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Reinforcement Effects on the Permanent Settlement of Sandy Slopes under Cyclic Loading

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ABSTRACT: Several strategies have been used to improve the engineering characteristics of soils for many years. However, in the last 50 years, advances in human knowledge of soil behavior and geotechnical hazards, on the one hand, and advances in other sciences like chemistry, on the other, have resulted in the development of creative methods for modifying soil specifications. The effect of a grid anchor as soil reinforcement on the settlement of strip foundations resting on sand slopes under cyclic loading is investigated in this study. Vehicle traffic, machine foundation, or loading and unloading due to filling and discharging oil tanks can all contribute to this loading. The effect of several variables on the permanent settlement of the strip foundation was investigated in this study, including the number of loading and unloading cycles, the number of reinforcing layers, the kind of reinforcement, and the ratio of cyclic load amplitude to static loading. The results reveal that as the number of loading and unloading cycles and the cyclic loading amplitude rose, the quantity of permanent settlement increased. However, it decreased as the number of reinforcement layers increased. The differences of permanent settlement and the number of loading cycles required to reach it have been examined based on the findings.

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1- Introduction

There are several examples of foundations for structures built near sand slopes. High-rise buildings near riversides, the placement of fuel tanks or chemicals on soil slopes, bridge supports, and foundations resting on embankments and roadbeds are only a few examples. The use of reinforcements is one of the most suitable and cost-effective strategies for changing soil behavior. Polymeric reinforcements can be used in various geotechnical projects, including enhancing soil carrying capacity, managing soil settlement, and stabilizing soil slopes and retaining walls. The tensile strength of the soil is usually low. Zornberg, Sitar, and Mitchell claimed that the reinforcements can help fix the soils' weaknesses, resulting in increased bearing capacity and less settlement [1]. Many methods for stabilizing natural and artificial slopes have been presented, including changing the geometry of the soil slope, installing a drain system, utilizing biological methods such as vegetation, implementing restraint on the slope face, nailing, wire mesh, shotcrete, and constructing a retaining wall. The use of geosynthetics reinforcements is one of the newest and most effective approaches for stabilizing soil slopes. The soil reinforcing technique includes quick and simple installation. Construction of steep earth slopes, on the other hand, can be accomplished with the use of reinforcements, particularly in areas where project field space is limited. In this study, a three-dimensional reinforcement was used in addition to a commercially available standard reinforcement called "Geogrid." For the first time, Mosallanezhad, Hataf, and Ghahramani coined the term "Grid Anchor" to describe this three-dimensional reinforcement [2].

The experimental and numerical behavior of shallow footing on reinforced sand with geo mesh and Geogrid under cyclic loads was explored by Boushehrian et al. [3]. They looked at the foundations of storage tanks under the frequent filling and discharging conditions, such as cycle loading with an amplitude more minor than the field's allowable bearing capacity. A trench diameter of 5.5×5×4 m was dug and filled with well-graded sand to conduct the tests. They proposed practical equations towards the end of their studies. The permanent settlement (S_d) and the number of loading cycles required to reach this settlement may be predicted using these formulas by knowing the load amplitude, foundation width (B), and soil unit weight (n_{cr}). The final settlement due to the cyclic load is a permanent settlement. Boushehrian et al. investigated the effect of the geogrid and geogrid anchor on the settlement of the railway ballast layer under dynamic loading [4]. A small-scale box test was used to simulate ballast performance in field circumstances for this purpose. The static load was calculated as the sum of the train, facilities, and passenger weights, but the dynamic load was calculated as the train vibration. To estimate the permanent settlement about the dynamic load and the number of reinforcement

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layers, various relationships based on the test results have been constructed. Under cyclic loads, Hataf et al. evaluated a shallow foundation's experimental and numerical behavior on reinforced sand with geogrid and grid-anchor [5]. The foundation settlement increases as the cyclic load amplitude increases, according to their findings. For constant stress levels, on the other hand, the number of loading cycles is reduced by increasing the number of reinforcement layers to achieve a constant settlement. For constant stress levels, on the other hand, the number of loading cycles is reduced by increasing the number of reinforcement layers in order to achieve a constant settlement. They also discovered that using the grid-anchor system reduces foundation settlement to a constant value by up to 17 percent when compared to a standard geogrid and up to 50 percent when compared to unreinforced conditions. These figures are based on the number of reinforcement layers and the applied load. Other researchers [Correia and Zornberg [6], Mehrjardi and Khazaei [7], Mehrpazhouh, Tafreshi, and Mirzababaei [8], Shin, Kim, and Das [9], Shin and Das [10], Tafreshi and Dawson [11]] have extensively reported on the behavior of foundations resting on soil reinforced with geosynthetics.

Under dynamic stress, Boushehrian and Afzali discovered the effect of several parameters on the amount of foundation settlement over reinforced sand with an embedded pipe. The permanent settlement of various pipe depths and load ratios is predicted using a new formula for reinforced soil under dynamic loading [12]. Model strip footings supported on a weak sandy slope and subjected to monotonic and cyclic stresses were explored by El Sawwaf and Nazir [13]. The effects of partially replacing a compacted sand layer and incorporating geosynthetic reinforcement were studied. The variation of cumulative settlements with different parameters has been given and addressed based on the test findings.

Several investigators have recently demonstrated both analytically and numerically the beneficial effects of using geosynthetic reinforcements to increase the bearing capacity of footing located near the edge of the slope [Halder and Chakraborty [14], Halder and Chakraborty [15], Alamshahi and Hataf [16], Ghazavi and Mirzaeifar [17], Sitharam and Sireesh [18], Zidan [19], Makkar, Chandrasethe [20].

According to a survey of recent publications, most studies have focused on determining the bearing capacity of foundations resting on unreinforced soil slopes and under static loading. The study by El Sawwaf and Nazir is one of a handful that investigates the behavior of foundations located on geogrid reinforced slopes under cyclic loadings [21]. Islam and Gnanendran applied 100,000 loading cycles on a strip foundation next to a sand slope [22]. They evaluated the influence of the frequency of the applied cyclic load on the amount of permanent and resilient vertical and horizontal displacement of the foundation. The findings of their study revealed that, while cyclic loading increases the bearing capacity of the foundation on the slope, the effect of this improvement diminishes as the frequency of loading increases.

Furthermore, the degree of permanent vertical and horizontal deformation is negatively influenced by loading frequency. In such a way, the deformations increase as the load frequency increases under the same amplitude and number of loading cycles. Under cyclic pressure, Alam, Gnanendran, and Lo investigated the behavior of strip foundations resting on an embankment reinforced with geosynthetics experimentally and statistically [23]. They looked at the impact of such loadings on the amount of permanent foundation settlement and accumulated residual stress. Their study looked at the effect of the number of reinforcement layers used, the length of the reinforcement, the distance between the foundation edge and the slope, the frequency of cyclic load application, and the number of loading cycles on the degree of strip foundation settlement. For the development of footings in soil slopes, several issues might be addressed.

Foundations subjected to cyclic loading with amplitudes well below their allowable bearing capacity include storage tank foundations with frequent discharges and filling and road embankments subjected to repeated traffic loads. The degree of uniform and non-uniform settlement of such structures is a source of worry. According to a review of previous research, most studies in recent decades have focused on determining the bearing capacity of shallow footings adjacent to soil slopes. There is only a limited amount of data on foundation settlement under cyclic loading. This study aims to develop a small-scale laboratory model for determining the effect of load amplitude, loading-unloading cycles, and grid anchor reinforcement layers on the permanent settlement of a strip foundation near a sandy slope. The results were compared in two conditions: unreinforced sandy slope foundation and geogrid-reinforced sandy slope foundation.

2- The loading model of the experiments

2- 1- The loading apparatus

A metallic box with dimensions of 1×1×1 m (Fig. 1) and a jack above it that can apply static and cyclic loads on the strip foundation located on compacted soil was employed in this study. The vertical and horizontal stiffeners have been used to constrain the wall around the box to prevent lateral deformations. A 20 mm thick glass panel on one side of the box wall enables observation of the soil beneath the foundation. The inside of the tank wall was polished to prepare a smooth surface. In all of the tests, the axisymmetric requirement was established. The strip foundation used has a length of 60 cm, a width of 10 cm, a thickness of 5 cm, and a weight of 2.405 kg. All of the trials were set up in such a way that the foundation's bed would be directly on the soil surface. The vertical load was applied to the foundation using a rigid frame. The footing settlement was measured using a linear variable displacement transducer (LVDT) device with a resolution of 0.01 mm. A magnetic base connects the LVDT to the apparatus's wall.

3- Materials

According to the unified soil categorization system, SW soil was employed in this study. The sand was recovered from Moradi's mine, which is located 12 kilometers from Shiraz

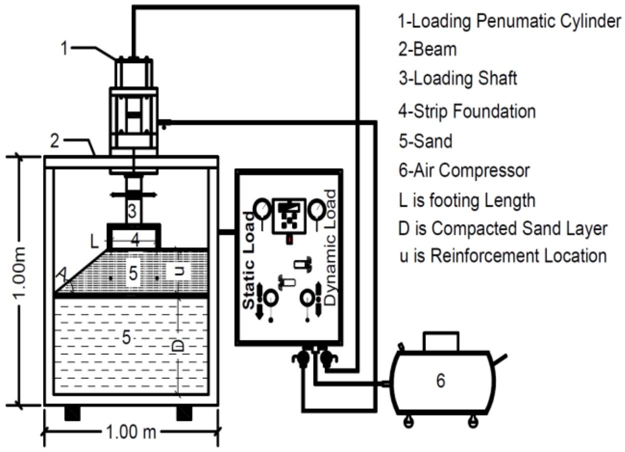

Fig. 1. The experiments Apparatus.

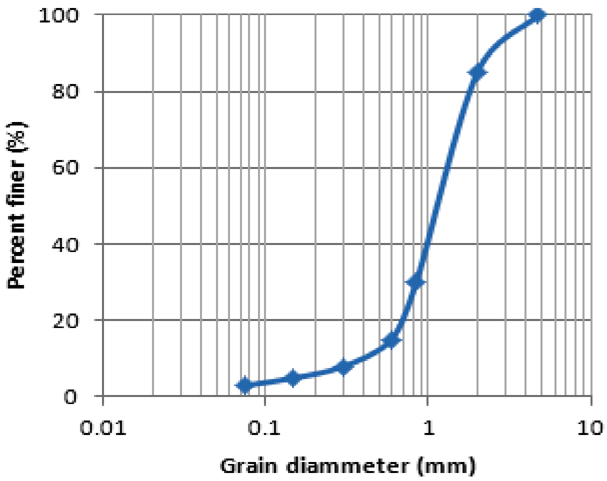

Fig. 2. The grading curve of the used sandy soil.

city. During the studies, the water content of the soil was kept below 2%. Fig. 2 depicts the soil's grain-size distribution curve. In all of the studies, the relative density of the sandy soil was kept below 35%.

A direct shear test on soil samples of similar compactness revealed an internal friction angle of 32 degrees for sandy soil in the laboratory. Table 1 shows some of the parameters for sandy soil. Grid anchor and geogrid were used as reinforcements in this investigation. The geogrid reinforcement type employed in the testing was a hexagonal Nelton-Ce131 grid with the technical characteristics listed in Table 2. The grid-anchor is a novel type of 3-dimensional reinforcement system created by attaching anchors at a 45^{o} angle to an ordinary geogrid sheet using plastic belt material that ends in two polymer cubes with dimensions 1×1×1 cm. Fig. 3 depicts how anchors are attached to a standard geogrid.

The sand was poured into the box in 70 mm layers using the raining technique, and after each layer's surface was leveled, the sand was compressed using a smooth wooden board weighing 7.65 kg and measuring 30×30 cm^2 that was dropped three times from a height of 30 cm. The relative density of soil was measured by this below equation:

$$D_r = \frac{\frac{1}{\gamma_{\min}} - \frac{1}{\gamma}}{\frac{1}{\gamma_{\min}} - \frac{1}{\gamma_{\max}}} \times 100 \tag{1}$$

The values of $\gamma_{\max}$ and $\gamma_{\min}$ were determined by the ASTM D4254 test. A small metal vessel with a given volume

Table 1. The specifications of the sand used in the experiments.

Property	Value
Effective grain size, D_{10} (mm)	0.40
Mean grain size, D_{50} (mm)	1.20
Uniformity coefficient, C_u	3.26
Coefficient of curvature, C_c	1.36
Angle of internal friction, ϕ (degrees)	32
Average wet unit weight, γ (kN/m^3)	17.75
Specific gravity, (Gs)	2.65
Average relative density D_r %	35
Maximum dry unit weight, $\gamma_{d\max}$ (kN/m^3)	19.20
Minimum dry unit weight $\gamma_{d\min}$ (kN/m^3)	16.55
Minimum void ratio, $e_{\min}$	0.38
Maximum void ratio, $e_{\max}$	0.60

Table 2. The specifications of the reinforcements used in the experiments.

Property	Value
The average thickness of geogrid cross members (mm)	2.20
Elastic axial stiffness (kN/m)	11.70
Axial stiffness of anchors (kN)	0.18
Geogrid opening size (mm)	27*27
Length of anchors (mm)	50.0

Fig. 3. Grid-Anchor component and production process.

Table 3. The summary of the performed experiments in the laboratory.

Series	Constant Parameters	Constant Parameters	Percent of Applied Load (q_d/q_{uns})
CS	Test on an unreinforced sand slope	-	25, 50, 80
GG1	Geogrid, One layer	U=0.75B, H=0.75B	25, 50, 80
GG2	Geogrid, Tow layers	U=0.75B, H=0.75B	25, 50, 80
GG3	Geogrid, Three Layers	U=0.75B, H=0.75B	25, 50, 80
GG4	Geogrid, Four Layers	U=0.75B, H=0.75B	25, 50, 80
GA1	Grid Anchor, One layer	U=0.75B, H=0.75B	25, 50, 80
GA2	Grid Anchor, Two layers	U=0.75B, H=0.75B	25, 50, 80
GA3	Grid Anchor, Three Layers	U=0.75B, H=0.75B	25, 50, 80
GA4	**Grid Anchor, Four Layers**	**U=0.75B, H=0.75B**	**25, 50, 80**

was placed randomly in different soil layers to determine the value of γ and to make sure the desired compaction was achieved. Immediately after compaction, the prepared layer's surface was carefully leveled.

This compaction technique may cause a shift in the stress state of the soil, removing it from its normal consolidation state. Due to the production of non-uniform compactness when the soil is wet, the raining approach is not suited for placing the soil in the apparatus.

4- Laboratory program

Cyclic load-settlement tests of the strip foundation on the sand slope in the presence and absence of reinforcement were part of the laboratory's test program. The initial outcome of the tests is the graphs of load cycles-foundation settlement. The load cycles-settlement curves can determine the amount of permanent foundation settlement and the number of loading cycles required to achieve this settlement. The load-settlement curve of the unreinforced sandy soil slope was used to determine the foundation's ultimate bearing capacity (q_{uus}) and indicate the various quantities of the cyclic loading amplitude. The foundation was subjected to a cyclic load in each test during the initial loading stage. The load was lifted when the reported settlement reached a constant value. The second step has been repeated in the same way as the first. The loading-unloading phases continued to reach a reasonably constant foundation settlement amount at the final stage. Table 3 summarizes the laboratory experiments, which included 24 unloading-reloading tests to investigate the influence of reinforcement on load cycles and settlement behavior, as well as one experiment to assess the ultimate bearing capacity of the strip foundation located on unreinforced soil. The type of reinforcement, the number of reinforcement layers, and the ratio of cyclic load amplitude (q_d) to an ultimate capacity of the strip foundation in the unreinforced condition (q_{uus}) were all variable parameters in all of the tests, as shown in the table.

Based on Mosallanezhad, Hataf, and Ghahramani, B is foundation width, U is the distance between their first layer and the foundation bottom, and H is the optimum spacing between succeeding reinforcement layers. According to their findings, adding more than four reinforcements does not influence the foundation's bearing capacity.

To make expressing the results easier, a parameter called the settlement reduction factor was utilized, specified by the equation below.

$$SRF = \frac{PS_{Unrein} - PS_{\mathrm{Rein}}}{PS_{Unrein}} \tag{2}$$

Where PS_{Rein} and PS_{Unrein} are the permanent settlement of reinforced and unreinforced soil. The SRF parameter was created to demonstrate the effect of reinforcement layers on permanent foundation settlement under cyclic loads.

5- The results of the experimental tests and discussion

5- 1- Unreinforced soil (CS series experiments)

The bearing capacity of the footing can be calculated using load–settlement diagrams. The bearing capacity is indicated as the curve's endpoint in Fig. 4. The bearing capacity of the foundation has been calculated by the tangent method [3, 24]. As a result, the bearing capacity of the strip foundation positioned on a sandy soil slope at a 60-degree angle was calculated to be around 34 kPa.

S_d shows the permanent settlement in the laboratory results. The influence of static and cyclic loadings is summed up in this settlement. Fig. 5 depicts the variations in S_d/B for the unreinforced soil as a function of loading cycles.

5- 2- The soils reinforced with Geogrid and Grid Anchor (GG and GA series)

The variation of the dimensionless settlement ratio (Sd/B) vs. the number of loading cycles for the geogrid reinforced soil is shown in Figs. 6 to 8. As can be observed, the use of geogrid reinforcement reduces permanent settlement by up

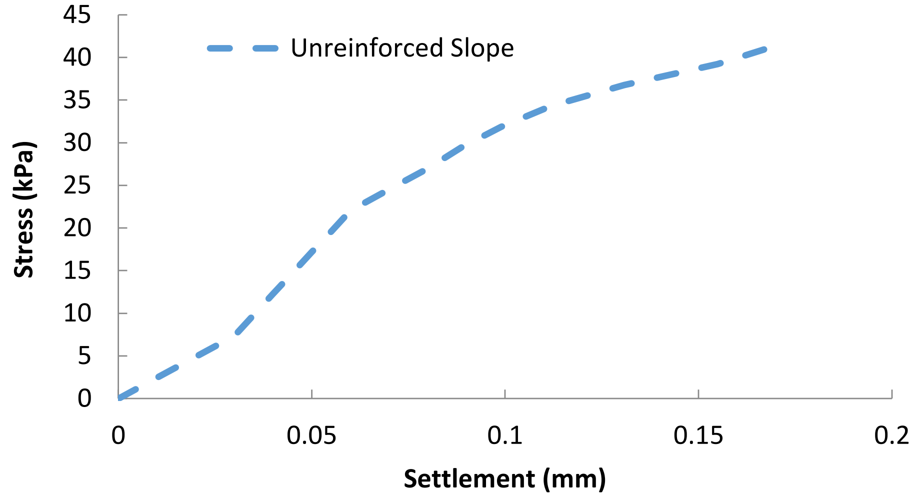

Fig. 4. The load-settlement diagram for footing located on unreinforced sandy soil slope

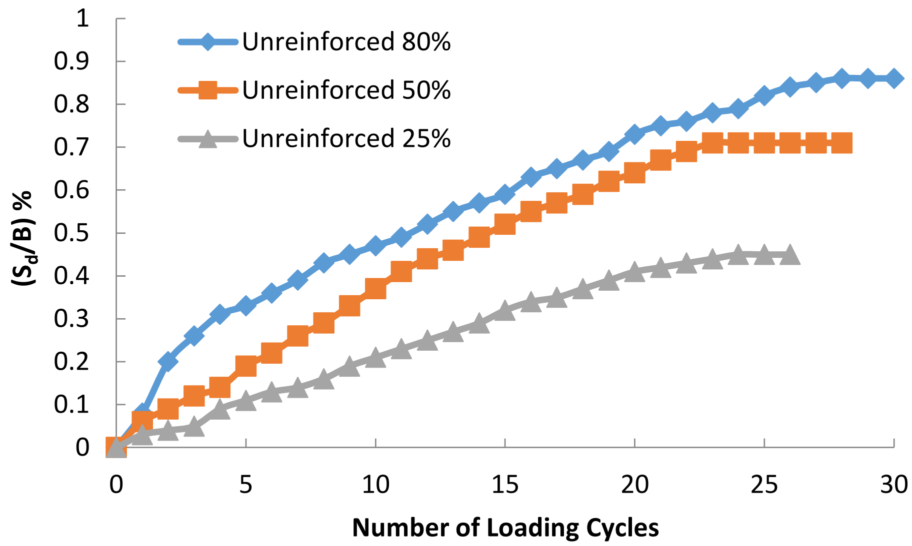

Fig. 5. Variations of (S_d/B) with the number of loading cycles for Series CS tests.

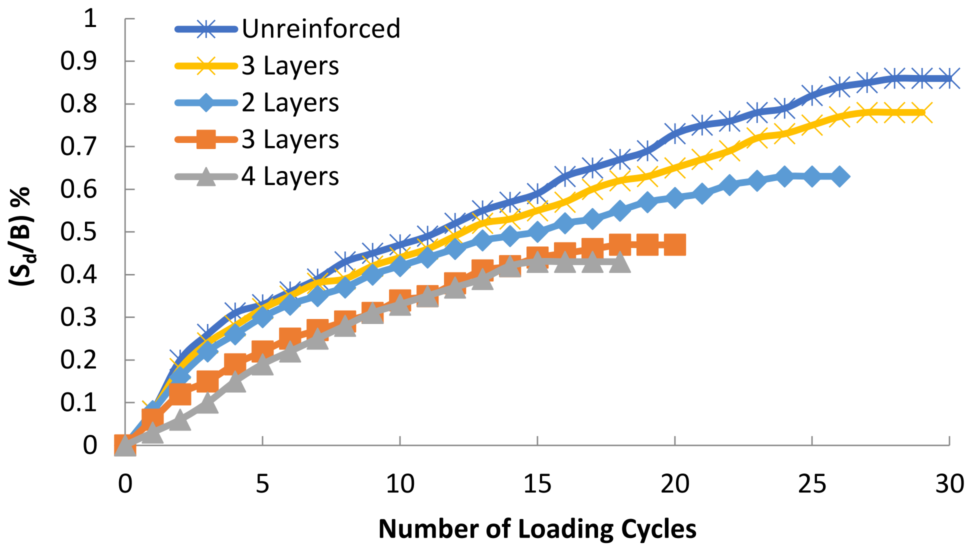

Fig. 6. Variations of (S_d/B) with the number of loading cycles when q_d=0.80q_u (geogrid).

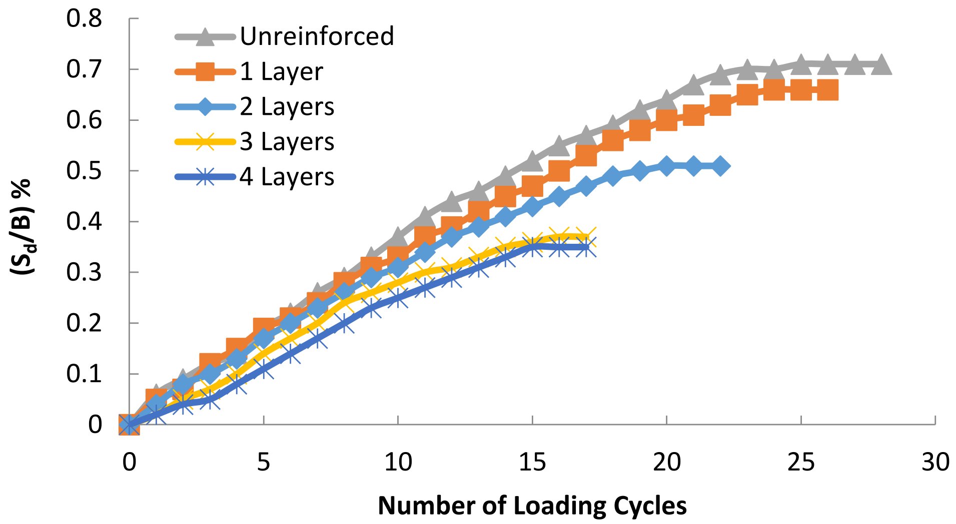

Fig. 7. Variations of (S_d/B) with the number of loading cycles when q_d=0.50q_u (geogrid).

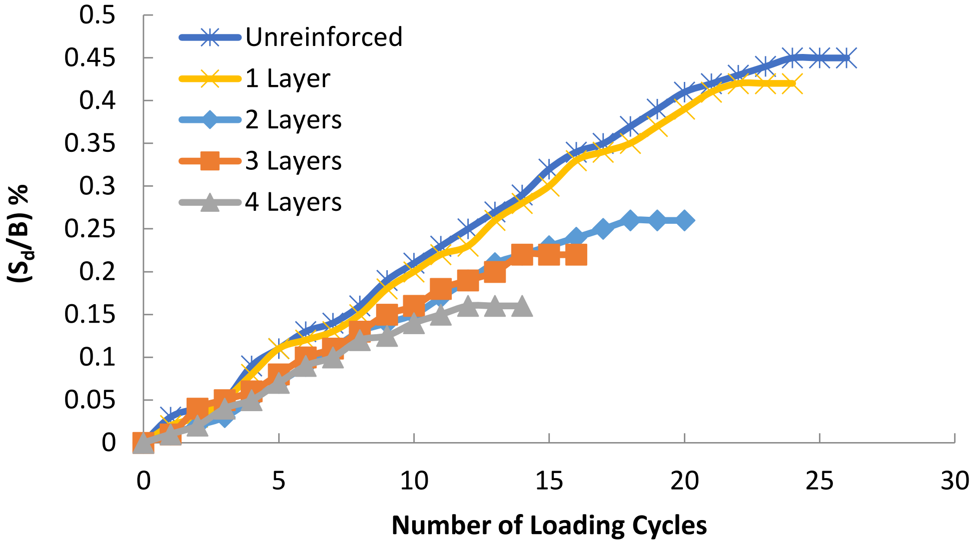

Fig. 8. Variations of (S_d/B) with the number of loading cycles when q_d=0.25q_u (geogrid).

to 64%. In geogrid reinforced slopes, the number of loading cycles required to achieve constant settlement decreases by up to 47%. The change of the dimensionless settling ratio vs. the number of loading cycles for the grid anchor reinforced soil up to four layers is shown in Figs. 9 to 11.

Permanent settlement is reduced by up to 67 percent when grid anchor reinforcement is used. In a geogrid reinforced slope, the number of loading cycles required to achieve constant settlement decreases by up to 50%. The grid anchor reinforcement has a greater effect on reducing permanent settlement and the number of loading cycles required to reach that settlement, according to the findings. Increasing the cyclic load amplitude, on the other hand, increases the permanent settlement and the number of loading cycles required to accomplish that settlement.

Fig. 12 depicts the relationship between geogrid and grid anchor reinforcement layers and the settlement reduction factor. As can be observed in the graphs, using the grid anchor system increases the amount of SRF by roughly 66 percent compared to the non - reinforced condition. When compared to the unreinforced condition, this value for standard reinforcement is around 64%. The ratio varies depending on the number of reinforcement layers and the applied load percentage. According to the findings, three-dimensional reinforcement has a more significant effect in reducing settlement than conventional reinforcement. Higher cyclic load amplitudes might magnify this effect. Higher tangling of soil grains with the three-dimensional reinforcement and improved pullout resistance of this type of geosynthetic would explain the increased effect.

In addition, as shown in Figs. 13 and 14, the number of loading cycles required to achieve constant permanent settling for the soil reinforced with grid anchor is reduced by around 57 percent when compared to the unreinforced condition. When compared to a geogrid reinforced slope, the number of loading cycles required to achieve consistent permanent settlement can be reduced by up to 14 percent by adopting grid anchor reinforcement.

According to the findings, increasing the number of reinforcement layers reduces the number of loading cycles required to achieve a constant permanent settlement. The fluctuations of applied load amplitude versus dimensionless permanent settlement are shown in Figs. 15 and 16. The use of a greater number of reinforcement layers results in a more significant slope of the load-settlement graph, as seen in these figures. The increase in the slope of the load-settlement curves, on the other hand, could be observed to be more significant in higher cyclic loading amplitudes, according to the reported results in the figures. This could be attributed to higher tensile load mobilization in the reinforcements, as well as an increase in soil stiffness as the number of loading cycles increases. Increased soil density and increased tangling of the soil grains with the reinforcement would improve soil stiffness. The quantity of settlement would not be affected by increasing the loading cycles beyond a defined value, as represented by n_{cr}.

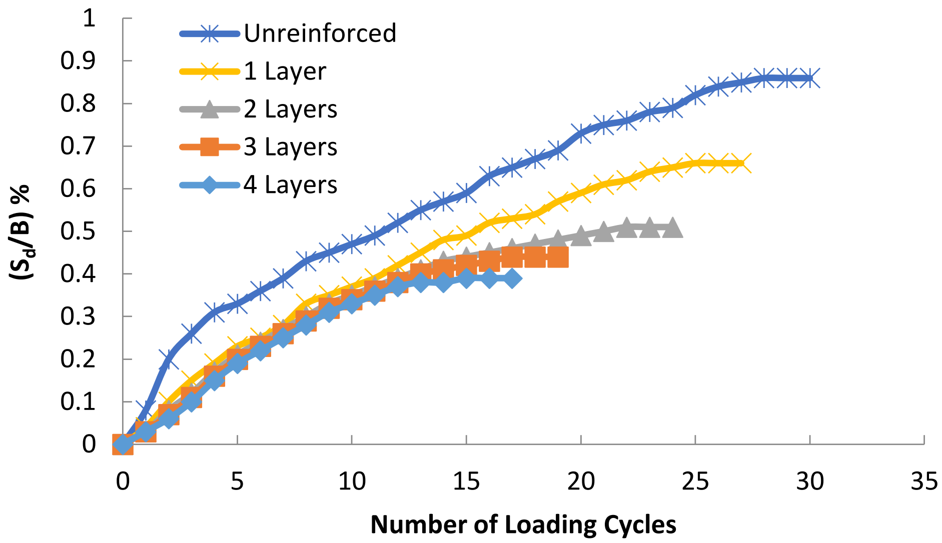

Fig. 9. Variations of (S_d/B) with the number of loading cycles when q_d=0.80q_u (grid anchor).

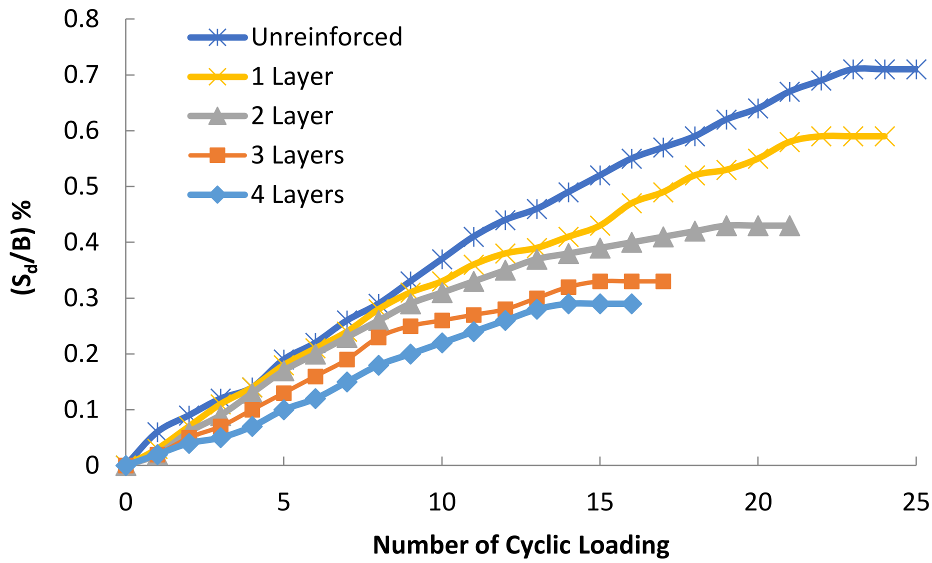

Fig. 10. Variations of (S_d/B) with the number of loading cycles for when q_d=0.50q_u (grid anchor).

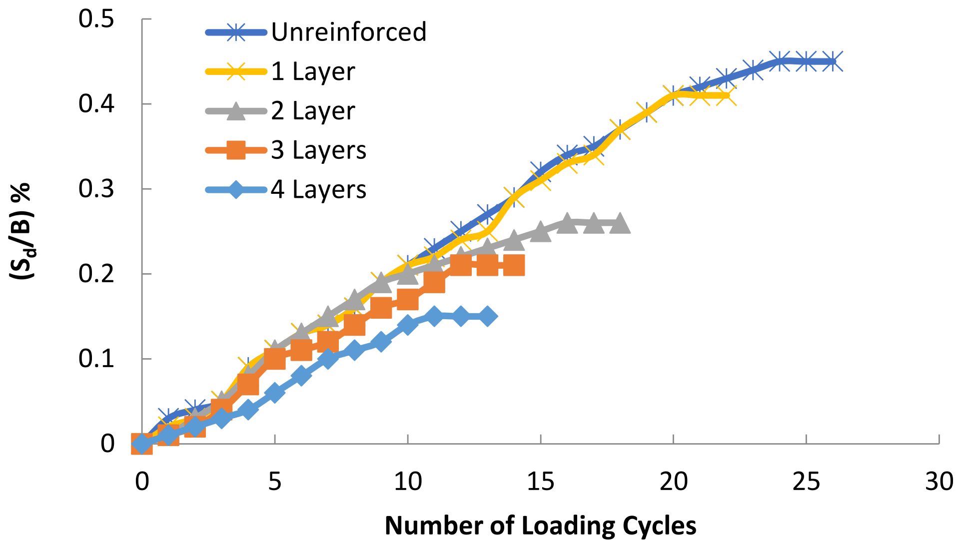

Fig. 11. Variations of (S_d/B) with the number of loading cycles when q_d=0.25q_u (grid anchor).

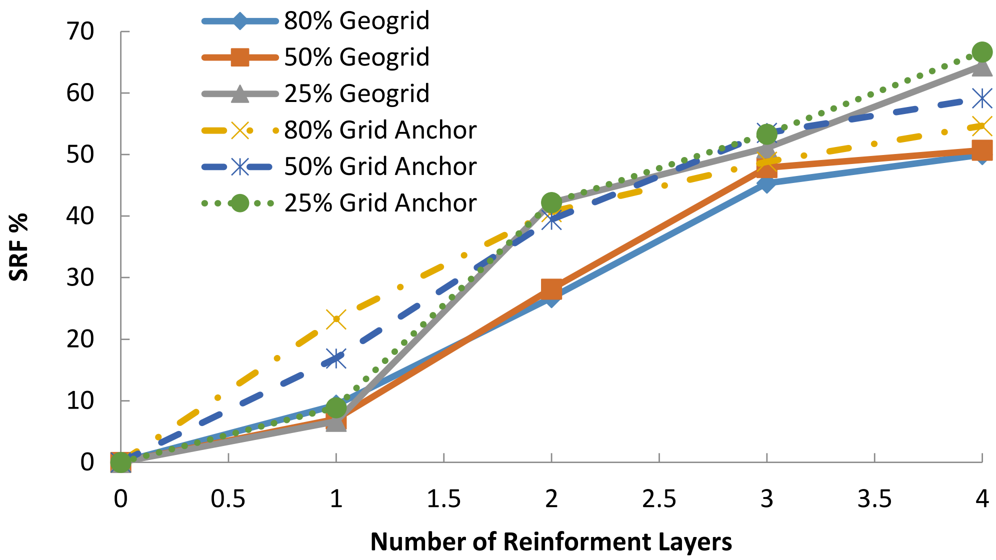

Fig. 12. Variations of SRF with the number of reinforcement layers.

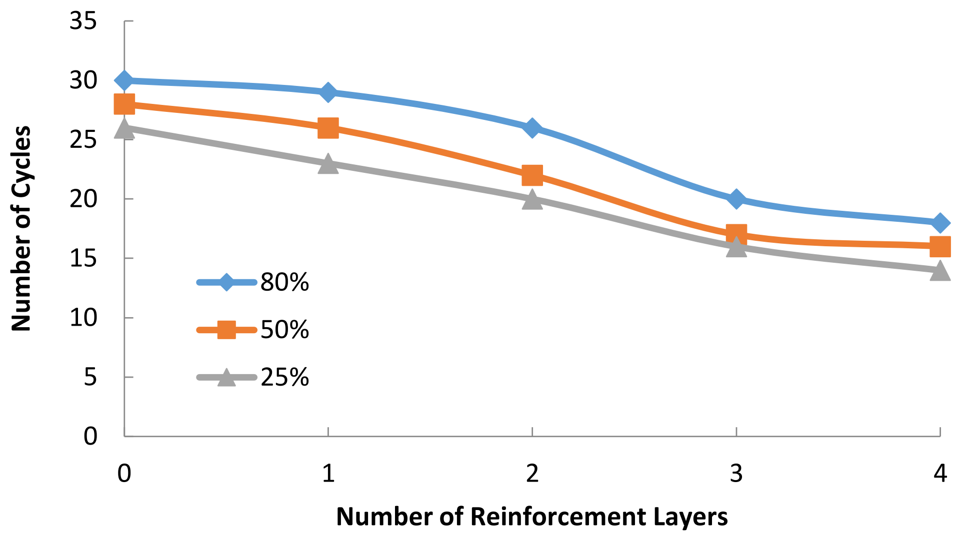

Fig. 13. Variations of SRF with the number of reinforcement layers (geogrid).

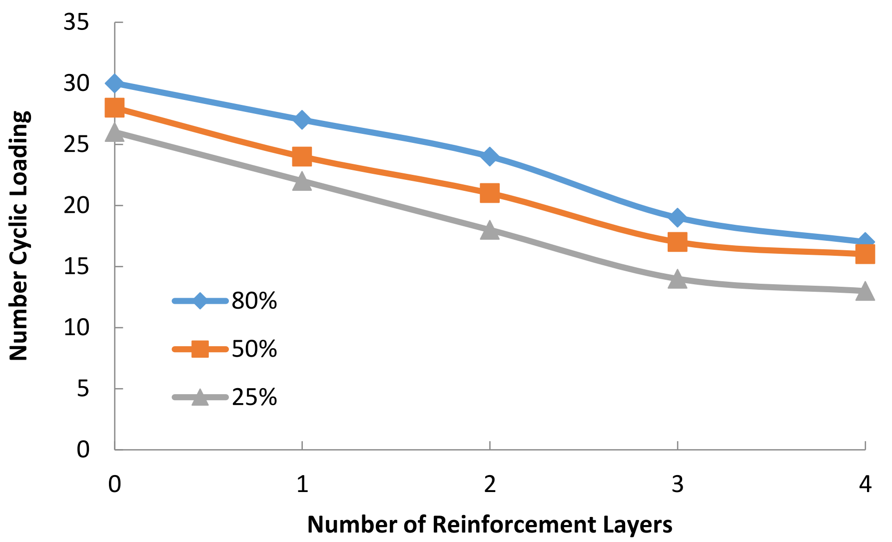

Fig. 14. Variations of SRF with the number of reinforcement layers (grid anchor).

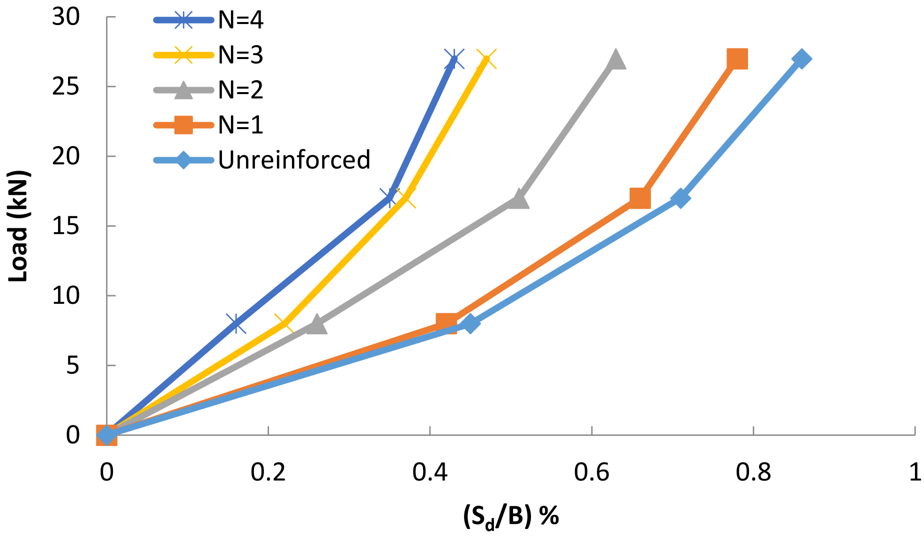

Fig. 15. Variations of load with (S_d/B) (geogrid).

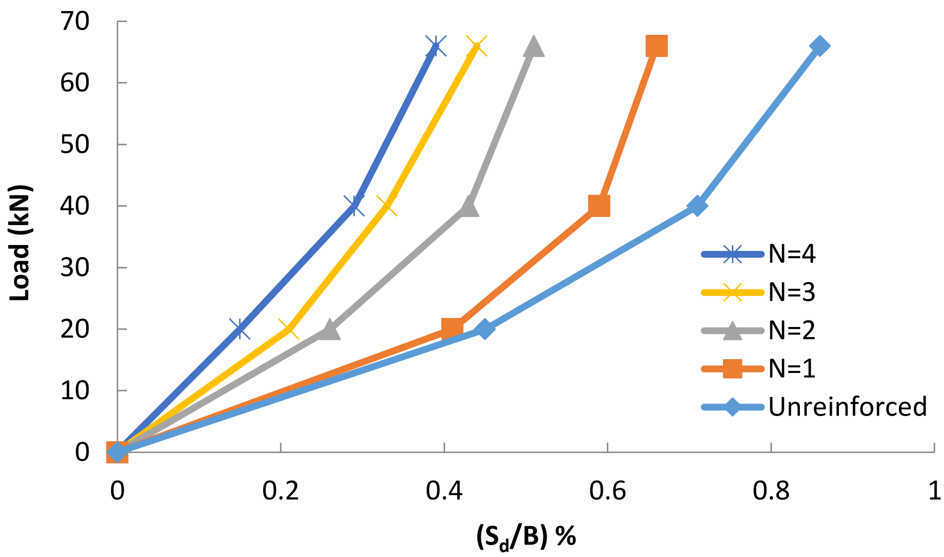

Fig. 16. Variations of load with (S_d/B) (grid anchor).

6- Conclusion

The cyclic response of strip footing resting on the reinforced sand slope was studied using a three-dimensional reinforcement method previously described by Mosallanezhad et al.

This innovative technique, known as a grid-anchor reinforcement system, has proven to be more efficient than traditional geogrid systems. With the frequent filling and discharging procedures and the railway ballast course under repetitive transportation loads, this innovative reinforcement generation can be employed to reduce uniform and non-uniform foundation settlement of storage tanks. The following items could be offered based on the presented laboratory results in this research.

1. As the number of reinforcements increased, the ratio of dimensionless permanent foundation settlement dropped for a constant loading ratio.

2. The dimensionless permanent settlement of the foundation increased as the amplitude of cyclic loading was increased for a constant static loading.

3. Compared to the slope reinforced with geogrid, the amount of reduction in permanent dimensionless settlement using the grid anchor system is up to 18%, and up to 67 percent compared to the unreinforced condition. The number of reinforcements and the amplitude of the applied load affects these values.

4. In addition, compared to geogrid reinforcement, the number of cycles necessary to achieve permanent dimensionless settlement utilizing the grid anchor system would be reduced by up to 14 percent, and by up to 57 percent compared to the unreinforced state.

References

[1] J.G. Zornberg, N. Sitar, J.K. Mitchell, Performance of geosynthetic reinforced slopes at failure, Journal of Geotechnical and Geoenvironmental Engineering, 124(8) (1998) 670-683.

[2] M. Mosallanezhad, N. Hataf, A. Ghahramani, Experimental study of bearing capacity of granular soils, reinforced with innovative grid-anchor system, Geotechnical and Geological Engineering, 26(3) (2008) 299-312.

[3] A. Boushehrian, N. Hataf, A. Ghahramani, Modeling of the cyclic behavior of shallow foundations resting on geomesh and grid-anchor reinforced sand, Geotextiles and Geomembranes, 29(3) (2011) 242-248.

[4] Hajiani Boushehrian, A. Vafamand, S. Kohan, Investigating the experimental behavior of the reinforcements effect on the railway traverse under the dynamic load, Scientia Iranica, 24(5) (2017) 2253-2261.

[5] N. Hataf, A. Boushehrian, A. Ghahramani, Experimental and numerical behavior of shallow foundations on sand reinforced with geogrid and grid anchor under cyclic loading, (2010).

[6] N. Correia, J. Zornberg, Strain distribution along geogrid-reinforced asphalt overlays under traffic loading, Geotextiles and Geomembranes, 46(1) (2018) 111-120.

[7] G.T. Mehrjardi, M. Khazaei, Scale effect on the behavior of geogrid-reinforced soil under repeated loads, Geotextiles and Geomembranes, 45(6) (2017) 603-615.

[8] A. Mehrpazhouh, S.N.M. Tafreshi, M. Mirzababaei, Impact of repeated loading on mechanical response of a reinforced sand, Journal of Rock Mechanics and Geotechnical Engineering, 11(4) (2019) 804-814.

[9] E. Shin, D. Kim, B. Das, Geogrid-reinforced railroad bed settlement due to cyclic load, Geotechnical & Geological Engineering, 20(3) (2002) 261-271.

[10] E. Shin, B. Das, Dynamic behavior of geogrid-reinforced sand, KSCE journal of civil engineering, 3(4) (1999) 379-386.

[11] S.M. Tafreshi, A. Dawson, Behaviour of footings on reinforced sand subjected to repeated loading–Comparing use of 3D and planar geotextile, Geotextiles and Geomembranes, 28(5) (2010) 434-447.

[12] A.H. Boushehrian, A. Afzali, Experimental investigation of dynamic behavior of shallow foundation resting on the reinforced sand with embedded pipes, International Journal of Geography and Geology, 5(9) (2016) 182-193.

[13] M. El Sawwaf, A.K. Nazir, Behavior of repeatedly loaded rectangular footings resting on reinforced sand, Alexandria Engineering Journal, 49(4) (2010) 349-356.

[14] K. Halder, D. Chakraborty, Bearing capacity of strip footing placed on the reinforced soil slope, International Journal of Geomechanics, 18(11) (2018) 06018025.

[15] K. Halder, D. Chakraborty, Effect of interface friction angle between soil and reinforcement on bearing capacity of strip footing placed on reinforced slope, International Journal of Geomechanics, 19(5) (2019) 06019008.

[16] S. Alamshahi, N. Hataf, Bearing capacity of strip footings on sand slopes reinforced with geogrid and grid-anchor, Geotextiles and Geomembranes, 27(3) (2009) 217-226.

[17] M. Ghazavi, H. Mirzaeifar, Bearing capacity of multi-edge shallow foundations on geogrid-reinforced sand, in: Proceedings of the 4th International Conference on Geotechnical Engineering and Soil Mechanics, 2010, pp. 1-9.

[18] T. Sitharam, S. Sireesh, Behavior of embedded footings supported on geogrid cell reinforced foundation beds, Geotechnical testing journal, 28(5) (2005) 452-463.

[19] A. Zidan, Numerical study of behavior of circular footing on geogrid-reinforced sand under static and dynamic loading, Geotechnical and Geological Engineering, 30(2) (2012) 499-510.

[20] F.M. Makkar, S. Chandrakaran, N. Sankar, Behaviour of model square footing resting on sand reinforced with three-dimensional geogrid, International Journal of Geosynthetics and Ground Engineering, 3(1) (2017) 3.

[21] M.A. El Sawwaf, A.K. Nazir, Cyclic settlement behavior of strip footings resting on reinforced layered sand slope, Journal of Advanced Research, 3(4) (2012) 315-324.

[22] M. Islam, C. Gnanendran, Slope stability under cyclic foundation loading-Effect of loading frequency, in: Geo-Congress 2013: Stability and Performance of Slopes and Embankments III, 2013, pp. 750-761.

[23] M.J.I. Alam, C. Gnanendran, S. Lo, Experimental and numerical investigations of the behavior of footing on geosynthetic reinforced fill slope under cyclic loading, Geotextiles and Geomembranes, 46(6) (2018) 848-859.

[24] J. A.R., Soil Mechanics, Affiliated East-West Press Pvt. Ltd., New Delhi, (1967).

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