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BEHAVIOR OF EXISTING TUNNEL DUE TO THE CONSTRUCTION OF A NEW TUNNEL PASSED PARALLEL UNDER IT

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The study of the behavior of existing underground structures, such as transportation tunnels, due to construction of a new tunnel is an engineering problem of soil-structure interaction. Many problems arise when parts of a new construction tunnel cross under, or near an existing tunnel during the construction. One of these problems is expected to occur related to soil stability around a new construction tunnel and between new and an existing one. Even though in engineering practice tunnels are often designed considering only static or quasi static (creep), loading conditions, a non-negligible research effort has been devoted to investigate their behavior in near-field construction conditions.
In the present study, the behavior of existing tunnels under passed by a new construction one by using Finite Element Method has been studied. The tunnel lining is meshed with two dimensional elements, called BEAM 6 element. The soil is meshed with two dimensional elements called LST, (Linearly Varying Strain Triangular Element. In this study, the main parameters were taken into consideration are excavated tunnel diameter (D_2), soil thickness between tunnels (H), and horizontal distance (X). The results obtained from this study were compared with the initial values obtained from case of no tunneling under the existing tunnel.

KEYWORDS: *Tunnel, Soil-structure interaction, Finite Element Method, Stresses, Forces, deformation, Construction*

1. INTRODUCTION

The construction of tunnels is a subject of considerable importance to geotechnical and structural engineers. The study of the behavior of these structures, such as transportation tunnels, due to construction of another one under it. During the construction of the lower tunnel under the existing tunnel, many geotechnical challenges are expected to occur related to soil stability around and between the tunnels. One of these problems arises when parts of new tunnel pass parallel under an existing tunnel. Mazek [1] studied the behavior of an existing sewage tunnel during the construction of the Greater Metro Line 2 (Shubra El-kheima-Mobarak) and El-Azhar road tunnels, which are installed by the Tunneling Boring Machine (TBM). He proposed a model to provide a prediction of the soil structure interaction using a 3-D model of the multi-crossing tunnel incorporating the effect of cement-bentonite grouting. The problem arises when parts of the metro and road tunnels cross under an existing sewage tunnel during the construction. To control the potential problem, the national authority for tunnels (NAT) has applied grouting to the soil around the sewage before the TBM crossed under it. Consequently, the measured settlement in the field when the metro and road tunnels passed under the sewage tunnel was found to be significantly less than the estimated value without grouting and well within the alloable limit of 10 mm set by the Egyptian standards (Abdel Salam, 1998: Documented file issued by NAT, 1999), [2]. Many problems related to the soil and tunnel stability were expected during the construction of the lower tunnel. In the present study, the behavior of existing tunnel including deformations and straining action is studied. To asses and understand effect of constructing a tunnel on the behavior of existing one has been performed. The study is conducted using a 2-D finite element model.

This research is carried out to investigate the behavior of the existing tunnel due to excavation of a new one under it. The major objectives of this research are: (i) determination the effect of a new tunneling on the behavior of the existing one, (ii) determination the changes in normal force, shearing force and bending moment on existing tunnel lining, and (iii) determination of the effect of the different tunnel diameter and position of the new tunnel relative to the existing one.

2. FINITE ELEMENT MODEL

The finite element computer program FINAL (Swoboda, [3]) has been used in this study. This finite element model takes into account the effects of the vertical overburden pressure and the lateral earth pressure using two methods of solution, Dead Loads or Initial Stresses, in this analysis, Dead Loads method has been used. Also, this program takes into account the nonlinear properties of the soils and the linear properties of tunnel lining. Fig. 1 shows the layout of the existing and new constructed tunnels.

The model has a length of 54.0 m and a height of 58.0 m including the tunnels. The finite element model is shown in Fig. 2. In addition, the dimensions of the 2-D model have been determined in order to eliminate the size effect in the prediction of the performance of the tunnels. The soils, the tunnel lining and the grouting are simulated using appropriate finite elements. A finite element model for soil, grouting, and tunnel lining for soil-tunnel interaction model was built. The soil and grouting were modeled using 2-D elements, called an LST element, (Linearly Varying Strain Triangular Element), whereas, the tunnel lining was modeled using another 2-D BEAM 6 elements. Both BEAM 6 and LST elements have six nodes, each having two translation degrees of freedom as mentioned by Swoboda [4], and shown in Fig. 3. Calculations are carried out on the assumption that the tunnel lining is perfectly bonded to the surrounding grouting. The BEAM 6 element provides an acceptable solution for the finite element modeling problem, as it considers all possible deformations of the lining. The advantages of this element are that it can describe the real behavior of the lining as an arched frame, it can combine with LST finite elements used for grouting and soil, and the number of elements required to model the lining with an acceptable accuracy is very small, Moussa [5].

Analysis of displacement, internal forces in tunnel lining and around the tunnel was carried out using a 2-D plane strain finite element taking into consideration the linear elastic behavior of the lining and the ground material as mentioned by Hasan, *et al.* [6].

2.1. Study Cases

The cross sections of the existing tunnel and a new excavated tunnel opening are a circle has $\mathbf{D_1}$ and $\mathbf{D_2}$ inner diameter and 0.40 m concrete lining thickness. The tunnels are surrounded with 0.20 m thickness grouting material. In this study, three group for different values of excavated tunnel diameter (D_2), soil thickness between tunnels (H), and horizontal distance (X) were studied. The details of each group are presented in Table 1.

Table 1. Details of study groups

Group	**I**			**II**			**III**		
D_1 (m)	8.35			8.35			8.35		
D_2 (m)	**4.0**	**6.0**	**8.35**	8.35			8.35		
H (m)	2.0			**2.0**	**3.0**	**4.4**	2.0		
X (m)	0.0			0.0			**0.0**	**4.0**	**8.0**

Where D_1 is the inner diameter of the existing tunnel,

D_2 is the inner diameter of the constructed tunnel,

H is the soil thickness between the tunnels as shown in Figure 1, and

X is the horizontal distance between the two tunnels as shown in Figure 1.

2.2. Material Constants

The material constants of tunnel line-2 of Cairo Metro, Egypt, at Km 4.234, were chosen for this study to represent the real properties of soil profile. These constants such as modulus of elasticity (E), Poisson's ratio (ν), density (γ), angle of internal friction (ϕ), cohesion (C)□and compressive strength (F_c) for different elements of the model are tabulated in Table 2, Mansour [7].

Table 2. Material constants of the model

Material constant	**Soil Layer 1**	**Soil Layer 2**	**Soil Layer 3**	**Soil Layer 4**	**Soil Layer 5**	**Soil Layer 6**	**Conc. Lining** 0.4 m Thick.	**Grouting** 0.2 m Thick.
E (KN/m^2)	6.0E6	9.0E6	36.0E6	80.0E6	95.0E6	16.0E7	33.5E9	1.1E9
ν	0.40	0.40	0.35	0.30	0.30	0.30	0.18	0.29
γ (KN/m^3)	18.0	18.5	19.0	20.0	20.0	20.0	25.0	22.0
ϕ	20.0	20.0	30.0	35.0	35.0	37.0	-	00.0
C(KN/m^2)	50.0	00.0	00.0	00.0	00.0	00.0	-	00.0
F_c (Mpa)	-	-	-	-	-	-	100.0	-

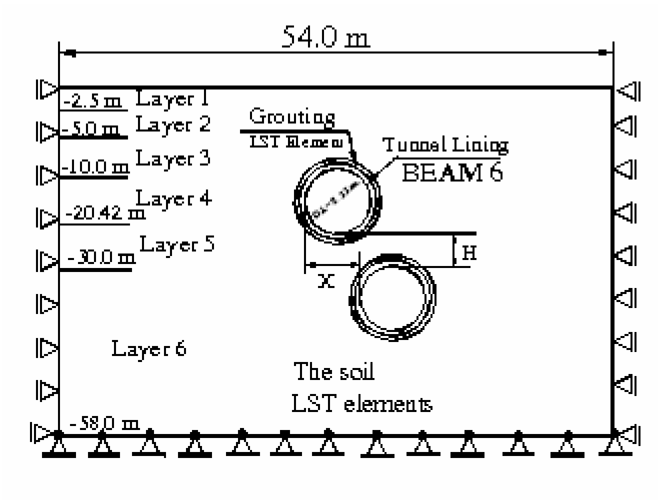


Figure 1. Layout of the model

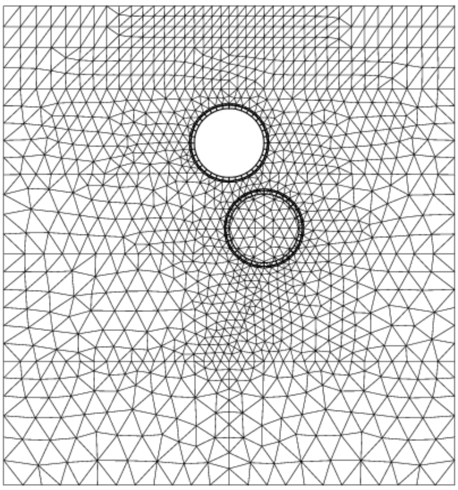


Figure 2. Finite element model

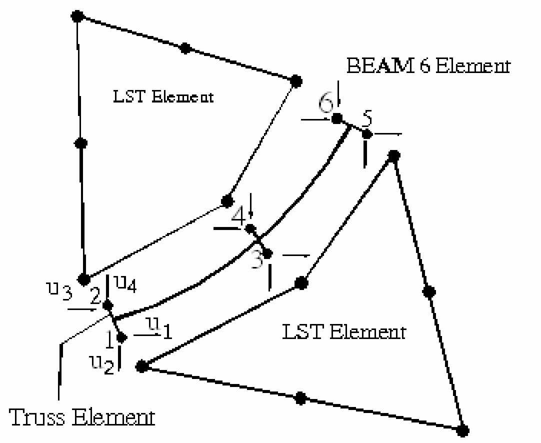


Figure 3: Combined action between BEAM 6 and LST elements (after Swoboda [4])

3. ANALYSIS OF RESULTS AND DISCUSSIONS

To study the behavior of the existing tunnel due to the construction of a new one under it, the internal forces in the critical points on the existing tunnel lining have been determined. These critical points such as *crown, shoulder R and L, spring line R and L, knee R and L, and invert* whose corresponding to position numbers **1, 2, 3,……….,** and **8** , respectively, were chosen as shown in Figure 4.

To analyze and illustrate the behavior of tunnel lining, many Figures were plotted such as displacements, deformation shapes, normal forces, shearing forces, and bending moment.

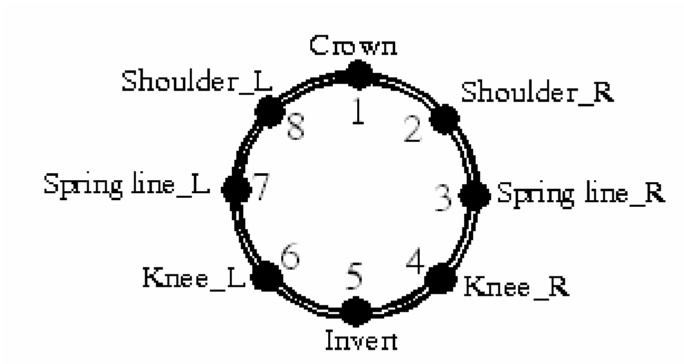
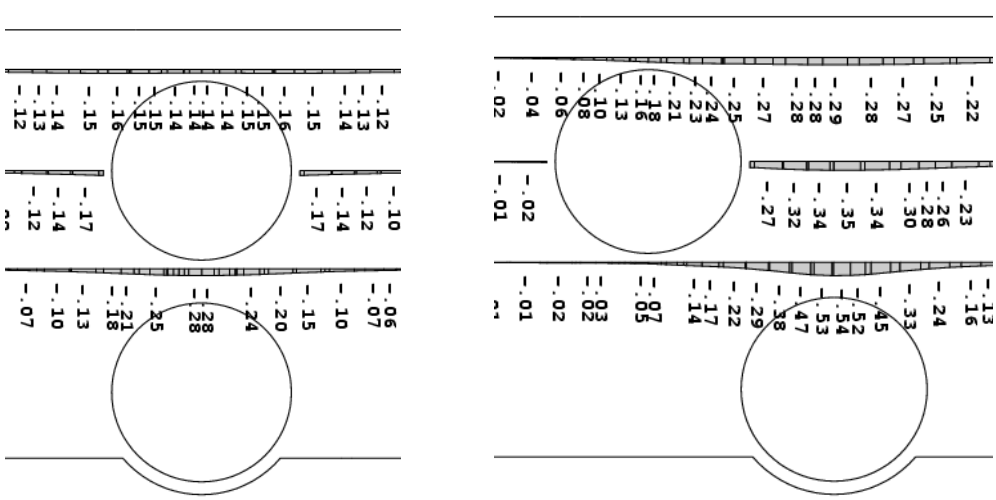


Figure 4: Layout of tunnel lining and critical points

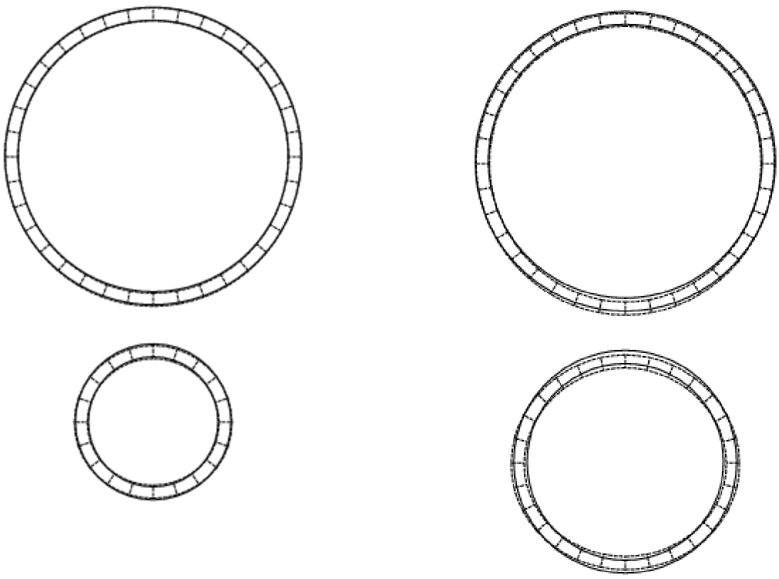
3.1. Displacements and Deformation Shapes

The additional vertical displacements for soil-tunnel model and deformation shapes for tunnel lining due to the construction of a new lower tunnel were illustrated as shown in Figures 5, 6 and 7. There are two main cases of construction position, case I, the new tunnel was constructed centrically under the existing tunnel, (X=0.0), case II, the new tunnel was constructed eccentrically under the existing tunnel, ($X \neq 0.0$).



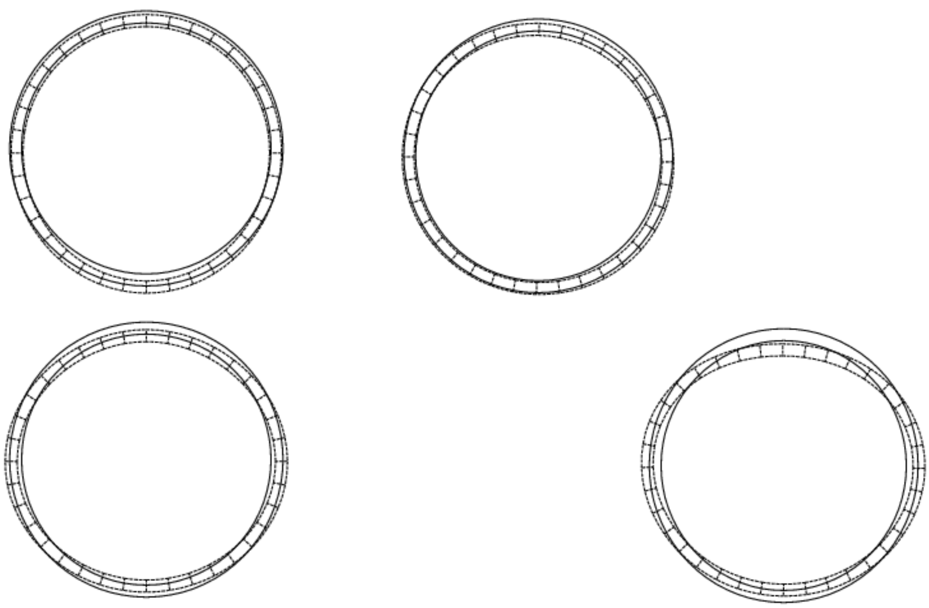
(a) Excavated tunnel when X = 0.0 m (b) Excavated tunnel when X = 8.0 m

Figure 5. Additional vertical displacements of tunnels due to the construction of lower tunnel (D_2 = 8.35 m, H = 2.0 m)



(a) Excavated tunnel D_2 = 4.0 m (b) Excavated tunnel D_2 = 6.0 m

Figure 6. Additional deformation shape of tunnels due to the construction of lower tunnel (H = 2.0 m, X = 0.0)



(a) Excavated tunnel D_2 = 8.35 m X = 0.0 (b) Excavated tunnel D_2 = 6.0 m X = 8.0 m

Figure 7. Additional deformation shape of tunnels due to the construction of lower tunnel (H = 2.0 m)

It can be seen that, in case I, the maximum vertical displacement in tunnel lining is at invert, as shown in Fig. 5-a. whereas, in case II, the maximum vertical displacements in tunnel lining are at nodes Knee_R and Spring line_R as shown in Fig. 5-b. Generally, it can be found that the estimated settlement of the existing tunnel did not exceed the allowable limit of 10 mm set by the Egyptian standards (Abdel Salam, 1998; Documented file issued by NAT, 1999)[2].

The deformation shapes of existing tunnel lining for the different cases of the new tunneling positions are shown in Figures 6 and 7. It can be seen that, in case I, invert and spring line nodes are more affected by the new tunneling than others, whereas, in case II, shoulder and knee nodes are more affected by the new tunneling than others.

3.2. Internal Forces at Tunnel Lining

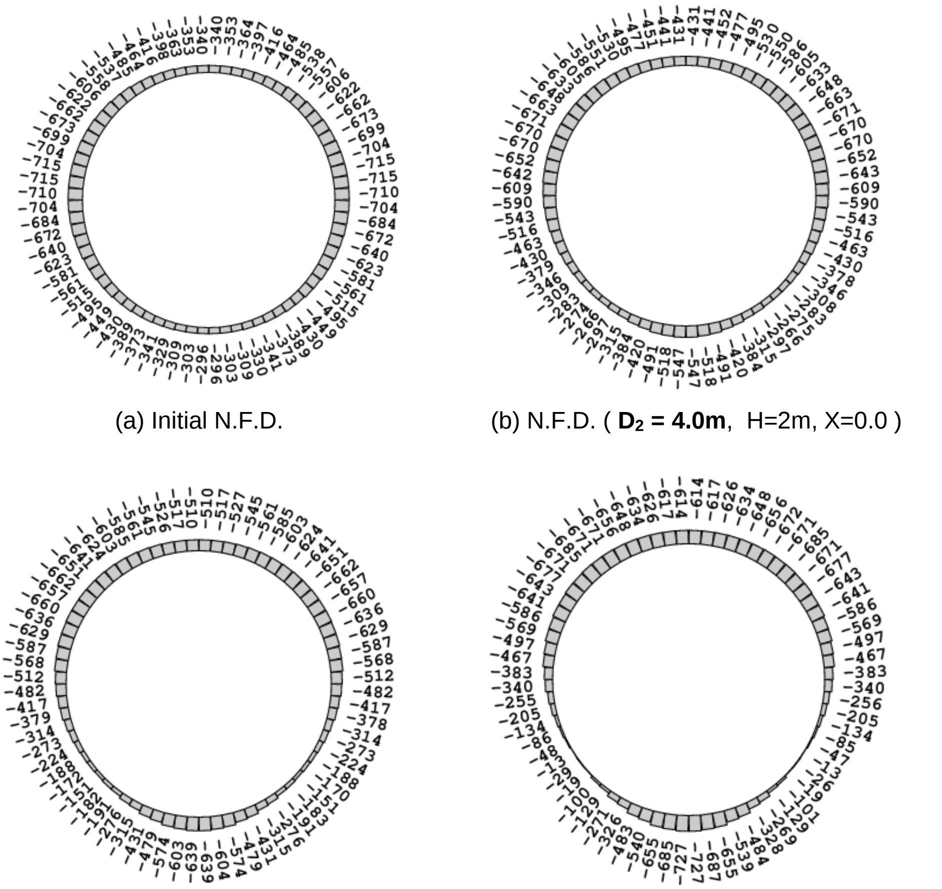
For all considered study cases of excavation, the normal forces, shearing forces and bending moment were plotted in the following Figures. The internal forces at critical nodes in existing tunnel lining were tabulated as shown in Table 3.

Table 3. Internal forces in existing tunnel lining due to the construction of lower tunnel

Internal forces (KN) or (KN.m)	Group I			Group II			Group III		
	D_2 (m)			H (m)			X (m)		
	4.0	6.0	8.35	2.0	3.0	4.4	0.0	4.0	8.0
N_1	-4.31	-510	-614	-614	-606	-587	-614	-481	-299
N_2	-633	-662	-685	-685	-668	-645	-685	-248	-235
N_3	-670	-512	-467	-467	-399	-391	-467	-217	-684
N_4	-308	-188	-19	-19	-47	-112	-19	-972	-1155
N_5	-547	-639	-727	-727	-702	-674	-727	-325	-126
N_6	-390	-188	-19	-19	-47	-114	-19	-175	-355
N_7	-670	-568	-467	-467	-399	-391	-467	-949	-958
N_8	-633	-622	-685	-685	-668	-645	-685	-1010	-919
M_1	21	-2	-34	-34	-31	-25	-34	26	90
M_2	-31	-35	-47	-47	-45	-40	-47	129	148
M_3	9	15	51	51	48	41	51	90	-41
M_4	72	115	166	166	154	139	166	-318	-263
M_5	-107	-169	-231	-231	-232	-210	-231	23	190
M_6	73	115	166	166	154	139	166	232	82
M_7	9	15	51	51	48	41	51	-72	-90
M_8	-31	-35	-47	-47	-45	-40	-47	-144	-138
Q_1	3	5	7	7	7	7	7	78	78
Q_2	-37	-26	-11	-11	-12	-14	-11	12	-62
Q_3	51	73	83	83	84	82	83	-50	-155
Q_4	-43	-137	-188	-188	-176	-154	-188	-203	112
Q_5	-20	-24	-26	-26	-28	-28	-26	229	71
Q_6	106	137	182	182	177	155	182	-125	-90
Q_7	-51	-73	-95	-95	-90	-82	-95	-101	-67
Q_8	39	31	-12	-12	-11	-8	-12	36	97

a) Normal Forces

Figures from 8 to 13 show the relationships between normal force and the different studied parameters.



(a) Initial N.F.D.

(b) N.F.D. (**D_2 = 4.0m**, H=2m, X=0.0)

(c) N.F.D. (**D_2 = 6.0m**, H=2m, X=0.0)

(d) N.F.D. (**D_2 = 8.35m**, H=2m, X=0.0)

Figure 8. N.F.D at the existing tunnel lining due to change in excavated tunnel diameter **D_2**

Figures 8 and 9 show the effect of excavated lower tunnel diameter D_2 on the values of normal forces at the existing tunnel lining. Three different diameters, 4.0m, 6.0m, and 8.35m were taken into consideration, (group **I**), as mentioned in Tables 1 and 3 and shown in Figures 8- b, c, and d, respectively. The estimated results were compared with the initial normal force obtained from case of no tunneling under the existing tunnel. It can be seen that invert and knee nodes are more affected by new tunneling than others, then crown, after that spring line nodes, Whereas, shoulder nodes are less affected by new tunneling than others as clear in Figure 9. From these Figures, it can be observed that the values of normal force increase for crown, invert, and shoulder nodes and decrease for other nodes as diameter of excavated lower tunnel increases. The range of change depends on the node positions and diameter of excavated tunnel D_2. In the case of invert node, the values of normal force became

1.85, 2.15, and 2.45 times the initial normal force due to the construction of a new tunnel which its internal diameter D_2 equal to 4.0 m, 6.0 m, and 8.35 m, respectively. Also, in the case of crown node, these values became 1.25, 1.5, and 1.8 times the initial normal force, respectively. On the other hand, in case of other nodes such as spring line and knee, the values of normal force decreased to become 0.85 to 0.05 times the initial values. Also, it can be concluded that crown and invert nodes represent the critical section for design.

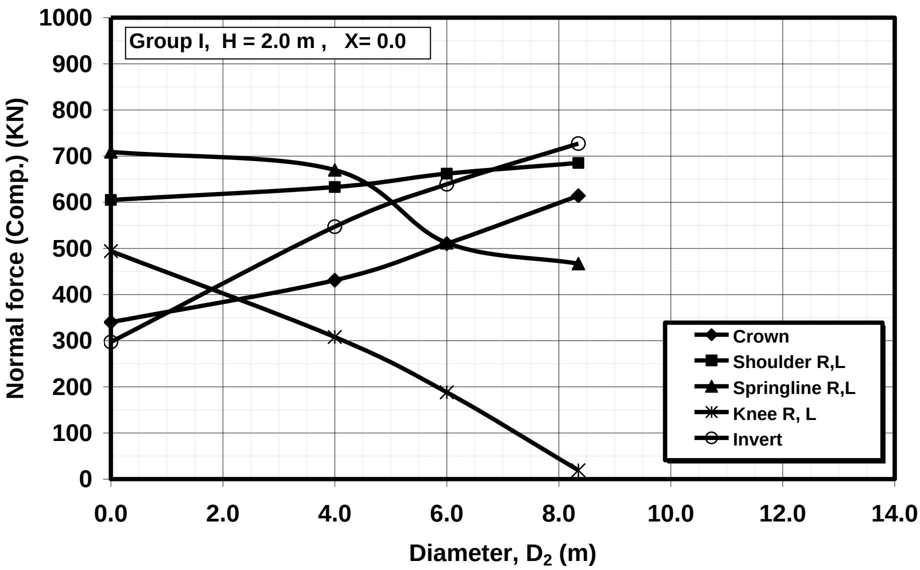
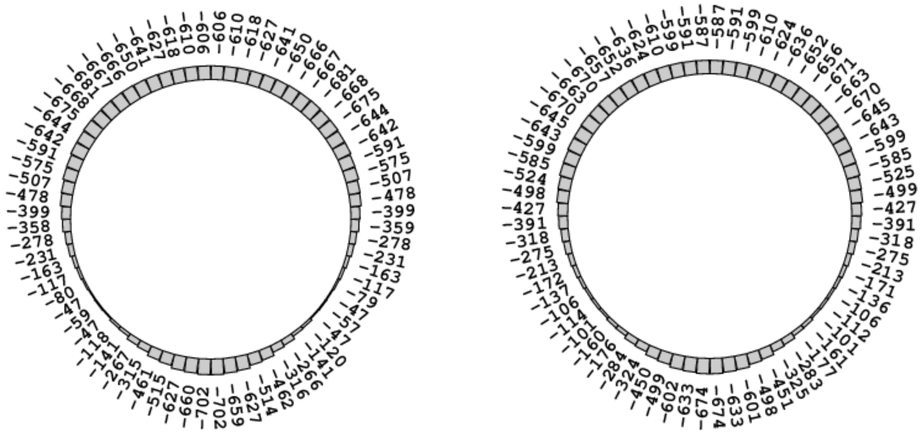


Figure 9. N.F. at existing tunnel lining versus excavated tunnel diameter D_2

To study the effect of soil thickness (H) between tunnels, three different thicknesses 2.0m, 3.0m, and 4.4m were taken into consideration, (group **II**), as mentioned in Tables 1 and 3. Due to the construction of a new tunnel with different depths under an existing one, the normal forces are shown in Figures 8-d, 10-a, b, and 11. From these Figures, it can be observed that, for all nodes except knee, the values of normal force decrease as soil thickness H increases, whereas, for knee nodes these values increase as H increases. From Figure 11, it can be found that spring line and knee nodes are more affect by soil thickness H than others. Also, it can be concluded that crown and invert nodes represent the critical section for design.



(a) N.F.D. (D_2 = 8.35m, **H=3m**, X=0.0) (b) N.F.D. (D_2 = 8.35m, **H=4.4m**, X=0.0)

Figure 10. N.F.D at the existing tunnel lining due to change in soil thickness **H**

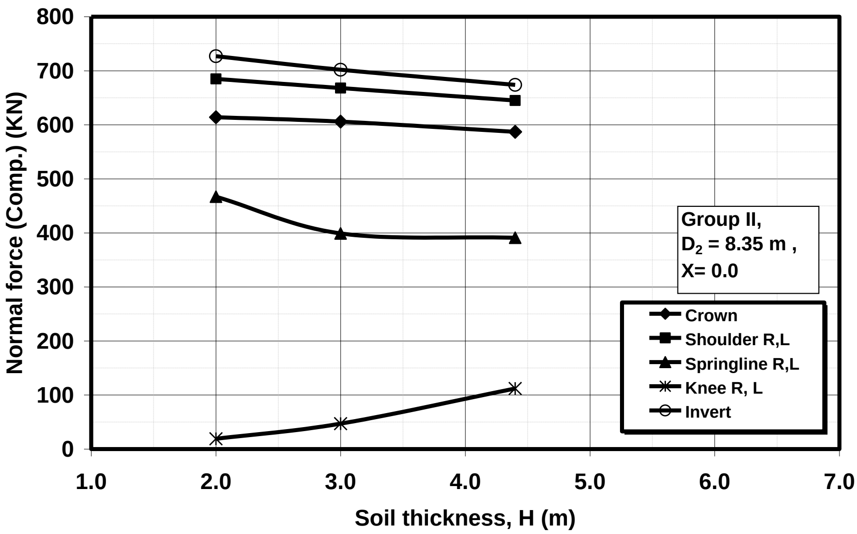
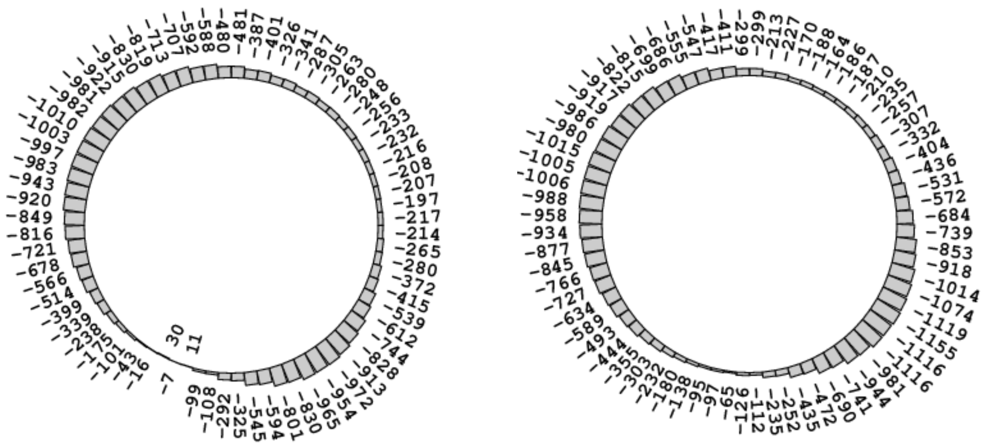


Figure 11. N.F. at existing tunnel lining versus soil thickness **H**

To study the effect of horizontal distance (X) between tunnels, three different distances 0.0, 4.0m, and 8.0m were taken into consideration, (group **III**), as mentioned in Tables 1 and 3. Due to the construction of a new tunnel under an existing one, the normal forces are shown in Figures 8- d, 12-a, b, respectively. Note that if the horizontal distance X was taken in negative x direction, the values of normal force in right half become in left half. From these Figures, it can be observed that, for nodes shoulder, spring line and knee, the values of normal force increase as distance X increases. These values are ranged between 1.0 to 2.3 times the initial values. On the other hand, for crown and invert nodes the values of normal force decrease as distance X increases. These values are ranged between 0.3 to 1.0 times the initial values. From

Figure 13, it can be found that spring line, knee and invert nodes are more affect by horizontal distance x than others. Also, it can be concluded that shoulder and knee nodes represent the critical section for design.



(c) N.F.D. (D_2 = 8.35m, H=2m, **X=4.0m**) (d) N.F.D. (D_2 = 8.35m, H=2m, **X=8.0m**)

Figure 12. N.F.D at the existing tunnel lining due to change in horizontal distance **X**

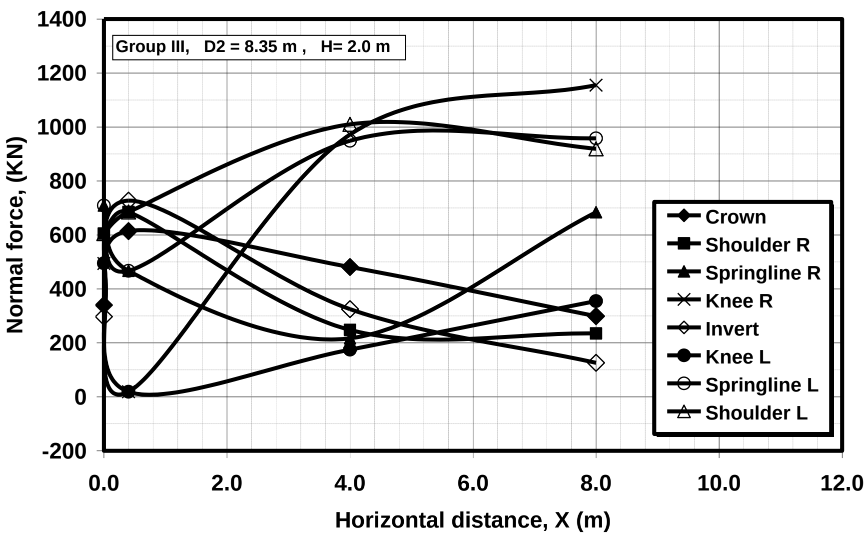
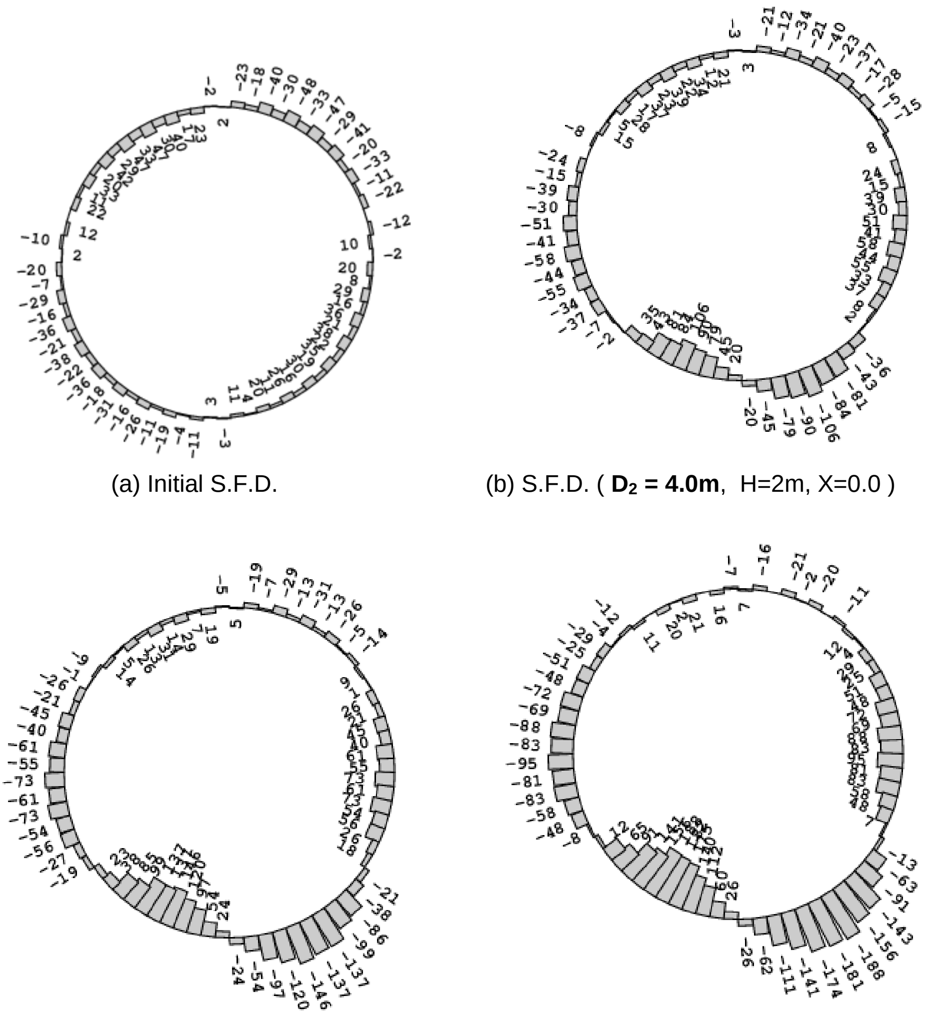


Figure 13. N.F. at existing tunnel lining versus horizontal distance **X**

b) Shearing Forces

Figures from 14 to 19 show the relationships between shearing force and the different studied parameters. Figures 14 and 15 show the effect of different values of excavated lower tunnel diameter D_2 on the values of shearing forces at the existing tunnel lining, (group **I**), as mentioned in Tables 1 and 3. The estimated results were compared with the initial shearing force obtained from case of no tunneling under the existing tunnel.



(a) Initial S.F.D.

(b) S.F.D. (**D_2 = 4.0m**, H=2m, X=0.0)

(c) S.F.D. (**D_2 = 6.0m**, H=2m, X=0.0)

(d) S.F.D. (**D_2 = 8.35m**, H=2m, X=0.0)

Figure 14. S.F.D at the existing tunnel lining due to change in excavated tunnel diameter **D_2**

From Figure 14 and 15, It can be seen that knee nodes are more affected by new tunneling than others, then spring line, after that shoulder nodes, whereas, crown and invert nodes are less affected by new tunneling than others as clear in Figure 15. Also, for knee nodes, it can be observed that the values of shearing force increase as diameter of excavated lower tunnel increases and change in sign from positive to negative or negative to positive. The range of change depends on the node positions and diameter of excavated tunnel D_2. In the case of knee and spring line nodes, the values of shear force ranged from 1.0 to 6.0 times the initial value due to the construction of a new tunnel and depend on internal excavated diameter D_2. In the case of other nodes, these values ranged from 1.0 to 3.0 times the initial shearing force. Also, it can be concluded that knee and spring line nodes represent the critical section for checking the shearing force.

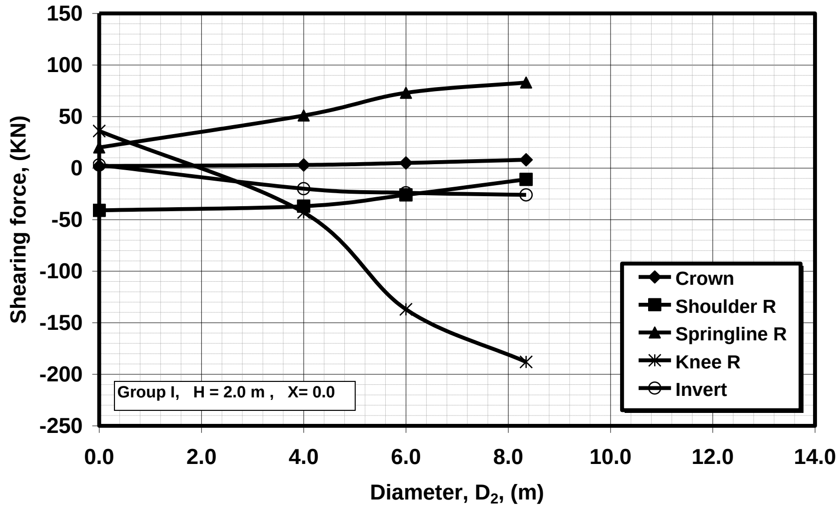
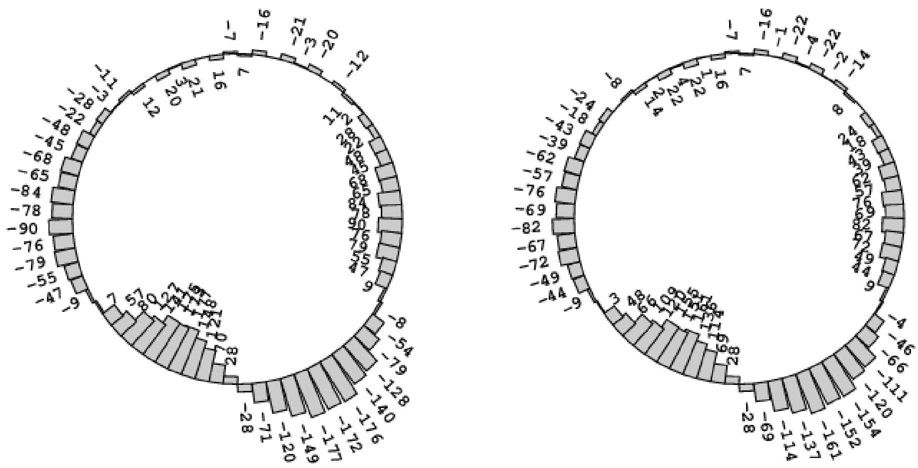


Figure 15. S.F. at existing tunnel lining versus excavated tunnel diameter D_2

Figures 16 and 17 show the effect of different values of soil thickness between tunnels H on the values of shearing forces at the existing tunnel lining, (group **II**), as mentioned in Tables 1 and 3. The estimated results were compared with the initial shearing force obtained from case of no tunneling under the existing tunnel. Due to the construction of a new tunnel with different depths under an existing one, the shearing forces are shown in Figures 14-d, 16-a, b, and 17.



(a) S.F.D. (D_2 = 8.35m, **H=3m**, X=0.0) (b) S.F.D. (D_2 = 8.35m, **H=4.4m**, X=0.0)

Figure 16. S.F.D at the existing tunnel lining due to change in soil thickness **H**

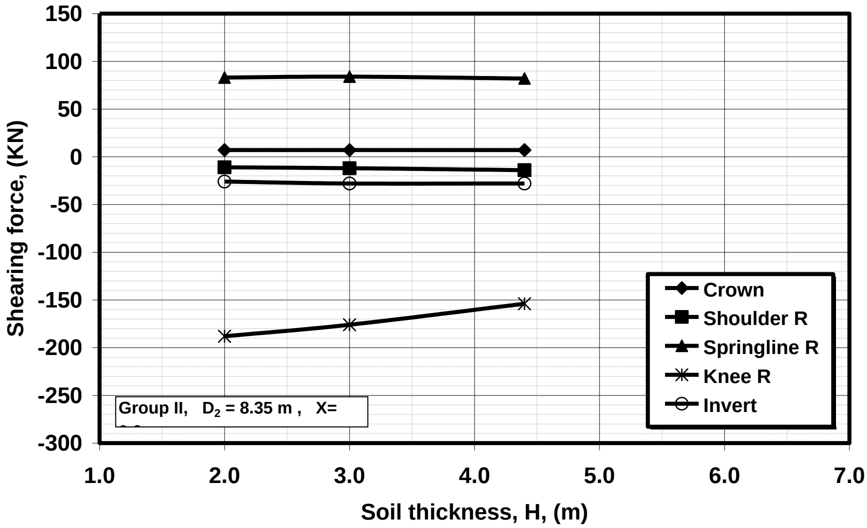
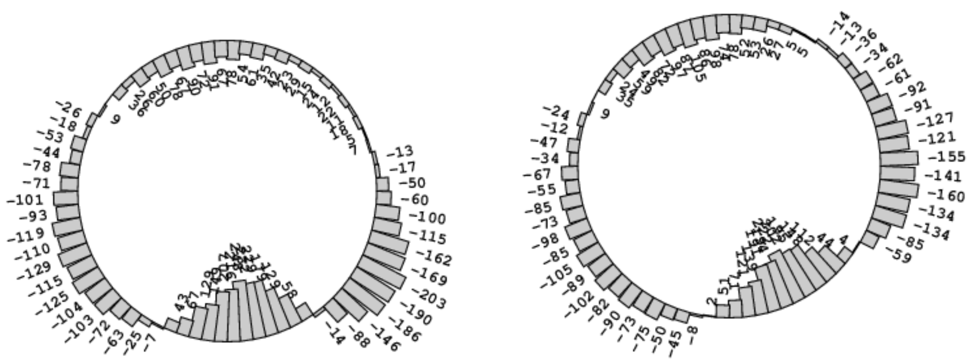


Figure 17. S.F. at existing tunnel lining versus soil thickness **H**

From these Figures, it can be observed that, for all nodes except knee, the values of shearing force did not affect by increasing soil thickness H. For knee node the shearing forces decrease as soil thickness H increases, whereas, for knee nodes these values increase as H increases as clear in Figure 17. It can be seen that only knee nodes are affected by new tunneling depth.

Figures 18 and 19 show the effect of different values of horizontal distance X on the values of shearing force at the existing tunnel lining, (group **III**), as mentioned in Tables 1 and 3. The estimated results were compared with the initial shearing force obtained from case of no tunneling under the existing tunnel.



(c) S.F.D. (D_2 = 8.35m, H=2m, **X=4.0m**) (d) S.F.D. (D_2 = 8.35m, H=2m, **X=8.0m**)

Figure 18. S.F.D at the existing tunnel lining due to change in horizontal distance **X**

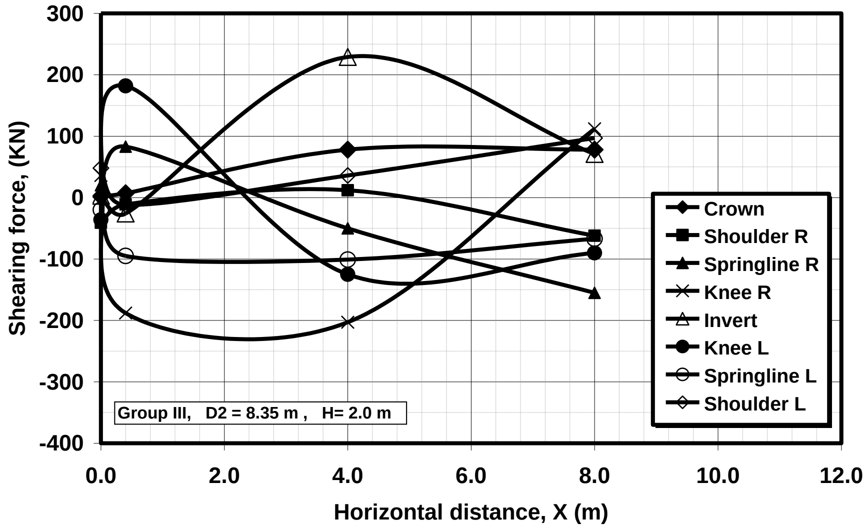


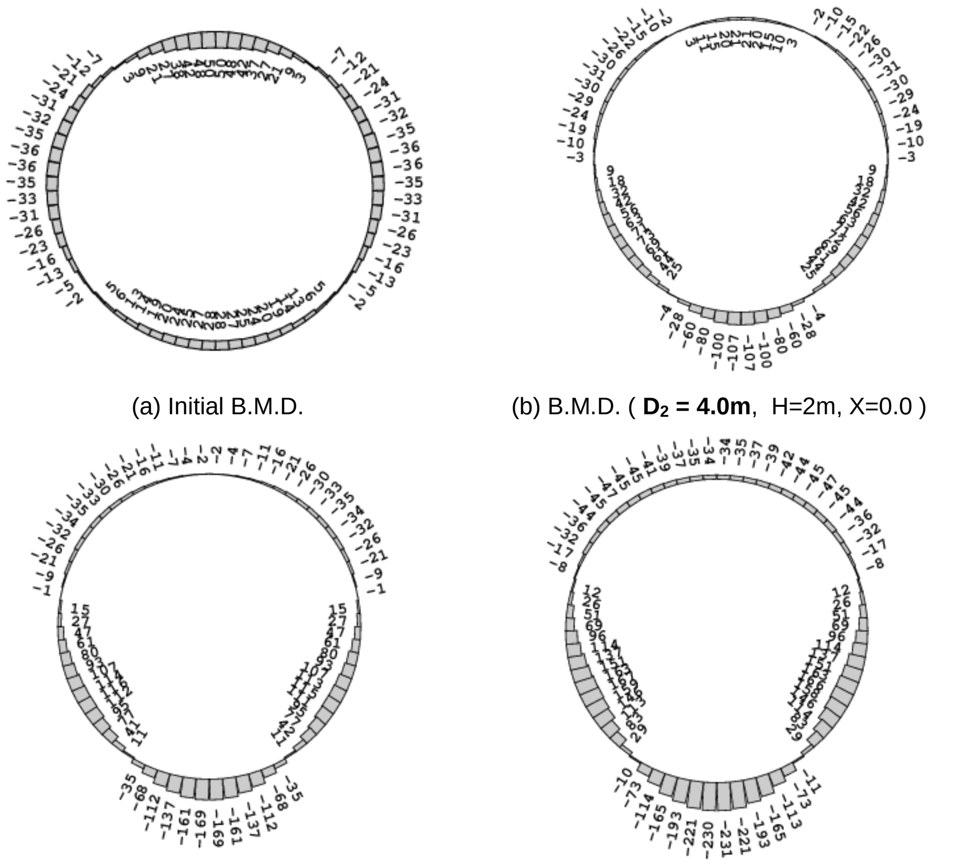
Figure 19. S.F. at existing tunnel lining versus horizontal distance **X**

Due to the construction of a new tunnel under an existing one, the shearing forces are shown in Figures 14-d, 18-a, b, and 19. From these Figures, it can be observed that, the nodes whose most affected by a new tunneling are knee, invert and shoulder. For these nodes the values of shearing force are increase as distance X increases, whereas, other nodes have a little effect. Also, it can be observed that, in the case of invert node, the shearing forces increase as distance X increases till reach to Max. values at X = 4.0 m then decrease as distance X increases. But, in the case of knee node, the shearing forces always increase as distance X increases.

c) Bending Moments

Figures from 20 to 25 show the relationships between bending moment and the different studied parameters. The estimated results were compared with the initial values obtained from case of no tunneling under the existing tunnel.

Figures 20 and 21 show the effect of different values of excavated lower tunnel diameter D_2 on the values of bending moment at the existing tunnel lining, (group **I**), as mentioned in Tables 1 and 3. From these Figures, It can be seen that invert and knee nodes are more affected by new tunneling than others, then crown, after that shoulder and spring line nodes. Also, for all nodes, it can be observed that the values of bending moment changed from negative to positive and vise versa. The range of change depends on the node positions and diameter of excavated tunnel D_2. In the case of invert and knee nodes, the values of bending moment ranged from 1.0 to 10.0 times the initial value due to the construction of a new tunnel and depend on internal excavated diameter D_2. In the case of other nodes, these values ranged from 0.1 to 0.35 times the initial bending moment. Also, it can be concluded that invert and knee nodes represent the critical sections for checking the existing cross sections.



(a) Initial B.M.D.

(b) B.M.D. (**D_2 = 4.0m**, H=2m, X=0.0)

(c) B.M.D. (**D_2 = 6.0m**, H=2m, X=0.0)

(d) B.M.D. (**D_2 = 8.35m**, H=2m, X=0.0)

Figure 20. S.F.D at the existing tunnel lining due to change in excavated tunnel diameter **D_2**

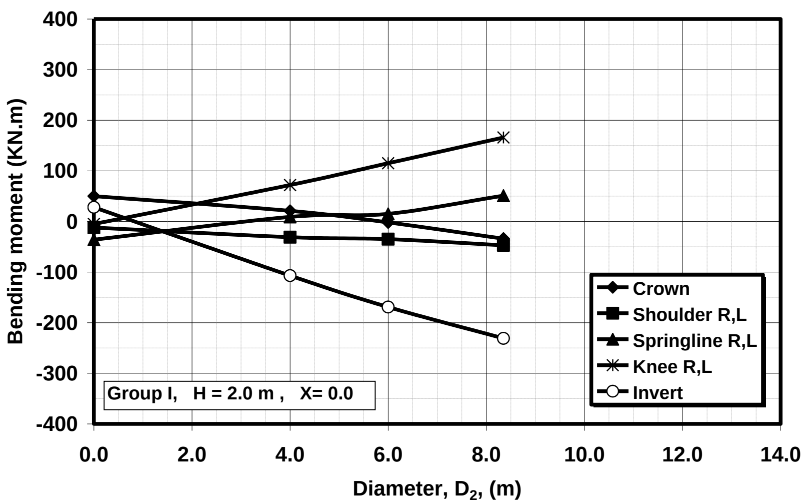
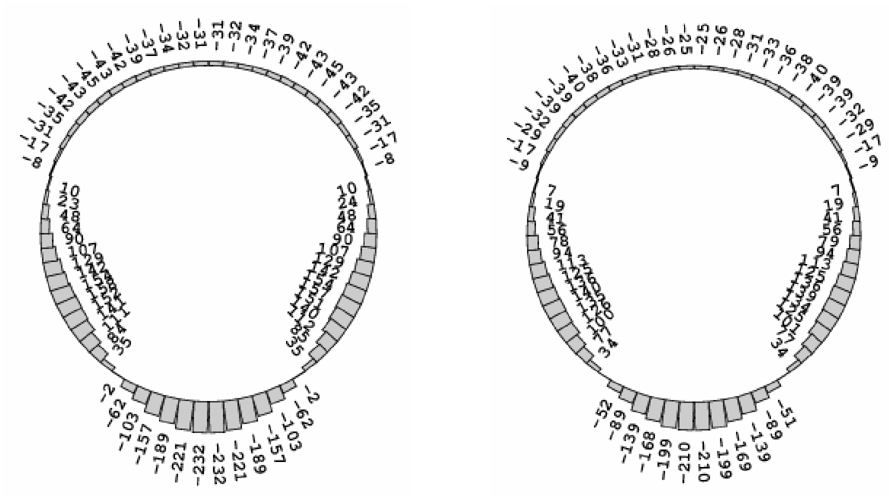


Figure 21. B.M. at existing tunnel lining versus excavated tunnel diameter D_2

Figures 22 and 23 show the effect of different values of soil thickness between tunnels H on the values of bending moment at the existing tunnel lining, (group **II**), as mentioned in Tables 1 and 3. Due to the construction of a new tunnel with different depths under an existing one, the bending moments are shown in Figures 20-d, 22-a, b, and 23.



(a) B.M.D. (D_2 = 8.35m, **H=3m**, X=0.0) (b) B.M.D. (D_2 = 8.35m, **H=4.4m**, X=0.0)

Figure 22. B.M.D at the existing tunnel lining due to change in soil thickness **H**

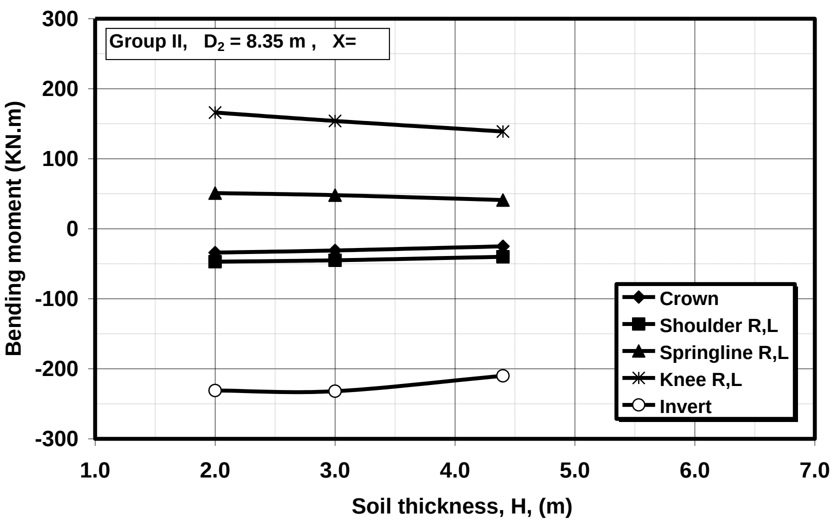
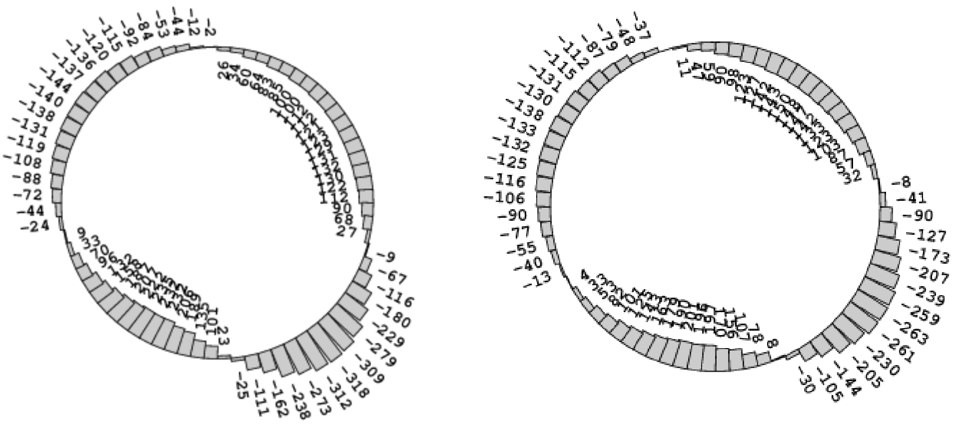


Figure 23. B.M. at existing tunnel lining versus soil thickness **H**

From these Figures, It can be seen that invert and knee nodes are more affected by new tunneling than others. Also, for all nodes, it can be observed that the values of bending moment changed from negative to positive and vise versa. The range of change depends on the node positions and soil thickness H. In the case of invert and knee nodes, the values of bending moment ranged from 7.0 to 8.5 times the initial values of bending moment. In the case of other nodes, these values ranged from 0.6 to 1.0 times the initial bending moment. Also, it can be concluded that invert and knee nodes represent the critical sections for checking the existing cross sections.

Figures 24 and 25 show the effect of different values of horizontal distance X on the values of bending moment at the existing tunnel lining, (group **III**), as mentioned in Tables 1 and 3. Due to the construction of a new tunnel under an existing one, the bending moments are shown in Figures 20-d, 24-a, b, and 25.



(c) B.M.D. (D_2 = 8.35m, H=2m, **X=4.0m**) (d) B.M.D. (D_2 = 8.35m, H=2m, **X=8.0m**)

Figure 24. B.M.D at the existing tunnel lining due to change in horizontal distance **X**

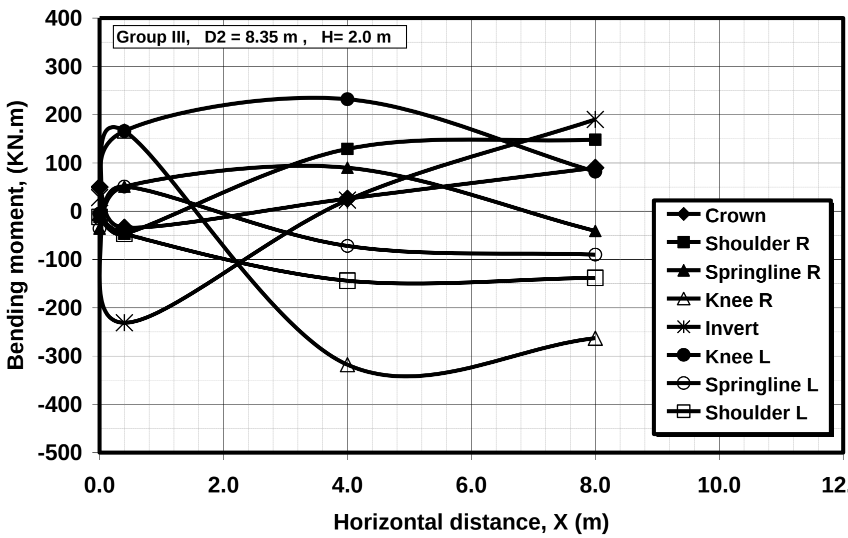


Figure 25. B.M. at existing tunnel lining versus horizontal distance **X**

From these Figures, it can be observed that, the nodes whose most affected by a new tunneling are knee, invert and shoulder. For these nodes the values of bending moment are increase as distance X increases, whereas, other nodes have a little effect. Also, for all nodes, it can be observed that the values of bending moment changed from negative to positive and vise versa. The range of change depends on the node positions and horizontal distance X.

4. CONCLUSIONS

The present study is concerned with the behavior of an existing tunnel lining due to the construction of a new one under it. In this study, the main parameters were taken into consideration are excavated tunnel diameter (D_2), soil thickness between tunnels (H), and horizontal distance (X). The results obtained from this study were compared with the initial values obtained from case of no tunneling under the existing tunnel.

Based on the presented discussion and analysis of obtained results, the following main conclusions are noted:

(1) The estimated settlement of the existing tunnel lining did not exceed the allowable limit of 10 mm set by the Egyptian standards.
(2) In the case of centrically construction of a new tunnel under an existing one, crown, invert, and spring line nodes are more affected by the new tunneling than others, whereas, in the case of eccentrically construction, shoulder and knee nodes are more affected by the new tunneling than others.
(3) All studied parameters have been affected in the behavior of existing tunnel lining, but, the parameter of horizontal distance X has a great influence especially at knee node.
(4) Due to the construction of a new tunnel under an existing one, all critical sections should be checked according to the new straining action.
(5) The danger of the construction of a new tunnel under an existing one is that some of internal forces at existing tunnel lining have been changed in sign from positive to negative and vise versa.

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سلوك نفق قائم نتيجة إنشاء نفق جديدماراً موازى أسفله

نظراً للكثافة السكانية العالية فى المدن الكبيرة مثل مدينة القاهرة ونظراً للإزدحام الشديد فى وسائل المواصلات مما قد يؤدى الى إنشاء خطوط جديدة مجاورة أو أسفل الخطوط القائمة وبالتالى يكون لها تأثيرعليها. والحالة التى لها اكبر الأثر عندما يقع النفق الجديد أسفل النفق القائم.

تعتبر دراسة الأنفاق من الموضوعات التى تهم المهندسين الإنشائيين ومهندسى التخطيط ونظراً لوجود هذه الأنفاق أسفل سطح الأرض مما قد ينتج عنها بعض المشاكل الناتجة من عملية تنفيذ الأنفاق الجديدة أسفل تلك القائمة. من هذه المشاكل الهبوط الناتج من حفر النفق الجديد ممايترتب على ذلك تغير فى الإجهادات فى المنطقة المحيطة بالانفاق و كذلك تغير القوى الداخلية فى جسم النفق القائم (Existing tunnel lining) وهذا يتوقف على عدة متغيرات معظمها مرتبط بالنفق الجديد المراد إنشاءه.

فى هذا البحث تم دراسة تأثير بعض المتغيرات على سلوك النفق القائم منها قطر النفق الجديد (D_2) المراد إنشاءه وعمق النفق الجديد عن النفق القائم و المتمثلة بسمك طبقة التربة المحصورة بين النفقين (H) وكذلك وضع النفق الجديد بالنسبة للقديم هل أسفله مباشرة (محورى) أو (غير محورى) مصحوباً بإزاحة أفقية مقدارها (X).

هذا وقد تم تحديد عدد من النقاط الحرجة على جسم النفق القائم وتم دراسة التغيرات الناتجة فيها من تأثير المتغيرات الثلاثة السابقة وقد وجد أنه نتيجة تأثير المتغيرات المدروسة فإن قيم الهبوط أقل من القيم المسموح و ذلك لجميع المتغيرات. و لوحظ أنه عندما يتم حفر النفق الجديد محورياً أسفل القائم فإن النقط التى تمر بالمحاور الرئيسية (Crown, Invert, and Spring line) تكون اكثر تأثراً عن باقى النقط ولكنه عندما يتم حفر النفق الجديد غير محورياً أسفل القائم فإن النقط (Shoulder and Knee) تكون اكثر تأثراً عن باقى النقط وقد وجد أنه أحياناً تتغير نوع القوى الداخلية من شد الى ضغط وبالعكس أومن موجب الى سالب وبالعكس وأن مقدار التغير يتوقف على وضع النقطة و المتغير المأخوذ فى الدراسة.