The Influence of Excavation on Behavior of Piles Supporting Excavation and an Adjacent Pile Foundation

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Abstract— In urban environment, most buildings are adjacent to each other. High rise buildings need deep excavation. The excavation will cause large soil movement and may cause damage to the adjacent building. For this reason, this research studies the effect of nearby excavation on existing pile group and piles supporting excavation numerically. This research investigates the behavior of piles supporting excavation and a triple-row of capped head piles located nearby an excavation. Response of piles in sand due to excavation-induced lateral soil movements is studied by using PLAXIS 2D finite element software version 8.2. A parametric study was performed to study the effect of adding strut to the pile supporting excavation and effect of pile supporting excavation length.

Index Terms— Adjacent pile group, excavation, soil movement, pile wall, wall support systems, finite element method, bending moment.

1 Introduction

One of the main design constraints is to prevent damages to adjacent buildings, especially during excavation for basement construction. There are several examples where pile foundations have been damaged by nearby excavation. As excavation proceeds, the surrounding soils will move towards the excavation and their movement will induce bending moments in the existing piles. One of the most famous damage caused by horizontal soil movement is the collapse of 13-storey building in China in 2009 under nearby surcharge loading and excavation works. Thus, attention here will be focused on the lateral response of piles to excavation-induced lateral soil movements

Poulos and Chen [1] studied the single pile response due to supported excavation-induced lateral soil movement in uniform clay layer using finite element program, which was named AVPULL. Elkady [2] presented the results of numerical simulations performed using a 3D finite element program ABAQUS (2010) to evaluate the behavior of a single pile nearby a cantilever side supported excavation. Liang et al. [3] presented an analytical method for response of an axially loaded pile group subjected to lateral soil movement. Qin and Guo [4] performed laboratory tests to investigate the responses of piles subjected to lateral soil movement. Xu and Gao [5] analyzed the interaction of foundation pit excavation and adjacent existing building's pile foundation, using ANSYS finite element software to simulate the deformation of adjacent pile foundation in case of foundation pit excavation. Zhang and Mo [6] presented analytical solution for pile response due to excavation-induced lateral soil movement to determine the behavior of adjacent pile based on Winkler model. Al-Abboodi et al. [7] studied the response of single pile subjected to lateral soil movement using three-dimensional finite element program PLAXIS 3D. Liyanapathirana and Nishanthan [8] investigated the behavior of a single pile, closer to an excavation, using a three-dimensional finite element program ABAQUS/Standard (2011). Mu and Huang [9] proposed a semi-empirical method to calculate the influence of excavations on adjacent piles. Nishanthan et al. [10] investigated the shielding effect within piles in a group adjacent to deep unbraced and braced excavations. A "shielding effect" is one of the ways to consider the interaction between piles in a pile group. Shaikhoun [11] presented results of numerical analysis to evaluate the interaction behavior between existing building piles and piles supporting excavation.

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2 Finite Element Analyses

The problem analyzed is shown in Fig. 1, where a triple-row of capped head piles located nearby a supported excavation. This study is carried out using PLAXIS 2D version 8.2. Selection of plane strain condition results in a two-dimensional finite element model with only two translational degrees of freedom per node. The main problem when modelling a pile with a plane strain model is the transition from three-dimensional to two-dimensional model so the out-of-plane rows of piles are simplified as wall elements. The wall element is defined per meter so the bending stiffness and the normal stiffness for the piles in the out-of-plane row of piles are smeared per meter. The finite element mesh dimensions must be sufficient for simulating the problem. The selected dimensions for the model are shown in Fig. 2. Staged construction provides an accurate simulation of various loading, construction and excavation processes. For the purpose of this research, the analysis is carried out in steps. The first step is installation of axially loaded existing building pile group. The second step is construction of piles supporting excavation. The third step is excavation by soil removal in 1m depth layers for each step and strut is placed.

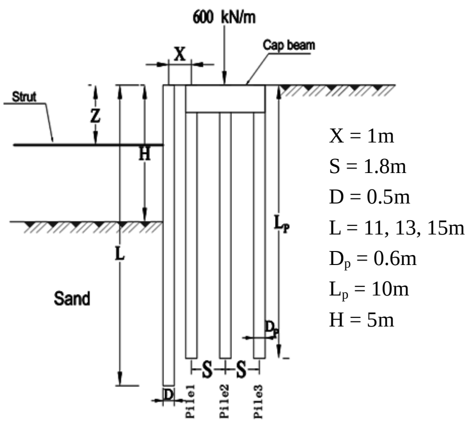

Fig. 1. Triple-row of existing building piles located nearby a supported excavation

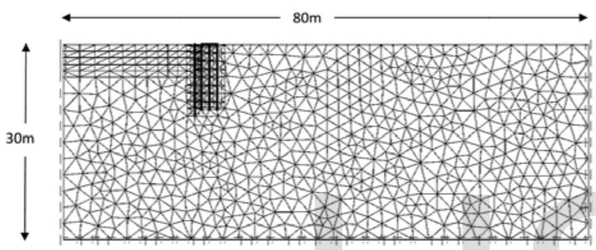

Fig. 2. Finite element mesh and dimensions

3 Input Parameters

In this study, the soil considered is sand. The properties of the sand layer are listed in Table 1. The piles are simulated as beam element of linear elastic properties. Pile Young's modulus (E) is 2.2x107 kN/m² and Poisson's ratio is 0.15. Out-of-plan clear spacing between piles supporting excavation and spacing between existing building piles are assumed to be 0.25m and 3m, respectively. Preliminary calculations were performed to determine the safe length of piles supporting excavation, and the factor of safety was taken 1.3. According to these calculations, it was found that the required safe length of piles supporting excavation is 10.4m for the 5m excavation depth. The existing building piles are assumed to be tied using beam element with thickness 1.0m.

TABLE 1
Soil Parameters

γ_{unsat} (kN/m³)	γ_{sat} (kN/m³)	E_{50}^{ref} (kN/m²)	E_{oed}^{ref} (kN/m²)	E_{ur}^{ref} (kN/m²)	ν_{ur}	C_{ref} (kN/m²)	ϕ (degree)	Ψ (degree)	R_{inter}
17	20	40000	40000	120000	0.2	1	32	2	0.67

4 Results and Discussion

4.1 Bending moment distribution along the piles

Figure 3 shows bending moment profiles for the pile supporting excavation in case of no strut and 11m length of the pile supporting excavation. While the bending moment profiles for the existing building piles are plotted in Fig. 4. It can be seen that nearby excavation has a major effect on both pile supporting excavation and existing building piles. It is important to check whether the existing piles can sustain the bending moment resulting from excavation or not. It is also apparent that bending moment profiles of the pile supporting excavation and the existing building piles are different in shape. In addition, the general trend of the pile bending moments observed for the three existing piles is noted to be dissimilar. This observation could be explained by every single pile pushes the soil behind it creating a shear zone in the soil. An overlap that occurs between shear zones in different rows is known as shadowing effect. In addition, negative bending moments along the upper part of the existing building piles are observed due to the effect of group interaction. A closer look at the data indicates that, the peripheral piles in the pile group always have higher bending moments than those of interior piles. This observation may be attributed to the pile cap transfers part of bending moment from the interior piles to the peripheral piles and the interior pile having a higher number of adjacent piles and therefore the effect of interaction among piles is more significant. Conversely, the peripheral piles are more exposed to the disturbance from soil movements as they have fewer piles around them. The location of maximum bending moment for the pile supporting excavation is at 1.5m below the dredge line. Likewise, the maximum bending moment for the existing building pile (1) is located below the dredge line. However, maximum bending moments in the existing building piles (2) and (3) are located at the top of the piles.

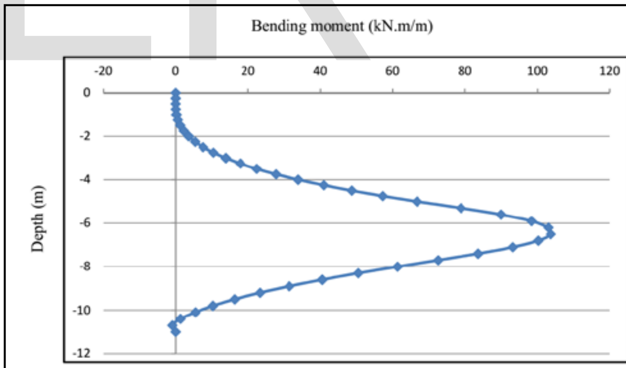

Fig. 3. Pile supporting excavation bending moment

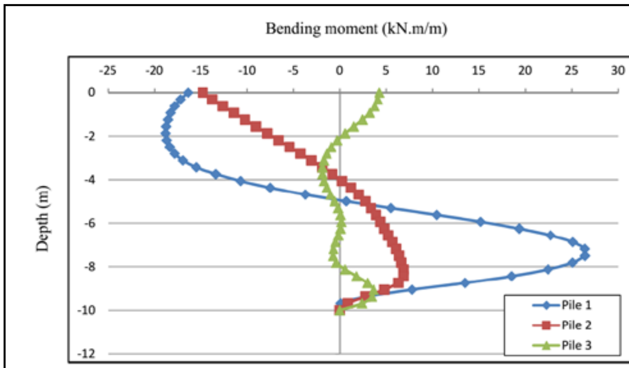

Fig. 4. Existing building piles bending moments

4.2 Effect of adding strut to the pile supporting excavation

For 11m length of the pile supporting excavation, the sides of the excavation are supported by piles, which are braced by horizontal struts at an interval of 5.0 m. Fig. 5 shows bending moment for the pile supporting excavation result for different cases of strut. Adding strut to the pile supporting excavation and position of the strut have a major effect on bending moment profiles for the pile supporting excavation. With reference to Fig. 5, it is inferred that the provision of struts reduces significantly maximum bending moment in the pile supporting excavation. In addition, the pile bending moment profiles for different strut positions are different in shape as clearly seen in Fig. 5. Also, it is observed that the maximum bending moment location changes with changing distance (Z). For comparison purposes, Fig. 6 show the maximum bending moment for the existing building piles for different cases of strut. It can be seen that, maximum bending moments in the existing peripheral piles decrease with increasing distance (Z), which are ranged from 1m to 4m. From the results shown in Fig. 5, it can be observed that the maximum bending moment in the pile supporting excavation decrease by 46% when the piles are braced by horizontal struts at (Z=2m). S0, it is recommended to use piles supporting excavation, which are braced by struts at (Z= 2m) to minimize maximum bending moment in the pile supporting excavation. However, the maximum bending moments in the existing piles are minimized when the piles supporting excavation are braced by struts at (Z= 4m).

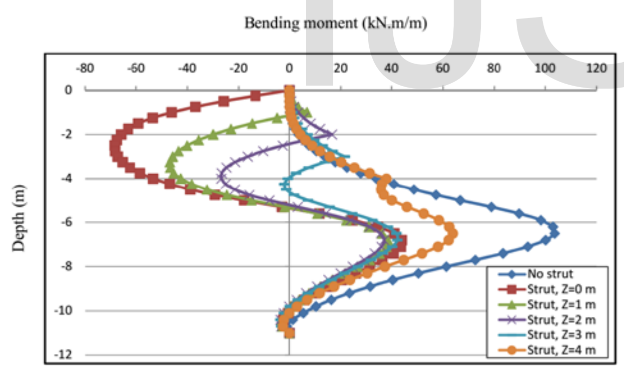

Fig. 5. Bending moment for the pile supporting excavation result for different cases of strut

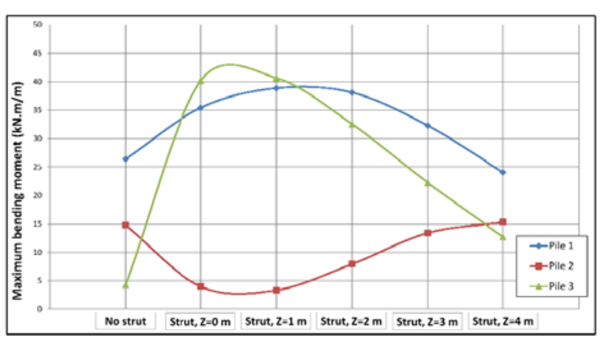

Fig. 6. Existing building piles bending moment results summary for different cases of strut

4.3 Effect of Pile Supporting Excavation Length

Although increasing pile supporting excavation length provides fixation to the bottom of the pile, length of the pile supporting excavation does not seem to have a significant effect on location and magnitude of the maximum bending moment of the pile supporting excavation, as shown in Fig. 7. However, the pile bending moment profiles for different pile lengths are partially different in shape. The maximum bending moment for the existing building piles are plotted in Fig. 8. It is observed that increasing length of the pile supporting excavation results in a minor change in maximum bending moments in the existing building piles.

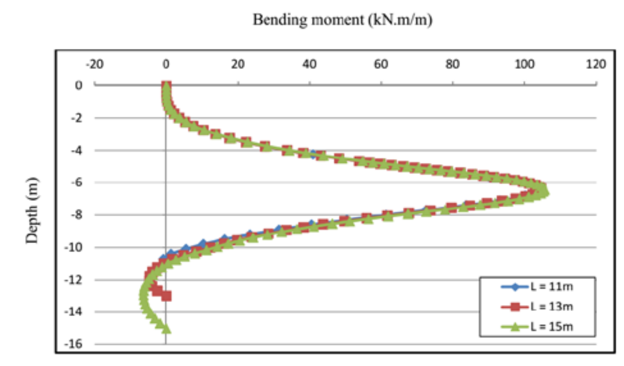

Fig. 7. Pile supporting excavation bending moment result for different pile supporting excavation lengths

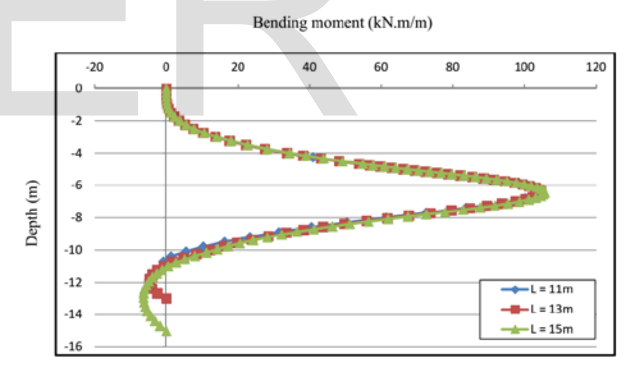

Fig. 8. Maximum bending moment for the existing building piles result for different pile supporting excavation lengths

5 Conclusions

Main conclusions that can be deduced from this study can be summarized in the following points:

- It is crucial to examine how the induced bending moments will impact the structural capacity of pile foundations and to check whether the existing piles can sustain the extra bending moment resulting from a nearby excavation or not.
- The provision of struts reduces significantly maximum bending moment in the pile supporting excavation.
- It is recommended to use piles supporting excavation, which are braced by struts at (Z= 2m) to minimize maximum bending moment in the pile supporting excavation.
- Maximum bending moments induced due to excavation

in the existing peripheral piles decrease with increasing distance (Z).

- The influence of increasing the length of pile supporting excavation becomes negligible on location and magnitude of maximum bending moment in the pile.
- The peripheral piles always have higher bending moments than those of interior piles in the pile group.

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