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The Effect of Tunneling on The Piled Foundation in Layered Soils

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ABSTRACT

It is believed that tunnel construction will have significant and intricate effects on structures supported by piles. One of the most popular approaches to research is numerical modeling. This study looked into how tunnel placement affected piled foundation systems in layered soil. In sixteen models utilizing PLAXIS 2D finite element analysis, a square foundation with dimensions of 26×26×2 meters and a load of 200 kPa was applied to the soil profile representing Istanbul's Avcilar district. In the 11×7 formation, two groups of piles were created, each with a fixed spacing of 2.4 meters and varying diameters of 0.8, 1.2 with 30 meters in length. The piles were placed 4 meters out of the plane and 1 meter from the edges. For every pile group, a 10-meter-diameter tunnel was examined at two various Z/D and four various X/D from the foundation's center to determine the influence of the tunnel location. According to the results, the surface total settlement values decrease, and the differential settlements increase as the tunnel is positioned farther in the x direction from the foundation center axis. The pile's bending moment slightly decreases as the tunnel's horizontal location gets farther away from it. The tunnel's effect decreases with increasing distance within the influence zone. Tunnel settlement cannot be significantly reduced by deepening the tunnel or increasing the pile's diameter.

Keywords: Tunnel; Piled Foundation; Settlement; Finite Elements.

Tabakalı Zeminlerde Tünel Açmanın Kazıklı Temel Üzerindeki Etkisi

ÖZ

Tünel inşaatının kazıklarla desteklenen yapılar üzerinde önemli ve karmaşık etkileri olacağına inanılmaktadır. Araştırma için en popüler yaklaşımlardan biri sayısal modellemedir. Bu çalışmada, tünel yerleşiminin tabakalı zeminlerde kazıklı temel sistemlerini nasıl etkilediği incelenmiştir. PLAXIS 2D sonlu eleman analizinin kullanıldığı on altı modelde, İstanbul'un Avcılar ilçesini temsil eden zemin profiline 26×26×2 metre boyutlarında kare bir temel ve 200 kPa yük uygulanmıştır. 11×7 formasyonunda, her biri 2.4 m sabit aralıklı ve 30 m uzunluğunda 0.8, 1.2 değişen çaplarda iki grup kazık oluşturulmuştur. Kazıklar düzlemin 4 m dışına ve kenarlardan 1 m uzağa yerleştirilmiştir. Her kazık grubu için, tünel konumunun etkisini belirlemek amacıyla temel merkezinden iki farklı Z/D ve dört farklı X/D noktasında 10 m çapında bir tünel incelenmiştir. Sonuçlara göre, tünel temel merkez ekseninden x yönünde uzaklaştıkça yüzey toplam oturma değerleri azalmakta ve diferansiyel oturmalar artmaktadır. Kazık eğilme momenti, tünelin yatay konumundan uzaklaştıkça hafifçe azalmaktadır. Tünelin etkisi, etki bölgesi içinde artan mesafe ile azalır. Tünel oturması, tünelin derinleştirilmesi veya kazık çapının artırılmasıyla önemli ölçüde azaltılamaz.

Anahtar Kelimeler: Tünel; Kazıklı Temel; Oturma; Sonlu Elemanlar.

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1. INTRODUCTION

In metropolitan areas, the effects of tunnel construction on nearby structures are thought to be profound and complex. For buildings that are supported by piles, this problem may be more significant. Several finite element analyses were also carried out by some researchers to investigate the effects of tunnels on existing pile foundations. Jongpradist et al, used the advanced soil models in PLAXIS to run numerical simulations of tunneling in the Bangkok subsoil. PLAXIS 2D analyzes all issues from well-documented case histories using reliable monitored data, assuming a plane strain condition with the appropriate analysis condition (Jongpradist, P., Detkhong, T., and Youwai, S., 2012). Shabna et al., in their research, applied a 2D numerical model to analyze and predict the detailed performance of the tunnel system. Predicting the stress distributions and soil deformations that result from the tunnel construction process and taking the necessary precautions are essential to avoiding damaging existing buildings or foundations in the soil above. They showed that these effects can be achieved using the finite element method (Shabna, P. S., & Sankar, N., 206).

Rishik discusses in his thesis the influence of a newly built tunnel on the existing pile foundation using the FEM (Finite Element Method), so the aim of this paper is to provide a parametric study to assess the extent of the settlement problem near piles. According to the variation in the pile's overall displacement, there is a variation in the tunnel's position. Only when the tunnel passes very close to the pile foundation does it affect the building structure's piled foundation; when the tunnel is located far from the building structure, its impact is negligible (KUMAR, 2022). Swetha et al, investigated the behavior of a pile group resulting from tunnel construction below ground using a two-dimensional finite element analysis using PLAXIS 2D. Additionally, it was found that when the tunnels were moved horizontally away from the building at a specific depth, the settlement decreased. In terms of reducing settlement, an increase in the horizontal distance between tunnels and the building is more significant than tunnel depth increments. To comprehend the settlement decrement pattern, a 45° pressure distribution line was drawn. For every twin tunnel location, the cross-sectional area of the tunnel that overlapped with the building load influence region was calculated. It was discovered that the building's settlement changed in tandem with variations in the overlapping region. All the tunnel locations showed signs of differentiating pile groups. However, it was discovered that when the pile group's horizontal and vertical depths increased, the disparity in the settlement of the individual piles decreased (Swetha, B., Sangeetha, S., & Hari Krishna, P., 2022).

Many researchers have previously used the FEM method to investigate tunnel and piled foundation interactions (Deshmukh, R., & Patil, P., 202) (El Houari, N., Taleb, O., Hamzaoui, F., & Bachir, E., 2022) (Raja, M. K., Premalatha, K., & Hariswaran, M. S., 2015) (Salim, N. M., & Lafta, S. J., 2020). Two sets of piles, each with a different diameter and fixed length and spacing, were formed in the 11*7 formation for this study to ascertain how tunneling and its location affected the settling of the piled foundation system. For each pile group, a 10-meter-diameter tunnel was examined at two distinct depths and four different horizontal positions from the foundation's center to determine the effect of the tunnel location. Through modeling and analysis, the settlement and other parameters were ascertained for the sixteen distinct designs using the Plaxis 2D finite element analysis program.

2. MATERIAL AND METHODS

In this research, the effect of tunneling on the settlement of pile foundation systems built on layered soils was investigated. For this purpose, a square foundation with dimensions of 26*26*2m and a load of 200 kPa, equivalent to the load of a high-story building, was applied. Table 1 lists the characteristics of the soils used in the models, which use various sources to simulate the soil of Istanbul's European side. Modeling is done with finite element software called "PLAXIS 2D". The embedded pile model was used to model the piles, while the foundation and tunnel were represented as plates. To determine how tunneling and its position affected the settling of the piled foundation system, two groups of piles were formed in the 11*7 formation, each with a different diameter of 0.8, 1.2 meter and 30 meters in length and a fixed spacing of 2.4 meters. The piles were placed 4 meters out of the plane and 1 meter from the edges. A tunnel with a 10-meter diameter was inspected for each pile group at two different depths and in four different horizontal positions from the center of the foundation to ascertain the impact of the tunnel position. The parameters used for piles, foundation and tunnel are presented in Table 2, Table 3, and Table 4, respectively. Z/D and X/D ratios indicated in Table 4 are respectively the ratio of the distance from the central axis of the tunnel to the central axis of a pile group to the tunnel diameter and the ratio of the net distance of the pile toe and tunnel cover to the tunnel diameter. These concepts and the model schematic are shown in Figure 1.

Table 1: Soils input parameters (DALGIÇ, S., TURGUT, M., KUŞKU, İ., COŞKUN, Ç., & COŞGUN, T., 2009) (Ertürk, 2015) (REZAI.A, 2013) (Tezcan, S. S., Kaya, E., Bal, I. E., & Özdemir, Z. , 2002).

		1	2	3	4	5
Formation	*Unit*	*ML*	*Limestone*	*CH*	*Sand*	*CH*
Thickness	m	10	7.5	4	15	64
γ_{sat}	kN/m^3	19.0	21.0	19.0	18.0	18.0
γ_{dry}	kN/m^3	16.0	19.0	16.0	16.0	16.0
Poisson's Ratio	-	0.35	0.20	0.30	0.30	0.20
E_{ref}	MPa	12	582	55	122	113
$\emptyset$	°	7	35	25	40	16
c	kPa	15	40	35	25	45

Table 2: Piles input parameters.

Material type	*Elastic*	*Unit*
D	0.8, 1.2	m
L	30	m
S	2.4	m
$L_{spacing}$	4.0	m
$Unit\ Weight$	24.0	kN/m^3
E_{ref}	$2*10^7$	kN/m^2
$Poisson's\ Ratio$	0.15	-

Table 3: Foundation input parameters.

$Dimensions$	26×26	m
$Thickness$	2.0	m
$Unit\ Weight$	24.0	kN/m^3
E_{ref}	2×10^7	kN/m^2
$Poisson's\ Ratio$	0.15	-

Table 4: Tunnel input parameters

D	10	m
$Thickness$	0.5	m
$Unit\ Weight$	24.0	kN/m^3
E_{ref}	2×10^7	kN/m^2
$Poisson's\ Ratio$	0.15	-
X/D	0, 1, 2, 3	-
Z/D	0.5, 1	-

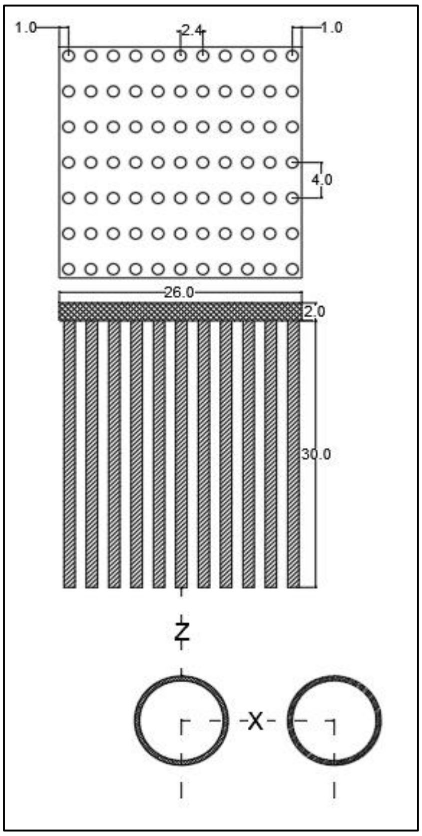

Figure 1: The dimensions of the piled foundation and the tunnel's placement in relation to it.

The combinations of the sixteen different models that were developed are shown in Figure 2.

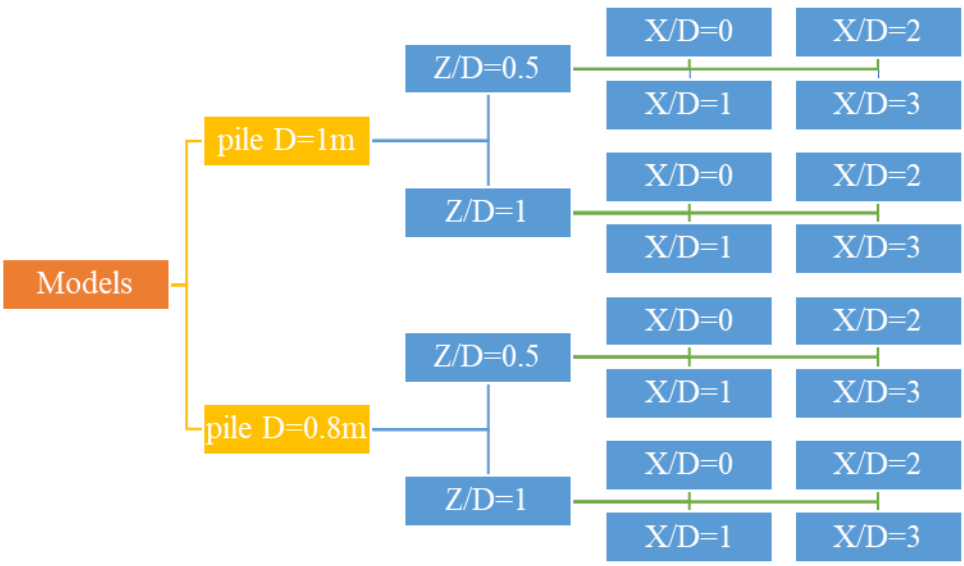

Figure 2: Models combinations.

3. RESULTS AND DISCUSSIONS

3.1. Effect of Tunnel on The Surface Settlement

Figures 3-6 illustrate the impact of two $Z/D$and four X/Dvariations on the amount of surface settlement for various pile diameters. The graphs below show that as the tunnel gets deeper, the settlement's value decreases with an increasing Z/D value. It can be said that the total settlement values decrease as the tunnel is located further from the foundation center axis in the x direction. However, differential settlements might take on greater significance. The figures show that the most crucial circumstances for each analysis are those in which X/D= 1.

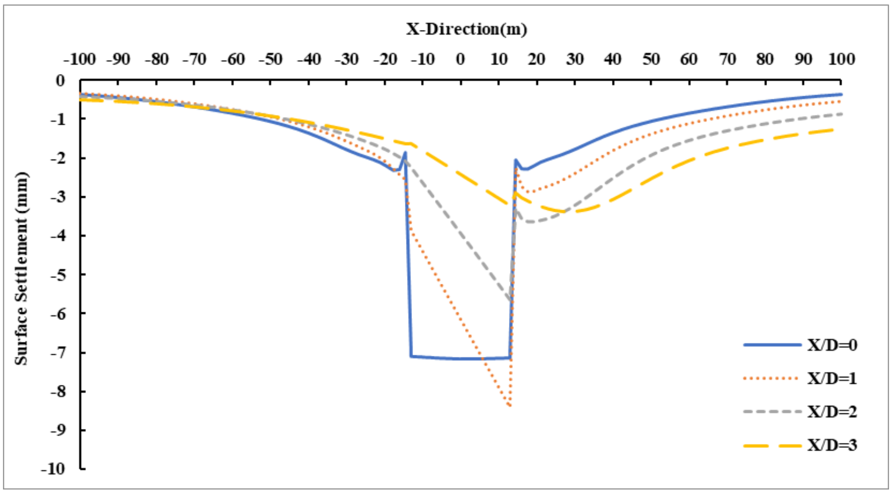

Figure 3: Variation in surface settlement with respect to X/D for piles with a diameter of 0.8m and Z/D = 0.5.

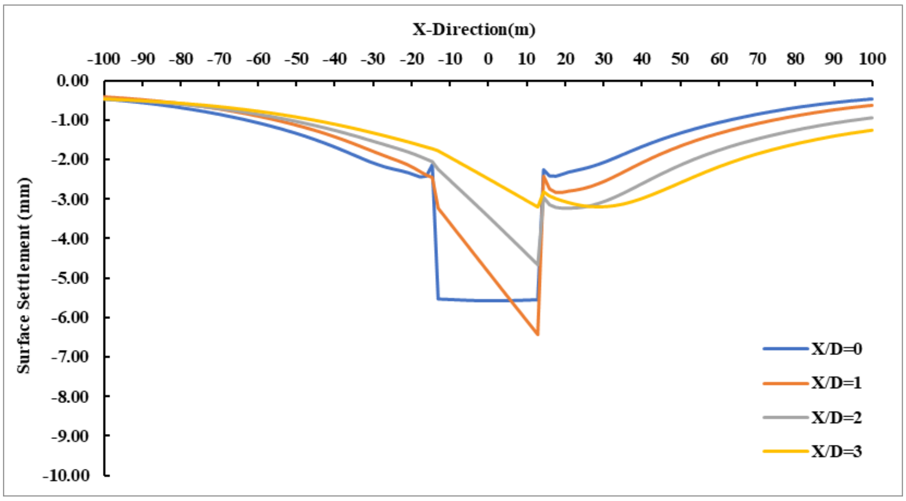

Figure 4: Variation in surface settlement with respect to X/D for piles with a diameter of 0.8m and Z/D = 1.

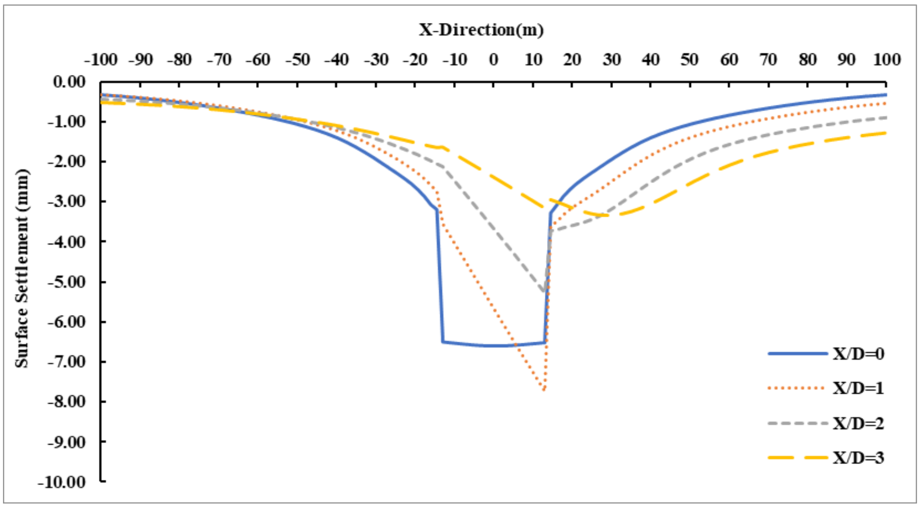

Figure 5: Variation in surface settlement with respect to X/D for piles with a diameter of 1.2m and Z/D=0.5.

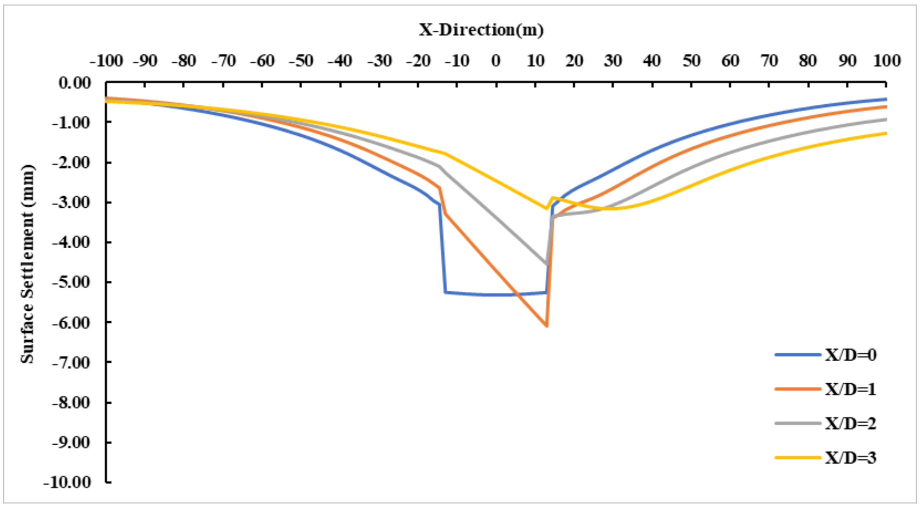

Figure 6: Variation in surface settlement with respect to X/D for piles with a diameter of 1.2m and Z/D=1.

3.2. Effect of Tunnel on the Piles Settlement

In this section, the effect of tunneling on the settlement of piles is given in Figures 7 and 8, respectively, for piles with diameters of 0.8 and 1.2 meters. It is evident that a decrease in settlements resulted from an increase in pile diameter and Z/D ratio. Increasing the X/D value in both Z/D values causes the settlement amount in the piles to decrease, but this decrease is greater in the piles on the left side of the foundation axis, that is in the piles that are farther from the tunnel. Increasing the X/D value increases the amount of differential settlement, and X/D = 1 is the critical value in terms of it.

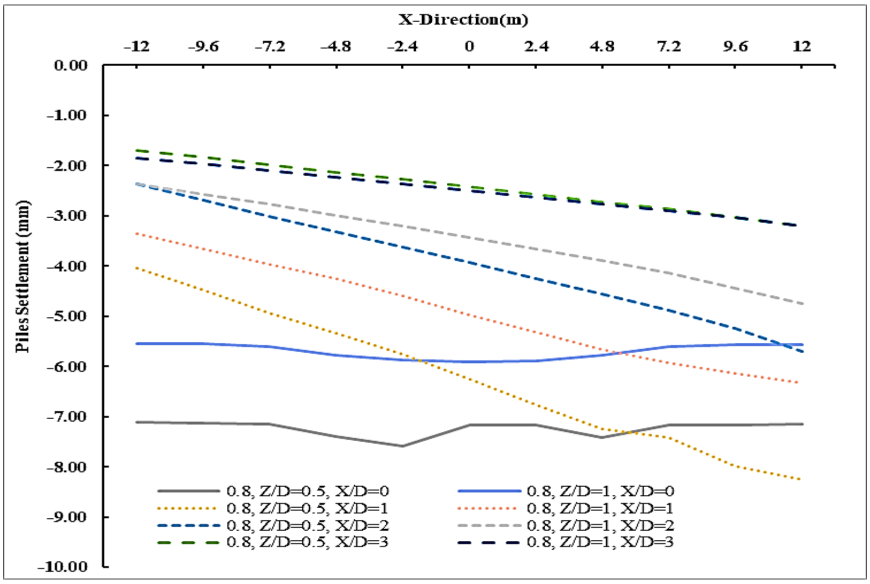

Figure 7: Piles settlement changes for pile with d=0.8m.

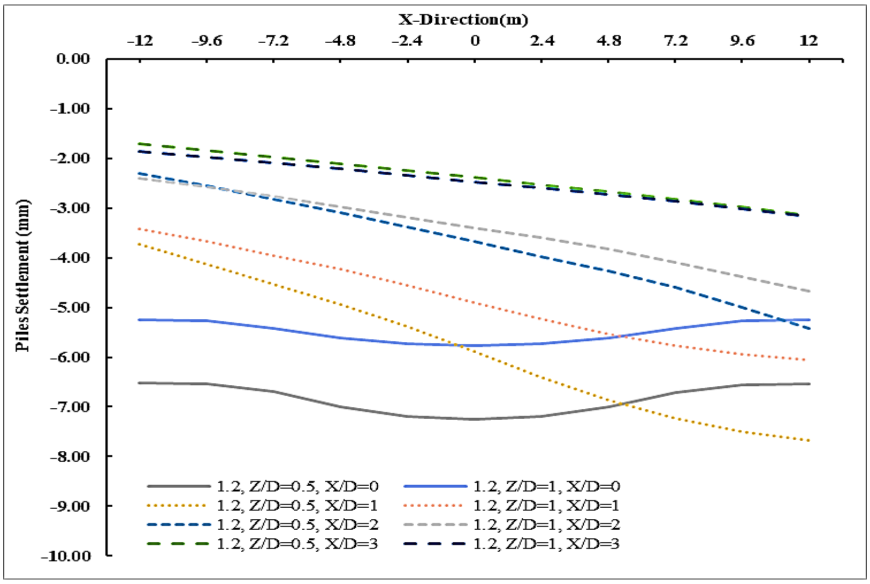

Figure 8: Piles settlement changes for pile with d=1.2m.

3.3. Effect of Tunnel on the Piles Bending Moment

A comparison of figures 9 and 10 reveals a significant drop in moment values as the pile diameter increases. The bending moment slightly decreases as the tunnel's horizontal location moves away from the pile. Due to the tunnel's new location in the +x direction, the pile on the left is the one that is most impacted. It's possible that the influence zones are too responsible. The effects are amplified when the tunnel is situated within the influence zone. The tunnel's effect decreases with increasing distance within the influence zone.

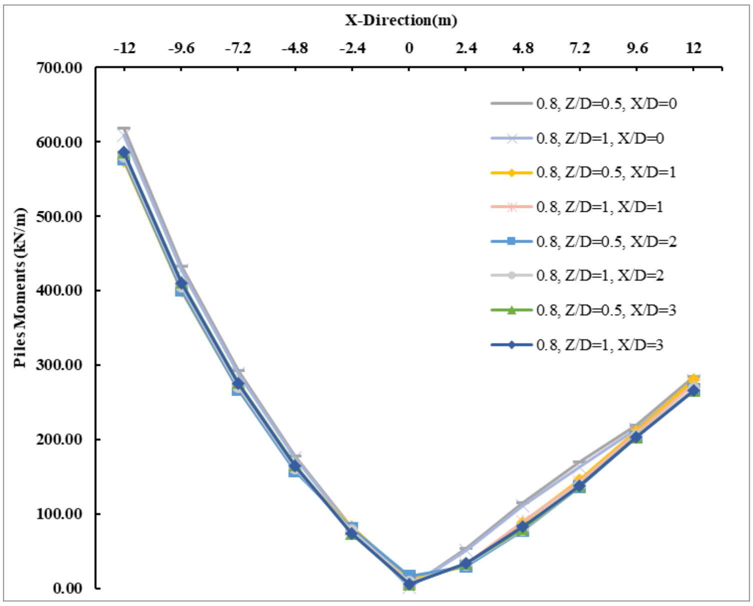

Figure 9: Bending moment variation in piles for d = 0.8m.

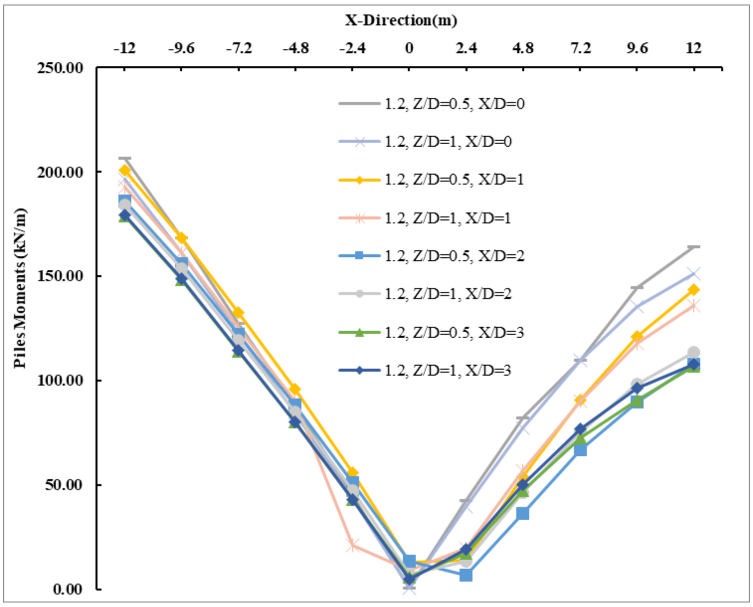

Figure 10: Bending moment variation in piles for d = 1m.

3.4. Effect of Tunnel Location on Tunnel Settlement and Axial Force

As Figure 11 illustrates, the amount of settlement in the tunnel is not significantly affected by increasing the diameter of the pile or deepening the tunnel; instead, the amount of settlement varies when the tunnel's horizontal position is altered and increases when it approaches the foundation.

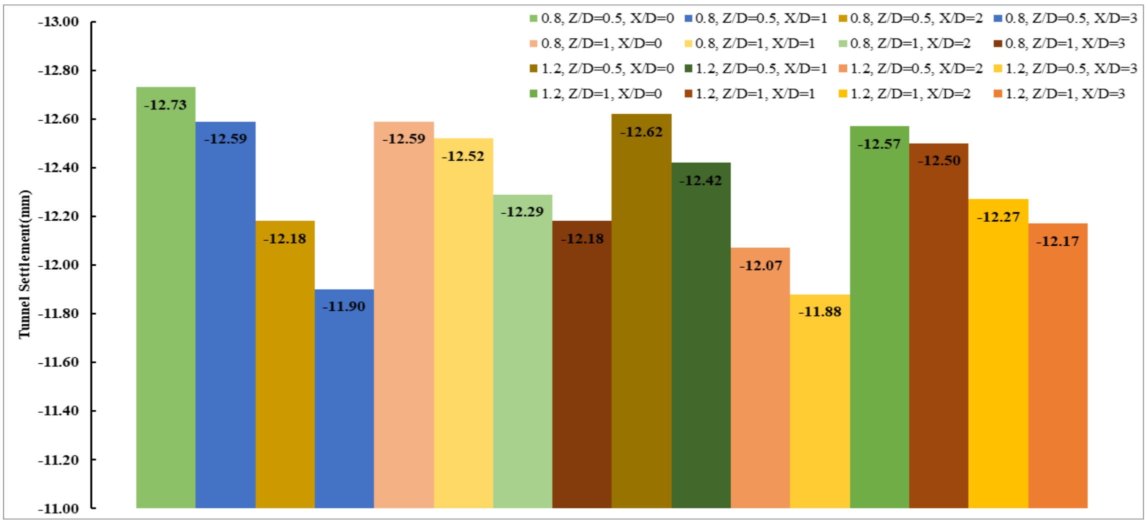

Figure 11: Effect of pile diameter and tunnel location on tunnel settlement.

Figure 12 shows the axial forces acting on the tunnel. The data indicates that there is no significant effect on the amount of axial force when the pile diameter is increased or the tunnel's horizontal position is altered. However, the axial force changes and increases as predicted when Z/D increases.

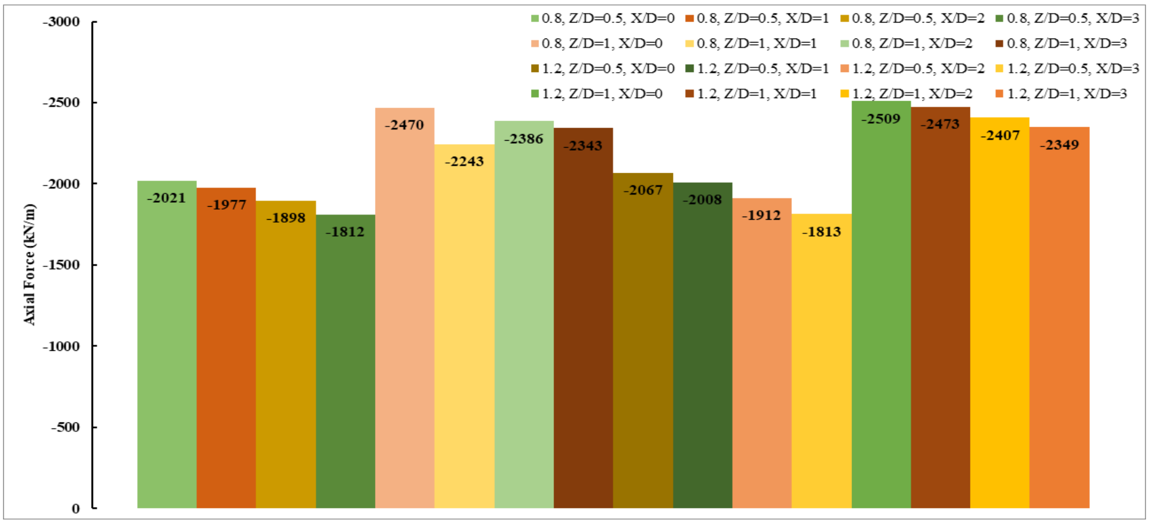

Figure 12: Effect of pile diameter and tunnel location on tunnel axial force.

4. CONCLUSIONS

The location of the tunnel is crucial when taking the influence zones into account. The main location parameters, which are also the main parameters in this study, are its depth and distance from the foundation center. The results of 16 analyses carried out in this study to investigate how tunneling and tunnel location affected the piled foundation system's settlement are presented below:

- It can be stated that as the tunnel is positioned farther in the x direction from the foundation center axis, the surface total settlement values decrease, and the differential settlements increase.
- Increasing the pile diameter and Z/D ratio led to a reduction in pile settlements.
- The amount of settlement in the piles decreases when the X/D value in both Z/D values is increased; however, the amount of settlement decrease is larger in the piles that are farther from the tunnel, or on the left side of the foundation axis.
- As the horizontal location of the tunnel moves away from the pile, the bending moment of the pile slightly decreases. The tunnel's effect decreases with increasing distance within the influence zone.
- Increasing the diameter of the pile or deepening the tunnel has no appreciable effect on the amount of tunnel settlement.
- The amount of tunnel settlement increases as the tunnel approaches the foundation and varies when the tunnel's horizontal position is changed.
- Increasing the pile diameter or changing the horizontal position of the tunnel has no noticeable impact on the tunnel axial force.
- When Z/D increases, the tunnel axial force changes and increases.
- One of the main issues in metropolitan areas these days is traffic congestion. Subway and underpass tunnels have proven to be a successful solution to these issues.
- In addition to estimating the possible deformations that may occur in the structures during the construction stages, any deformations should be periodically monitored by taking measurements at relevant locations inside the tunnel and on the structures using instrumental observations.

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest among the authors.

CONTRIBUTIONS OF AUTHORS

H.Z.A.: Conceptualization, methodology, software, validation, formal analysis, investigation, resources, writing—original draft preparation.

O.Y.: Validation, investigation, writing—review and editing.

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