ISSN 1996-3343

Asian Journal of Applied Sciences

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Asian Journal of Applied Sciences 7 (1): 30-37, 2014
ISSN 1996-3343 / DOI: 10.3923/ajaps.2014.30.37

Influence of Long Term Loading on Deep Foundation Response

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ABSTRACT

The long term effect of loading has been evaluated on deep foundation response with different load intensities. The study was deal with three-dimensional finite element approach. This method includes three main constitutive models to cover all geotechnical system (i.e., linear elastic model to simulating the pile material, elasto-plastic model for representing surrounded soil and Boit's equations to satisfying consolidation effect). In this study two types of soil have been used (i.e., sandy and clayey soil). It has been concluded that the numerical results show that long term loading can considerably influence pile and soil response. Thus, higher deformation was detected with time due to consolidation process and maximum applied load intensity.

Key words: Pile, consolidation, lateral loading, 3D FEM

INTRODUCTION

The use of piled foundations has become more widely known in many previous years. In general the pile as any type of foundation is design to resist the axial reaction coming from axial load, but same times the some pile foundation is designed to carry lateral load as well as axial loads. The result of horizontal load maybe come from earthquakes any many case studies, soil movement that occurred in many places, sometime from waves which act on for example bridges foundations, transmission towers, offshore structures and other type of huge structures.

According to literature the analysis of time dependent behavior of a vertical pile received little attention of geotechnical engineering fields. This is mainly due to the complexity of the problem and the difficulties when solving the problem analytically or experimentally. In addition the comparison of the lateral response of piles embedded in cohesionless and cohesive soil is little in case of time dependent performance. Only few studies available for solving this kind of issues like Taiebat and Carter (2001) and Carter and Booker (1983). Many example for the relative study on present time such as Yang and Jeremic (2002), Karthigeyan *et al.* (2006, 2007), Zhao *et al.* (2008) and Kahyaoglu *et al.* (2009) that used three-dimensional FEM to solve pile foundation problems.

It necessity be emphasized that there are no informed work on time dependent performance of lateral pile reaction carry lateral loading in mutually sandy and clayey soils. Thus, this study offering a numerical simulation based on the 3D finite element method to evaluate time dependent effect on the actions of vertical pile surrounded by sandy and clayey soils.

MATERIALS AND METHODS

The finite element program was used to perform a series of analysis on pile subjected to pure lateral load and obey Biot's equation of consolidation in cohesionless and cohesive soil. The analysis was performed to study the influence of time-dependent factor on the lateral pile response. The

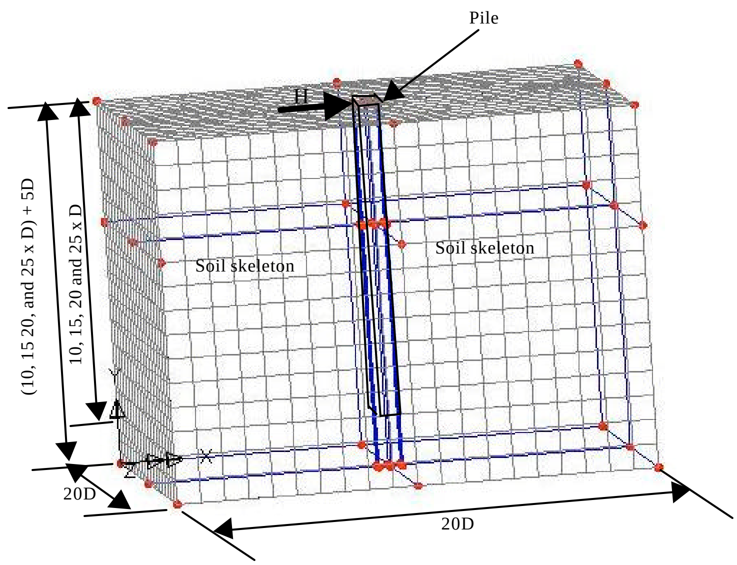

Fig. 1: 3-Dimensional finite element mesh

details of finite element simulation and time-dependent effect discussed with details in the next sections. The finite element program has been developed based on the program created by Smith and Griffiths (2004) for solve axisymmetric geotechnical problems for such as consolidation. The program includes the Transient formulation of Biot's equation and Mohr-Coulomb model, the program allows one to assign linear elastic behavior to any part of the problem geometry. Figure 1 shows all description of three-dimensional finite element mesh of the pile-soil continuum. The pile and the soil continuum are represented using 8-node brick elements.

The pile material was simulated as linear elasticity this model based Hooke's law. The soil was represented by well-known elasto-plastic (Mohr-Coulomb) model which is based on soil parameters that are known in most practical situations. Mohr Coulomb's failure surface criterion is obey the equation $F(\{\sigma'\}, \{k\}) = \sigma_1' - \sigma_3' - 2c'\cos\phi - (\sigma_1' + \sigma_3')\sin\phi$ (Potts and Zdravkocic, 1999).

The consolidation of poro-elastic media was govern by the equation that developed early by Biot (1941). In the resent time, the finite element formulation was established by Smith and Griffiths (2004). The details of the convert of the basic consolidation equation to finite element formulation not present in this study but the final finite element equation are given as:

$$\begin{bmatrix} K & L \\ L^T & S+\bar{\alpha}H\Delta t_k \end{bmatrix} \begin{Bmatrix} \bar{u} \\ \bar{p} \end{Bmatrix} = \begin{bmatrix} K & L \\ L^T & S-(1-\bar{\alpha})H\Delta t_k \end{bmatrix} \begin{Bmatrix} \bar{u} \\ \bar{p} \end{Bmatrix} + \begin{Bmatrix} dF/dt + C \\ \bar{F} \end{Bmatrix} \tag{1}$$

where, K is element solid stiffness matrix, L is element coupling matrix, H is element fluid stiffness matrix, $\bar{u}$ is change in nodal displacements, p is change in nodal excess pore-pressures, S is the compressibility matrix, $\bar{F}$ is load vector, Δt is calculation time step, $\bar{\alpha}$ is time stepping parameter (equal to one in this work), dF/dt is change in nodal forces.

In order to examine the time dependent consolidation behavior of the pile, it is convenient to introduce a non-dimensional time factor T, defined as Carter and Booker (1983), Taiebat and Carter (2001) and Small and Liu (2008):

$$T = \frac{c_v t}{D^2}$$

Where:

$$c_v = \frac{k(1-\upsilon_s')E_s'}{\gamma_w(1-2\upsilon_s')(1+\upsilon_s')} \quad (2)$$

Then:

$$T = \frac{k(1-\upsilon_s')E_s't}{\gamma_w(1-2\upsilon_s')(1+\upsilon_s')D^2} \quad (3)$$

where, the coefficient of consolidation c_v is defined in term of the permeability k, the drain modulus E' and poison's ratio v', the unit weight of water γ_w and the diameter of pile D.

RESULTS AND DISCUSSION

To cover the scope of this study, the paper consist of four categories: (1) Study the maximum lateral load amount influence which taken as 45 γ_w D^3, (2) Study time factor effect that taken from 0.0001 which means rapid load to 1.0 for long time after loading, (3) Two type of soil are considered (i.e., sandy and clayey soil) to study the influence of soil type on the lateral pile reaction, (4) Study the maximum axial load amount influence which taken as 450 γ_w D^3.

A vertical pile, with a diameter of 1.0 m and a length of 10, 15, 20 and 25 m, subjected to a lateral load of γ_w D^3 and then with vertical load of 450 γ_w D^3 is analyzed using the 3D finite element suggested program. The pile's Young modulus, E and Poisson's ratio, v are 2.9×10^7 and 0.15, respectively. Consequently, the surrounded soil properties consist of cohesionless soil with depth of 30D, unit weight, γ of 20.0 kN m^{-3}, Young's modulus, E of 1.3104 kN m^{-3}, Poisson's ratio, v of 0.3, angle of internal friction, ø of 31.

In all of the calculation, an eight-node brick element was employed. Each node had three degrees of freedom and used to describe shape functions for geometry. The responses of the pile in the elasto-plastic soil subjected to lateral load simultaneously and deforming under rapid loading conditions followed by consolidation are studied.

In the design of lateral pile response, the key depend on the maximum lateral pile displacement as well as the ultimate lateral soil resistance in addition maximum shear stresses. In this section the lateral pile displacement with depth when the maximum occurred at the tip of pile is draw with time factor. On the other hand the lateral soil pressure developed with depth to understand the lateral soil distribution that help to know the position of the ultimate lateral load and similarly the shear stresses is descriped.

Analysis of maximum pile displacement: The lateral pile displacement that developed with depth is illustrated in Fig. 2 and 3 for both sandy and clayey soil, respectively. Normally, the maximum lateral pile deflection occurred in the tip of pile because of the pile. Therefore, the calculated lateral displacement with time at the point on the head of pile in both sandy and clayey soil is shown different measurement depending on the length of the pile. The figure draw in case of differences in displacements with time factor (T = 1.0) and different load magnitude.

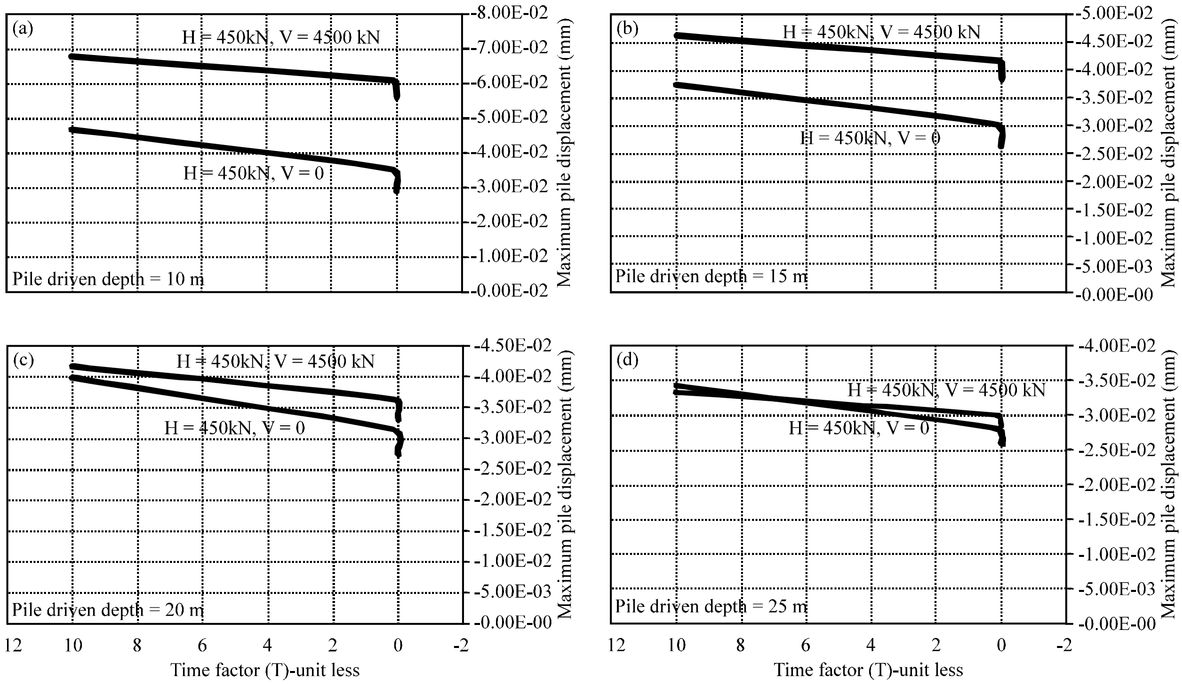

Fig. 2(a-d): Maximum pile displacement vs. time factor (sandy soil), Pile driven depth, (a) 10 m, (b) 15 m, (c) 20 m and (d) 25 m

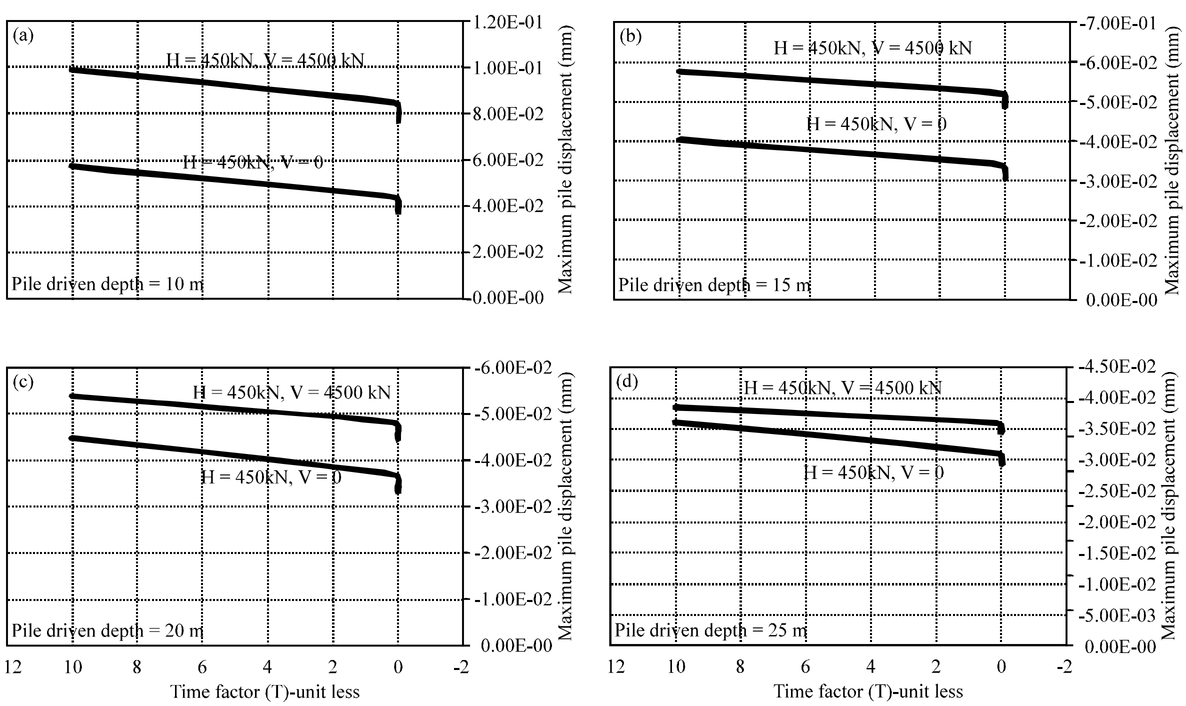

Fig. 3(a-d): Maximum pile displacement vs. time factor (clayey soil), Pile driven depth, (a) 10 m, (b) 15 m, (c) 20 m and (d) 25 m

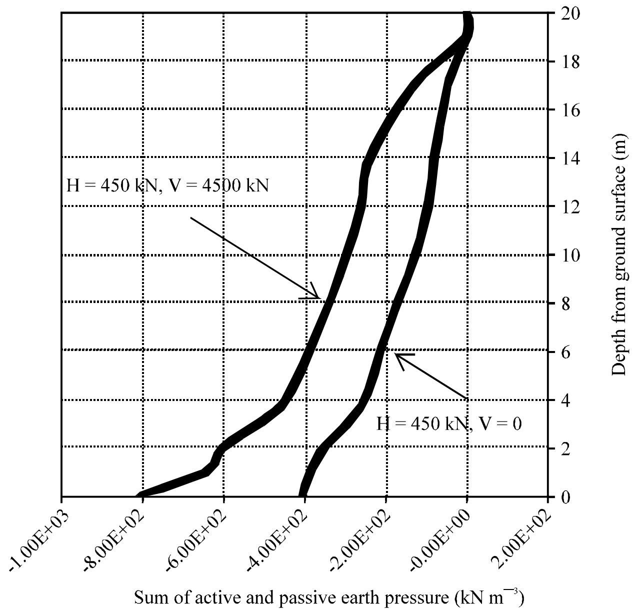

Fig. 4: Increase of lateral earth pressure calculated deep from the ground surface

These four figures are clearly showed and represent the pile response with time. The time gave indication to the researchers regarding the time of fully consolidated system. And this can be used to re-propose the design equation for this kind of loadings and conditions.

Figure 2 show the maximum pile displacement occurred at tip of pile with time for case of sandy soil. It can be seem that the pile in early time of loading has a little change in lateral displacement. This is possibly because of the water between the voids is not fully dissipated. This phenomenon is one of the main problems in soil mechanics and need more studies. This figure is included four pile length (i.e., L=10, 15, 20, 25 m). It can be seemed that the pile with length of 10 and 15 m have much more settlement compared with another to pile length. This is due to low lateral soil resistance in case of short piles. It is also can conclude that the short pile have more differences in lateral displacement when applied firstly pure lateral load and secondly applied axial load as well as lateral load. While this issue is different in case of long piles, these variances are less and some time is not effected. This because of the long pile can be equally response in both cases (i.e., pure lateral load and combined load).

In addition the maximum pile displacement occurred at tip of pile with time for case of clayey soil is illustrated in Fig. 3. This case can be show that the differences of the lateral pile displacement compared with pile driven in sandy soil. The indication can be explains the lateral pile response when subjected to long term loading in different subsoil condition. As previous case, the piles transfer the most of load to the surrounding soil in the early stage of loading. The short pile is usually carry capacity less than the short pile in both pure lateral load and also for combined load.

Analysis of lateral earth pressure: Lateral soil pressures p in soil resulting from the lateral loads is shown in Fig. 4 and 5. Higher values of pressure occurred in the position of L/D between 1-4 of pile diameter from the pile base, Broms (1964a, b) is also recommended that with 1.5 D. In fact, the previous studies take into account either passive or active pressure, this is not closed with the fact. While this study is take into account the algebraic summation of passive and active

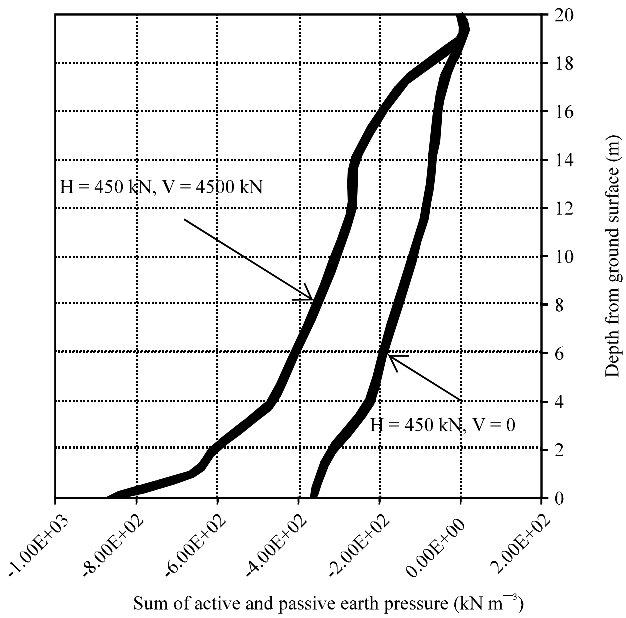

Fig. 5: Increase of lateral earth pressure calculated deep from the ground surface

pressure. This possibly closed to the real, because the real case of laterally loaded pile include the response of soil in opposite direction and this issue maybe increase or decrease the lateral pile response. Therefore, the following section has been included the real soil reaction based on previous discussions. In addition, the pile length has been fixed as 20 m. Because this case can be used as case study and can estimate all other cases depend on is.

In case of sandy soil (Fig. 4), the soil closed to the ground surface carry very little capacity and it is started from zero exactly at the ground surface until 1D from surface. This is possibly due to full collapse of soil surface due to applied load. This issue occurred for both case of loadings (i.e., pure axial load and combined load). The lateral earth pressure is increase with depth until reach the maximum value at the bottom of the piles in case of pure lateral load. The maximum value in case of combined load is about 1.5 from maximum lateral earth pressure from the first case. This is due to the pile transfer more load when carrying axial load as well as lateral load.

In case of clayey soil the surface soil failed as early stage of loadings and then the soil resist the lateral load when move downward from the surface as illustrated in Fig. 5. The maximum earth pressure occurred at the bottom of pile but the magnitude from combined load is about 2 times that measured from pure lateral load case.

Analysis of side shear resistance: The soil friction is one of the important element for assessment most of foundations. This element used to known the pile-soil resistance to carry any amount of loading. The previous study take into account the lateral soil stresses either in front of pile or at back. Sometime these values are parallel or usually opposite. In case of opposite sign, the reaction should be changed and maybe more or less than the values measured by previous method. In addition, this study take into account the axial load action on this response and this is new finding observed from this study.

The soil friction stresses with depth under different loading and time factor is shown in Fig. 6 and 7 for both types of soil. The friction stresses has lowest values at the top of pile (near the

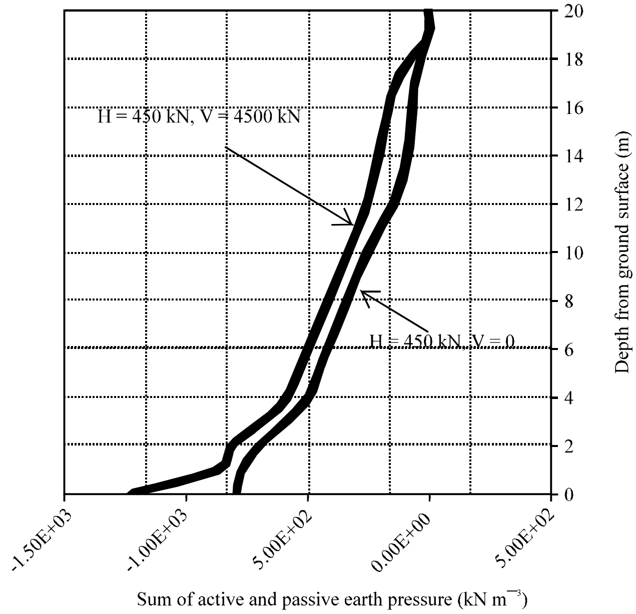

Fig. 6: Increase of lateral earth pressure calculated deep from the ground surface

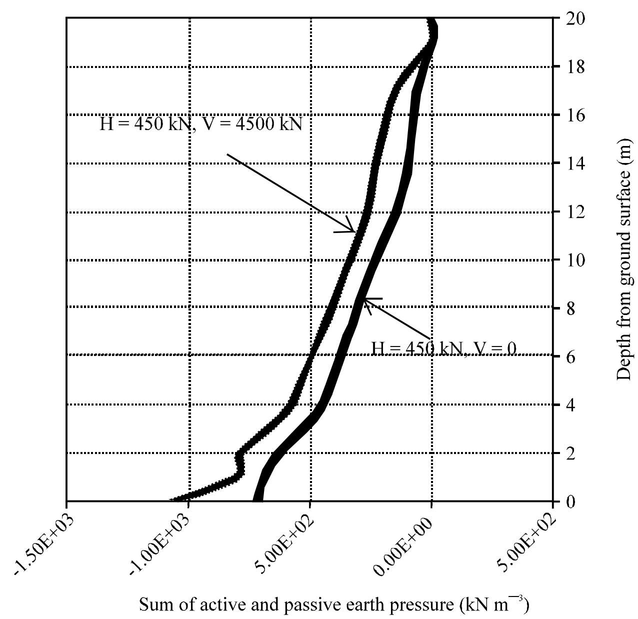

Fig. 7: Increase of lateral earth pressure calculated deep from the ground surface

surface) and then increase with depth to reach the maximum values at base of pile. This stresses assist to increase in lateral pile resistance. In addition, little differences in the friction stresses with different time of consolidation because it is less influenced by pore water pressure effect. The axial load intensity made little differences compared with the case of pure lateral load. This means that the lateral shear stresses is less influenced by the action of axial load.

CONCLUSION

The pile in early time of loading has a little change in lateral displacement. The pile with length of 10 and 15 m has much more settlement compared with another to pile length. The soil closed to the ground surface carry very little capacity and it is started from zero exactly at the ground surface until 1 D from surface. The maximum value in case of combined load is about 1.5 from maximum lateral earth pressure from the first case. The friction stresses has lowest values at the top of pile (near the surface) and then increase with depth to reach the maximum values at base of pile.

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