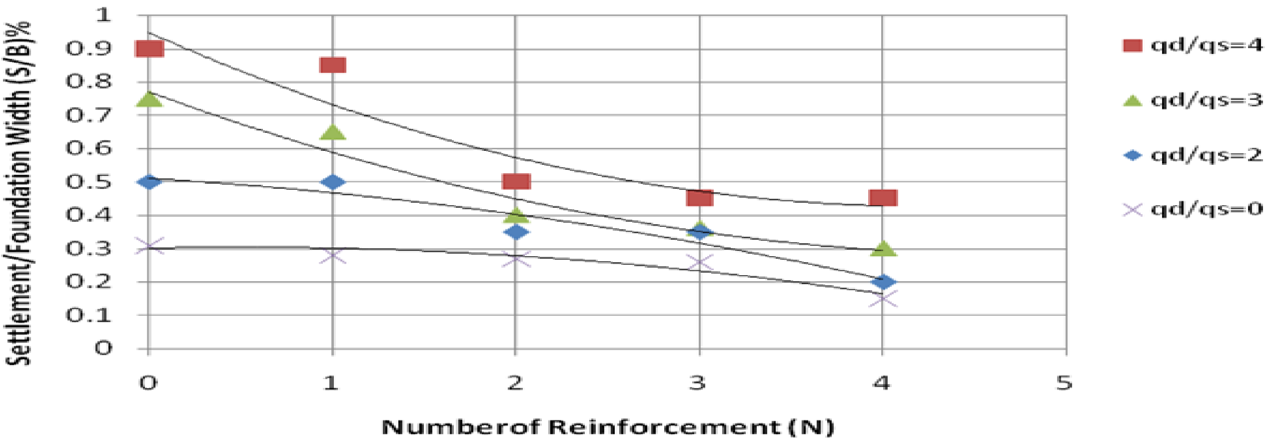

Fig-11. The variations of the dimensionless settlement of the soil in comparison to the number of grid-anchor layers for the different load ratios

4. CONCLUSION

A three dimensional reinforcement system previously introduced by Mosallanezhad *et al.* (2007) was used to investigate the dynamic response of square footing resting on reinforced sand with embedded pipe. This new system is called a grid-anchor reinforcement system and has been found to be more efficient in comparison with conventional geomesh systems. This new reinforcement generation can be used to decrease the uniform and non-uniform foundation settlement of the storage tanks with the numerous filling and discharging processes and the railway ballast course under repeatable transportation loads. An experimental test program was employed to study the effect of the grid-anchor and geomesh reinforcements on the dynamic behavior of grid-anchor reinforced sand. The following results were obtained.

1. By applying the initial constant static load and increasing the pipe depth, as well as applying the dynamic load, the amount of settlement is reduced.
2. By applying the initial constant static load to the soil with the pipe located at the depth of 25 cm, the amount of settlement will be increased by increasing the dynamic load. As compared to the soil without pipe, this amount is greater.
3. Through applying the initial constant static load and constant dynamic load to the soil with the pipe situated at the depth of 25 cm and a geomesh layer located at the depth of 5 cm below the foundation, the settlement will be decreased by 17%, as compared with the unreinforced soil, however, in the same condition a grid-anchor layer will decrease the soil settlement up to 33% in comparison with unreinforced soil.
4. By use of the initial constant static load, the various dynamic loads (33%, 50% and 66% of the allowable load), the grid-anchor system, the pipe with a constant depth of 25 cm, and the two grid–anchor layers at the depth of 5 and 10 cm below the foundation to reinforce soil, the amount of soil settlement will be reduced by 37% in comparison to the unreinforced soil.
5. By utilizing the initial constant static load and various dynamic loads (33%, 50% and 66% of the allowable load), the grid-anchor system, the constant pipe depth of 25 cm, and the three grid-anchor layers at a depth of 5, 10 and 15 cm below the foundation to reinforce the soil on the pipe, the amount of soil settlement will be decreased by 44%, as compared with the unreinforced soil.
6. By using the initial constant static load, the different dynamic loads (33%, 50% and 66% of the allowable load), the grid-anchor system, and the constant pipe depth of 25 cm, and the four grid–anchor layers to reinforce the soil on the pipe, the amount of soil settlement will be reduced by 54% as compared to the unreinforced soil.
7. Increasing the soil density leads to decrease the soil settlement. The results obtained from the experiments revealed that the grid-anchor leads to a considerable reduction in the soil settlement. Hence, in order to construct the embankment on the pipe, the compaction energy will be decreased, thereby reducing the construction costs.

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Contributors/Acknowledgement: All authors contributed equally to the conception and design of the study.

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