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Behaviour of a strip footing adjacent to the existing supported excavation

Mevcut destekli kazıya bitişik bir şerit temelin davranışı

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Research Article

Abstract

This study investigates the results of the numerical analysis on effect of existing supported excavation on ultimate bearing capacity (q_{ult}) of strip footing adjacent to supported excavation in sandy soil. The influence of distance (L) between the foundation and the supported excavation was studied as well as the effect of the excavation depth (H_e). For this purpose, on a full-scale model, a series of numerical calculations were carried out to determine how (L) and (H_e) affected the behavior of strip foundation. Based on finite element approach, the computer software Plaxis 2D code was utilized. Non-linear hardening soil model, a sophisticated elastoplastic stress-strain constitutive soil model, was used to characterize sandy soil. Based on Mindlin's beam theory, the strip footing and sheet pile wall were identified as elastic beam components with significant flexural rigidity (EI) and axial stiffness (EA). The sheet pile was installed at three different distances (L) away from the face of the strip foundation 1B, 1.5B and 2B, where B is the width of foundation. For each distance, three different excavations (H_e) were used with dimensions 1B, 1.5B and 2B. The numerical outcomes show that the ultimate bearing capacity (q_{ult}) of shallow foundation is decreased when distance between strip foundation and supported excavation is decreased, and vice versa. Additionally, (q_{ult}) is reduced as the depth of excavation behind sheet pile wall is increased, and vice versa.

Keywords: Finite element methods, Supported excavation, Strip foundation, Sheet pile, Excavation depth

Özet

Bu çalışmada, kumlu zeminde destekli bir kazıya bitişik olan bir şerit temelin nihai taşıma gücüne (q_{ult}) mevcut destekli kazı etkisinin sayısal olarak incelenmesi ve sonuçları araştırılmıştır. Şerit temelin taşıma gücü üzerinde, temel ile destekli kazı arasındaki mesafenin (L) etkisi ile kazı derinliğinin (He) etkisi incelenmiştir. Bu amaçla, tam ölçekli bir model üzerinde, (L) ve (He)'nin şerit temelin davranışını nasıl etkilediğini belirlemek için bir takım sayısal hesaplamalar yapılmıştır. Sayısal analizlerde sonlu elemanlar yaklaşımına dayalı olarak çalışan bir bilgisayar yazılımı olan Plaxis 2D paket programı kullanılmıştır. Kumlu zemini karakterize etmek için doğrusal olmayan sertleşen zemin modeli (sofistike bir elastoplastik gerilme-gerinim yapıcı zemin modeli) kullanılmıştır. Mindlin'in kiriş teorisine dayanarak, şerit temel ve palplanş duvar, önemli eğilme rijitliğine (EI) ve eksenel rijitliğe (EA) sahip elastik kiriş bileşenleri olarak tanımlanmıştır. Palplanş, şerit temelin yüzünden, 1B, 1.5B ve 2B olmak üzere üç farklı mesafede (L) yerleştirilmiş olup burada B temelin genişliğini göstermektedir. Her mesafe için 1B, 1.5B ve 2B boyutlarında üç farklı kazı derinliği (He) kullanılmıştır. Sayısal sonuçlar, şerit temel ile desteklenen kazı arasındaki mesafe azaldıkça şerit temelin nihai taşıma kapasitesinin (qult) azaldığını ve arttıkça da bunun tersinin oluştuğunu göstermektedir. Ayrıca, duvarın arkasındaki kazı derinliği arttıkça taşıma gücünün (q_{ult}) azaldığı ve kazı derinliği azaldıkça taşıma gücünün arttığı sonucuna da varılmıştır.

Anahtar kelimeler: Sonlu elemanlar metodu, Destekli kazı, Şerit temel, Palplanş, Kazı derinliği

1. Introduction

In constructing an excavation, controlling ground surface settlement near excavation area is an important duty. In a number of instances, it is recommended that buildings in metropolitan areas have basement construction or subsurface features like cut-and-cover tunnels excavated adjacent to them. The most dangerous constructions are those that are supported by shallow foundations that do not extend below the excavation's effect zone. When new structure's foundation excavation depth is larger than existing structure's foundation level, the excavation must be supported by

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a retaining structure while new building's foundation is being built. It is extremely important to prevent or reduce damage to neighboring building by using different types of support structures [1]. The bearing capacity of strip foundation near supported excavation is influenced by numerous factors, such as stiffness of excavation support system, installation procedures of the system, soil conditions, distance of foundation from excavation, and size of the foundation. Excavation-related limiting requirement depends on shear strength parameters of soil, methods of excavation, building type, and type of ground support system [2]. Studying characteristics of shallow foundations near deep-supported excavation is a complicated geotechnical issue. Changes occur as soil is excavated behind the sheet pile wall or any retaining structures, such as state of stress in soil around the excavation and movement of soil, and these changes affect also buildings or any structure near the excavation [3]. The assessment of ground movements has attracted interest in several research due to significant impact that deep excavation has on ground movements on nearby buildings or structures. These studies have mostly concentrated on predicting lateral movement related to deep excavation and settlement of existing building foundations [4-11]. The work done by Peck [4] was expanded by Clough [5] and they proposed analytical settlement envelopes. Oue et al., [6] gathered and examined field data relating to wall displacement in connection with deep excavation, and characterized the obvious impact range for estimating damage to surrounding structures. Yoo [8] gathered field data from more than 60 various excavation sites on lateral wall movement for walls built in overlying rock soils and analyzed the data regarding walls and types of support. Leung and Ng [11] gathered and analyzed field monitoring data from the execution of 14 multi-supported deep excavations in various ground conditions on the lateral deflection of walls and settlement of ground surface. Recently, numerical modelling analysis based upon the finite element methods (FEM) has become very popular in the analysis and design of geotechnical structures such as tunnels, dams, slope stability, shallow and foundations [12-16] . Many researchers have used FEM also to study the effects of deep excavation on the existing nearby structures [17-21].

The purpose of this study is to investigate the effect of supported excavation on the bearing capacity of the adjacent strip foundation in sandy soil. The FEM code, PLAXIS 2D, was selected as the numerical tool, the studied factors were the distance (L) between the face of the shallow foundation and supported excavation and the depth of the excavation (He). For this purpose, sheet pile was installed at three different distances (L) away from the face of shallow foundation which is (1B, 1.5B and 2B), where B is the width of the foundation. For each distance, three different excavation was used with dimensions (1B, 1.5B and 2B).

2. Materials and Numerical Modelling

The hardening soil model was employed in this study to simulate the soil's nonlinear behavior. One of the most sophisticated soil models available, this constitutive model simulates many kinds of soil. Table 1 and 2 provides an overview of the material properties of sandy soil, sheet pile wall, and strip footing obtained from Plaxis 2D material model manual [22]. The strip footing and sheet pile wall were defined as elastic beam elements based on Mindlin’s beam theory with important flexural rigidity (EI) and axial stiffness (EA). Since the full volume element method is slow from the point of view of computation time, therefore Mindlin's Beam Theory Constitutive Model was used as it reduces the computation time. Interface components are used to describe the interaction between sheet pile wall and soil on both sides, allowing for the specification of reduced wall friction relative to soil friction. This study investigates the bearing capacity of strip footing near supported excavation, the effect of distance (L) between strip footing and supported excavation and depth of excavation behind supported excavation (He) will be studied. For this purpose, a series of finite element analyses were done. Two-dimensional finite element method was used with 15-node plane strain model using Plaxis 2D computer program. The numerical analysis programs with various parameters are summarized in Figure 1. The impact of mesh dependency on the outcomes of the numerical analysis was minimized by using a fine enough mesh. The typical produced mesh for full-scale geometry and boundary conditions is shown in Figure 2. Model boundary conditions were assumed as follows; the vertical boundary is vertically deformable and laterally fixed while bottom boundary was meant to be certainly fixed. For groundwater conditions, it is assumed that water table is located deep below sand layer and therefore has no effect on the results of the analysis.

Table 1. Parameters of the sand used in FEM analysis [23]

Parameters	**Value**
Drainage type	Drained
Dry Unit Weight (γ_d) (kN/m^3)	17.0
E_{50}^{ref} (P_{ref} = 100 kPa) (kN/m^2)	43000
E_{ur}^{ref} (P_{ref} = 100 kPa) (kN/m^2)	129000
E_{oed}^{ref} (P_{ref} = 100 kPa) (kN/m^2)	22000
Cohesion, (c) (kN/m^2)	1.0
Friction angle, (ϕ) (^{0})	34.0
Dialatancy angle (ψ) (^{0})	4.0
Poisson's ratio (ν_{ur})	0.20
K_0^{nc}	0.34
m, Power	0.50
R_{inter}	0.70

Table 2. Parameters of the sheet pile wall and strip footing [23]

Parameters	**Sheet pile**	**Strip footing**
Material type	Elastic; Isotropic	Elastic; Isotropic
Flexural rigidity (EA), kN/m	$12 * 10^6$	$11.5 * 10^6$
Normal stiffness (EI), kN m^2/m	$12 *10^4$	$2396 *10^2$
Thickness (d), cm	35.0	50.0
Weight (w) kN/m/m	8.3	0
Poisson's ratio	0.15	0

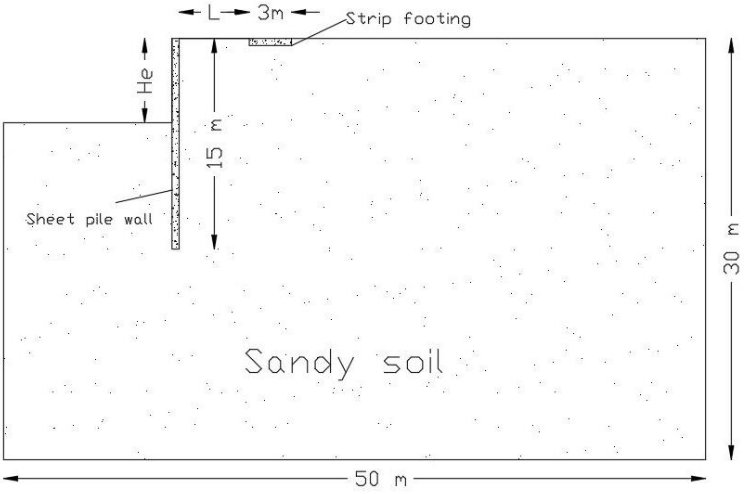

Figure 1. Geometric parameters studied in numerical analysis

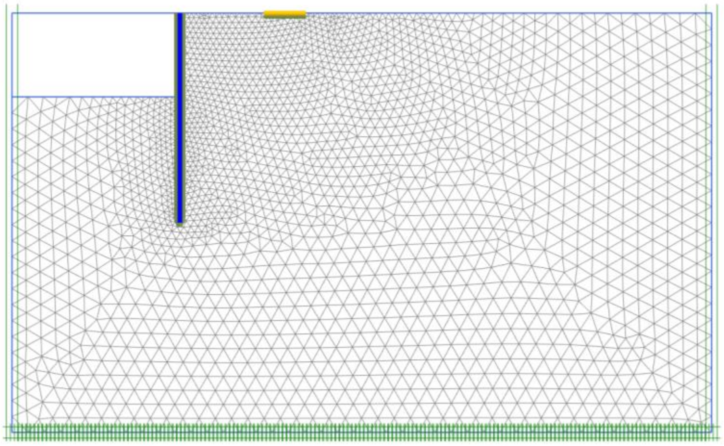

Figure 2. Typical generated mesh for prototype geometry

3. Results and Discussion

After performing numerical analysis to investigate the effects of distance (L) between shallow foundation and supported excavation by sheet pile wall. To this end, sheet pile was installed at three different distances (L) away from the face of the shallow foundation with dimensions (1B, 1.5B and 2B). The sand behind sheet pile was excavated with dimensions (1B, 1.5B and 2B) For each distance. This section discusses the findings from numerical analysis. Ultimate bearing capacity of strip footing was determined by applying prescribed line displacement on the footing. It is assumed that the strip footing reaches the settlement value of 25 mm and the required load corresponding to this settlement value is calculated. The settlement values of 25 mm are considered ultimate bearing capacity loads [24]. After performing FEM analysis, the results were obtained as load-vertical displacement and load-lateral displacement for shallow foundation and sheet pile wall, respectively. The typical deformation mesh of the soil, sheet pile wall displacement, and foundation displacement are shown in figure 3. Figures 4 through 9 show the load-vertical displacement curves of the foundation and load-lateral displacement sheet pile with different distances (L) and different excavation depths (H_e).

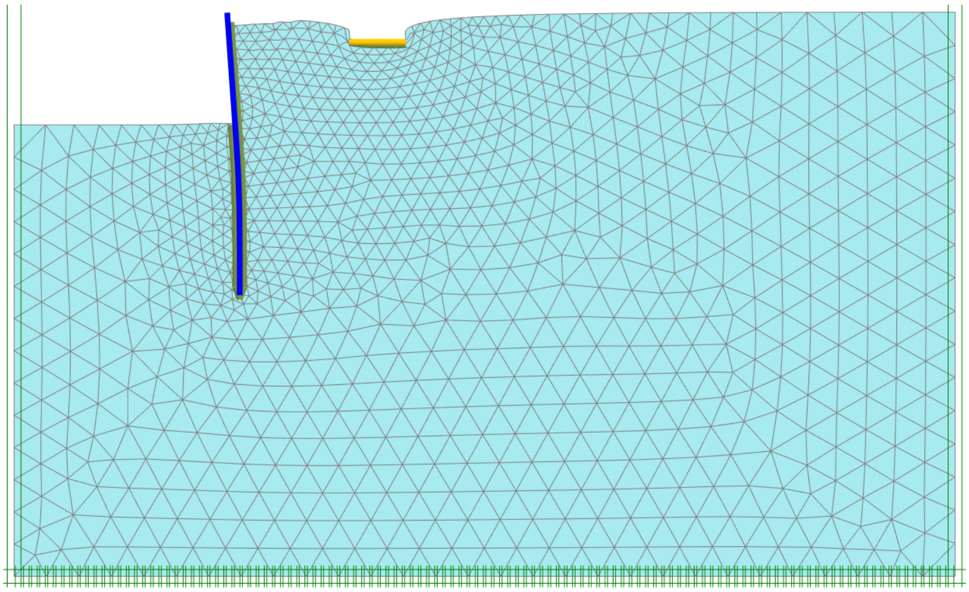

Figure 3. Deformed mesh (logarithmically scaled up 150 times)

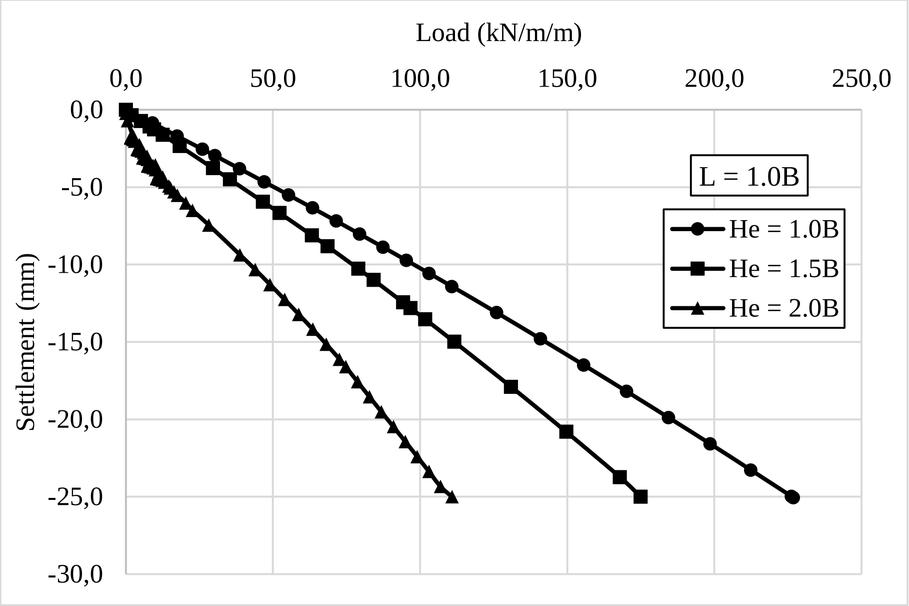

Figure 4. Load-vertical displacement curves for strip footing by 1.0B away from the supported excavation with different excavation depths (He)

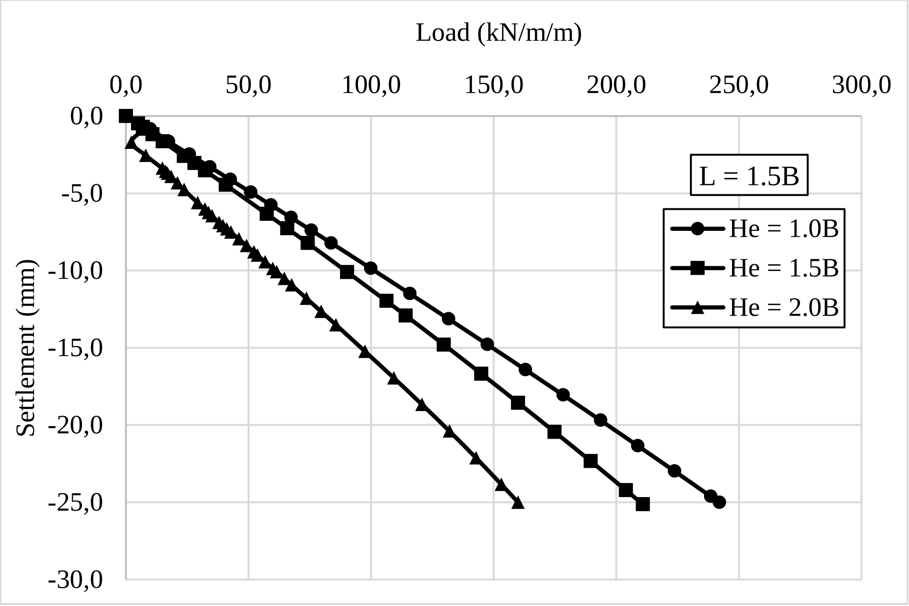

Figure 5. Load-vertical displacement curves for strip footing by 1.5B away from the supported excavation with different excavation depths (He)

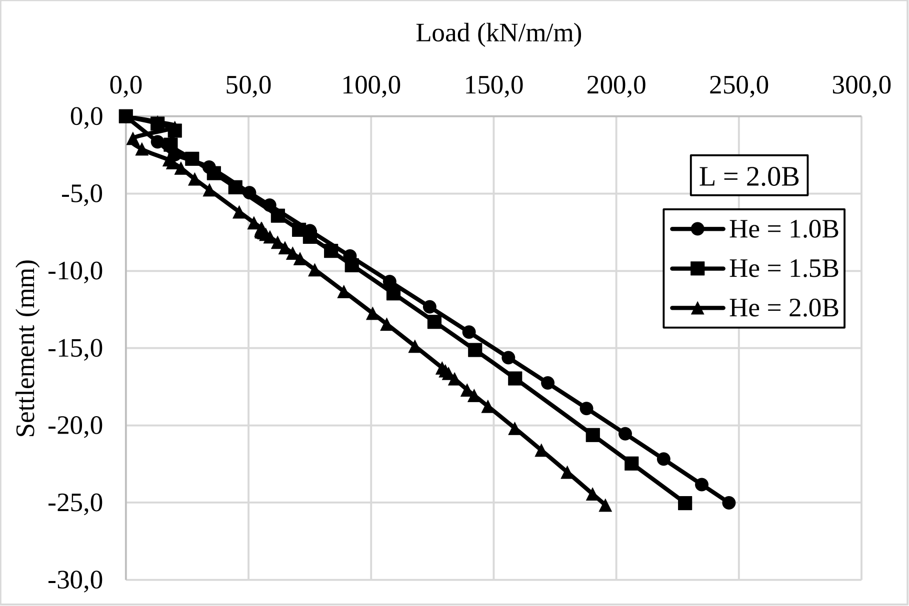

Figure 6. Load-vertical displacement curves for strip footing by 2.0B away from the supported excavation with different excavation depths (He)

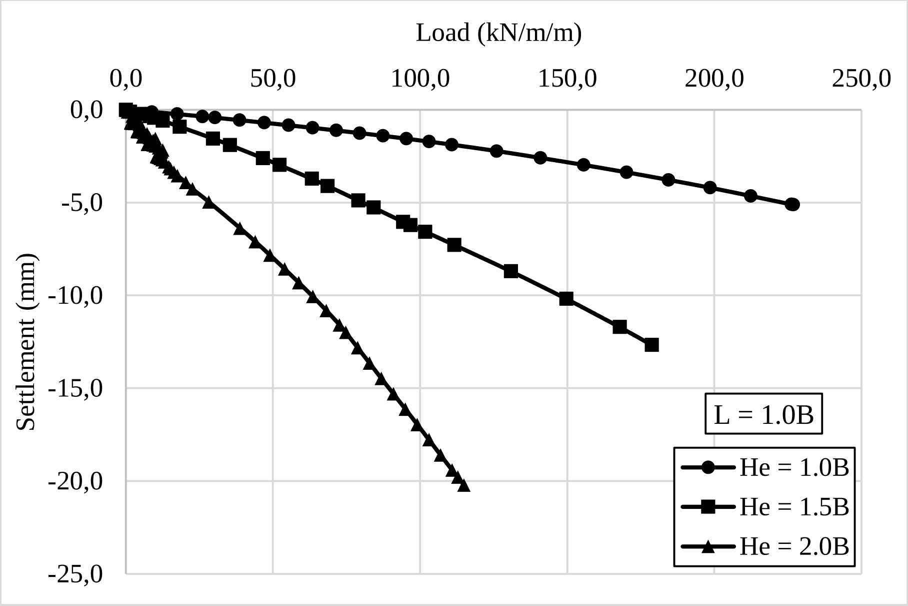

Figure 7. Load-lateral displacement curves for sheet pile by 1.0B away from the strip footing with different excavation depths (He)

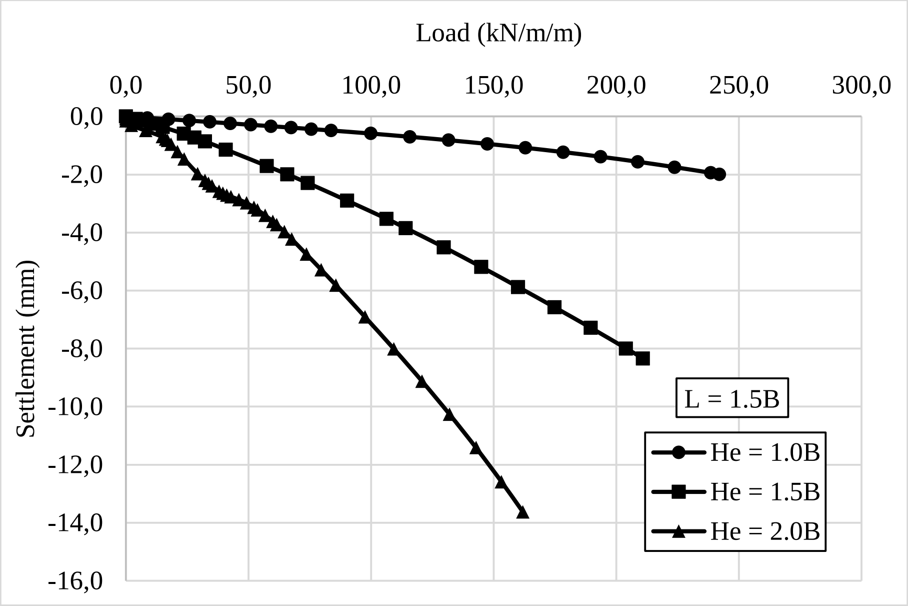

Figure 8. Load-lateral displacement curves for sheet pile by 1.5B away from the strip footing with different excavation depths (He)

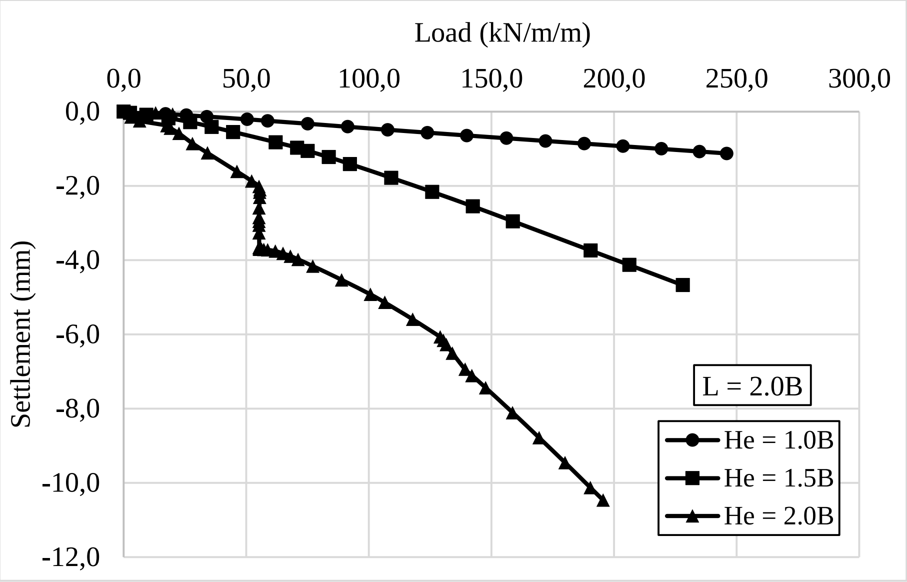

Figure 9. Load-lateral displacement curves for sheet pile by 2.0B away from the strip footing with different excavation depths (He)

The impact of existing supported excavation with different distances from strip footing and different excavation depths behind supported excavation on bearing capacity of foundation is presented in Figure 10. It can be seen that as the distance between strip footing and supported excavation increases, its bearing capacity increases, also, it is decreased with increasing excavation depth behind supported excavation. The change in lateral displacement at top of sheet pile with excavation depth/foundation width is shown in Figure 11. It is obvious the lateral displacement of sheet pile increases with increasing excavation depth/foundation width with different distances from the foundation. The variation of the maximum moment force of the sheet pile with different distances from the foundation and different excavation depths is illustrated in Figure 12. It is evident that the maximum moment of the sheet pile is observed when the supported excavation is 1.0B away from the foundation with an excavation depth equal to 2B. When the distance between supported excavation and foundation increases the maximum moment of the sheet pile decreases and vice versa.

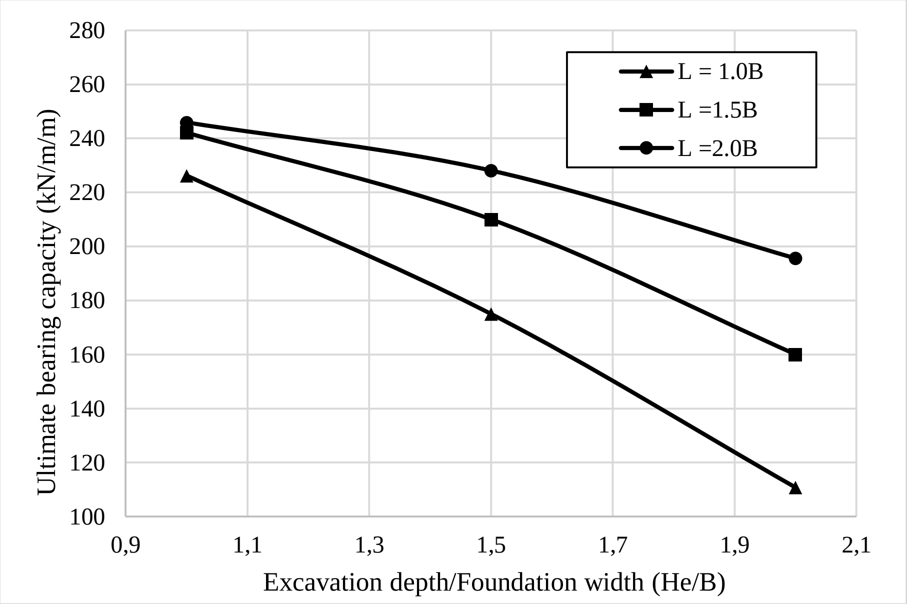

Figure 10. Change in the ultimate bearing capacity of the strip footing with (He/B)

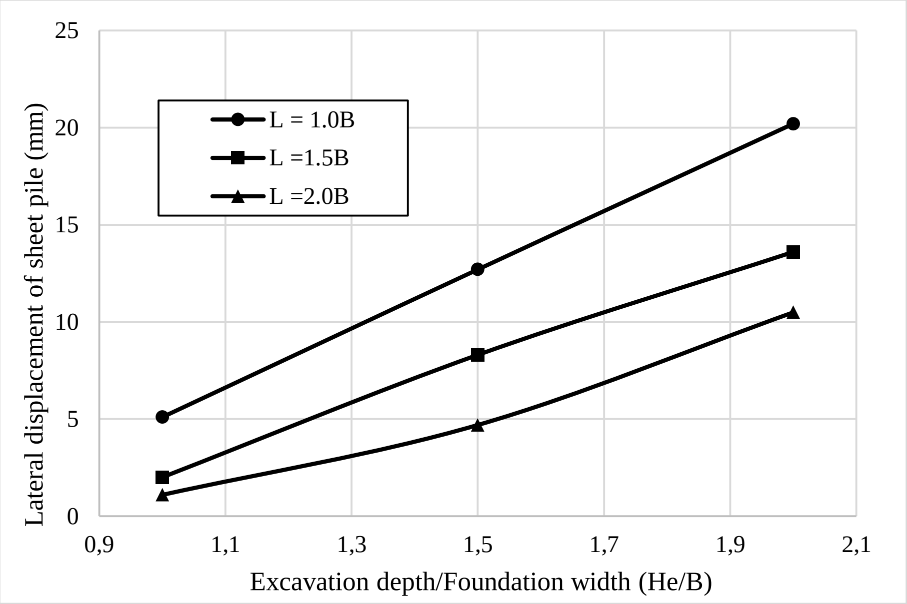

Figure 11. Variation of lateral displacement of the sheet versus (He/B**)**

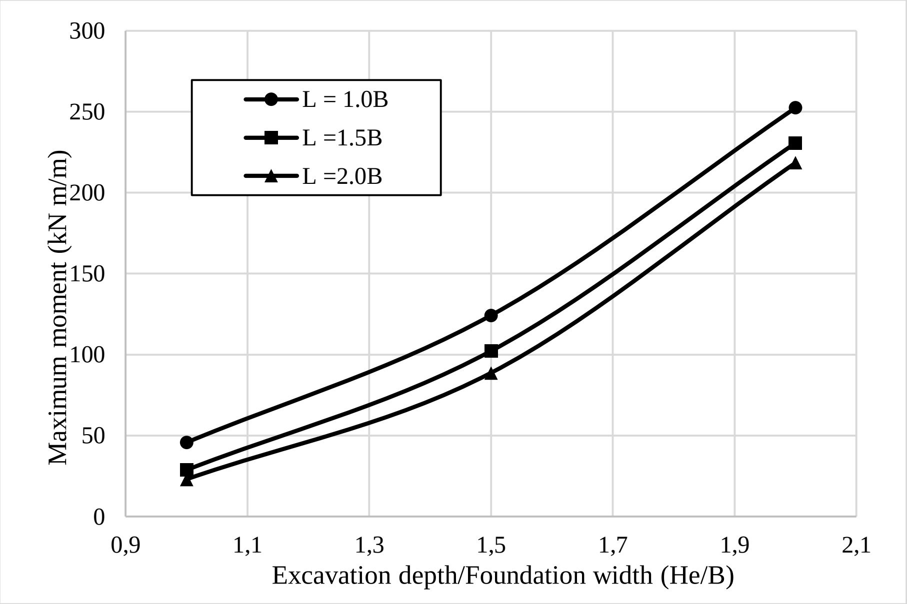

Figure 12. Variation of maximum moment of the sheet pile versus (He/B)

4. Conclusion

In this study, Plaxis 2D FEM code was used to numerically examine the impact of existing supported excavation on strip foundation's bearing capacity. The influence of different distances (L) between supported excavation and face of foundation and different excavation depths (H_e) was examined. The following inferences can be made in light of numerical analysis results:

- The ultimate bearing capacity of strip foundation nearby supported excavation is decreased as the distance between supported excavation and foundation increases and the excavation depth as well.

- The lateral displacement of sheet pile increases with decreasing distance (L) between supported excavation and sheet pile. When the (L) equals foundation width (1.0B), the sheet pile is exposed to a considerable displacement as excavation depth (He) increases, but When the (L) equals (2.0B) the increase of lateral displacement of sheet pile is small with increasing excavation depth (He).
- The maximum moment in sheet pile wall is increasing with decreasing the distance (L) between supported excavation and strip foundation and excavation depth behind sheet pile as well.

5. Acknowledgment

This section is optional. However, this section should not be left blank when the article is submitted for the first time. If the article is supported by any institution, project, person, etc., the relevant information can be specified in this section.

6. Author Contribution Statement

Mesut GÖR and Nichirvan Ramadhan TAHER: Methodology, Software, Data collection and/or processing, Data analysis and interpretation, Writing - original draft. Hüseyin Suha AKSOY: Literature search, Critical revision of manuscript, Writing – review & editing.

7. Ethics Committee Approval and Conflict of Interest

“There is no conflict of interest with any person/institution in the prepared article”

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