Influence of Geogrid Reinforced Loose Sand In Transfer of Dynamic Loading To Underground Structure

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ABSTRACT:

Underground facilities are an integral part of the infrastructure of modern society and are used for a wide range of applications, including subways and railways, highways, material storage, and sewage and water transport. Underground facilities built in areas subject to dynamic activity must withstand both dynamic and static loading.

This study focuses on the effect of the geogrid reinforcement in transfer of the dynamic load to the underground structure. The underground structure was simulated as a PVC pipe 110 mm in diameter inside the sandy soil. In order to investigate the response of soil, footing and underground tunnel to dynamic loading, a physical model was manufactured. The manufactured physical model could be used to simulate the application of dynamic loading.

The total number of the tests carried out is 4 models. All the 4 model tests with relative density equal to 40% corresponding to loose sand. The applied harmonic load has an amplitude of 0.5 ton and a frequency of 2 Hz. For each amplitude and frequency of the load, the sand models were tested without geogrid and with geogrid of three series of geogrid depths from the model surface (0.5B, 1B and 1.5B) and width equal to (1B), where B is the strip footing width. The dynamic load was applied in the tests by a hydraulic jack system. The response of the tunnel to dynamic loading includes measuring the pressure above the crown of the tunnel by using a pressure cell (manufactured by Geokon company) as well as measuring the amplitude of displacement by using a vibration meter. The response of footing was elaborated by measuring the total settlement using sensors in the dynamic load apparatus.

It was found the pressure above the crown of the tunnel decreased by about (14-33) % when using geogrid reinforcement. Also, it was found the settlement decreased by about (13-20) % when using geogrid reinforcement.

Keywords : Tunnel, dynamic load, geogrid, load transfer.

INTRODUCTION

The behavior of underground structures is usually complicated in comparison with super structures. This is mainly due to the soil-structure interaction, which in many cases can hardly be predicted. Among the underground structures, lifelines are of great importance and sensitivity because they are quite spread in the urban areas and serve the vital needs of the societies. Although different codes and provisions are suggested for the safe design of lifelines,

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the so designed and constructed lifelines could not escape damaging when subjected to severe dynamic loadings particularly strong blasts or earthquakes.

In recent decades, due to engineers' desire to optimize geotechnical structures, geogrid are widely used, particularly in the form of geosynthetics. Their economy, easy of installation, performance and reliability have led to the use of reinforced soil in geotechnical engineering applications such as in the construction of roads, railway embankments, stabilization of slopes, and improvement of soft ground, etc. Some researchers have studied the behaviour of pipes in planar reinforced soil, [1] described laboratory tests on small-diameter high-density polyethylene (HDPE) pipes buried in reinforced sand subjected to repeated loads to simulate the vehicle loads. Figure (1) shows the physical model test.

The amplitude of applied stress was 5.5 kg/cm^2 in all tests. Deformation of the pipe was recorded at eight points on the circumference of the tested pipes to measure the radial deformations of the pipe. Also, settlement of the soil surface was measured throughout the test for up to 1000 cycles of loading. These values increased rapidly during the initial loading cycles; thereafter the rate of deformation reduced significantly as the number of cycles increased. The variables examined in the testing program included relative density of the sand, number of reinforced layers, and embedment depth of the pipe. The influence of various reinforced layers at relative densities of 42%, 57%, and 72% in different embedded depths of 1.5–3 times of pipe diameter were investigated.

The results showed that the percent vertical diameter change (DD) and settlement of soil surface (SSS) can be reduced up to 56% and 65% for DD and SSS, respectively, by using geogrid reinforcement, and increase the safety of embedded pipes. Also, the efficiency of reinforcement was decreased by increasing the number of reinforcement layers, the relative density of soil and the embedded depth of the pipe as shown in Figure (2).

The influence of the first cycle was also found to be one of the main behavioral characteristics of buried pipes under repeated loads. The ratio of deformation of the pipe from the first cycle to the last cycle changes from 0.5 to 0.9 in different tests. It should be noted that only one type of pipe, one type of geogrid, and one type of sand are used in laboratory tests.

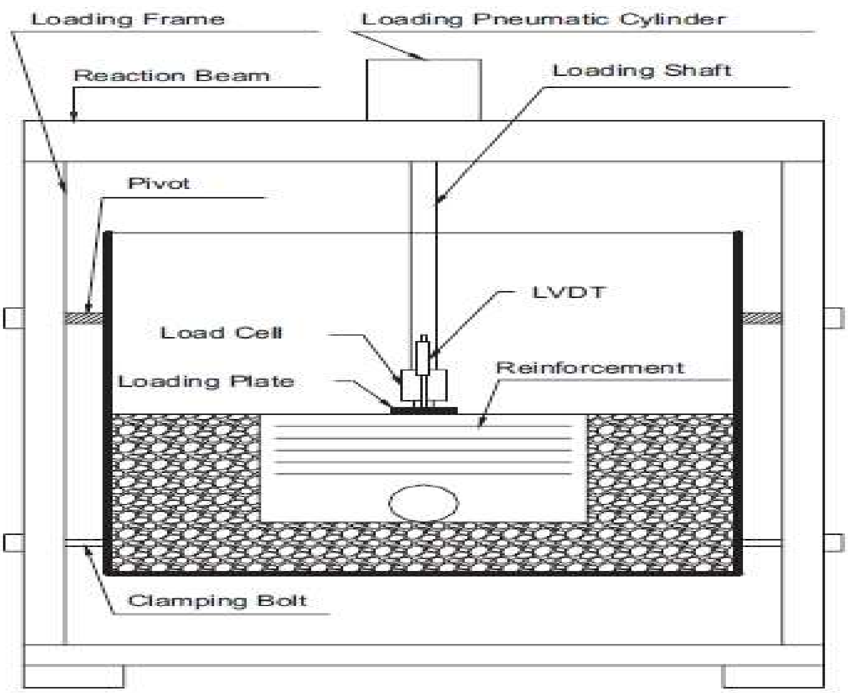


Figure (1): Schematic representation of the test setup (after Tafreshi , and Khalaj, 2007).

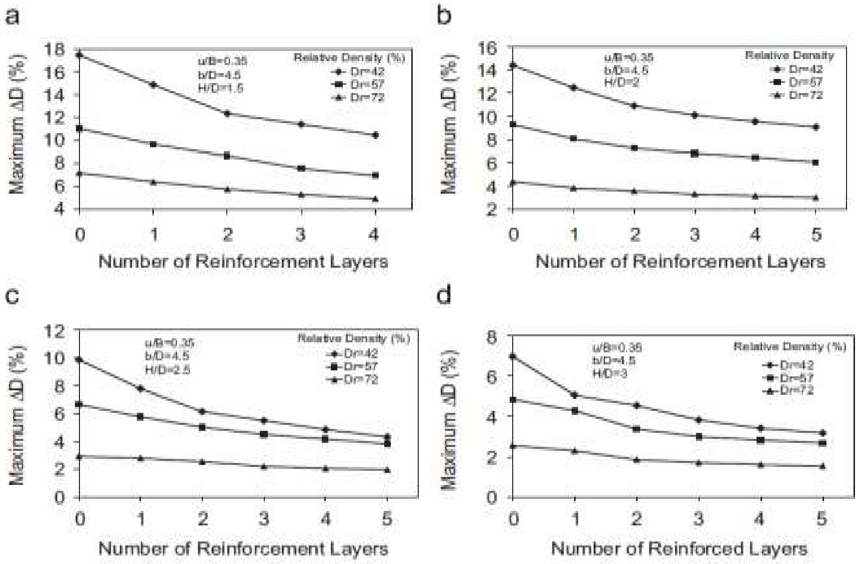


Figure (2): Variation of the maximum ΔD with the number of reinforcement layers for H/D = (a) 1.5, (b) 2.5, (d) 3 (after Tafreshi , and Khalaj, 2007).

[2] studied artificial neural network and regression model for predicting the vertical deformation of high-density polyethylene (HDPE). Small diameter flexible pipes buried in reinforced trenches, which were subjected to repeated loadings to simulate the heavy vehicle loads were proposed. The experimental data from tests showed that the vertical diametric strain (VDS) of pipe embedded in reinforced sand depends on relative density of sand, number of reinforced layers and height of embedment depth of pipe significantly. Therefore, the value of VDS was related to above pointed parameters. A database of 72 experiments from laboratory tests were utilized to train, validate and test the developed neural network and regression model. The results showed that the predicted vertical diametric strain (VDS) using the trained neural network and regression model are in good agreement with the experimental results but the predictions obtained from the neural network are better than regression model as the maximum percentage of error for training data is less than 1.56% and 27.4%, for neural network and regression model, respectively. Also the additional set of 24 data was used for validation of the model as 90% of predicted results have less than 7% and 21.5% error for neural network and regression model, respectively. A parametric study was conducted using the trained neural network to study the important parameters on the vertical diametric strain.

[3] investigated the validity of using transmitting boundaries in dynamic analysis of soil-tunnel interaction problems. As a case study, the proposed Baghdad metro line was considered. The information about the dimensions and material properties of the concrete tunnel and the surrounding soil were obtained from a previous study. A parametric study was carried out to investigate the effect of several parameters including the peak value of the horizontal component of earthquake displacement records, and the modulus of elasticity of the soil surrounding the tunnel.

Both the computer program (Mod-MIXDYN) and (ANSYS) software were used for the analysis. The program « Mod-MIXDYN » is a finite element code modified in this study by adding a 5-noded mapped infinite element. The results are compared for three cases, the first case presents the problem with finite boundaries (traditional boundaries), the second case simulates the problem with infinite boundaries using infinite elements (5-node mapped infinite element) presented by Selvadurai and, Karpurapu in 1988, and redefined in this study. Finally, the third case simulates the infinite boundaries using viscous boundaries (dash-pot elements) as adopted in the program ANSYS. It was concluded that the viscous boundaries are more effective in absorbing the waves resulting from dynamic loads than mapped infinite elements. This is clear when comparing the results of both types with those of transient infinite elements.

[4] examined the effect of performing geogrid to increase the uplift resistance of buried pipelines. And the effect of burial depth, pipe diameter, length of geogrid layers and the number of geogrid layers on the peak uplift resistance (PUR) of loose sand. Thirty three small-scale tests were performed in the laboratory. Results of laboratory tests revealed that the depth of burial and pipe diameter have a direct effect on the PUR results. It was shown that the number of geogrid layers does not have a remarkable influence on PUR values, while the residual PUR values are of interest, for the same length of geogrid, the use of two layers of geogrid instead of one is advantageous. To verify the experimental results, 33 experiments were back analyzed using ‘‘PLAXIS 3D TUNNEL’’ program. It was found that experimental and numerical results are in good agreement.

The objectives of this paper is:

1. Investigating the influence of geogrid reinforced loose sand in transfer of dynamic loading to underground structures.
2. Investigating the displacement that occur above underground structures especially tunnels due to dynamic loads induced by above structures.
3. Determination of the optimum depth of geogrid reinforcement.
4. Investigating the influence of geogrid on the surface settlement that occurs due to dynamic loading.

Testing Program

The total number of the tests carried out is 4 models. All the 4 model tests of sand were tested under dynamic load with relative density equal to 40% corresponding to loose sand. All the 4 dry sand models were subjected to dynamic load with load amplitude equal to 0.5 ton using frequency equal to 2 Hz. The sand models were tested without geogrid and with geogrid of three series of geogrid depths from the model surface (0.5B, 1B and 1.5B where B is the footing width) and width equal to (1B).

Material used and soil characterization

Karbala sand is used in this study. Standard tests were performed to determine the physical properties of the sand. The tests were performed on sand with two different densities; loose and dense. The details of these properties are given in Table (1).

Table (1) : Physical properties of sand used.

No.	Index property	Index Value
1	Specific gravity	2.65
2	D_{10} (mm)	0.15
3	D_{30} (mm)	0.3
4	D_{60} (mm)	0.48
5	Coefficient of uniformity (Cu)	3
6	Coefficient of curvature (Cc)	1.33
7	Maximum void ratio	0.68
8	Minimum void ratio	0.45
9	Maximum dry unit weight (kN/m^3)	18.185
10	Minimum dry unit weight (kN/m^3)	15.7
11	Angle of internal friction (at Dr. = 40%)	34^o
12	Angle of internal friction (at Dr. = 80%)	38^o

13	Soil classification (USCS)	SP

PVC pipe

A PVC pipe was used in all tests to simulate the underground tunnel. The pipe has a diameter of 110 mm and 700 mm long, it was placed at a depth equal to 500 mm from the surface. Plate (1) shows the PVC pipe used.

Plate 1: PVC pipe.

Geogrid reinforcement

The geogrid was used in some tests, it was manufactured by Al-Latifia Factory for plastic mesh. A of geogrid was used from test to test but was replaced whenever any of the strands become visibly overstressed.

Model design and devices

To study the effect of geogrid in transfer of dynamic load to the underground structure in sandy soil, it is necessary to simulate the conditions as close as possible to those occurring in the field. To achieve this aim, a special testing apparatus and other accessories were designed and manufactured by [5] and modified in this study. The apparatus has the capability of applying different dynamic loads and different frequencies, The general view of the apparatus is shown in Plate (2).

The apparatus consists of the following parts:

1. Loading steel frame,
2. Axial loading system,
3. Model footing,
4. Data acquisition,
5. Shaft encoder,
6. Steel container

Plate 2: General view of the apparatus..

Loading steel frame

To support the verticality of piston system used in applying the central concentrated load, a steel frame was designed and constructed as shown in Figure (3).

The steel frame consists mainly of four columns and four beams. The cross sectional area of each column and beam are made of steel with square cross section area of (100 mm×100 mm) and 4 mm thick. The dimensions of the steel frame (length× width× height) are (1700 mm× 700 mm×1700 mm). To strengthen the steel frame, two beams were added (No. 4 in Figure 3).

A 20 mm thick steel plate with dimensions of (700 mm×500 mm) was welded on the center of the frame in order to carry the hydraulic jack system and the settlement measurement device (Encoder) as shown in Plate (3).

The steel frame was fixed to the floor base using four base plates of dimensions (200 mm×200 mm×20 mm). Each base plate was fixed with the floor using four bolts of 16 mm diameter.

Axial loading system

The axial loading system consists of :

1. Hydraulic jack system: The cross sectional area of the piston is 176 mm^2, the length of the piston is (1300 mm) and the maximum limit of load that can be applied is (8 tones) as shown in Plate (4) .

2. Hydraulic control system: The control device consists of a system responsible for application of the dynamic loading, and the movement of The piston. the control system contains a valve which is responsible for controlling the force of dynamic load. as shown in Plate (5).

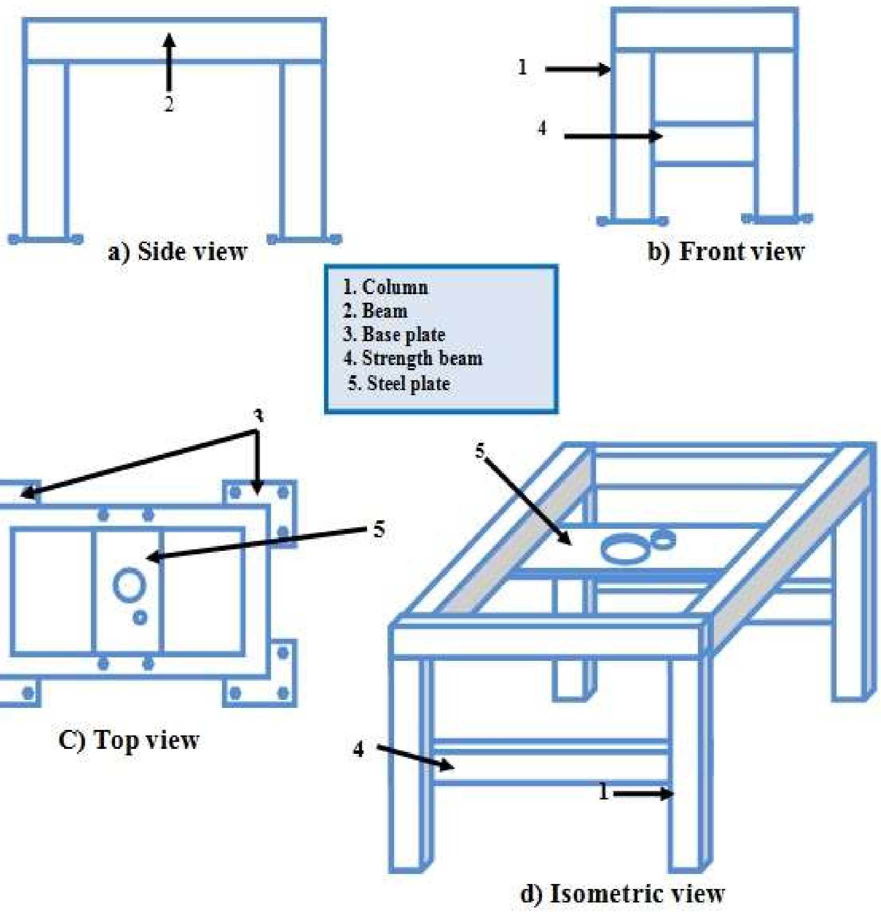


Figure (3): Loading steel frame.

Plate 3: The upper and lower faces of steel plate.

Plate 4: Hydraulic jack.

Plate 5: The hydraulic control system.

Model footing

A strip footing of dimensions 710 mm * 110 mm with 30 mm thickness was manufactured to simulate a road or any strip footing above the underground structure

Data acquisition

To study and investigate the real behavior of the tested models during the application of the dynamic load, it is necessary to find a new procedure to measure and sense the occurring displacement during the test, which enable the tester to obtain the total accurate information that consists of a huge data of readings in a very short time. For this reason, data acquisition system was used.

A Programmable Logic Controller (PLC) is used. For further information about the PLC system is found in [5] and [6].

Shaft Encoder

A shaft encoder type (Rotary) can be defined as an electro-mechanical device that converts the angular positions or motion of the shaft to an analog or digital code. The output of incremental encoder provides information about the motion of the shaft which is typically further processed elsewhere into information such as speed, displacement, revolution per minute (rpm) and position. For further information about encoder is found in [5] and [6].

Steel container

The container was used to prepare the test sample, the internal dimensions are 1000 mm length, 750 mm width and 700 mm depth. Each part of the container is made of steel plates of 5 mm thick.

Earth pressure cell and readout

Earth pressure cells provide a direct means of measuring total pressure in the soil. They may also be used to measure earth bearing pressure on foundation slabs and footings and at the tips of piles. Plate (1) shows the earth pressure cell model 4800 manufactured by GEOKON company in U.S.A which is used in this study.

Vibration meter

The vertical amplitude of tunnel was measured at the surface of the tunnel. Vibration meter (**VT-8204**) of one channel was used in the test. This vibration meter has a working capacity of 0.001 to 2.217 mm, it is capable of measuring the displacement, velocity, and acceleration of motion depending on the function set prior to the test. The components of the VT- 8204 vibration meter probe on pipe is shown in Plate (1).

Sand deposit preparation

The sand deposit was prepared using a steel tamping hummer manufactured for this purpose. The relative density chosen is 40% (for loose sand). This means that the weight required to achieve the relative density is predetermined since the unit weight and the volume of the sand are predetermined also.

The soil of each layer was compacted to a predetermined depth. A PVC pipe that simulate a tunnel was installed on a soil bedding of 250 mm. After that, the pressure cell and vibration meter probe were installed above the pipe crown and then the soil deposit preparation was completed. Then, the geogrid was placed in the desired depth and width. After completing the final layer, the top surface was scraped and leveled by a sharp edge ruler to get as near as possible a flat surface. The strip footing was then brought in contact with top surface of the model. Plate (6) shows the model test after preparation.

Plate 6: Model test.

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 the following equation:

$$F(t) = a_0 * \sin \omega t \quad (1)$$

where : $a_0 =$ Amplitude of load,

$\omega =$ 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 (4).

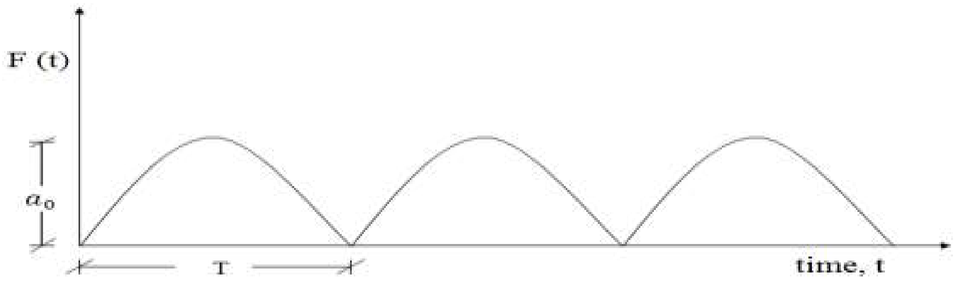


Figure (4): Dynamic load wave.

Model Test Results under Dynamic Load

1- Effect of depth of the reinforcement on the vertical pressure:

The vertical pressure was measured by a pressure cell. Figures (5) to (7) show the variation of the vertical pressure on the crown of a tunnel embedded in loose sand with time. In general, the curves follow the same trend and it can be noticed that when the geogrid at depth equal to (0.5B) from the surface the pressure will decrease by about (33)% This decrement because the soil with geogrid reinforcement will behave as a stiff bed and that redistributes the pressure over a wide area according to [7], but when the depth equal to (1B) the pressure will decrease by about (14)% because the distribution of load at depth (1B) smaller than at depth (0.5B), whereas no decreasing in pressure was noticed when the geogrid is placed at depth equal to (1.5B) because the geogrid was placed at depth out of the bulb of stresses below the footing in comparison between results with geogrid and without geogrid.

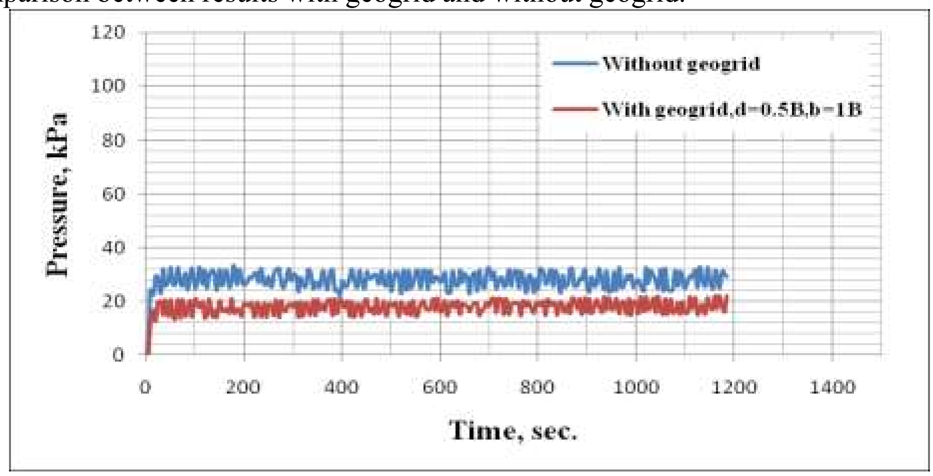


Figure (5): Variation of the vertical pressure above the tunnel crown with time for a =0.5 ton, ω = 2Hz and Dr. =40%, without geogrid and with geogrid (d= 0.5B and b= 1B).

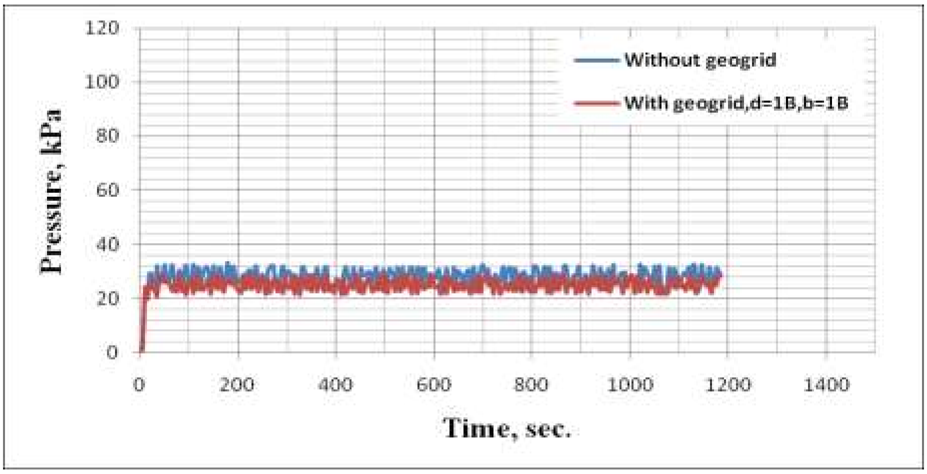


Figure (6): Variation of the vertical pressure above the tunnel crown with time for a =0.5 ton, ω = 2Hz and Dr. =40%, without geogrid and with geogrid (d= 1B and b= 1B).

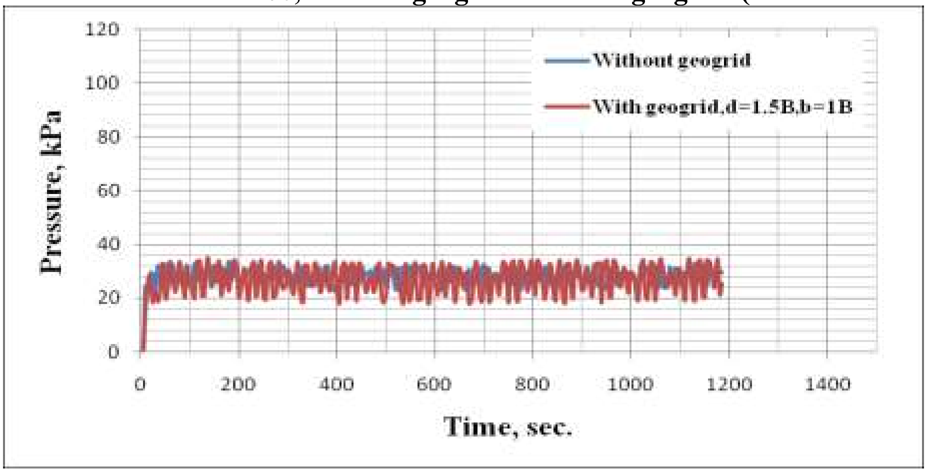


Figure (7): Variation of the vertical pressure above the tunnel crown with time for a =0.5 ton, ω = 2Hz and Dr. =40%, without geogrid and with geogrid (d= 1.5B and b= 1B).

Effect of depth of the reinforcement on the surface settlement:

The surface settlement was measured by sensors in dynamic load apparatus. Figures (8) to (10) show the variation of the surface settlement with time for model footing on loose sand. The results show that the percent vertical settlement can be reduced by about (20)% when using geogrid reinforcement at a depth equals to (0.5 B).

This decrease is attributed to the smaller soil mass above the reinforcing layer which could have insufficient overburden to generate enough friction and tension resistance at the soil reinforced interface according to [2] who studied the laboratory tests of small diameter pipes buried in reinforced sand under repeated load. Furthermore, this percentage will decrease to about (13-37)% when the geogrid is placed at a depth equal to (1B) because the soil mass increases so the friction and tension resistance decreases. In addition, when the geogrid is placed at a depth equals to (1.5B), the results of vertical settlement without geogrid are approximately close to results of vertical settlement with geogrid. This indicates that the efficiency of geogrid decreases when the depth increases. The geogrid has no efficiency at a depth equal to (1.5B) this can be attributed to the stress zone below the foundation, when the geogrid is placed at a depth of 0.5B or 1B, it is within the stress bulb, so that its presence affects considerably the values of displacements induced by the dynamic load. These percentages are different according to the state of load and geogrid. This behavior was also noticed by [1] who observed an increase in the bearing capacity up to approximately 2.7 times by placing the reinforcement within a homogenous sand at a depth within the range of u/B= 0.25-0.75 (u is the reinforcement depth and B is the footing width).

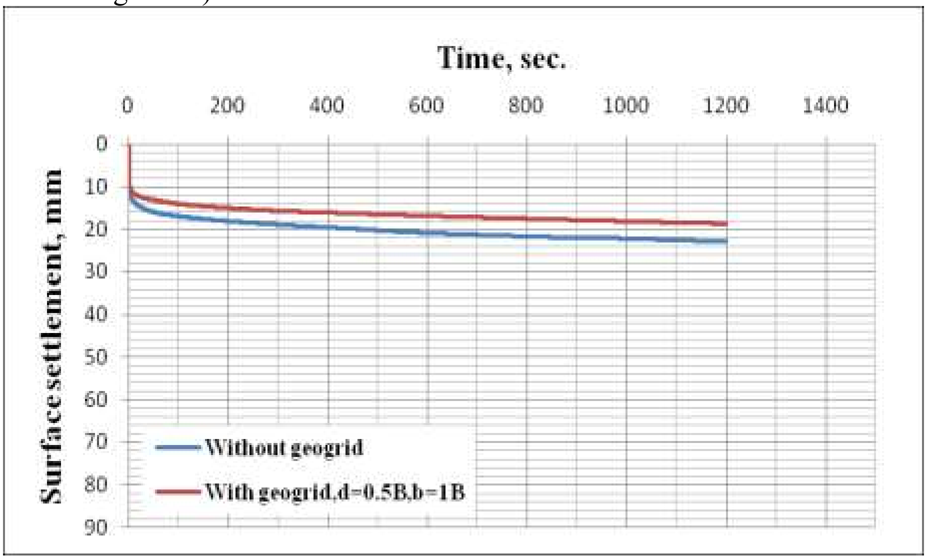
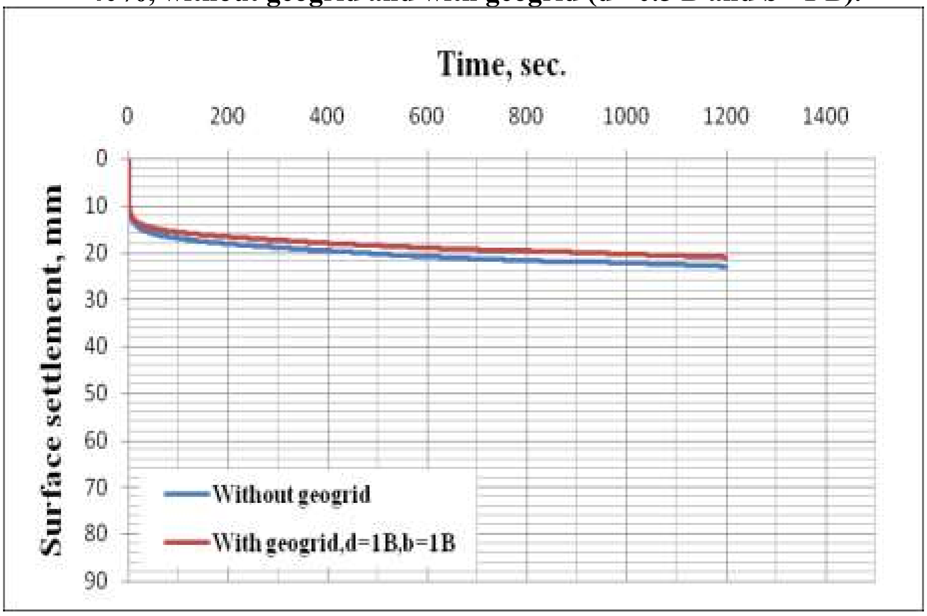


Figure (8): Variation of the surface settlement with time for a =0.5 ton, ω = 2 Hz and Dr. = 40%, without geogrid and with geogrid (d= 0.5 B and b= 1 B).



Figure(9) : Variation of the surface settlement with time for a =0.5 ton, ω = 2 Hz and Dr. = 40%, without geogrid and with geogrid (d= 1 B and b= 1 B).

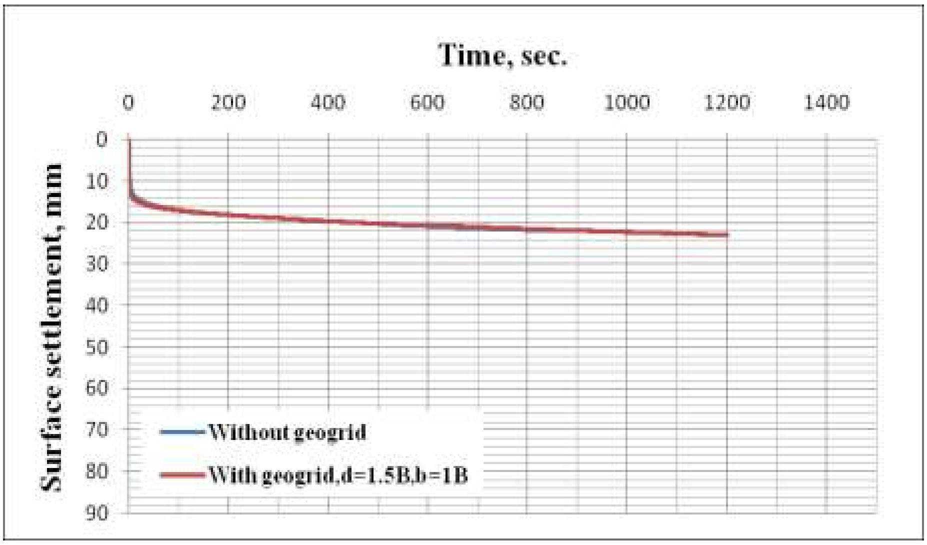


Figure (10) : Variation of the surface settlement with time for a =0.5 ton, ω = 2 Hz and Dr. = 40%, without geogrid and with geogrid (d= 1.5 B and b= 1 B).

Effect of depth of the reinforcement on the amplitude of displacement

The amplitude of displacement of the tunnel crown was measured by a vibration meter as shown in Figure (11). The results show that there is no effect of geogrid on the amplitude of displacement, so that the results of other cases are not presented.

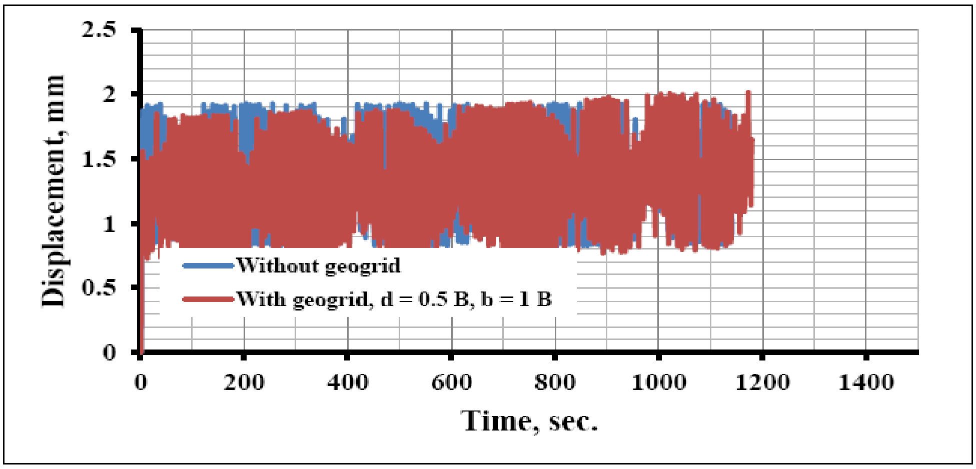


Figure (11): Displacement of the tunnel crown with time for a =0.5 ton, ω = 1 Hz and Dr. = 40%, without and with geogrid (d= 0.5 B and b= 1 B).

CONCLUSIONS

The main conclusions can be listed as follows:

1. When the geogrid at depth equal to (0.5B) from the surface in loose sand, the pressure on the crown of tunnel will decrease by about 33%, but when the depth equals to (1B), the pressure will decrease by about 14%, whereas no decreasing in pressure was noticed when the geogrid is placed at depth equal to (1.5B) in comparison between results with geogrid and without geogrid
2. The percent vertical settlement in loose sand is reduced by about 20% when using geogrid reinforcement at a depth equals to (0.5 B). Also, at depth equal to (1 B), the percent vertical settlement is reduced by about 13%. In addition, when the geogrid is placed at a depth equals to (1.5B), the results of vertical settlement without geogrid are approximately close to

results of vertical settlement with geogrid. This indicates that the efficiency of geogrid decreases when the depth increases. The geogrid has no efficiency at a depth equal to (1.5B)

3. There is no effect of geogrid reinforcement on the amplitude of displacement of the underground tunnel.

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