Nexo Revista Científica
Vol. 36, No. 02, pp. 188-198/Marzo 2023

ISSN-E 1995-9516
Universidad Nacional de Ingeniería

http://revistas.uni.edu.ni/index.php/Nexo
https://doi.org/10.5377/nexo.v36i02.16061

Numerical Modeling of Retaining Piles and Comparison of Results with Theoretical Relations

Modelado Numérico de Pilotes de Retención y Comparación de Resultados con Relaciones Teóricas

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(recibido/received: 28-noviembre-2022; aceptado/accepted: 26-enero-2023)

ABSTRACT

In this research, the retaining structure of the project, which was implemented as a pile, was investigated. To investigate this research, the models were modeled in ABAQUS software and statically loaded. After analyzing the above mentioned retaining structure with the modeling soil, it is shown that, increasing the distance between the piles causes to increase the tensions and strains in the soil between them and results in more critical soil. It is also observed that the amount of tension and its distribution in the piles at a time when their distances are less is more than that of their distance between them was increased. Also, the comparison of numerical results with the results of theoretical relations indicates that the numerical values are greater than the values obtained from the theoretical relations.

Keywords: Pile, Soil, Numerical analysis, Retaining Structure.

RESUMEN

En esta investigación se investigó la estructura de contención del proyecto, que se implementó como un pilote. Para investigar esta investigación, los modelos fueron modelados en el software ABAQUS y cargados estáticamente. Después de analizar la estructura de contención mencionada anteriormente con el suelo de modelado, se muestra que, al aumentar la distancia entre los pilotes, se incrementan las tensiones y deformaciones en el suelo entre ellos y se obtiene un suelo más crítico. También se observa que la cantidad de tensión y su distribución en los pilotes en el momento en que sus distancias son menores es mayor que la de su distancia entre ellos se incrementó. Asimismo, la comparación de los resultados numéricos con los resultados de las relaciones teóricas indica que los valores numéricos son mayores que los valores obtenidos a partir de las relaciones teóricas.

Palabras Clave: Pilote, Suelo, Análisis Numérico, Estructura de Contención.

1. INTRODUCCION

One of the common ways to retain and protect the shells with varied conditions, including hard to soft grounds, is to use in-situ piles, which are often used as temporary or permanent retaining walls by economic analysis.

Nowadays, with the development of deep excavations in urban areas and a variety of methods for retaining and stabilizing excavations, the time of the analysis of operations and possible costs for the project and the selection of the most appropriate method of work is one of the most important decision-making issues in the projects. Two-dimensional, three-dimensional models and exact theoretical methods can be used in numerical studies of retaining piles.

The MiarMiar project of Tabriz is one of the oldest and most important projects under construction in the city of Tabriz. The project is located in the city center and its trade section, and the project environment is full of old buildings and urban decay. Due to the deep excavation needed for the construction of the project, it is necessary to provide an economical, as well as optimal, and safe, layout for excavation retaining system.

In this research, due to the fact that a retaining pile will be used temporarily for the excavation retaining system in a part of the project, the economic review and optimization of the retaining piles design will be necessary, so that, discussion about the applied tensions to the retaining pile system will be performed with two-dimensional, three-dimensional modeling and exact solution of the problem with theoretical relations, and the optimal analysis of this type of retaining system will be presented.

In order to analyze the system of soil and structure in the substructure method, it is first necessary to determine the force-displacement relation for some points of the soil environment, which are located on the foundation and the soil interface, which leads to the determination of the dynamic stiffness of the soil environment. For precise determination of the dynamic stiffness of the viscoelastic and infinite soil environment, numerical methods including boundary element method or a combination of them can be used.

Due to the complexity and timing of these methods, their use is justified only in large projects. In other cases, an approximate method is used to determine the dynamic properties of the soil infinite environment. Nateghi et.al. (2006) relations which are proposed for the foundations located on the surface of a homogeneous half-infinite soil, and cone models (Ramirez et.al, 2003) which are proposed for surface and buried foundations in the soil, are among the approximate methods, which are widely used in the estimation of the dynamic stiffness of the soil environment. Since approximate methods are widely studied in soil and structure interaction problems, we will look at the details of each of them in the following.

2- LITERATURE REVIEW

Excavation is carried out in areas where all or part of the building is constructed below the natural ground surface, which may sometimes the depths reach up to several meters according to the earth's material (Olapoor and Salighezadeh, 2012). Excavations are generally divided into two groups, protected or braced, unprotected or unbraced. Existing dangers in excavation include, falling the walls and debris, suffocation due to lack of oxygen, dangers from collisions with underground installations, poisoning from toxic gases, falling from height. The main objectives of the safety making of excavation are to preserve the life of people inside and outside of the excavation, inside and outside properties and providing safe and secure conditions for the work (Ashrafi, 2007). On the other hand, it is a very important issue to provide a preliminary plan for the protection of excavation. Important points to be considered in this regard are: type of soil and its classification, internal friction angle, soil adhesion, swelling due to watering and shrinkage due to water loss, examination of the presence of additional substances in soil such as gypsum or salt, the amount of water that can saturate the soil, the existing overhead load beside the excavation, the soil type, the status of water penetration, the topography, The slope of the excavation crust and so on. Most soils are stable for a long time after excavation, but gradually their sustainability is reduced (Olapoor and Salighezadeh, 2012).

This phenomenon has several reasons, including the gradual deformation caused by the removal of created lateral retainer, which, after a while, causes it to slip and slide. In high wet clay soils, soil dryness may be accompanied with shrinkage cracks and leads to the creation of gaps inside the soil which causes to the sustainability weakness. In dry clay soils, the increase in moisture can cause soil loss and falling, in clean sandy soils and without clay, a slight vibration that occurs through the inside or outside of the excavation due to the machinery passing, causes to the creation of cracks and leads to water penetration inside them.

In order to protect the excavation, in-situ pile due to unlimited diameter and depth of the excavation has the highest application and is used as the best option in the following cases; in cases where there is no possibility of a shield, or the stiffness and density of the earth are too strong than shielding power, in the event that there is a need for the sealing of crust due to the presence of groundwater and the high level of surface water, in cases where there is no possibility of the creation of lateral retainers (tensile) under adjacent buildings due to the excavation, in the cases where there is a confluence with urban infrastructure and structures Underground such as tunnels, and in the cases where it is possible to use the excavation protection system as a part of main structure and load-bearing member. The advantages of this method include the absence of a limitation of the diameter, the possibility of an increase in the section of the piles at the section end and the increase in the load capacity, easier preparation of drilling machines than piling, suitable for use in urban environments due to less noise and completeness of studies and identification of soil during the drilling.

Studies on stabilization in cast in-situ pile method have implications for both the protection of the deep excavation wall and slope stability. In the most of the internal and external studies on the pile retaining wall, the ground lateral pressure has been studied on the deformation of the wall, and its bending effect has been studied and evaluated, and there are few studies of the impact of the earthquake on these walls. Watson and Carder investigated the pile retaining wall executed in a hard clay soil in a state in the United States. The wall was monitored during construction, and the parameters of ground displacement, lateral tension, and pore water pressure are monitored. Then, the results of the monitoring were compared with the numerical analysis of the finite element method and the Mohr-Coulomb behavioral model and a good fitness was obtained between the results of the monitoring and the numerical results (Goh, 2010 and Watson, 1994).

Teparaksa (2011) and Wen et.al. (2001) compared the monitoring results of the pile retaining wall constructed along the river bank to construct a large medical building with numerical modeling analyzes. The results of the monitoring with the results of the software output are well-matched. This study indicates the effectiveness of using the numerical analysis to construct calculations and predict the results of the pile retaining walls in the construction projects. Olipour and Salighehzadeh (2012) in a research, studied the methods of excavation protection such as in-situ piles, diaphragm walls, Nailing and truss for two metro stations in Ahvaz using the 2008 price list from the management view.

In this research, due to having the implementation time and cost of the methods and considering the conditions of the soil bed such as the level of groundwater, the implementation method of the in-situ pile compared to the diaphragm wall and nailing is more economical and easier to run (Wen et.al. 2001). Kiani and Shekari studied the genetic modeling of the maximum shear force of continuous concrete retaining piles under the influence of lateral load in the coarse-grained soil. In this study, the genetic algorithm was used for evolution of models for predicting maximum shear force of piles, which is one of the most important parameters for designing a pile retaining structure. Input parameters include the modulus of elasticity, the specific weight and the internal friction of the soil, the center-to-center distance of the piles, and the depth and length of the excavation and the output parameter is the maximum shear force of the piles (Wen et.al. 2001).

3- PROBLEM EXPRESSION AND MODELING

3-1- Elements used in ABAQUS

For the modeling of soil and concrete with regard to the two-dimensional foundation and the soil environment, in this thesis, a four-node two-dimensional element (CPE4R) was used. The advantage of the two-dimensional elements is that they can be meshed in any arbitrary form. In this element, plain strain is used to solve the problem. Also, in this element, the reduced integral method is used.

3-2 Soil environment modeling

In homologous objects, the current is independent of the loading direction, and therefore the conditions of current can be defined based on the unchangeability of tension tensor. Von Mises and Treseca failure criterion are obtained with the assumption that the material resistance is independent of the hydrostatic tension. This assumption is true for materials without internal friction such as metals, although the behavior of most porous geological environments is different from metals and their resistance is dependent on hydrostatic tension. Under drained conditions, soil resistance often increases with increased average pressure and frictional properties. Herein, according to the results of the studies, Mohr-Coulomb theory has been considered for soil materials.

Table 1. Specifications of the soils used in analysis

Material	ρ ($^{Kg}/_{m^3}$)	E (Mpa)	υ	C ($^{KN}/_{m^2}$)	φ (Degree)	ψ (Degree)
Siltty Clay	1700	21	0.45	17	30	0

3-3- Geometric properties of soil environment

Due to the growing extension of numerical studies in the field of engineering, today the most of the complex analysis is done by numerical software. ABAQUS is one of the most powerful softwares for numerical simulation of many issues with graphical environment and modeling and analyzing in separate stages. In dynamic analysis, such as static analyzes, the use of constant boundary conditions is not impossible. In the dimension determinations of a model in dynamic analysis, the important problem is the return energy of the waves generated by the earthquake load. To solve this problem, there are various methods in which the easiest way is to use a larger model, with the boundaries of the model far enough away from the field near the structure, to create zero tension conditions at the boundary. Due to much computational time and the need for a robust processor, this method cannot be used in the all cases. Other methods are the use of a viscous damper element or absorbent boundary.

3-4- Soil environment meshing

In order to correct transmit the wave with the given frequency 10 knots per wavelength λ are required. Using less than 10 nodes can cause numerical damping, as the discontinuity of the problem causes loss of distinct peaks from the wave. In order to determine the maximum meshing distance, the maximum frequency associated with the model should be obtained performing Fourier analysis of the inertial motion, which is usually about 10 in seismic analyzes.

3-5- Modeling of piles

The purpose of this study is to investigate the effect of the distance among the piles group and its impact on the seismic behavior of the soil system and the retaining pile. The dimensions of the foundation are selected according to the size of the excavation, so, for 10 meters in length of the piles, 80 cm in diameter is considered. The pile is concrete and is modeled using 8-node Solid element. In this study, the behavior of concrete materials for the foundation is considered linear elastic. The distance among the piles is from the side to the side of the pile and is equal to 0, 30, 50, 75 and 100 meters. The properties of concrete materials of foundation and pile group are presented in the table below according to the properties of materials presented by Shahroor.

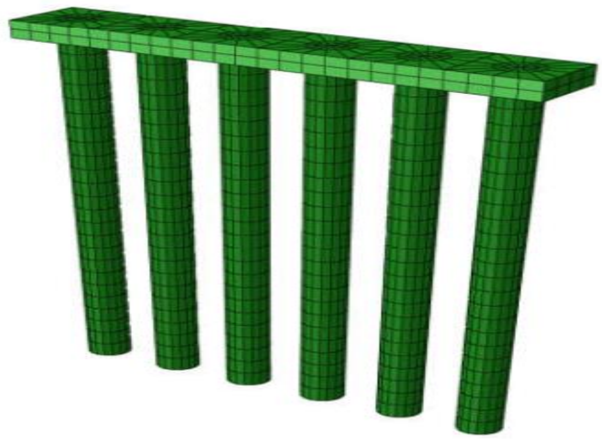


Figure 1. Three-dimensional model of pile group

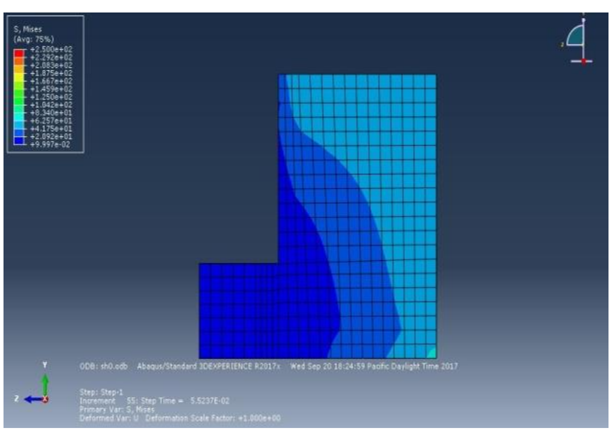
Table 2. Mechanical properties of concrete material for foundation

Material	(kg/m^3)ρ	E(kg/cm^2)	υ	Ref
concrete	2500	20e4	0.2	Shahrour, 2012

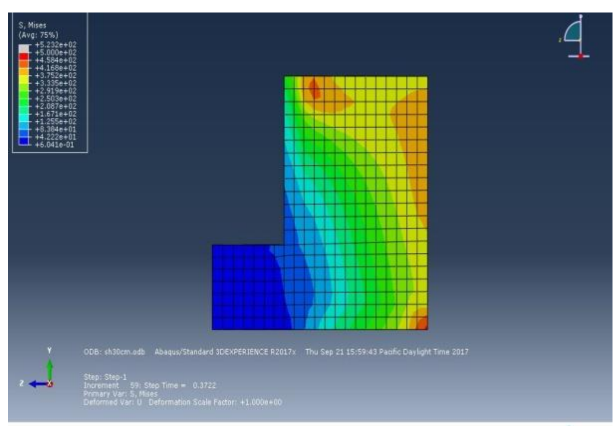
4- RESULT DISCUSSION

4-1- Investigation of soil tension

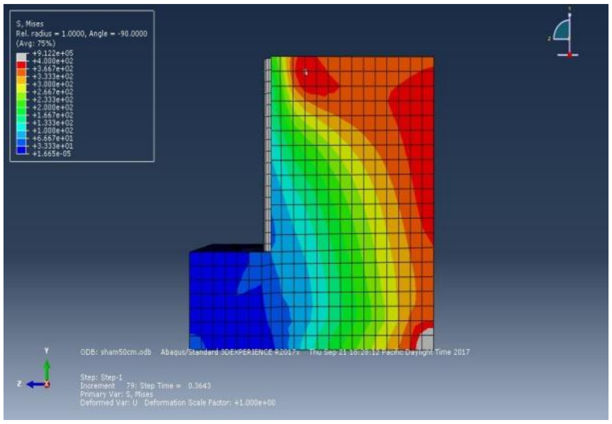
In the retaining piles, because the soil, between them resists against lateral loads, so they also cause significant tension. For this purpose, the amount of tension in the soil was investigated. In this research, the distances among the piles are 0, 0.3, 0.5, 0.75 and 1 meter. Therefore, at all distances, the distribution of tension in the soil was investigated. The results are presented in Fig. 2.



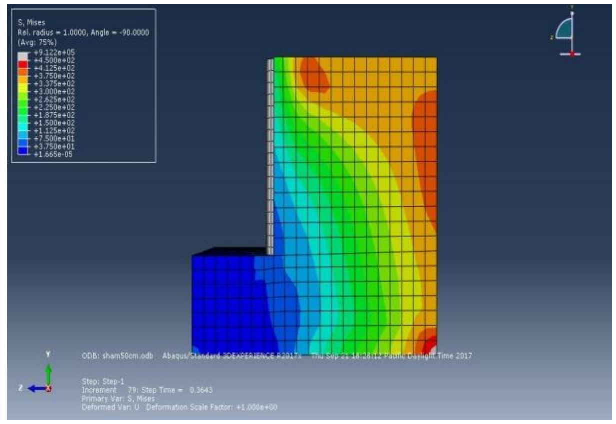
Pile distance is 0 cm



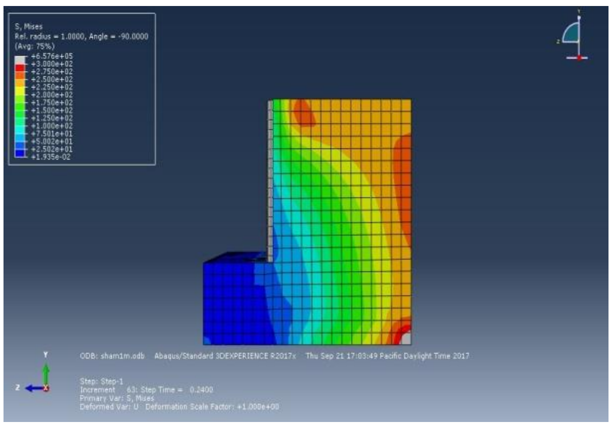
Pile distance is 30 cm



Pile distance is 50 cm



Pile distance is 75 cm



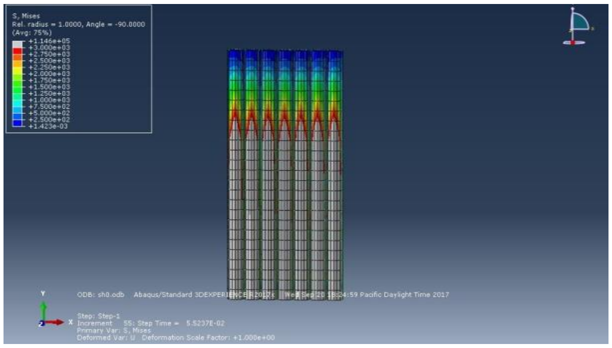
Pile distance is 100 cm

Figure 2. Tension distribution in soil

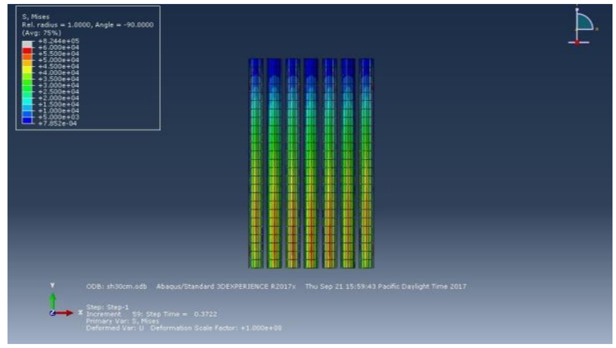
As it was observed, the amount of tension on the soil among the piles was significant. The results indicate that the tension level on the ground is more than the other parts. Therefore, it can be said that at lower depths, the amount of tension in the soil is less than the Earth's surface, and the instability of the soil under static loading on the ground is more than its instability in depth. It is also observed that with the increase in the distance of the piles, the amount of tension in the soil increases, so that when the piles are spaced 1 m apart from each other, the tension is about 8 times as much as the condition in which there is no distance between them. This represents that increasing the distance among the piles increases the probability of instability in soils.

4-2- Investigation of pile tension

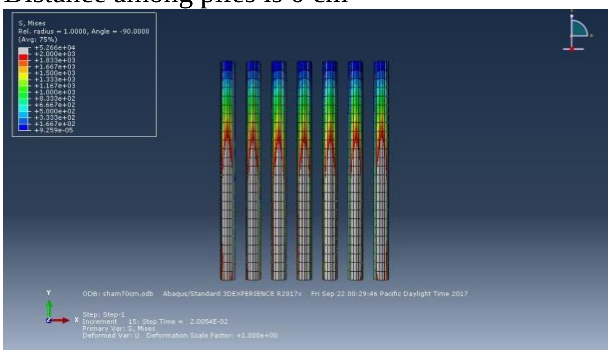
Considering that in this study the distance among the piles were changed in order to evaluate its effect on the stability of the piles, therefore the tension distribution in the piles was evaluated for different distances. The results of the static distribution of the piles are presented in Figures 4-6 to 4-10. It needs to be explained that the distribution of the above tension is based on Von Mises criterion and their values are presented in Fig. 3.



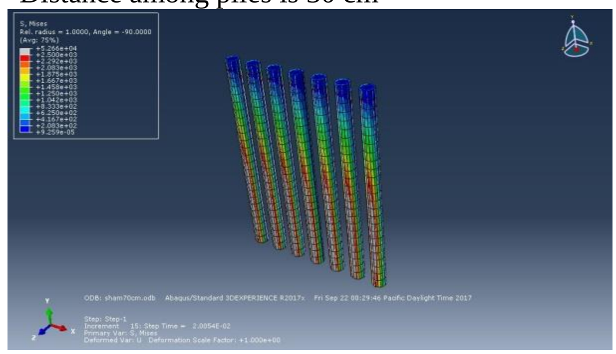
Distance among piles is 0 cm



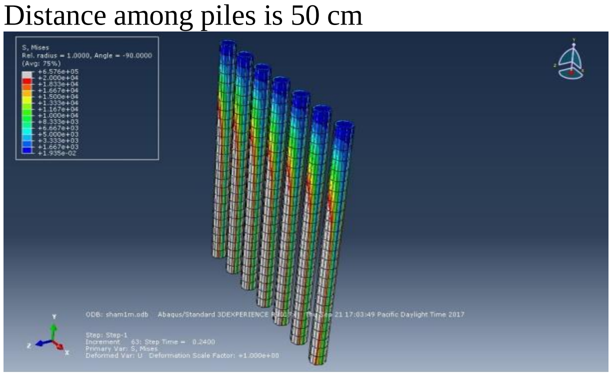
Distance among piles is 30 cm



Distance among piles is 50 cm



Distance among piles is 75 cm



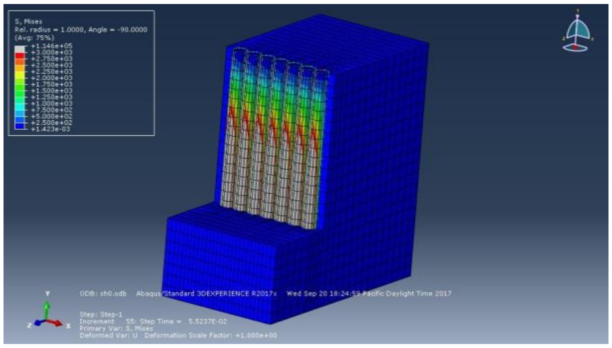
Distance among piles is 100 cm

Figure 3. Tension distribution in piles

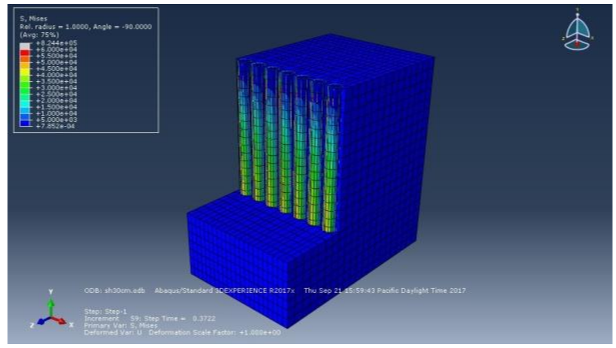
The results indicate that the distribution of tension in the piles in contrast with the soil between them, at the excavation floor is greater than the ground level. This indicates that the pile section on the floor will be damaged more than that of ground level. The numerical results also indicate that with increasing the amount of distance between the piles, the amount of tension in the piles increases considerably. So that when the distance between the piles is 1 meter, the tension at the pile base is about 6.3 times as much as the condition in which there is no distance between them.

4-3- Investigation of the general tension of the pile and soil

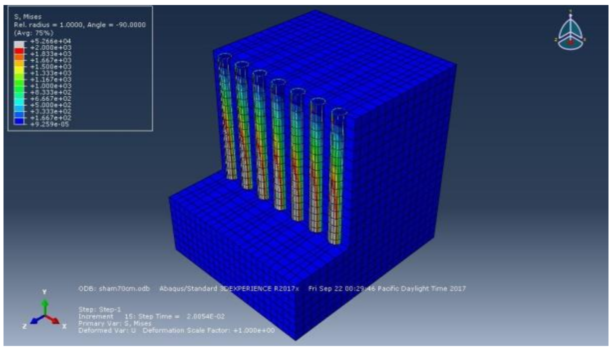
In order to better investigate the distribution of tension in the pile and soil and to compare them with each other, the distribution of tension in the pile and soil is generally combined. Based on the results, we can examine the effect of changes in the distance between the piles on the amount of tension in the pile and soil and compare the numerical values of tension in the soil and the pile at the ground and floor of the excavation. The results are shown in Figure 4.



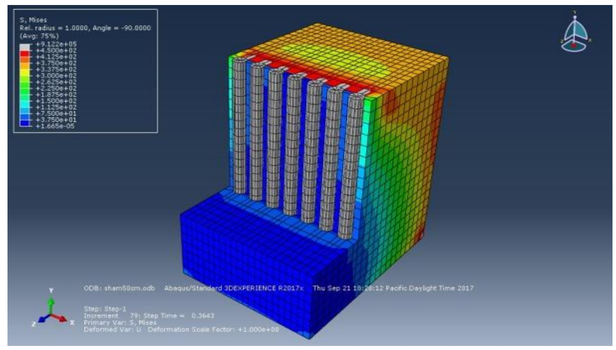
Pile distance is 0 cm



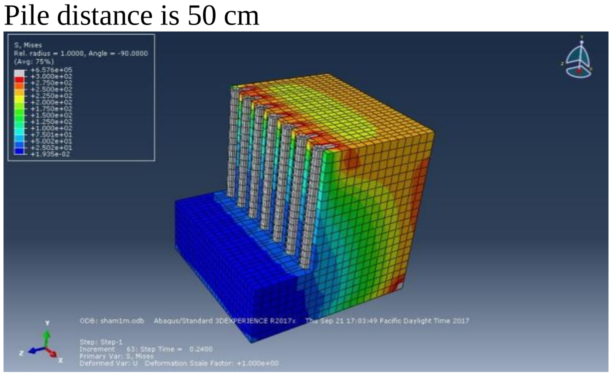
Pile distance is 30 cm



Pile distance is 50 cm



Pile distance is 75 cm



Pile distance is 100 cm

Figure 4. Tension distribution in soil and pile

The figures of the general distribution of tension in the piles and the soil indicate that the amount of tension in the pile is much higher than the amount of tension in the soil between them. Also, the results indicate that the amount of tension on the ground for soil much more and for the piles is less than the amount of tension on the floor. That is, if the soil becomes unstable, the instability is from the surface of the earth, and if the pile becomes unstable, the instability is from the floor. It is also observed that increasing the distance in the pile causes to increase tension in the soils and its effects on the depth of the soil are also observable.

4-4- Investigation of pile lateral displacement

In retaining piles, the amount of lateral displacement of the piles is very significant for controlling its side behavior, and the pile deformation can be evaluated. In this section, the maximum displacement of the piles was investigated for different distances. The result is shown in Fig. 6. It is worth noting that the way of lateral displacement increase of the piles top against the increase in the load pressure on the soil surface is shown.

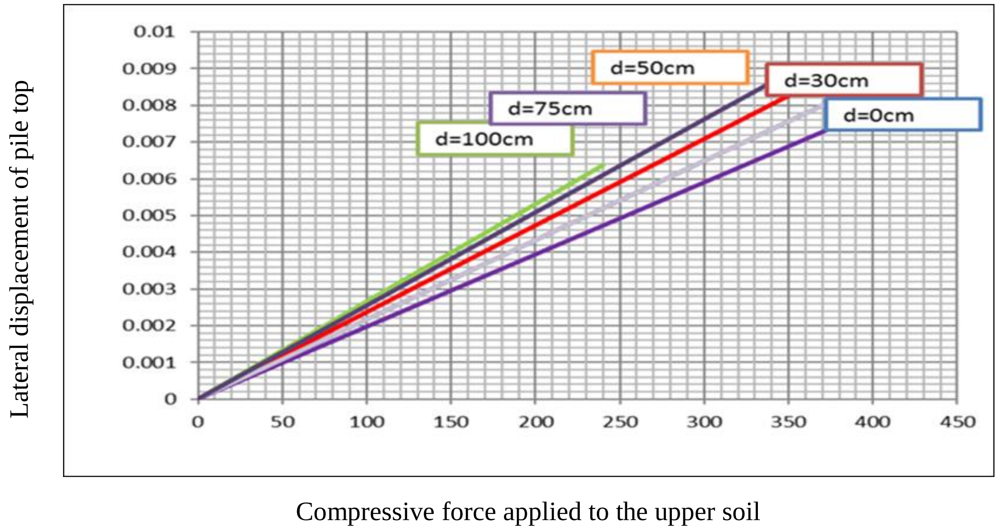


Figure 6. Piles lateral displacement

By evaluating the amount of lateral displacement on the piles, it was observed that, the amount of displacement of the pile top for various distances is different from each other. In a stationary compressive force applied to the soil surface, it is observed that the highest displacement values at the top of the pile are in a state where the distance between the piles is 1 meter. In this case, the displacement is 6.5 mm. The lowest amount of displacement is in the state where the other piles stick together. In this case, the amount of displacement above the pile is 4.9 mm.

4-5- Investigation of base shear and base moment in piles

Considering that the back soil of the pile applying the lateral pressure to the piles creates a flexural and shear behavior in the piles, it is important to examine the base moment and bese shear of the piles on the excavation floor. In this section, the bending moment and shear at the pile section at the floor of the excavation were investigated. The result is shown in Figures 7 to 8 for different pile distances.

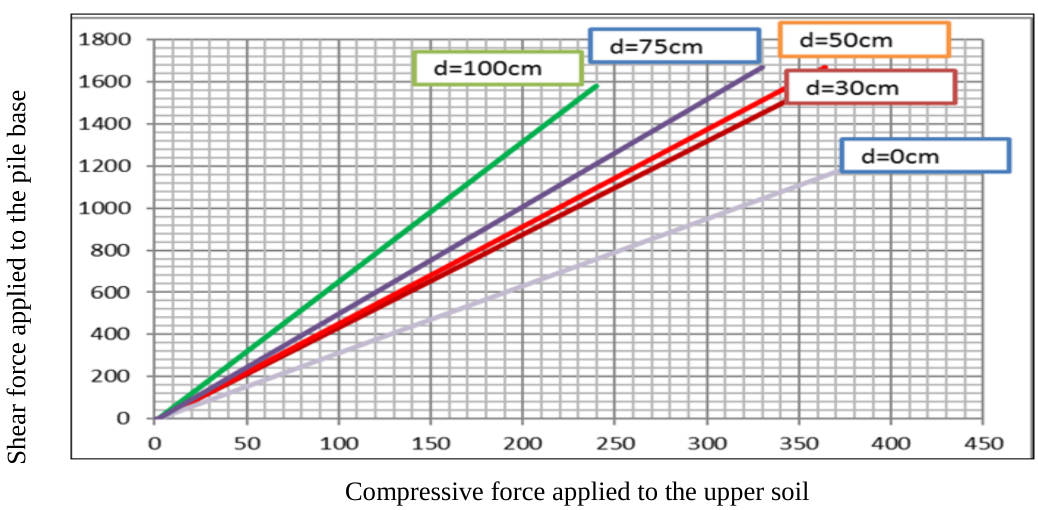


Figure 7. Base shear in piles

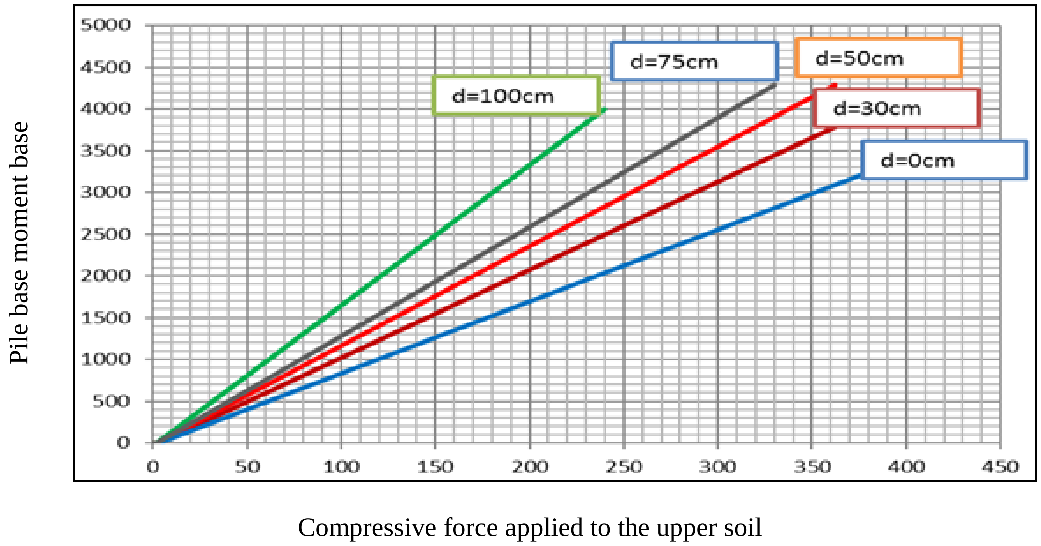


Figure 8. Base moment in piles

The results indicate that, increasing the distance increases the amount of base moment and base shear of the piles. According to the results, it is seen that the amount of pile base shear for 1 m and zero m distances are 1600 kg and 790 kg respectively. Also, the bending moment values for 1 m and zero m distances are 3800 kg / m and 2000 kg /m respectively.

4-6- Investigation of the analysis outputs of the retaining piles with theoretical relations

In this study, the results of the analysis of the response of retaining piles with the theoretical relations toward numerical analysis were investigated. In this study, the piles at different distances are evaluated based on the theoretical relations of the analysis and design of the beams. In order to investigate the theory of piles, the design concepts were used which have many assumptions in the analysis of the piles and retaining structures. In this research, the Terzaghi method was used to apply the lateral load to the pile. The results are shown in Figure 1.

Table 1. Theoretical results of the retaining piles

Pile Distance(meter)	Displacement on Top(meter)
D=0	0.0050
D=0.3	0.0035
D=0.5	0.0025
D=0.75	0.0017
D=1.0	0.0012
Pile Distance(meter)	Moment at Bottom point (Kg.m)
D=0	2752
D=0.3	2915
D=0.5	3102
D=0.75	3243
D=1.0	3426
Pile Distance(meter)	Shear at Bottom point (Kg)
D=0	813
D=0.3	951

D=0.5	1012
D=0.75	1128
D=1.0	1312

5- CONCLUSIONS

By evaluating the results, it is observed that the tension at the foot of the piles is approximately 6 times as much as that of the ground, representing a greater damage to the pile foot than the section near the surface of the earth. Based on the results, it can be said that increasing the distance between the piles in the amount of tension in the piles is very influential.

The results showed that in the case of static loading, the amount of tension on the ground surface for the soil is much higher than the tension in the excavation floor. Therefore, if there is instability in the soil among the piles, it starts from the floor, which is more important and more critical in the case of the distance among the piles is 1 meter than other cases.

The results indicate that the amount of lateral displacement on the top of the piles is more than the other cases for a distance of 1 m. This represents that increasing the distance between the piles increases the lateral displacement of the piles.

It was also observed that, based on the results of the amount of shear force and bending moment in a constant tension applied to the soil surface, increasing the distance increases the amount of shear force and bending moment at the foot of the pile and it can significantly affect on the shear flexural behavior of the pile.

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