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Comparison of dynamic behavior of shallow foundations based on pile and geosynthetic materials in fine-grained clayey soils

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Abstract. In this paper, the geotechnical report of the Northern Fereshteh area in Tabriz is used and the characteristics of shallow foundation of a single pile and compared pile group and geogrid in terms of the settlement of a building foundation on clayey soil. Additionally, impacts of existing variables such as the number of geogrid layers, the length of the pile, and the depth of groundwater level affected by the dynamic load caused by the Taiwan Jiji earthquake via numerical analysis using PLAXIS software are examined. The results of fifty-four models indicated that the construction of a pile group with a diameter of 1 meter and a length of 14 meters significantly diminished the consolidation settlement of the soil in the Northern Fereshteh area, where the settlement value has been triggered by the load inflicted by earthquake. Moreover, the construction of four layers of geogrid at intervals of one meter led to a significant decrease in the settlement. Finally, after reaching a maximum depth, it had no reducing effects on the foundation settlement.

Keywords: shallow foundation; single pile; pile group; geogrid; PLAXIS; consolidation settlement

1. Introduction

Study of dynamic response of foundations through an accelerograph, is one of the important issues in earthquake resistant design and soil-structure interaction. A structure or foundation may be affected by several successive earthquakes, each of which has a different effect on that part of the structure (Khorami *et al.* 2017). Therefore, in general, when a foundation or earthquake experiences several earthquakes in a short period of time, it can exhibit a very different behavior, which will also affect the settlement of the foundation. Therefore, in this research, the level of settlement of foundations on clayey fine-grained soil in Jiji earthquake has been investigated using an accelerograph (Taheri *et al.* 2019). In this regard, for the purpose of this research, a foundation type of single pile and a pile group as well as a geogrid located on the soil of the Northern Fereshteh area is modeled in the PLAXIS finite element software. Earthquake is one of the natural phenomena that has not yet been harnessed by human being and always brings about many financial and human casualties (Zirakian *et al.* 2015). The structures and their behavior should be meticulously studied so as to meet their seismic requirements (Taheri *et al.* 2019, Xu *et al.* 2019). In most investigations on the seismic behavior of structures, the soil under the foundation is considered to be rigid. While, practically, the behavior is ductile and the assumption of rigidity for the underlying structure can affect the seismic responses of structures and the precise performance of the lateral elements (Jalali *et al.* 2012, Mohammadhassani *et al.* 2013b), because the level of soil-structure interaction can have a great effect on seismic responses of structures. This issue is especially momentous when the soil under the foundation the foundation has less bearing capacity. According to many studies, it has been proved that overlooking the effect of soil-structure interaction on structural design might have increasing effects in some circumstances instead of decreasing effects (Seed 1970, Terzaghi *et al.* 1996, Ornek *et al.* 2012, Shariat *et al.* 2018).

In classical state for the analysis of a structure with a fixed support, the motion applied to the structure base equals the free field motion of the ground (Liu *et al.* 1997, Lozovyi *et al.* 2014, Ziaei-Nia *et al.* 2018). In flexible support cases, a rotational component is added to the horizontal motion of the structure. Part of the vibrational energy of the structure can be dissipated by transferring to the soil under the foundation, and due to the radiation damping precipitated by wave propagation and the Hysteresis damping of the soil material. While in the

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classical state, with the assumption of rigidity for the subsoil, this energy dissipation was not considered (Toghroli *et al.* 2018a, Zandi *et al.* 2018, Afrazi and Rouhanifar 2019, Shao *et al.* 2019, Xie *et al.* 2019, Shariati *et al.* 2019d). On the other hand, the results of structural analysis under this kind of seismic loading have also shown that despite the common assumption that overlooks the soil-structure interaction is an utmost assumption, in some structures under some sorts of seismic loading that can be the least assumption which needs to be considered; this effect is more noticeable in heavier and harder structures with seismicity covering a wide frequency range (Tahmasbi *et al.* 2016, Heydari *et al.* 2018, Shariati *et al.* 2019b, Shi *et al.* 2019b). Therefore, the effect of this assumption should be evaluated for each structure in each type of loading, individually. Foundation settlement in fine-grained soils can be estimated less accurately than its bearing capacity, since estimating their settlement depends on several factors that justifying their behavior requires appropriate engineering judgment (Neighbors *et al.* 2012). The most important factors in this case are boundary conditions, degree of saturation, and the estimation of pre-consolidation pressure, which is related to the maximum pressure that has been applied to the soil so far. All in all, according to the mentioned reasons, the settlement level attained through calculation may has up to 100% of error (Jalali *et al.* 2012). The settlement of the structure based on coarse-grained soils is generally obtained by empirical formulas. Settlements in these soils often occur quickly, and during construction process after applying the maximum load (Van Baars 2014). Long-term settlements of these loads are negligible. Of course, the long-term settlements may be due to other factors, such as dynamic loads (traffic, pile driving, vibrations from machinery, etc.), changes in the groundwater level, earthquake, explosion, formation of cavities, and pore spaces under the ground and flood in which the empirical equations and formulas are not adequate, and other criteria should be considered in designing. For fine-grained soils, such as silt and clay which are close to saturation or saturated, with a permeability coefficient of $k_z < 10^{-7}$ m / day (Mayerhof 1976, Budhu 1984, Heydari and Shariati 2018), the occurrence of settlement requires a relatively long time due to the slow fading rate of the excess porewater pressure associated with the loading, and consequently, void ratio will be reduced, and, therefore, it is important to anticipate the amount of settlement and the required time for calculations (Budhu 2015). All types of settlements are functions of excess stress applied on soil by the foundation (Terzaghi *et al.* 1996, Abu-Farsakh *et al.* 2008, Shao *et al.* 2015, Abu-Farsakh *et al.* 2018, Hosseinpour *et al.* 2018). Therefore, acquaintance with the equations for calculation of stress distribution in soil due to the effect of foundation load is of particular importance. Several equations have been proposed to find the state of stresses in depth after loading, among which the Boussinesq and Westergaard's equations are more common, and are explained in soil mechanics books or other geotechnical sources (Toghroli *et al.* 2018a). Of course, it is necessary to note that having accurate stress distribution in depth is a necessary condition for accurate estimation of the settlement but not enough. In the design of shallow foundations in non-cohesive soils (sand, gravel and non-plastic silt) (Fig. 7), either natural residual soils or engineering embankments, mostly the criterion is the settlement in bearing capacity, either, due to the importance of accurate estimation of the settlements in these soils, the utilized method must be reliable (Abu-Farsakh *et al.* 2008). The worst earthquake data in recent decades is associated to an earthquake that struck the city of Jiji in September 1999 (Fig. 1). The earthquake with the severity of 7.6 Richter had the toll of 2,400 dead. The island of Taiwan is near the connection of two lithospheric plates (two vibrational layers of the earth); and, as a result, it is usually susceptible to earthquake (Menard *et al.* 1975, Budhu 1984, Li *et al.* 2005, Shao *et al.* 2018, Zandi *et al.* 2018, Shi *et al.* 2019a).

2. Geotechnical characteristics of the under-study area

Tabriz is located in the north-western part of Iran and

Fig. 1 The location of the Jiji city of Taiwan in 1999 earthquake

Fig. 2 The location of Fereshteh Street on the Google Earth map in Tabriz city (Mahmoudi Azar 2017)

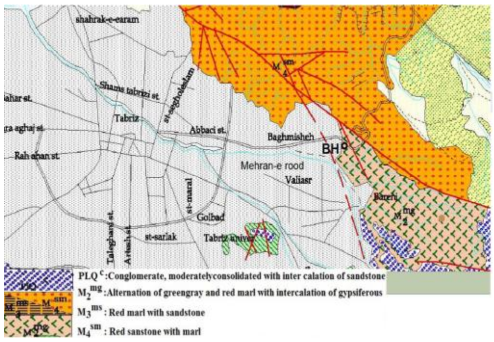


Fig. 3 Borehole location on the Geological Reference Map of the region (Based on map 1:100000 Mapping Organization of the Country) (Alizadeh and Dabiri 2018).

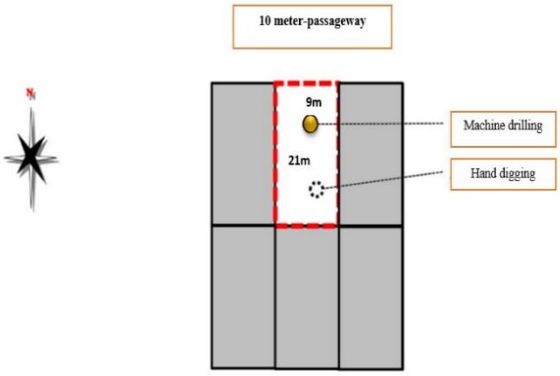


Fig. 4 Location of the property under study and drilled borehole (Mahmoudi Azar 2017).

(a) 2 m (b) 4 m (c) 6 m (d) 8 m

Fig. 5 Samples taken from boreholes of study at depths of (a)-(d) (Mahmoudi Azar 2017 and Alizadeh and Dabiri 2018)

Table 1 Characteristics of the under-study structure

Depth of drilling	Embedment depth	Number of floors	Area of the land
-1.2 m	-1.2 m	6	189 m^2

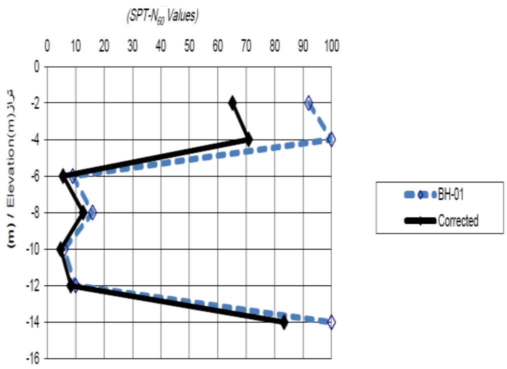


Fig. 6 SPT value changes with depth

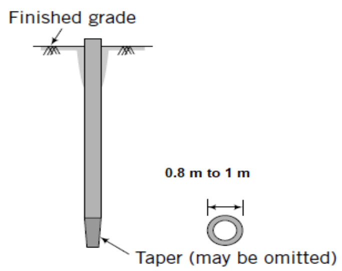
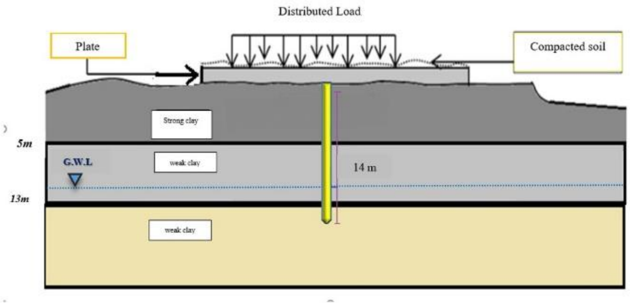
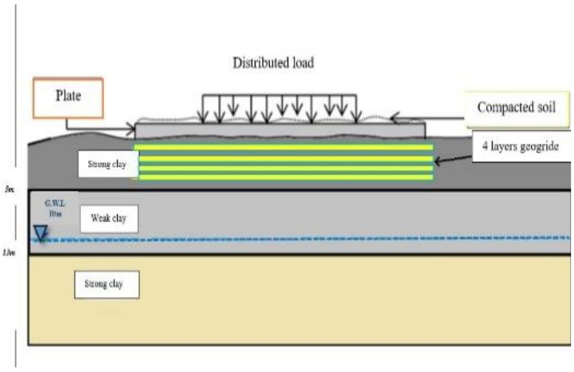


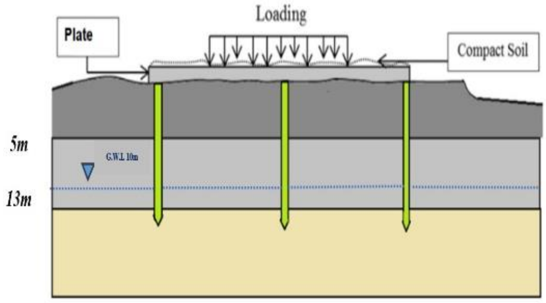
Fig. 7 Precast and pre-stressed single concrete pile with a circular cross section of different diameters (Mahmoudi Azar 2017)



(a) Single pile



(b) Geogrid



(c) Pile group

Fig. 8 Geotechnical models of the soil profile of the studie area in the presence of (a)-(c)(Mahmoudi Azar 2017)

Fig. 9 Uniaxial geogrid (Guido *et al.* 1986)

close to one of the most important and well-known faults of Iranian plateau. Dynamic loads applied on the foundation may be precipitated by earthquakes, explosions, vibrations of machinery, and sea waves. If a structure is subjected to earthquake-induced vibrations, the loads applied to the foundation of this structure during an earthquake include alternating vertical loads, horizontal loads, and moments around one or more axes (Abu-Farsakh *et al.* 2018). Likewise, an earthquake causes inertia in the soil mass under the foundation, which affects the settlement of the soil. In the field of geotechnic, a plethora of recent studies have examined soil settlement in the construction of structures. Major studies in this regard have intended to establish an immediate consolidation settlement. The relationship between the settlement of the foundation and the soil under the foundation was investigated via analytic and numerical methods and empirical observations in terms of its maximum rate and distribution Tong 2005, Toghroli *et al.* 2018a, Zandi *et al.* 2018, Xie *et al.* 2019, Zhao *et al.* 2019).

Ali Masumi *et al.* (2008) used a single pile foundation with specific geometric dimensions on sand-clayey soil to reach a dynamic settlement of the foundation. The selected model was analysed using the PLAXIS analytical software via the finite difference method and the vertical component of the accelerograph of the Firouzabad-Kajor (Sari station). The results indicated that the dynamical settlement significantly decreased on the pile group foundations. Tabriz, as one of the major metropolises of the country, has special geotechnical conditions. In some areas of the city, some structures have been damaged due to the presence of fine-grained layers and high groundwater level (Van Den Einde *et al.* 2004, Zandi *et al.* 2018, Trung *et al.* 2019). The Northern Fereshteh in Baghmisheh is one of those areas. The location of the boreholes was selected within rather an intact and natural land of that region. According to Fig. 2, the research borehole is considered in the Northern Fereshteh area and within silty clayey soils, which is identified by red color (Alizadeh *et al.* 2018, Trung *et al.* 2019). The borehole location on the geological reference map is presented in Fig. 3. In this area, layers have been formed in fine-grained sandy silty clayey soils due to the topography of the area and without any significant compression and consolidation. Unwillingness of some owners and employers to construct deep foundations due to economic issues in a number of projects in Fereshteh area of Tabriz as well as the manipulation of legal stipulations as a result of disobeying the opinions of design engineers, supervisors, and executors has led to unallowable settlements. Likewise, infiltration of surface waters and precipitation in the area are resulted in water accumulation under the foundations and the saturation of the mentioned layers (The water level is less than 2 meters deep). Hence, a result of an indiscriminate construction of foundations and ignorance of the geotechnical status of these layers in the foundation design, some of these structures have titled.

In this project, the locations of the boreholes in the land under study are shown in Fig. 4. During drilling, samples were taken for examination and laboratory tests. After analyzing the obtained data, we determined the bearing capacity of the soil is determined, and then, prepared the present report.

A borehole with a depth of 15 m and another one with a depth of 1 meter were drilled using machine drilling and hand digging in the studied land. During drilling and in-situ tests, the samples were taken from different depths, packed appropriately, and transferred to a lab for various physical and mechanical tests. In Fig. 5, sample images are shown.

According to the drilled borehole log and the state of the layers (Table 2), it is stated that in the soil of the under-study region (Table 3), the top soil was observed with a thickness of about 0.5 m. Under the disturbed soil up to a depth of 5 meters, a fine-grained layer with sand grains

Table 2 Soil properties

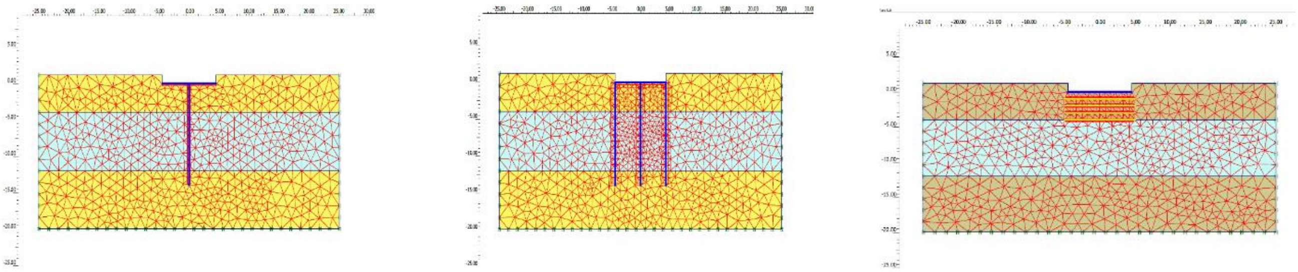
Type of soil layer	Soil sampling	Depth of layer (m)	Es (kN/m^2)	Constitutive model	γ_s (kN/m^2)	PI (%)	C (kN/m^2)	C_u (kN/m^2)	ϕ (°)	Mv (kN/m^2)	ν
CL	undisturbed	4.5	20000	Mohr-coulomb	18.1	12	7	30	24	1.25	0.30
CL	undisturbed	8	10000	Mohr-coulomb	16.6	8	10	30	18	0.9	0.35
CL	undisturbed	2	10000	Mohr-coulomb	18	14	7	10	24	1.25	0.30

Table 3 Concrete wall properties

EA (kN/m^2)	EI (kN/m^2/m)	L (m)	B (m)	d (m)	W (kN/m^2)
18×108	107×15	9	1	1	7

Table 4 Geogrid properties

EA (kN/m^2)	Material Type	L (m)
104	Linear Elastic	10



(a) Single pile (b) Group pile (c) Geogrid

Fig. 10 Modeling for six-floor structure with (a)-(c) in different layers and lengths

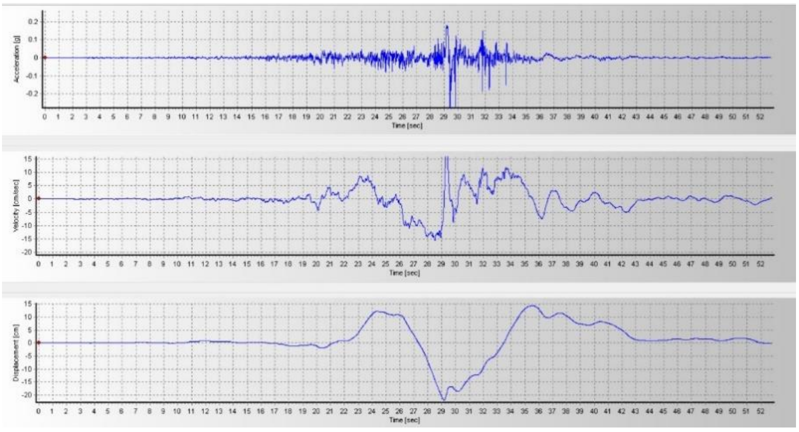


Fig. 11 Corrected accelerograph of Jiji (Taiwan) earthquake

and a relatively suitable compaction was observed. From the depth of 5 to 13 meters, brown-red sandy fine-grained soil, which is very loose, was found to be the dominant soil layer. From the level of 13 meters to the end of the borehole (depth of 15 meters), silty clay was found with a high relative compaction, and the water level was observed at a depth of 10 meters with respect to previous drilling experiments.

The characteristics of the studied property are summarized in Table 1. Fig. 6 illustrates the graph of SPT (Standard Penetration Test) values based on borehole information. According to the Fig. 6, despite SPT values is increased up to the depth of 2 m, this value is plummeted at the depths of 2 to 26 m. Hence, based on the same data, numbers of N_1 = 8 for loose soil layer (for depths between 5 to 13 m) and N_1 = 35 for the underlying layer (at the depth of 26 m) can be cautiously considered as average SPT value. Atterberg test was performed on disturbed soil samples according to ASTM-D4318. The average Liquid limit (LL) was almost in the range of 16 to 27, and the plastic limit (PL) was ranged from 8 to 14. Therefore, the plasticity index equaled to PI = 12 (Fig. 12).

Due to the fact that the structures of the Northern Fereshteh area (Figs. 12-13) have been susceptible to consolidation settlement in recent years, in the present project, a precast concrete pile with a circle section in-situ,

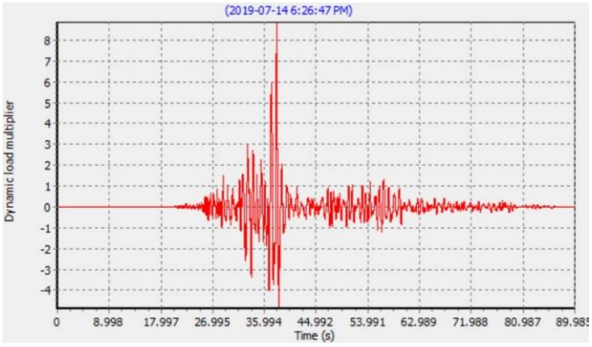
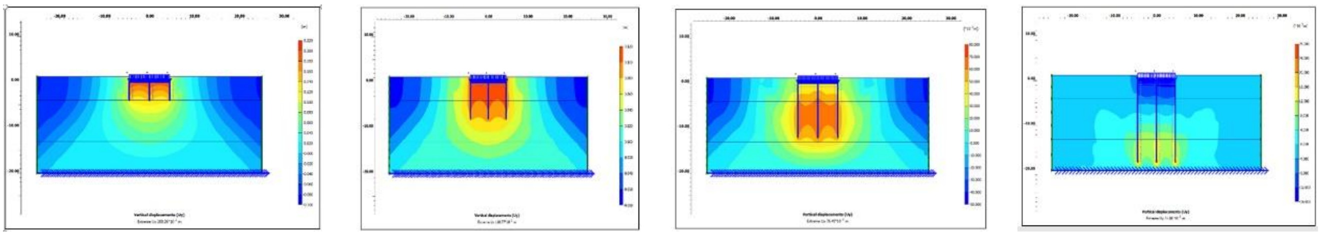
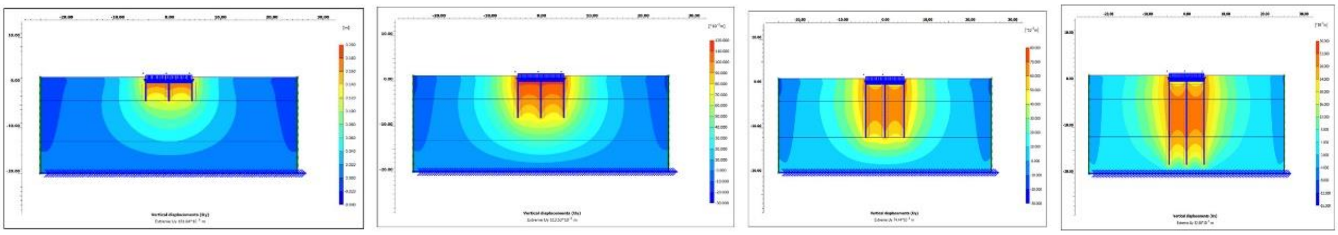


Fig. 12 Accelerograph record



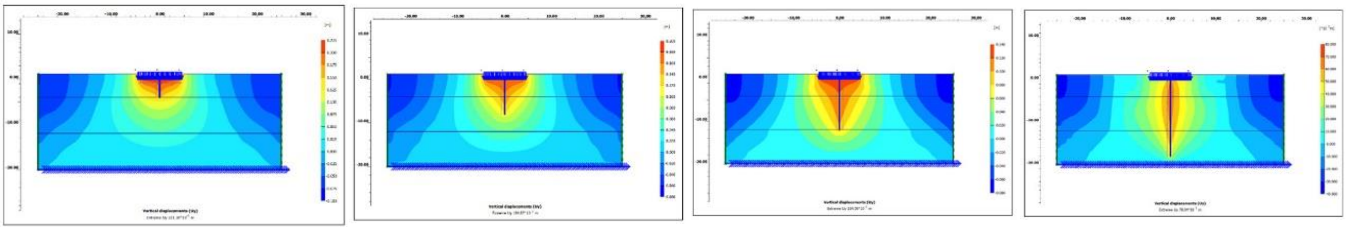
(a) 4 m (b) 8 m (c) 12 m (d) 18 m

Fig. 13 The settlement of the six-floor structure in the presence of a raft foundation based on pile group with a diameter of 0.8 meter after application of the seismic load



(a) 4 m (b) 8 m (c) 12 m (d) 18 m

Fig. 14 The settlement of the six-floor structure in the presence of a raft foundation based on pile group with a diameter of 1 meter after application of the seismic load

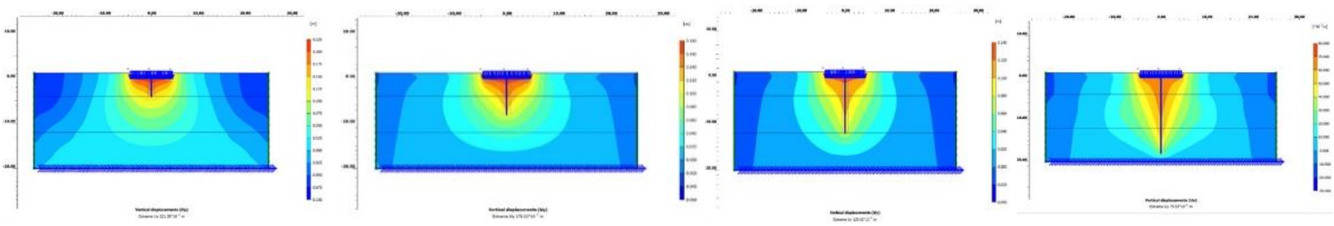


(a) 4 m (b) 8 m (c) 12 m (d) 18 m

Fig. 15 The settlement of six-floor structure in the presence of raft foundation based on a single pile with a diameter of 0.8 m after the application of seismic load

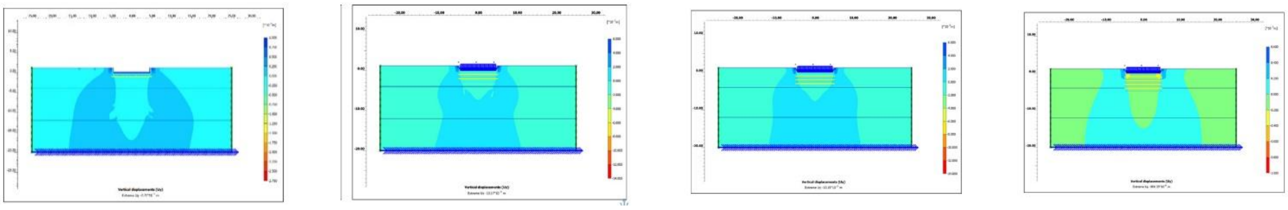
the length of 14 meters, the capacity of 39 tons, and a diameter of 0.8 meters was used to stabilize the corresponding structure. This type of pile was selected in accordance with the dead and live loads. Fig. 8 indicates the effect of three states on consolidation settlement during the 21s of the earthquake in the geotechnical model. Thus, the comparison of the consolidation settlement of a load in: the single pile foundation (Fig. 8(a)), in the presence of the geogrid (Fig. 8(b)), and the pile group foundation (Fig. 8(c)) was finalized via altering the level of the groundwater and the length and diameter of the pile (Figs.13-17).

Based on the results of field and laboratory tests and engineering judgment, the geotechnical parameters were estimated as follows and used in the following calculations. In this paper, the mechanism of clay soil failure under a deep foundation (single and group pile) was investigated in the presence of reinforcing materials such as geogrid. In the following sections, a terse description of the utilized geogrid in modeling and numerical analysis is provided. Owing to the fact that geogrid is widely used for reinforcing the soil, its properties such apertures with suitable dimensions for fixing and fastening to the surrounding soil



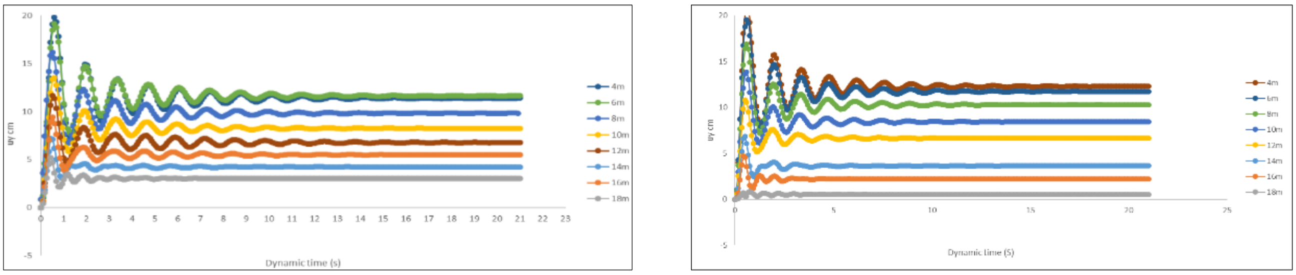
(a) 4 m (b) 8 m (c) 12 m (d) 18 m

Fig. 16 The settlement of six-floor structure in the presence of raft foundation based on a single pile with a diameter of 1 m after the application of seismic load



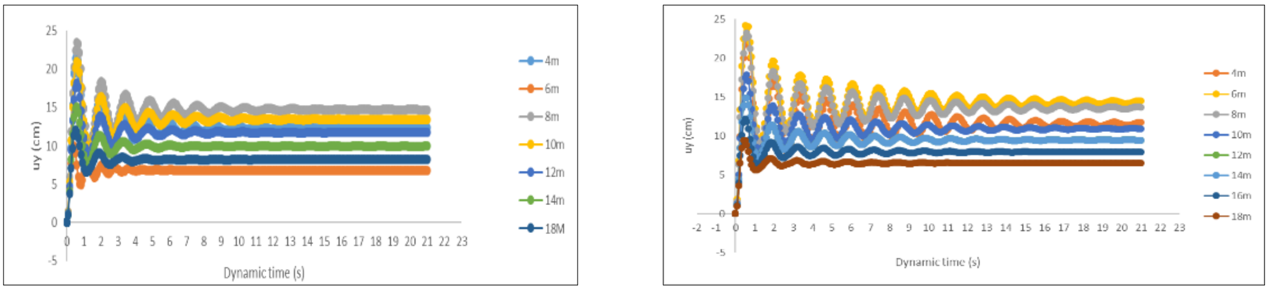
(a) One layer (b) Two layers (c) Three layers (d) four layers

Fig. 17 The settlement of six-floor structure in the presence of geogrid after the application of seismic load



(a) 0.8 m (b) 1 m

Fig. 18 Dynamic Time-Settlement graph, the effect of the length of the pile group with diameters of (a)-(b) under seismic load for 21 seconds



(a) 0.8 m (b) 1 m

Fig. 19 Dynamic Time-Settlement graph, the effect of single pile length with diameters of (a)-(b) under seismic load for 21 seconds

can play a reinforcing role in settleable soils. The geogrid is used to examine its effect on increasing or decreasing soil consolidation settlement in Northern Fereshteh, which was modeled as a uniaxial type in PLAXIS software (Fig. 9). In order to improve the foundation, geogrid in the distance range of 0.33 to approximately 0.7 times width under the foundation to achieve better results is used. In other words, if we denote the distance of geogrid from the bottom of foundation with D and the width of the foundationwith W, we observe the best performance for the geogrid when the D/W ratio is between 0.33 and 0.4 (Figs. 18-20).

3. Numerical modeling

Empirical tests have always been like a barrier in front of the new ideas due to its hardships such as time-consuming process and costly apparatuses. However, employing intelligence solutions is one of the practical ways to address these issues. Whereas, artificial intelligence techniques have performed on a variety of experimental studies and proved to be reliable not only in case of parameters estimation but also the prediction of crucial design characteristics (Tables 6-7) (Sinaei *et al.* 2012,

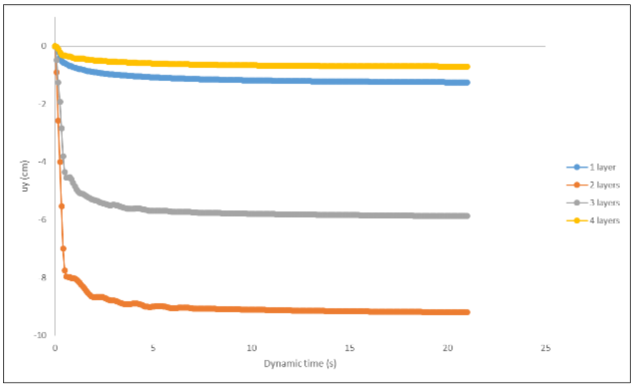


Fig. 20 Dynamic Time-Settlement graph, the effect of geogrid layering on soil settlement over a period of 21 seconds

Table 6 Seismic analysis of six-floor structures in dynamic duration of 21 seconds based on the variables of length and diameter of pile group

	Diameter (m)	Length (m)	Settlement (cm)	Status of the settlement regulations
Pile groups	0.8	4	20	Unallowable
		6	15.2	
		8	11.8	
		10	9.5	
		12	7.6	
		14	5.9	Allowable
		16	4.7	
		18	2.4	
	1	4	18.1	Unallowable
		6	14.2	
		8	11.3	
		10	9.2	
		12	7.4	
		14	5.9	Allowable
		16	4.5	
		18	3.2	

Chuanhua Xu 2019, Shariati *et al.* 2019a, Shariati *et al.* 2019b, Trung *et al.* 2019). Different kind of algorithms has introduced which have their traits and advantages (Shariati *et al.* 2019c). Using the relevant algorithms in order to analytical assessment has been carried out on different types of studies (Mohammadhassani *et al.* 2013a, Mohammadhassani *et al.* 2014, Toghroli *et al.* 2014, Shah *et al.* 2015, Safa *et al.* 2016, Shahabi *et al.* 2016, Shariati *et al.* 2016, Khorami *et al.* 2017, Khorramian *et al.* 2017, Chahnasir Sadeghipour *et al.* 2018, Sedghi *et al.* 2018, Shariat *et al.* 2018, Toghroli *et al.* 2018b, Katebi *et al.* 2019, Luo *et al.* 2019, Mansouri *et al.* 2019, Milovancevic *et al.* 2019, Shariati *et al.* 2019a, Shariati *et al.* 2019b, Suhatril *et al.* 2019, Trung *et al.* 2019, Xu *et al.* 2019). That being the case, performing the artificial intelligence algorithms is a potential method to avoid non-linearity and sophisticated

Table 7 Seismic analysis of six-floor structures in dynamic duration of 21 seconds based on the variables of length and diameter of single pile

	Diameter (m)	Length (m)	Settlement (cm)	Status of the settlement regulations
Single pile	0.8	4	18.8	Unallowable
		6	17.2	
		8	15.3	
		10	12	
		12	13	
		14	11	
		16	9.6	
		18	7.8	
	1	4	20	Allowable
		6	17.1	
		8	14.1	
		10	12.5	
		12	10.8	
		14	9.1	
		16	8.3	
		18	7.5	

analysis of the nanoscale problems. Due to the expansion of numerical studies in the field of engineering, today, most of the complex analyses are carried out using statistical software. For this reason, defining an appropriate constitutional model for the materials considered in numerical analysis is

extremely important. In homogeneous objects, the failure is independent of the loading, and therefore, the conditions of failure can be defined based on the inelasticity of the stress tensor. The Von Mises and Tresca's failure mechanism are obtained assuming that the material resistance is independent of the hydrostatic stress. While the behavior of most geological porous media is different from metals, their resistance depends on hydrostatic stress. In drained condition, soil resistance often increases when average pressure rises, and frictional characteristics are more noticeable. Accordingly, based on the results of the studies, in the presented paper, the Mohr-Coulomb Theory is considered for soil compositions. According to Fig. 10, the selected model is considered to be minuscule in order to increase the accuracy of meshing computing in all areas. The meshing of the model is considered to be four times more than the width of the foundation vertically and nine times more than the width of the foundation laterally, which is appropriately consistent with the recommendations of the previous researchers. Finally, the model has a depth of 20 meters and width of 25 meters. Similarly, because of the height of the groundwater level at a depth of 10 meters, the soil behavior is in the drained condition. Since the homogeneous clayey soils are practically impermeable, the permeability coefficient k_z for the region selected in this paper is considered to be $<10^{-7}$(Budhu, 2010). In addition, the properties of soil layers and concrete wall and utilized geogrid in the software are indicated in Tables 2-4. Fifty-two numerical two-dimensional models were formulated using static analysis based on Mohr-Coulomb constitutional model. The settlement of the soil in the study area was compared in three conditions, considering the length of a single concrete pile with a circular cross section of 0.8 m in the first state with the involvement of the parameter of height and diameter of 1 m, in the second state with the concrete pile group, taking into account the length and diameter of the pile group and in the third state, only with the presence of four layers of geogrid. The distributed load of 120 kN/m^2 which equals to a six-floor structure was applied on a deep foundation. Fig. 10 shows a sample of meshed models of single concrete piles with the diameter of 0.8 meters. In dynamic and static analyses, constant boundary conditions cannot be assumed. In determining the dimensions of the model in dynamic analyses, in which the soil environment is also part of the studied system, the important problem is the energy return of the waves generated by the seismic load (Prakash, 2014). There are various methods for solving this problem. The simplest method is to use a larger model in which the boundaries of the model are suitably far away from the field near the structure; therefore, zero stress conditions can be created at the boundary. This method is not practical for all cases due to a high rate of computing time and the need for an accurate processor. Other methods use viscous damper elements (or the use of absorbed boundary). The corrected accelerograph used in the analysis via the PLAXIS software is indicated in Fig. 11. Regarding the main objective of the study, which is to investigate the effect of the earthquake on the dynamic response of the pile group, the single pile, and the geogrid, a regional station was selected to record the earthquake, which possessed a shear wave velocity similar to the soil used in the analysis.

In the present article, because of the construction of the foundation and the structure is sequential, stress analysis for sequential construction has been used and the stages of model analysis are as follows:

1- Activation of soil layers and definition of groundwater level. In this stages, the displacement due to the soil weight is considered to be zero.

2- Activation of single pile foundation, pile group and geogrids, and interaction between soil and foundation system.

3- Construction of the building floors and loading application in separate phases.

4- Application of the horizontal component of the earthquake dynamic load based on accelerograph of the Jiji Taiwan earthquake.

Figs. 13-14 reveal that results of a seismic analysis of foundation based on a pile group with diameters of 0.8 and 1 meter and with different lengths of 4, 8, 12, and 18 m for settlement during 21 second earthquake.

Figs. 15-16 illustrate the results of seismic analysis of the foundation based on a single pile with diameters of 0.8 and 1 m different lengths of 4, 8, 12, and 18 for vertical settlement during 21 seconds of earthquake.

By examining the results of the settlement for foundations located on different soil types, it can be concluded that if the intrinsic parameters of soil such as cohesion and friction angle remain constant, there will be a significant decrease in the settlement of the foundation against the earthquake loads. This occurs through an increment in the diameter and the length of the pile group. This fact illustrates that the construction of a single pile in the Northern Fereshteh area is not only ineffective but also is unallowable according to the seventh part of the National Building Code of Iran (2013). Therefore, the construction of a single pile is not recommended. Moreover, according to the results, it can be posited that the construction of four geogrids with length of 10 meters under the foundation at intervals of 1 meter would significantly reduce soil settlement during the earthquake. Hence, after the application of earthquake load for 21 seconds, the foundation will reach a maximum of 1.21 cm. Tables 6-7 indicate the settlement under the earthquake force in the condition of using a single pile and pile group in different modeling states. Based on the building codes, in case of using a pile group, an unallowable settled state of the structure will almost change to allow for all models.

4. Conclusions

In the present study, after examining 54 models and the effects of four parameters including length, diameter, depth of groundwater, and number of geogrid layers under the foundation, we specified the increasing or decreasing trend of consolidation settlement perpendicular to the foundation application is identified during 21 seconds of seismic load application. The performances of pile-raft foundation with reinforced soils and geogrid under the same geotechnical conditions as well as the effects of piles with different lengths and diameters on the pile foundation system (to achieve an optimal design) are the main issues to be addressed in this chapter.

• Construction of a concrete pile group instead of a single pile in the Northern Fereshteh area is recommended due to the weakness of its soil.

• Minimum optimal length to prevent an unallowable settlement in constructing a concrete pile group is 14 meters, and the diameter should be 1 meter.

• The results indicate that the increase or decrease in the parameters of c and f as well as the groundwater level in the foundation based on the single pile and the pile group will not affect the consolidation settlement.

• The construction of a single concrete pile either long or short does not have any significant effect on reducing the settlement during earthquake. Therefore, its installation is not recommended.

• Based on the results, it can be concluded that a large amount of foundation settlement occurs under initial earthquake. Then, as a result of the reoccurrence of earthquakes, the amount of settlement increases. However, the settlement level is not as high as the one in initial earthquake.

• Construction of four geogrids with the length of 10 meters under foundation at intervals of 1 meter will also have an acceptable effect on reducing the soil settlement during earthquake. Thus, the settlement will have a 0.98 cm decrease in its level.

In order to prevent possible future damages, it is recommended to avoid shallow settlements for all structures in Northern Fereshteh area in Tabriz city. This is due to the fact that the soil in this area is loose and is likely to experience settlement, especially during an earthquake.

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