



Effects of Geogrid Layers on Improving Bearing Capacity of Vibrating Machines Foundation

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ABSTRACT

The main aim of this study is an investigating the effect of using geogrid layers in the reinforcement of soil under the foundation to estimate the reaction of industrial machines' foundations under periodic loading based on finite element method using ABAQUS software. Also, the effect of the number of geogrid layers, the effect of depth and width of geogrid, different loading frequencies along with the effect of using geogrid layers on the first to the third modes of frequency values of the soil were evaluated. The results showed that as the number of geogrid layers increases, bearing capacity of foundation rises and the optimum depth of geogrid layers for dynamic mode is equal to 0.6 times the width of the foundation strip. Furthermore, increasing frequency of dynamic load does not lead to a significant change in capacity.

Keywords: *Vibrating machine foundation, Improving, Geogrid, Periodic loading, Bearing capacity.*



1. Introduction

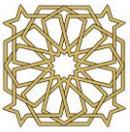
Soil, as the most important building material and the main support structure, is of interest to engineers. However, due to the discontinuous structure and lack of shear strength along with lack of resistance to tensile forces, the researchers have constantly been looking for the ways to increase bearing capacity, resistance, and improvement of soil properties through various methods including mechanical corrections such as density, chemical modification such as stabilization with lime, and the use of reinforcements such as variety of geosynthetics. Soil reinforcement is known as an effective and reliable method to reform the soil due to its resistance to environmental conditions, ease of implementation, cost-effectiveness, and high impact in improving soil properties. Geosynthetics are actually artificial products made of polymeric compounds and are used in constructional activities. One important use of geosynthetics in construction projects is their use as reinforcement in the manufacture of industrial machines' foundations. Geosynthetics, according to the type of ingredients and manufacturing methods, have various applications in the construction processes such as materials separation from each other, reinforcement and strengthening of soil, water filtration in marine structures, drainage, and sealing. According to the types of mentioned applications and projects conditions, many researchers have worked on this subject. Raymond and Comos [1] investigated the behavior of the surface strip foundations under vertical cyclic loadings and reported that the permanent settlement rises with an increase in the number of cycles and its time. Poulos [2] investigated foundation types on sandy soils and conducted some experiments on foundation models on sand with various relative densities of vertical cyclic loadings. Yeo et al. [3] investigated ultimate bearing capacity and settlement of rectangular and strip foundations on the network of reinforced sand exposed to synchronized static and cyclic vertical loads with varying degrees of intensity. Arayee [4] focused on experimental and numerical studies of sandy trenches reinforced with geosynthetic under a loading foundation. Sarand et al. [5] conducted a research about the behavior of reinforced and non-reinforced sandy soils under the strip foundation. This study investigated the failure mechanism of sandy soil deformation, and reinforcement effect on the process under a strip foundation. Zamani et al. [6] examined bearing capacity of surface foundation based on sand reinforced with chip worn tires



using static analysis. The results indicated that the usage leads to an increase in bearing capacity to a large extent and significantly amortizes earthquake vibrations. Gholamhoseinpour and Soltani [7] conducted a research on bearing capacity of foundations to compare different methods for determining the bearing capacity. Besides, the effect of parameters such as joint inclination angle along with cohesion parameters of the rock mass and fractures were examined on the bearing capacity strip foundation. Nazari and Dabiri [8] studied to explore the effect of geotextile layers place in various depths of the body of pavement layers located on soft soil. Results showed that in static loading, the maximum safety factor of stability is that of layers in which the geotextile exists in the partition between subgrade and embankment layers. Also, between dynamic loading and increasing number of geotextile layers favorable result is not achieved. Although more studies need to be carried out in this area.

2. Foundation design and soil reinforced

Based on the literature review and previous work and the results of conducted laboratory studies, four modes of failure for foundations located on reinforced soil was proposed as presented in Figure 1. A) Failure above the top layer of reinforcements (Binquet and Lee, [9]) B) Failure between the two reinforce layers (Wayne et al., [10]) C) Failure similar to foundation failure on two layers of soil (strong soil layer on the weak soil layer) (Wayne et al., [10]) D) General failure among the reinforce layers [11]. To avoid the first two types of failures, it suffices to make the top layer depth (u), and the vertical distance between the layers of reinforcement (h) as small as possible. Laboratory experiments by Chen [12] and Abu-Farsakh et al. [13] revealed that the top layer depth (u), and the vertical distance between the layers of reinforcement (h) must be smaller than $0.5B$ so that this type of error does not occur (B is foundation width). Compliance with these considerations is not difficult for engineers, so it is better to examine two other types of failure modes. Based on the results of experimental studies, geogrids directions in clay or sandy reinforced soil under ultimate loading would be almost horizontal. Due to its porous and geometric structure, the soil penetration from one side of geogrid is allowed to the other side. As a result, punching



effect of the reinforcement mechanism powering over clay or sandy soils is reinforced with geogrid. As mentioned earlier, punching effect could resist the possible lateral deformation or tensile strain in the soil. This results in an increase in the bearing capacity of the soil under the foundation and is the prerequisite for their use.

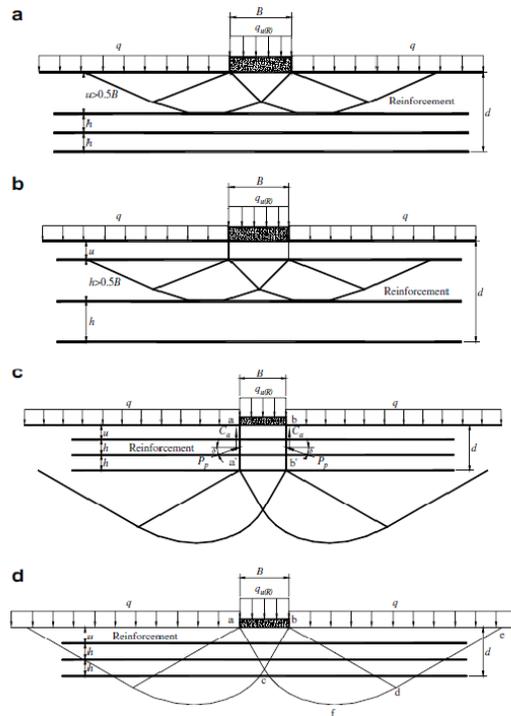


Fig 1. Failure modes of reinforced soil foundation, (a) Failure above top layer reinforcement [9], (b) Failure between reinforcement layers [10], (c) Failure similar to footings on a two-layer soil system [10], (d) Failure within reinforced zone.

3. Numerical modelling

In the present investigation, the created area had a width and height of 10×10 m, respectively. This is suitable for foundation strip with a width of 2=B m. However, for accuracy in modeling, we used unlimited elements for modeling boundary conditions. Besides, foundation behavior is assumed to be rigid and its rigidity effect is only considered in modeling using boundary conditions. Generally, small meshing is used in the whole model and based on the model analysis done to test sensitivity of the results to the size of mesh. Size of the elements was considered to be 0.5 meter. Sharma [11] proposed the dimensions of the area of foundation failure spread with a



width of B5 and depth of B3 for the central foundations points for foundation-based granular soils. In the current research, the width and depth of the critical section was considered $3B$ with respect to foundation central point. In the critical area, smaller mesh was used compared to the general state due to the importance of the deformation and stress concentration. Geometrically, the distance of the first geogrid layer under the foundation (u) is assumed as the distance between geogrid layers towards each other (h). The Width of the geogrid layers (b) varied and its optimum amount is calculated using numerical analysis during the following stages of the research. In addition, in the expression of boundary conditions, assuming placement of model bottom on the rigid bed, all degrees of freedom of the bottom edge were bound. Regarding the outer side of the edges, unlimited elements were used and in the symmetry border, the degrees of freedom were bound perpendicular to the border.

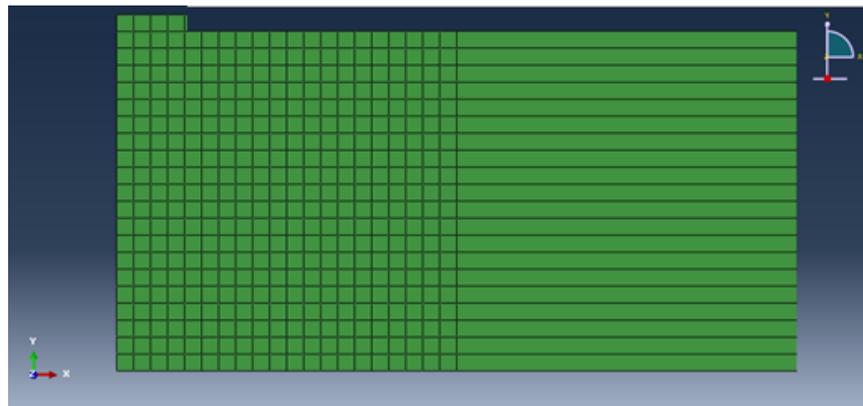


Fig 2. Numerical model made based on Abaqus software.

The behavior of the soil materials under the foundation is assumed as elastic and in isotropic stress conditions and its plastic behavior is simulated using Mohr-coulomb model. In the conducted model, three types of sand soil were used including loose, medium-density, and high-density. For the geogrid modeling, elastic model was used. Geogrid and soil layers materials' features are presented in Tables (1) and (2), respectively.



Table 1: Properties of geogrid [11].

Parameter	Unit	Geogrid
Density	Kg/m ³	1000
Young Modulus (E)	MPa	472
Poison ratio	-	0.3

Table 2: Soil layers properties below vibrating machine foundation.

Parameters	Unit	Loose	Medium	Dense
Density	Kg/m ³	1500	1700	1900
Young modulus	mPa	100	200	300
Poison ratio	-	0.3	0.3	0.3
Internal friction (φ°)	-	20	25	30
Cohesion	kPa	1	1	1

4. Dynamic loading

Loading of foundation strip in this model consists of two stages. In the first stage, the ultimate bearing capacity of soil (q_{ult}) is extracted from the software output. Then, the maximum amount of bearing capacity of foundation strip, emanating from equation 1, is entered to the foundation as a linear load to create permanent static settlements in the foundation.

$$q_{all} = \frac{q_{ult}}{F.S} \tag{1}$$

In the above equation, F.S is the reliability that is usually considered between 3 and 4 which was chosen to be 3 in the present study. In the second stage of the loading, a percentage of the ultimate static load (q_{ult}) is added to the foundation as a dynamic load in a linear fashion. In this kind of modeling, dynamic load values for different analyses is assumed as a quarter-final static load ($0.25q_{ult}$). The load caused by vibration machines entered on the foundation is usually similar to periodic cycle load presented in Figure 3. In the present study, applied frequency alternating load was 1, 3, and 6 Hertz (Hz).

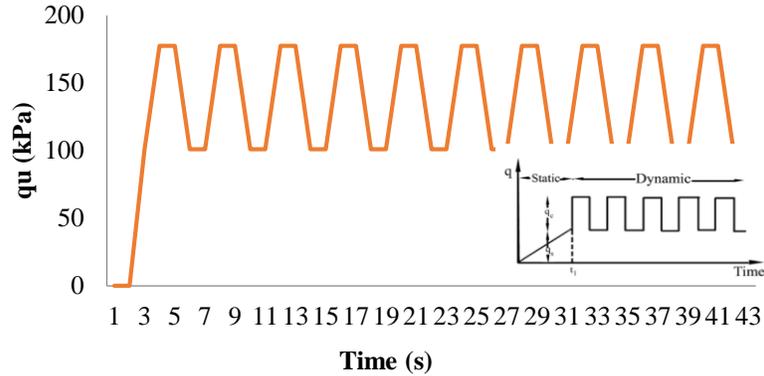


Fig 3. Properties of dynamic loading due to vibrating machine.

Finally, to calculate the ultimate bearing capacity of foundation, the loading was modeled as a displacement control and the one-meter modeled section of the foundation was uniformly displaced in the vertical direction to enter nonlinear area and reach failure at the end.

5. Results

5.1. Effects of geogrid width

At this stage, geogrid optimum width is calculated for dynamic loading mode for the concrete foundation strip of the industrial machines. In the numerical model, it is assumed that the foundation strip is created on the sand in three modes and a layer of geogrid for the reinforcement. To determine the optimal width, 10 different modes are taken into account for the geogrid (b) which is presented in Figure 4. To calculate the bearing capacity of foundation, suitable uniform settlement (2 inches) is applied under the foundation, and ultimate bearing capacity is assessed for different values of the settlement.

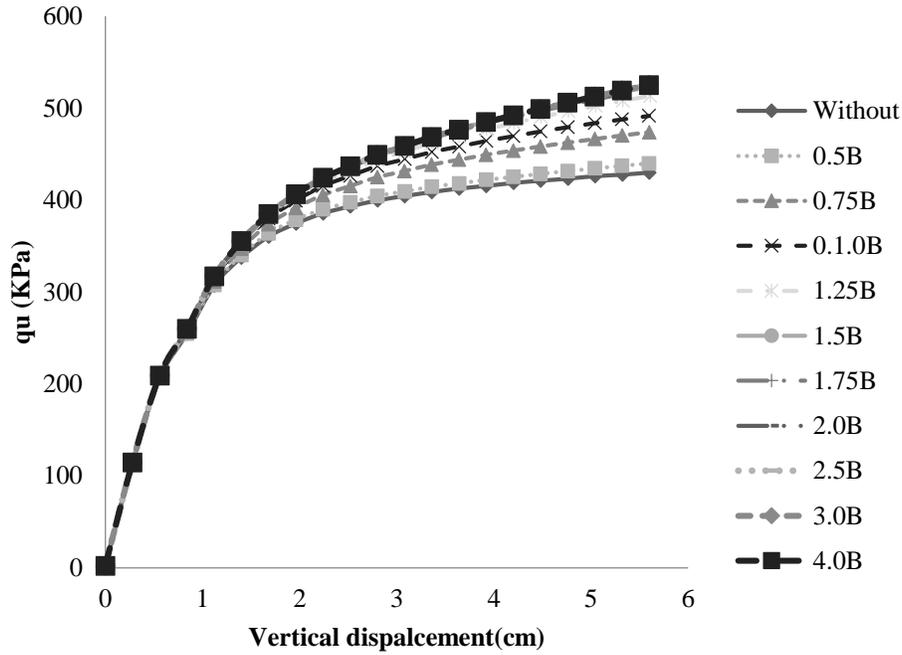


Fig 4. Changes of ultimate bearing capacity of foundation versus vertical displacement for values of geogrid layers width in dense sand.

According to Figure 4, it could be concluded that assuming the width of the geogrid as 2.5 of foundation strip width, changes in vertical settlement and ultimate bearing capacity in a dynamic loading conditions reach to an equal amount. As evident in Figure 5, the optimum width for the geogrid layers changes based on soil density. The optimum width for geogrid increases in line with the degree of looseness in sandy soil structures. In high-density sandy soil, optimum geogrid width was $b=2.5B$, while this was $b=3B$ and $b=4B$ for medium-density and loose soil, respectively.

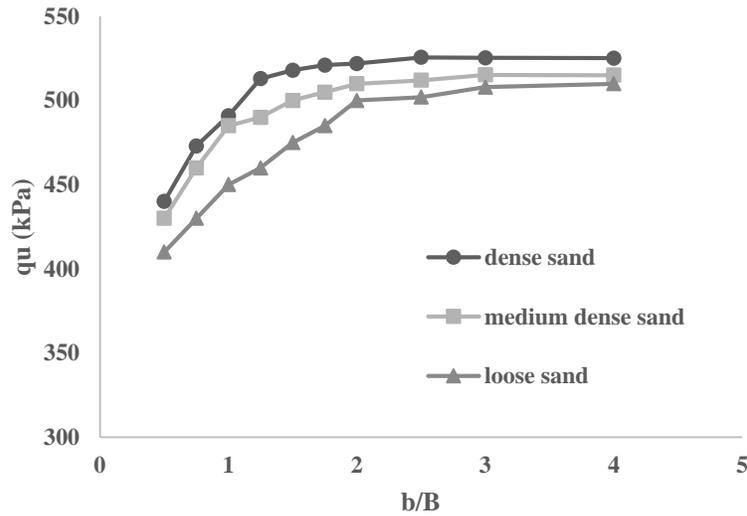
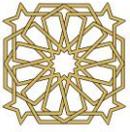


Fig 5. Effects of geogrid layers width on bearing capacity of in sandy soil in several density.

5.2. Determining optimum depth of geogrid

The optimum depth placement of geogrid layer was done for dynamic loading of concrete foundation strip. For modeling, it was assumed that foundation strip is assessed for three different modes of sand depending on their density. One layer of geogrid was used for the reinforcement. To determine the optimum amount, five different values are taken into account for the depth of geogrid (u). These values are presented in Figure 6, and suitable uniform settlement (2 inches) is applied under the foundation. Ultimate bearing capacity is assessed in high-density soil for different values of the settlement. As indicated in Figure 7, increasing the depth of reinforcement elements (u) of 0.2 equal to the width of foundation up 0.6 of foundation of the width leads to a vertical settlement decline under the foundation affected by the dynamic load.

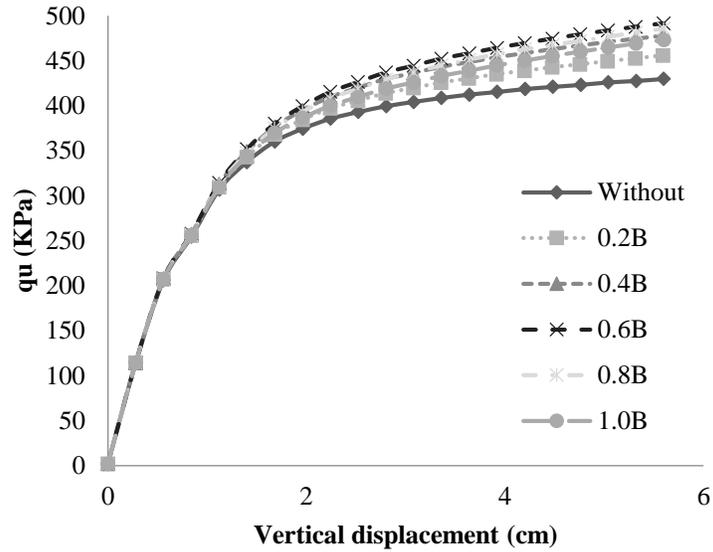
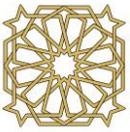


Fig 6. Effects of geogrid layer locating depth on bearing capacity and vertical displacement.

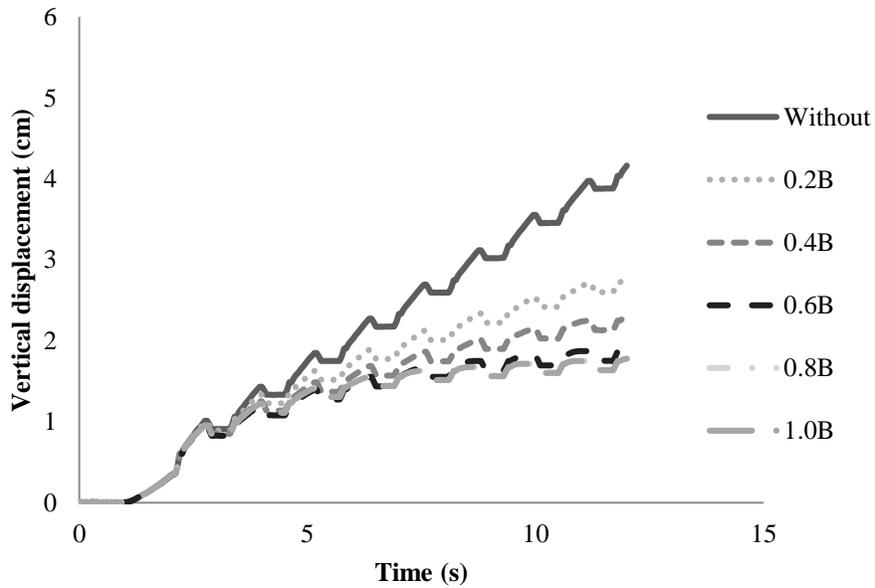


Fig 7. Effects of geogrid layer locating depth on vertical displacement under dynamic loading.



As it can be observed in Figure 8, in all types of sand soil with differing density levels, with an increase of 0.2 in reinforcement element depth (u) equal to the width of foundation up 0.6, the bearing capacity of the foundation rises. However, increasing $b=0.6B$ up to $b=1B$ results in a bearing capacity reduction. That is why the optimal geogrid width is considered $b=0.6B$ for the dynamic mode.

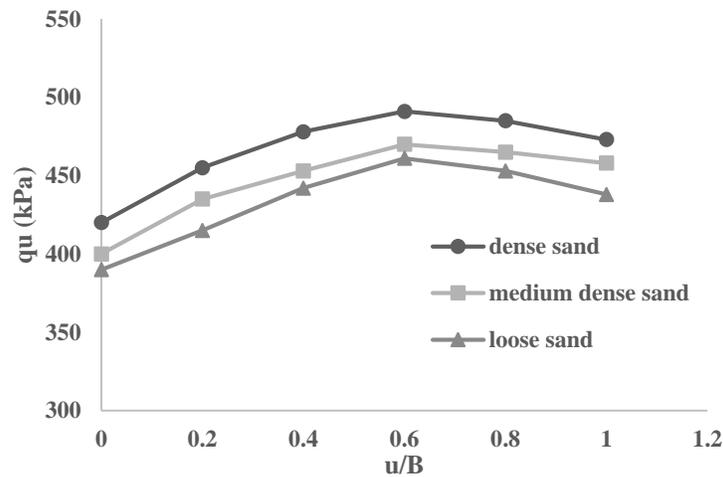


Fig 8. Effects of geogrid layers locating depth on bearing capacity of in sandy soil at several density.

5.3. Number of geogrid layer

To investigate the effect of the deformations of geogrid layers, the created model consisted of one to five geogrid layers with a vertical distance of $0.6B$. A sample of the research on sandy soil with high density is presented in Figure 9. As it is indicated in Figures 9 and 10, increasing the geogrid layers leads to a rise in foundation bearing capacity, and under foundation deformations continue to a deeper level. This mechanism results in more of the nearby soil to be engaged in the applied loading and accordingly, the soil could bear more loading.

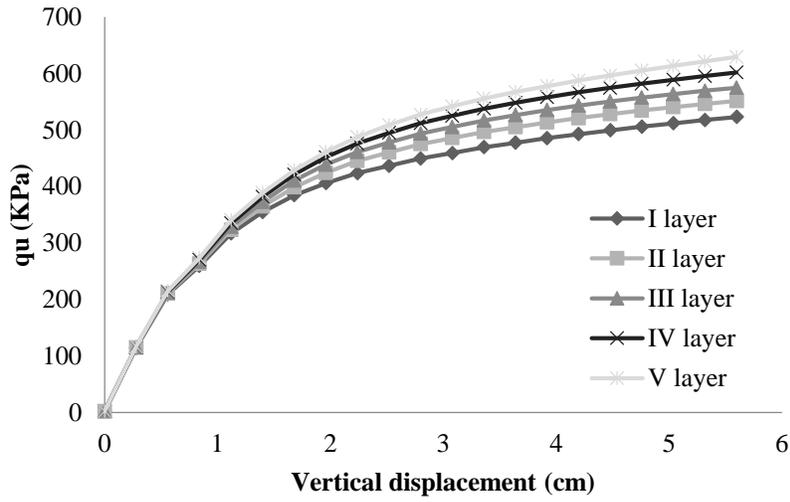
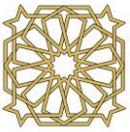


Fig 9. Effects of number of geogrid layers on bearing capacity of in dense sand.

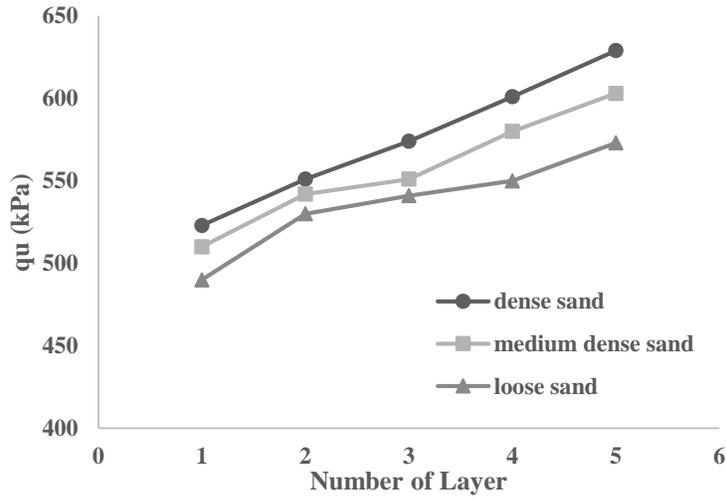


Fig 10. Effects of number of geogrid layers on bearing capacity in sandy soil at several density.



5.4. Effects of loading frequency

To study the effect of dynamic load frequency on foundation settlements, a dynamic load equivalent to 25% of the ultimate static load with frequencies of 1Hz, 3Hz, and 6Hz were applied to the foundation. Geogrid used in this analysis was modeled with an optimal length of 2.5 times the width of foundation and optimal depth of 0.6 of foundation width. Figure 11 presents the frequency of the possible loading against settlement percentage. As it is illustrated, increasing the loading frequency from 1Hz to 6Hz, no significant change occurs in the level of vertical settlement in all different densities of sandy soil.

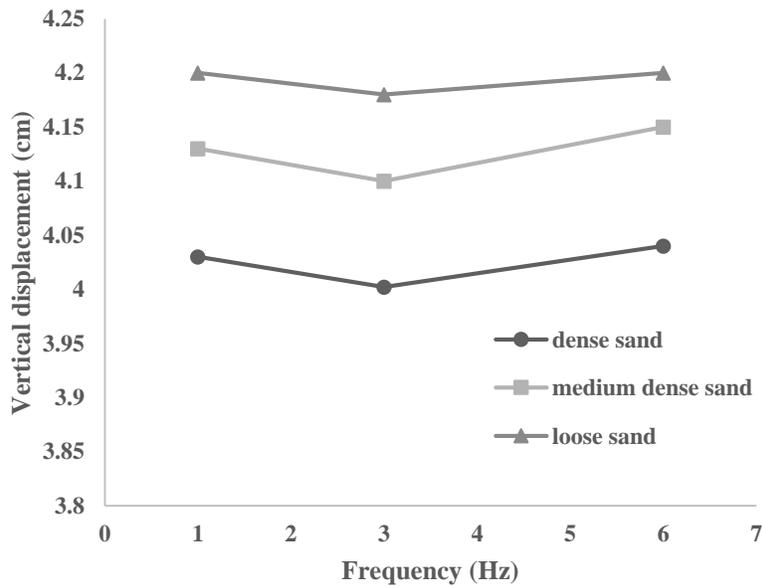


Fig 11. Effects of dynamic frequency loading on vertical displacement in sandy soil at several density.

6. Conclusion

Due to periodic type of loading in industrial machines and also given the high sensitivity of the foundations of these machines to displacement and deformation (settlement) of the soil under foundation, it seems vital to use improved foundations by reinforcements. Thus, it is essential to



study the usage of reinforcements in increasing the bearing capacity of the foundations and lowering the amount of possible settlements. As it was mentioned, the objective of the present article was to investigate the usage possibility of geogrid layers in soil reinforcement under foundation to fathom the behavior of the periodic loading foundation caused by vibrating machinery. The results could be summarized as follows:

1. Ultimate bearing capacity of the foundation for different values of the geogrid is an optimal value and does not change significantly after increasing geogrid width of the bearing capacity. In this study, the optimum width of the geogrid in the dynamic mode was determined in three different densities for the foundation strip based on the sand. The results showed that bearing capacity in the dynamic mode rises by increasing the width of the geogrid. Thus, geogrid optimum width for dynamic load was evaluated to be $b=2.5B$, $b=3B$ and $b=4B$ for high-, medium-density, and loose soil, respectively.

2. The results of the study also revealed that with an increase of 0.2 in reinforcement element width (u) equal to the width of foundation up 0.6, the bearing capacity of the foundation rises. However, increasing $b=0.6B$ up to $b=1B$ results in bearing capacity reduction. That is why the optimal geogrid width is considered $b=0.6B$ for the dynamic mode. This condition holds true for all sand soil density modes.

3. The findings, in addition, proved that increasing the geogrid layers leads to foundation bearing capacity growth, and under foundation deformations continues to a deeper level. This mechanism results in more of the nearby soil to be engaged in the applied loading, and consequently, the soil could bear more loading. The more the layers get, the more the gradient of the changes declines.

4. Then, dynamic load equivalent to 25% of the ultimate static load with frequencies of 1Hz, 3Hz, and 6Hz were applied to the foundation. Geogrid used in this analysis was modeled with an optimal length of 2.5 times the width of foundation and optimal depth of 0.6 of foundation width. It could be deduced that reinforcements affect resistance more than frequency.

Based on the results of the present study, it could be stated that the use of geosynthetic materials is very effective in soil improvement under foundations in vibrating machines. However, it is also



suggested that further research need to be conducted on the use of other geosynthetic materials in soil improvement under the foundations of industrial machines. Furthermore, seismic behavior of the soil and dynamic responses of the foundation in these machines are important and warrant further investigation.

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