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Finite Element Analysis of the Geogrid-Pile Foundation System under Earthquake Loading

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Abstract

The finite element method is one of the important methods in analyzing geotechnical engineering problems; its main advantage is the ability to apply for the materials exhibiting non-linear stress-strain behavior. In this study the finite element program **PLAXIS 3D 2013** is used to study the behavior of the piles under the influence of seismic waves in saturated sandy soil and the effect of adding geogrid with the pile foundation. The program has been used to facilitate the representation of the real model, input the required soil parameters and implementation of seismic data. Seismic wave, the soil geometry and the pile dimensions were fixed in all models, while dimension and depth of the geogrid used were varied to study the influence of different depth and dimension in reducing the pile displacements and the pore water pressure of soil. The results show that The reduction in settlement ratio (the difference between settlement of pile without and with using geogrid to the settlement without using geogrid) for (L/2 ×L/2), (L×L) and (2L×2L) are 10.6%, 17% and 21.3% respectively. And the settlement ratio for geogrid at depths 8.33% and 12.5% of pile length are 9.6% and 17% respectively

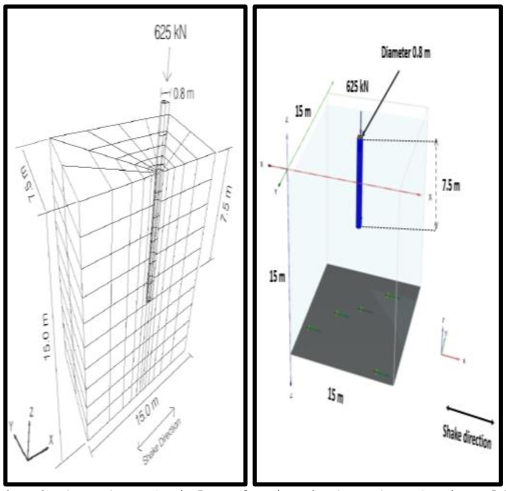
Keywords: Finite Element Analysis, Pile, Geogrid, Loose Sand, Earthquake, Mohr-Columb Model.

1. Introduction

Increasing seismic activity in Iraq areas lead researchers to investigate the effect of dynamic effects on the behavior of pile foundations in sandy soils like Al-Recaby [3], Al-Tameemi [4], Salem [8] & Sa'ur [9]. Some of these researches highlighted the behavior of pile under real earthquakes like Al-Tameemi [4] & Sa'ur [9] that used Halabjah and Ali Al Gharbi earthquake respectively. Previous researches confirmed that the soil improvement reduces the damage of foundations and structures thus the geogrids were used to improve the soil (Fakhraldin [6] & Taha [10]). Different researches likes Abdulrasool [1], Al-Recaby [3], Salem [8] & Sa'ur [9] used PLAXIS 3D in dynamic analysis of foundation which provide good results when simulating the real models, so that it is used in this study. And because of rare information about using geogrid with pile foundation under the real earthquakes in sandy soils, this research has been carried out. The investigations were carried out on pile foundation model, which subjected to Halabjah earthquake, with acceleration equal to 0.1 g.

2. The Geometry Model of Pile-Geogrid System

The model used in the current study is single pile 0.8m in diameter and 7.5m depth embedded in saturated sandy soil performed by Al-Tameemi [4] using FLAC^{3D} program. The dimensions of finite element model used are 15×15×15m long, wide and depth respectively as shown in Fig.(1). Then investigate the effect of adding different dimensions and depths of Nelton CE121 geogrid which tested by Fakhraldin [6] & Al-Essawi [2] to study the pile settlement and pore water pressure under the effect of Halabjah earthquake. The applied load concentrated above the pile is 625 kN as described by Al-Tameemi [4].



a- Analysis using FLAC^{3D} b- Analysis using PLAXIS3D
Figure (1): The geometry model

3. The Information for Models Used

3.1 The Models of Soil and Pile

The soil used is loose sandy soil with relative density 33%; the other properties listed in Table (1). The pile used in all models is single concrete pile, its length is 7.5m with a diameter 0.8m (i.e., L/d is 9.4) and the applied load was 625 kN (Al-Tameemi, 4). The pile was designed as cylinder and give the properties of plate, the input properties for the soil and pile (plate properties) are listed in Table (1), the material models are Mohr Coulomb for soil and linear elastic for pile as used by Al-Recaby [3].

Table (1): Material properties for soil and pile models (after Al-Tameemi, 4)

Parameter	Loose sand	Pile (plate)
$\gamma_{unsat.}$ (kN/m^3)	15.65	25
$\gamma_{sat.}$ (kN/m^3)	18.5	-
E (kN/m^2)	234×10^3	24.96×10^3
ν	0.3	0.2
ϕ (degree)	34	-
Ψ (degree)	4	-
V_s (m/s)	237.4	-
V_p (m/s)	444.1	
Raylieh α	0.05	-
Raylieh β	0.2	-
Data set	Standard	-
$R_{interface}$	0.8	-

3.2 The Geogrid Model

The geogrid induced in **PLAXIS 3D** is Nelton CE121, which has stiffness equal to 221 kN/m, 3534 kN/m and 400000 kN/m for L/2×L/2, L×L and 2L×2L respectively according to Meymand et al. [7], El-Emam et al. [5] & Taha [10] as shown in Fig. (2), since they multiplied the geogrid stiffness by λ^2.

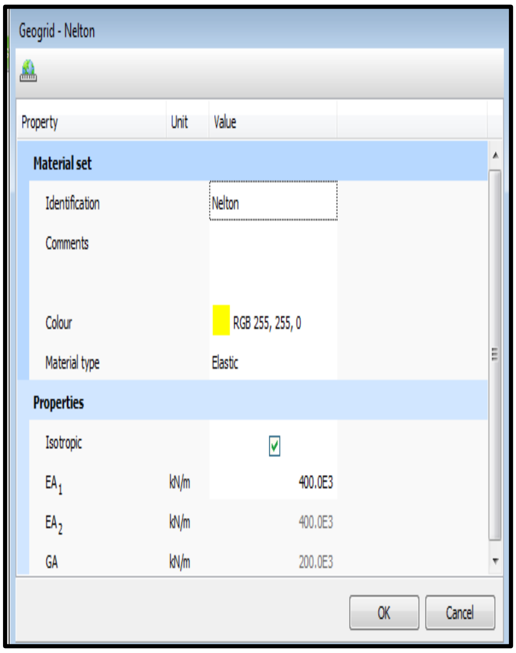


Figure (2): Specification of Nelton CE121 geogrid

3.3 Earthquake Modeling

The earthquake inserted into the base of the model using prescribed displacement in the X-direction as indicated by Abdulrasool [1] & Sa'ur [9]. The earthquake information used in the current research is Halabjah earthquake, the readings of the earthquake entered as a table of time and acceleration records in (s) and (g) respectively. Acceleration-Time records of earthquake are shown in Fig. (3).

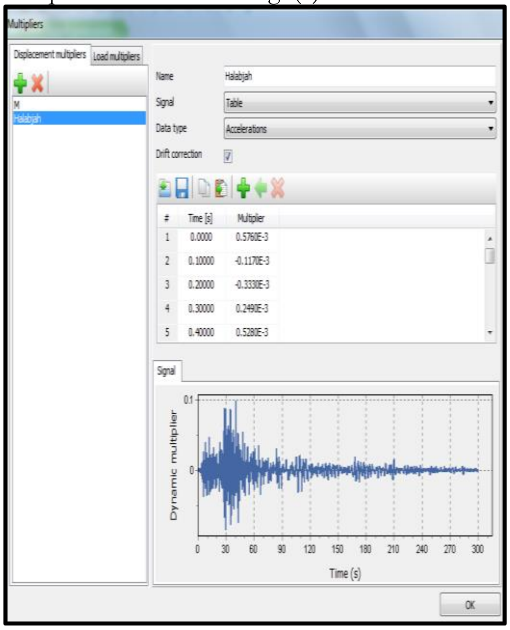


Figure (3): Acceleration–time records of Halabjah earthquake during 300 second

4. Mesh Generation

Figure (4) show the mesh generation of the soil, the pile and the geogrid used. The mesh consists of 10-node tetrahedral element, the coarse mesh created because of the large model dimensions.

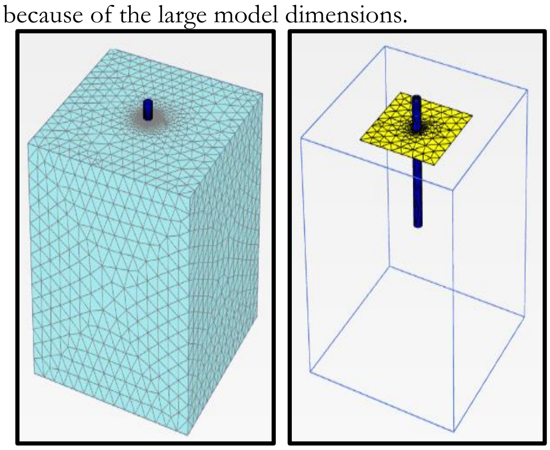
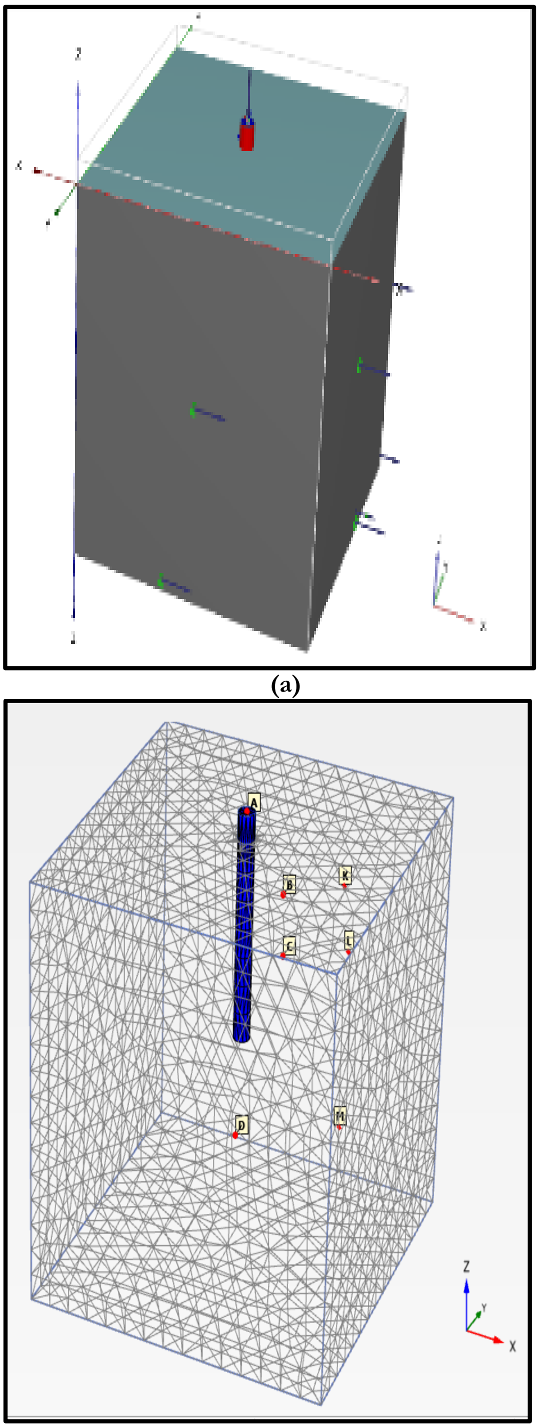


Figure (4): The mesh generation

5. Performing Calculations

Calculations performed by using four phases as shown in Fig. (5-a). The initial phase is generated to calculate the initial stresses of soil and the pore water pressure. The first phase calculation type used is plastic and the pressure used from the previous phase, inserted soil, pile and geogrid in the model explorer. Second phase, the pore pressure calculation type is phreatic and model explorer contain surface load in addition to that contain in the previous phase. Third

Phase is the dynamic type, in this phase, activate the reset displacement to zero, surface displacements in model explorer and the dynamic, then choose viscous boundary condition, close the ground water flow and select four points for curves as shown in Fig. (5-b).



(a)

(b)

Figure (5): The staged construction

6. Results

6.1 The Comparison between FLAC^{3d} and PLAXIS 3D 2013

The comparison between results obtained by FLAC^{3D}and PLAXIS 3D 2013 is inserted in Table (2). The results show that the pore water pressure of the saturated soil in PLAXIS 3D is smaller than that obtained by FLAC^{3D}, and the settlement is greater than recorded by FLAC^{3D}, this may be due to the different in the mesh generation of the model, and then the coordinates of the points at which the results recorded vary.

Table (2): The comparison between the maximum values of pore water pressure and settlement

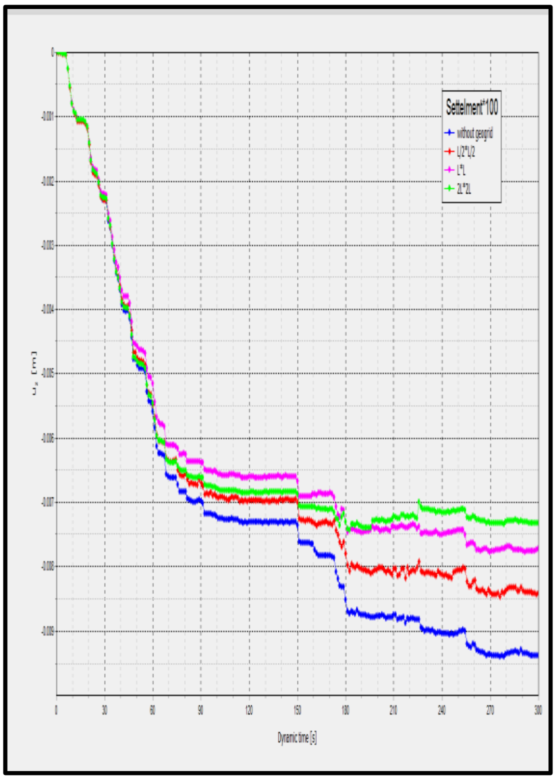
Earthquake type	Parameters	FLAC^{3D}	PLAXIS 3D
Halabjah	u_1 (kN/m^2)	55	71
	u_2 (kN/m^2)	95	90
	u_3 (kN/m^2)	215	165
	Settlement(mm)	756	938

6.2 Effect of Geogrid Dimensions

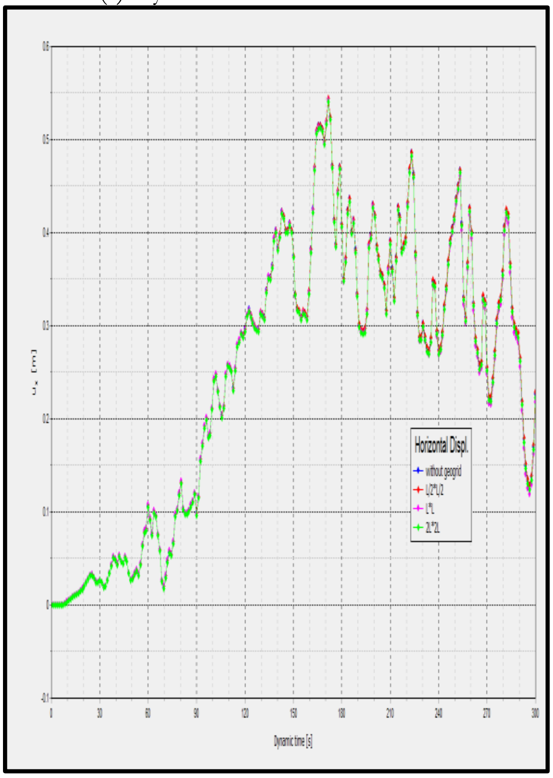
The dimensions of geogrid used are (3.75m×3.75m), (7.5m×7.5m) and (15m×15m) which correspond to $(\frac{L}{2}\times\frac{L}{2})$, (L×L) and (2L×2L) respectively. The results given in Fig. (6) illustrate that adding geogrid to soil will reduce the settlement and this reducing will increase as geogrid dimensions increase. The reduction in settlement ratio (the difference between settlement of pile without and with using geogrid to the settlement without using geogrid) for $(\frac{L}{2}\times\frac{L}{2})$, (L×L) and (2L×2L) are 10.6%, 17% and 21.3% respectively. It has been found that the horizontal displacement in shaking direction are unaffected. The horizontal displacement in opposite shaking direction is reduce with reducing dimensions of geogrid. In addition, the pore water pressure in first layer decrease with small dimension and increase with large dimension which may be due to increasing in acceleration, while in lower layers the pore water pressure decreasing with increasing geogrid dimensions.

6.3 Effect of Geogrid Depth

Figure (7) show the comparison between the results for pile foundation reinforced with geogrid mesh of dimension L×L at different depths L/12 and L/8 that corresponds to 8.33% and 12.5% of pile length. The results illustrate that when geogrid spread deeper in the soil, the settlement and the horizontal displacement in the direction opposite to shaking are reduce, while the displacement in the shaking direction is unaffected, also the pore water pressure are decrease in the upper layer and increase in the lower layers due to increasing the pressure beneath the geogrid mesh. The settlement ratio for geogrid at depths 8.33% and 12.5% of pile length are 9.6% and 17% respectively.

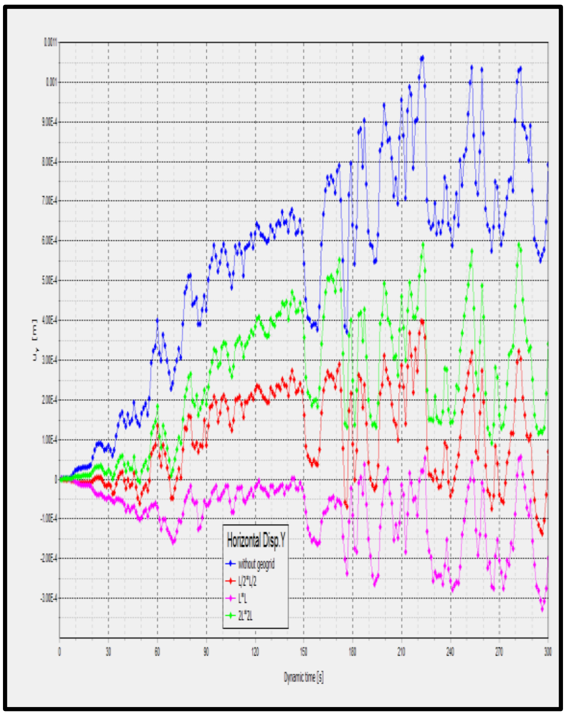


(a) Dynamic time versus settlement

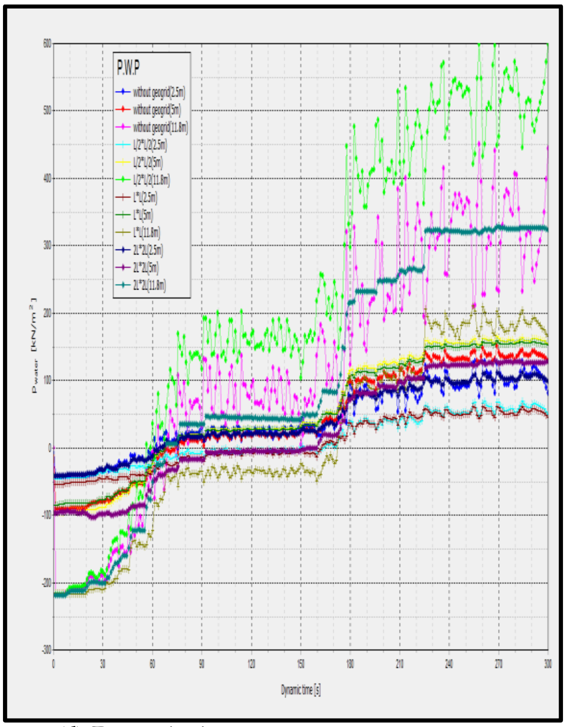


(b) Dynamic time versus horizontal displacement X

Figure (6): The comparison between different dimensions of geogrid

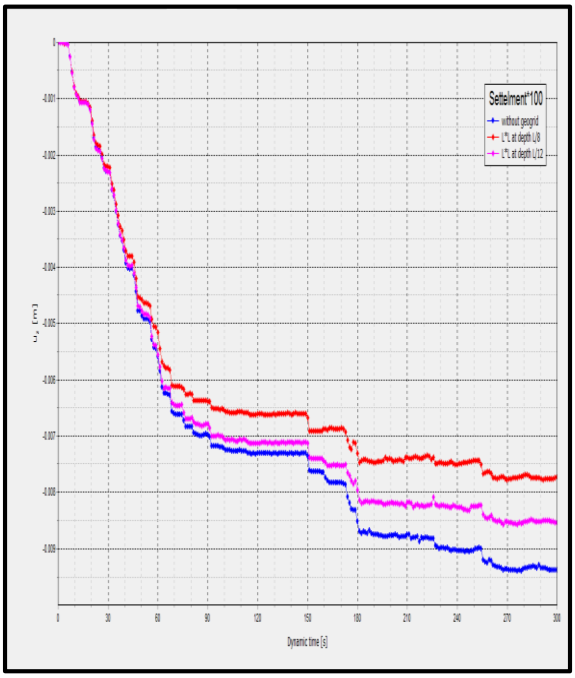


(c) Dynamic time versus horizontal displacement Y

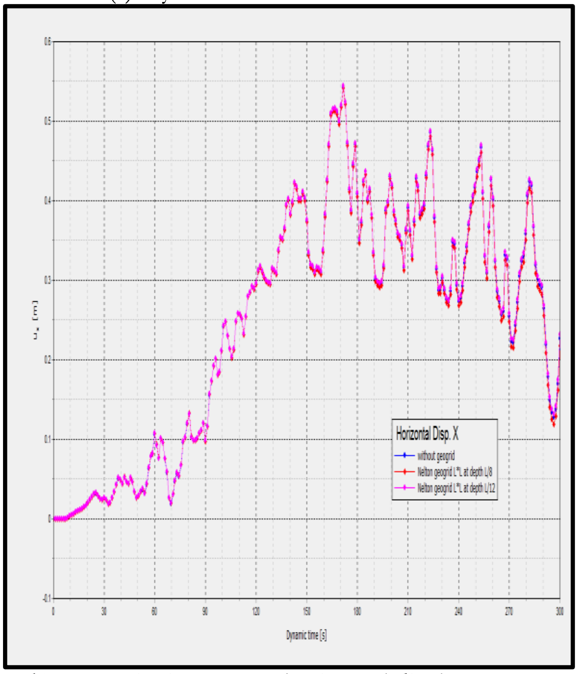


(d) Dynamic time versus pore water pressure

Figure (6): Continued

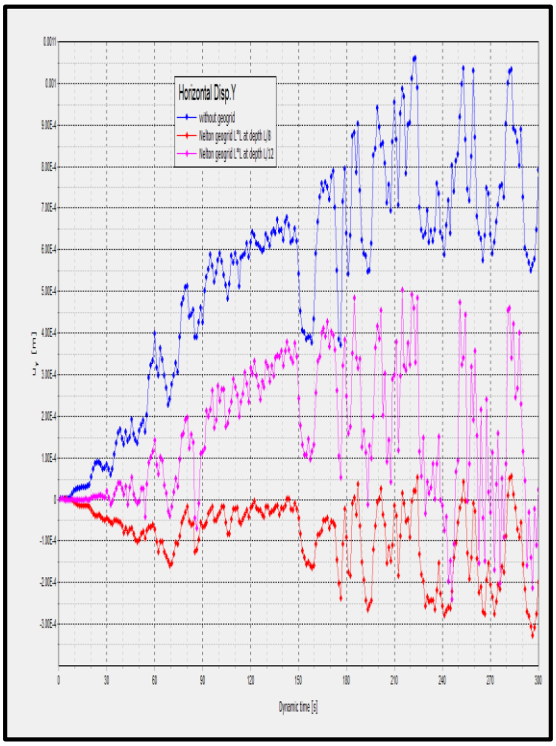


(a) Dynamic time versus settlement

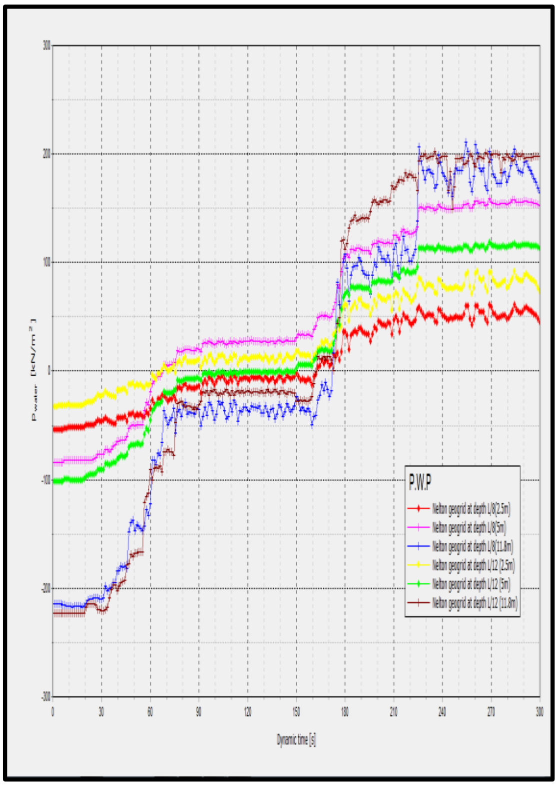


(b) Dynamic time versus horizontal displacement X

Figure (7): The comparison between different depths of placing geogrid



(c) Dynamic time versus horizontal displacement Y



(d) Dynamic time versus pore water pressure

Figure (7): Continued

7. Conclusions

1. When comparing the results of FLAC^{3D} and PLAXIS 3D 2013. The pore water pressure of the saturated soil in PLAXIS 3D is smaller than that obtained by FLAC^{3D}, and the settlement is greater than recorded by FLAC^{3D}. In general, the compatibility between the results considered as good.

2. When the dimensions of geogrid are increased (L/2×L/2), (L×L) and (2L×2L), the settlement of the pile decrease, then increasing the settlement ratios to 10.6%, 17% and 21.3% respectively. Increasing the dimensions of geogrid over the length of pile leads to increase the total acceleration of the pile and increase the pore water pressure in first soil layer while decrease in the lower soil layers.
3. Putting the geogrid deeper from 8.33% to 12.5% of pile length into the soil will reduce the displacements of pile and the settlement ratio is 9.6% and 17%
and the pore water pressure in the upper layer while it increases the pore water pressure in the lower layers. Since the settlement ratio for geogrid at depths 8.33% and 12.5% of pile length are 9.6% and 17% respectively
4. The horizontal displacement towards shaking direction is unaffected with placing geogrid inside the soil.

8. References

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