

Full Length Research Paper

Using Finite Element method for Pile-Soil Interface (through PLAXIS and ANSYS)

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This study investigated the pile-soil interaction and its effect on the pile settlement and shear stress in the interaction zone. The impact of loading on the pile displacement was explored applying Mohr-Coulomb as well as Hard-soil behavior laws. First, the modeling proposed by the PLAXIS Bulletin (No. 16) was duplicated in which Hard-soil behavior law was taken into consideration. Next, the modeling took place through behavior law. The data were analyzed by PLAXIS. Finally, the results obtained from the two models were compared to each other. Moreover the dynamic analysis was performed to investigate the interface effect between soil and pile through ANSYS software. The results revealed that the variance of velocity at the head or the bottom of the pile does not make a significant difference in the interface coefficient. Finally, the natural frequencies and the mode shape were determined for the pile.

Key words: Pile-soil interaction, PLAXIS, Mohr-coulomb, hard-soil, ANSYS, Finite Element Analysis.

INTRODUCTION

While piles have been used literally for millennia, many aspects of piling are not to this day modeled with much vigor. Pile installation, particularly in the case of driven piles, can not yet be simulated accurately.

Laterally, loaded piles are designed using a semi empirical technique the p-y method- which is used almost universally. The frame work of elasto-plasticity has been usually used for representing the mechanical behavior of interfaces.

Relative movements between bodies in contact are described either by a local high velocity gradient or by a kinematic discontinuity. In both cases, the development of a nonlinear behavior within contact, inducing a very slow rate of convergence of the global solution except for models of thin layers.

Two major kinds of constitutive equations are used for modeling the soil-structure interface behavior, often associated with the Finite Element method. The first one

considers the soil-structure interface as a thin continuum (Desai, 1981; Ghaboussi et al., 1973), thus the thickness of the interface elements should then be specified. In the second approach, the interface zone is replaced by a two-dimensional continuum (Boulon and Jarzebowski, 1991; Gens et al., 1989), subjected to kinematic discontinuities and exhibiting tangential as well as normal displacement jumps. Most interface models were employed in Elastic-plastic form by Boulon, Gens, Desai and Ghaboussi. This paper aims at investigating pile-soil interaction through changing pile-soil interface coefficient and studying this phenomenon for the settlement of pile, shear stress and forces in the pile.

The numerical modeling is going to be carried out by means of the Finite Element method as it allows for modeling complicated nonlinear soil behavior and various interface conditions, with different geometries and soil properties. PLAXIS program will be used, which has a series of advantages:

1. Excess pore pressure: Ability to deal with excess pore-pressure phenomena. Excess pore pressures are

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computed during plastic calculations in undrained soil.

2. Soil-pile interaction: Interfaces can be used to simulate intensely shearing zone in contact with the pile, with values of friction angle and adhesion different to the friction angle and cohesion of the soil.
3. Better insight into soil-structure interaction.
4. Soil model: It can reproduce advanced constitutive soil models for simulation of non-linear behavior.

MODEL ELECTION: SOIL, PILE AND INTERFACE

Linear elastic model

It is the simplest available stress-strain relationship. According to the Hooke law, it only provides two input parameters, that is, Young's modulus E and Poisson's ratio ν . It is not suitable because soil under load behaves strongly in elastically. However, this will be used to model the pile.

Mohr-Coulomb model

It is a perfectly elasto-plastic model of general scope, thus, it has a fixed yield surface. It involves five input parameters, that is, E and ν for soil elasticity, the friction angle ϕ and the cohesion c for soil plasticity, and the angle of dilatancy ψ . It is a good first-order model, reliable to provide us with a trustful first insight into the problem. Mohr-Coulomb model represents a first-order approximation of soil or rock behavior. It is recommended to use this model for a first analysis of the problem considered. For each layer one estimates a constant average stiffness. Due to this constant stiffness, computations tend to be relatively fast and one obtains a first estimate of deformations.

Hardening-soil model

It is an advanced hyperbolic soil model. The main difference with the Mohr-Coulomb model is the stiffness approach. Here, the soil is described much more accurately by using three different input stiffnesses: tri-axial loading stiffness E_{50} , tri-axial unloading stiffness E_{ur} and the oedometer loading stiffness E_{oed} . Apart from that, it accounts for stress-dependency of the stiffness moduli, all stiffnesses increase with pressure (all three inputs relate to reference stress, 100 kPa). Hardening Soil Model (HS-model) is formulated in the framework of classical theory of plasticity. In this model the total strain is calculated using a stress-dependent stiffness, different for both virgin loading and un-/reloading. The plastic strains are calculated by introducing a multi-surface yield

criterion. Hardening is assumed to be isotropic depending on both the plastic shear and volume strain. For frictional hardening a non-associated and for cap hardening an associated flow rule is assumed.

In this paper the Finite Element Analysis is used for a monopole installed in the sand. To this end, the PIAXIS and two dimensional Finite Element program (version 8) was run. Tables 1 and 2 show the parameters of the soil and pile in two different Mohr-Coulomb and Hard soil models.

This study attempts to determine the pile-soil behavior for different interface coefficients, thus the modeling results of the two Mohr-Coulomb and Hard soil are compared to each other. Figure 1 shows the meshing of the Finite Element of the mono pile installed in the sand. Moreover, the permeability of soil is the necessary input of model for calculations.

After developing the meshes of the Finite Elements, the principal stresses and the total stress in the soil were simulated for the measurements. In this study, since the soil is unsaturated and there is no pore pressure, the total stress would be equal to the effective stress based on Terzaghi relationship. Figure 2 show the effective stress in the soil.

To perform the experiment, the loading of the pile was done in five separate, successive phases. The loading values for each phase are shown in Table 3.

The deformation of the pile is demonstrated in Figure 3 after the loading of the pile in soil was completed.

FINITE ELEMENT ANALYSIS

Pile settlement in the soil

The settlement of pile for two different interface coefficients of Mohr-Coulomb and Hard soil were estimated and compared to each other, the results of which are shown in Graphs 1 to 7.

In these graphs the dimension of settlement is in terms of meter and that of load for installing of pile is Kpa.

According to the reference graphs of Vesic and Meyerhof, at the end of loading, as the final extremity of the graph gets closer to the horizontal level and the horizontal asymptote, the measurement of the pile settlement becomes more accurate. Graphs 1 to 7 indicate the settlement of the pile for the interface coefficients of 0.7 to 1 in the two Mohr-Coulomb and Hard soil models.

The measurements based on the Mohr-Coulomb Behavior Law are much more accurate compared to those performed through Hard soil Behavior Law (Graphs 1 to 4), when the appropriate interface is taken into consideration. However, the results of Graphs 4 to 7 shows that Hard soil Behavior Law is more accurate and precise compared to Mohr-Coulomb Behavior law, when the interface is less effective.

Table 1. Parameters of pile and soil in Mohr-Coulomb model.

Permeability (m/day)	Friction angle	Cohesion (kpa)	Poisson ratio	Young modulus (Mpa)	Density (Knm ⁻³)	Model	Material
0.0864	35	1	0.2	90	21	Mohr-Coulomb	Sand
			0.3	20000	25	Linear elastic	Pile

Table 2. parameters of pile and soil in the Hard soil model.

Permeability (m/day)	Friction Angle	Cohesion (kpa)	Poisson ratio	E _{ref} (Mpa)	E ₅₀ (Mpa)	E _{ur} (Mpa)	E _{oed} (Mpa)	Density (Knm ⁻³)	Model	Material
0.0864	35	1	0.2		45	135	45	21	Hard Soil	Sand
			0.2	30000				25	Linear elastic	Pile

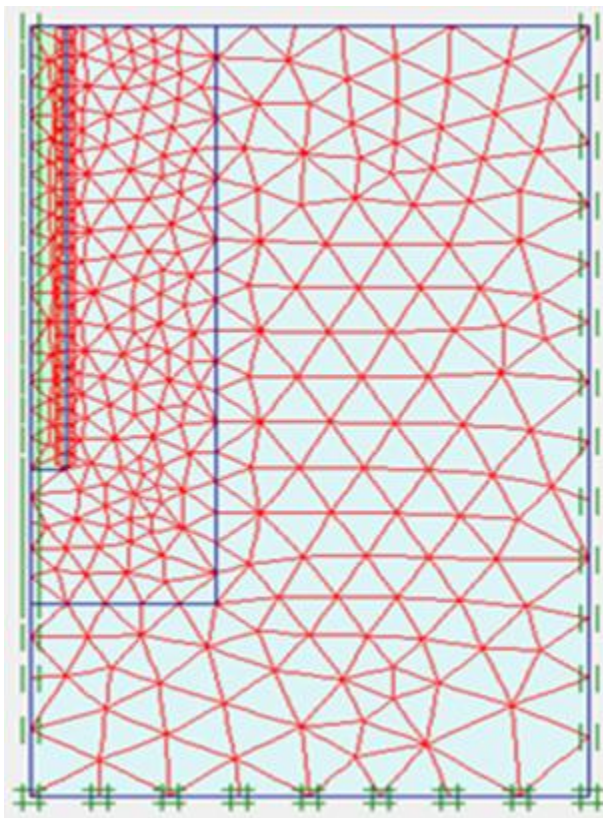


Figure 1. The meshing of the pile and soil.

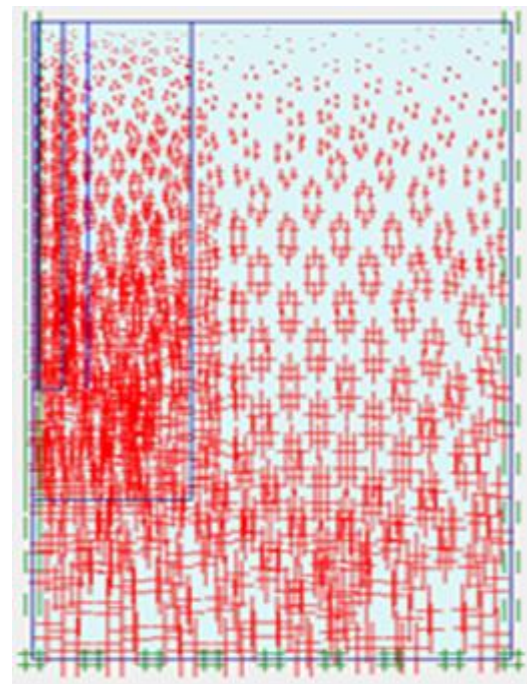


Figure 2. The effective stress in the soil.

Table 3. Loading values of the pile in each phase.

Phase	Loading intensity (Kpa)
1	1000
2	2000
3	3000
4	6000
5	9000

Pile forces

The Finite Element Analysis was also performed for the forces developed in the pile. Furthermore, the interface coefficients were measured for these forces. For this purpose, the forces acting at the lower end or bottom of the pile and the pile-soil interface were evaluated. Mohr-Coulomb and Hard soil Behavior laws were taken into consideration to compare the interfaces of the two Mohr-Coulomb and Hard soil models. The results are shown in Graphs 8 to 14.

In these figures, the horizontal axis is the loading effect on the upper end or head of the pile during the six

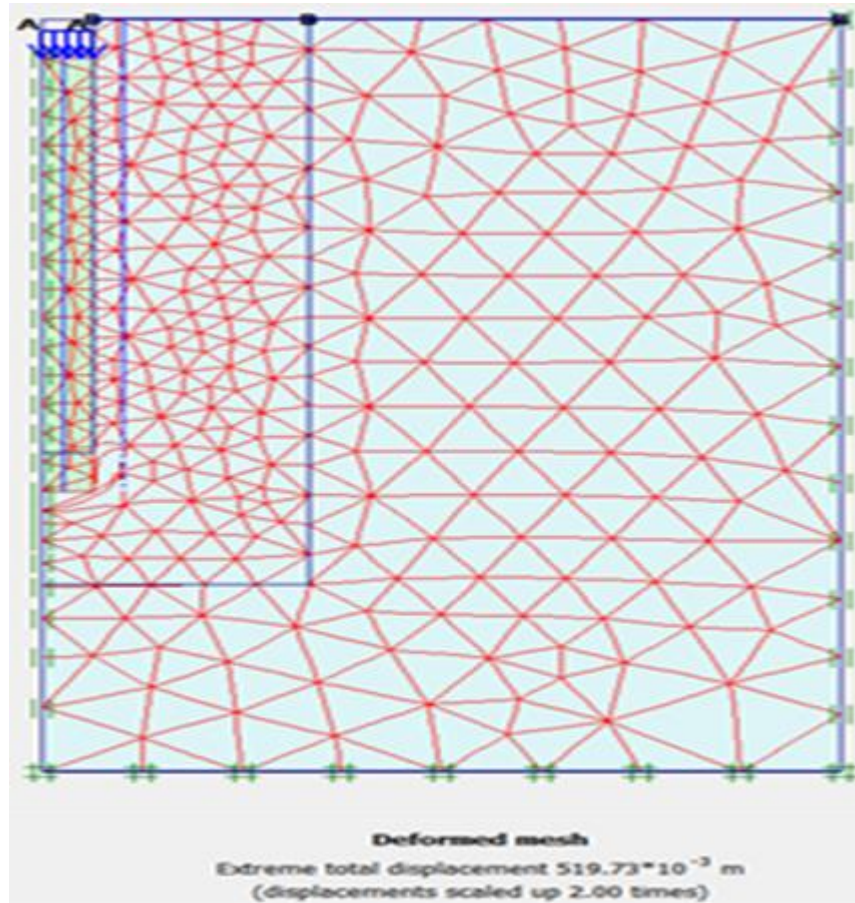
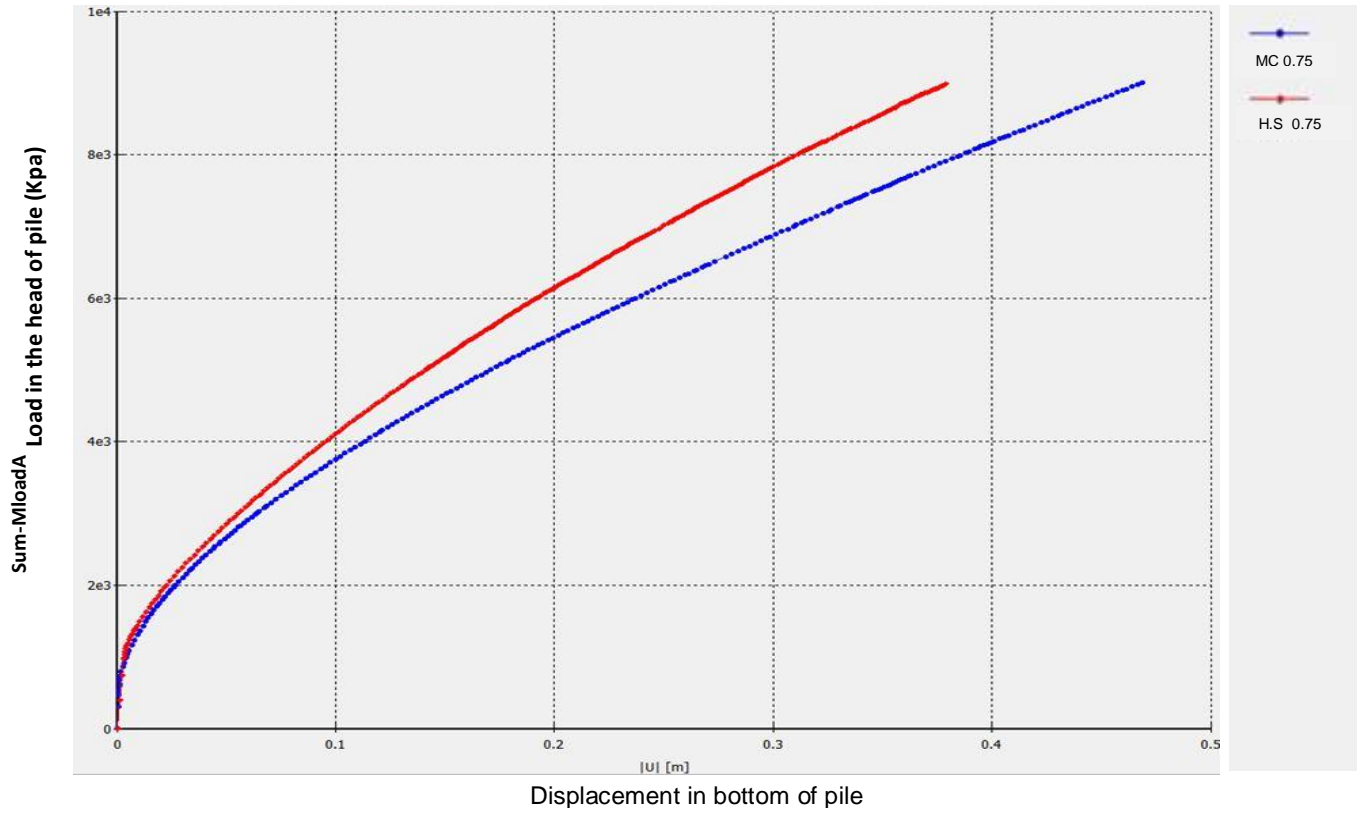


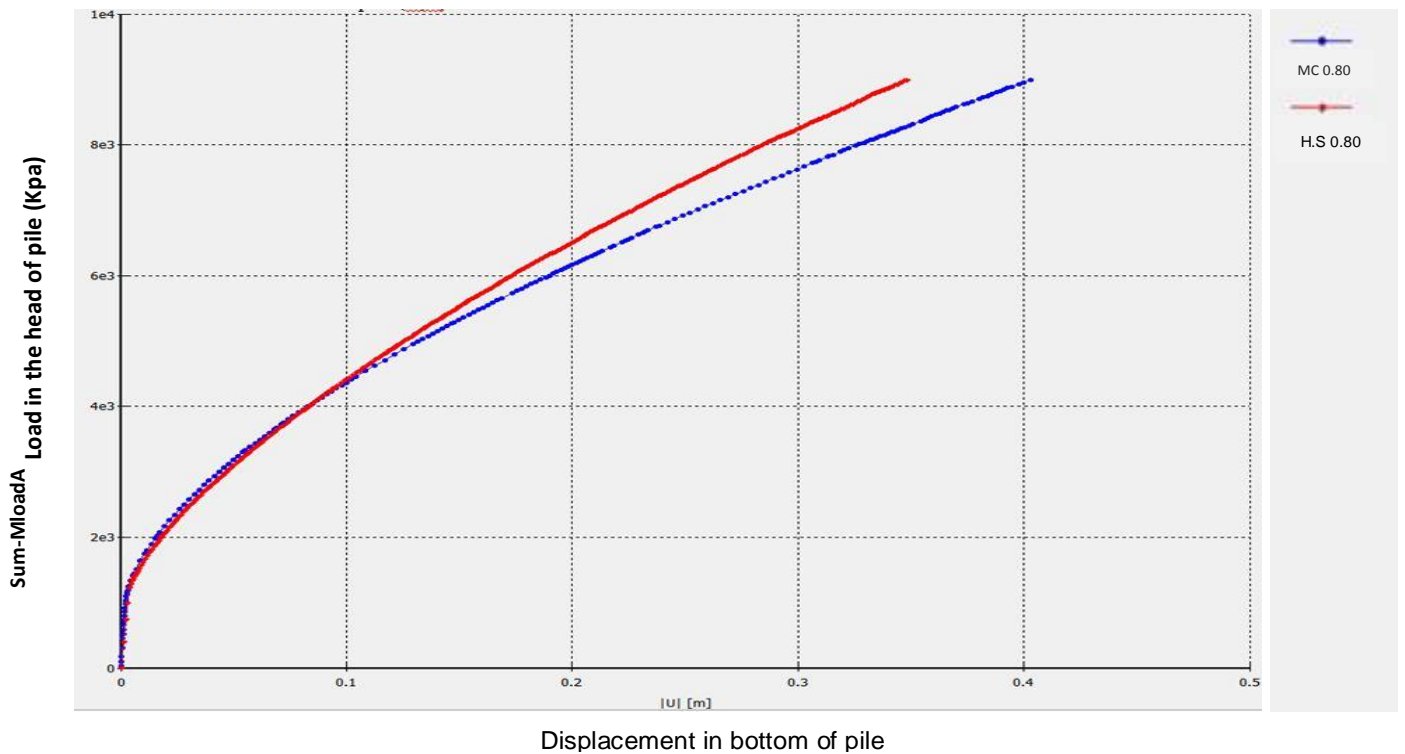
Figure 3. The deformation of the pile.



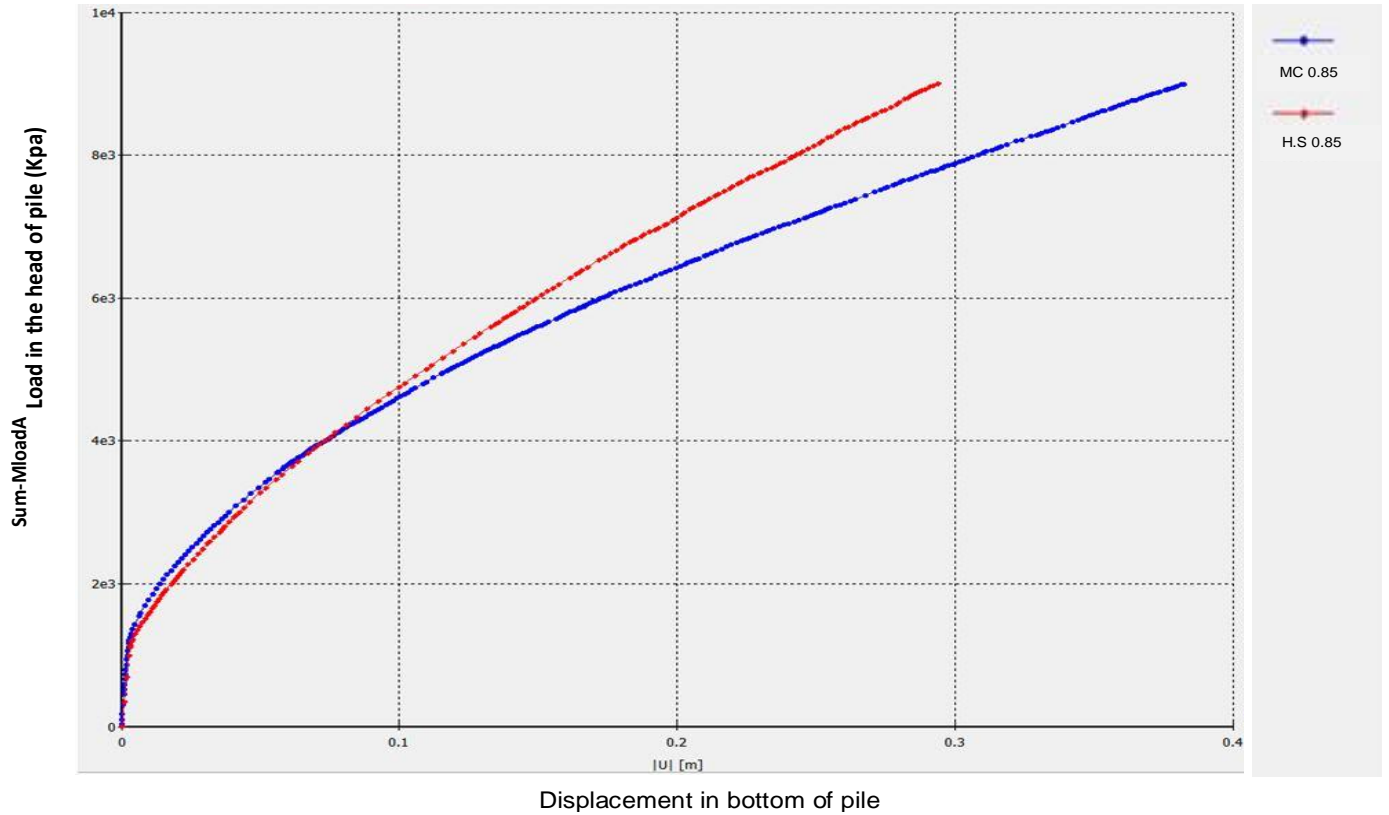
Graph 1. The settlement of pile for the interface coefficient of 0.70 (Mc and Hs).



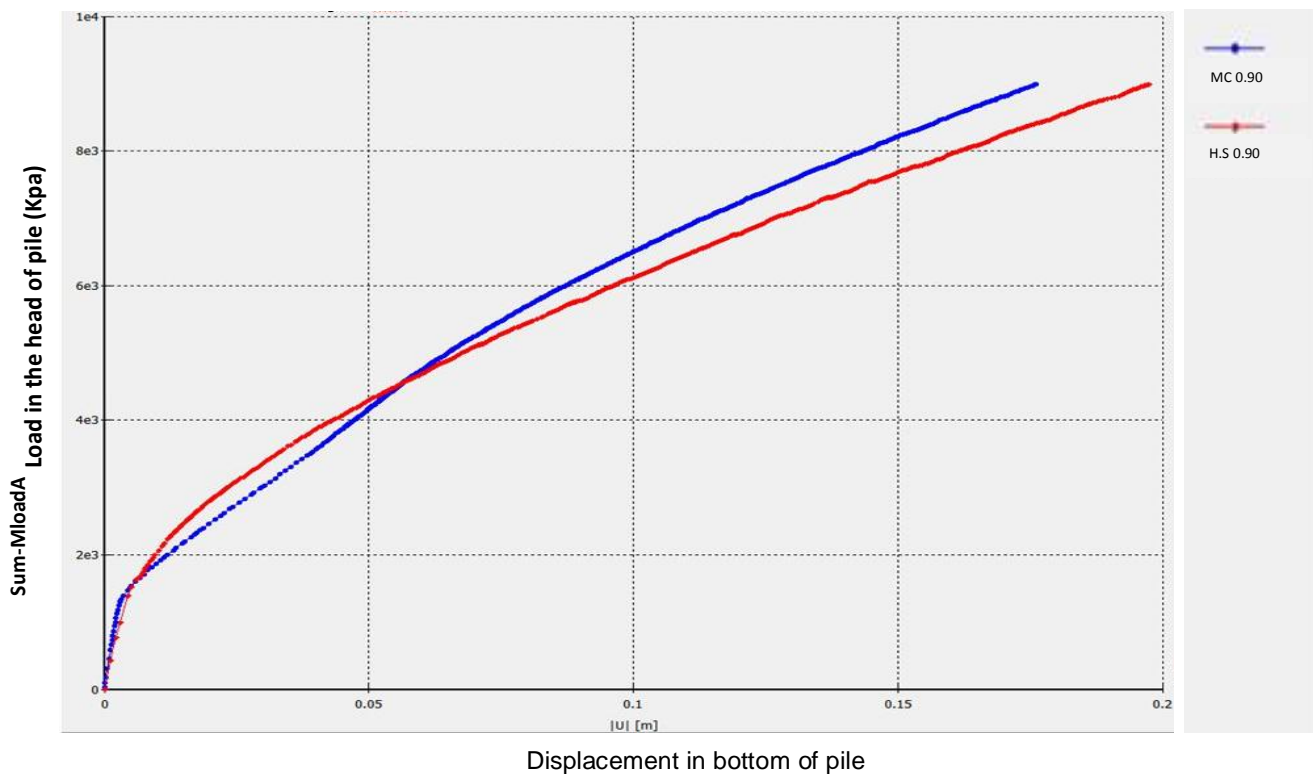
Graph 2. The settlement of pile for the interface coefficient of 0.75 (Mc and Hs).



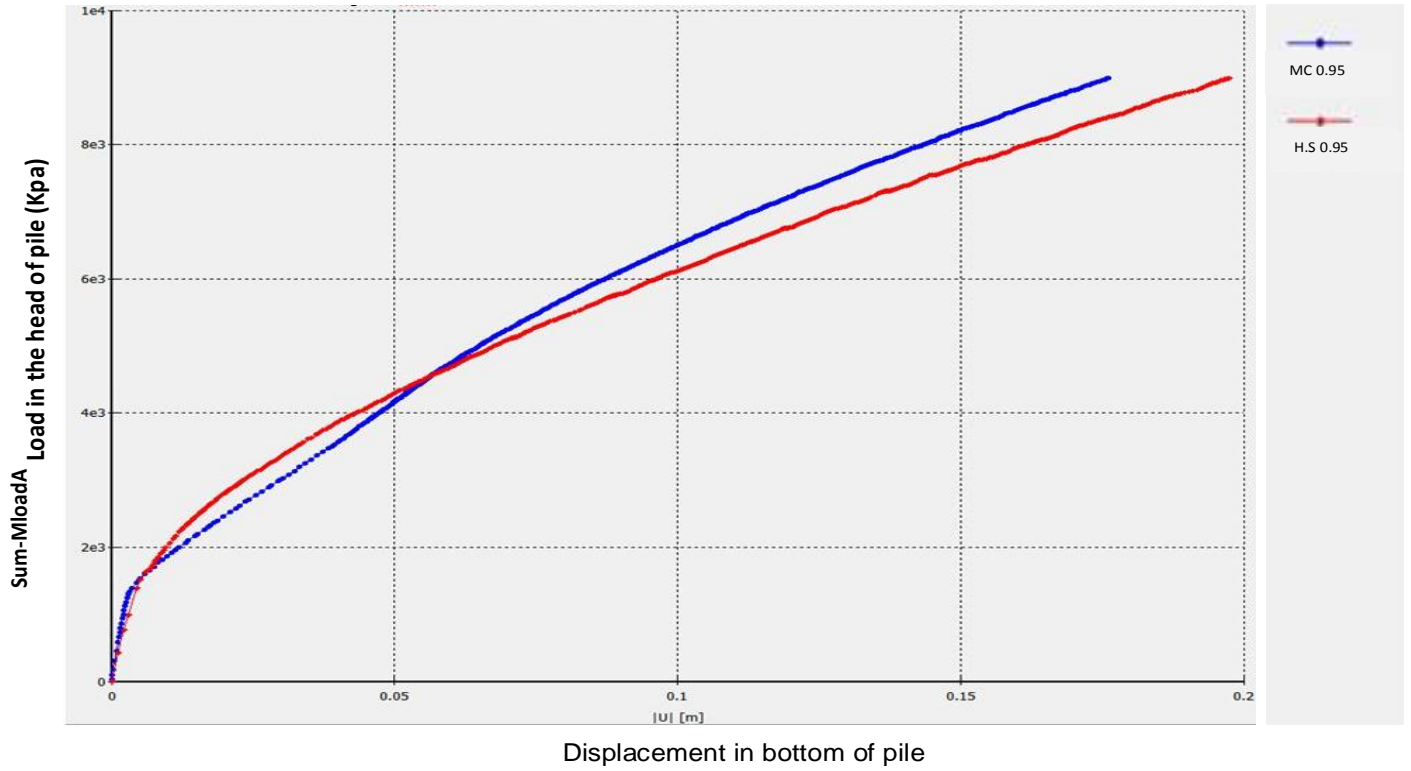
Graph 3. The settlement of pile for the interface coefficient of 0.80 (Mc and Hs).



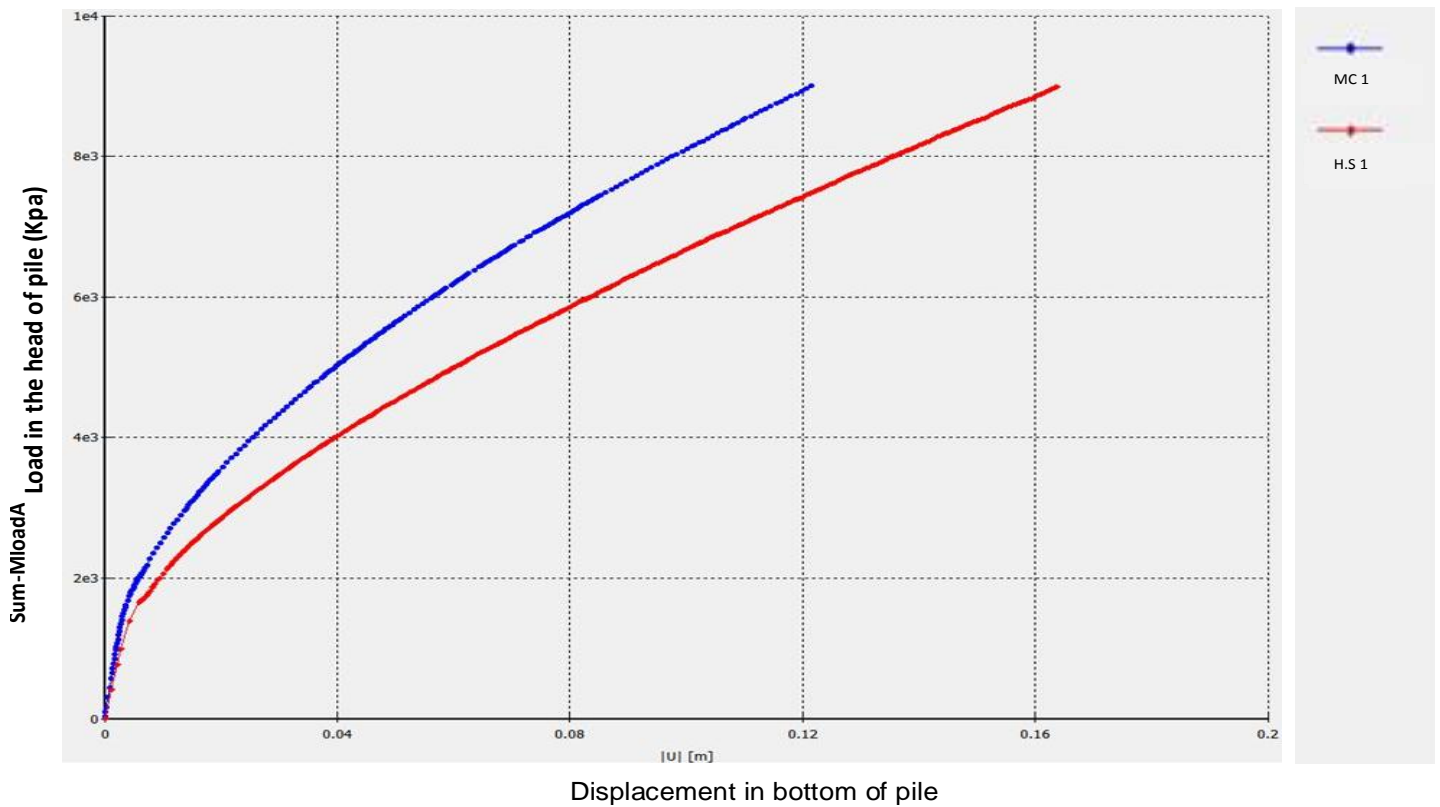
Graph 4. The settlement of pile for the interface coefficient of 0.85 (Mc and Hs).



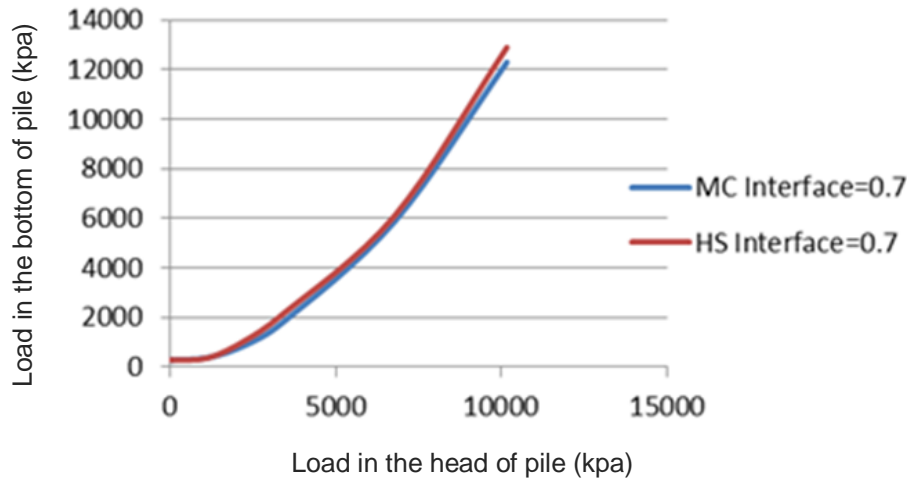
Graph 5. The settlement of pile for the interface coefficient of 0.90 (Mc and Hs).



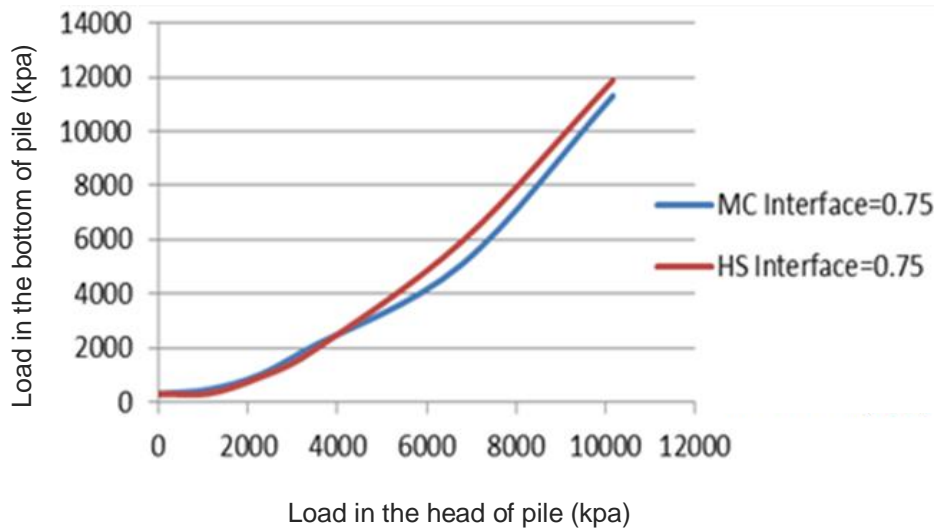
Graph 6. The settlement of pile for the interface coefficient of 0.95 (Mc and Hs).



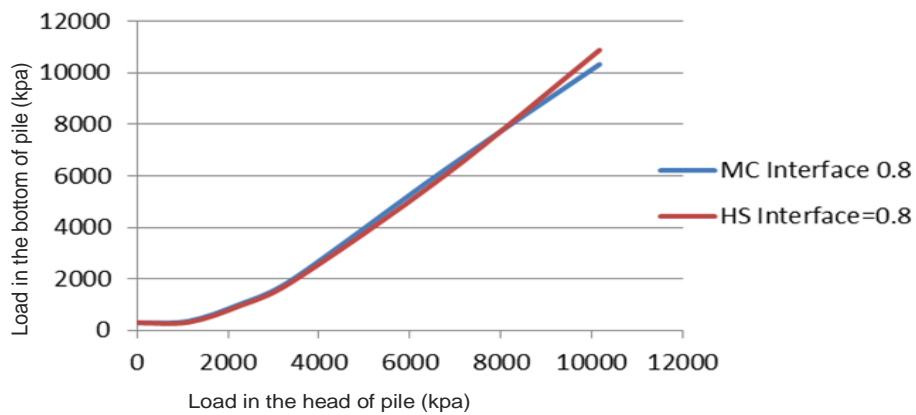
Graph 7. The settlement of pile for the interface coefficient of 1 (Mc and Hs).



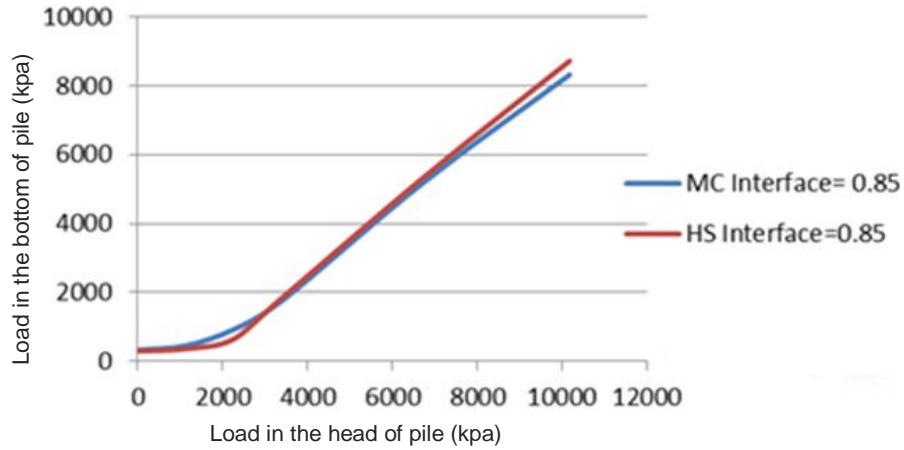
Graph 8. Forces in the pile for the interface coefficient of 0.70 (Mc and Hs).



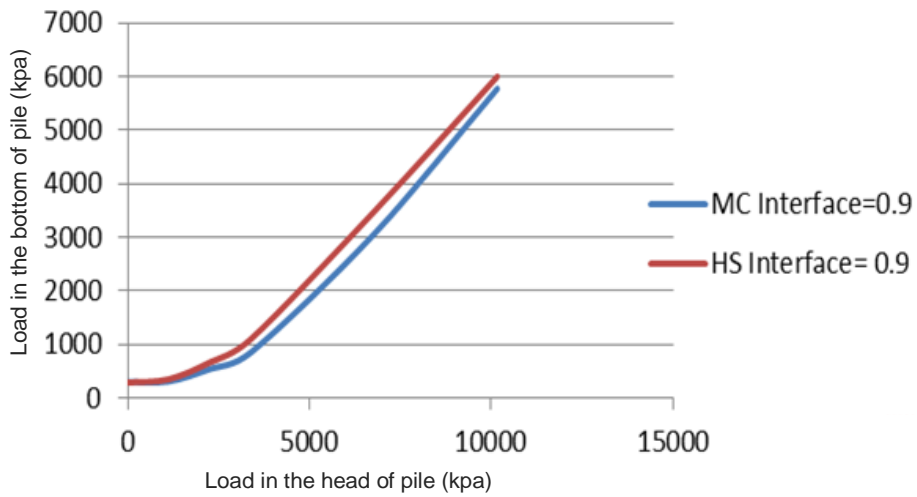
Graph 9. Forces in the pile for the interface coefficient of 0.75 (Mc and Hs).



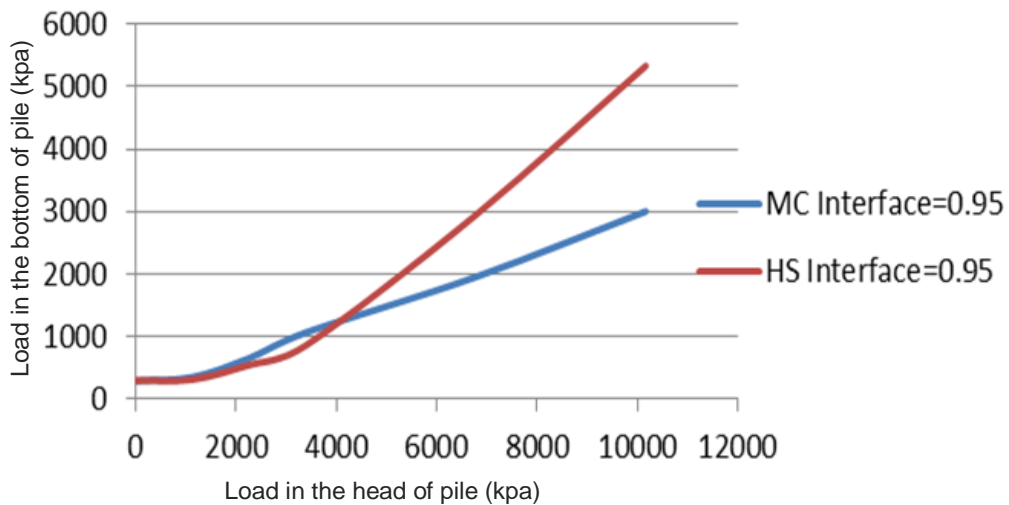
Graph 10. Forces in the pile for the interface coefficient of 0.80 (Mc and Hs).



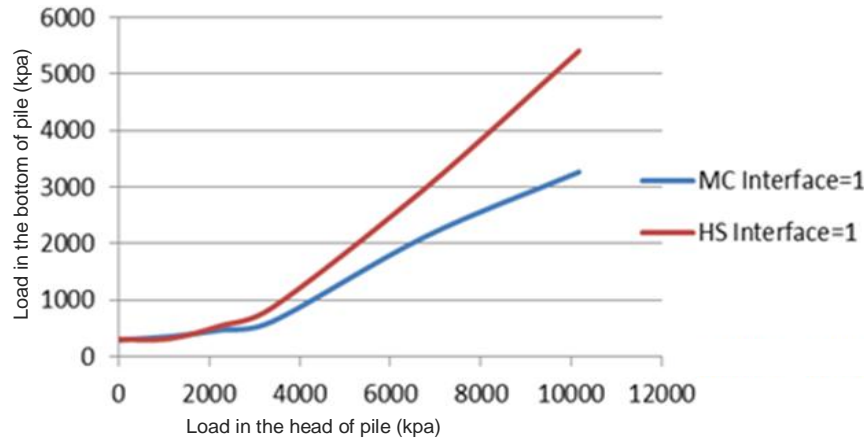
Graph 11. Forces in the pile for the interface coefficient of 0.85(Mc and Hs).



Graph 12. Forces in the pile for the interface coefficient of 0.90 (Mc and Hs).



Graph 13. Forces in the pile for the interface coefficient of 0.95 (Mc and Hs).



Graph 14. Forces in the pile for the interface coefficient of 1 (Mc and Hs).

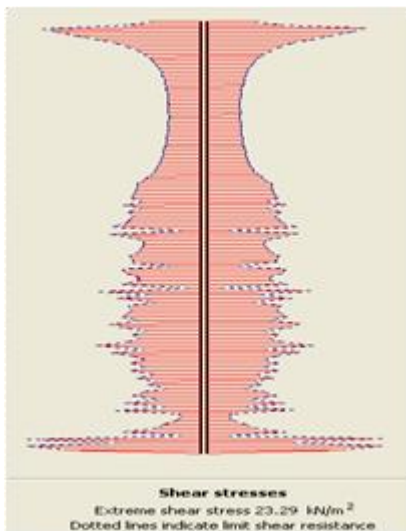


Figure 4. Mc 0.70 interface co.

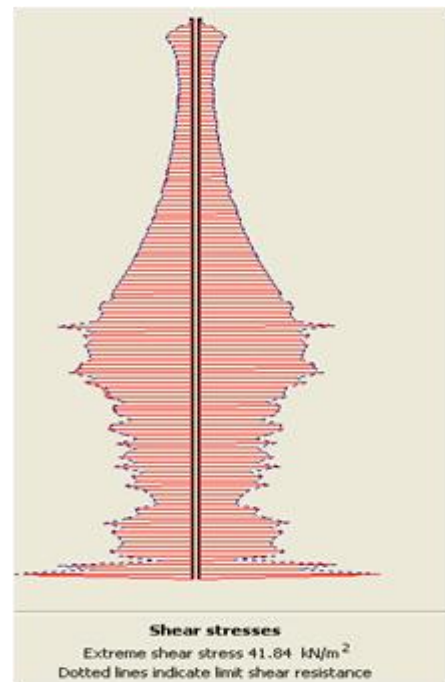


Figure 6. Mc 0.80 interface co.

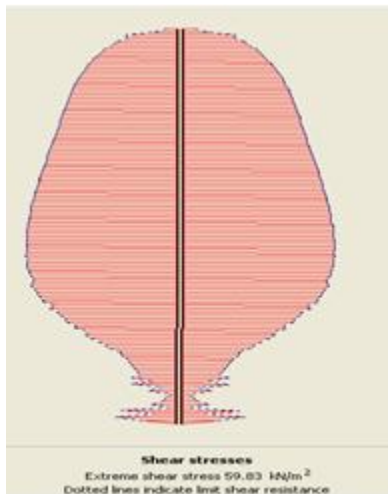


Figure 5. Hs 0.70 interface co.

different loading phases. The vertical axis is the loading effect on the lower end or the bottom of the pile. As it is observed in Graphs (8 to 14), the different loading effects at the lower end of the pile decrease with the increase of the interface coefficient. The results are the same for both behavior laws of Mohr-Coulomb and Hard soil.

Shear stress in interface area of pile-soil

Figures 4 to 11 show the shear stress in the interface area of pile and soil. As it is observed in the figures the shear stress increases with the increase of interface

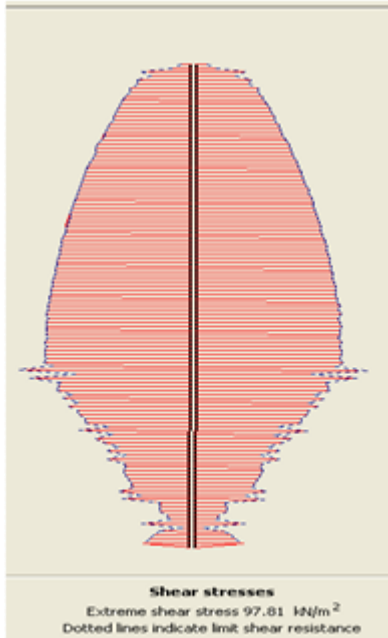


Figure 7. Hs 0.80 interface co.

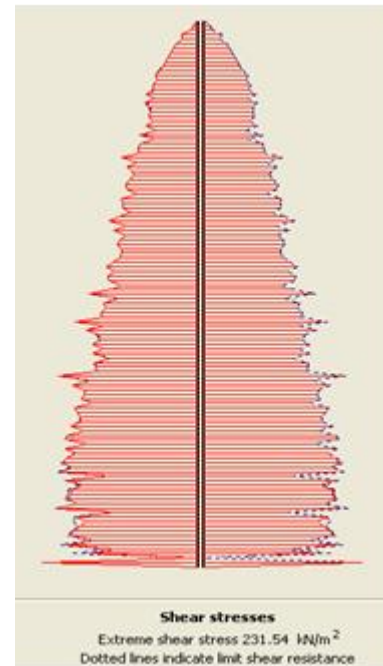


Figure 9. Hs 0.90 interface co.

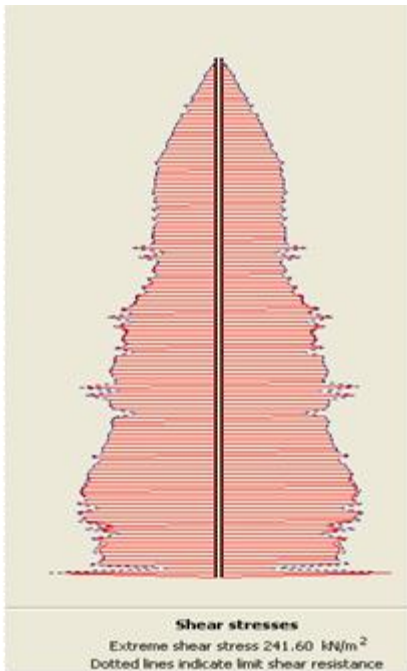


Figure 8. Mc 0.90 interface co.

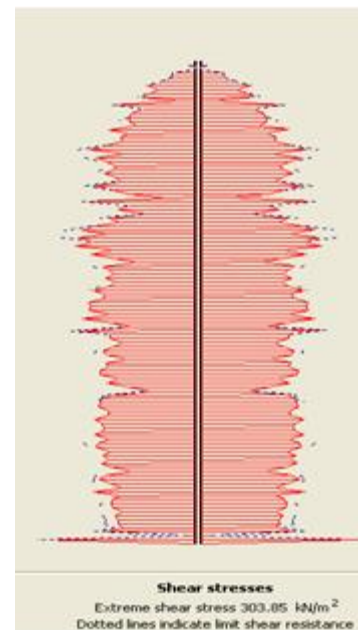


Figure 10. Mc 1 interface co.

coefficient. In Mohr-Coulomb Behavior Law, the shear stress is measured more accurately when the appropriate interface coefficient is taken into consideration (Figures 4 to 7). While the interface coefficient is less effective, the Hard soil Behavior Law measures the shear stress more accurately (Figures 8 to 11).

Three-dimensional Dynamic Analysis by ANSYS

ANSYS is used to perform the Transient Three-dimensional Analysis. The material properties were also modeled through ANSYS. Based on the Drucker-Prager Behavior Law, the soil behavior was examined. In order

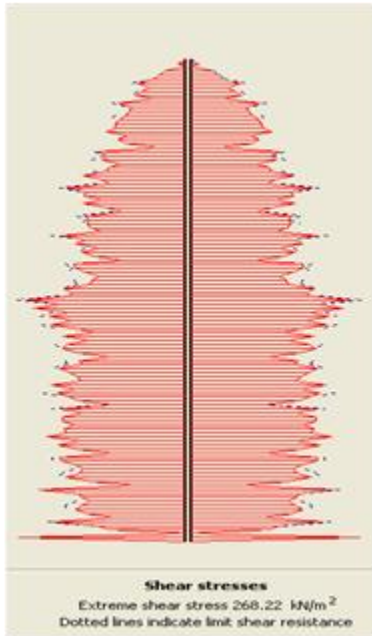


Figure 11. Hs 1 interface co.

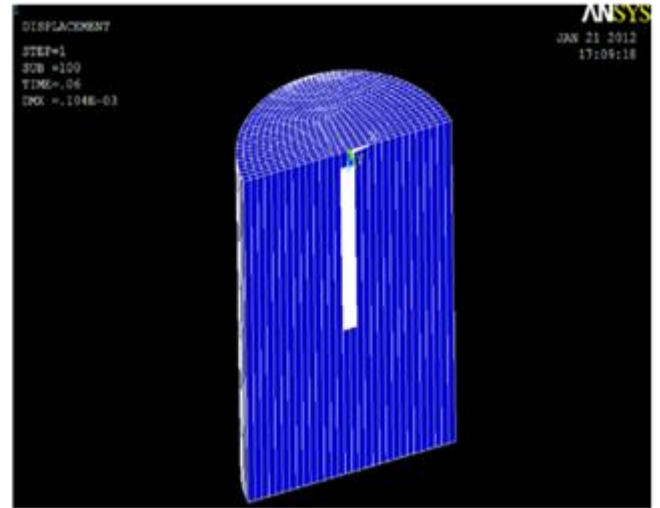


Figure 13. The three dimensional deformation of the pile.



Figure 12. The meshing of the pile and soil.

to analyze the pile behavior, the linear elasticity of the concrete pile in ANSYS was applied. The transient elements of the coupled field were used for performing these analyses. The selected sub-elements were vector Quad 13 of the plane strain state and vector Brick 62 from the coupled field. The two-dimensional element vector Quad 13 was employed along with the three

dimensional vector Brick 62 to give volume to the model. The meshing of model is shown in Figure 12.

To examine the pile-soil interface, the two elements of target 169 and contact 171 were selected from the contact sub-elements. Then the dynamic analysis was conducted for the interface coefficients of 0.70, 0.80, 0.90, and 1 in four different and separate modelings to determine the interface coefficient effect on the pile-soil behavior. The loadings were based on ANSYS and Table 3.

Results of the Three-dimensional Transient Dynamic Analysis

To perform the Transient Dynamic Analysis, the Newton-Raphson Law was applied to obtain more precise results. The deformation of pile after loading is shown in Figure 13. Moreover the velocity and displacement of pile in z direction are shown in Figures 14 and 15.

Moreover, the velocity of pile in z direction and the degree of freedom of z direction is similar for the all interface coefficients of (0.7 to 1).

Time History Analysis assigns the Vz (velocity at the lower end of the pile). The results are similar for the different interface coefficients (0.7 to 1) of Graph 15.

Time History Analysis Vz (velocity at the upper end or head of the pile) is also performed. The results show no significant difference for the different interface coefficients of (0.7 to 1) (Graph 16).

Similar results are also obtained for Time History Analysis of Uz (degree of freedom) at the lower end (bottom) of the pile for interface co. (0.70 to 1). Graphs 17 and 18) indicates that it can be concluded from the dynamic analysis that various interface coefficients do not make significant difference in the velocity and degree of freedom in the z direction.

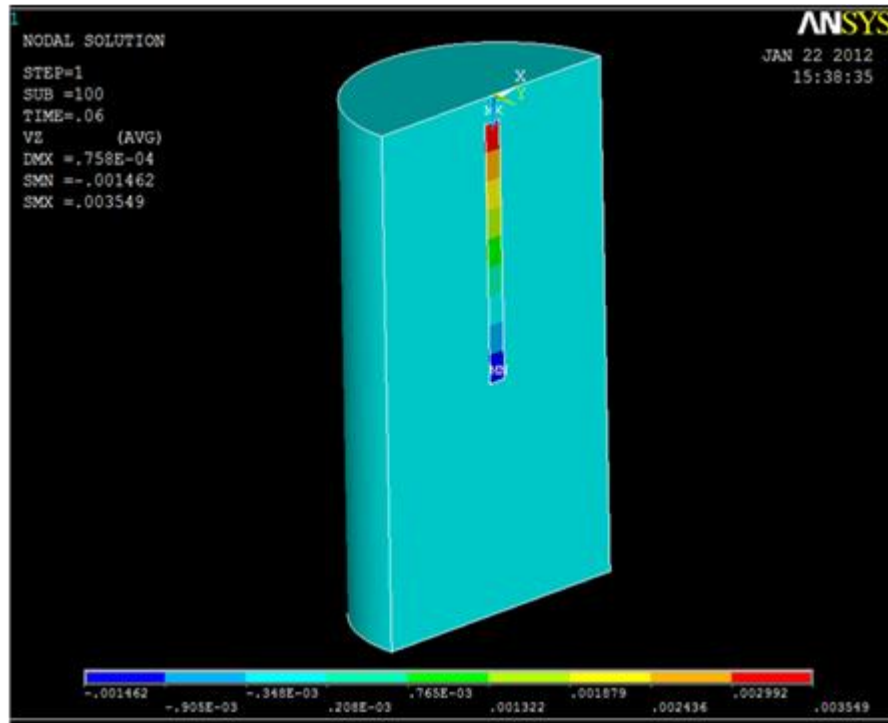


Figure 14. The velocity of pile in z direction for interface co. (0.70 to 1).

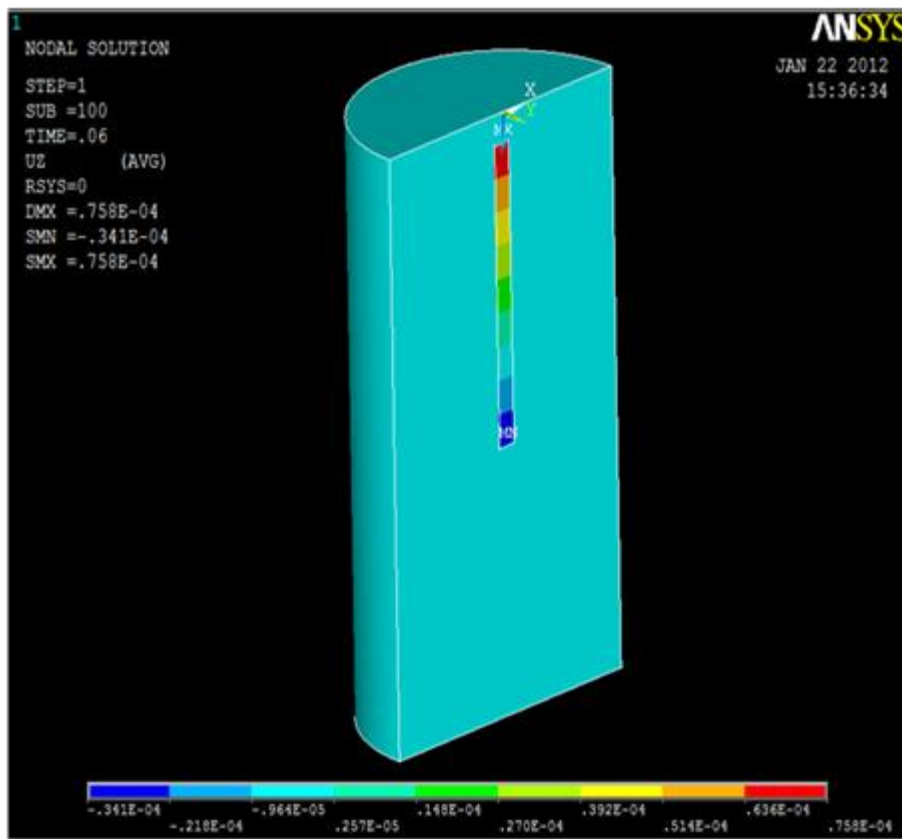
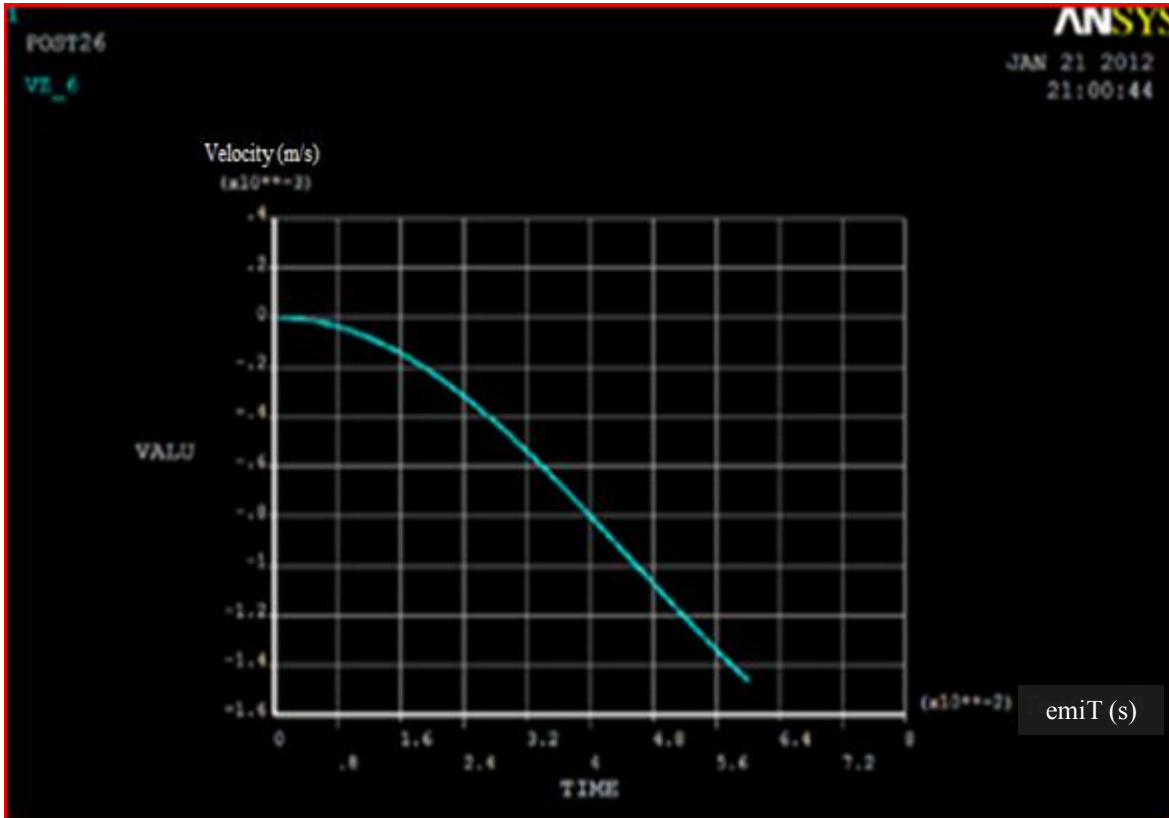
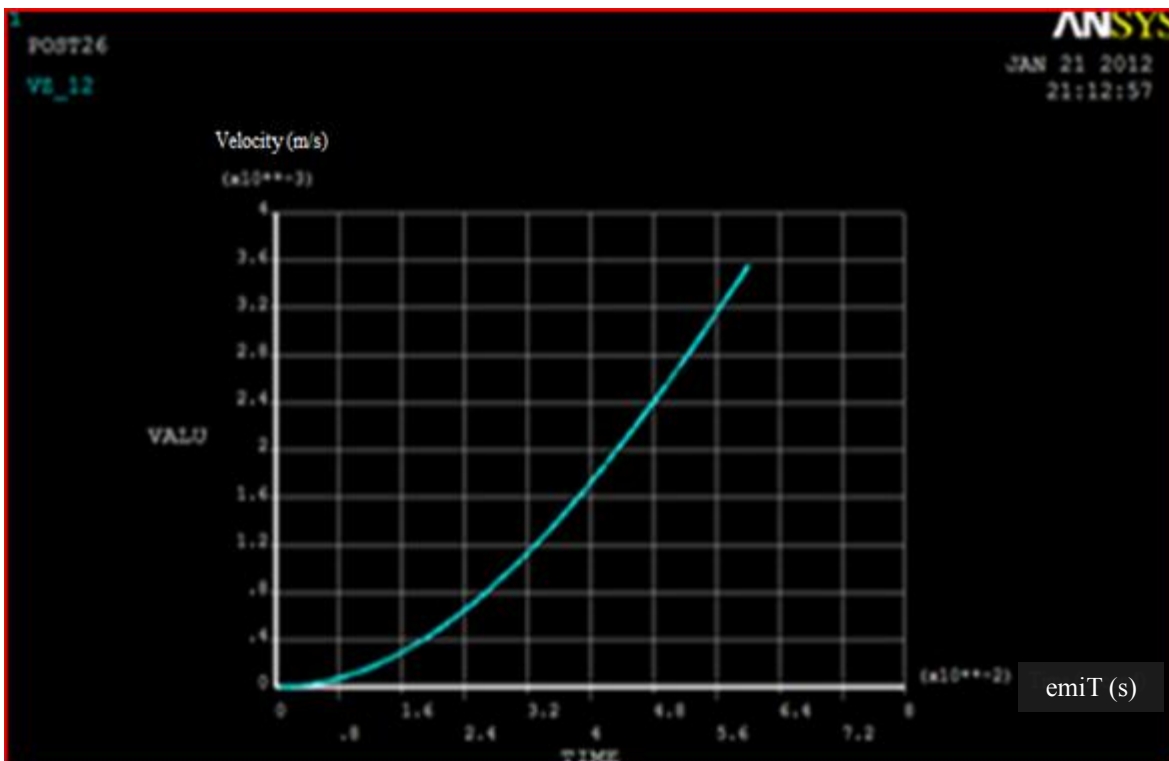


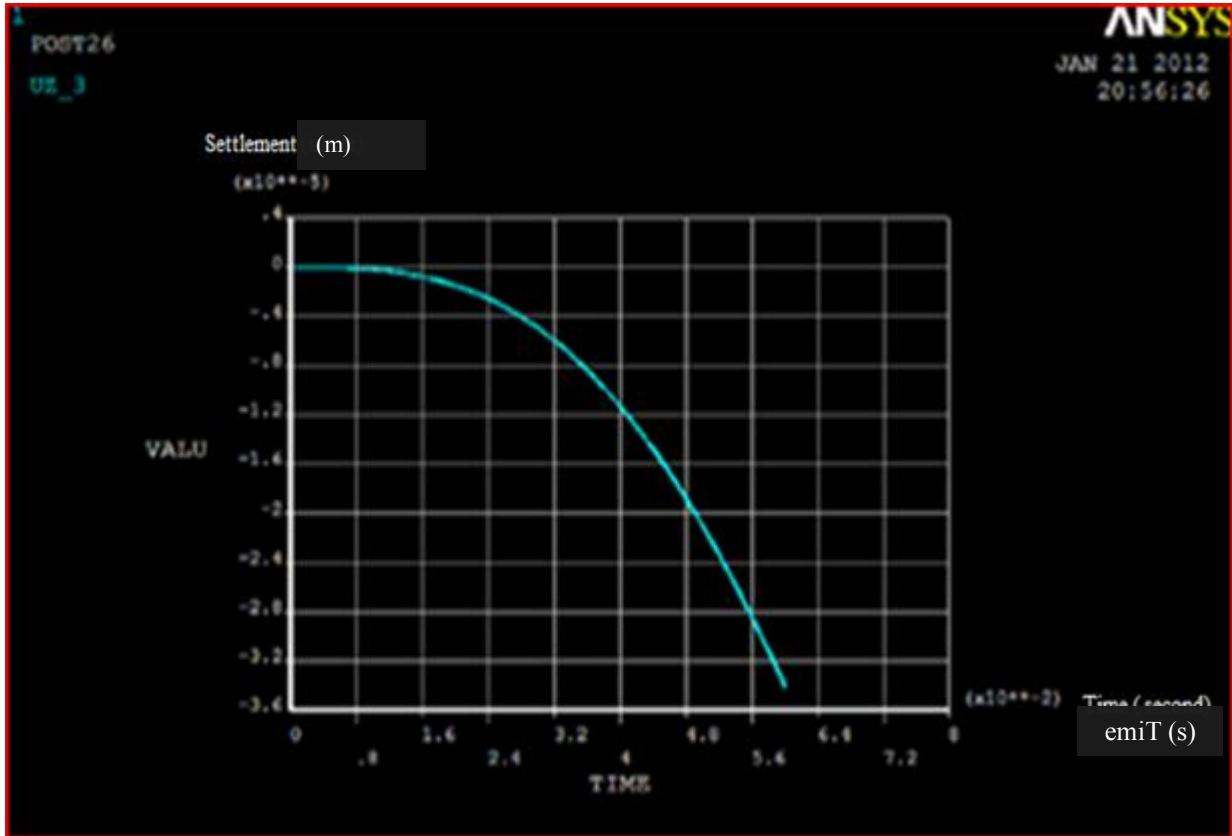
Figure 15. The degree of freedom of z direction for interface co.(0.70 to 1).



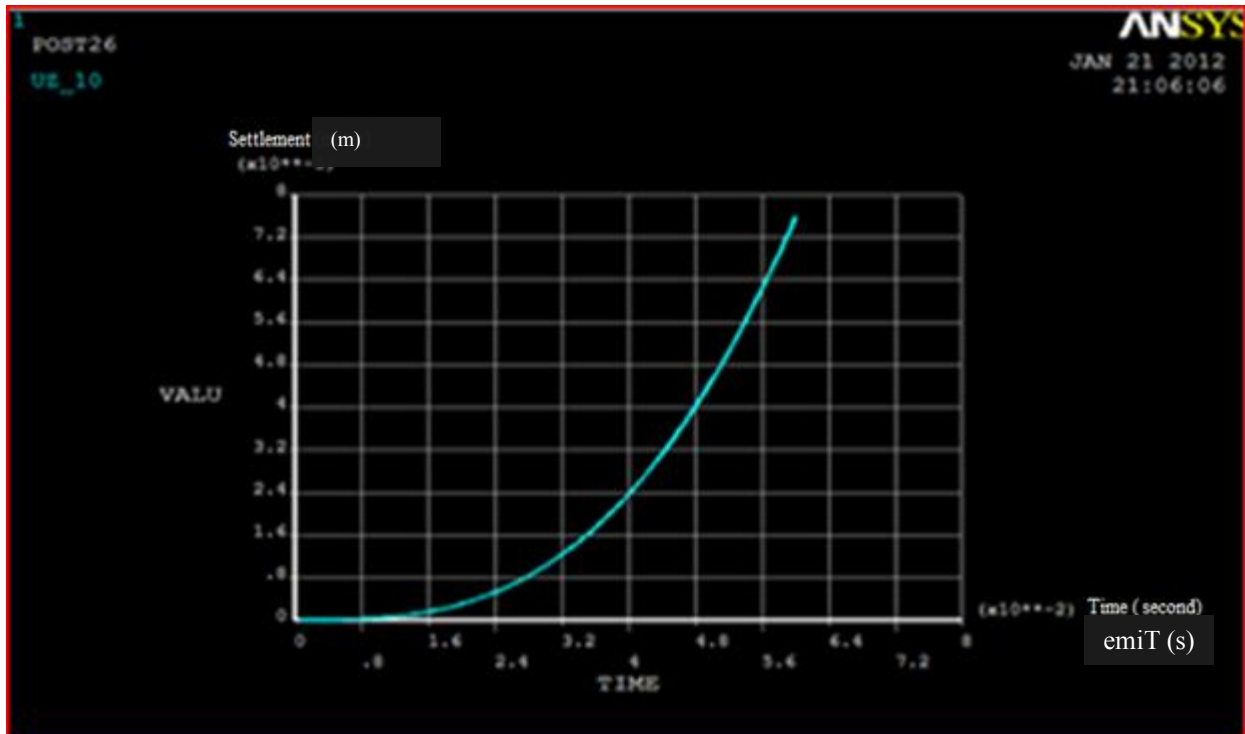
Graph 15. Time History Analysis of (Vz) velocity at bottom of the pile.



Graph 16. Time History Analysis of (Vz) velocity at head of the pile.



Graph 17. Time History Analysis of (Uz) degree of freedom at bottom of the pile.



Graph 18. Time History Analysis of (Uz) degree of freedom at head of the pile.

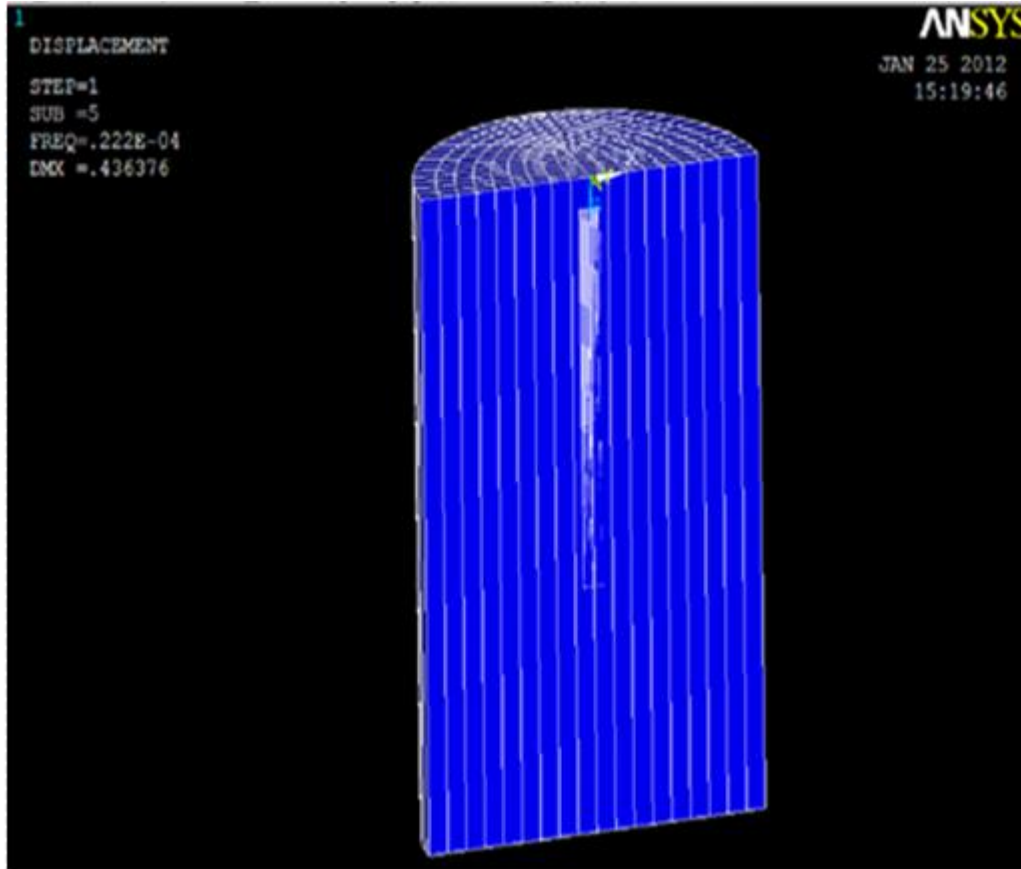


Figure 16. The mode shape for the fifth frequency.

Table 4. Natural frequencies for the different interface co. (0.7 to 1)

Set	Frequency	Sub step	Cumulative
1	0	1	1
2	0	2	2
3	1.14325e-05	3	3
4	1.40820e-05	4	4
5	2.22481e-05	5	5

interface coefficients do not make significant difference in the velocity and degree of freedom in the z direction.

Modal Dynamic Analysis

The Modal Dynamic Analysis was performed to determine the natural frequencies and their mode shapes. Basically, the natural frequencies and their mode shapes depend on the structure type, structure shape and boundary conditions. Therefore, the structure should be designed away from the resonant frequency limit. In the present study, the analysis of five natural frequencies of pile does not show any significant difference for

different interface coefficients of (0.7 to 1). Figure 16 shows the deformation of the mode shape for the fifth frequency.

Table 4 shows that the five natural frequencies for the pile and for the different interface coefficients of (0.7 to 1) are similar.

DISCUSSION

The present study demonstrated that the Finite Element Analysis is an appropriate method to determine the effect of interface coefficient of pile and soil.

The Static Analysis of PLAXIS revealed that the pile settlement may be measured more accurately for the interface coefficients of (0.7 to 1) with Mohr - Coulomb behavior law of pile –soil compared to the Hard soil model because according to the reference graphs of Vesic and Meyerhof at the end of loading, as the final extremity of the graph gets closer to the horizontal level and the horizontal asymptote the settlement of pile can be measured more precisely. In addition, the shear stress measured at pile–soil interface area by Mohr-Coulomb behavior law is more accurate than Hard soil when the appropriate interface coefficient is taken into

consideration based on the reference graphs of Vesic and Meyerhof. Furthermore, the findings revealed that the increase of interface coefficient decreases the loading effect at the lower end of the pile.

The Transient Dynamic Analysis through ANSYS indicated that different interface coefficients have no significant influence on the dynamic parameters of velocity and degree of freedom in the z direction.

Considering the importance of the pile–soil interface and with regard to the findings of this study, it is recommended that researchers make simulations through other software such as FLAC and based on the Finite Difference Method to compare their findings with the results obtained from the present study in which Finite Element Method was employed.

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