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Dynamic Finite Element Analysis of Sandy Soil-Pipe System Reinforced by Geogrid

Abstract- The stability of tunnels and other underground structures under the influence of dynamic load is one of the important issues that should be studied carefully. The objective of the present paper is to study the effect of the geogrid reinforcement in transfer of the dynamic load to the underground structure. The underground structure was simulated as a plastic pipe within the soil. The investigation focuses on the influence of parameters such as load amplitude, depth of geogrid layer and width of geogrid layer using the finite element method by QUAKE/W computer program for the analysis. It was concluded that when the geogrid reinforcement width equals (1B), the total stress on the crown of pipe decreases by about (17%) compared with unreinforced soil, but this percentage decreases to (10%) when the geogrid width equals to (2B). The percent vertical settlement on the pipe crown decreases by about (35%) when using reinforcement of width equals (2B) compared with test results unreinforced soil, while when the width equals (1B), the percent vertical settlement decreases to about (15%), this indicates that when the width of reinforced soil increases, the vertical settlement decreases.

Keywords- Finite element, load transfer, sand, and underground structure

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1. Introduction

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. Pipelines buried in the soil are inaccessible for visual inspection, making damage detection a difficult task. Damage assessment to lifelines after natural disasters is vital for effective emergency response and recovery efforts. Of particular interest are water supply systems as water is an essential component for human sustenance. Even minor damages to water pipelines may result in contamination and epidemic outbreaks [1].

Klischewicz [2] presented 3D numerical analysis of interaction of a pipeline structure with stratified subsoil loaded across a certain area to evaluate the effort state of the pipe and the changes taking place in the soil mass. The model analyzed consists of a rectilinear section of a PVC pipe and the surrounding mass of strongly stratified soil. It was found that the clear disturbances in the distribution of stresses in the direct surrounding of the pipe and in the further zones of the soil. As the load is situated specifically as shifted in relation to the pipe axis, the deformation and effort state of the pipe side surface is non-uniform. This signifies irregular distribution of generalized internal forces in such

structure. Such results of the activity of surface loads onto the pipe structure situated in stratified subsoil are identifiable only by building numerical pipe soil system models and by analyzing their behavior when simulating the activity of loads. The reliability of the outcomes obtained is linked to the correct construction of the model including correct model dimensions, discretization density, selection of appropriate material parameters and an adequate constitutive model of soil and of the modeled structure. Numerical analyses can be regarded as an attractive tool for examining limit states of the bearing capacity and serviceability of buried piping.

Stress Analysis of Buried Gas Pipeline Traversing Sliding Mass has been examined by Chen et al. [3] based on the theory of one-dimensional beam finite element stress analysis, the junction of the conventional buried pipeline and the landslide has been confirmed as coming under the heaviest loads. Therefore, stress checks against accidental loads should be emphasized during the stress analysis of gas pipelines traversing sliding masses. It was found that the stress analysis of the pipeline laterally and longitudinally traversing the slide mass, the junction of the conventional buried pipeline and the slide mass is the section that sees the most stress. From the pipeline stress and the displacement distribution, the stress under an accidental load is the biggest in both laterally and longitudinally traversing situations. Therefore, it

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is suggested that when analyzing the stress in the engineering phase, the pipeline stress under accidental landslide loads should be carefully investigated in order to avoid costly repairs.

Mehrjardi et al. [4] carried out a numerical simulation of laboratory model tests to develop an understanding of the behavior of pipes in a trench prepared with 3-Dimensional reinforced sand and rubber-soil mixtures, under repeated loadings. The study used overall performance of buried pipes in different conditions of pipe-trench installations and the influence of pipe stiffness on backfill settlements, stress distribution in the trench depth and stress distribution along the pipe's longitudinal axis. It was found that the results demonstrate that combined use of the geocell layer and rubber-soil mixture can reduce soil surface settlement and pipe deflection and eventually provide a secure condition for buried pipe even under strong repeated loads.

Armaghani et al. [5] examined the effect of performing geogrid to increase the uplift resistance of buried pipelines, the effect of burial depth, pipe diameter, length of geogrid layers and the numbers of geogrid layers on the peak uplift resistance (PUR) of loose sand, 33 small-scale tests were performed in the laboratory. Results of laboratory tests reveal that depth of burial and pipe diameter has a direct effect on the PUR results. It was concluded 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.

A major damage to pipelines can occur during earthquakes. During an earthquake, propagation of seismic waves through the earth causes ground shaking. The seismic waves transfer the energy to substructures (buried) and superstructures (above ground). The objectives of the present study is to investigate the load transfer to underground structures caused by surface machines and the effect of using geogrid reinforcement in decreasing loads transform, to the tunnels and buried pipes.

2. Description of the Problem

A foundation soil of dimensions 750 mm deep and 1200 mm wide is modeled by a finite element analysis. A 100 mm wide footing is placed at the middle of the top surface. The properties of loose sand are summarized in Table 1. The plane strain problem is analyzed using the QUAKE/W program. The finite element mesh used for the analysis is shown in Figure 1. The mesh consists of 8 noded quadrilateral isoparametric

elements. The time of the analysis is taken as 100 sec with a time step $\Delta t = 0.1$ sec.

Table 1: Properties of loose sand soil used in the parametric study*

Material Properties	Loose sand
Modulus of elasticity, $E(\text{kN/m}^2)$	20000
Poisson's ratio, ν	0.3
Unit weight $\gamma_t, (\text{kN/m}^3)$	16.6

* Based on Bowles [6].

The dynamic load was applied for a period of 60 sec. The dynamic load function is represented by the following equation:

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

Where:

a_0 = Load amplitude,

ω = Load frequency, and

t = Time.

Dry loose sand models were assumed to be excited by dynamic load having two load amplitudes which are (5 kN and 10 kN) applied in two frequencies 1 and 2 Hz.

For each amplitude and frequency of the load, models were analyzed without geogrid and with geogrid having two widths (1B and 2B) where B is the footing width. Furthermore, two series of analysis, which include geogrid placed at depths from the model surface at (1B and 1.5B), were analyzed.

The details of abbreviation for the analysis as well as example of models naming are explained below:

B: width of strip footing, **b:** width of geogrid, and **d:** depth of geogrid from the surface.

A PVC pipe was used in the analysis to simulate the underground structure. The tensile strength at 10% axial strain of the pipe were 21 MPa. The pipe has a diameter of 120 mm and a thickness of 3 mm, it was placed at a depth equal to 500 mm from the surface [7]. Table 2 shows the technical properties of geogrid reinforcement used. Table 3 shows the physical properties of geogrid reinforcement used.

Table 2: The technical properties of geogrid used [8]

Property	Data
Tensile strength (kN/m)	140
Elongation (%)	4
Hole size (mm*mm)	25.4*25.4
Elastic modulus (Gpa)	76

Table 3: The physical properties of geogrid used [9]

Property	Data
Mesh type	Square
Polymer type	HDPE
Packing	Rolls

Rib thickness (mm)	1.2
Junction thickness (mm)	3.9

3. Results and Discussion

Figure 1 presents the variation of vertical displacement with time along Sec. (A-A) shown in Figure 2 under different load amplitudes when the soil is unreinforced. It can be noticed that the vertical displacement is always maximum at the point of application; it increases with time and load amplitude.

Figure 3 traces the variation surface settlement at the point of load application with time under two load amplitudes and frequencies.

The displacement amplitude is affected by both the load amplitude and frequency. The maximum surface settlement increases by about (18%) with the increase of frequency from (1) to (2) Hz while

it increases by about (99%) when the load amplitude increases from (5) to (10) kN.

The same trend of variation of displacement with time is obtained at node (a) located at the pipe crown.

Comparison between Figures 2 and 4 shows that the amplitude of displacement decreases by about (167%) for frequency equal to (1) Hz due to attention of load waves in the soil.

Figure 5 displays the variation of vertical total stress at point (a) with time under two load amplitudes and frequencies. It is noticed that the vertical stress is also affected by the load amplitude and frequency. The stress increases by vertical stress is also affected by the load amplitude and frequency. The stress increases by about (1%) with the increase in frequency from (1) to (2) Hz and increases by about (7%) with the increase of dynamic load amplitude from (5) to (10) kN.

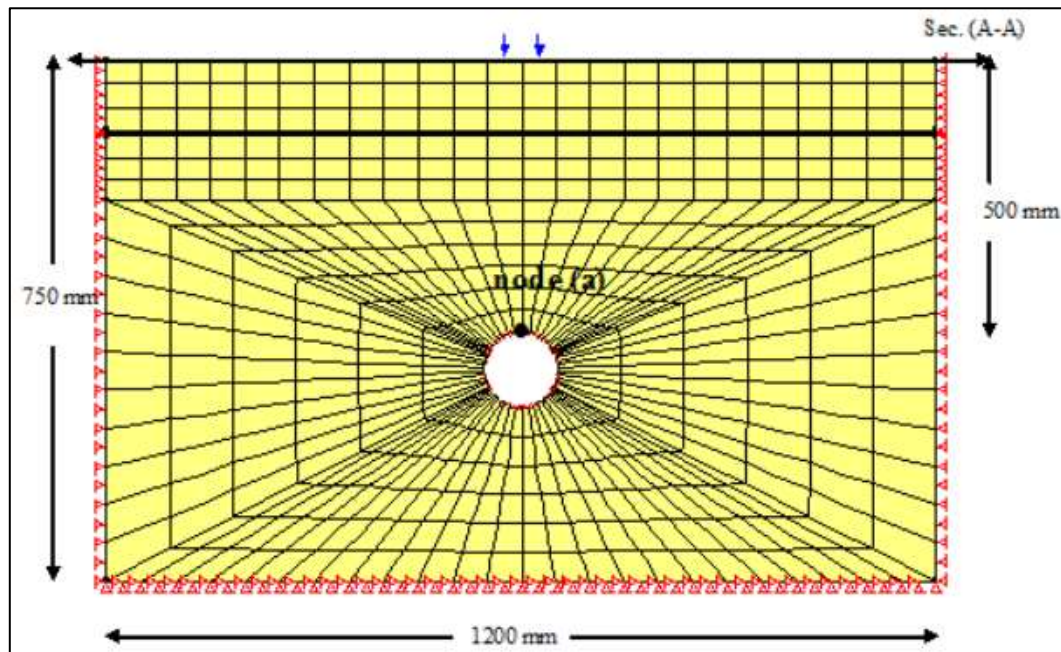


Figure 1: Typical finite element mesh

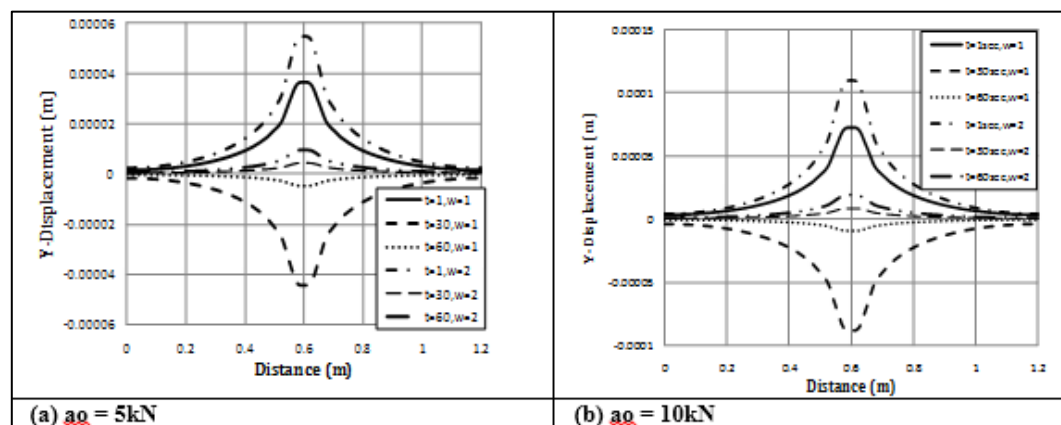


Figure 2: Displacement–time history along sec. (A-A) under different load amplitudes and frequencies, unreinforced soil

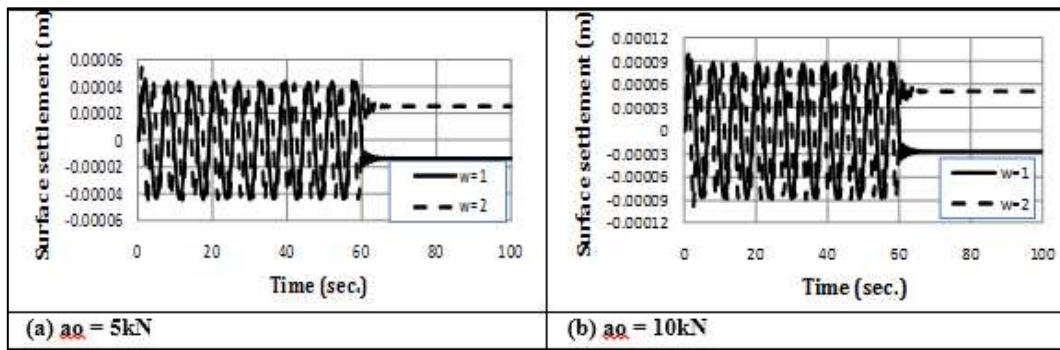


Figure 3: Variation of surface settlement with time under different load amplitudes and frequencies, unreinforced soil

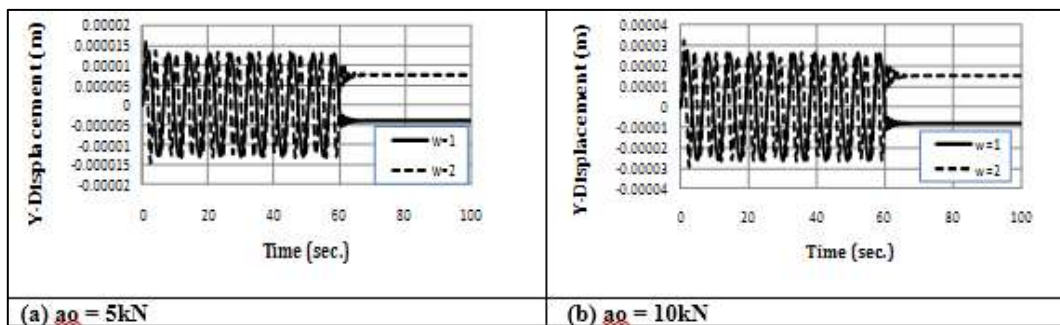


Figure 4: Displacement–time history of node (a) located at the pipe crown under different load amplitudes and frequencies, unreinforced soil

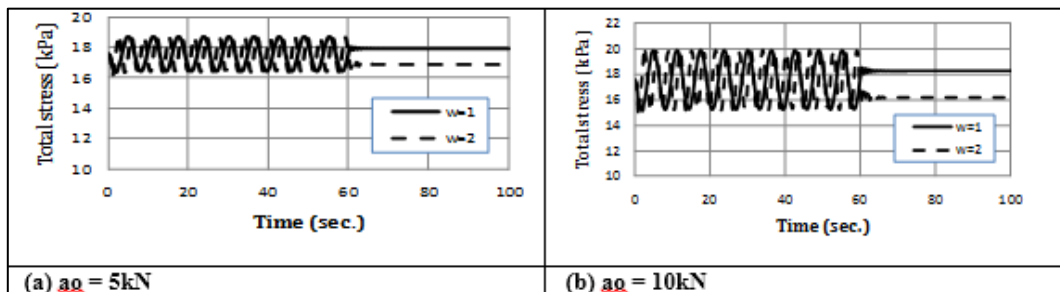


Figure 5: Vertical total stress–time of node (a) located at the pipe crown under different load amplitudes and frequencies, unreinforced soil

Figure 6 presents the variation of vertical displacement with time along Sec. (A-A) shown in Figure (1) under different load amplitudes in soil reinforced with a geogrid of width $b = B$ and depth $d = B$. It can be noticed that the vertical displacement is always maximum at the point of application; it increases with time and load amplitude.

Figure 7 traces the variation surface settlement at the point of load application with time under two load amplitudes and frequencies.

In reinforced soil, the displacement amplitude is affected by both the load amplitude and frequency. The maximum surface settlement increases by about (18%) with the increase in

frequency from (1) to (2) Hz while it increases by about (100%) with the increase in the load amplitude from (5) to (10) kN.

The same trend of variation of displacement with time is obtained at node (a) located at the pipe crown.

Comparison between Figures 6 and 8 shows that the amplitude of displacement decreases by about (163%) for frequency equal to (1) Hz due to attention of load waves in the soil.

Figure 9 displays the variation of vertical total stress at point (a) with time under two load amplitudes and frequencies. It is noticed that the vertical stress is also affected by the load amplitude and frequency. The stress in reinforced

soil increases by about (2%) with the increase in frequency from (1) to (2) Hz and increases by about (9%) when the dynamic load amplitude is increased from (5) to (10) kN.

Figure 10 presents the variation of vertical displacement with time shown in Figure 1 under different load amplitudes in soil reinforced with a geogrid of width $b = 2B$ and depth $d = B$. It can be noticed that the vertical displacement is always maximum at the point of application; it increases with time and load amplitude.

Figure 11 traces the variation surface settlement at the point of load application with time under two load amplitudes and frequencies. There is a noticeable decrease in surface settlement due to

widening of geogrid reinforcement. The displacement amplitude is affected by both the load amplitude and frequency. The maximum surface settlement increases by about (19) % with the increase in frequency from (1) to (2) Hz while it increases by about (99%) when the load amplitude increases from (5) to (10) kN.

The same trend of variation of displacement with time is obtained at node (a) located at the pipe crown.

Comparison between Figure 10 and 12 shows that the amplitude of displacement decreases by about (147%) for frequency equal to (1) Hz due to attention of load waves in the soil.

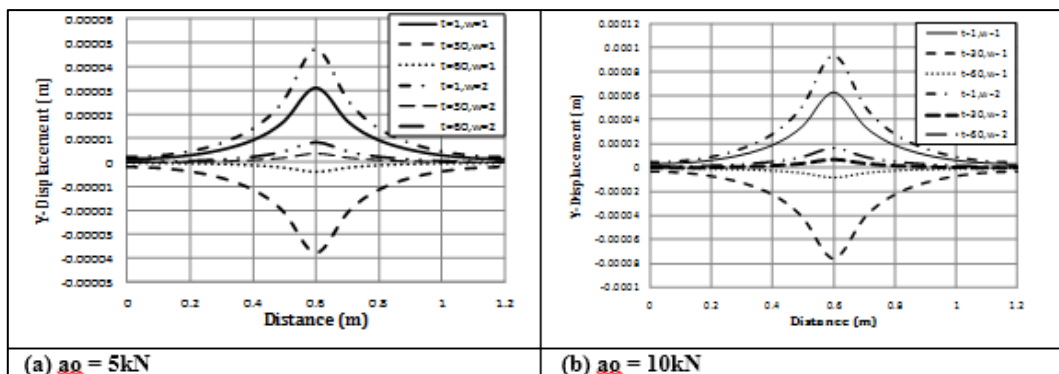


Figure 6: Displacement-time history along sec. (A-A) under different load amplitudes and frequencies, reinforced soil ($d = 1B$ and $b = 1B$)

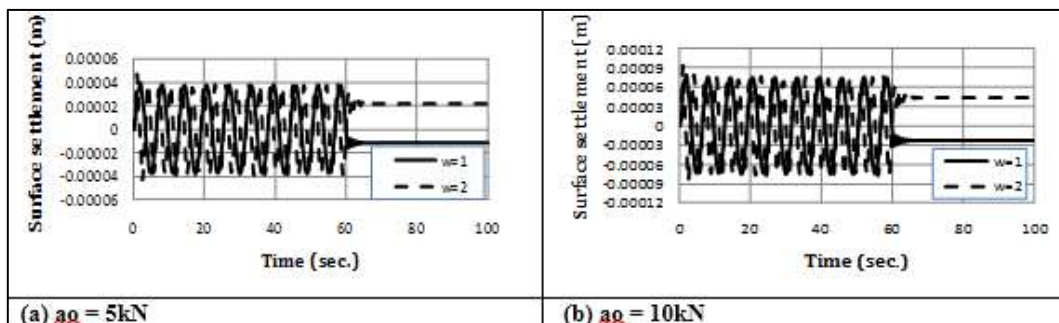


Figure 7: Variation of surface settlement with time under different load amplitudes and frequencies, reinforced soil ($d = 1B$ and $b = 1B$)

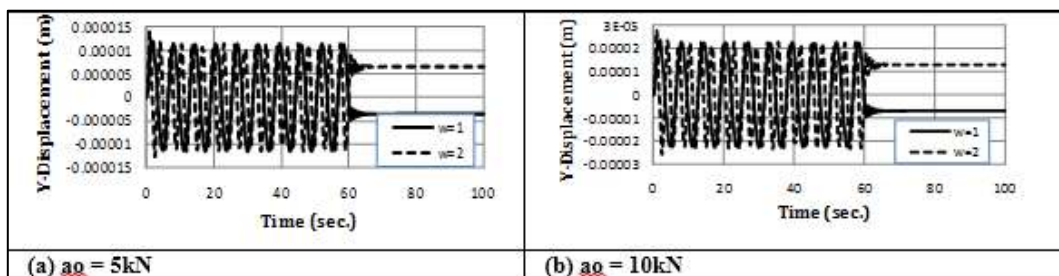


Figure 8: Displacement-time history of node (a) located at the pipe crown under different load amplitudes and frequencies, reinforced soil ($d = 1B$ and $b = 1B$).

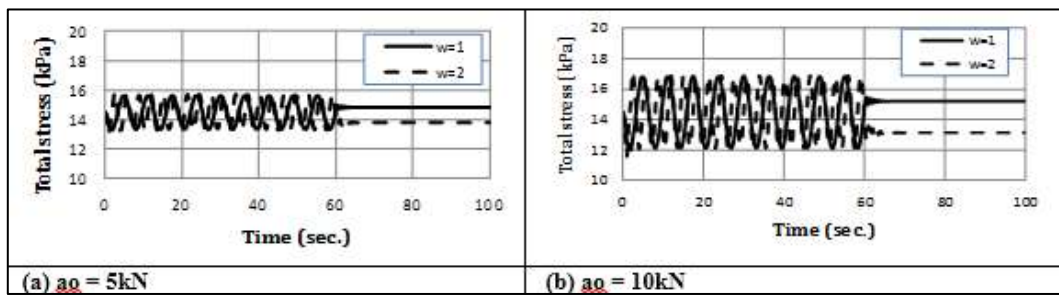


Figure 9: Vertical total stress–time of node (a) located at the tunnel crown under different load amplitudes and frequencies, reinforced soil. ($d = 1B$ and $b = 1B$).

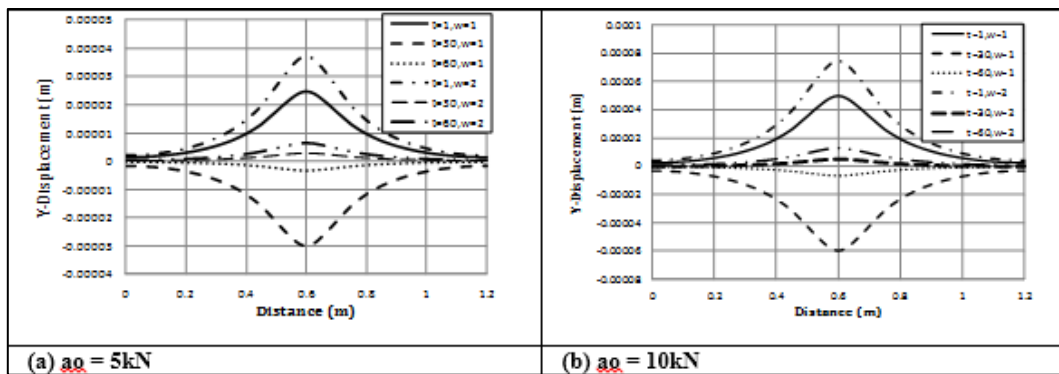


Figure 10: Displacement–time history along sec. (A-A) under different load amplitudes and frequencies, reinforced soil ($d = 1B$ and $b = 2B$)

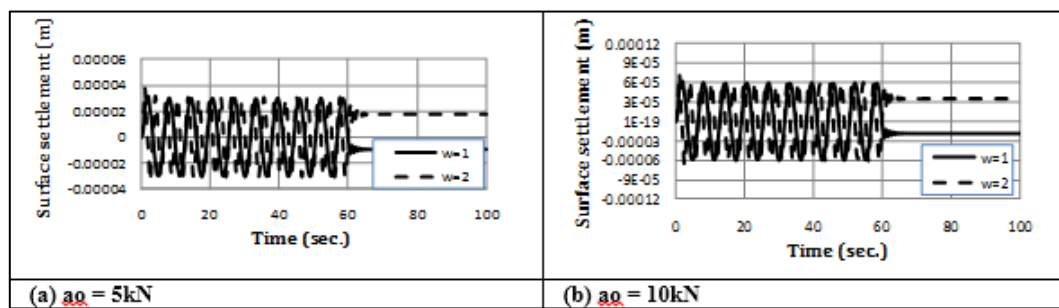


Figure 11: Variation of surface settlement with time under different load amplitudes and frequencies, reinforced soil ($d = 1B$ and $b = 2B$)

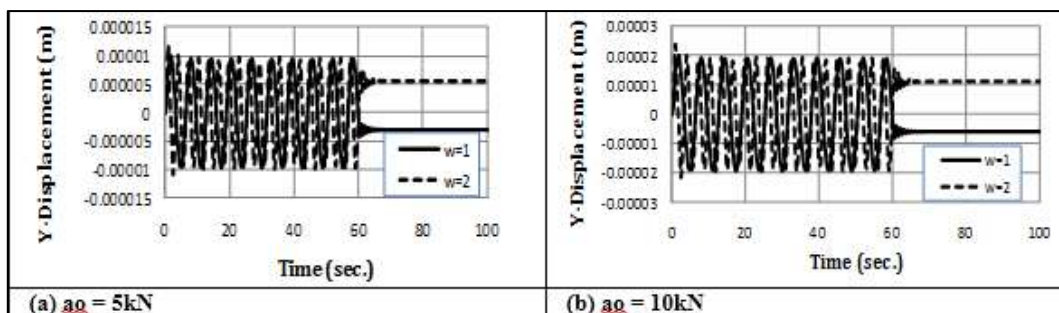


Figure 12: Displacement–time history of node (a) located at the pipe crown under different load amplitudes and frequencies, reinforced soil ($d = 1B$ and $b = 2B$)

Figure 13 displays the variation of vertical total stress at point (a) with time under two load amplitudes and frequencies. It is noticed that the vertical stress is also affected by the load amplitude and frequency. The stress increases by about (2%) with the increase in frequency from (1) to (2) Hz and increases by about (10%) with the increase in the dynamic load amplitude from (5) to (10) kN.

Figure 14 presents the variation of vertical displacement with time along Sec. (A-A) shown in Figure 1 under different load amplitudes in soil reinforced with a geogrid of width $b = B$ and depth $d = 1.5 B$. It can be noticed that the vertical displacement is always maximum at the point of application; it increases with time and load

amplitude. It is noticed that changing the depth of geogrid has small effect on settlement.

Figure 15 traces the variation surface settlement at the point of load application with time under two load amplitudes and frequencies. The displacement amplitude is affected by both the load amplitude and frequency. The maximum surface settlement increases by about (20%) with the increase of the frequency from (1) to (2) Hz while it increases by about (98%) when the load amplitude increases from (5) to (10) kN. The same trend of variation of displacement with time is obtained at node (a) located at the pipe crown.

Comparison between Figure 14 and 16 shows that the amplitude of displacement decreases by about (160%) for frequency equal to (1) Hz due to attenuation of load waves in the soil.

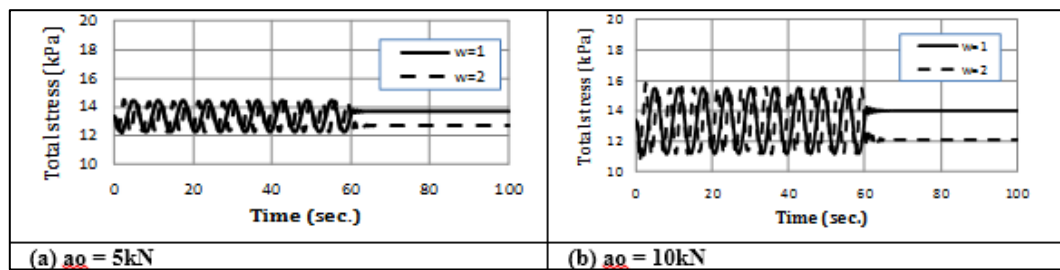


Figure 13: Vertical total stress–time of node (a) located at the pipe crown under different load amplitudes and frequencies, reinforced soil. ($d = 1B$ and $b = 2B$).

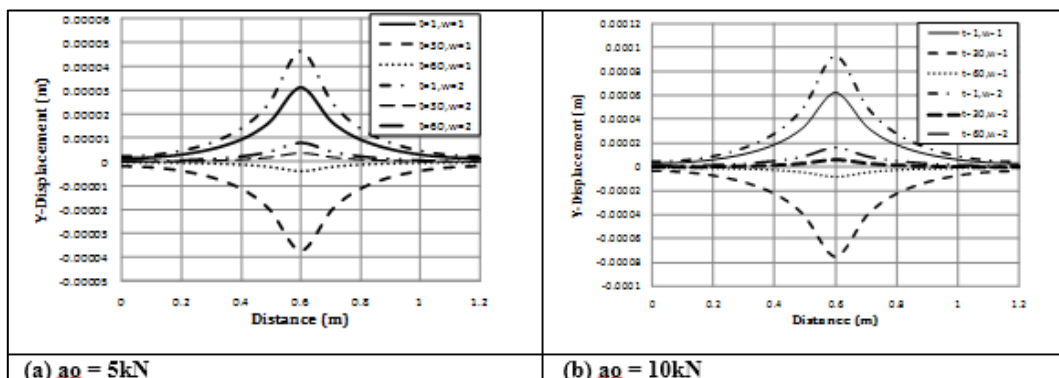


Figure 14: Displacement–time history along sec. (A-A) under different load amplitudes and frequencies, reinforced soil ($d = 1.5B$ and $b = 1B$).

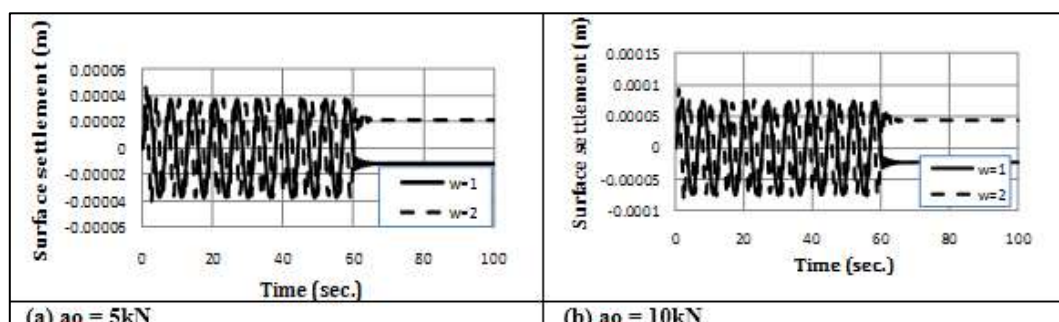


Figure 15: Variation of surface settlement with time under different load amplitudes and frequencies, reinforced soil ($d = 1.5B$ and $b = 1B$).

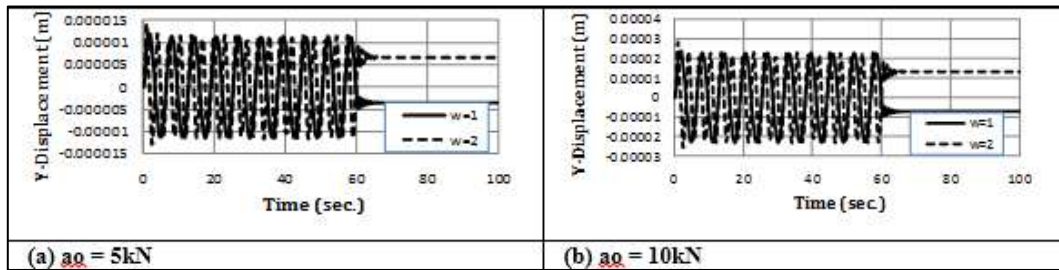


Figure 16: Displacement–time history of node (a) located at the pipe crown under different load amplitudes and frequencies, reinforced soil ($d = 1.5B$ and $b = 1B$).

Figure 17 displays the variation of vertical total stress at point (a) with time under two load amplitudes and frequencies. It is noticed that the vertical stress is also affected by the load amplitude and frequency. The stress increases by about (1%) with the increase of the frequency from (1) to (2) Hz and increases by about (8%) with the increase in dynamic load amplitude from (5) to (10) kN.

Figure 18 presents the variation of vertical displacement with time along Sec. (A-A) shown in Figure 1 under different load amplitudes in soil reinforced with a geogrid of width $b = 2B$ and depth $d = 1.5B$. It can be noticed that the vertical displacement is always maximum at the point of application; it increases with time and load amplitude.

Figure 19 traces the variation surface settlement at the point of load application with time under two load amplitudes and frequencies.

The displacement amplitude is affected by both the load amplitude and frequency. The maximum surface settlement increases by about (21%) with the increase of the frequency from (1) to (2) Hz while it increases by about (100%) when the load amplitude increases from (5) to (10) kN. The same trend of variation of displacement with time is obtained at node (a) located at the pipe crown.

Comparison between Figure 18 and 20 shows that the amplitude of displacement decreases by about (141%) for frequency equal to (1) Hz due to attention of load waves in the soil.

Figure 21 displays the variation of vertical total stress at point (a) with time under two load amplitudes and frequencies. It is noticed that the vertical stress is also affected by the load amplitude and frequency. The stress increases by about (2%) with the increase of the frequency from (1) to (2) Hz and increases by about (9%) with the increase in dynamic load amplitude from (5) to (10) kN.

The present results are compatible with experimental results obtained by Fattah et al. [1] who found that the pressure above the crown of the tunnel decreased by about (14-33%) when using geogrid reinforcement. In addition, they found the settlement decreased by about (13-20%) when using geogrid reinforcement.

On the other hand, Abbas [10] found that the effective length of reinforcement ratio (LR/B), where LR is the length of geogrid reinforcement equal to 2.25 for sand with relative density (60%), while it is equal to 1.75 for sand with relative density (80%). This is compatible with the present findings where the effective length of reinforcement was found equal to (2B) when the relative density is about (40%).

Fattah and Redha [11] found that, there is a considerable decrease in the percent of improvement when geocell reinforcement width decreased from (3.2) times the width of footing to (1.5B). This behavior is attributed to the geocell reinforcement, which is functioning as an interconnected cage, the geocell vertical walls are working as a series of plate anchors which mobilizes substantial resistance against the settlement of the footing, in addition to increasing the performance improvement.

4. Comparison of Dynamic Load with and Without Geogrid

I. Comparison between the total stress on the pipe crown result without and with geogrid reveals that when the load amplitude equals 10 kN, the total stress decreases by about 17%, compared with result of soil reinforced by geogrid, but this percentage decreases to about (20%) when the load amplitude equals 5 kN.

II. Comparison between the vertical displacement on the pipe crown result without and with geogrid reveals that when the load amplitude equals 10 kN, the vertical displacement decreases by about 15%, compared with result of soil reinforced by geogrid,

but this percentage decreases to about (14%) when the load amplitude equals to (5) kN. It can be noticed the amplitude of vertical displacement of the pipe crown that there is no effect between with and without geogrid.

III. Comparison between the surface settlement in case of soil without and with geogrid reveals that

when the load amplitude equals 10 kN, the surface settlement decreases by about 16%, compared with result of soil reinforced by geogrid, but this percentage decreases to about 15% when the load amplitude equals to 5 kN.

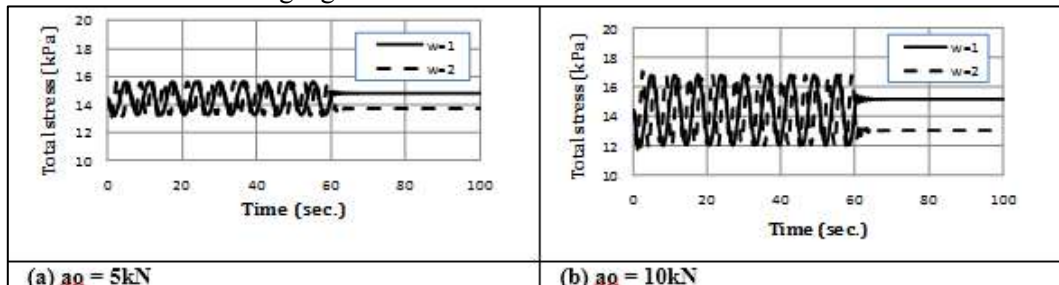


Figure 17: Vertical total stress–time of node (a) located at the pipe crown under different load amplitudes and frequencies, reinforced soil ($d = 1.5B$ and $b = 1B$).

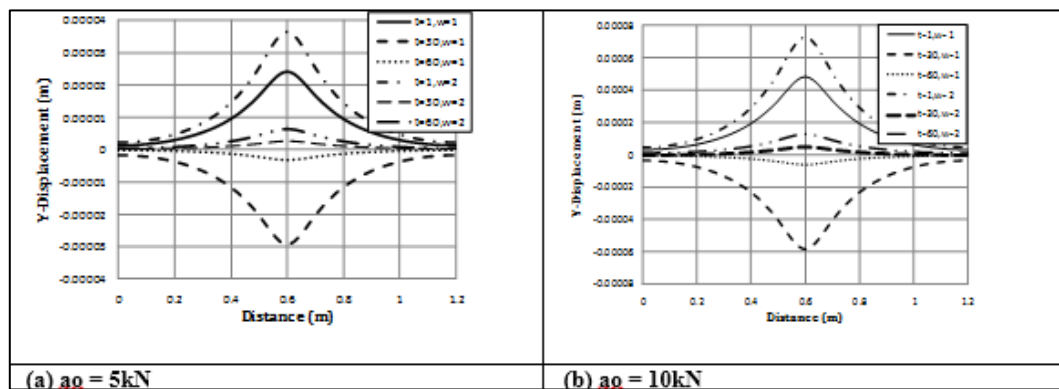


Figure 18: Displacement–time history along sec. (A-A) under different load amplitudes and frequencies, reinforced soil ($d = 1.5B$ and $b = 2B$).

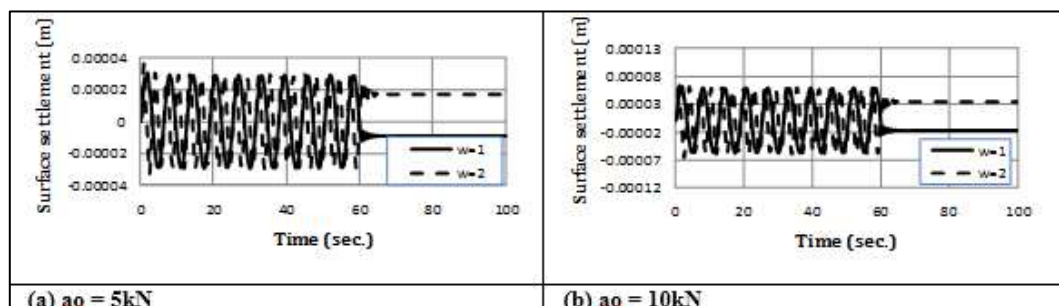


Figure 19: Variation of surface settlement with time under different load amplitudes and frequencies, reinforced soil ($d = 1.5B$ and $b = 2B$).

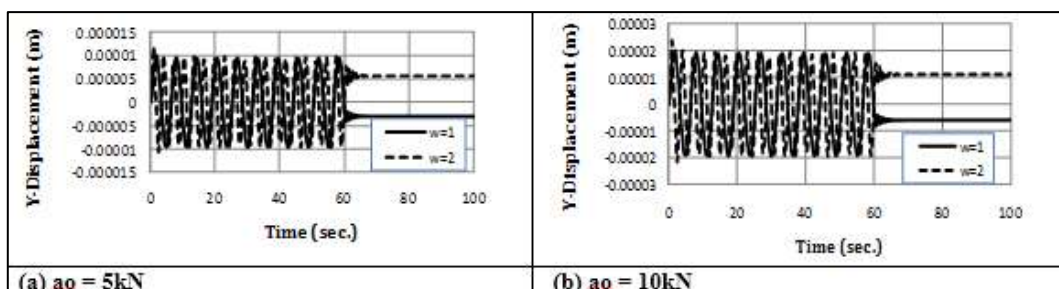


Figure 20: Displacement–time history of node (a) located at the pipe crown under different load amplitudes and frequencies, reinforced soil ($d = 1.5B$ and $b = 2B$).

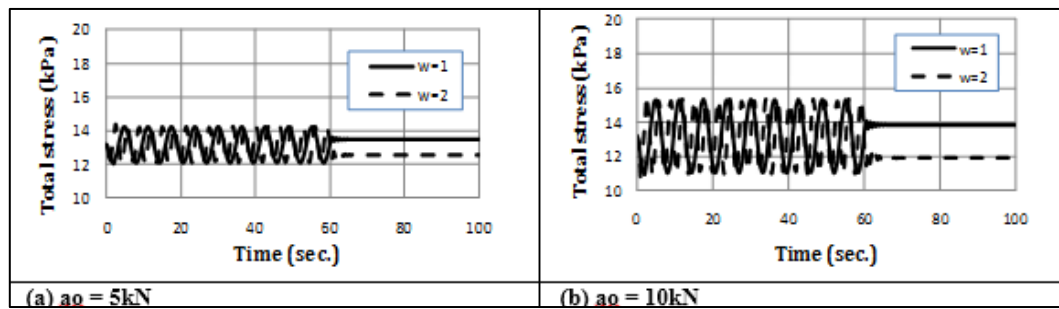


Figure 21: Vertical total stress–time of node (a) located at the pipe crown under different load amplitudes and frequencies, reinforced soil ($d = 1.5B$ and $b = 2B$).

5. Conclusion

1. When the geogrid reinforcement width equals (1B), the total stress on the crown of pipe decreases by about (17%) compared with unreinforced soil, but this percentage decreases to (10) % when the geogrid width equals to (2B).
2. The percent vertical settlement on the pipe crown decreases by about (35%) when using reinforcement of width equals (2B) compared with test results unreinforced soil, while when the width equals (1B), the percent vertical settlement decreases to about (15%), this indicates that when the width of reinforced soil increases, the vertical settlement decreases.
3. When the load amplitude of the dynamic load increases from (5) kN to (10) kN, the total stress at the pipe crown increases too by about (7-9%).
4. The percent vertical displacement at the pipe crown is increased by about (99) % when the load amplitude increased from (5) kN to (10) kN. While, the percent vertical displacement is increased by about (19%) when the frequency increased from (1) Hz to (2) Hz.
5. When the geogrid is placed at a depth equal to (1B) or (1.5 B), the results of vertical displacement the total stress on the crown of pipe are approximately close, it can be noticed that the reinforcement is not effective at depth equals to (1.5B).

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