Response of single pile under axial and lateral loads

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Abstract: The response of pile, subjected to axial (vertical) and lateral (horizontal) loads, is presented in this paper. PLAXIS 2D finite element software version 8.2 is used in this analysis. The pile is simulated as beam element of linear elastic properties. The Hardening soil model under drained condition was employed to simulate the soil stress-strain behavior. A horizontal force of 93.75, 187.5, and 375 kN is applied to the top, middle, and bottom of the pile which is embedded in loose sand, while maintaining 375 kN as axial load on the pile. Bending moment and lateral displacements along the pile length is explored in this paper. The effect of lateral force position, lateral force value, and axial load value on the pile response was studied. Results revealed that the distribution of bending moment and lateral displacement along the pile length is affect considerably by position and value of lateral load. However, the effect of vertical force value on pile response is not significant.

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1. Introduction

Concrete piles are usually used to sustain vertical and horizontal loads. Piles can transfer axial and lateral loads to stronger soil, or to bedrock. Although the load applied to pile foundations is a combination of vertical and horizontal loads, the second component is considered to be more critical, as piles are usually designed to sustain significant vertical loads. Pile foundations must be capable to resist the lateral forces due to earthquake and wind. In the design of piles, the effect of combination of vertical and horizontal components must be taken into account. This paper will concentrate on pile response under axial and lateral loads as they are the major criteria on the design.

There have been few researches on behavior of piles subjected to combined loadings to investigate pile response. Anagnostopoulos and Georgiadis (1993) carried out a series of tests on instrumented model piles to investigate the effect of interaction on the axial and lateral responses of piles in clay. Karthigeyan et al. (2006) studied the influence of vertical load on the lateral response of piles in sand. Khelifi et al. (2011) presented behavior of a single pile subjected to axial and lateral loads, with taking into account the interaction between the soil and the pile. Zhang and Li (2012) used software ANSYS to study the response of axially loaded piles under lateral ground movements. Response of piles subjected to horizontal loading was investigated by Conte et al (2013). Khodair and Abdel-Mohti (2014) performed an analysis of the composite pile–soil system using the finite difference software LPILE. In addition, soil's modulus of elasticity, radius of the soil surrounding the pile in Abaqus/Cae, and the number of springs in SAP2000 was studied. A lateral displacement was applied to the top of the pile while maintaining a zero slope in a guided fixation. The axial and lateral behaviors of non-welded composite piles were investigated based on pile load test results by Park (2016). Hazard et al. (2017) evaluated the influence of vertical loads on the lateral performance of pile foundations.

2. Finite element model

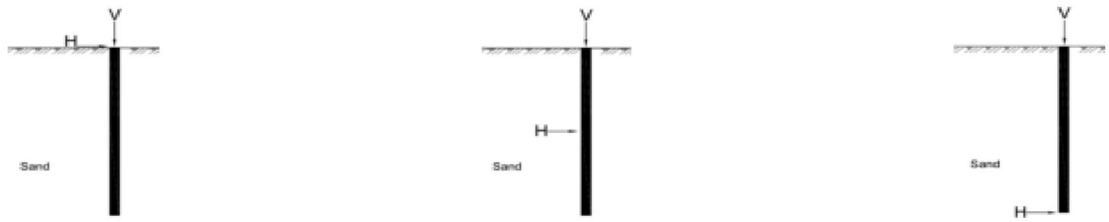
Table 1. Soil parameters.

Parameter	Sand layer
γ_{unsat} (kN/m^3)	17
γ_{sat} (kN/m^3)	20
E^{ref}_{50} (kN/m^2)	40000
E^{ref}_{oed} (kN/m^2)	40000
E^{ref}_{ur} (kN/m^2)	120000
ν_{ur}	0.2
C_{ref} (kN/m^2)	1
Φ (°)	32
Ψ (°)	2

The problem analyzed is shown in Fig. 1, where a pile subjected to vertical and lateral loads. A series of (2D) finite element analyses is conducted to evaluate the influence of vertical and horizontal loads on the response of pile foundations. Stress deformation analyses were performed using the finite element program PLAXIS 2D. For comparison purposes, horizontal force was applied to the top, middle, and bottom of the pile, as presented in Figs. 1(a) to 1(c), respectively. Combined load analyses were performed for vertical (V) and horizontal (H) loads equal to 93.75, 187.5, and 375 kN.

Soil modeling

In this study, the soil considered is loose sand. The behavior of sand has been idealized using the Hardening-soil model under drained condition. Properties of the soil used are given in Table 1.



(a) Horizontal force was applied to the top of the pile (b) Horizontal force was applied to the middle of the pile (c) Horizontal force was applied to the bottom of the pile

Fig. 1. General layout of the pile subjected to combination of vertical and horizontal loadings.

Pile modeling

The pile wall is simulated as beam element of linear elastic properties. The beam element is defined per meter so the bending stiffness and the normal stiffness are smeared per meter in the out-of-plane. Pile Young's modulus (E) is 2.2 x 10^7kN/m^2 and Poisson's ratio is 0.15. Pile diameter is assumed to be 0.5 m with clear spacing of half pile diameter between pile edges. The interface elements are used to simulate the interaction between the pile and the soil.

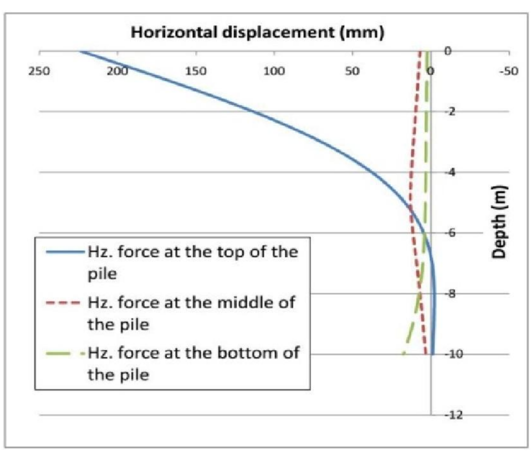
Analysis procedure

For the purpose of this research, the analysis is carried out in steps. The first step is installation of pile. The second step is applying vertical axial load on the top of pile. The third step is applying horizontal load on the existing pile.

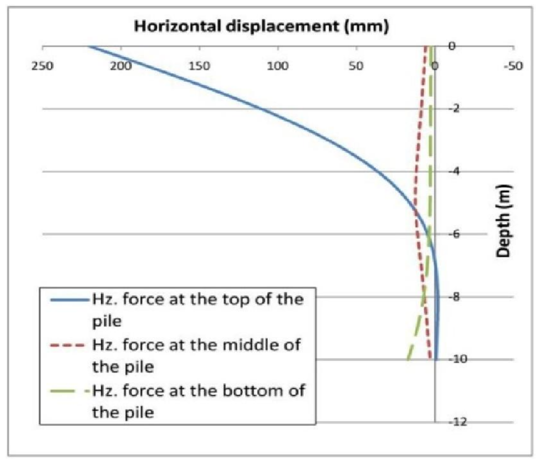
3. Results and Discussion

This section presents results for pile horizontal displacement and bending moment as a result applying vertical and horizontal loads on the pile foundations.

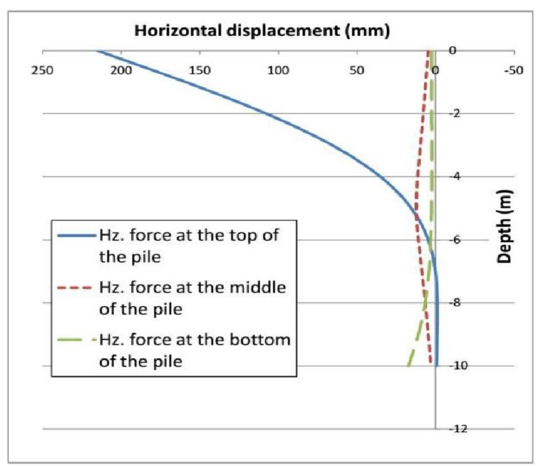
Effect of horizontal force position



(a) (V=93.75 kN and H=375 kN)



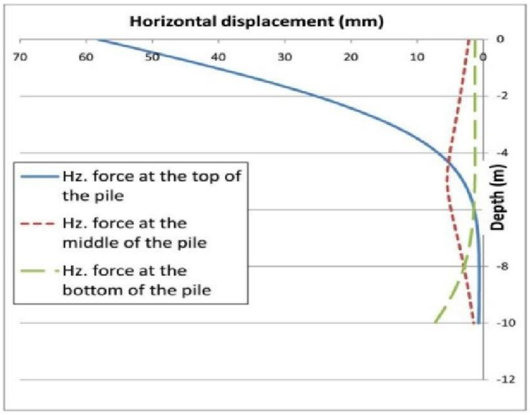
(b) (V=187.5 kN and H=375 kN)



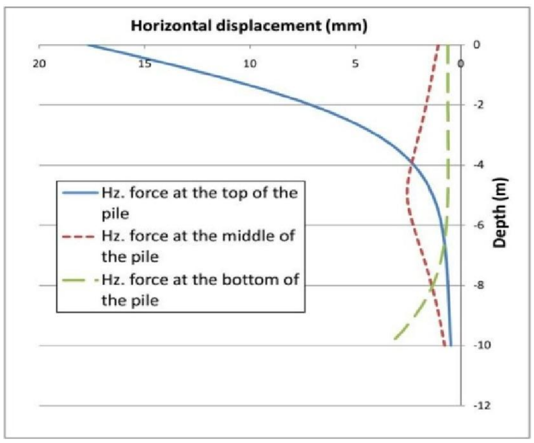
(c) (V=375 kN and H=375 kN)

A) Pile horizontal displacement

Figure 2 shows the pile horizontal displacement (pile lateral deformations) at different values of (H) and (V) and different positions of (H). It is apparent that for all vertical load values, position of Hz. force has a significant effect on pile horizontal displacement. Maximum horizontal displacement occurs at the point of horizontal force application. The biggest horizontal displacement is produced when (H) is applied to the top of the pile.

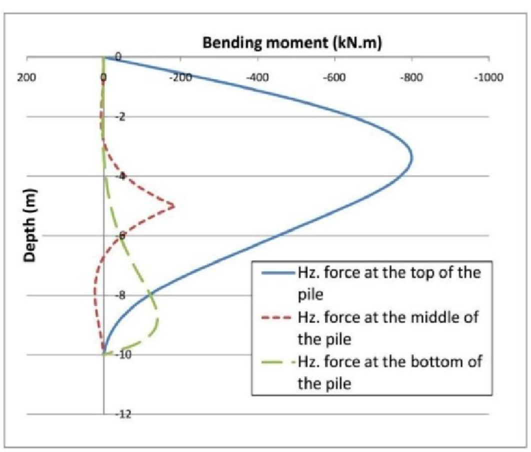


(d) (V=375 kN and H=187.5 kN)

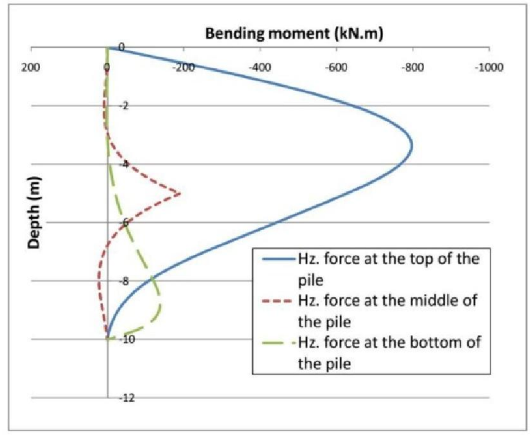


(e) (V=375 kN and H=93.75 kN)

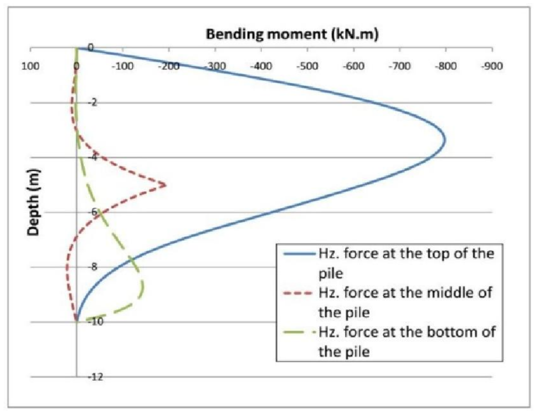
Fig. 2. Pile horizontal displacement at different position of horizontal force



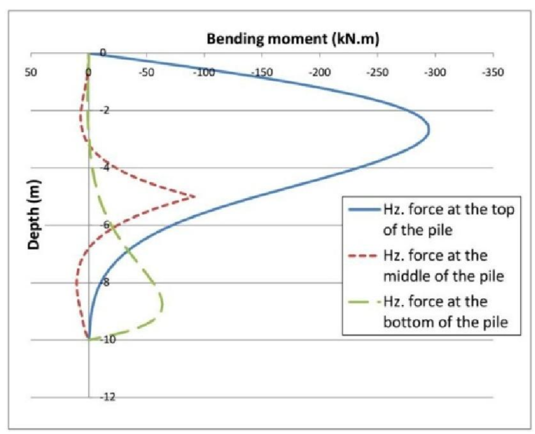
(a) (V=93.75 kN and H=375 kN)



(b) (V=187.5 kN and H=375 kN)



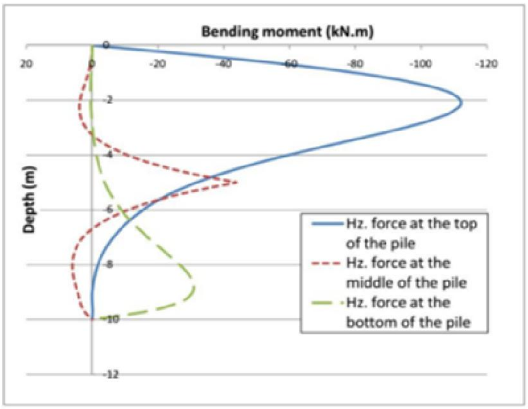
(c) (V=375 kN and H=375 kN)



(d) (V=375 kN and H=187.5 kN)

B) Pile bending moment

Figure 3 shows bending moment along the pile shaft at different values of (H) and (V) and different positions of (H). It is observed that, position of Hz. force has a major effect on bending moment profiles. When (H) is applied to the middle of the pile, the maximum bending moment occurs at the point of horizontal force application. Moreover, the pile bending moment profiles for different positions of (H) are different in shape. When (H) is applied to the top of the pile, it is clear that pile will have the biggest bending moment.



(e) (V=375 kN and H=93.75 kN)

Fig. 3. Bending moment along pile shaft at different position of horizontal force.

Effect of horizontal force value

A) Pile horizontal displacement

The influence of horizontal force value with constant vertical force (V=375 kN) is presented and compared in Fig. 4. As a result of increasing horizontal force, maximum horizontal displacement increases by more than 100% at all cases.

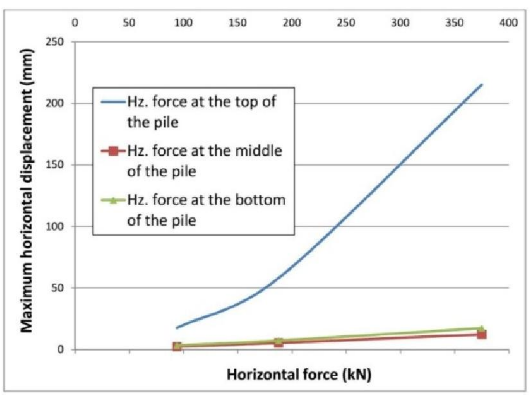


Fig. 4. Maximum horizontal displacement-horizontal force curves of piles (V=375 kN)

B) Pile bending moment

The pile maximum bending moment increases as a result of increasing (H) which is applied to the middle of the pile. In addition, the pile maximum bending moment is slightly changed when (H), applied to the bottom of the pile, changes. For all cases, the most significant parameter affecting the pile maximum bending moment is the value of (H). The pile maximum bending moment is increased by more than 100% when (H) increases from 93.75 kN to 187.5 kN and from 187.5 kN to 375 kN.

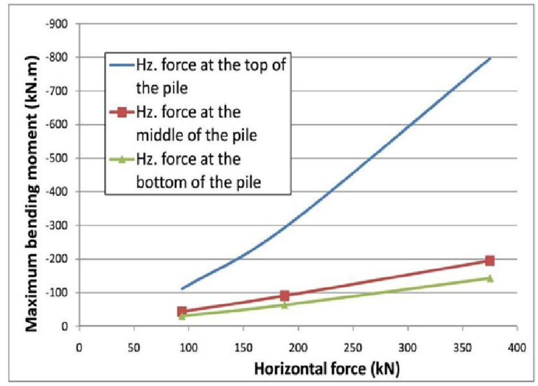


Fig. 5. Maximum bending moment-horizontal force curves of piles (V=375 kN)

Effect of vertical force value

A) Pile horizontal displacement

The effect of vertical force value on pile horizontal displacement is not significant, as shown in Fig. 6. Indeed, maximum horizontal displacement slightly decreased for Hz. force at the top and middle of the pile as a result of increasing (V).

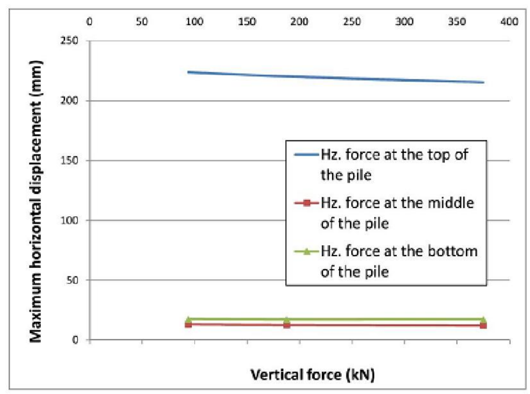


Fig. 6. Maximum horizontal displacement-vertical force curves of piles (H=375 kN)

B) Pile bending moment

Figure 7 indicates the effect of vertical force on pile maximum bending moment. It seems that, the values of vertical loads did not significantly affect the response of the piles under horizontal loads. When (H) is applied to the middle of the pile, the maximum bending moment increases by about 2% and 3% when (V) increases from 93.75 kN to 187.5 kN and from 187.5 kN to 375 kN, respectively.

Conclusions

This paper has attempted to demonstrate the effect of lateral force position, lateral force value, and axial load value on the bending moment and lateral displacements along the pile length. The software results revealed that the pile response is affected considerably by position and value of lateral load. However, the effect of vertical force value on pile response is not significant. Maximum horizontal displacement occurs at the point of horizontal force application.

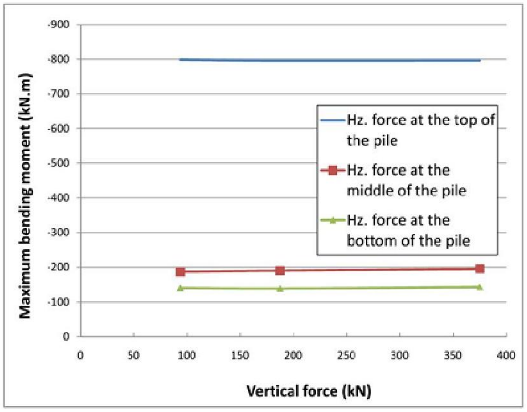


Fig. 7. Maximum bending moment-vertical force curves of piles (H=375 kN)

References

1. Anagnostopoulos, C., & Georgiadis, M. (1993). Interaction of axial and lateral pile responses. Journal of Geotechnical Engineering, 119(4), 793-798.
2. Conte, E., Troncone, A., & Vena, M. (2013). Nonlinear three-dimensional analysis of reinforced concrete piles subjected to horizontal loading. Computers and Geotechnics, 49, 123-133.
3. Hazzar, L., Hussien, M. N., & Karray, M. (2017). Influence of vertical loads on lateral response of pile foundations in sands and clays. Journal of Rock Mechanics and Geotechnical Engineering, 9(2), 291-304.
4. Karthigeyan, S., Ramakrishna, V. V. G. S. T., & Rajagopal, K. (2006). Influence of vertical load on the lateral response of piles in sand. Computers and Geotechnics, 33(2), 121-131.
5. Khelifi, Z., Berga, A., & Terfaya, N. (2011). Modeling the Behavior of Axially and Laterally Loaded Pile with a Contact Model. EJGE, 16.
6. Khodair, Y., & Abdel-Mohti, A. (2014). Numerical analysis of pile–soil interaction under axial and lateral loads. International Journal of Concrete Structures and Materials, 8(3), 239-249.
7. Park, J. H., Shin, Y., & Chung, M. (2016). Experimental study on axial and lateral bearing capacities of nonwelded composite piles based on pile load test results. In Proceedings of the 17th Nordic Geotechnical Meeting.
8. PLAXIS 2D Manual.
9. Zhang, Z. F., & Li, J. P. (2012). Analysis of Piles Subject to axial load and lateral soil movement. In Advanced Materials Research (Vol. 383, pp. 1708-1713). Trans Tech Publications.

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