DOI: 10.2478/sspjce-2024-0020

A Simplified 3D Model for Tunnel Pile Interaction

Bousbia Nawel

Faculty of Technology, Department of Civil Engineering, LMGHU Laboratory, University of 20 August 1955, Skikda, Algeria
e-mail: bousbia1101@yahoo.com/ n.bousbia@univ-skikda.dz

Abstract

Due to the development of communication routes (metro, railways), it is frequently necessary to build underground structures in order to improve traffic flow, which is a key factor in the metropolitan areas' regeneration. Taking in account of the interaction between tunnel-soil-piles is a significant topic and a vital factor in the analysis the total solutions of these underground projects. The significance of the impacts communicated depends on a number of factors, including the genre of structure, and the soil type. The main purpose of the present paper is to study numerically the immediate influences that will result from the new tunnels construction near existed piles (micropiles), this model will be employed to an existent case of an Algerian East-West highway tunnel section, while using the code of calculation Plaxis3D tunnel. A detailed parametric survey that will be made to put in evidence influences it of the different parameters geometric and mechanical on the interaction between shallow tunnel and an existing piles and security objectives. And for understand furthermore the problem of interaction mechanism between micropiles and tunnel, principally when piles are positioned in close proximity to tunnels. The obtained findings show that the tunneling may affect in nearby piles a considerable bending moments, lateral deflection, compressive forces, and axial forces.

Key words: interaction, tunnel, pile, three dimensional simulations, Plaxis3

1 Introduction

In Algeria, the rapid development of land has indirectly increased the congestion situation of the traffic in cities. As a result, network of highways, railroads... known significant development in recent years, and might have to be constructed to accommodate the transportation system, communication and utility networks such as highway East-West 7000 km of length. This project imposes often the difficult crossing of the relief, as the mounts, which request underground works (construction of tunnels). An evaluation of the effect of tunneling on the stability and integrity of existing piles is sometimes required prior to the construction of the shallow tunnels. Tunneling may cause critical axial stresses and bending moments in nearby piles, particularly when piles are installed in fragile soils, according to laboratory research by Morton and King and centrifuge experiments by [1]. Therefore, it is very important to understand in detail the interaction mechanism between tunnel and pile

during their construction processes. Several works of research studied the interaction between tunneling and groups piles at different position of the pile tip concerning the horizontal axis of the tunnel; the numerical analyses were used to study this problem as well.
The tunnel T4 comes within the framework of the realization of the Maghreb Unit Highway which is about 7000 kilometers. The tunnel is part of section 4 of this highway. The highway tunnel T4 comprises two substantially parallel tubes of a total length of 2500 m; this case includes evaluating the underground and ground movement (settlements), the internal forces in the existing piles (constructs in first) before and after interaction with newly adjacent tunnel (to construct in second) using the finite element method [2].
In this work, we suggest using completely three-dimensional finite element modeling to investigate the micropiles reactions to tunneling at the kilometer point (231+220), which is in a zone of weak cover (shallow tunnel).
It ducts to search for suitable solutions adapted to this type of ground. The recent research moves toward the reinforcement of soil by the micropiles, in this part we are going to pass to the numerical modeling for a calculation model that is dedicated by the interaction between tunnel-pile. The interaction mechanism between tunnel - soil- piles is a difficult problem. It is divided into two major categories:

- The impact of tunneling on existing piles.
- The impact of pile building and loading on already-existing tunnels.

An overview of the impact of tunnel building on already-existing neighboring pile foundations was provided by [3-4]. They gave two instances where pile movements related to building tunnels had been measured

2 Problematic

For several reasons, we construct the shallow tunnels (weak cover zone). The excavating of the shallow tunnels can induce movements of ground that are susceptible to provoke some distortions and in extreme cases the important damages and can conclude the collapses, the slips to the level of the ground surface, therefore. For resolving the problems results to the excavation of the underground works at weak cover. We start in the first place with the reinforcement of this zone by bored piles, after the reinforcement, we pass by the excavation of tunnel to double tubes. The right tube of the tunnel is excavated in first, the one of left in continuation, in accordance with the exposed method. This operation creates a problem of the interaction between piles and tunnels [5-6]. For analyzing and resolving the tunneling-piles interaction problem. We can achieve some analyses by finite element to study the displacement; axial forces; bending moment and the lateral deflection in the micropiles resulting from tunneling located close proximity to them.

3 Site of Tunnel “T4”

The tunnel “T4”is located to the North - East of Constantine. It crosses from South to North Jebel El Cantor over a total length of 2500m. The tunnel is characterized by a zone of low coverage above which extends over a very significant length. The tracing of the tunnel is raised on the geological card of S'mendou at 1/50.000th [7].

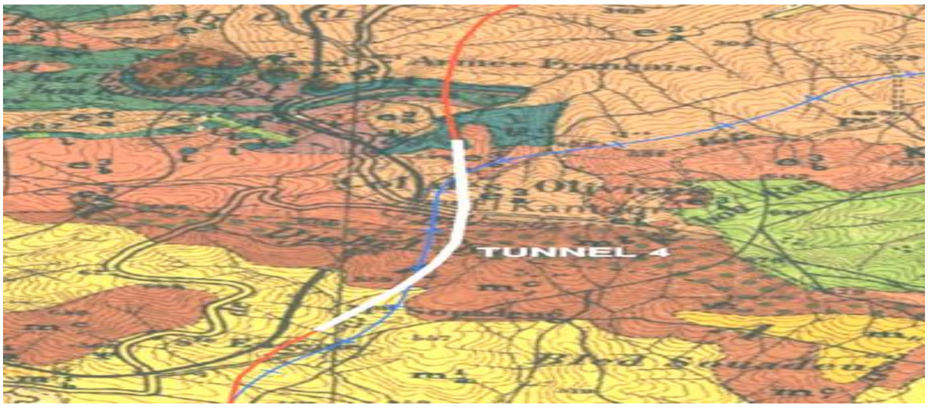


Figure 1: Location of the tunnel T4 on the geological map of Smendou

4 Simulation model (Tunnel-Micropile interaction)

4.1 Terrain to be treated using micropiles

Micropiles are generally used when there are difficult ground conditions, such as natural or man-made obstructions, sensitive ground with adjacent excavations, are also an option for use as in-situ reinforcements to provide stabilization of excavations. Micropiles are high-performance drilled deep foundation elements typically between 5–12 inches in diameter that can extend to depths of 200 feet depending on the design requirements and site condition.

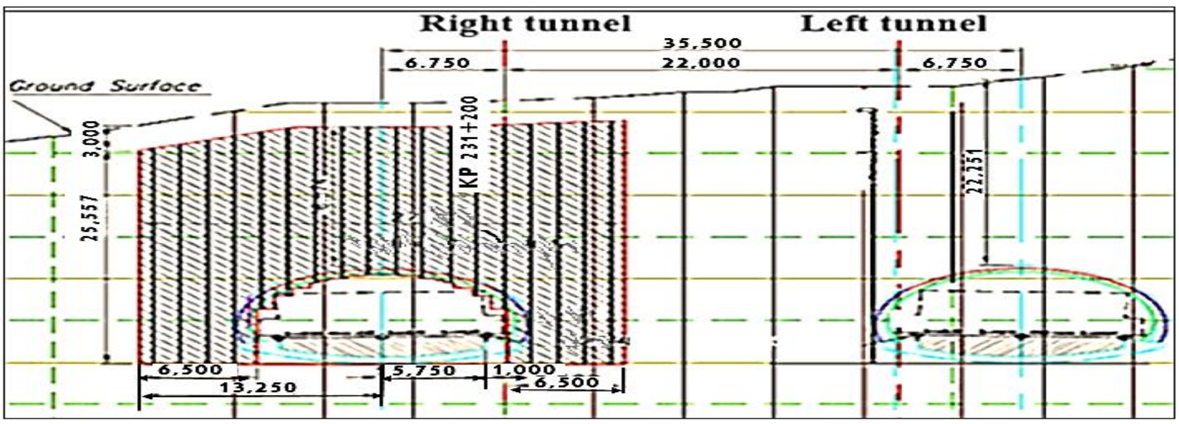


Figure 2: The extended of the section to treat

4.2 Section model to stabilize

The soil will be treated up to the bottom of the tunnel for maximum efficiency. Width of the terrain to be treated: an enlarged excavation zone of 5m on all sides. Improving and reducing

the ground movements induced by excavation of tunnel T4 using micropiling is an appropriate solution for the present study in the most critical section (PK 231+220) corresponds to the lowest coverage of the tunnel, which is 22,5m [7].
The micropiles are modeled by plate element, in reality a micropile is made up of a T32 steel bar and a cement grout, finally the diameter is 10 cm and the length is 40 m. (Figure 4)

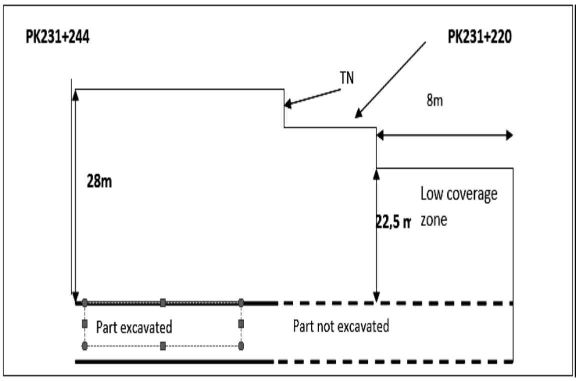


Figure 3: Parts of the T4 tunnel concerned

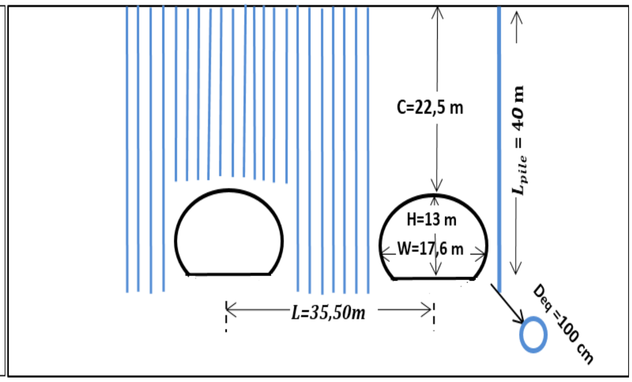


Figure 4: Relative location of tunnels and micro-piles

Figure 4 presents the relative location of tunnels and the micropiles. Mohr coulomb model (MMC) has been applied in this analysis. This model is appropriate to simulate the behavior of soil below the conditions of excavation, with the introduction of group's micropiles.

5 Mechanical characteristics of the chosen section

We take a model section at kilometer point (231+220) that is in a weak coverage zone = 22,5m. The parametric mechanical of the soil that is located at this zone is adopted in the table 1, according to the Mohr Coulomb model.

Table 1. Mechanical and geotechnical characteristics of soil used the Mohr Coulomb Model

Soil	γ (kN/m^3)	E (kpa)	ν	C (kPa)	ø (°)
Marly clay	17,50	30000	0.30	5	27

The lining of the tunnel is composed of a reinforced concrete ring. The tunnel lining properties are given in table 2.

Table 2: Properties of lining tunnel's thickness (40cm)

	E (MPa)	A (m^2)	I (m^4)	d	EA_{eq} (kN/m)	EI_{eq} ($kN.m^2/m$)	ν	$d_{equival}$ (m)
Shotcrete	$1x10^4$	0,4	$5.33*10^{-3}$	1	$5{,}18x10^6$	$6{,}9x10^4$	0,20	0,4
Steel H200*200	$2x10^5$	$78.1x10^{-4}$	$0.569x10^{-4}$	1				

6 Model calculation

The tunnel is consisting of two tubes that practically parallel. The right tube is excavated in first, the left tube in continuation, in accordance with the method pro0posed. We excavate the totality of the section of the tunnel (in order to simplify the studied model, we take a simplified equivalent model (Figure 5). In the present analysis, the two tubes are circular in equivalent cross-section with 15.25 m outer diameter and 0.40 m of concrete lining thickness. The centers of the tunnels are to 1,97D below the surface of soil (coverage + radius), the distance between the centers of the two tubes is to 35.5m. For micropiles, the length and width are equal to L_p = 40 m and D_{eq} = 10 cm. The pile has an axial stiffness and a bending stiffness EA=3 E7 kN/m/m and EI=3 E4 $kN.m^2/m$, respectively.
Numerical simulation has been carried out for this investigation using the PLAXIS3D finite element approach. The modeled domain has dimensions of 100 m, 60 m, and 50 m in depth. The two tubes and micropiles are supposed constructed in a homogeneous soil.

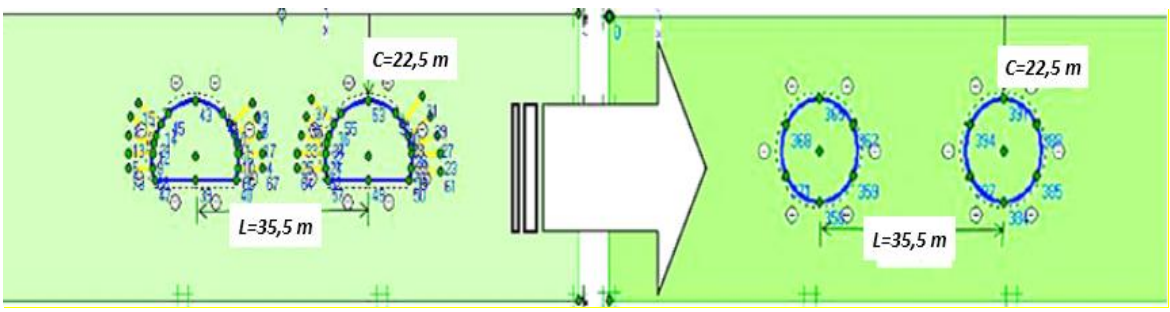
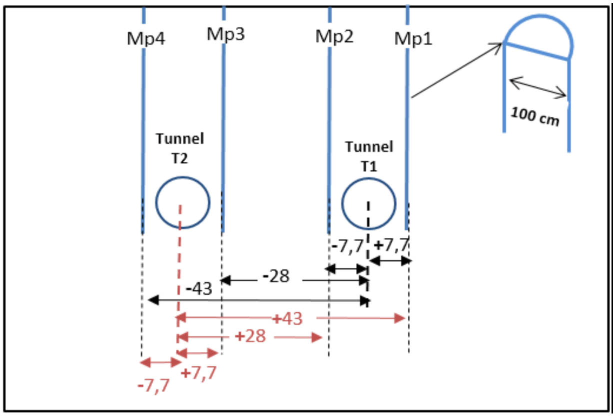


Figure 5: The equivalent model simplified

7 Calculation model according to bored tunnel method

Convergence confinement method is used as an approach simplified of the analysis of the interaction between tunnel-soil [8.9].; and the shape of the tunnel plays a vital function in the lining tunnel convergence.
The micropiles have been localized enough distant that tunnels; this rapprochement of the tunnels gives some effects on the answer of the micro-piles, which could be studied. Due to the symmetry and the simplicity, we take simply the group from four micro-piles that have been simulated with the two tunnels (right and left). The distances between the axis of the micro-piles and the centers of tunnels T1 and T2 are shown in the figure 6. Following the

results of auscultation done to this zone of the weak cover = 22,5m that has given a settlement of 15 cm after 10m excavation, we take only a section longitudinally equal to 10m. Figure 7 displays the finite element mesh used in the numerical modeling; the horizontal (x), vertical (y) and longitudinal (z) is respectively 100, 60 and 10 m. Given that the bottom boundary is outside of the tunnel excavation's influence, it is assumed that there has been no horizontal or vertical displacement there.



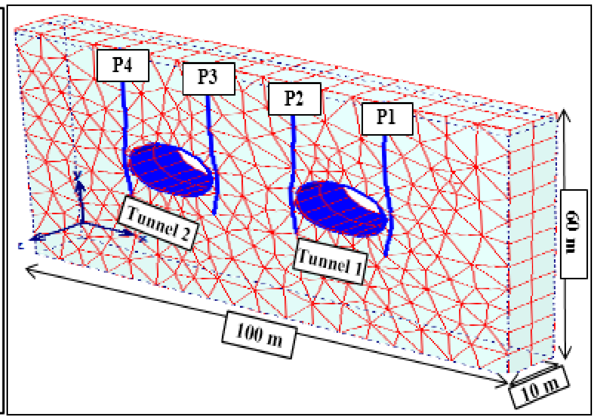


Figure 6: Emplacement of micropiles relative to T1 and T2 Figure 7: Deformed Mesh 3D

Convergence confinement approach is one of the various similar approaches that enables control of the deconfinement process. The convergence confinement method is used as an approach simplified of the analysis of the interaction between tunnel-soil [8.9]; and the shape of the tunnel plays a vital function in the lining tunnel convergence.

8 Results analysis of interaction between tunnels and micropiles

8.1 Settlement at surface soil Result of analyses

A comparison between the results gotten as the curves, settlements at surface soil measured before and after the presence of the micropiles and the two tubes T1 and T2, therefore we present considered three cases (Micropile in virgin ground, micropile with single right tunnel excavation, and micropile with both tunnels). The curves give variable values in relation to the distinguished cases. It can be viewed from this figure that the settlement is negligible if there are only micropiles. However, the two cases remnant, we note that the values of settlement are more important in the both tunnels case with the presence of the piles, the value max is to the level of the vertical axis (Y) of the left tunnel (T2). It has been observed that, in comparison to building tunnel T1 alone, the two tunnels together construction resulted in a settlement of more than 50%. This is due to that soil after the first excavation already entered in state of instability, once we dig the tunnel T2, reproduces a more important state.

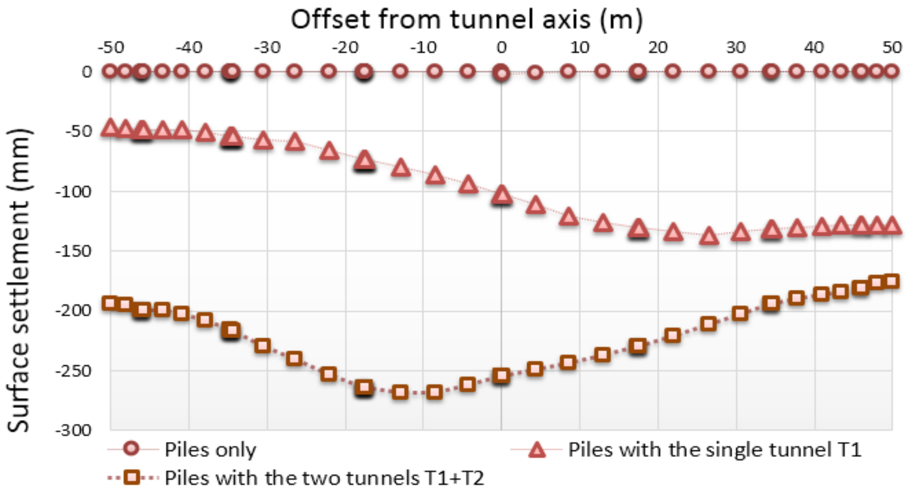


Figure 8 Settlements at surface soil induced by tunneling

8.2 Lateral deflection of mircopiles

Figure 8 presents the lateral displacements profiles in the four micropiles (P1, P2, P3 and P4) before and after the tunnels excavation; the investigation of the pile's movement in a lateral section shows a negligible deflection (practically zero) before the tunneling. Once the tunnel T1 is excavated, the lateral deflections are produced in the four micropiles P1, P2, P3 and P4 and move in either a positive or negative direction toward the tunnel T1 according to the pile-tunnel position, these lateral deflections of the micropile due to the tunnel T1's construction, which is the cause of the ground movement. This behavior is different compared with each pile where the lateral deflection is greater (until the 250 mm) for P2 nearest to the tunnel T1, per contrary this value decreased to 18% when the micropile P4 is distant to the tunnel T1, and can be explained by their relative distance of the tunnel T1. (-7.7; - 28 and - 43.1). We dig the second tunnel T2, the lateral displacements for each micropile are modified either from point of view aspect or from the value. The second excavation modifies the piles' behavior, causing each micropile to move in the direction of the nearby tunnel. Following the opening of the 1st tunnel T1 and the opening of the two tunnels together T1+T2, figure 8 combines the profiles of the lateral displacements obtained in the four (4) micropiles into one illustration.

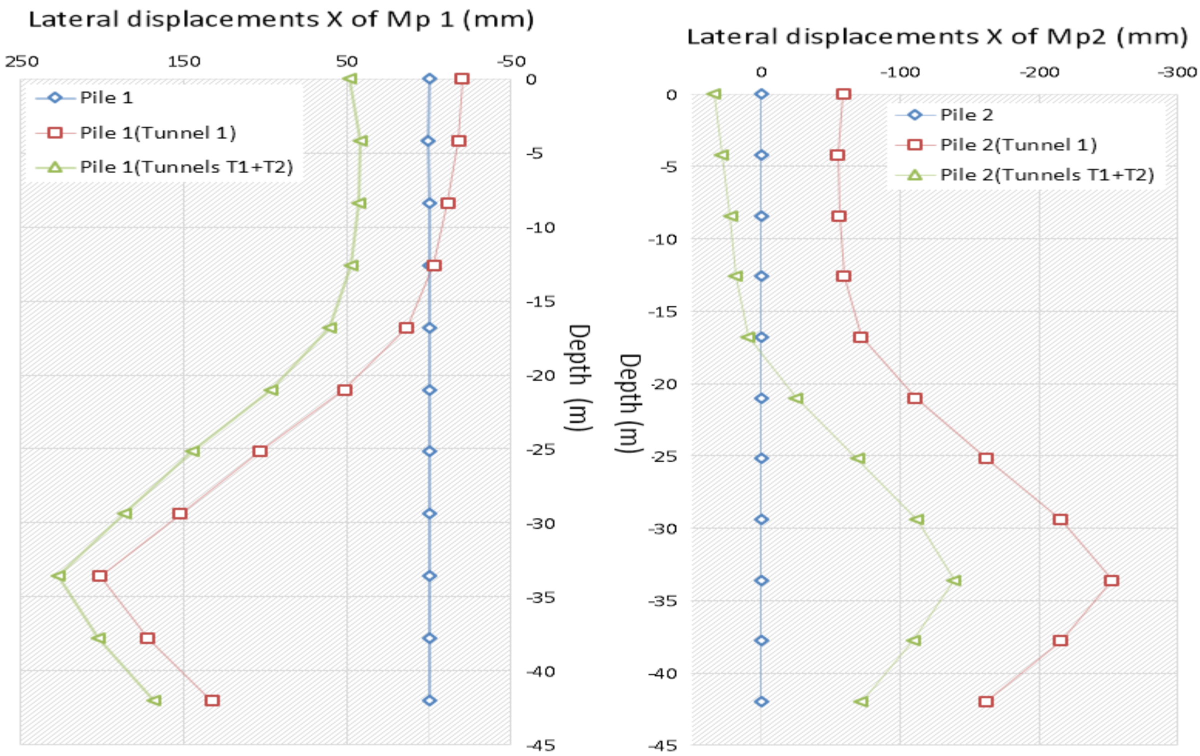


Figure 9.a: Variation lateral displacement in the micropiles P1 and P2 with the passage of the tunnels

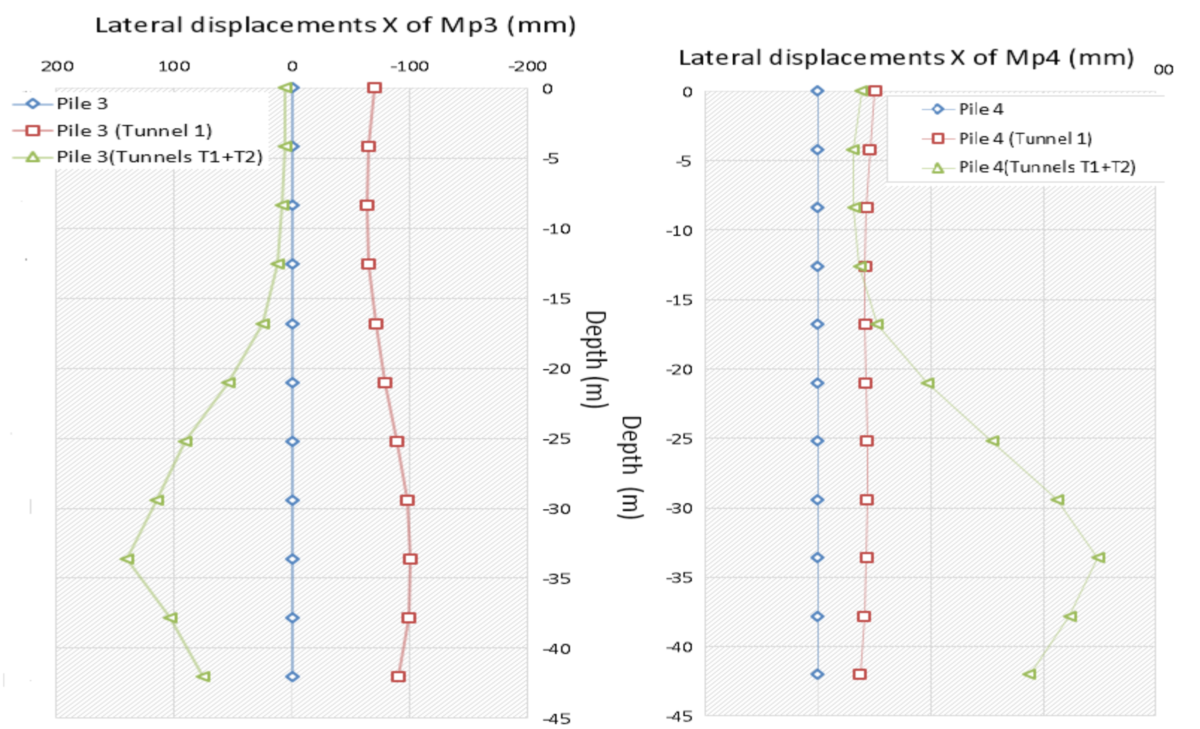


Figure 9.b: Variation lateral displacement in the micropiles P3 and P4 with the passage of the tunnels

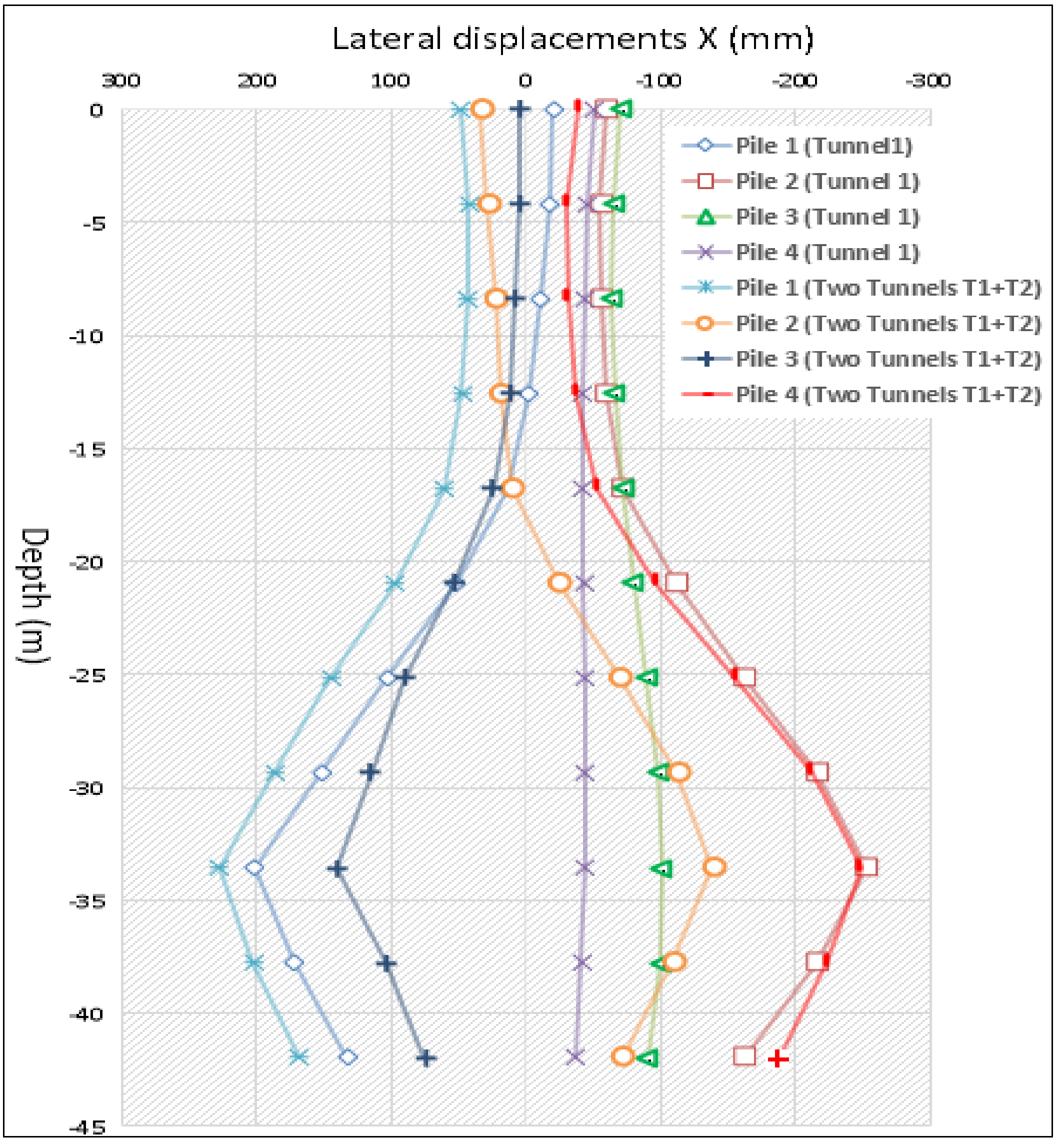


Figure 10: Variation of lateral displacement induced in the four micropiles with the passage of the tunnel T1 alone, and the two tunnels together T1+T2

8.3 Axial forces in mircopiles

We determine the fields of the axial force in the four micropiles according to the three distinguished cases, before and after the excavation of two tunnels; the axial forces of micropiles are negligible before tunnel excavation, nevertheless, they rapidly grow if a tunnel is dug, reaching a maximum value of 17650 KN in the micropile P1 closest to the tunnel, this value is observed in a section localized to the depth (X_p=0, 8Lp) and a minimum value until the 1570 kN in the micropile P4 is distant to tunnel T1. Once the left tunnel T2 was in existence, Two tunnels together (T1+T2), the axial profiles are changed, becoming more significant than in the first tunnel T1. It has been found that the internal axial force generated in the micropiles is significantly increased by the excavating of second tunnel T2.

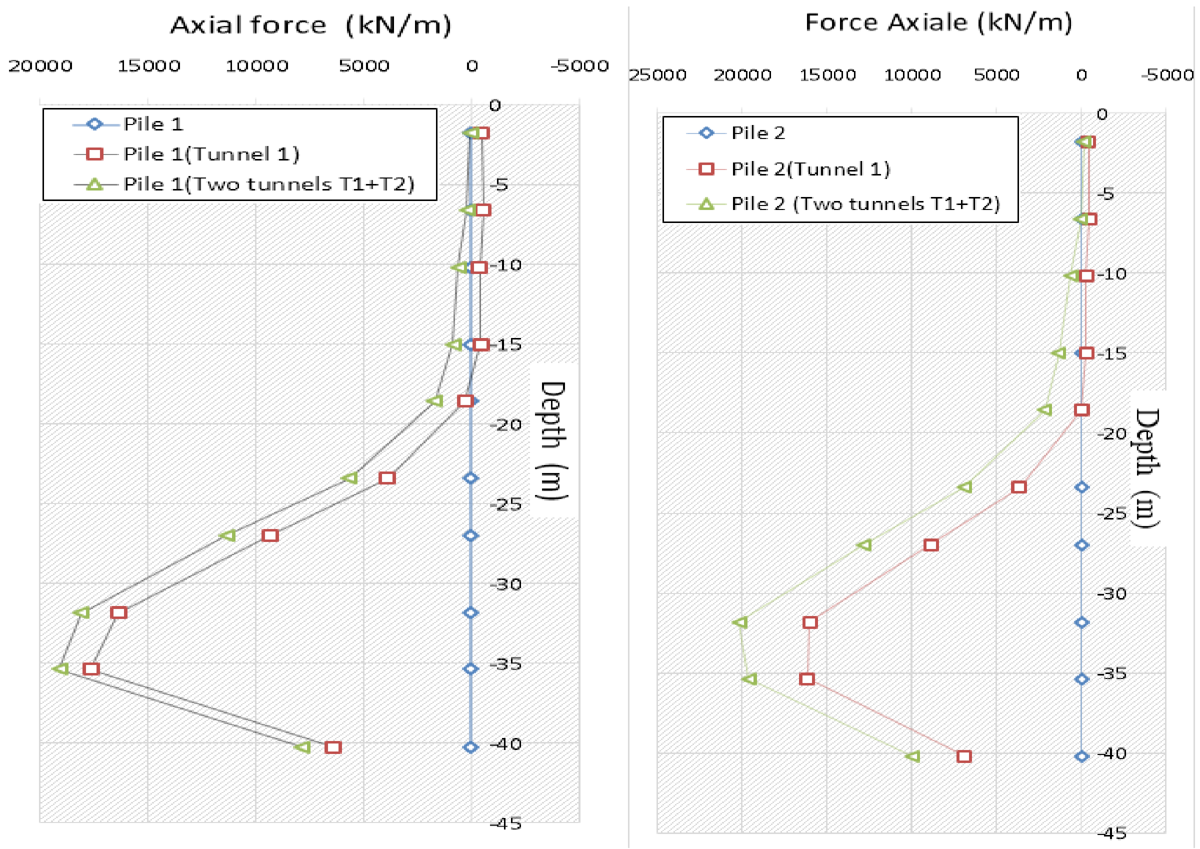


Figure 11a: Variation of Axial Force induced in the micropiles P1, P2 with the passage of the tunnels

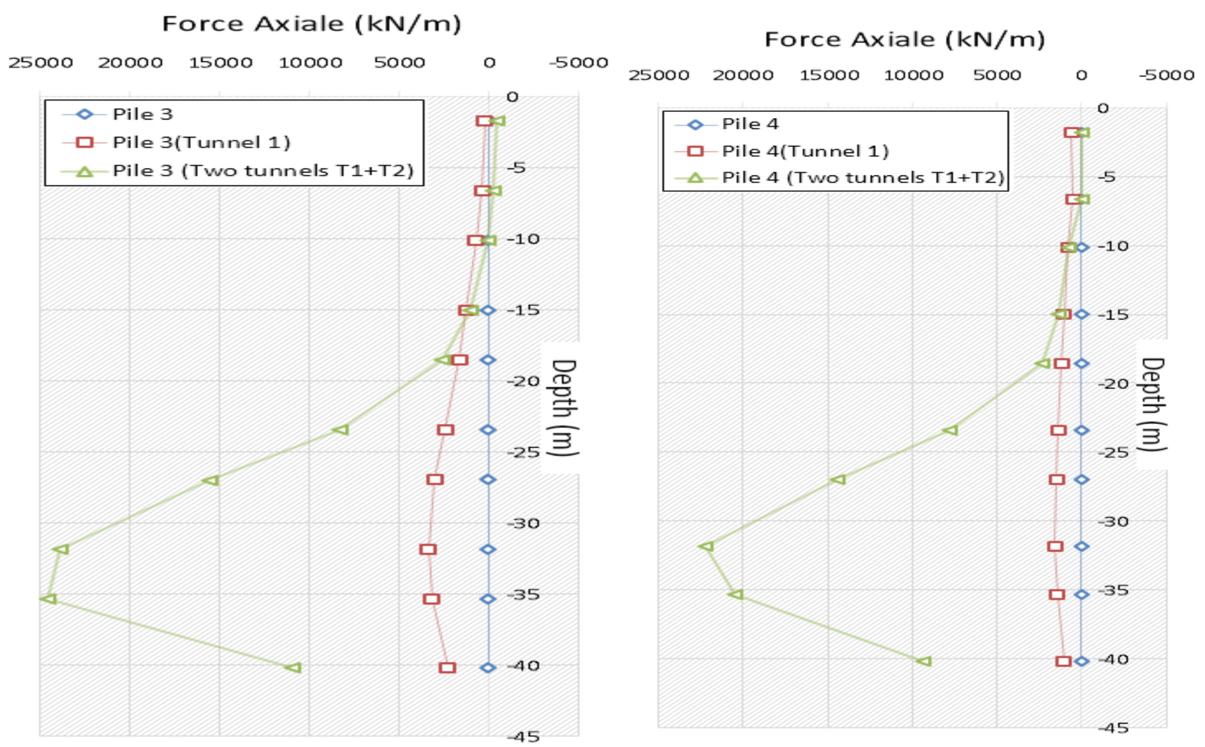


Figure 11b: Variation of Axial Force induced in the micropiles P3, P4 with the passage of the tunnels

8.4 Bending moment in mircopiles

We determine the fields of moments bending in the micropiles in the three distinguished cases. In an unperturbed ground without digging, with tunnel T1's construction and with the two tunnels together (T1+T2). The moments bending in the micropiles are negligible before the tunneling, after the digging, these moments will have maximum values in the micropiles P1 and P2 that are nearest to tunnel T1 that attain to 24 kN.m (interaction between pile-tunnel). In contrary, the farther micropiles P3 and P4, where we have the relatively modest values, are unaffected by digging. The moments of P1 and P2 practically remain the same after we construct the second left tunnel T2, changing only (increase) in the micropiles P3 and P4

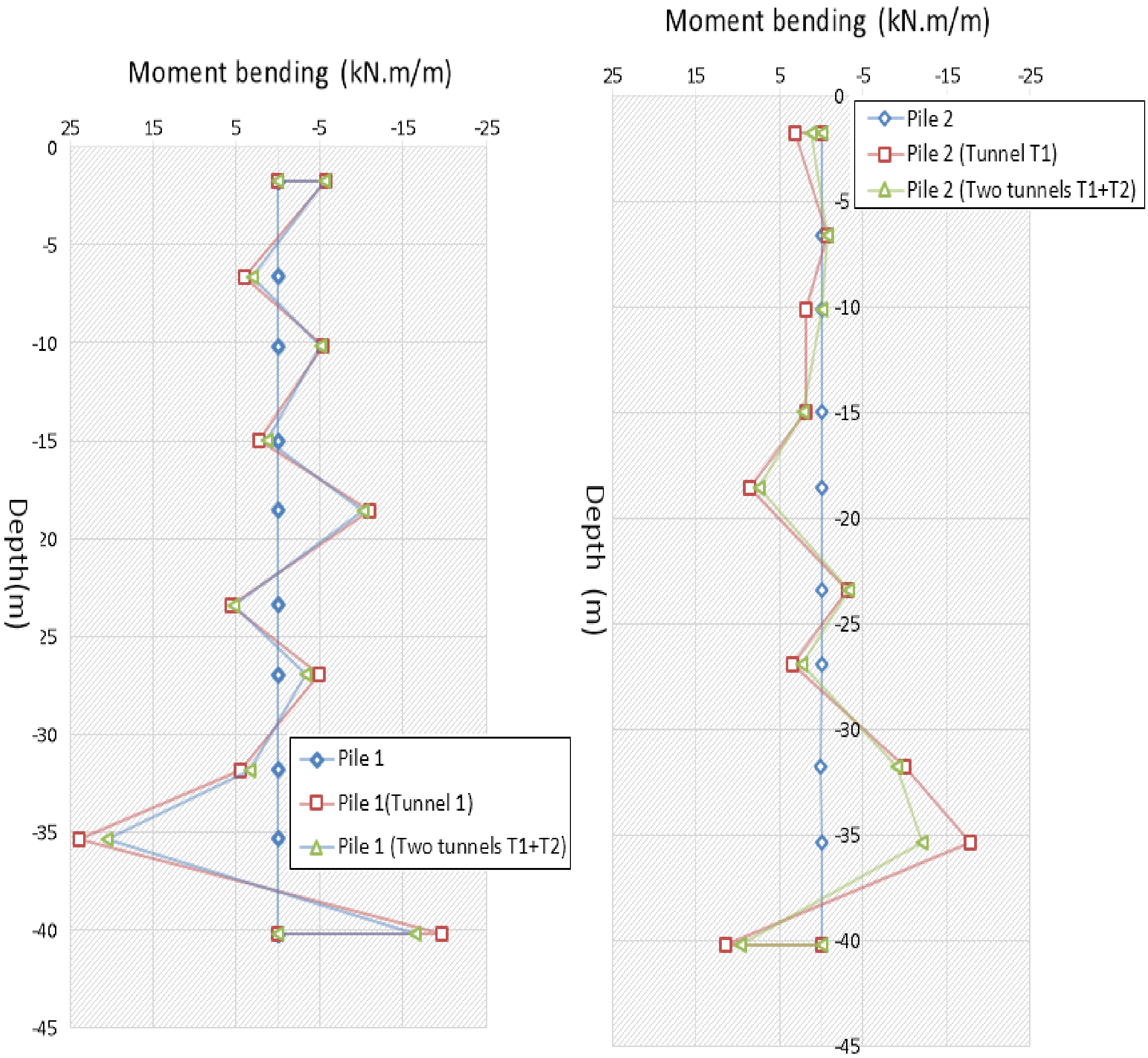
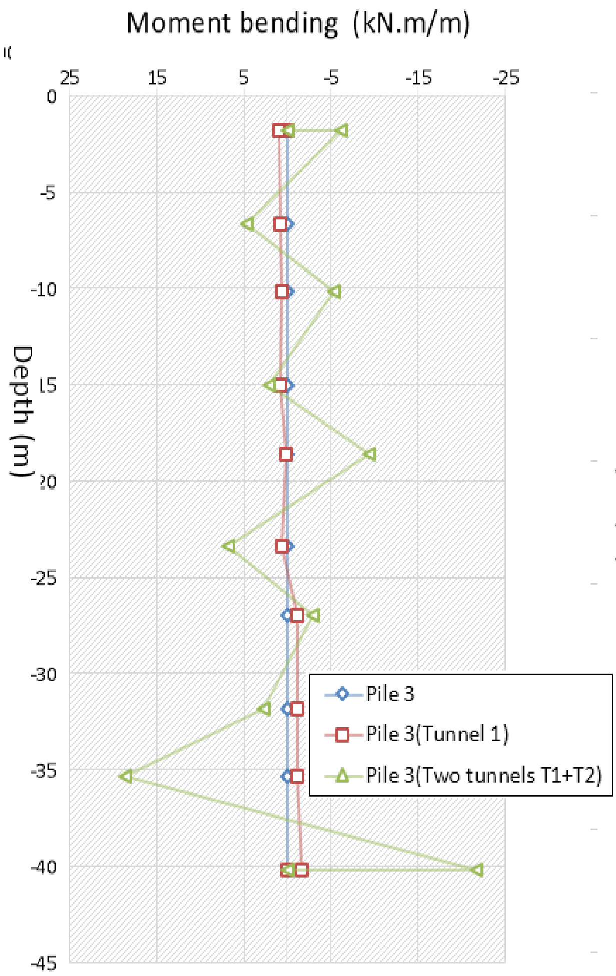


Figure 12 a: Variation of moment bending induced in micropiles P1 and P2 with the passage of the tunnels



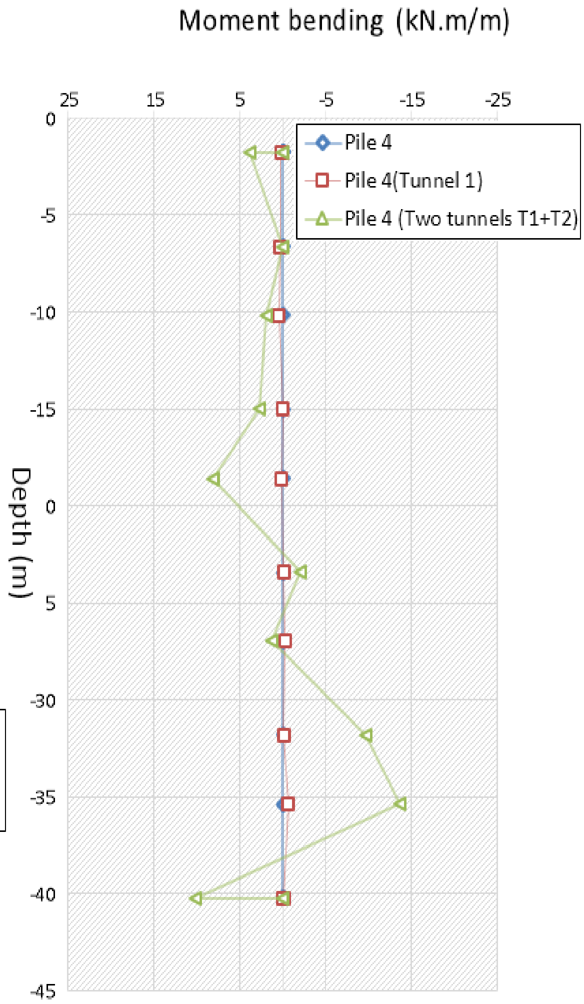


Figure 12 b: Variation of moment bending induced in micropiles P3 and P4 with the passage of the tunnels

9 Investigating the effect of micropiles depth on the interaction

9.1 Zone of influence and pile location effect

According to Yang Min et al. [10], we used four different lengths of micropile to investigate the impact of pile length on the interaction between pile and tunnel, and the stability of this micropile; therefore, the length of micropile relative to tunnel is examined. L_{pile}/H_{tunnel} of 0.5; 0.7; 1 and 1.4. In order to cover the zones of influence delineated by the lines that projecting 45° from the tunnel. The depth tunnel ($H_{tunnel)}$ and the length of the micropile ($L_{pile)}$ are 30 and 40 meters, respectively.
Figure 13 illustrates the micropile- tunnel configuration at different positions of L_{pile}/H_{tunnel} and constant X_{pile}/D_{tunnel} values of 1.0.

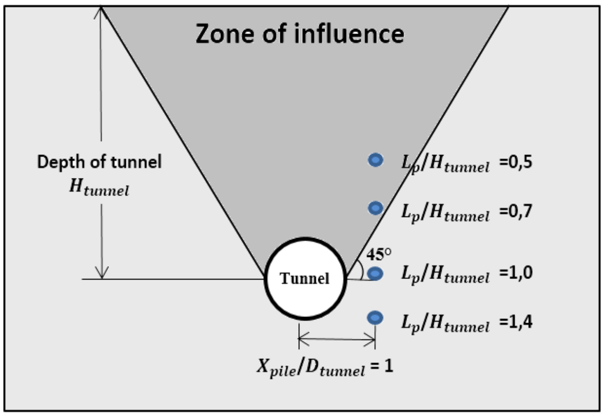


Figure 13: Micropile-tunnel configuration

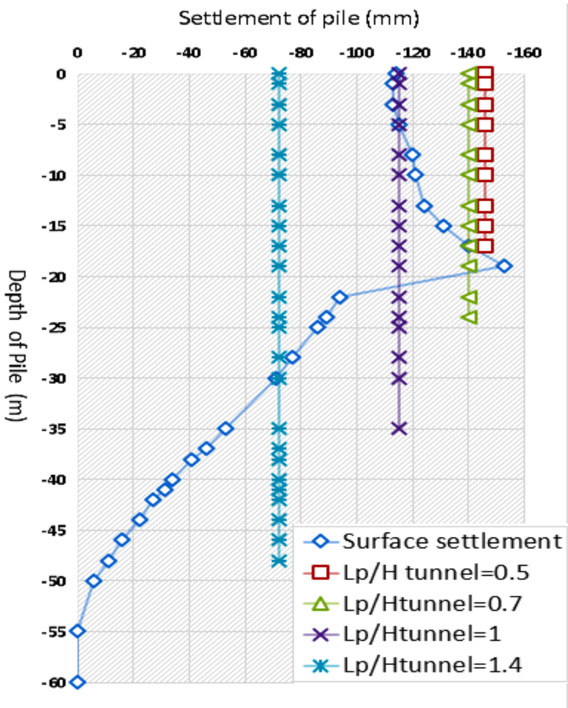


Fig. 14 Pile settlement profile at various L_{pile} /H_{tunnel}

It is evident that the micropile settlement in the zone of influence, measured by L_{pile}/H_{tunnel} values of 0.5 and 0.7, is greater than the Greenfield surface settlement. When the length of the micropile is increased (i.e., L_{pile}/H_{tunnel} of 1 and 1.4), the micropile settlement is drastically reduced. It can be concluded that the line differentiates the two behaviors is projected at an angle of 45° from the tunnel spring-line in this instance because the pile head settlement becomes less than the greenfield surface settlement due to support from the "toe effect" (i.e. Pile length prolonging outside the zone of influence) [11]; (Figure 14). The zone of influence appears to emanate from nearby the tunnel spring-lines, initially at an angle of approximately 45°. The zone on influence can be sub-divided based on the amount of settlement that the micropiles had undergone at a volume loss of 1.5% comparative to that of the surface.

9.2 Influence the passage of tunneling on micropile

Many authors [5-11-10] suggested investigating the interaction between the tunnel and piles foundations. H. Mroueh et al. [5] studied a considerable influence passage of tunneling on piles and their answers. Figure 15 shows the longitudinal section of the passage of tunneling and adjacent micropile, in order to study the interaction problem between tunnel-pile. The micropile lateral deflection due to tunneling in the lateral section is shown in the figure 16.
Analysis of the soil movement in the lateral section shows that tunneling induces a minimum translation of the micropile while the passage of the tunnel faces on the same vertical plan with micropile ($\Omega_{Ft\text{-}Micopile}$ =0),

These lateral deviations increase when the distance of the tunnel face from the micropile becomes superior than a slice that equal 10 m ($\Omega_{Tf\text{-}Mictopile} > +1$ slice). The maximum value of the lateral deflection is about 100 mm at X_{Mp}/L_{Mp}=0.8.

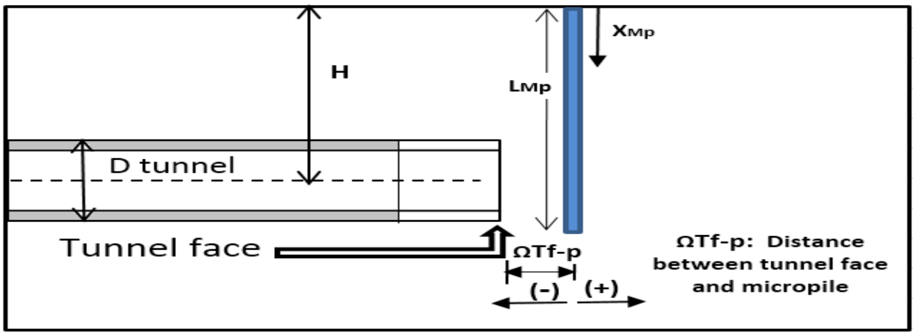


Figure 15: Longitudinal section of tunneling and adjacent micropile

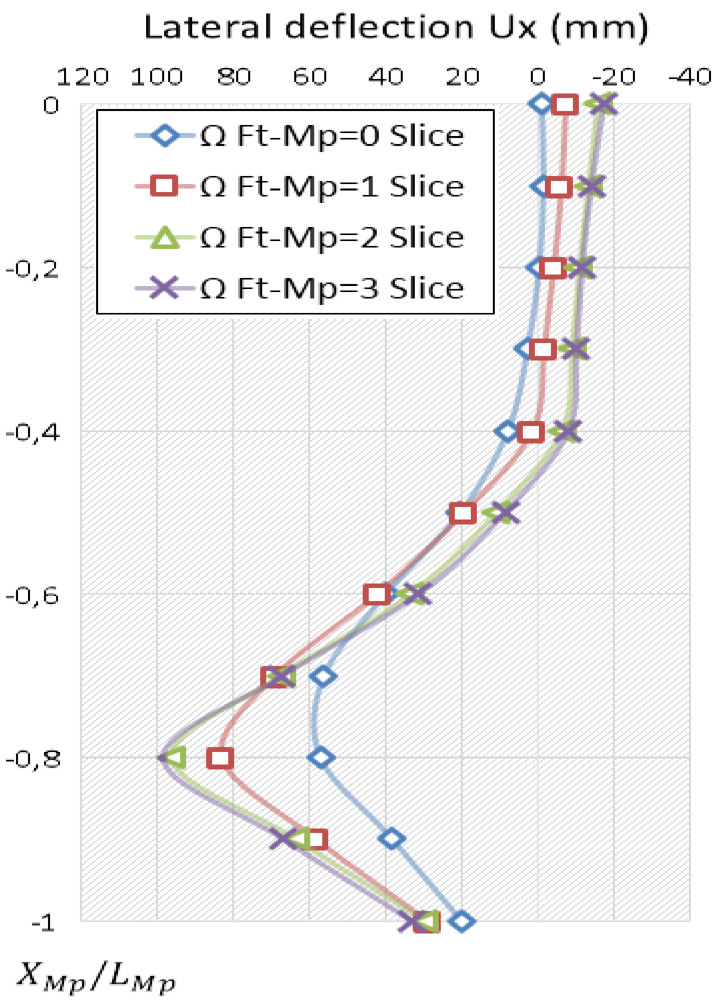


Figure 16: Micropile deflection due to tunneling in the lateral section

10 Investigating the effect of the tunnel position on the interaction

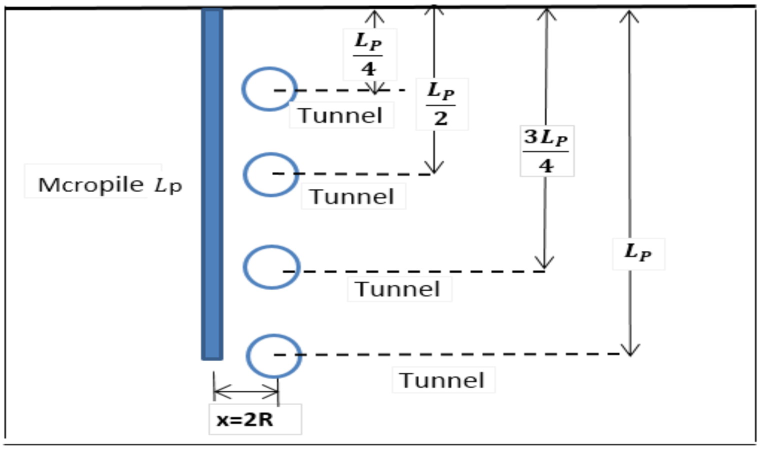


Figure 17: Tunnel positions relative to micropile

In this part, we present the effect of new tunnel position relative to micropile length on the existing micropile, this study was performed to examine the effect of the vertical locations of a new tunnel relative to an existing micropile, the distance x between the new tunnel and micropile was kept constant at two times the tunnel radius (x=2R).

The stability of this micropile has been investigated, we use four different locations of tunnel (0.25 L_p; 0.5L_p; 0.75L_p; L_p); therefore, the tunnel locations investigated as shown in the figure 17. Length micropile L_p is equal 40m, the tunnel's locations are equal 10 m; 20m; 30m and 40m respectively.

Figure 18 shows the interaction problem between tunnel to be excavated and the an existing micropiles. It presents the lateral displacements profiles in the micropile after the tunneling at different positions. These curves give different values in relation to the distinguished locations. It has been noted a negligible deflection in the micropile (practically zero) before tunneling, After the tunnel is dug, this micropile endures lateral displacement. This is because once the tunnel was dug, the ground became unstable, which was brought on by ground movement.

Prior to excavation, the value of lateral displacement is 1 mm, almost negligible.

After to excavating tunnel T4, we note that the values of lateral displacement in the micropile begin to increase, and by changing the vertical level of excavating tunnel location following to the micropile length, the esteemed maximum values of lateral displacements in the micropile, when excavating tunnel T4 at a height of: Quarter length, half length, two-thirds length and whole length are 25,6 mm/ 13,7 mm/ 17.8 mm and 22 mm respectively.

We recommended digging the new tunnel at a location half the length of the existing micropiles to reduce the impact of tunneling on them.

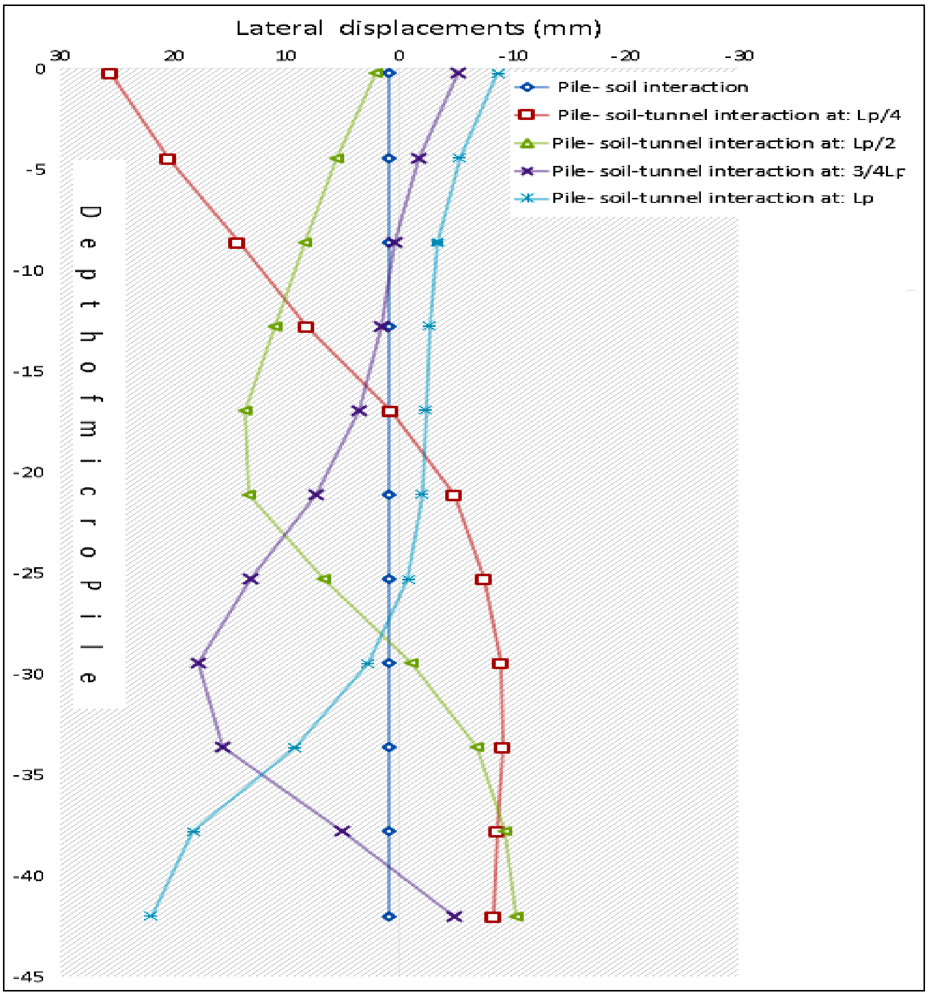


Figure 28: Lateral displacements profiles in the micropile after the excavating tunnel at different positions

11 Conclusion

In this study, it will be required to reinforce the soil with micropiles to enable tunnel excavation in order to increase the stability of the ground from the shallow tunnels excavation (weak cover zone), however this technique often necessitates research into the interaction between shallow tunnel and an adjacent micropiles.

- This study includes a numerical analysis of the interaction between the initially constructed micropiles and the future designed tunnels; the gotten results illustrate the effect of tunneling on the pre-existing micropiles. The analysis of the data demonstrates that the evolution of the axial force, the moment bending, and the lateral deflection in the nearby micropiles are always significantly impacted by the excavation of a single tunnel T1, excavating the two tunnels together (T1+T2) intensifies these affects. In this case, each micropile deviates in the direction of the tunnel next to it.

- The micropile settlement value must be greater than or equal to the surface soil settlement value to be considered within the influence zone; otherwise, the micropile settlement must be less than the settlement of the surface soil outside of the influence zone. The stability of these micropiles is affected when they are positioned in a zone of influence.
- Investigating how the length of the micropile relative to depth tunnel impact on the interaction between shallow tunnel and an adjacent micropiles. As a result, when the length of the micropile is increased, the settlement of the micropile is drastically reduced.
- The passage of the tunneling face affects how tunnels and micropiles interact.
- Investigating how the tunnel position relative to length tunnel impact on the interaction between tunnel and adjacent micropiles. As a result, we recommended digging the new tunnel at a location half the length of the existing micropiles
- The obtained findings show that the tunneling may affect in nearby micropiles a considerable lateral deflection, bending moments, compressive forces, and axial forces.

Tunnelling in densely populated areas is generally associated with undesirable ground movement and subsequent damage to adjacent piles (Micropiles). This work can provide a practical experience in the field for the constructing new tunnels in close proximity to existing piles (Micropiles). It has been shown that the tunneling process significantly affects current micropiles, which calls for more research.

References

[1] Loganathan, N., Poulos, H.G., Stewart, D.P. (2000). Centrifuge Model Testing of Tunnelling-Induced Ground and Pile Deformations.” *In Geotechnique* 50 (3), 283–94.

[2] Bousbia Nawel, Messast Salah. (2015): Numerical modeling of two parallel tunnels interaction using Three-dimensional Finite Elements Method. *Geomechanics and Engineering*. 9 (6) ,775-791.

[3] Mair RJ, Taylor RN, Burland JB (1996): *Prediction of ground movements and assessment of risk building damage due to bored tunneling*. Proceedings, Geotechnical Aspect of Underground Construction in soft Ground, Balkema: Rotterdam

[4] Bousbia Nawel, Messast Salah, Houssou Noura (2021).: A simplified 3D model for existing tunnel response to piles construction. *Journal of civil engineering SSP*. 16 (2) ,87-103.

[5] H. Mroueh and I. Shahrour (2002). Three-dimensional finite element analysis of the interaction between tunneling and pile foundations. *International journal for numerical and analytical methods in geomechanics*. Vol 26, 217-230

[6] Yang Min, Sun Qing, LI Wei-chao, MA Kang (2011): Three-dimensional finite element analysis on effects of tunnel construction on nearby pile foundation, *J. Cent. South Univ, Technol.* Vol.8, 909−916

[7] Dar Al-Handasah (Shair and Partners) (2009). *Documents d’autoroute Est Oust Lot Unique Est*”, Consortium Japonais pour L’autoroute Algérienne COJAAL

[8] Panet, M. and Guenot, A (1982): *Analysis of convergence behind the face of a tunnel*. Proceedings of the 3rd International Symposium, Brighton, UK, June

[9] Pierpaolo Oreste (2009): The Convergence-Confinement Method: Roles and Limits in Modern Geomechanical Tunnel Design, *American Journal of Applied Sciences*. 6(4), 757-771

[10] Felix Christian Schroeder (2002): *The influence of bored piles on existing tunnels.* Ph.D. Dissertation, Department of Civil and Environmental Engineering, London

[11] Bousbia Nawel (2021): Effects of different processes of tunneling on displacements soil using

3D Finite Element Method. *Journal of civil engineering SSP*. 16 (2) ,203-217

[12] Mair RJ, Taylor RN, Burland JB (1996): *Prediction of ground movements and assessment of risk building damage due to bored tunneling*. Proceedings, Geotechnical Aspect of Underground Construction in soft Ground, Balkema: Rotterdam

[13] C.H. Pang, K.Y. Yong & Y.K. Chow (2005): Three-dimensional numerical simulation of tunnel advancement adjacent pile foundation. *Underground Space Use*

[14] Afifipour, M., Sharifzadeh, M., Shahriar, K. and Jamshidi, H (2011): Interaction of twin tunnels and shallow foundation at Zand underpass, Shiraz metro, Iran. *Tunnelling and Underground Space Technology*. 26(2), 356-363

[15] Alec M. Marshall, Twana Haji (2015): An analytical study of tunnel–pile interaction. *Tunneling and Underground Space Technology*,45, 43–51

[16] Andrea Franza, Alec M. Marshall, Twana Haji, Amged O (2017). Abdelatif, Sandro Carbonari, Michele Morici.: A simplified elastic analysis of tunnel-piled structure interaction. *Tunnelling and Underground Space Technology*. 61, 104– 121

[17] C.J. Lee (2012): Three-dimensional numerical analyses of the response of a single pile and pile groups to tunneling in weak weathered rock. *Tunneling and Underground Space Technology*.

[18] Chen, L.T., Poulos H.G. and Loganathan (1999): Pile responses caused by tunneling. *J. Geotechnical and Geoenvironmental Engineering*, ASCE. 125(3), 207-215

[19] C.Y. Cheng, G.R. Dasari, Y.K. Chow, C.F. Leung (2007): Finite element analysis of tunnel–soil–pile interaction using displacement-controlled model. *Tunnelling and Underground Space Technology*. 22, 450–466

[20] F. Hage Chehade, I. Shahrour (2007): Numerical analysis of the interaction between twin-tunnels: Influence of the relative position and construction procedure. *Tunneling and Underground Space Technology*. 23(2), 210-214

[21] Francesco Basile (2014): Effects of tunneling on pile foundations, *Soils and Foundations*. 54(3), 280–295

[22] G.A. Torres-Alves, C.M.P. 't Hart, O. Morales-Nápoles, S.N. Jonkman (2022): Structural reliability analysis of a submerged floating tunnel under copula-based traffic load simulations. *Engineering Structure*s. 269, 1147521

[23] Giorgia Giardina, Matthew J. DeJong, Robert J. Mair (2015): Interaction between surface structures and tunnelling in sand: Centrifuge and computational modeling. *Tunnelling and Underground Space Technology*. 50(2),465-478

[24] Jiao-Long Zhang, Christoffer Vida, Yong Yuan, Christian Hellmich, Herbert A. Mang, Bernhard Pichler (2017): A hybrid analysis method for displacement-monitored segmented circular tunnel rings. *Engineering Structures*.148, 839–856

[25] H. Mroueh, I. Shahrour (2008). A simplified 3D model for tunnel construction using tunnel boring machines. *Tunneling and Underground Space Technology*. 23, 38-45

[26] Hassan Obaid Abbas (2020): Influence of Tunnel Excavation on Tower Foundation Settlement Constructed on Sandy Soil. *Transportation Infrastructure Geotechnology*.7, 651–663

[27] Hergarden H.J.A.M., Van der POEL J.T. & Van der SCHRIER J.S (1996): *Ground movements due to tunneling: Influence on pile foundations*. Proceedings, Geotechnical Aspects of Underground construction in Soft Ground, Mair & Taylor, Rotterdam

[28] Khadija Nejjar, Daniel Dias, Fahd Guira, Gilles Chapron, Hervé Le Bissonnais (2022) : Numerical modelling of a 32 m deep excavation in the suburbs of Paris. *Journal of Engineering structures*. 268

[29] M. Wasif Naqvi, M. F. Akhtar, Mohammad Zaid (2021) : Effect of Superstructure on the Stability of Underground Tunnels. *Transportation Infrastructure Geotechnology*. 8, 142-161