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INFLUENCE OF PILE SUPPORTING EXCAVATION PROPERTIES ON EXISTING PILE FOUNDATIONS

MOSTAFA A. ABD EL-NAIEM[1], MOHAMMED M.A. HUSSEIN[2,] MAMDOUH A. KENAWI[3],

, AND MOHAMED G. SHAIKHOUN[4]

1 Associate Prof, Civil Engineering Department, Assiut University,

Email: mostafaabdo6689@gmail.com

2Associate Prof, Civil Engineering Department, Sohag University,

Email: mohamed.ma_2000@yahoo.com

3 Assistant Prof, Civil Engineering Department, Sohag University,

Email: mkenawi1@yahoo.com

4 Demonstrator, Civil Engineering Department, Sohag University,

Email: engm_gamal2013@yahoo.com

Abstract: One of the main design constraints is to prevent damages to adjacent buildings, especially during excavation for basement construction. As excavation proceeds, the surrounding soils will move toward the excavation and their movement will induce bending moments and deflections in the existing pile groups. The existing pile response due to the excavation-induced lateral soil movements had been studied previously by using numerical analysis and laboratory analysis, but there are some parameters did not study. For this reason, this research studies numerically the interaction between existing pile groups and piles supporting excavation. Commercial program Plaxis 2D is used in the numerical analysis. This research contains two groups with different cases: piles supporting excavation only and quadruple-row of capped head existing piles are nearby a supported excavation. A parametric study was performed to study the effect of pile supporting excavation diameter, length, and excavation depth. Results indicated that as a result of increasing diameter of the pile supporting excavation, bending moment in the pile supporting excavation increases, however bending moments in the existing building piles decrease. Moreover, by increasing the excavation depth, the maximum bending moment increases in both pile supporting excavation and existing building piles but this bending moment does not occur at the same depth. Furthermore, the peripheral piles in the pile group always have higher bending moments than those of interior piles.

INTRODUCTION

In urban environment most buildings area are closely spaced. Although an excavation will cause both vertical and lateral soil movements, the second component is considered to be more critical, as piles are usually designed to sustain significant vertical loads. In contrast, lateral loads

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imposed by soil movements may lead to structural damage. There are several examples where pile foundations have been damaged by excavation, for example, the collapse of 13-storey building in China in 2009[1]. Several researches have used numerical analysis, for example, Poulos et al.[2], Kok and Bujang[3], Iliadelis[4], Elkady[5], and El-Kabbany[6] to evaluate the performance of existing pile adjacent to excavation. Zhang and Li[7] and Al-Abboodi et al.[8] studies numerically the pile response under lateral ground movements. Zhang and Mo[9] presented analytical solution for pile response due to excavation to determine the behavior of adjacent pile. Leung et al.[10] and Goh et al.[11] described a series of laboratory tests on piles subjected to lateral movement.

FINITE ELEMENT ANALYSIS

Stress deformation analyses were performed using the finite element program PLAXIS 2D. Model dimensions were selected so that the boundaries are far enough to cause any restriction or strain localization to the analysis, as shown in Figure 1. The analysis was carried out in steps. The first step was installation of existing building pile groups. The second step was construction of piles supporting excavation. The third step was excavation to the required depth.
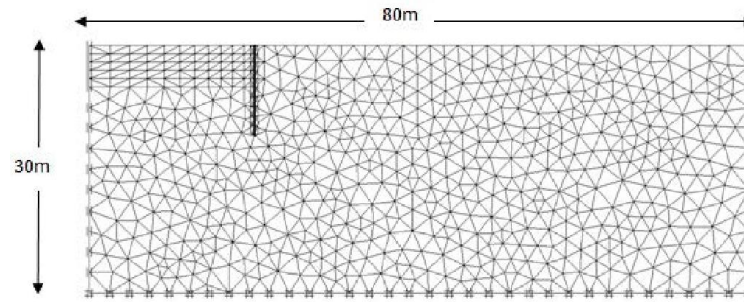

Figure 1. Finite element mesh and dimensions

Input Parameters and Model Variables

The Hardening soil model under drained condition is used to simulate the behavior of the selected sand soil. The properties of the sand layer are listed in Table 1. The piles are simulated as beam element of linear elastic properties. The pile parameters are presented in Table 2. 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. The factor of safety was taken from 1.2 to 1.4 according to the Egyptian code of soil mechanics and foundation design, part 7[12]. According to these calculations, variations of pile safe length with excavation height are listed in Table 3.

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

Table 2. Input parameters of pile supporting excavation and existing building pile

component	Pile diameter (m)	Young's modulus (kN/m^2)	Poisson's ratio
Pile supporting excavation	0.5, 0.6, and 0.7	2.2 x 10^7	0.15
Existing building pile	0.6	2.2 x 10^7	0.15

Table 3. Variation of pile supporting excavation length and excavation depth

Excavation depth (m)	5.00	6.00	7.00
Safe length of piles supporting excavation (m)	11.00	13.00	15.00

Model Description
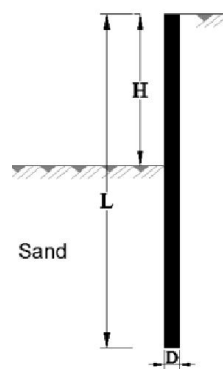
Figure 2. Piles supporting excavation only model
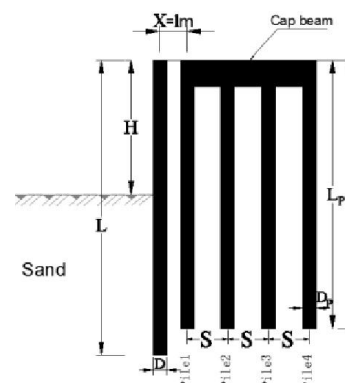
Figure 3. Quadruple-row of piles model

Modeling Parameters

Table 4. Parametric study program

modeling cases	Case number	H (m)	L (m)	D (m)	X (m)	L_p (m)	D_p (m)	S (m)
piles supporting excavation only	1	5	11	0.5	--	--	--	--
	2	5	11	0.6	--	--	--	--
	3	5	11	0.7	--	--	--	--
	4	5	13	0.5	--	--	--	--
	5	5	15	0.5	--	--	--	--
	6	5	17	0.5	--	--	--	--
	7	6	13	0.7	--	--	--	--
	8	7	15	0.7	--	--	--	--
Quadruple-row of piles tied using cap with thickness 1.0 m	9	5	11	0.5	1	10	0.6	1.2
	10	5	11	0.6	1	10	0.6	1.2
	11	5	11	0.7	1	10	0.6	1.2
	12	6	13	0.7	1	10	0.6	1.2
	13	7	15	0.7	1	10	0.6	1.2

RESULTS AND DISCUSSION

Piles Supporting Excavation Only

Effect of Pile Supporting Excavation Diameter, D (Cases 1, 2, 3): Figure 4 shows that, the maximum bending moment increases by 6% and 5% when the pile diameter increases from 0.5m to 0.6m and from 0.6m to 0.7m, respectively. This increase is due to the increased pile stiffness.
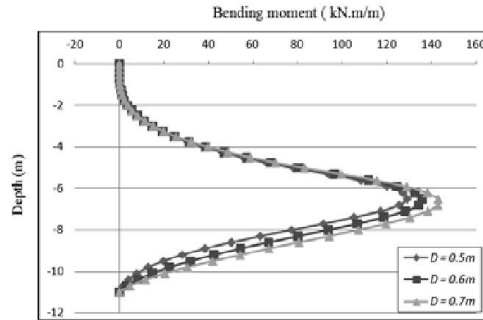

Figure 4. Pile supporting excavation bending moment result for different pile supporting excavation diameters (*Cases 1, 2, 3*)

Effect of Pile Supporting Excavation Length, L (Cases 1, 4, 5, 6): The pile length does not seem to have a significant effect on location and magnitude of the maximum bending moment in pile, as shown in Figure 5. However, the pile bending moment profiles for different pile lengths are partially different in shape.

Effect of Excavation Depth, H (Cases 3, 7, 8): The maximum bending moment in pile increases by approximately 67% when the excavation height increases from 5m to 6m. In the same way, the maximum bending moment in pile increases by approximately 55% when the excavation height increases from 6m to 7m, as shown in Figure 6. In addition, the maximum bending moments are located at about 1.50m, 1.75m, and 2.0m below the dredge line for the 5m, 6m, and 7m excavation height, respectively.
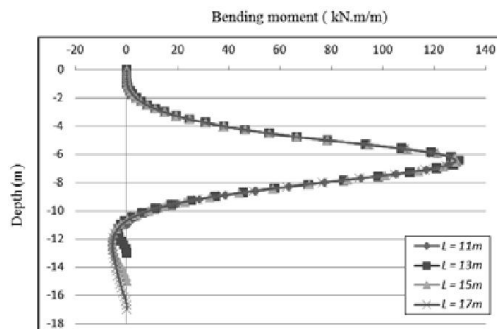

Figure 5. Pile supporting excavation bending moment result for different pile supporting Excavation lengths (*Cases 1, 4, 5, 6*)
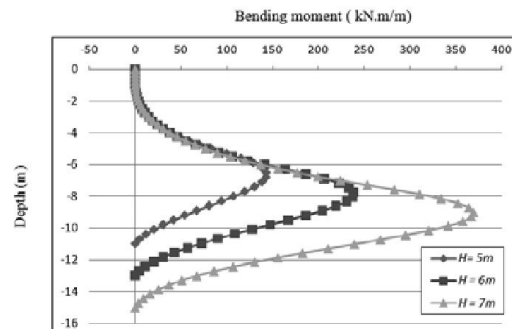
Figure 6. Pile supporting excavation bending moment result for different excavation depths (*Cases 3, 7, 8*)

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One Group of Piles (Quadruple-Row of Piles)

Effect of Pile Supporting Excavation Diameter, D (Cases 9, 10, 11): Figures 7 to 11 show variation of pile bending moment for different pile supporting excavation diameters (*D*). For the pile supporting excavation, the maximum bending moment increases by 7% and 9% when the pile diameter increases from 0.5m to 0.6m and from 0.6m to 0.7m, respectively. Increasing diameter of the pile supporting excavation from 0.5m to 0.6m results in a decrease ranging from 5% to 9% in maximum bending moments in the existing building piles and increasing diameter of the pile supporting excavation from 0.6m to 0.7m results in a decrease ranging from 6% to 9% in maximum bending moments in the existing building piles. With reference to Figures 4 and 7, it is inferred that the provision of existing building pile reduces bending moment in the pile supporting excavation. The bending moment is plotted for the pile supporting excavation for different groups in Figure 12. Furthermore, the peripheral piles in the pile group always have higher bending moments than those of interior piles. This observation may be attributed to the interior pile having a higher number of adjacent piles and therefore the effect of interaction among piles is more significant but the peripheral piles fewer piles around them and the pile cap transfers part of bending moment from the interior piles to the peripheral piles.
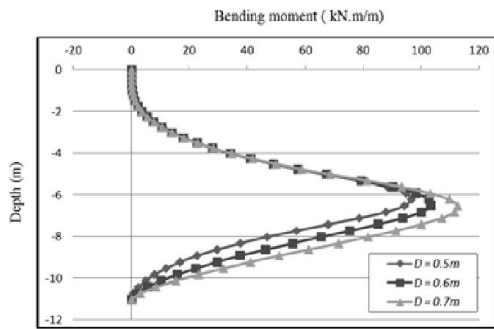

Figure 7. Pile supporting excavation bending moment result for different pile supporting excavation diameters (*Cases 9, 10, 11*)
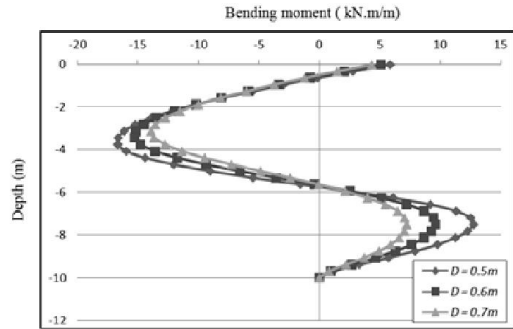

Figure 8. Existing building pile (1) bending moment result for different pile supporting excavation diameters (*Cases 9, 10, 11*)
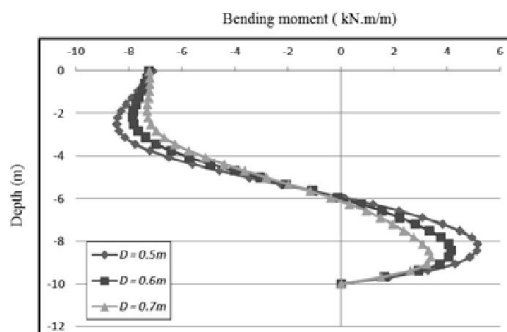

Figure 9. Existing building pile (2) bending moment result for different pile supporting excavation diameters (*Cases 9, 10, 11*)
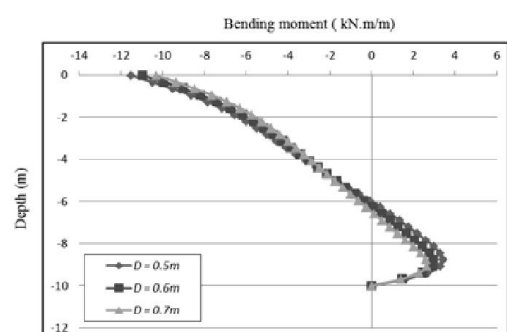

Figure 10. Existing building pile (3) bending moment result for different pile supporting excavation diameters (*Cases 9, 10, 11*)
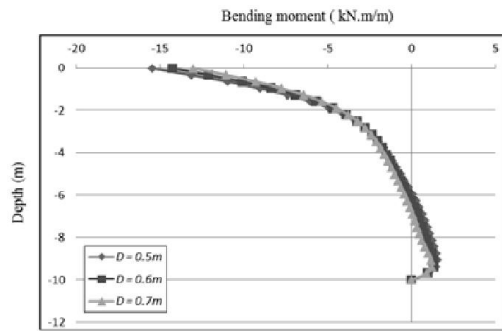
Figure 11. Existing building pile (4) bending moment result for different pile supporting excavation diameters (*Cases 9, 10, 11*)
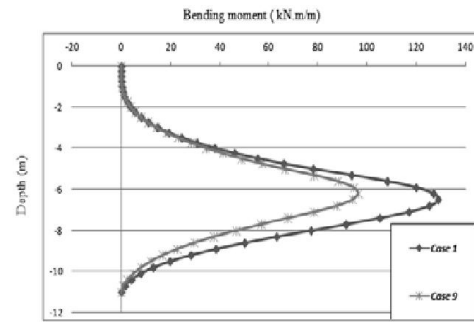
Figure 12. Bending moment for the pile supporting excavation result for different groups (*Cases 1, 9*)

Effect of Excavation Depth, H (Cases 11, 12, 13): Figures 13 to 17 show variation of pile bending moment for different excavation heights (*H*). From Figure 13, it is observed that maximum bending moment in the pile supporting excavation increases by 54% and 46% when the excavation depth increases from 5m to 6m and from 6m to 7m, respectively. For the existing building piles, the increase of the excavation depth from 5m to 6m causes an increase of maximum bending moment by 23% for pile (1), 22% for pile (2), 11% for pile (3), and 44% for pile (4). A further increase of the excavation depth from 6m to 7m results in an increase ranging from 9% to 28% in maximum bending moments in the existing building piles, as shown in Figures 14 to 17. This increase is due to larger lateral soil movements. It is further concluded that maximum bending moment in both the pile supporting excavation and the existing building pile does not occur at the same depth. In addition, maximum bending moments in the existing building piles (3), and (4) are located at the top of the piles.
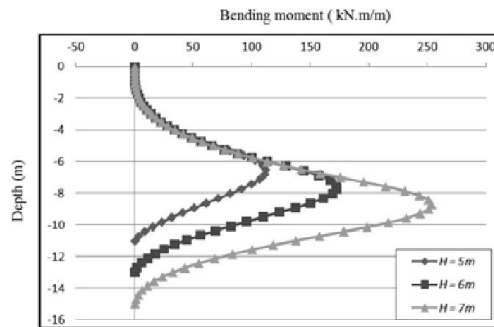

Figure 13. Pile supporting excavation bending moment result for different excavation depths (*Cases 11, 12, 13*)
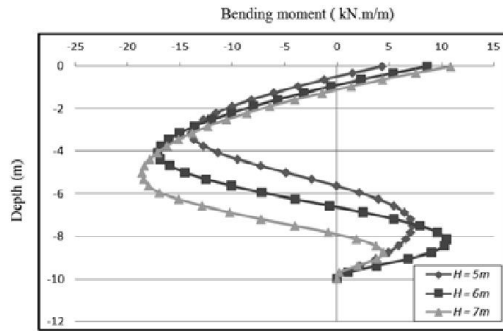
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Figure 14. Existing building Pile (1) bending moment result for different excavation depths (*Cases 11, 12, 13*)
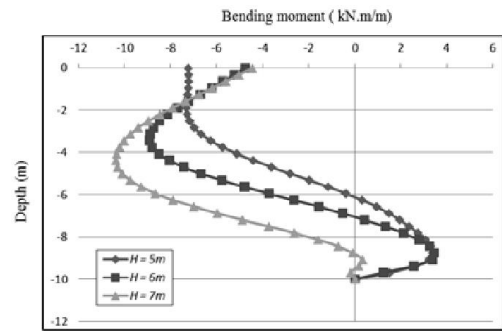

Figure 15. Existing building Pile (2) bending moment result for different excavation depths (*Cases 11, 12, 13*)
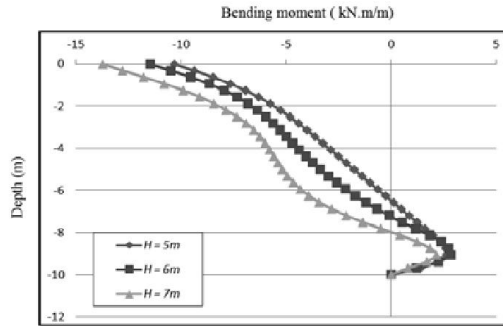

Figure 16. Existing building Pile (3) bending moment result for different excavation depths (*Cases 11, 12, 13*)
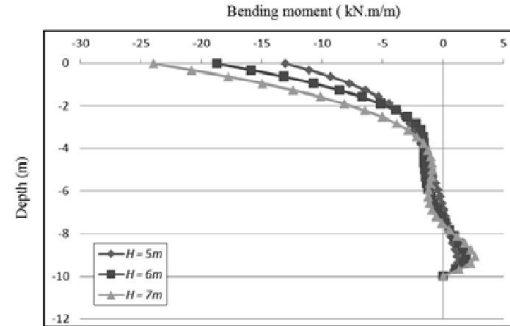

Figure 17. Existing building Pile (4) bending moment result for different excavation depths (*Cases 11, 12, 13*)

CONCLUSIONS

1. The maximum bending moments in the existing building piles decrease and the maximum bending moment in the pile supporting excavation increases, with the increase of pile supporting excavation diameter.
2. As a result of increasing the excavation depth, maximum bending moment in the pile supporting excavation increases, and also maximum bending moments in the existing building piles increase.
3. The provision of existing building pile reduces significantly bending moment in the pile supporting excavation.
4. The peripheral piles in the pile group always have higher bending moments than those of interior piles.
5. The influence of increasing the length of pile supporting excavation becomes negligible on location and magnitude of maximum bending moment in the pile.

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Notation

D	Pile Supporting Excavation Diameter
D_p	Existing Building Pile Diameter
H	Excavation Depth
L	Pile Supporting Excavation Length
L_p	Existing Building Pile Length
S	Spacing between Piles
X	Distance between pile supporting excavation and existing building pile

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