Interaction Analysis of Supporting Excavation Piles and Adjacent Existing Strap Footing

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***Abstract* — In country with high population intensity, there is no distance between buildings. New buildings need excavation. As excavation proceeds, the surrounding soils will move toward the excavation and that may cause damage of adjacent buildings. The present study mainly aims to provide remarks for the design of excavation for sandy and clayey soils in order to prevent damage of adjacent buildings. This paper investigates effect of nearby excavation on adjacent strap footings and studies the interaction behavior between supporting excavation piles and adjacent existing strap footing. The strap footing is used to connect an eccentrically loaded column footing close to the property line to an interior column. Contiguous pile wall is selected to support the excavation on the adjacent buildings sides. Commercial program PLAXIS 2D is used in the numerical analysis. A parametric study was performed to study the effect of strap stiffness, pile diameter, and pile length.**

***Index Terms* — Excavation, Supporting Piles, Strap Footing, Soil.**

I. Introduction

In urban environment most buildings in the same block area are closely spaced or adjacent to each other. In country with high population intensity, there is no distance between buildings. New buildings are built adjacent to old existing buildings. New buildings with basements need excavation. As excavation proceeds, the surrounding soils will move toward the excavation. One of the main design constraints is to prevent damages to adjacent buildings. There are several examples where foundations have been damaged by nearby excavation. It is common to use contiguous pile wall to support the excavation on the adjacent buildings sides. Such type of wall is the most economic and rapid option. A contiguous pile wall is a row of concrete piles. Contiguous pile wall is suitable where the groundwater table is below excavation level. The wall consists of discrete piles typically installed at spacing, leaving gaps where soil is exposed during excavation. The design of excavation should include a stability check of the adjacent buildings.

In many buildings, the external columns are very near to the property line so that their footings cannot be spread beyond the property line, so external footing is connected to the nearest internal footing by a strap. The strap footing is used to connect an eccentrically loaded column footing close to the property line to an interior column, as shown in Fig. 1. The strap is used to transmit the moment caused from eccentricity to the interior column footing. Strap must be rigid. This rigidity is necessary to control rotation of the exterior footing. The strap should be securely attached to the column and footing so that the system acts as a unit. The present study mainly aims to provide remarks for the design of excavation in order to prevent damage of adjacent buildings.

Potts and Addenbrooke [9] presented the results of a parametric study of the influence of an existing structure on the ground movements due to tunnelling. *Laefer* [7] presented results of analysis to evaluate the interaction between the installation of retaining systems and the potential occurrence of building damage. *Finno and Bryson* [4] studied the effect of an adjacent excavation on school building supported by shallow foundations and the excavation support system was a secant pile wall braced by both cross-lot struts and tiebacks. Building damage due to excavation-induced ground movement was evaluated using a damage criterion by *Son and Cording* [12]. *Dimmock and Mair* [1] investigated response of storey buildings to bored tunnelling in order to determine the effect of building stiffness on tunnelling-induced ground movement. The sliding of the soil underneath continuous footings behind the excavation has been studied by *Elshafie* [3] in his centrifuge model experiments. *Schuster et al.* [11] presented a simplified model for evaluating damage potential of a building adjacent to a braced excavation. *El Sawwaf and Nazir* [2] presented the results of laboratory model tests on the influence of deep excavation-induced lateral soil movements on the behavior of a model strip footing adjacent to the excavation and supported on reinforced granular soil. *Goh and Mair* [5] examined the significance of horizontal strain caused by deep excavation in buildings on individual footings. *Ramadan et al.* [10] provided recommendations for the design of contiguous pile wall in cohesive soil. *Goh and Mair* [6] studied the influence of frame action on the response of buildings to deformations induced by deep excavations using finite element method. They developed a design charts to calculate the induced deflection ratios and horizontal strains, caused by adjacent excavation and tunnelling activities. Several numerical and experimental studies were conducted to examine the behavior of piles subject to excavation-induced soil movement, for example, *Xu and Gao* [13] analyzed the interaction of foundation pit excavation and adjacent existing building's pile foundation, using ANSYS finite element software.

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).

II. FINITE ELEMENT MODEL

Geometry and meshing

This study is carried out using PLAXIS 2D version 8.2. Selection of plane strain condition results in a two-dimensional finite element model. The foundation of the adjacent building is assumed to be strap footings, as shown in Fig. 1. Out-of-plane spacing between straps is assumed to be 4 m. The columns loads are defined per meter so loads of the exterior and interior columns in the out-of-plane are 170 kN/m and 320 kN/m, respectively. Finite element model meshing is shown in Fig. 2.

Soil modeling

In this study, the soil considered are sand and clay. The Hardening soil model under drained condition is used to simulate the behavior of the selected soils. The 15-node triangular element is used in this analysis to model the soil. The soil parameters are listed in Table 1.

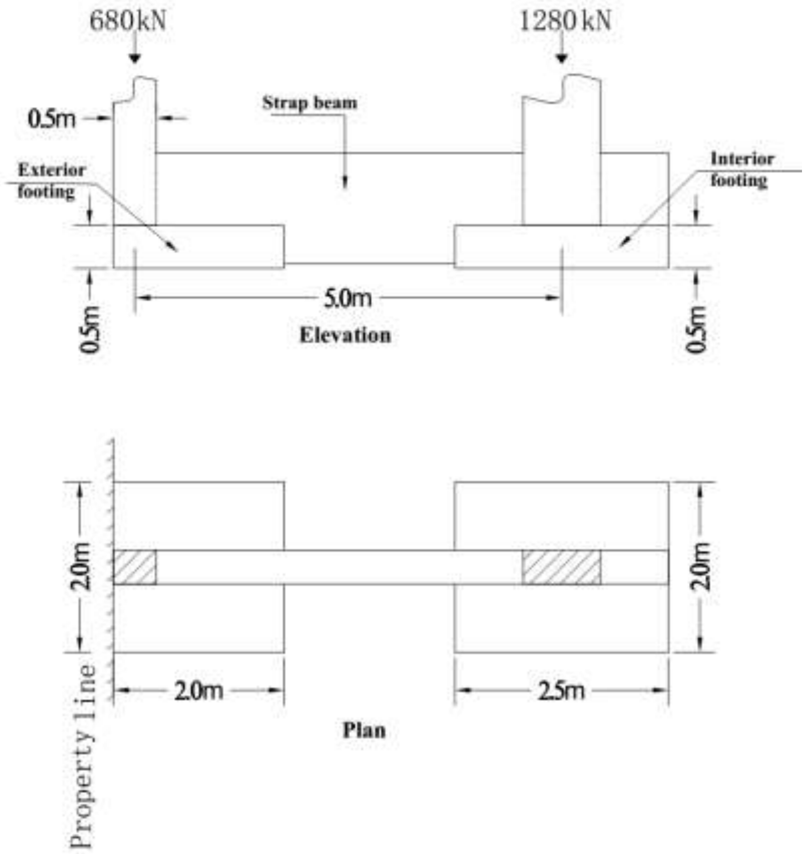

Fig. 1. Details of strap footing analyzed.

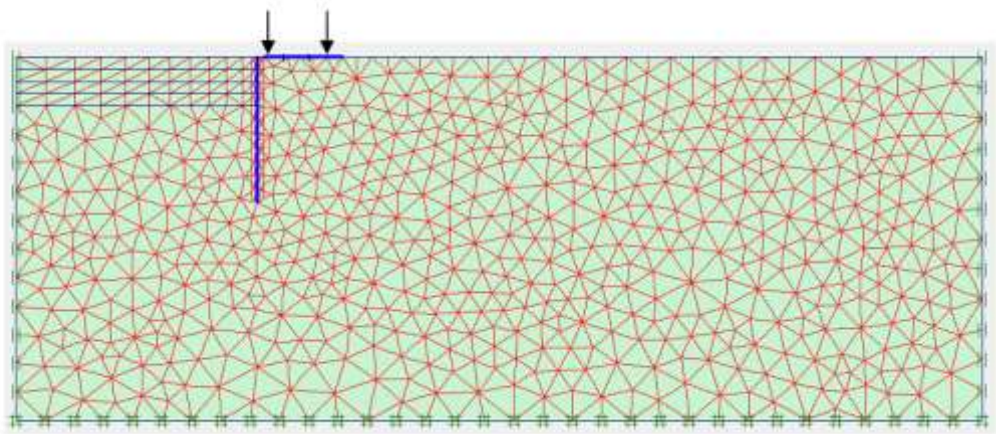

Fig. 2. Finite element meshing.

Table 1. Soil parameters

Parameter	Sand	Clay
γ_{unsat} (kN/m^3)	17	20
γ_{sat} (kN/m^3)	20	22
E_{50}^{ref} (kN/m^2)	40000	40000
E_{oed}^{ref} (kN/m^2)	40000	40000
E_{ur}^{ref} (kN/m^2)	120000	120000
ν_{ur}	0.2	0.2
C_{ref} (kN/m^2)	1	60
Φ (°)	32	16
Ψ (°)	2	0

Pile and foundation modeling

The contiguous pile wall and various parts of the strap footing are 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 10^7 kN/m^2 and Poisson's ratio is 0.15. Pile diameter is assumed to be 0.4 m and 0.5 m with spacing of half pile diameter between pile edges. The interface elements are used to simulate the interaction between the pile and the soil. The interfaces are placed at both sides of the pile.

Analysis procedure

For the purpose of this research, the analysis is carried out in steps. The first step is installation of existing loaded strap and footings. The second step is construction of piles supporting excavation. The third step is excavation by soil removal in 1 m depth layers for each step.

Table 2. Parametric study program

	Case number	Soil type	Dimensions of strap beam (m x m)	Pile diameter (m)	Pile length (m)
Before excavation	1	Sand	0.4 x 1.3	--	--
	2	Clay	0.4 x 1.3	--	--
After excavation	3	Sand	0.4 x 1.3	0.4	8
	4	Sand	0.5 x 1.5	0.4	8
	5	Clay	0.4 x 1.3	0.4	8
	6	Clay	0.5 x 1.5	0.4	8
	7	Sand	0.4 x 1.3	0.5	8
	8	Clay	0.4 x 1.3	0.5	8
	9	Sand	0.4 x 1.3	0.4	12
	10	Clay	0.4 x 1.3	0.4	12

III. RESULTS AND DISCUSSION

Effect of excavation (Cases 1, 2, 3, and 5)

Figure 3 shows bending moment profiles for the strap beam before and after nearby excavation. It can be seen that nearby excavation has a significant effect on bending moment of the strap footing. Additional negative bending moments are developed in the strap due to nearby excavation. Maximum negative bending moment (M –max) in the strap increases by 84% and more than 100% for sandy and clayey soils, respectively. However, Maximum positive bending moment (M +max) in the strap decreases by 59% and 67% for sandy and clayey soils, respectively. It is important to check whether the existing foundations can sustain the further redistribution of bending moment resulting from excavation or not. As would be expected after excavation, maximum bending moment in the pile wall in clayey soil is about 44% of its value in sandy soil.

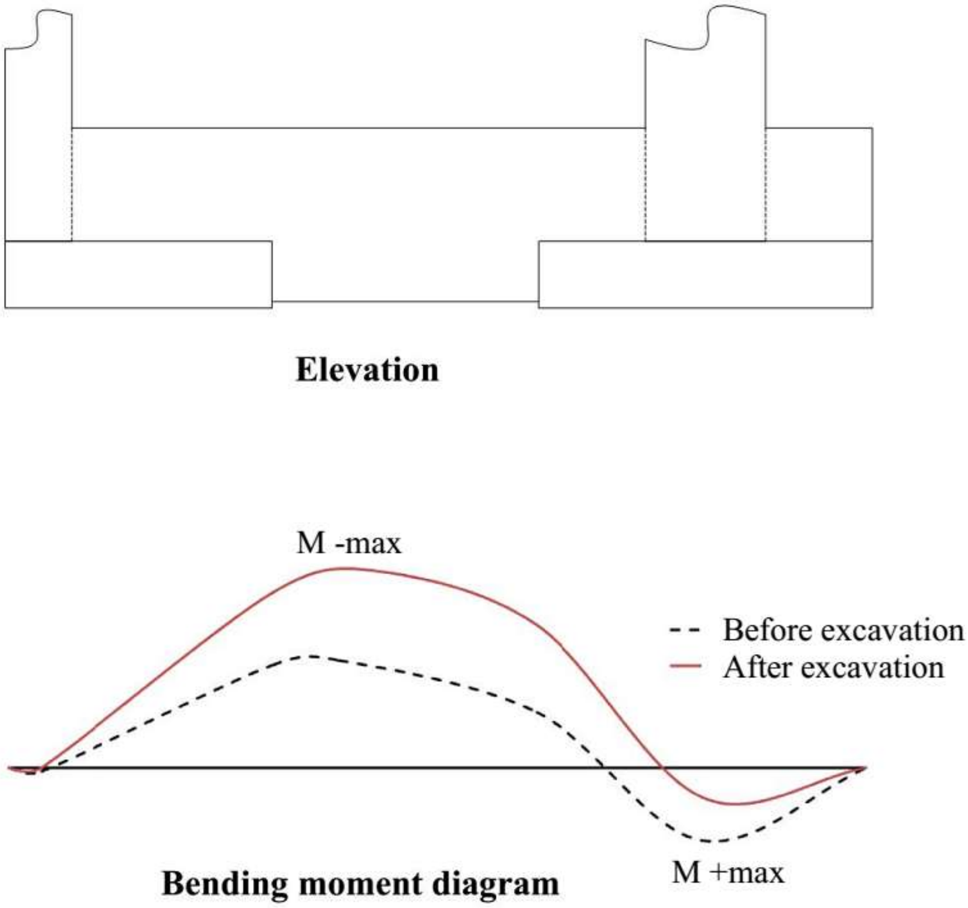

Fig. 3. Bending moments at various parts of the strap footing before and after excavation.

Effect of Strap stiffness (Cases 3, 4, 5, and 6)

For sandy soil, increasing dimensions of strap beam from 0.4 m x 1.3 m to 0.5m x 1.5 m results in a negligible increase in (M –max), however it results in a minor decrease in (M +max). For clayey soil, (M –max) decreases by 6% and (M +max) increases by 1% as a result of increasing strap beam dimensions.

From the pile wall results presented in Fig. 4, a closer look at the data indicates that, the maximum bending moment increases by approximately 3% when the strap beam dimensions increase. In contrast, maximum bending moment decreases by approximately 3% when the strap beam dimensions increase in clayey soil.

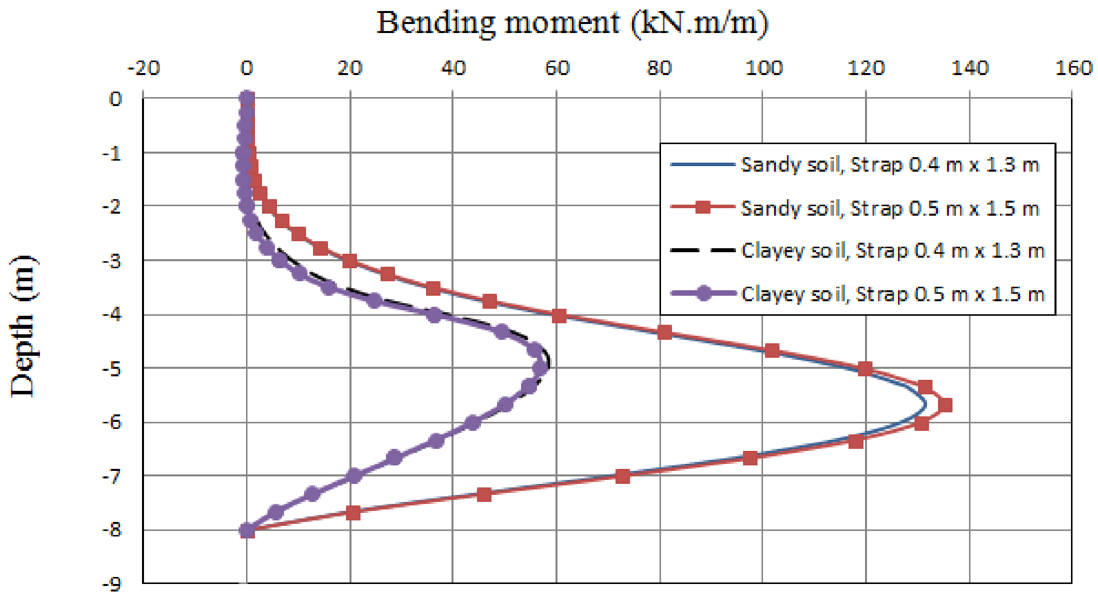

Fig. 4. Bending moment in the pile wall result for different strap beam dimensions.

Effect of pile diameter (Cases 3, 5, 7, and 8)

The effect of pile stiffness (expressed as pile diameter) on Maximum bending moment in the strap is presented in Fig. 5. As a result of increasing the pile diameter from 0.4 m to 0.5 m, (M –max) in the strap decreases by 4% and 7% for sandy and clayey soils, respectively. It can be observed that, (M +max) in the strap increases by 10% and 2% for sandy and clayey soils, respectively. Figure 6 shows clearly that, increasing the pile diameter leads to increasing maximum bending moment in the pile wall by 9% and 19% for sandy and clayey soils, respectively. This increase is due to the increased pile stiffness which leads to increased moments.

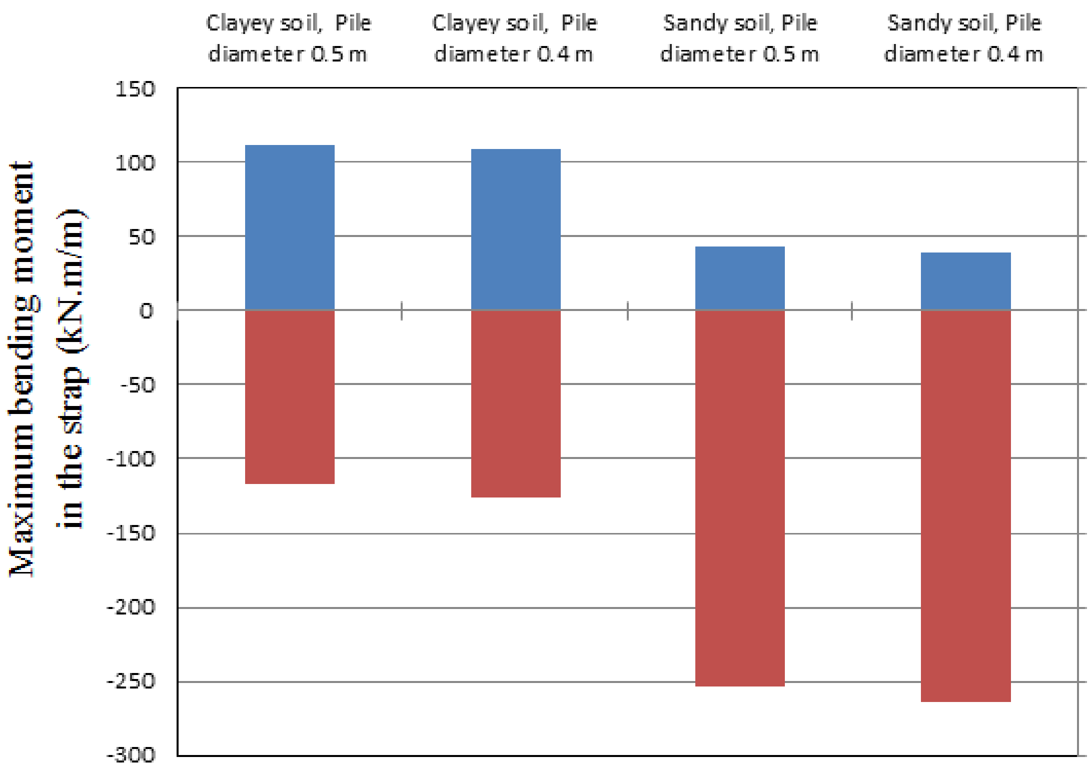

Fig. 5. Maximum bending moment in the strap result for different pile diameters

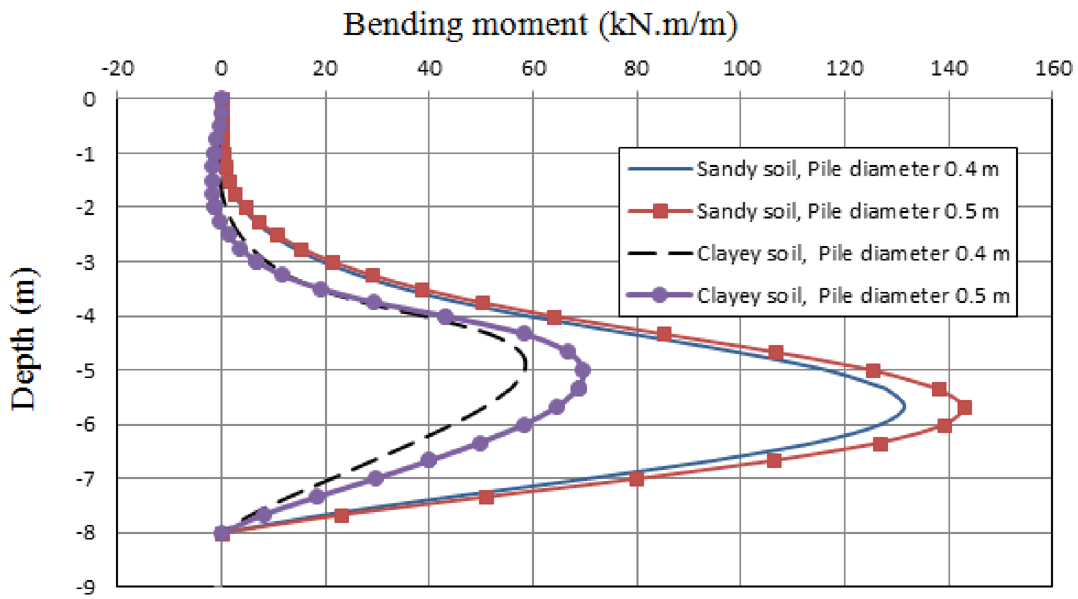

Fig. 6. Bending moment in the pile wall result for different pile diameters.

Effect of Pile Length (Cases 3, 5, 9, and 10)

Figure 7 shows maximum bending moment in the strap result for different pile lengths. When the pile length increases from 8 m to 12 m, there is a corresponding decrease in (M –max) in the strap by 2% and 5% for sandy and clayey soils, respectively. It is noted from Fig. 7, (M +max) in the strap increases by 8% and 1% for sandy and clayey soils, respectively. The maximum bending moment in the pile wall increases by 7% for sandy soil and decreases by 2% for clayey soil with increase in the pile length, as shown in Fig. 8.

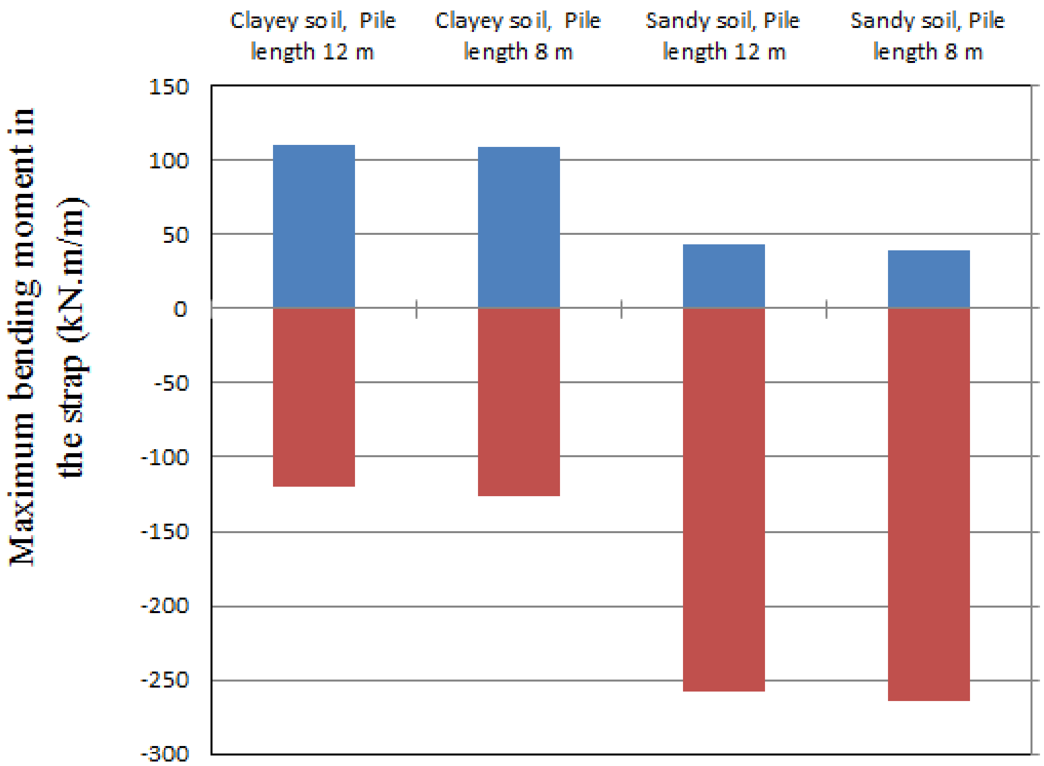

Fig. 7. Maximum bending moment in the strap result for different pile lengths.

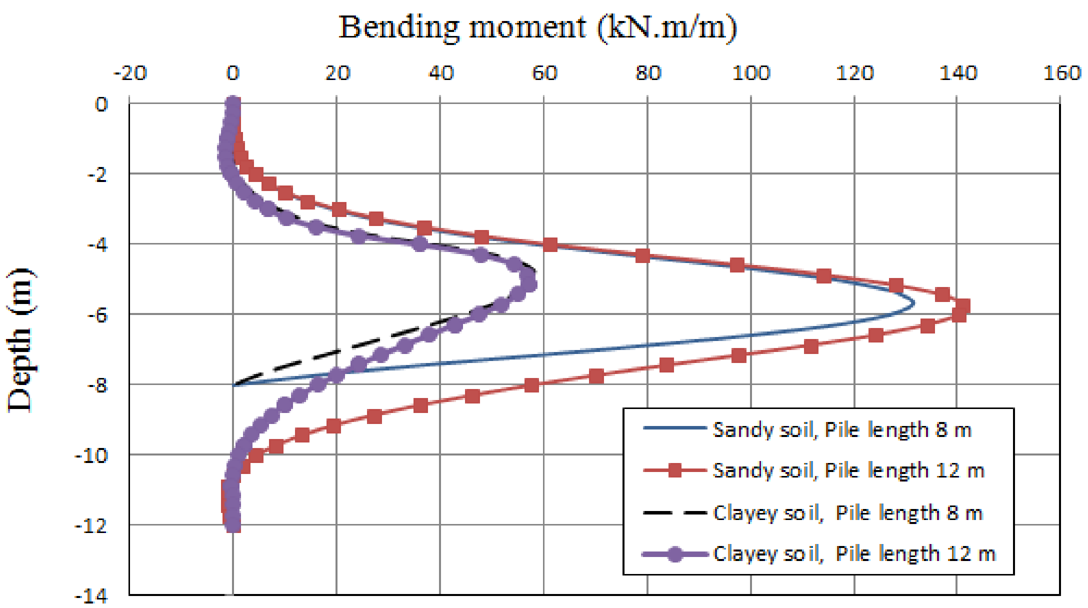

Fig. 8. Bending moment in the pile wall result for different pile lengths.

Appendix I. Summary of PLAXIS 2D Results

Table I. Summary of PLAXIS 2D results for different cases

Case number	M –max (kN.m/m)	M +max (kN.m/m)	Maximum bending moment in the pile wall (kN.m/m)
1	143.49	97.64	--
2	116.66	116.13	--
3	263.91	39.72	131.48
4	264.34	38.36	135.15
5	125.94	108.69	58.33
6	118.33	109.87	56.92
7	253.51	43.61	142.76
8	116.61	111.02	69.69
9	257.34	42.92	141.08
10	119.93	109.75	57.01

Where: M –max (kN.m/m) and M +max (kN.m/m) are the maximum negative and positive bending moments in the strap in kN.m/m.

IV. CONCLUSIONS

This paper investigated effect of nearby excavation on adjacent strap footings using a two-dimensional finite element model. From the previous results and discussion the following conclusions can be summarized:-

- Adjacent excavation has a huge impact on bending moment distribution on various parts of the strap footing.
- It is important to check whether the existing foundations can sustain the further redistribution of bending moment resulting from excavation or not.
- Negative bending moment in the strap increases and positive bending moment in the strap decreases due to nearby excavation.
- Increasing dimensions of strap beam results in a negligible increase in (M –max) in the strap, however it results in a minor decrease in (M +max) in the strap for sandy soil. In contrast, (M –max) decreases and (M +max) increases a result of increasing strap beam dimensions for clayey soil.
- Increasing the pile diameter leads to decreasing (M –max) and increasing (M +max) for sandy and clayey soils.
- Maximum bending moment in the pile increases when the pile diameter increases.
- When the pile length increases, there is a corresponding decrease in (M –max) in the strap, but (M +max) in the strap increases.
- The maximum bending moment in the pile wall increases for sandy soil and decreases for clayey soil with increasing the pile length.

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