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THREE DIMENSIONAL ANALYSIS RESPONSE OF PILE SUBJECTED TO OBLIQUE LOADS

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Abstract— Pile foundations are commonly used to resist vertical and lateral loads applied to structures. Usually, these kinds of loads will act together to form a combination of loads, such as oblique forces that have a component of vertical and lateral forces. Predicting the behavior of piles subjected to oblique loads still remains a challenging task to geotechnical engineers. In this paper, results of numerical simulation of behavior of piles as embedded in cohesionless soil under oblique loads are presented by using ABAQUS. For the cohesionless soil, the Mohr-Coloumb constitutive law has been used to simulate the surrounding soil while the linear elastic model is used for modeling of the pile. The interactions between the pile and the surrounding soil are modeled thoroughly using contact elements based on slave-master concept. The results are shown in terms of load/displacement curves for the components of vertical and the lateral loading portions in different inclination angles. Finally, conclusions and recommendations are given concerning the design of piles under oblique loads.

Index Terms—: FEM model, Abaqus, Oblique load, Pile, Pile/soil interaction

1. Introduction

Pile foundations serve as one of the most important structural components in the design and construction of off-shore and on-shore facilities such as oil-rig platforms, jetties and naval bases. Normally the vertical loading of the pile is predominant. In special cases, for instance piles supporting offshore wind energy foundations or conductors, the vertical load is accompanied by a lateral load.

Current design practice involves separate analysis of the vertical and lateral responses of piles and does not consider the effect of interaction between the different load directions. Several results of investigations on the behavior of piles subjected to inclined loading have been reported in the literature [(Yoshimi, 1964), (Meyerhof, 1995), (Amde et al., 1997) and (Johnson et al., 2006). These investigations indicate that the pile response to horizontal loading is only slightly affected by a vertical load, whereas lateral loads significantly affect the vertical pile response. However, there has as yet been no clear and comprehensible presentation of important parameters and a quantification of interaction effects. This paper presents result of three-dimensional finite element analysis carried out in ABAQUS to investigate the behavior of vertical piles embedded in cohesionless soil under variable oblique loads.

2. Finite Element Modelling

Recently, with the rapid development of computing technology, numerical analysis methods involving finite element method (FEM) are widely used to understand the bearing capacity behavior of piles, especially for piles under combined loading conditions [(Lee et al., 2002) and (Rajagopal and Karthigeyan, 2008)]. The advantage of numerical analysis method lies in its ability to address complex soil layer and the interaction between soil and structure. In this paper, the finite element software ABAQUS is used to analyze the response piles as embedded in cohesionless soil under oblique loads are presented. Two different diameters D = 0.5 and D = 1.0 m were chosen in order to study the effect of pile geometry. The pile is supposed to be elastic and the soil is modeled using Mohr-Coulomb constitutive relationship (Poulos and Davis, 1980).

3. Validation of the Numerical Model

The validity of the numerical model was verified using ABAQUS of the behavior of a single pile under vertical loading based on the example of (Johnson et al., 2006). The schematic diagram of the single pile subjected to vertical load is shown in Figure 1. Solid concrete piles with a diameter 0.5 m and length of 7.32 m considered. The parameters of the pile and soil are shown in Table 1 (Johnson et al., 2006).

Table 1 The parameters of the pile and soil

Material	Young Modulus (MPa)	Poisson's Ratio	Internal Friction Angle
Pile	30000	0.15	---
Soil 1	19	0.3	35o
Soil 2	52.8	0.4	40.5o

Thus, the finite element mesh of half of the pile and the surrounding soil of the present model and (Johnson et al., 2006) model is illustrated in Figure 2. The single pile and soil of the present model was simulated such that it had the same dimension and boundary conditions. The FEM model was con-

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sidered only one-half of the pile taking advantage of symmetry as shown in Figure 2a. The interaction between the pile and the soil is simulated using a penalty-type interface between the pile and the soil. This type of interface is capable of describing the frictional interaction between the pile surface and the soil in contact. Several mesh densities and fixed boundary locations were trailed until a converged numerical solution was achieved.

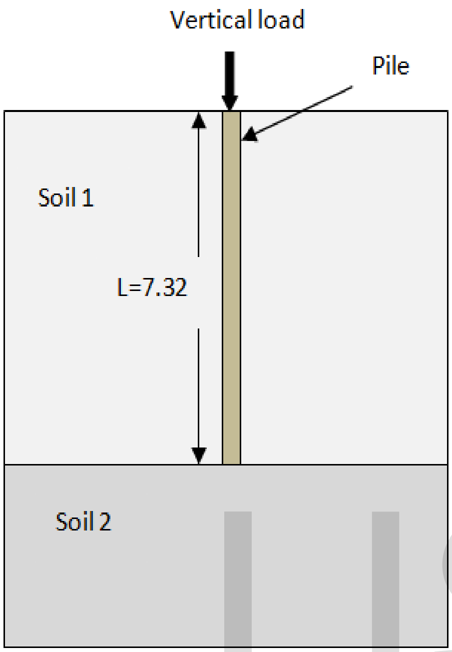
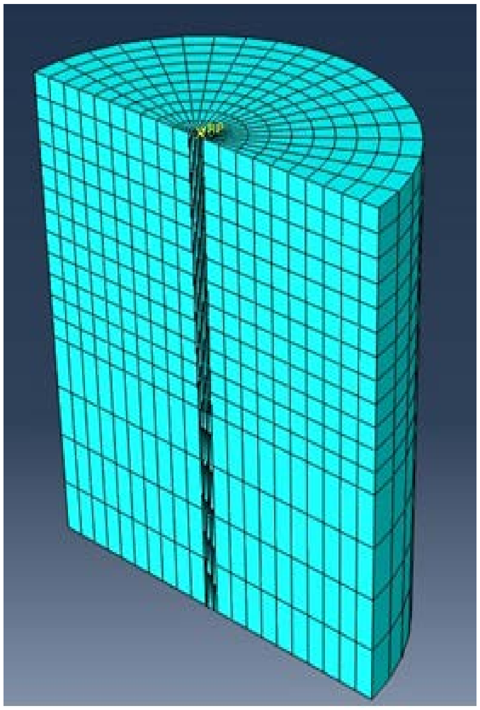
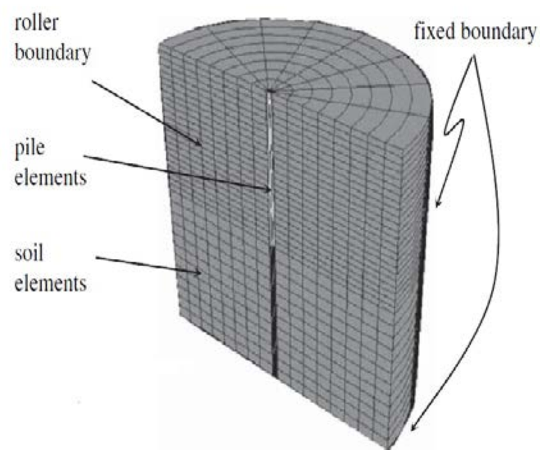


Figure 1: Schematic diagram of single pile group subjected to vertical load (Johnson et al., 2006)



a) Present FEM model



b) (Johnson et al., 2006) Model

Figure 2: Comparison between present model (a) and the (Johnson et al., 2006) (b)

Then, this single is loaded to vertical load to verify the results accuracy between the present model and (Johnson et al., 2006) model. The comparison between the present FEM results and FEM results obtained by (Johnson et al., 2006) for the pile load-displacement response is shown in Figure 3. Comparison between the results of ABAQUS simulations of this case and the result obtained by (Johnson et al., 2006) shows very good agreement, giving confidence in the validity of this software and its use by the author.

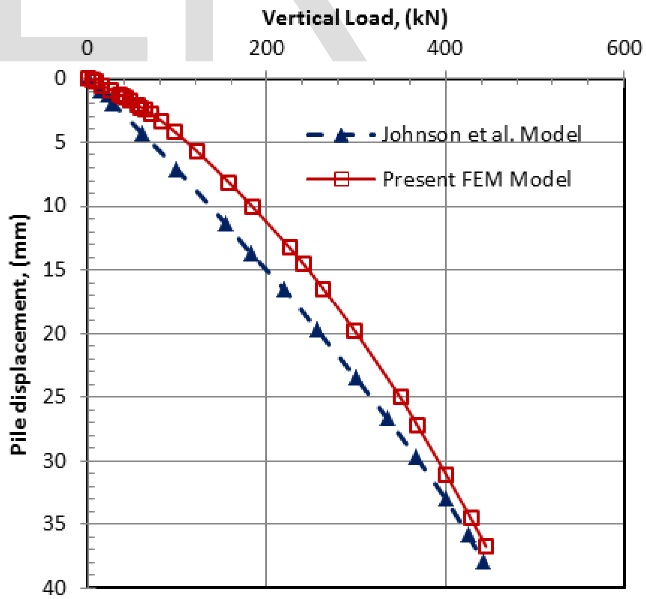


Figure 3: Typical pile load displacement response for pile (D=0.5 m)

4. Pile Subjected to Oblique Loads

For the investigation of the behavior of single piles under oblique loading conditions the same three-dimensional numerical model was used. The pile were subjected to variously oblique loads (α = 30o, 45°, 60o), with α measured from the horizontal direction, whereby the positive sign of α stands for compression loads (Figure 4).

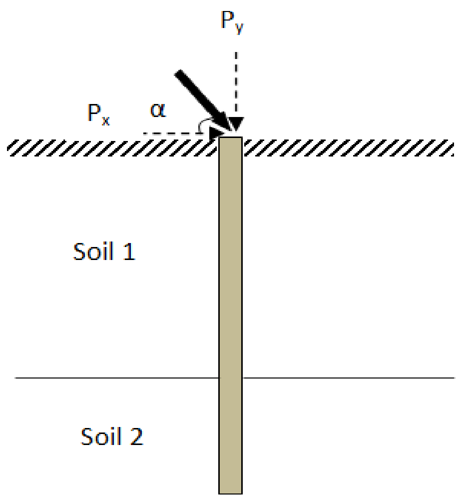


Figure 4: Single pile undergoing oblique load

5. Results of Numerical Modelling

5.1 Lateral Load Deformation Response

The lateral load deformation response of the pile with a diameter of 0.5 m and an embedded length of 7.32 m is shown in Figure 5. These results show the lateral displacement (Px) to be almost dependent of the oblique angle and thus dependent of a vertical load component acting together with the horizontal load. Different behavior were found in experiments by (Sastry and Meyerhof, 1990) and also in a numerical study of the behavior of steel pipe piles under oblique loads by two of the authors (Abdel-Rahman and Achmus, 2006).

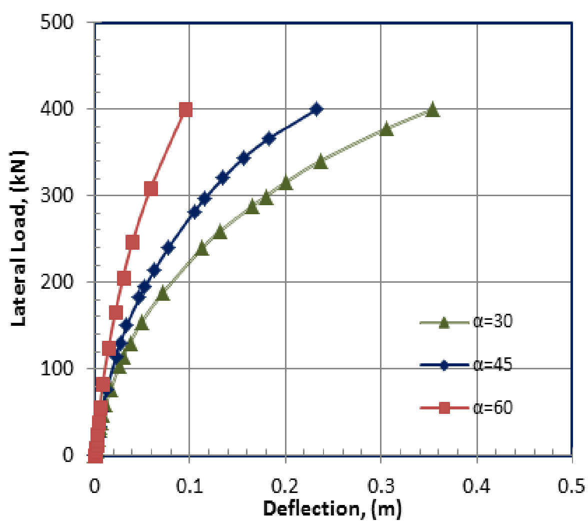


Figure 5: Lateral deformation at the pile dependent on lateral load component (D=0.5m, L=7.32m)

Since the same behavior is obtained for the (second case) with a pile diameter 1 m (Figure 6), this finding seems to be independent of the pile diameter and the relative stiffness. For the pile have bigger diameter, the differences in the load-deformation responses are even lower than the pile have smaller diameter. This behavior is in agreement with (Salini and Girish, 2009).

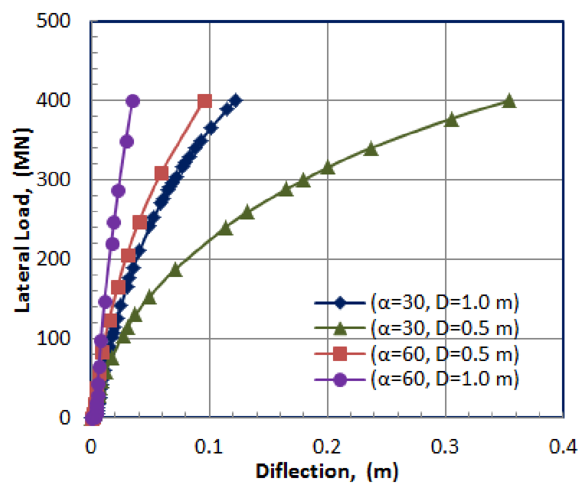


Figure 6: Load deformation comparison between both piles

5.2 Vertical Load Displacement Response

The pile head displacement in the vertical direction versus the applied vertical load (Py) is shown in Figure 7. This plot illustrates that for a lower inclination angle, the vertical force required to displace a pile vertically is reduced. This means, the horizontal load has a significant effect, since it leads to a softer behavior in the vertical direction.

The pile displacement responses in the Figure 7 change their slope rapidly corresponds to the loading step where the incremental shaft resistance (skin friction resistance) of the piles becomes zero, i.e. the ultimate shaft friction capacity (Q_f) is reached. This means that the remaining stiffness and capacity is only due to the end bearing resistance (Q_b) of the pile.

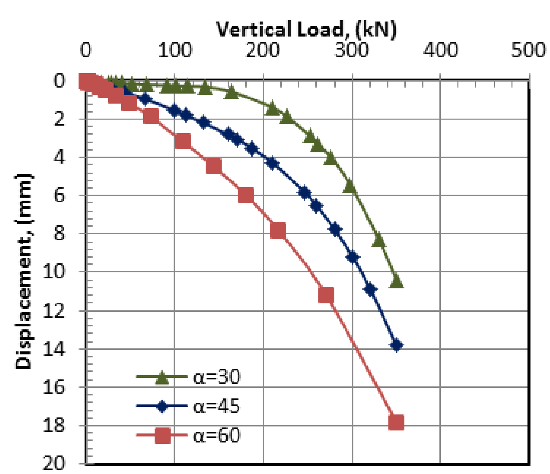


Figure 7: Vertical displacement at the pile top dependent on the vertical load component (D=0.5 m)

Figure 8 shows the vertical load-displacement curve for the both chosen piles. It is apparent that the vertical capacity is

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decreased by the presence of a horizontal load. Since for the smaller diameter D=0.5 m the load portion carried by the base resistance (Q_h) is lower, the displacement responses for different oblique angles is slightly greater than for D=1.0 m (see Figure 8).

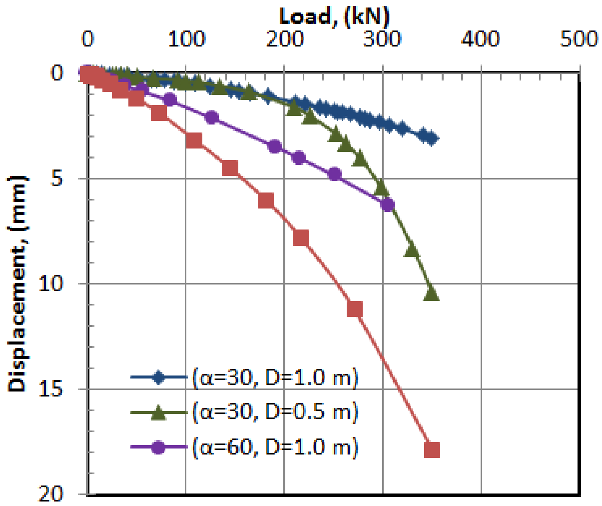

Figure 8: Load displacement comparison between both piles

6. Conclousion

The finite element models used in this paper allowed the investigation into the response of the pile under oblique loads. A 3D numerical model is developed with ABAQUS software is used to in this investigation. This study provides a comparison of common techniques for analysis of single piles subjected to oblique loads in different inclination angle. The piles were subjected to variously inclined loads (α=30o, 45o, 60o), with α measured from the horizontal direction. The following conclusions are drawn from the present investigation:

1. The stiffness of pile is almost affected on the behavior of pile subjected to combine vertical and lateral loading (oblique loads).
2. The vertical and horizontal loads level itself strongly depends on the load inclination angle (α).
3. The ultimate vertical pile capacity of the pile is decreased by additional horizontal loading.

References

1. Abdel-Rahman, K. and Achmus, M. Numerical modelling of combined axial and lateral loading of vertical piles. *Proc., 6th European Conference on Numerical Methods in Geotechnical Engineering, Graz, Austria, September*.
2. Amde, A. et al. (1997). Model study of H-piles subjected to combined loading. *Geotechnical & Geological Engineering*, **15**(4), 343-355.
3. Johnson, K. et al. (2006). Modelling the load–deformation response of deep foundations under oblique loading. *Environmental Modelling & Software*, **21**(9), 1375-1380.
4. Lee, C. et al. (2002). Numerical modelling of group effects on the distribution of dragloads in pile foundations. *Geotechnique*, **52**(5), 325-335.
5. Meyerhof, G. (1995). Behaviour of pile foundations under special loading conditions: 1994 RM Hardy keynote address. *Canadian Geotechnical Journal*, **32**(2), 204-222.
6. Poulos, H. G. and Davis, E. H. (1980). Pile foundation analysis and design.
7. Rajagopal, K. and Karthigeyan, S. (2008). Influence of combined vertical and lateral loading on the lateral response of piles. *International Association for Computer Methods and Advances in Geomechanics (IACMAG)*, 3272-3282.
8. Salini, U. and Girish, M. (2009). Lateral Load Capacity of Model Piles on Cohesionless Soil. *The Electronic Journal of e-Government*.
9. Sastry, V. and Meyerhof, G. (1990). Behaviour of flexible piles under inclined loads. *Canadian Geotechnical Journal*, **27**(1), 19-28.
10. Yoshimi, Y. (1964). Piles in cohesionless soil subject to oblique pull. *ASCE J Soil Mech Found*, **504**(90), 6.