Engineering and Technology Journal
Journal homepage: engtechjournal.org

A Comparison Study on the Effect of Various Layered Sandy Soil Deposited on Final Settlement under Dynamic Loading

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Submitted: 17/01/2020 Accepted: 23/02/2020 Published: 25/04/2020

K E Y W O R D S

Multilayered soils, Machine footing, reinforcement's material, medium density, dense density.

A B S T R A C T

*The foundation is expansion in base of column, wall or other structure in order to transmit the loads from the structure to under footing with a suitable pressure with soil property. There are two conditions to design foundation: 1. The stress is applied by footing on soil is not exceeded allowable bearing capacity (qa). 2. The foundation settlement and differential settlement are due to applied loads are not exceeding the allowable settlement that based on the type and size of structure, the nature of soil. Rigid square machine footing with dimension 200*200 mm with two types of relative density (50 and 85)% medium and dense density respectively are using in this study in different 28 models to show the effect of layered sandy soil in two configuration, medium-dense MD and dense-medium DM on the final settlement in magnitudes and behaviors under dynamics loads applying with different amplitude of loads (0.25 and 2) tons at surface with amplitude-frequency 0.5 Hz with explain the effect of reinforcements material on reduction the magnitude of settlement. The final results appeared with respect to the specified continuous pressure and the number of loading cycles, the resulting settlement from the dynamic loading increases with the increase in the dynamic pressure magnitude, the variation on densities of layered soil effect on the amount of settlement due to different loads applied. It's found that for increasing load amplitude increasing of settlement values particularly with low density soil when other variables are constant. As the amplitude of loading is increased from 0.25 ton to 2 tons, the settlement has been increased. MD soil density lower values of settlement can be obtained with type I of reinforcement where load amplitude equal to 0.25 ton with percent of enhancement between (28.4-34.3)% for different configuration of layers of reinforcement, for load amplitude equal to 2 tons the value of enhancement of settlement reached to about (35-38.4)%; while for DM density soil values of settlement can be obtained with type I of reinforcement where load amplitude equal to 0.25 ton percent of enhancement between (20-34.35)% for different configuration of layers of reinforcement, but the best value of enhancement of settlement get with load amplitude equal to 2 tons reached to about (38.7-41.17)%.*

How to cite this article: H. H. Karim, Z. W. Samueel and M. A. Hussein, "A comparison study on the effect of various layered sandy soil deposited on final settlement under dynamic loading," Engineering and Technology Journal, Vol. 38, Part A, No. 04, pp. 594-604, 2020.
DOI: : https://doi.org/10.30684/etj.v38i4A.1569

1. Introduction

The soil is subject to periodic shear pressure on-site in many conditions like earthquakes, wind forces in high-rise buildings, building piles, machine vibrations and traffic loads. Model tests have been reported to determine the permanent settlement of a shallow footing subject to different types of dynamic loads by [1-4]. Deliver dynamic load versus displacement results for dense sand-based strip footings [5]. Presented the results of a laboratory model on the permanent settlement of circular footing subjected to vertical vibrations on granular soil [6]. Different researches have been done in the latest years to assess the advantage of geogrids to get better soil resilience, for example [7-10]. This paper reveals the laboratory model tests conducted to measure the settlement of a solid square footing on the surface of the sand reinforced by a geogrid under a dynamic loading.

Types of Dynamic Loads on Footings

Dynamic loads can arise from various sources such as employing machinery, building work, motion loads on bridges, shocks, and earthquakes [11]. Deterministic loads are a portion of these dynamic loads that may be a task of time, while non-deterministic loads are random dynamic loads. Periodic loads are the loads show repeated vibration cycles while harmonic loads are the loads shown sinusoidal cycles. Otherwise, loads in different shapes with short intervals called Nonperiodic loads. If the load is affected in an extremely shortened interval of time-lapse, termed impulsive load. Nonperiodic loads might happen infrequently, such as an earthquake. Figure 1 shows the exemplary dynamic loads. The footings that undergo dynamic loads fluctuate in a manner that relies on the conductor of the soil, mass, geometry, foundation hardness and the type of thrilling dynamic moments and forces. An exemplary rigid foundation detected to different methods of vibration is clarified in Figure 2. The following sources can have an effect on the foundations [12]:

1. Machines that result in transient and fixed state dynamic loads contain unstable rotating and reciprocating parts. 2. Impact loads. 3. Close to the environment of vibration. 4. Earthquakes.
5. The forces generated by the wind. 6. Powers and other periodic moments as those produced by exploding, mining, excavation, and piling workings and sonic blast. 7. Active loads.

Under the influence of the enjoined loads, the modes of vibrates footing Figure 2 [13]:

a. Vertical (displacement in Z-direction)
b. Yawing (rotation about Z-axis)
c. Lateral (displacement in X-direction)
d. Pitching (rotation about X-axis)
e. Longitudinal (displacement in Y-direction)
f. Rocking (rotation about Y-axis)

At any various movement, the moving in Z-axis and turning about it happens alone. Moreover, the moving in X-axis or Y-axis and the turning about X-axis or Y-axis, alternately, broadly, happen jointly and are named coupled modes.

1. Machine Footing

The dynamic design for a footing prepared to bear an operating machine needs complete details for it, like whole weight, pieces moving weight, movement frequency, expected defect in moving parts and further [14]. As soon as possible, a full inspection is required to obtain an isolated vibration machine, which reduces or averts the transfer of dynamic loads to the footing. If not, the manufacturer may equip an advised method for preparing the device immediately on a footing or on a special basis with a damping part [11]. The equipment and soil relate needful how to realize. Depending on the type of movement, categorized of the machines are as Rotary, Impact and Reciprocating machines [15]. The ideal machine footing system is shown in Figure 3.

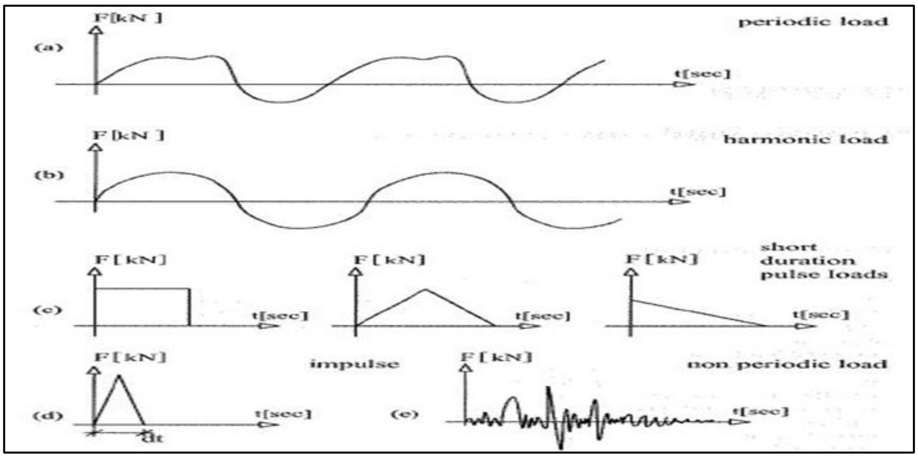

Figure 1: Dynamic loads typical [11]

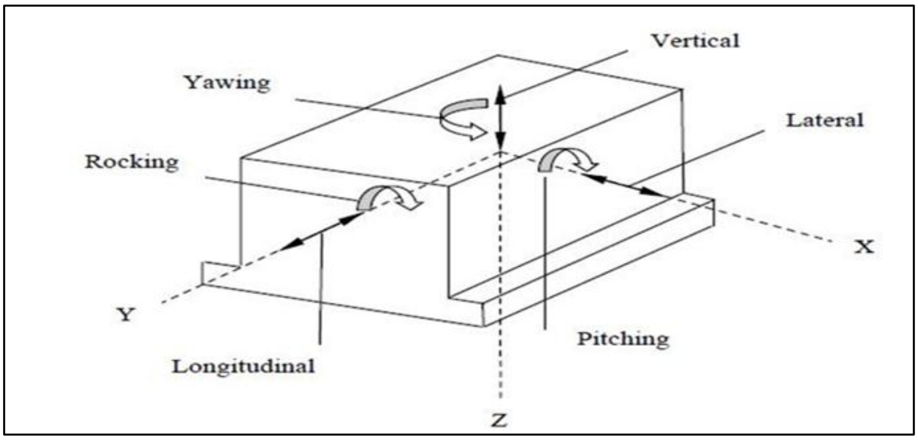

Figure 2: Rigid foundation vibration modes [13]

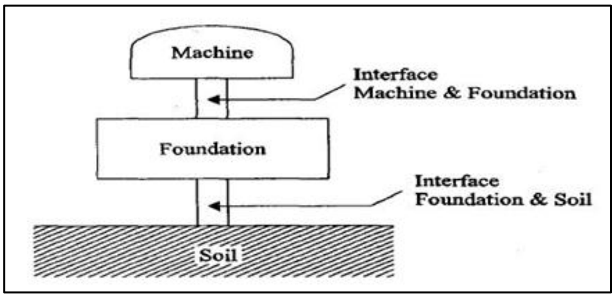

Figure 3: System of ideal footing machine [15]

Settlement of Machine Footings on Granular Soils

Final settlements under the vibrating machine base can be placed in two groups [16]:

- Flexibility and consolidation settlement due to the constant pressure.
- Settlement because of the vibratory pressure of the base soil.

The public nature of the settlement-time relationship for footings is shown in Figure 4. The footing settlement progressively increases over time and the maximum value reaches, after which it remains fixed. Regarding the machine footing that is subjected to vertical vibrations, many researchers believe that peak acceleration is the main criterion for controlling the base settlement.

Solid particles come to balance below a certain level the peak acceleration depending on the relative density of granular soils. This threshold acceleration level must be exceeded before additional densification can take place [16].

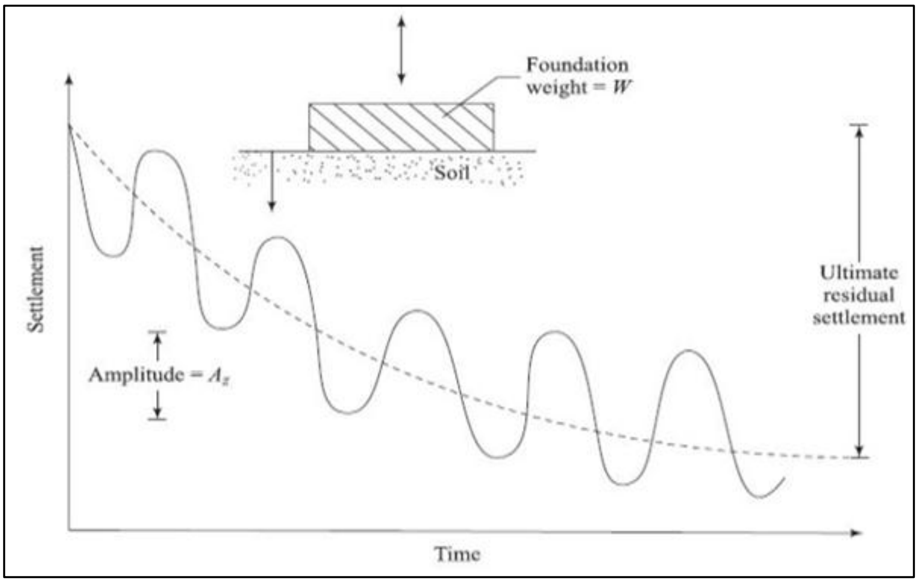

Figure 4 Vertical vibration of the machine foundation as a settlement-time relationship [16]

2. Previous Background

Francois et al. formulated a numerical model for soils under repeated dynamic loading. It is assumed that the dynamic part of the loading is small with respect to the static part, reflecting the stress conditions in the soil underneath buildings. The grouping model is applied under a finite element framework, using a fixed tangent with a merger the of Euler integration system. The triaxial test is the first numerical example. The analytical solution available for this problem allows numerical application validation. Second, the differential settlement of the two-story building was built on loose sandy soil under frequent car lanes is regarded. Differential settlement of the footing increases pressure on the bottom of the wall, which may cause damage [17].

Al-Ameri investigated experimentally the response and behavior of machine foundations resting on dry and saturated sand. A physical model was built to simulate a harmonic load constant state applied on a foundation on sandy soils with various working frequencies. 84 physical models were implemented. The maximum settlement amplitude shows its ultimate value at the resonant frequency, that founded to be around 33.34 to 41.67 Hz. Generally, the embedment leads to an advantageous reduction in the dynamic response of the foundation in the sandy soil (displacement and water pressure from excess pores) for all types of soil in various percentages, a joined by an increase in soil strength [18].

Fattah et. al focus on the influence of geogrid reinforcement on transfer of the dynamic load to the underground structure. A PVC pipe 110 mm in diameter inside the sandy soil as subsurface constructing simulated, carried out 4 models with a relative density equal to 40% represent loose sand. Used frequency 2 Hz and harmonic load 0.5 ton. Sand models without geogrid and with it tested; by using a geogrid of three series depths of model surface (0.5B, 1B and 1.5B) and equal width to (1B), where B is the width of the strip footing. The dynamic load was applied in the tests by a hydraulic jack system. The stress above the tunnel crown found minimized by about (14-33) % when geogrid used. Also, it was found the displacement reduction approximate (13-20) % when geogrid used [19].

Puri et al. performed typical tests conducting in the laboratory to study the settlement of small size foundation resting on a geogrid reinforced sand layer subjected to dynamic loads. The tests were performed by first exposing the foundation to a fixed initial static load and then composing further the predefined dynamic loads. Dynamic load frequency was kept at 1 Hz which was much lower than the system's resonant frequency. From test outcomes observation, the nature of the difference in the permanent settlement of the footing with the concentration of static and cyclic loading capacity in this paper presents, that was: 1. For a given sustained stress and number of load cycles , the settlement due to dynamic loading increases with increase in magnitude of dynamic stress and, 2. For given values of dynamic stress and number of load cycles, the dynamic settlement increases with increase in magnitude sustained static stress [20].

3. Laboratory Tests Model

By using a rigid model foundation 200 mm x 200 mm x 4 mm to conduct laboratory tests. Using SP sand with relative densities of 85% and 50% physical properties of the soil shows in Table 1. Two types of reinforcement material were used, type I is the geogrid used by [21-23], and type II is geogrid fiberglass [24]. 28 different models were conducted in steel container measuring 800mm x 800mm x 800mm with all sides reinforced enough to prevent lateral yield. A layer of foam was glued to the bottom of the test tank to avoid the effect of reflected waves on the footing settlement, the general view of the apparatus is shown in Plate 1. Sand deposited for tests in 50 mm thick layers by using a steel tamping hummer manufactured for this purpose.

The relative densities chosen are 50% and 85% (for medium and dense sand respectively). Since the unit weight and the volume of the sand are predetermined so, the weight required to achieve the relative density is predetermined also. Sand placement accuracy and consistency density setting were examined in each case.

Table 1: Physical properties of sandy soil

No.	Index Properties	Value	Specification
1	Specific gravity	2.6	ASTM D 854 [25]
2	D 10 [mm]	0.15	ASTM D 422 [26]
3	D 30 [mm]	0.2	
4	D 60 [mm]	0.5	
5	Coefficient of Uniformity (Cu)	3.3	
6	Coefficient of Curvature (Cc)	0.53	
7	Soil classification(USCS)	SP	
8	Maximum Void ratio	0.49	
9	Minimum Void ratio	0.33	
10	Maximum dry unit weight [kN/ m^3]	19.5	ASTM D 4253 [27]
11	Minimum dry unit weight [kN/ m^3]	17.4	ASTM D 4254 [28]
12	Angle of internal friction (R.D =50%)	40°	ASTM D 3080 [29]
13	Angle of internal friction (R.D =85%)	44°	ASTM D 3080 [29]

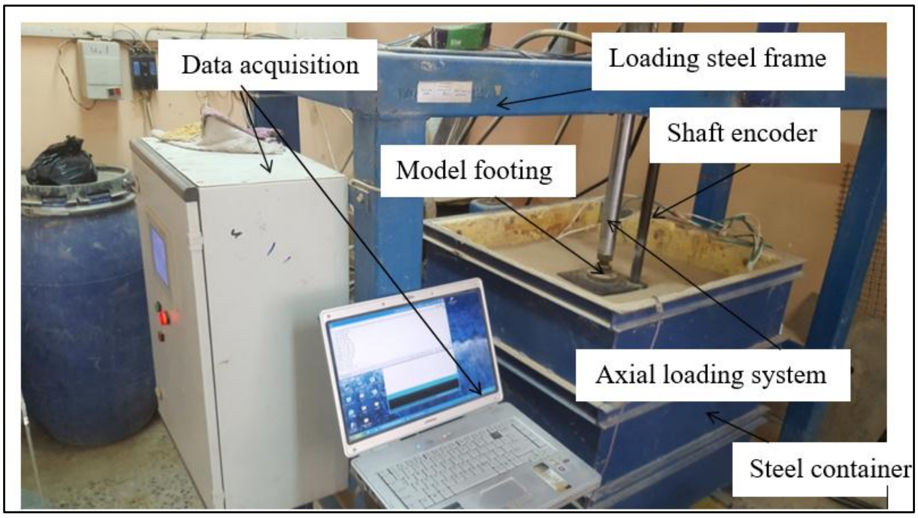

Plate 1: General view of the apparatus

4. The Geometry of the Problem

In many practical engineering causes, it may be necessary to lay shallow foundations on stratified deposits. A layer of deposits below shallow foundation that influences the bearing capacity is called subsoil. A simplified analysis shows that the thickness of the subsoil can be expressed as Eq. 1 by [30]:

$$H = \frac{B}{2}(\tan 45 + \frac{\phi}{2}) \quad (1)$$

where B is a width of a shallow foundation, and ϕ is the angle of soil internal friction. The subsoil displays a layered structure if the thickness of the deposit surface layer is less than H. In the most practical problems, the subsoil is two-layered as shown in Figure 5.

5. Dynamic Loading Test

After the preparation of footing on the surface of the sand layer, a dynamic load was applied throughout a predetermined sequence. The application of dynamic load continues for 20 minutes. The function of the dynamic load is represented by Eq.2

$$F(t) = a_o * \sin \omega t \qquad (2)$$

where : a_o = Amplitude of load,
ω = Frequency of load,
t = time, and T = Period.

The shape of the dynamic wave loading applied is of the form close to the sinusoidal compressive type as shown in Figure 6.

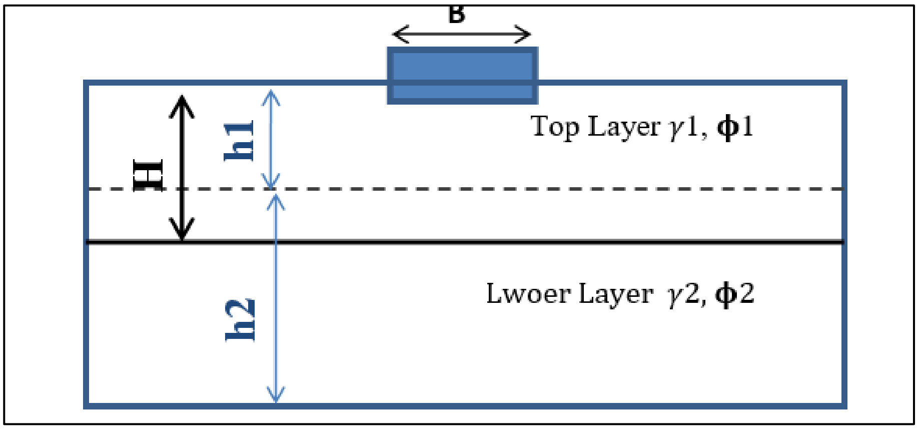

Figure 5: Geometry of the problem, h1 depth for the top layer, h2 depth for the lower layer

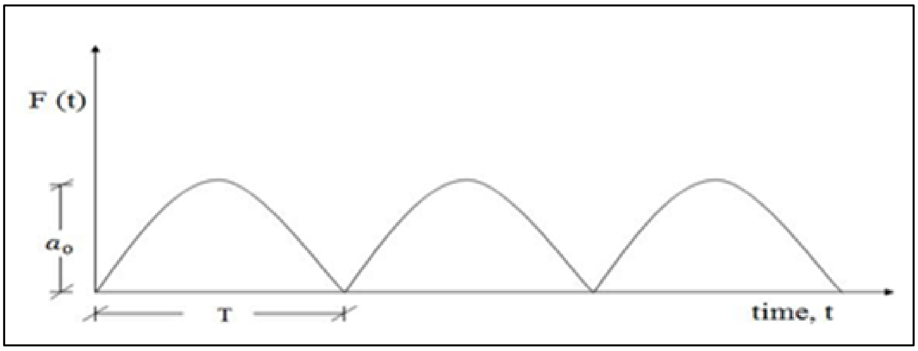

Figure 6: Dynamic load wave

6. Model Test Results under Dynamic Load

I. displacement of MD and DM configurations of layered soil without reinforcement

Figures 7 and 8 illustrate the vertical settlement respected to the various configurations of relative density conditions medium – dense MD and dense – medium DM at amplitude loading of 0.25 ton and 2 tons respectively with amplitude-frequency 0.5Hz without reinforcement.

As it appears in Figure 7 the start of the first test of MD density soil configuration showed that the settlement increased gradual and then appeared more stable because at beginning of test the medium density layer compresses quicker than the second layer, this behavior is occurred because of the soil particles get close to each other due to load subjected, while for DM density soil configuration for same figure can be noticed the displacement stay in low magnitude with continuous of test until the top layers fail and the load reached to lower layer that be low density so low bearing (dense layer tolerate bearing load amplitude until it fails). For the Figure 8, it can clearly be shown that the curves follow the same trend with the same starting and clearly various in end as the dynamic loading capacity increases to 2 tons. When the surface displacement increases, the stability rate in the medium sand decreases in comparison with the dense sand, this may be due to an increase in particle pressure. This figure shows sudden settlement in the first layer then gradually increased until reach approximately stable of settlement for MD density soil while the other test continuously increasing as low density layer and the soil is more compressible.

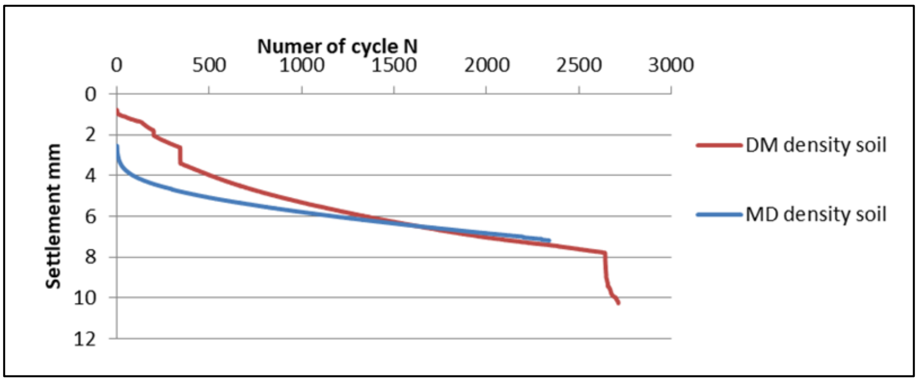

Figure 7: Settlement of surface foundation of MD and DM sandy soils for 0.25ton load amplitude, 0.5Hz frequency without reinforcement

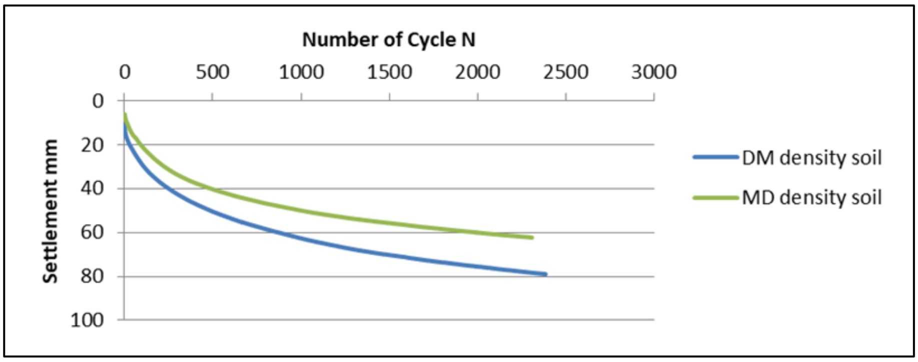

Figure 8 Settlement of surface foundation of MD and DM sandy soils for 2ton load amplitude, 0.5Hz frequency without reinforcement

II. Settlement of MD and DM of layered soil with type I of reinforcement

Figures 9 to 12 show the typical relationship of settlement versus number of cycles at frequency amplitude 0.5Hz for different load amplitudes (0.25 and 2) tons with or without different level of geogrid reinforcement (type I); In MD density soil, figures showed sudden settlement in the first layer then gradual increase until reach approximately stable of sample that means the second layer of soil (dense layer stay bearing load amplitude until it fails, that very clear with amplitude load 2 tons) on the contrary of DM density soil that showed high bearing for the load at start of test depends on the type of reinforcement existence and the other studied parameters. After that, for MD soil density less values of settlement can be obtained with type I of reinforcement where load amplitude equal to 0.25 ton with percent of enhancement between (28.4-34.3)% for different configuration of layers of reinforcement, for load amplitude equal to 2 ton the value of enhancement of settlement reached to about (35-38.4)%; while for DM density soil values of settlement can be obtained with type I of reinforcement where load amplitude equal to 0.25 ton percent of enhancement between (20-34.35)% for different configuration of layers of reinforcement, but the best value of enhancement of settlement get with load amplitude equal to 2 tons reached to about (38.7-41.17)%.

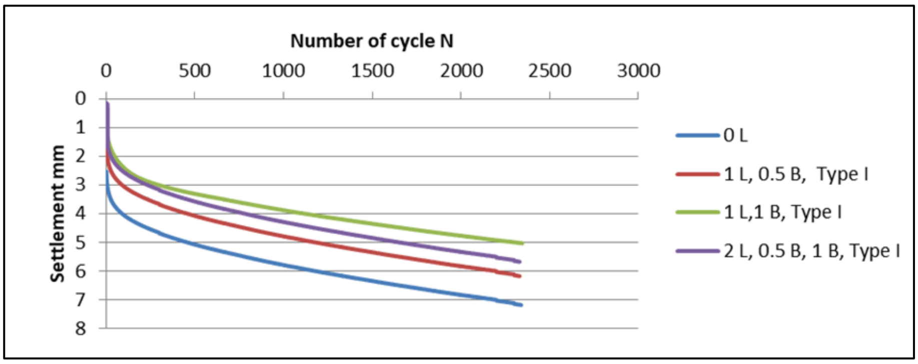

Figure 9: Settlement of surface foundation of MD sandy soils for 0.25 ton load amplitude, 0.5Hz frequency with type I of reinforcement

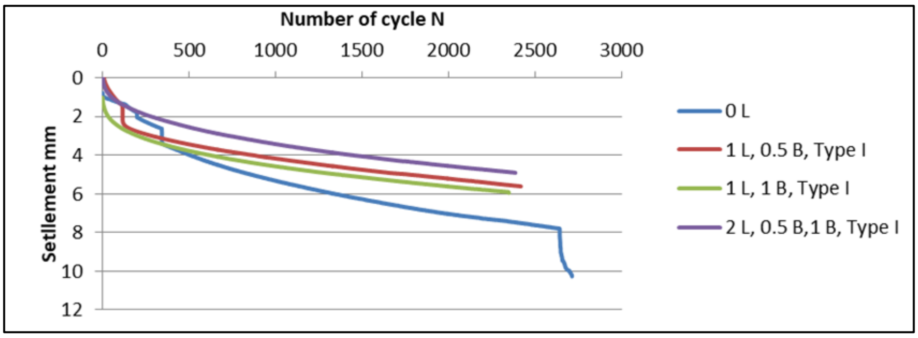

Figure10: Settlement of surface foundation of DM sandy soils for 0.25 ton load amplitude, 0.5Hz frequency with type I of reinforcement

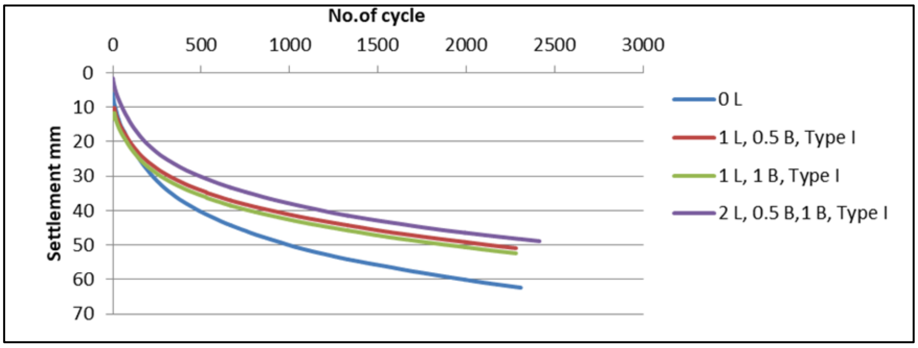

Figure11: Settlement of surface foundation of MD sandy soils for 2 tons load amplitude, 0.5Hz frequency with type I of reinforcement

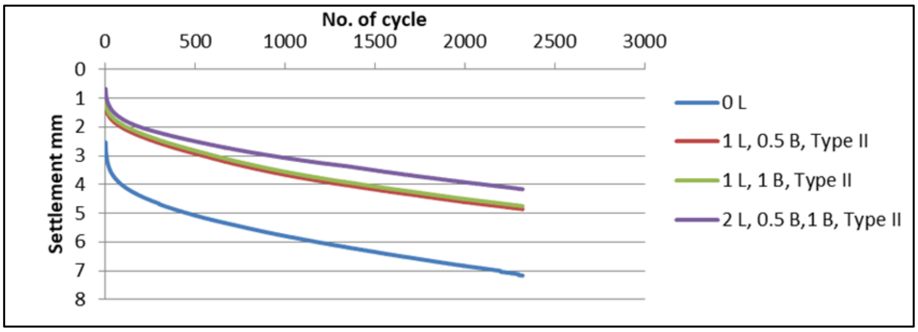

Figure12: Settlement of surface foundation of DM sandy soils for 2 tons load amplitude, 0.5Hz frequency with type I of reinforcement

III. Settlement of MD and DM of layered soil with type II of reinforcement

For the other type of reinforcement, type II of fiberglass geogrid, Figures 13 to 16, also show the typical relationship of settlement versus number of cycles at frequency amplitude 0.5Hz for different load amplitudes (0.25 and 2) tons with or without various level of reinforcement, these figures show clearly different in trend of curves between 0.25 and 2 tons. By increasing the dynamic load amplitude, the surface settlement increases, in MD density soil, figures showed less dropping of settlement in the first layer compared that without reinforcement for amplitude load of 0.25 ton, where after increasing the load to 2 tons the higher identical in all curves, with little effect of this type of reinforcement, wherein MD density soil, can see the significant improvement in settlement can be obtained from type I of reinforcement where load amplitude equal to 0.25 ton with percent of enhancement between (32.2-42)% for different configuration of layers of reinforcement, while where load amplitude equal to 2 tons the best value of enhancement of settlement reached to about (28-29.3)% for type II, while for DM density soil values of settlement can be obtained with type II of reinforcement where load amplitude equal to 0.25 ton percent of enhancement between (28.53-40.14)% for different configuration of layers of reinforcement, but the value of enhancement with load amplitude equal to 2 ton reached to about (25.15-29.26)%.

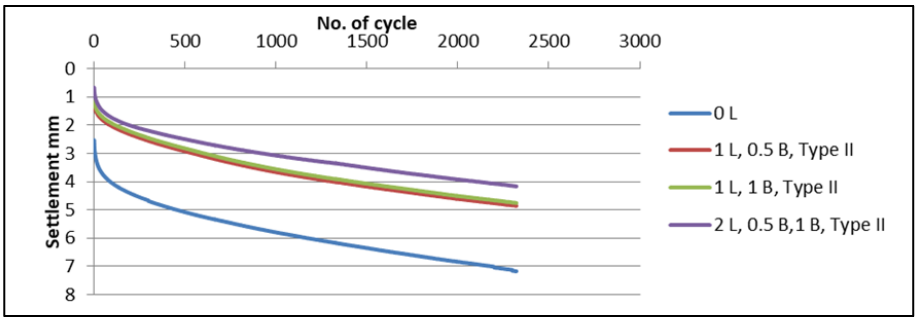

Figure13: Settlement of surface foundation of MD sandy soils for 0.25ton load amplitude, 0.5Hz frequency with type II of reinforcement

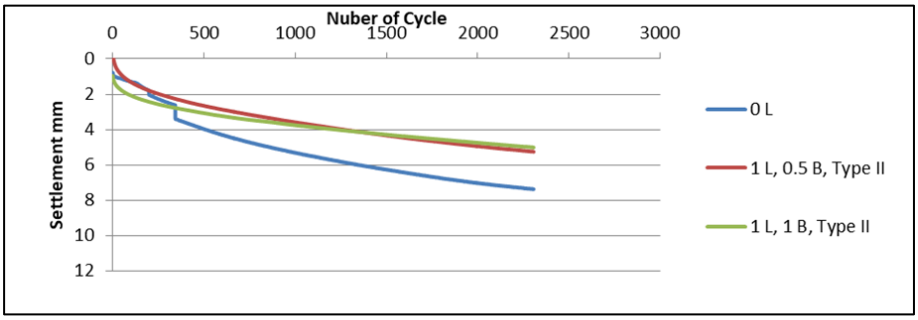

Figure14: Settlement of surface foundation of DM sandy soils for 0.25 ton load amplitude, 0.5Hz frequency with type II of reinforcement

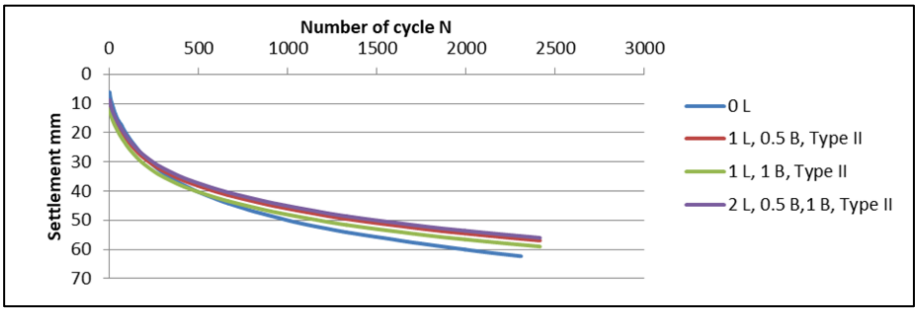

Figure15: Settlement of surface foundation of MD sandy soils for 2 tons load amplitude, 0.5Hz frequency with type II of reinforcement

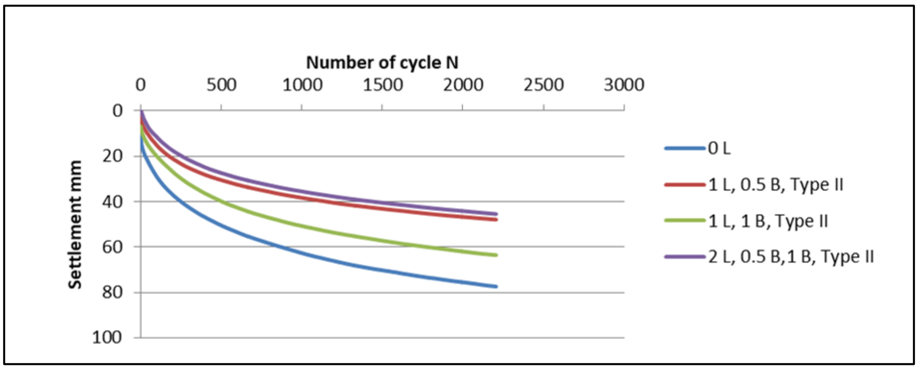

Figure16: Settlement of surface foundation of DM sandy soils for 2 tons load amplitude, 0.5Hz frequency with type II of reinforcement

7. Conclusion

1. It is found that the settlement of medium- dense MD soil configuration has maximum values in the first stage (layer) then try to be more stable.
2. At the start of the test, the settlement of dense-medium DM density soil configuration will have less values because the dense layer bearing the load until it fails, then the values increased gradually.
3. The best enhancement of geogrid reinforcement (type I) about (38.7-41.17) % when using with DM density soil configuration.
4. The best enhancement of geogrid fiberglass reinforcement (type II) about (32.2-42) % when using with MD density soil configuration.
5. For a given sustained stress and number of load cycles, the settlement due to dynamic loading increases with the increase in magnitude of dynamic stress.
6. It's appeared that the difference of layered of soil effect on the controlling of the amount of settlement due to different loads.

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