Effect of different geosynthetic reinforcement materials on transmitted pressure under dynamic machine foundation

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Abstract-The present study has been carried out to study experimentally the contact pressure transmitted of dynamic machine foundation on unreinforced and reinforced multi-layered sandy soil (medium-dense sand MD). The relative density of the first layer was 50% corresponding to medium sand soil, while the relative density of the second layer was 85% corresponding to dense sand soil. The tests have been carried out on 8 models. The amplitude of the applied harmonic load was 0.25 ton and 2 ton with a frequency of 0.5 Hz. For each load amplitude, models of sand were tested in two cases reinforced and unreinforced models. Three types of reinforcements were used at 0.5B depth where B is the width of the square foundation. Analyzing the dynamic behavior of tested soil samples and presenting of some concluded remarks were done.

1. Introduction

Footings are created to withstand dynamic loading such as rotating or reciprocating machines or earthquake as irregular dynamic loading. Commonly, the wave or explosion movement is prepared for dynamic and static loading because pure dynamic loads do not happen alone in the real cases and the state is permanently a collection of dynamic and static loads. As an example, in the affair of a well-designed footing that a machine supporting, the dynamic load caused by the operation of the machine is a small fraction of the firm's constant weight [1]. For soils under dynamic cases, it was concluded that the behavior of loaded soil is ruled by many elements and it is indispensable for many researchers [2]. These elements are:

1) Nature of soil (permeability of the soil, relative soil density, etc.).
2) Environmental factors in which the soil (static pressure condition and pressures of groundwater).
3) The nature of dynamic loading (stress size, contortion rate and loading cycles number).

Geosynthetic is the general term applied to permeable textile materials used in geotechnical engineering. These materials are made from a variety of synthetic polymers in a process involving the combination of plastic fiber by weaving or bonding into a continuous sheet, referred to as a fabric. Closely related to this fabric is a range of other products such as webbing strips, mats and grids [3]. Geosynthetics can be classified


into eight various sections as follows: geomembranes, geogrid, geocells, geotextiles geosynthetic clay liners, geons and geofoam.

The present study has been carried out to study experimentally the contact pressure transmitted of dynamic machine foundation on unreinforced and reinforced multi-layered sandy soil (medium-dense sand MD). Three types of geosynthetics were used as reinforcement materials.

2. Previous Studies of Geosynthetic

Chan [4] conducted several full-size tests to study the repercussions of geogrid reinforcement on the properties of the constant deformity of the granulated course in the pavement bases. Various hardness and types of geogrids were examined with various levels positioning in the layer of the granular base. The outcomes exhibited that:

1) The constant disfigurement of maximum granular footings had enhanced.
2) Amelioration quantity builds upon robustly on the depth and goodness material of the base and geogrid site inside the base.

Geeta et al. [5] studied the interaction between soil and foundation on the modeled square footing to explore contact pressure influenced by different types of geogrid and its effect on settlement and elastic strain path. Geogrids were made of three different types; polyester, non-polymer and polypropylene polymer (PET, NP and PP).

Karim et al. [6] conducted a sequence of typical tests that underwent a static vertical load to stabilize the capacity of gypsum soil with geosynthetic composition materials using single and double geogrid layers placed at different levels. It was found that the rate of settlement without using geogrid raised linearly, so increment of stress with a ratio of bearing 0.75 with failure local shear mode appeared. A high bearing capacity with lowering in the settlement was observed after employing an alone layer of geogrid reinforcement contrasted with untreated soil.

Boushehrian et al. [7] presented an experimental and numerical study of the geocell effect on the first layer depth (u), the spacing between reinforcements (h), and rigidity of the reinforcement ring and circular footings sand on the bearing capacity. Both studies specified that when using a single layer of geocell there is the best depth of reinforcement embedment at which the largest bearing capacity. Reinforcements were found in the range of effective depths for many layers reinforced. Also, the analysis indicated that the reinforcement soil bearing capacity increased with a multiplying number of reinforcement layers.

Mohammed [8] studied the experimental behavior of the ring foundation with various circular and radius foundation remaining on dry sandy soil strengthened by geocells under the influence of periodic and static load. A comprehensive of ninety-six models of behavioral screening (shallow) were tested under axial periodic load. The test results indicated that by providing geocell enhancements in the covered sand layer, significant improvements can be achieved in term of increasing load-carrying capacity and reducing surface deformation.

3. Contact Pressure Below Footing

The rising pressure resulting from soil response and the applied loads are in equilibrium, although, the variation in the distribution of contact pressure along the cross-section of footing is the point of benefit to be conversed about here.

Figure 1 displays the contact pressure with load variation below a foundation. Many elements interfere with the distribution of contact pressure beneath a foundation like [10]:

1) Foundation inflexibility.
2) State condition and type of soil under the foundation.
3) Form of the applied load.
4) Foundation shape.

Problems of contact pressure distribution over a rigid circular and strip footing loaded uniformly and put to the elastic substance semi-infinite were construed by Borowicka [11]. Shear stress was assumed zero at the base of the footing.

![Figure 1. Clarification of contact pressure and applicable loads variation [9].](image)

The explication exhibited that the distribution of contact stress is based upon a non-dimensionality factor $K_r$, as below:

$$K_r = \frac{1}{6} \left( \frac{1-v_s^2}{1-v_f^2} \right) \left( \frac{E_s}{E_f} \right) \left( \frac{T}{b} \right)^3$$

(1)

where:
- $K_r$ is a non-dimensionality factor,
- $v_s$ is soil Poisson’s ratio,
- $v_f$ is footing Poisson’s ratio,
- $E_s$ and $E_f$ are soil and footing modulus of elasticity,
- $b$ is half base width for strip or radius of the circular footing,
- $T$ is the thickness of footing.

Figure 2 illustrates a circular footing with contact pressure distribution of cohesionless soil. Note that $K_r = 0$ points out a fully flexible footing, and $K_r = \infty$ means a fully rigid footing [10].

![Figure 2. Circular footing with contact pressure distribution of cohesionless soil [10].](image)

4. Testing Program

The total number of conducted tests are 8 models. All models are of dry sand tested under dynamically load with a relative density of 50% and 85% corresponding to medium and dense sand layers, respectively. All models are subjected to dynamic loads of with an amplitude of 0.25 and 2 ton employing a frequency of 0.5 Hz. Three types of reinforcement are used with the sand models.
4.1 Geometry of the Problem
For many practical engineering reasons, it may be necessary to lay shallow foundations on stratified deposits. A layer of deposits below shallow footing affecting bearing capacity is named an underground. The thickness of underground by a simplified analysis can be shown as (1) by [9]:

\[ H = \frac{B}{2} \left( \tan 45 + \phi \right) \]  

(2)

where B is a shallow foundation width and \( \phi \) is the angle of internal friction of soil. If the thickness of the deposit surface layer is less than H, then subsoil displays a layered structure. Often practical problems are two-layered of the subsoil as shown in Figure 3.

**Figure 3.** Reinforcement layer at 0.5B depth (\( h_1 \): depth of top layer and \( h_2 \): depth of the lower layer.

4.2 Location of geogrid
Several researchers, [12-14], have successfully performed test models using geogrid and found that the bearing capacity ratio increases with an increase of the number of layers within a depth of 3B below the footing base, but placing geogrid reinforcement beyond the depth of 1.3B would not significantly increase the bearing capacity. Therefore, in this research one reinforcement layer is used at a depth of 0.5B from the surface. Figure 3 illustrates the geogrid and soil layers.

4.3 Soil characterization
In this study, Karbala sand was used. Main tests were performed to calculate physical sand properties and two different sand densities (medium and dense) were performed on these tests. The details are given in Table 1.

| Index Properties          | Value       | Specification                  |
|---------------------------|-------------|--------------------------------|
| Specific gravity          | 2.6         | ASTM D 854 (2006)              |
| \( D_{10} \) (mm), \( D_{30} \) (mm), \( D_{60} \) (mm) | 0.18, 0.35, 0.51 | ASTM D 422 and 2487 (2006)    |
| Coefficient of Uniformity (Cu) | 3.4       |                                |
| Coefficient of Curvature (Cc) | 1.6       |                                |
| Soil classification (USCS) | SP         |                                |
| Maximum Void ratio       | 0.49        | ASTM D4254 (2014)              |
| Minimum Void ratio       | 0.33        | ASTM D4254 (2014)              |
| Maximum dry unit weight (kN/ m²) | 19.5     | ASTM D 4253 (2006)            |
Minimum dry unit weight (kN/m$^3$)  
Angle of internal friction (RD =50%)  
Angle of internal friction (RD =85%)  

4.4 Reinforcement material
Three types of reinforcement materials were used in this study, these are:

1) Type I geogrid manufactured by Al-Latifya Factory for the plastic mesh. The engineering properties provided by the manufacturing company are given by [6] and [15-16].

2) Type II, geogrid fiberglass, which is consists of fiberglass strands coated with an inorganic sizing agent. Good properties are possessing, like as low elongation, high tensile strength, good anti-age alkali-resistance and excellent temperature range [17].

3) Type III, geocells are using as reinforcing material, made from geotextile as non-woven an innovative approach. The pocket-size of the geocell kept constant of 50 mm when the geocell filled with soil [8].

4.5 Devices and design model
Studying the effects of reinforcement material on transmitted pressure to the subsurface layers is the main objective of this study, thus it is needful, as possible as, to simulate the conditions adjacent to what happening in the field. To perform the goal, a significant apparatus testing with accessories were created and produced by [18]. The device can stratify various frequencies and dynamic loads. The device common sight has appeared in Figure 4. The device is made up of the following parts:

1) Steel loading frame.
2) System of axial loading.
3) Footing model.
4) Acquisition data.
5) Steel container.

![Figure 4. The common sight of the used device.](image)

4.6 Pressure tactile sensors
Adaptable tactile of ultra-thin pressure sensors with 1500 kPa capacity model A-201TEKSCAN Flexi strength was used to measure the stresses under the footing directly by using three load senores placed equally beneath midline of footing at depths of (0.5B,1B and 1.5B). Tactile pressure sensors size and thickness enable then to be an agreeing placed multitude and to be built-up under small footings, with a 9.53
mm diameter of area sensing over a width of 14 mm, and a thickness of 0.203 mm. Details of the used sensors can be seen in Figure 5

Fig. 5. Details of A201 TEKSCAN sensor.

4.7 Data logger
A proper data logger in conformity to the recommendations of sensors manufacturing company. A 16 ports supporting electrical circuit was used manufactured with Arduino Italian made Mega board as appeared in Figure 6. A precise and accurate environmental variation of the sensors is to interpolated from electrical signals to legible engineering stress unites taking in actual time interest of the low reaction time of the sensors (5 μsec) permitted by manufactured programming with its data logger.

Figure 6. Data logger board

4.8 Preparation of sand deposit
By using a steel tamping hummer, the sand deposit was prepared. The relative density was chosen as 50% and 85% for medium and dense sand, respectively. To attain the relative density, the required weight was calculated since the volume and unit weight of the sand are calculated before also.

The soil of each layer was compacted to the predetermined depth then the soil deposit was completed. Through that, the reinforcement layers were placed at the required depth and width. Finally, the top surface was scraped and leveled by a ruler to get a flat surface. The square foundation (200×200) mm leads in touch with the upper face of the model. PLC (programmable logic control) system is found as in [18-19].

4.9 Dynamic loading test
A dynamic load was applied to the foundation after preparation of the surface sand layer during an agreed sequence. The implementation of the dynamic load was carried on for 20 minutes.

5 Result and Discussion

5.1 Effect of different types of reinforcement on transmitted stress
As mentioned above, three pressure cells have been used which were placed at (0.5B, 1B 1.5B) depth to measure the transmitted stress to the sand layers. Figure 7 to 10 exhibit the relation linking the number of
cycles with the transmitted stresses in the three cells used the tests. As it appears, the stresses in the unreinforced model almost begin at a certain level and continue at this level for an interval of the same range at each cell. While at reinforced models, the stresses increased rapidly to extend a greater magnitude (this is very clear with type II reinforcement). This status almost takes place in cell 1 which is under the loading effect caused directly by geogrid and sand interlocking, which influences the sand particles through confinement, whereas the transferred stresses are growing by the growing at confinement. The interlocking at the starting of the test is low and increases with time causes reorientation of sand particles. In addition, low strain must occur in the geogrid or reinforcement material before its activation. So the transfer stress at the starting of the test is less than that after some time because sand gets lower confinement than at the beginning of the test.

![Stress vs. No. of cycles graph](image)

Figure 7. Pressure transmitted to unreinforced medium-dense (MD) sand with an amplitude load of 0.25 ton and a load frequency of 0.5 Hz.

![Stress vs. No. of cycles graph](image)

Figure 8. Pressure transmitted to reinforced medium-dense (MD) sand with an amplitude load of 0.25 ton and load frequency of 0.5 Hz (Type I reinforcement).
5.2 Influence amplitude of load on average maximum vertical stress transitions

Figure 11 to 14 present the relationship between transmitted stress and number of cycles for a load amplitude of 2 ton in the three used cells. If these figures are compared with Figure 7 to 10, it can be seen that the transferred average vertical stress increases with the increase in load amplitude. Stress level increases approximately 62.3% when the load amplitude increases from 0.25 ton to 2 ton. The transmitted stress was in high values at the starting of each test at 0.5B depth and then it seems to be stable with a low value, stresses are highly transferred to reinforcement because it is adjacent to the face. This creates either slippage between geogrid and sand particles or destruction of geogrid material destroyed, which lowers the combining between reinforcement with sand particles minimizing the stress transferred to others layer.
Figure 11. Pressure transmitted to unreinforced Medium-Dense (MD) sand with an amplitude load of 2 ton and a load frequency of 0.5 Hz.

Figure 12. Pressure transmitted to reinforced Medium-Dense (MD) sand with an amplitude load of 2 ton and a load frequency of 0.5 Hz (Type I reinforcement).

Figure 13. Pressure transmitted to reinforced Medium-Dense (MD) sand with an amplitude load of 2 ton and a load frequency of 0.5 Hz (Type II reinforcement).
Conclusion

The following are the concluded remarks for the present work:

1. The average vertical stress transferred to the underlying layers increases with the increase in the amplitude of load depending on the reinforcement type.
2. Presence of reinforcement layer increases the transmitted stress especially to the first layers that closed to the foundation.
3. Stress level increases approximately 62.3% when the load amplitude increases from 0.25 ton to 2 ton.

References

[1] Barkan D D 1962 *Dynamics of bases and foundations* McGraw-Hill, New York.

[2] Daghigh Y 1993 *Numerical simulation of dynamic behavior of an earth dam during seismic loading* Ph.D. Thesis, Delft University of Technology, Netherland.

[3] Fannin R J 1986 *Geogrid Reinforcement of Granular Layers on Soft Clay - A Study at Model and Full Scale*, Ph.D. Thesis, University of Oxford, Magdalen Collage

[4] Chan W K 1990 *Permanent Deformation Resistance of Granular Layers in Pavement* Ph.D. Thesis, University of Nottingham, United Kingdom.

[5] Geeta B Bhadoriya S S and Sleem A 2013 *Model Studies on Footing Beam Resting on Geogrid Reinforced Soil Bed*, International Conference on Recent Trends in Applied Sciences with Engineering Applications, Vol. 3, No. 6, pp. 345-352.

[6] Karim H H Zeena W S and Huda K 2017 *Performance of Geosynthetic-Reinforced Gypseous Soil* International Journal of Current Engineering and Technology, (Available at http://inpressco.com/category/ijcet)

[7] Boushehrian AH Hataf N and Ghahramani 2011 *A Modeling of the cyclic behavior of shallow foundations resting on geomesh and grid-anchor reinforced sand*, Geotextiles and Geomembranes Vol. 29, No. 3, pp. 242–248.

[8] Mohammed S A 2015 *Cyclic Loading on Ring and Circular Footing Resting on Geocell Reinforced Dry Sand* M. Sc. Thesis, Building and Construction Engineering Department, University of Technology, Iraq.

[9] Smith G N and Pole E L 1980 *Elements of foundation design* 1st edition, garland publishing, New York.
York USA.

[10] Das B M 2014 *Advanced soil mechanics* 4th edition, CRC press, Boca Raton, London, New York.

[11] Borowicka H 1938 *The distribution of pressure under a uniformly loaded elastic strip resting on elastic-isotropic ground*, 2nd Congress Int. Assoc. Bridge Struct. Eng., Berlin, Germany, Final Report, Vol. 8, No. 3.

[12] Guido V A, Chang DK and Sweeney M A 1986 Comparison of geogrid and geotextile reinforced earth slabs Canadian Journal of Geotechnical Engineering, 23(4): 436–440.

[13] Omar M T, Das B M, Yen S C, Puri V K and Cook E E 1993 Ultimate bearing capacity of rectangular foundations on geogrid–reinforced sand Geotechnical Testing Journal, 15(2): 246–252.

[14] Yetimoglu T, Wu J T H and Saglamer 1994 A Bearing capacity of rectangular footings on geogrid–reinforced sand”, Journal of Geotechnical Engineering 120(12): 2083–2099.

[15] Abbawi Z W S 2010 Evaluation of improvement techniques for ballasted railway track model resting on soft clay Ph.D. Thesis, Building and Construction Engineering Department, University of Technology, Iraq.

[16] Karim H H, Zeena W S and Huda K K 2016 Iraqi Gypseous Soil Stabilized by Ordinary and Encased Stone Columns International Journal of Civil Engineering and Technology (IJCIET), 7(6), pp. 179–192.

[17] Qingdao Chemetals Industries Co Ltd 2001 [http://www.bossgoo.com/product-detail/fiberglass-geogrids-15739735.html](http://www.bossgoo.com/product-detail/fiberglass-geogrids-15739735.html), No. 1, 41st Bldg., 1 Zhanghua Road, Qingdao, Shandong, China.

[18] Abd Al-Kaream K W 2013 The Dynamic Behavior of Machine Foundation on Saturated Sand M.Sc. Thesis, Building and Construction Engineering Department, University of Technology, Iraq.

[19] Ismaiel M S 2015 Effect of Geogrid Reinforced Ground in Transfer of Dynamic Loading to Underground Structure M. Sc. Thesis, Building and Construction Engineering Department, University of Technology, Iraq.