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Influence of the Angular Position of a New Tunnel on Movement in the Surrounding Existing Tunnel

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Abstract

The development of transportation in large cities requires the construction of new structures subterranean in close proximity to existed structures subterranean. Finding the best appropriate position of the new structure subterranean will help to minimize the magnitude of movement there will be in soil surrounding the existing one. The purpose of this study is to involve assessing the immediate influences that will result from the new tunnel excavation in close proximity to existed tunnel at different angular positions ß (0° to 180°) relative to existing one, especially destabilization of the soil surrounding, including movements, displacements of soil mass and surface settlement, in addition to internal efforts generated in lining of old tunnel, and to provide a solution by selecting an ideal angular position for the tunnel that will be excavated relative to the existing one. This is a crucial factor when searching for a full solution to the problem of interactions between subterranean structures. This study uses numerical analysis to examine the movements and displacements of soil mass surrounding, the settlement and the internal efforts induced in the old tunnel's lining impacted by the new tunnel excavation. Several factors, such as the excavation technique, tunnel spacing, liner thickness, etc., had a favorable impact on diminishing the extreme values acquired at the critical angle position (ß =135°). A parametric study was conducted to minimize the maximum values obtained. As a result, these elements could affect planning and security objectives.

Key words: tunnel, displacement, settlement, angular position, Plaxis

1 Introduction

Subterranean space is a solution that works well over an extended period of time and can even help handle specific problems that are difficult to resolve on the surface, as the overpopulation of infrastructure and facilities gets more. In certain towns, new tunnels must be constructed adjacent to the existing ones due to subsurface and geotechnical characteristics. The impact of the construction of new subterranean structure on old one and its surroundings, particularly structurally, where it seems to be of significance to evaluate the interaction between underground constructions. Among the most significant subterranean structures are the tunnels, whose construction requires careful planning, particularly with regard to dimensionality and interaction with other subterranean structures in crowded cities [1]. Many new tunnels must be planned and constructed either parallel to or next to an existing tunnel. Due to the significant connection between these tunnels brought about by the increase in their use in urban areas, study on the interactions between tunnels and soil is essential. Thus, the designer has to take into account a minimum of two crucial factors: The way the new tunnel interacts with the old tunnel: To maintain the integrity of the current tunnel, the additional predicted movements and displacements caused in the surrounding soil. Many studies have been carried out in order to understand the mechanics of the interaction between the tunnel and soil [2]. A summary of the impact of tunnel construction on the nearby existing tunnel was also provided by a number of researchers [3-4-5-6-7-8]. The goal of this research is to simulate numerically the effect of constructing a new tunnel in the shallow cover zone at different angular positions ß (0°à 180°) relative to an existing tunnel on soil mass surrounding. The tunnel T4 at twin tubes is still being studied in our research case. The 2500 m long highway tunnel is made up of two tubes that are essentially parallel to one another. (Figures 1 and 2). The present case involves assessing the vertical and horizontal displacements of soil mass as well as the displacements and movements. The tunnel T4 at twin tubes is still being studied in our research case. The present case involves assessing the vertical and horizontal displacements of soil mass as well as the displacements and movements.

Figure 1: General view of the tunnel T4

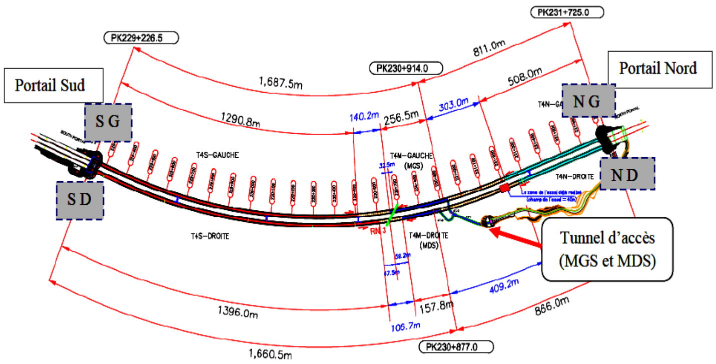

Figure 2: Trace in plane of the Tunnel T4

2 Presentation of tunnel t4

The relief between the kilometer point (KP 229+220 and 231+750) will be crossed by double tubes, and the Tunnel T4 functions as an underground way. The transverse section of each tube is 17.9 m wide and 13 m high. The 320-meter access tunnel's goal is to speed up construction toward the South Portal while establishing two more fronts of attack in the center of the tunnel. It links to the main tube at 811 meters to the North Portal. The tunnel's tracing is elevated at 1/50.000th on the S'mendou geological card [9].

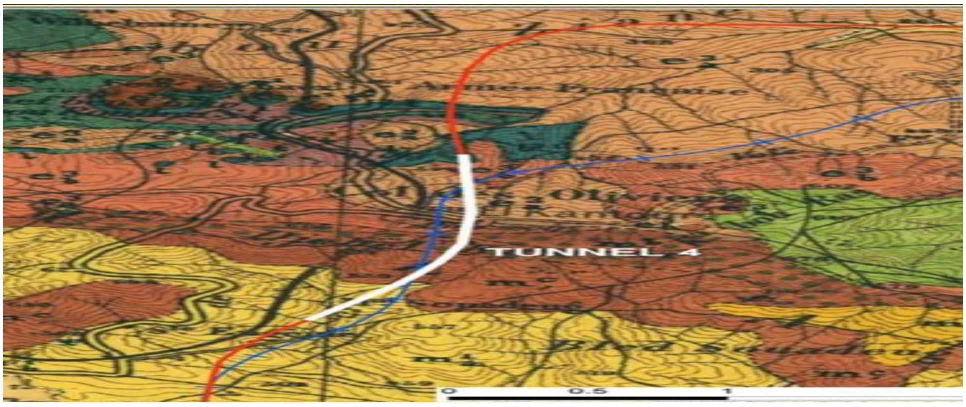

Figure 3: Site of the tunnel T4 on S'mendou the geological card (Constantine-Algeria)

3 Numerical model of tunnel section

One useful method for studying difficult problems of tunneling in the deep cover zone is numerical analysis [10]. The commercial program Plaxis2D was developed specifically to analyze the behavior of soil and infrastructure under stress. The program allows a repetitive geometric cross section to be used as the basis for the creation of a two-dimensional finite element mesh. This section had a 200 m wide by 100 m deep. In this study, we examined at the effects of changing the new tunnel's angular position that will be excavated relative to an old tunnel on the movements and displacements of surrounding soil. It was assumed that the first tunnel would be excavated before moving on to the second.

3.1 Numerical model definition

The cross-section of the tunnels is circular, with an outside diameter of 15 m and a concrete lining thickness of 0.40 m. The tunnel's crown C was 32 m below the soil's surface, meaning that C/D=2,13. 200 m x 100 m was the chosen grid space for the problem analysis. The Mohr-Coulomb failure criteria was utilized to obtain the requisite Elasto-plastic response of the soil.

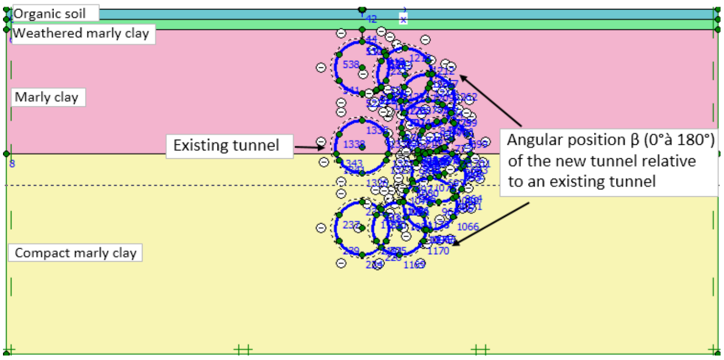

Figure 4: Angular position β (0°à 180°) relative to an existing tunnel via Plaxis 2D model

3.2 Model simulation

The behavior of the soil was described by the Mohr-Coulomb model. The two tunnels, each with a circular piece of 15 meters in diameter, were supposed to open in a circle. After completely excavating the pre-existing bored tunnel, the tunnel is immediately secured to its lining. The tunnel is assumed to have been built in homogeneous soil. Furthermore, the research was conducted using the linear elastic model of the tunnel lining. There are four distinct layers of soil around the two tunnels. The following is a precis of the geotechnical section that was chosen for the analysis:
0.0-3.0m Unit 1 / Organic soil /
0-5.5m Unit 2 / Weathered marly clay
5.5m -41.0m Unit 5 / Marly clay
H >41.0m Unit 4 / Compact marly clay

An elastic-plastic constitutive model provided by the properties listed in table 1.
Tunnel lining properties used in the present study are shown in table 2.

Table 1: Parameters of the soil layers applied in the numerical modelling

Soils	Thick (m)	γ (kN/m^3)	E (MPa)	ν	C (KPa)	ø (°)
Unit 1	3	16,50	5	0.30	5	27
Unit 2	2.5	27,50	25	0.30	5	27
Unit 3	35.5	20	140	0.30	25	20
Unit 4	24.5	22	240	0.30	30	22

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

<table>
<tr><th></th><th>E (MPa)</th><th>A (m^2)</th><th>I (m^4)</th><th>d</th><th>EA_{eq} (kN/m)</th><th>EI_{eq} (kN.m^2/m)</th><th>ν</th><th>$d_{equival}$ (m)</th></tr>
<tr><td>Shotcrete</td><td>$2.8x10^4$</td><td>0,4</td><td>$5.33*10^{-3}$</td><td>1</td><td rowspan="2">$5,18x10^6$</td><td rowspan="2">$6,9x10^4$</td><td rowspan="2">0,20</td><td rowspan="2">0,4</td></tr>
<tr><td>Steel H200*200</td><td>$2.1x10^5$</td><td>$78.1x10^{-4}$</td><td>$0.569x10^{-4}$</td><td>1</td></tr>
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4 Presentation of tunnel T4

The "NATM" will be followed in the construction of the tunnels, what characterizes it notably is the precocious application of the support in order to control the first deformation and to prevent all laxity to the tunnel front. We selected a simplified model in the form of a circular section for this study. In this section, we aim to compute the kilometer point [231 + 253] to the left of the north portal (weak cover zone = 32 m). Measurements taken up to this point indicate that, following a 10-meter excavation, settlement Z1 reached a height of 15 cm. Up to 20 cm, settlement stabilizes. (Figure 5)

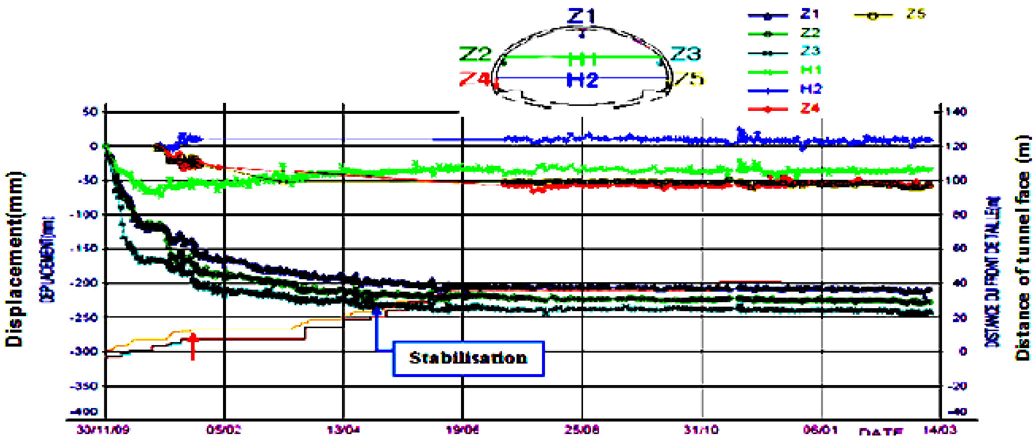


Figure 5: Settlement & convergence of point (231+253) (Reference case)

5 Influence of the new tunnel angular position relative to an existing on movements and displacements surrounding soil

5.1 Modelling of excavation according to bored tunnel type

The convergence confinement method has been applied in this study for analyzing the tunnel-soil interaction, according to [11-12]. Each tunnel's construction process has been modeled; we use a step-by-step approach. Generally, the process has been modeled in two steps, with each stage's excavation process consisting of: (I) fully deactivating any soil elements contained in the segment that needs to be excavated; (II) fully activating the tunnel lining and relieving all stresses in that segment. The second tunnel's excavation followed the same methodology used for the first tunnel's completion. As part of this process, the movements, displacements, and settlement at surface soil at each position ß of the new tunnel in relation to an existing tunnel are to be determined numerically: The approval for the finite element modeling of the two tunnel buildings is as follows: (I-1) Excavation of the first tunnel with $\lambda_1 = 0.3$ stress release factor. This factor relates to the proportion of the stress release prior to the liner installation. (I-2) Installing the first tunnel's lining (II-1) utilizing the same technique and stress release factor for the construction of the second tunnel. In terms of boundary conditions, displacements are restricted in both directions at the bottom and must be zero horizontal at lateral limits.

5.2 Result of analyses

5.2.1 Description of the problem

The fundamental issue for analysis is depicted in figure 6. It includes building a circular tunnel with a diameter of 15 meters and a concrete liner that is 0.40 meters thick. The tunnel is 32 meters below the level of the soil. The distance between the two tunnels was kept at three times the tunnel radius (3R) measured from center to center. There could be intolerable soil movement as a result of building the new tunnel. The position, space, and stiffness of the lining between tunnels determine the type of interaction that occurs between them.

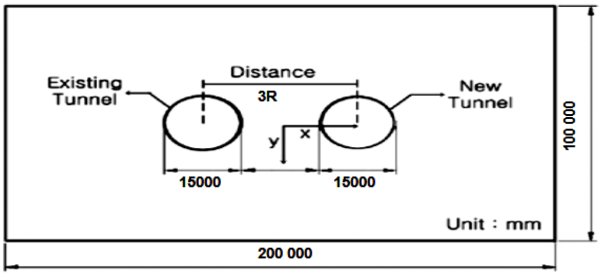


Figure 6: Description of the problem

5.2.2 Settlement and displacements due to tunneling

Möller, S.C. et al. [13], state that the tunneling causes the in situ stress to decrease. The section and position of the tunnel to be constructed, and the excavation technique to be used, also the soils type all influence the magnitude of movement there will be. The ground movements in surrounding tunnel are the cause of the surface soil subsidence. This study has to examine at the immediate effects of a new tunnel's angular position in respect to the surrounding soil displacements. We proceed to determine the impact of the newly excavated tunnel next to the existing tunnel based on different angular locations β. Initially, we will limit the movements occurring from the excavation of one tunnel, followed by the excavation of both tunnels.

❖ **First Case: Single tunnel**

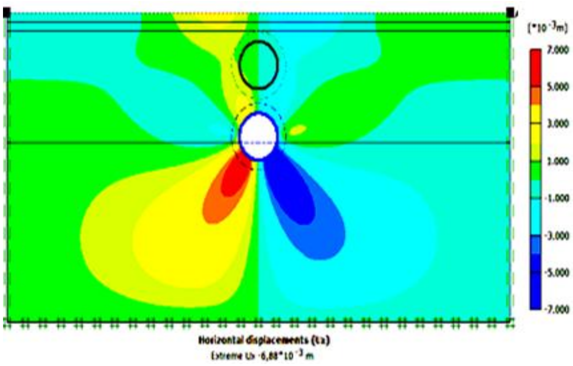


Figure 7: Contours of horizontal displacements (U_x= -6.88mm) around the single tunnel

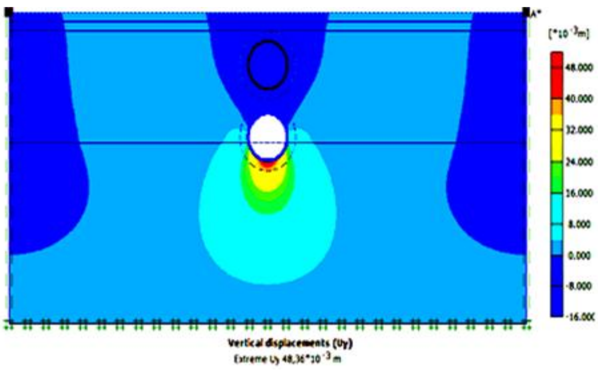


Figure 8: Contours of vertical displacements (U_y= -48.36mm) around the single tunnel

❖ **Second Case: Both tunnels (New – old)**

Secondly, we go to test the influence the angular position of the new tunnel to be excavated relative to an existing on the movements soil surrounding. Nine positions ß (0°; 22.5°; 45°; 67.5°; 90°; 112.5°; 135°; 157.5°; 180°) were modelled. The results are showing in the table 3.

Table3: Summary of settlement and displacements values generated by new tunnel excavation

Positions	Angle (ß)	Settlement (mm)	Horiz displ (mm)	Vert displ (mm)
1	0°	11.71	-10.62	58.65

2	22.5°	13.32	8.29	59.62
3	45°	10.10	8.41	60.39
4	67.5°	-5.70	9.76	58.73
5	90°	-5.14	7.99	52.96
6	112.5°	-15.76	12.48	62.28
7	135°	-19.55	-10.94	66.11
8	157.5°	-15.31	-16.57	65.02
9	180°	-11.96	-18.24	63.85

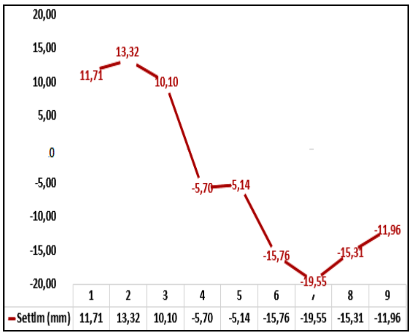


Figure 9: Variation of settlement

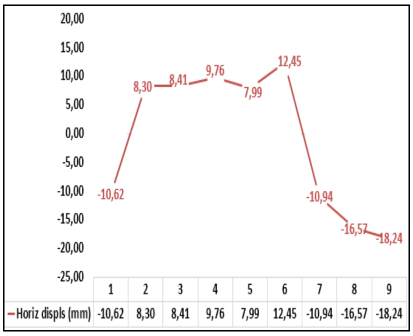


Figure. 10 Horiz-displacement

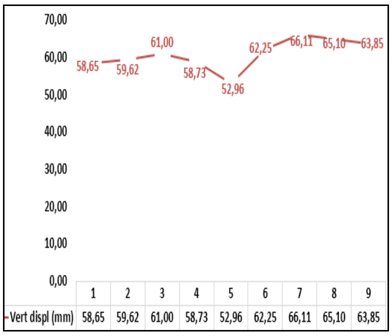


Figure.11: Vert-displacement

Figures 9, 10, and 11 show the maximum settlement, horizontal displacement, and vertical displacement values that correspond to the various angular positions ß of the new tunnel (0° to 180°). it is clear that the minimal values of displacement and settlement occur at 90°. The two tunnels are designed to be horizontally aligned on the same elevation (ß = 90°),

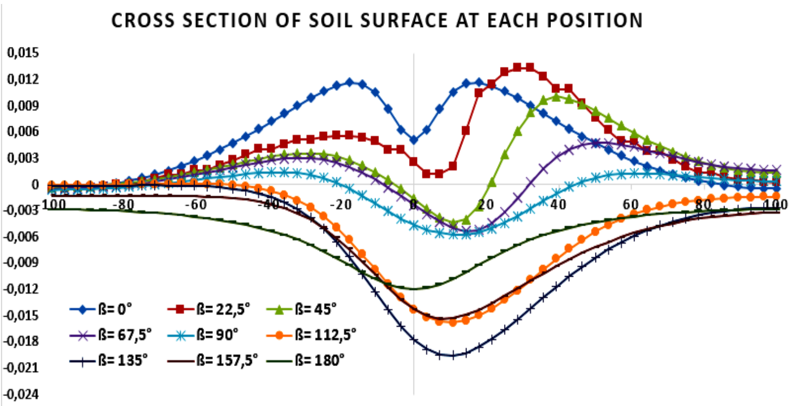


Figure 12: Shape of ground surface profiles

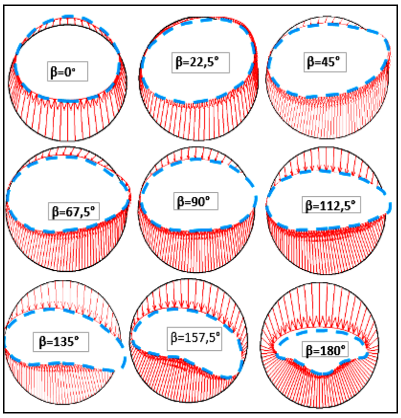


Figure 13: Contour of convergence around the tunnel

The shape of ground surface settlement profiles along the longitudinal axis X at each angular position β, and the contour of the convergence around the old tunnel caused by new excavating, are shown in the figures 12 and 13 respectively. The position of the new tunnel in relative to the old one has a substantial effect on the movements and convergence around the old tunnel. The angular positions of the new tunnel, which range from 0° to 45°, make an ascendance of soil level (Fig.12). However, at 90°, the settlement at surface soil is easily visible. An angle of 135° indicates the maximum settlement value. This can be explained by the fact that excavating a new tunnel beneath an existing one reduces the ground's vertical stiffness, which results in more vertical deformation. The extreme convergence around the existing tunnel lining is 61.56 mm for a position of 45o (Fig. 13), when the new tunnel interacts with the old tunnel. This position was arranged in a way to cover the zone of influence that is designated by lines extending 45° from the tunnel spring-line.

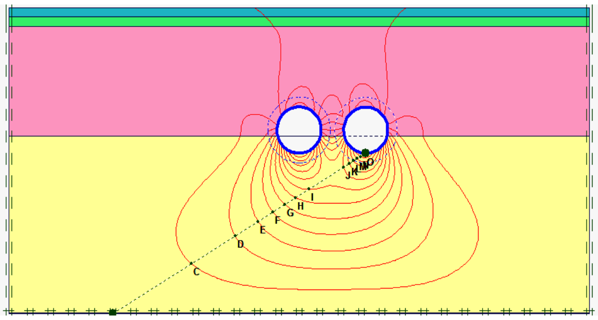


Figure 14a: Contour lines of total displacements at 90° (Extreme Utot=52.96 mm)

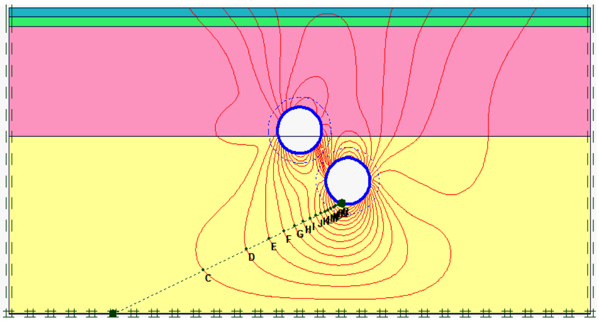


Figure 14b: Contour lines of total displacements a t 135° (Extreme Ut =66.11 mm)

The contour lines showing the total displacements in the surrounding soil mass caused by the second tunnel excavation (Fig.14a) and (14b) at two angles positions (90° and 135°), in relation to the existing tunnel. The analysis' findings demonstrate that the angular position of the new tunnel has a significant impact on the surrounding soil movement (displacements). As expected, a large gradient of displacements in the surrounding at an angle of 135° is visible. This results from the excavation of the new tunnel beneath the old tunnel, which weakens the earth's vertical stiffness and produces more vertical deformation. This instability of the soil is the reason of this.

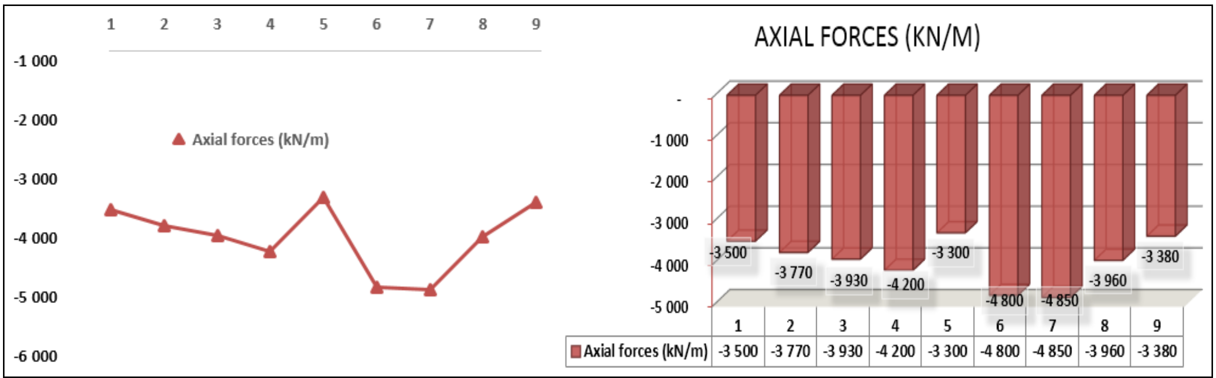
6 Influence of the new tunnel angular position on the lining behavior of the existing tunnel.

Ngoc Anh Do et al. [1] examined the impact of distance between tunnels on the bending moment generated in the jointed and continuous lining of the existing tunnel. The new tunnel in the present analysis has a circular cross section, a 15-meter outer diameter, and 0.40-meter-thick concrete lining. The internal efforts (axial force, bending moment, and shear force) generated in the old tunnel's lining as a result of the newly excavated are shown in table 4.

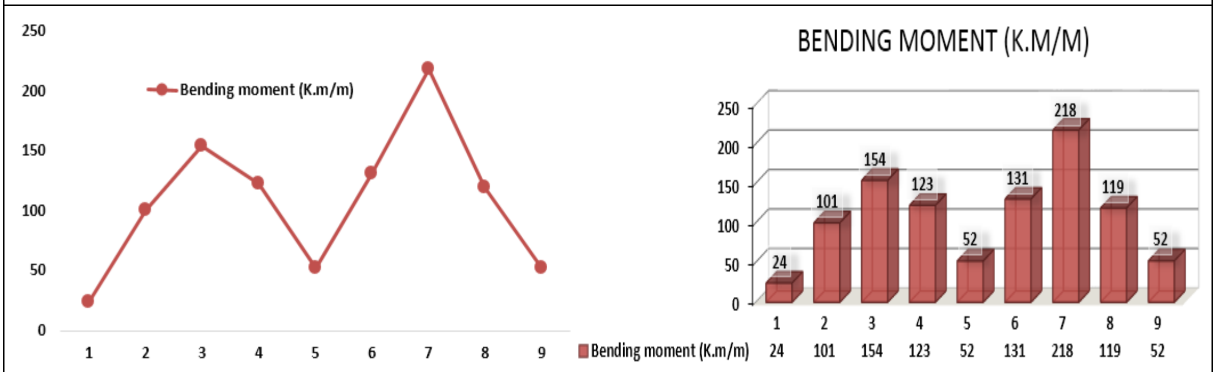
Table 4: Summary of internal efforts values generated in the lining of the existing tunnel

Positions	Angles	Axial force (kN/m)	Bending moment (kN.m/m)	Shear force (kN/m)
1	0°	$-3.50*10^3$	24.38	16.46
2	22.5°	$-3.77*10^3$	100.61	66.80
3	45°	$-3.93*10^3$	154.40	107.65

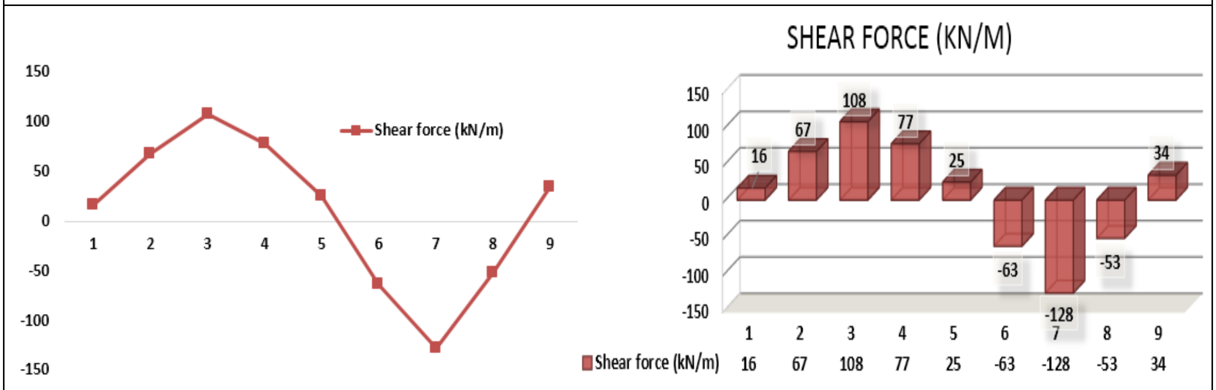
4	67.5°	$-4.20*10^3$	122.69	77.25
5	90°	$-3.30*10^3$	52.25	24.72
6	112.5°	$-4.80*10^3$	130.72	-63.33
7	135°	$-4.85*10^3$	218	-127.73
8	157.5°	$-3.96*10^3$	119.35	-52.56
9	180°	$-3.38*10^3$	52.45	34.3



(a) Axial force profile



(b) Bending moments profile



(c) Shear force profile

Figure 15: Variation of internal efforts (existing tunnel) in relation to the location of a new one

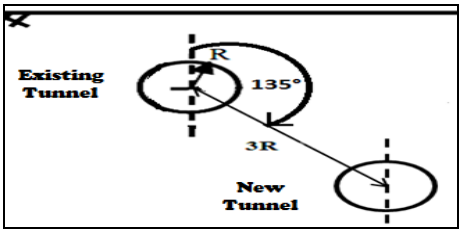
Figure 15 illustrates how the new tunnel position in relation to the old tunnel has a major impact on the internal efforts generated in the old tunnel's lining. Excavation of the new tunnel induces internal effort in the existing tunnel due to interaction with it. At an angular position of 135°, the values of internal efforts generated in the old tunnel's lining increased by approximately 75% compared to values before excavation, which are maximum values compared to other positions. On the other hand, we obtained the minimum values of the internal efforts generated in the lining of the old tunnel, when excavating the new tunnel at an angle of 90°. Thus, because of what we observed, we may say that:

- ❖ There is a decrease in settlement at surface soil, displacements in soil mass surrounding, and internal efforts generated in the existing tunnel lining, when the new tunnel is excavated parallel and aligned horizontally to the existing one, on the same elevation (ß = 90°)
- ❖ There is an increase in the settlement, displacements and internal efforts generated in the existing tunnel lining, when the new tunnel is excavated at an angular position of 135°

7 Parametric study at a critical angular position of 135°

7.1 Investigation the excavation method of the new tunnel on an old tunnel

According to previous results, excavation of the new tunnel at an angle of 135° in relation to old one. This led to significant instability in the soil surrounding the old tunnel as well as the extreme values of settlement, displacements and internal efforts generated in the lining of the old tunnel. A parametric study will be investigated of some factors related to the two tunnels and their surroundings in an attempt to reduce the maximum values obtained in the critical angular position of 135°. An investigation has been undertaken into the impact of the excavation method of the new tunnel at an angle position of 135° on the old tunnel and its soil surrounding. The tunnel's cross-section was divided into different headings as needed (heading, bench, invert), the partial excavation method was used. The effect impact is demonstrated by simulating a sequential process in which each portion is dug at full face. We examined and compared five different partial-face excavation scenarios with full-face excavation.



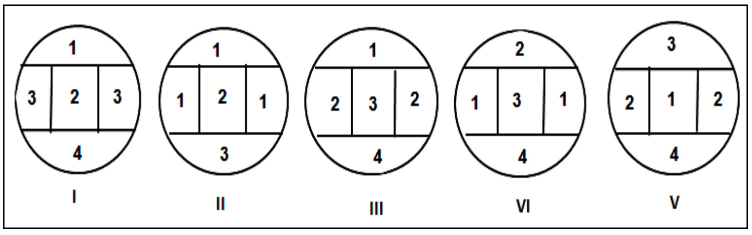


Figure 16: The new tunnel relative to an existing tunnel   Figure 17: Cases partial-face schematic

In five distinct scenarios, the effects of several method of partial-face excavation with partial support installation were examined. In all investigation, face advance was applied only after the whole segment had been excavated. Table 5 displays the analysis of the displacements of soil mass surrounding and the settlement surface soil based on an angle of 135°.

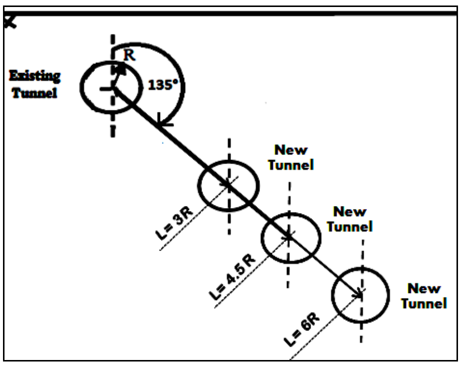
Table 5: A Summary of displacements and settlement according to different excavation method

Position (ß)	Settlement (mm)	Horiz displ (mm)	Vert displ (mm)
Full face Excavation 0	-19.55	-10.94	66.11
Partial-face Excavation I	-13.72	-11.43	58.13
Partial -face Excavation II	-16.38	-10.12	60.60
Partial -face Excavation III	-7.42	-9.23	35.56
Partial -face Excavation IV	-14.16	-10.11	48.78
Partial -face Excavation V	-16.53	-10.12	51.63

Based on the present investigation, we can conclude that the tunneling technique significantly affects the settlement and displacements. A difference in results was observed when comparing the five partial-face excavation technique with the reference case at a fixed angular position of 135°. The partial-face excavation method gives lower results in terms of displacements (Ux= -9.23 and Uy=35.56) and settlement (δ= -7.42) compared to the full section method (Ux= -10.94 and Uy=66.11) and settlement (δ= -19.55). This difference in results is mainly due to more galleries being opened in the tunnel front. Digging with a large number of galleries causes ground movement which may last a short time due to the implementation as quickly as possible of support, on the other hand the excavation of the tunnel using the section method, the displacements will be important because the excavating section is large. So, excavating with a partial-face offers a front stable than the method of full section method. Moreover, we note that the third scenario provides less displacements than the other scenarios. We must admit that to dig a tunnel, we must return to the third scenario because it is the best solution to reduce displacements.

7.2 Investigating of the impact of tunnels spacing on interaction

Three various tunnel spacing (1, 1.5, and 2) L; where L=3R have been used to study the effect of the inclination spacing between the two tunnel centers (L) on soil stability. An angle of 135° was chosen for the new tunnel's position.



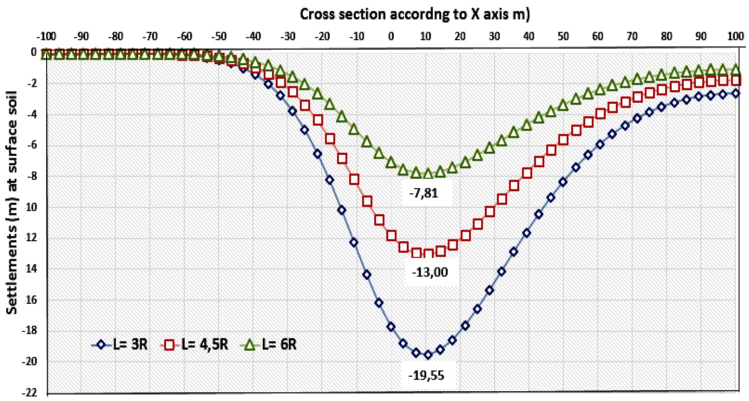


Figure 18; The new tunnel relative to an existing tunnel at 135° according to different spacing

Figure 19: Settlement troughs for inclined spacing L, 1.5 L, 2 L

Figure 19 shows the settlements at surface soil caused by the new tunnel excavation for the different inclined spacing between the two tunnels (3R, 4.5R, and 6R). It is evident that the distance between tunnels has a significant effect on the settlements. At the distance equal 2L = 6R, we observe as the minimum value (-7.81mm). However, we see a maximum value (-19.55mm) at L = 3R. As expected, the settlements diminish as the distance between the tunnels increases. This demonstrates that there are more vertical constraints and less horizontal constraints designated as the distance between tunnels decreases, which explains why settlement is increasing.

7.3 Impact of lining thickness on interaction

In this study, four lining thickness values were used: 100 mm and 150 mm (indicating very elastic lining), 400 mm (indicating equitably rigid lining), and 700 mm (indicating very rigid lining). The lining thickness of the new tunnel has been changed from 100 mm to 700 mm for a fixed value of the lining thickness of the existing tunnel (40 cm). The effects of the thickness of the new tunnel's lining are assessed in terms of displacement, settlement, and internal efforts that accumulate during the construction. The results of this analysis for different new tunnel lining thicknesses at an angle of 135° are shown in table 6.

Table 6: Results of the settlements, displacements, moment, and stress for different thicknesses

Thickness	Settlement(mm)	Displacements (mm)	Moments (Kn.m/m)	Stresses (Kn/m^2)
100mm	-43.00	63.66	-7.29	1115
150mm	-41.05	60.15	51	1132
400 mm	-19.55	48.06	218	1220
700 mm	-15.03	37.25	553.9	1270

7.3.1 Settlement analysis

Figure 20 shows the settlement after the completion of the new tunnel's excavation for different lining thicknesses. These data suggest that reducing the lining's thickness had a substantial impact on the settlement. This indicates that more flexible the lining will occur the more settlements. Therefore, it is evident that lining thicknesses of 150 mm or less cause the most settlement at surface soil, suggesting that lining thicknesses of less than 150 mm should not be selected. These analysis' findings, which demonstrate that excessive surface settlement is caused by lining thicknesses of even less than 150 mm, support this claim [15]

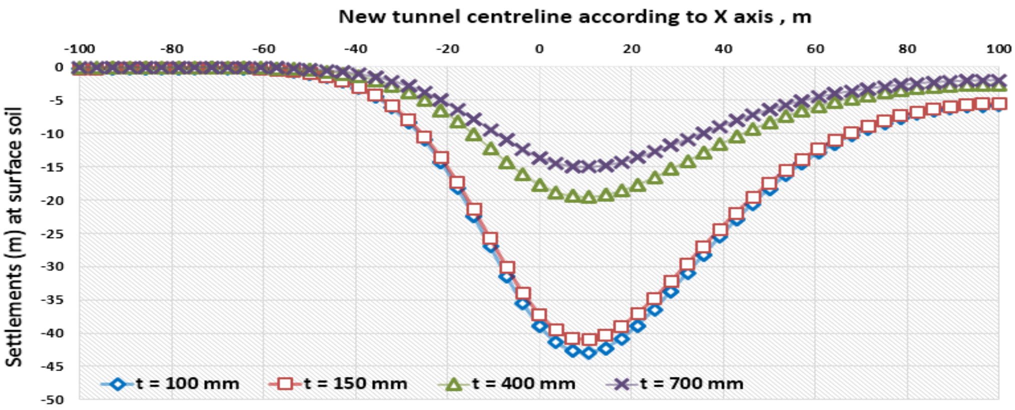


Figure 20: Surface settlement curves for different lining thickness

7.3.2 Analysis of displacements total, moments and stresses in existing tunnel lining

Figure 21 shows the extreme total displacement in the existing tunnel lining hoop for various lining thicknesses after the new tunnel is completed. The results show that increasing more thickness to the new tunnel's liner actually affects the total displacements. This indicates that a greater degree of lining flexibility allows for the prediction of larger displacements. Thus, it is clear from the lining thickness equal to 150 mm or less causes an increase in the displacement in the existing tunnel, suggesting that a lining thickness of less than 150 mm should not be selected. Changing the lining thickness has a major impact on the lining hoop moment. The moment distribution was very large at the 700 mm liner thickness. Increasing the lining thickness led to the lining behaving in a stiffer mode, i.e., with a decrease in the flexibility of the lining, Large moment profiles were therefore predicted. Changing the lining thickness had no marked impact on the stress expected in the lining. The maximum stress distribution was produced by the 700 mm liner thickness. The ground stresses surrounding the tunnel can be used to explain variations in the lining's hoop stress concentration.

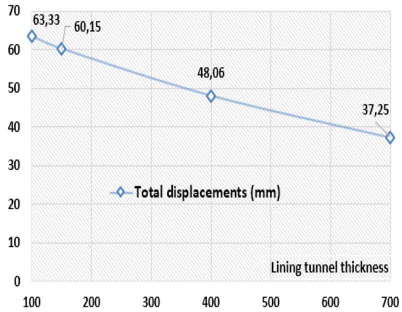


Figure 21: Total displacements

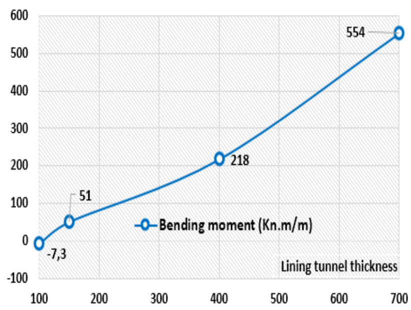


Figure 22: Hoop moments

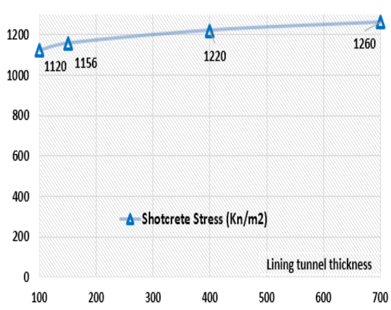


Figure 23: Maximum stress

Figure 24 shows how changing the lining thickness can change the hoop stress in lining while at few points (E, F, G, and H).

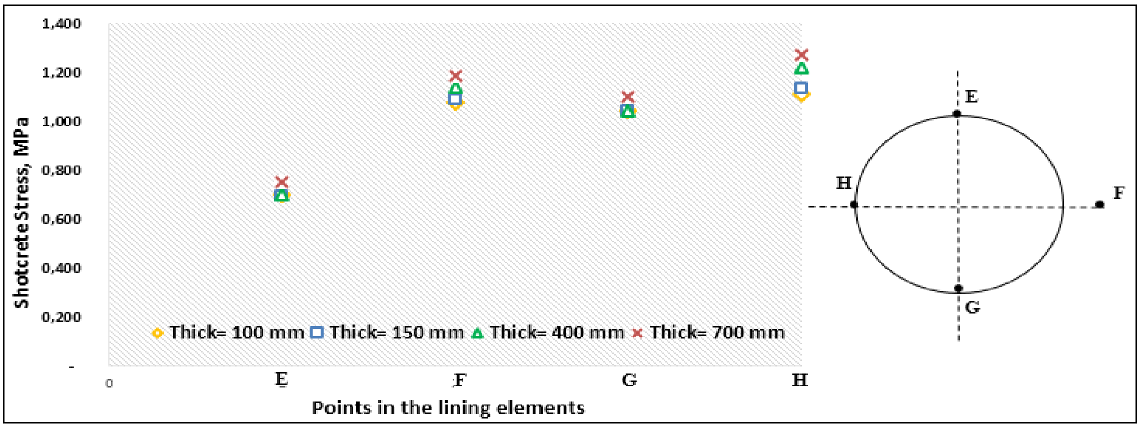


Figure 24: Hoop stress in lining with positions of some points for different lining thicknesses

Figure 24 illustrates that varying the lining thickness affects the lining hoop stress along with the projected positions of few points (E, F, G, and H) in the lining elements. A significant stress distribution was produced by the 700 mm lining thickness, especially at point H (the tunnel's crown). We also see that, for varying lining thicknesses, the stress values are approximately identical at every point (at point E, it is very similar; the stress value = 700 kN/m^2 for the four lining thicknesses); it is also the minimum value).

8 Conclusion

Effect of new tunnel construction in close proximity to an existing tunnel at different angular positions ß (0° to 180°) relative to an existed one are investigated in this paper. A numerical study was evaluated this impacts on the surrounding soil in terms of movements, displacements, settlement, and internal efforts generated in the lining of the existed tunnel using the finite element method. The results of the study allow for the following conclusions.

- Constructing process of a new tunnel has a significant influence on the soil's internal stability, and its position relative to the existed one, significantly impacts on the disturbance of the surrounding soil, which causes movements, displacements, settlement and internal efforts in the existed tunnel.
- A decrease in the settlement, displacements and internal efforts generated in the existing tunnel lining, when the new constructing at an angular position ß equal to 90°, where the two tunnels are regarded as aligned horizontally, on the same elevation (ß = 90°)
- A max increase in the settlement, displacements and internal efforts, when the new constructing at an angular position ß equal to 130°. This can be explained by the fact that the new tunnel's excavation beneath the existed one decreases the earth's vertical stiffness, which leads to additional vertical deformation because of the unstable soil.
- A parametric study will be carried out at angle position 135º (critical angular position) in order to reduce the influences of new constructing in this critical position

1. New constructing technique at the fixed angular position of 135° had a most influence on soil surrounding, including displacement, settlement and internal forces generated in the existed tunnel. The investigation found that the new constructing according to third technique (scenario) gave small values regarding settlement and displacements soil compared to the other remarkable scenarios and reference case. We conclude that new

constructing technique according to the third scenario has a great advantage in reducing the values of settlement and displacements.

2. Tunnel spacing between the new constructing and existed tunnels has an evident influence on the soil surrounding movement. When the distance is equal or more than 6R, the influence on settlement surface is not significant, while the effect increases rapidly with its decrease when it is equal or less than 3R. Therefore, it is explained that there are more vertical limitations and fewer horizontal constraints as the distance between tunnels gets smaller, this suggests that settlement increases.
3. Investigating how the thickness of the new tunnel's lining affects the old one. It is essential to determining the settlement, total displacements, moment and stresses in the existing tunnel lining. The interaction between the two tunnels is relatively important in a tunnel with a very flexible lining, while it is fairly inconsequential in a tunnel with a stiff or very rigid lining. The lining thickness must always be at least 150 mm; it was also mentioned.

The development of transportation in large cities requires a new tunnels construction in close proximity to existing tunnels. This work can provide a practical experience in the field and reference to real-world for the construction of new tunnel at different positions relative to existed one. The angular position of the new to be constructed have been demonstrated to have significant influence on the movement in the soil surrounding the existed tunnel in this study. This impact might be diminished by constructing the new tunnel at precise position relative to the other, which requires further investigations.

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