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EFFECT OF TUNNEL CONFIGURATION ON THE BEHAVIOR OF TWO ADJACENT TUNNEL

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ABSTRACT

It has now become very important to increase means of transportation in urban areas due to the large population, especially underground metro lines. In the present research a parametric study on two circular adjacent tunnels was carried out based on numerical analysis using PLAXIS 3D finite element package. The proposed model was verified based on the results of case study by Hamid et al. (2014). The verified model was modified for the parametric study based on characteristics soil profile from Greater Cairo Metro Line 4. The parametric study included the spacing between the tunnels, and lining thickness. The effect of distance between the twin tunnels was investigated for range of 1.50 to 5.5 times the diameter of tunnel, and thickness of lining thickness for the range of 0.025 to 0.105 of tunnel diameter, for tunnel with diameter of 6.00 m. The effect of these parameters on ground surface settlements, the tunnel deformed shape and induced stresses at the tunnels top were analyzed and discussed. It was found that increasing the tunnel spacing from 1.5D to 5.5 had decreased settlement of ground surface by an average value of 11%. On the other hand, increasing lining thickness of tunnel from 0.025D to 0.105D decreased maximum vertical displacement at crown of tunnel by average value of 23%. On the other hand, the maximum horizontal induced stress decreased by about 67%. Maximum soil lateral stress decreases with the increases of distance between the twin tunnels up to 4.5D, after which the stress around tunnel increased as each tunnel behaves as a single tunnel.

KEYWORDS: Tunnels, spacing between two tunnels, lining thickness of tunnel, surface settlement- total stress in surrounding soil

تأثير المسافه البينيه وسمك النفق علي سلوك نفقين متجاورين

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الملخص:

أصبح الآن من المهم جدًا زيادة وسائل النقل في المناطق الحضرية نظرًا للزياده في الكثافة السكانية الكبيرة وخاصة وسائل النقل تحت الأرض مثل خطوط المترو. في هذه الدراسه تم إجراء دراسة بارامتريه عدديه بأ ستخدام برنامج PLAXIS- 3D علي نفقين متجاورين بعمل نموذج عددي تم بناءه علي حاله دراسيه بها قياسات حقليه تم نشرها بواسطه حميد وآخرون (2014). وقد تم تعديل النموذج الذي تم التحقق منه للدراسة البارامترية بناءً على خصائص التربة من الخط الرابع لمترو القاهرة الكبرى. وتضمنت الدراسة البارامترية المسافة بين الأنفاق وسمك البطانة. وذلك بدراسة تأثير التباعد بين النفقين لمدى من 1.50 إلى 5.5 مرة قطر النفق، وسمك البطانة للمدى من 0.025 إلى 0.105 من قطر النفق، لنفق قطره (D) 6.00 م. وتم تحليل ومناقشة تأثير هذه العوامل على هبوط سطح الأرض وتشوه شكل النفق والإجهادات الناتجة حول النفق. ومن هذه الدراسة لقد وجد أن زيادة المسافة بين النفقين من من D1.50 إلى D5.50 أدى إلى انخفاض الهبوط السطحي بمعدل حوالى 11%. من ناحية أخرى فإن زيادة سمك بطانة النفق من0.025D إلى0.105D أدت إلى تقليل الإزاحة الرأسية القصوى عند تاج النفق بقيمة متوسطة 23%. ، وكذلك انخفض الحد الأقصى للإجهاد الأفقي بنحو 67٪ ، من ناحية أخرى فإن الحد الأقصى للإجهاد الجانبي للتربة يتناقص مع زيادة المسافة بين النفقين حتى 4.5D ، وبعد ذلك يزداد الضغط حول النفق حيث يتصرف كل نفق كنفق مفرد.

الكلمات المفتاحية: الأنفاق، المسافة بين نفقين، سماكة بطانة النفق، الهبوط السطحي- الإجهاد الكلي المحيط بالنفقين.

1. INTRODUCTION:

Far, Metro tunnels can be single or double tunnels, and they may be close to each other, as well as from other infrastructure lines. The effect of the induced stresses and the tunnel lining is of great important and must be taken into account when designing.

The relationship between the surface subsidence in the soft ground of the Tabriz metro in Iran, and the impact of the separation between the twin tunnels, which have pillar widths of 0.5D, 1.0D, and 1.5D had been studied [1]. The results indicated that, the highest settlement was observed to at the offset from the of first tunnel's centerline. The settlement increases as the distance between the tunnels gets smaller. A study on the effect of tunnelling on existing tunnels found that, the tunnels deform as a result of normal pressures [2]. A significant effect was observed on surface settlement curve if the twin tunnels were built with a distance of less than three tunnel diameters (D) [3]. Moreover, when the spacing exceeds 4D, the interaction factor is nearly nil. A study on the effect of variation of the tunnel lining thickness with distance between twin tunnels on the induced displacements, and stresses in the surrounding soil showed that, with the increase of thickness of lining tunnel and decreasing spacing between two tunnels, the deflection above the crown tunnel decreased [4]. Also, with the increase of lining thickness the shear force and bending moment resulting from in lining decreased, with optimum at lining thickness of (0.030D) and spacing of 2D. Generally, increasing lining thickness decrease bending moment and shear force value at top of crown. Impact of distance between two tunnels on the surface settlement using FLAC3D. Indicated that, interaction between the two tunnel decreases with the increase of spacing, and become less effective after spacing of 3D [5]. It was also observed that, settlement above the second tunnel was higher than that at the first, as the soil was affected by the weakened zone around the second tunnel. The effect of five crucial variables for twin tunnels spacing, depth of soil above tunnel, soil strength, stiffness ratio and the anisotropy degree revealed that, the surrounding soil to be extremely significant in simulating the twin-tunnel construction, simple design errors could happen if the soil anisotropy is overlooked [6]. Effect of distance on twin adjacent oval-shaped tunnels, the factors included: the loss of volume around the tunnel, the transport of internal forces and the horizontal soil deformation, the results showed the impact of distance between the two oval tunnels, and also, crack propagation represents a significant problem in cross-section tunnels [7]. A study on the effect of constructing a tunnel under an existing tunnel, taking into consideration the undercrossing angle, vertical spacing, and soil parameters when examining the effects of the existing tunnel's crown settlement, it was found that, the cohesion (c) was the least significant factor influencing crown settlement[8]. On the other hand, the friction angle (φ) was the main factor to maintain a vertical distance between the new metro tunnel and the existing A comparative study was made to evaluate the approximate methods used to estimate surface settlement of single and double tunnels, the impact of ground assumptions and tunneling technologies on the settlements were also studied [9]. The results indicated that, the settlement trough for single tunnel extends to (3 to 4) diameter. All researchers used Peck's model and finite element analysis to predict the total settlement. The result showed that, the type of tunneling methodologies, the type of soil, and diameter of tunnel has a combined and important effect on the made surface settlements [10]. A study on the settlement troughs between two tunnels in multi layered soils based on the unloading trouble zone and plastic zone circulation model [11]. The surface settlement width was significantly influenced by the characteristics of the layered soil, a Gaussian curve can define the extra drop that exists between two adjacent tunnels.

In the present study a model proposed for twin adjacent tunnels was developed and verified based on field case study by Hamid et al. (2014) [3], the results of the developed model were in fair agreement with those of the case study. The verified model was modified for the present study parametric study based on characteristics soil profile from Greater Cairo Metro Line 4. Variation of the twin tunnels spacing and lining thickness were investigated using Plaxis-3D finite element program. The twin tunnels spacing was investigated for the range of 1.50 to 5.50 tunnel's diameter (D), and lining thickness in the range of 0.025D to 0.105D, the tunnel diameter is kept constant with 6.00 m. The induced ground settlements, tunnel deformed shape, and lateral soil stresses were analyzed and discussed.

1. Case Study and Proposed Model

The analysis was performed using finite element analysis to study the effect of spacing between two tunnels on surface settlement. The spacing used in this study is assumed as used of the calibrated numerical model a (3). **Fig.1** shows the finite element mesh used in the verification.

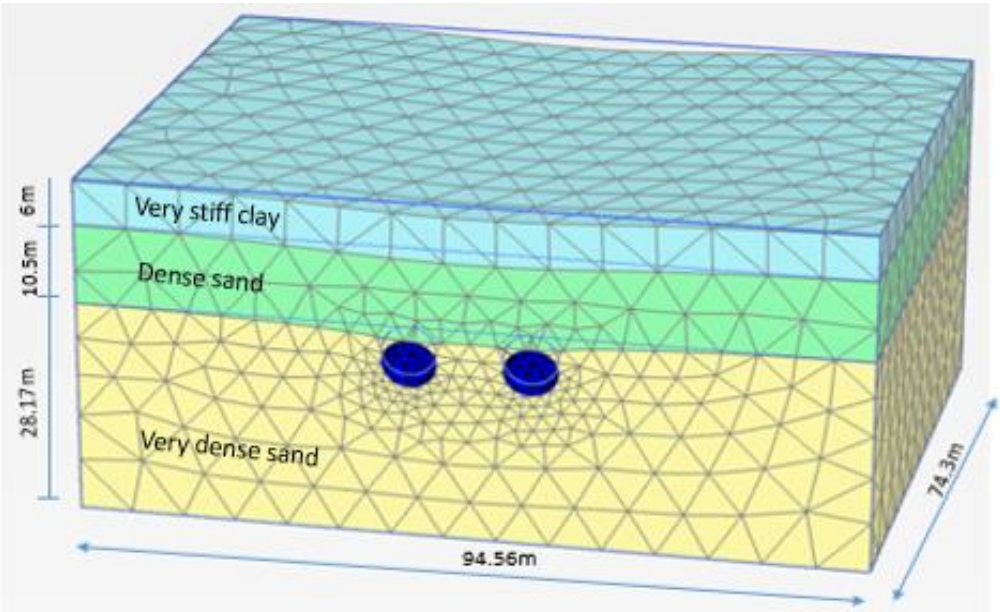

Fig. 1. Deformed mesh and type of soil by plaxis-3D. according to verification .

According to the verification the results of the developed model were in, fair agreement with the observed measured field data. The highest possible surface settlement value was obtained between two tunnels. The distance between two tunnels (1.5D, 2.2D, 3.0D, 3.5D and 4.0D). The surface settlement values have been measured at adjacent tunnels. The comparison between measured settlement values and the settlement values from the finite element analysis was presented.

3. Modeling Configuration:

The soil and the tunnel lining were simulated according to the finite element in the present study. **Fig.1** illustrates the three- dimensional views that has been developed to examine the impact of tunnel spacing [(1.5D, 2.2D, 3.0D, 3.5D and 4.0D), where (D) is diameter of tunnel]. **Table 1.** provides properties, layer arrangement, and thickness of all layers used in the geometric model. The dimension geometry of the physical model was chosen using Plaxis-3D software to simulate the module of taken according to (3).

Table 1. Soil properties and geotechnical design data in the area project by (Ayson 2005).

Layers	Type of soil	Depth Layers (m)	Unit weight (kN/m^3)	Su (kpa)	Cohesion (kPa)	Angle of internal friction ∅ (deg)	Youngs Modulus (E) (MPa)	Deformability parameters Poisons ratio (μ)
Layear1	Very stiff clay with medium dense silty sand	6	18	85	20	9	51	0.35
Layear2	Dense sand	10.6	19	40	1	35	24	0.25
Layear3	Very dense sand	28.17	19.5	50	1	35	30	0.30
Layear4	Limestone	Km 4+450 to 4+500	26.4	-	100	45	1260	0.35

The settlement result for site is obtained according to (3) was presented by verification. **Fig.2.** shows the impact of spacing between two tunnels on surface settlement and comparison between plaxis-3D, FLAC3D and site (field measurement).

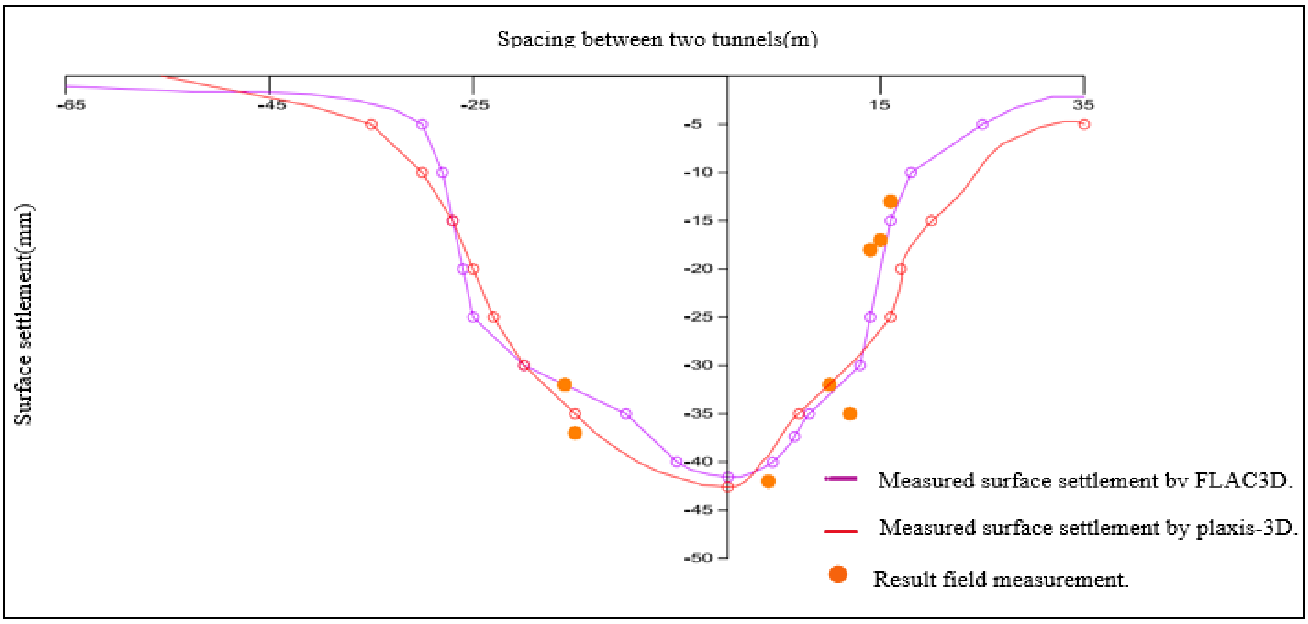

Fig.2. Surface settlement and spacing between two tunnels=2.2D. for the result Plaxis3D, FLAC3D and field measurement.

It can be observed a fair agreement between the settlement data obtained from site (field measurement), FLAC3D by (Hamid et al. 2014) and plaxis3D by present study.

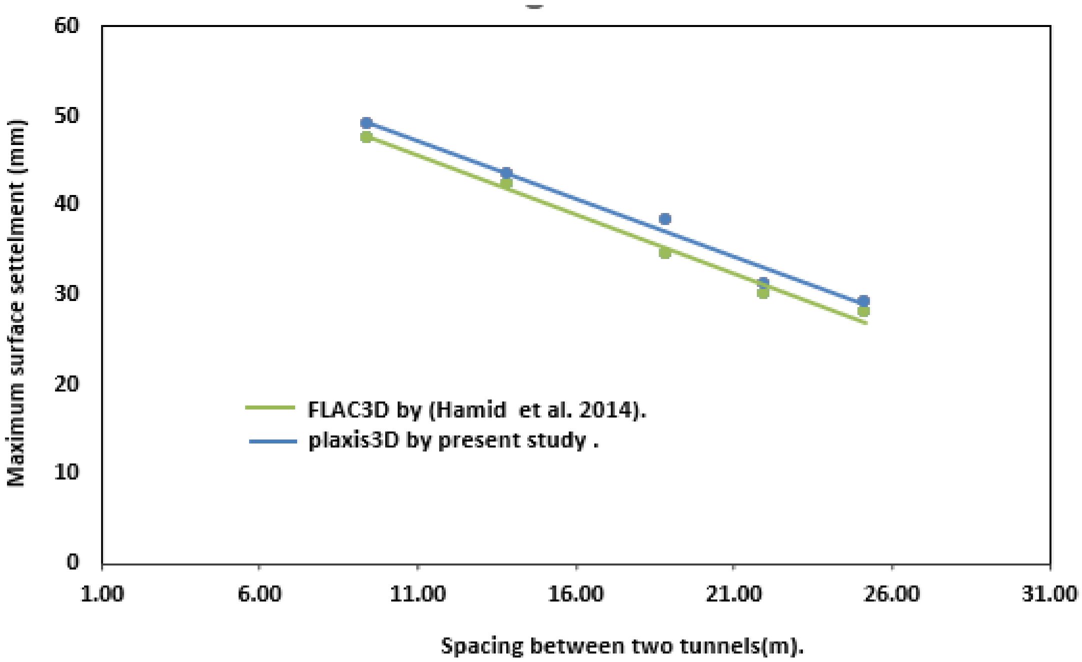

Fig.3. Relationship between maximum surface settlement and spacing between two tunnels to shown comparison result plaxis3D and FLAC3D.

It was found good agreement by rate 80% the results of the program FLAC3D by to (Hamid et al. 2014) and Plaxis3 by present study.

4. Parametric Study:

In this study the purposed verified model was modified to represent an Egypt case as tunnel in metro line No.4.[12]. as shown in **fig.4.** modified model mesh and twin circular tunnels. The soil grouping and the geotechnical design data of the selected site are listed in **Table 2.**

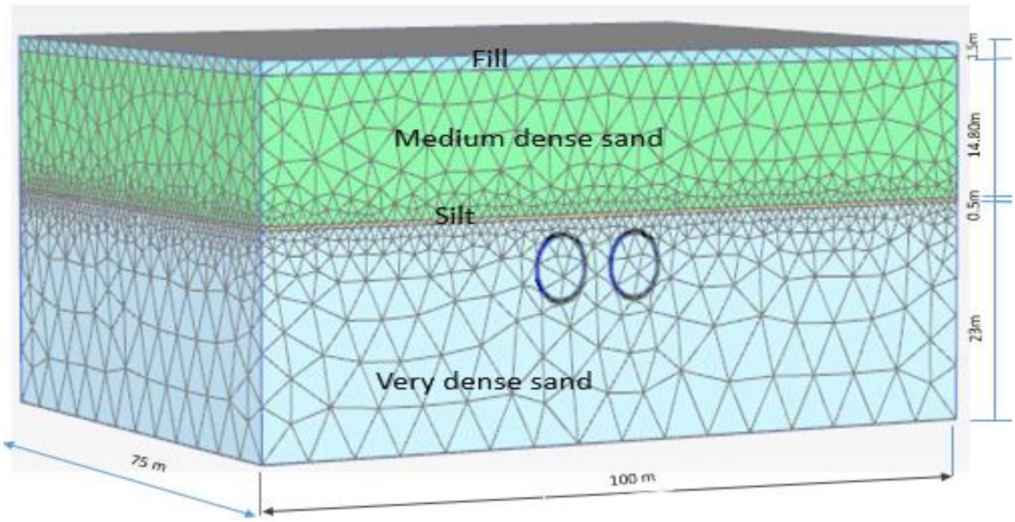

Fig.4. Three-dimensional model Deformed mesh by plaxis-3D.

Table 2. Type of soil and geotechnical design data in the area project.

Layers	Type of soil	Thickness layer (m)	Unit weight kN/m^3	Cohesion (c) kN/m^2	Angle of internal friction(ϕ) deg	Young's modules (E) kN/m^2	Poisson's ratio (μ)
Layer1	Fill	1.5	16	0.25	25	10000	0.2
Layer2	Medium Sand dense to very dense,	14.80	18.2	2	35	30000	0.23
Layer3	Silt	0.5	17	20	9	5000	0.33
Layer 4	Very dense, fine to medium Sand	23	20	1	40	50000	0.3

4.1. Configuration of The Modified Numerical Model:

Fig.5. Shown the dimensions of the planned numerical model.

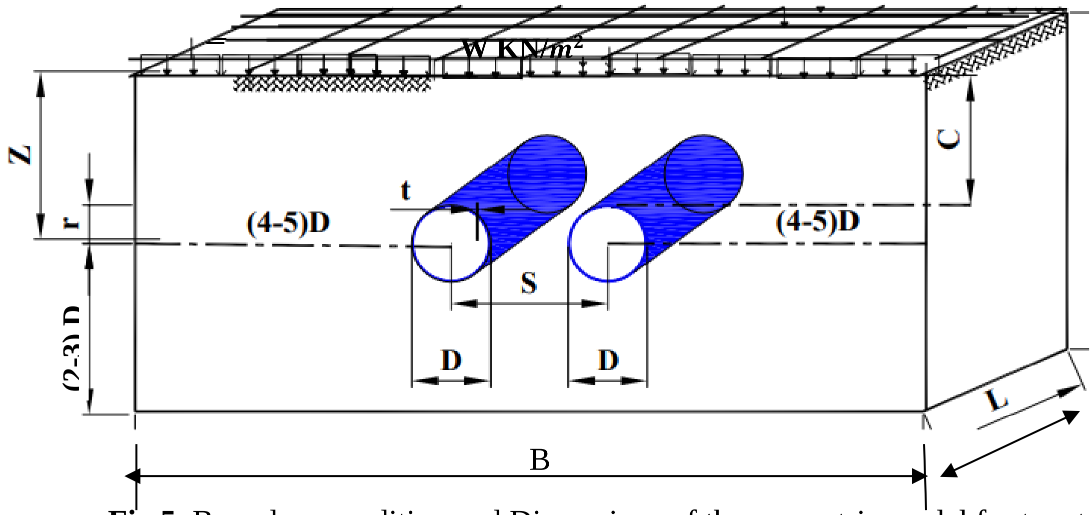

Fig.5. Boundary condition and Dimensions of the geometric model for two tunnels.

Where:

D : Diameter of Tunnel.
S : Spacing between twin tunnels.
t : Tunnel lining thickness.
B : Horizontal length dimension.
R : radius (D/2).
C : Cover above crown of tunnel.
W : Surcharge load (15 kN/m^2)
Z : Distance measured form surface to center line tunnel.

4.2. Surface settlement:

So as to examine the effect of the spacing between twin tunnels on surface setelment.as shown in **fig. 6.** to **fig.7.**

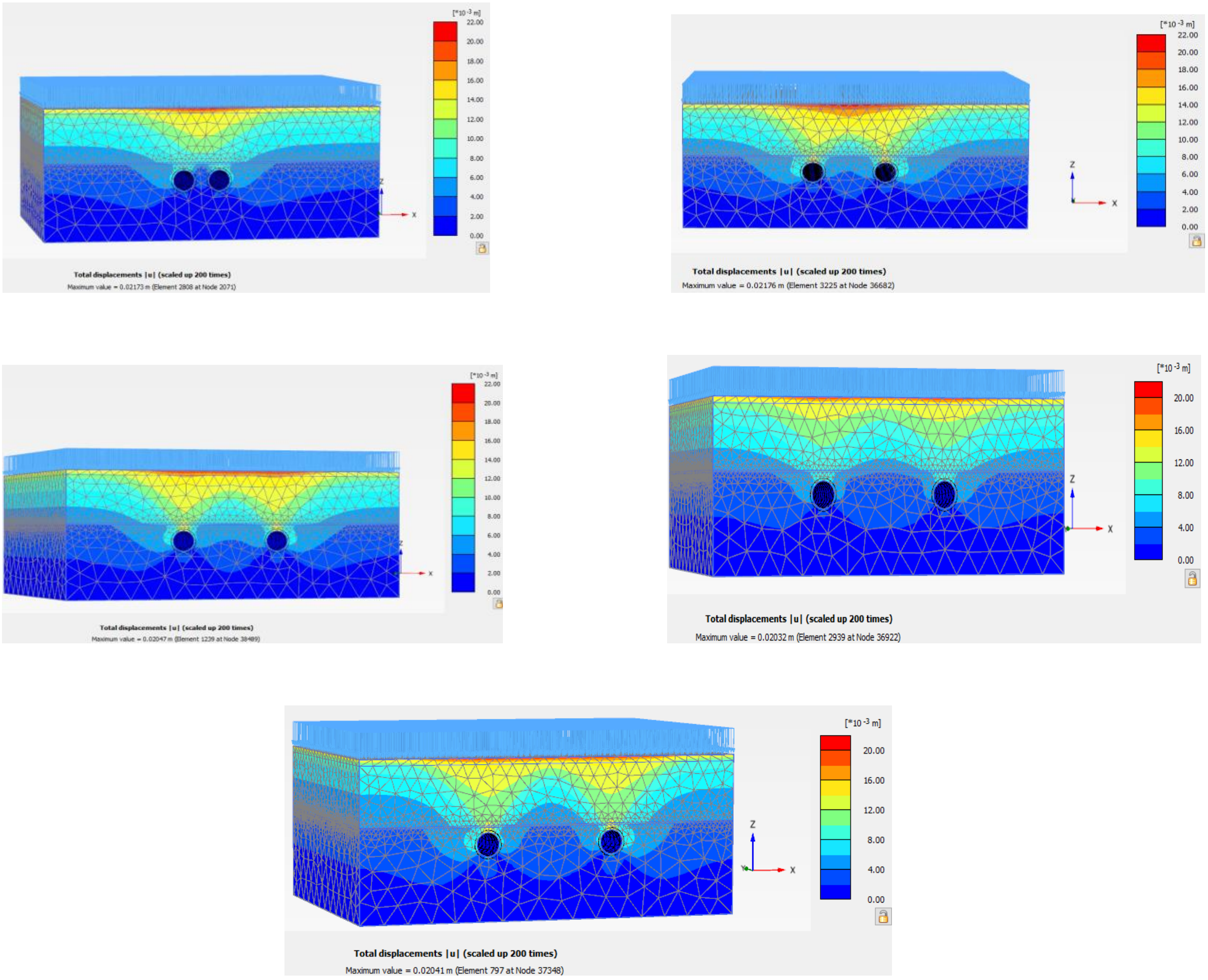

Fig. 6. Maximum vertical displacements in soil at crown of tunnel for (S = (1.5, 2.5, 3.5, 4.5, 5.50)) D, lining thickness (t= 0.025D)) for parallel twin tunnels.

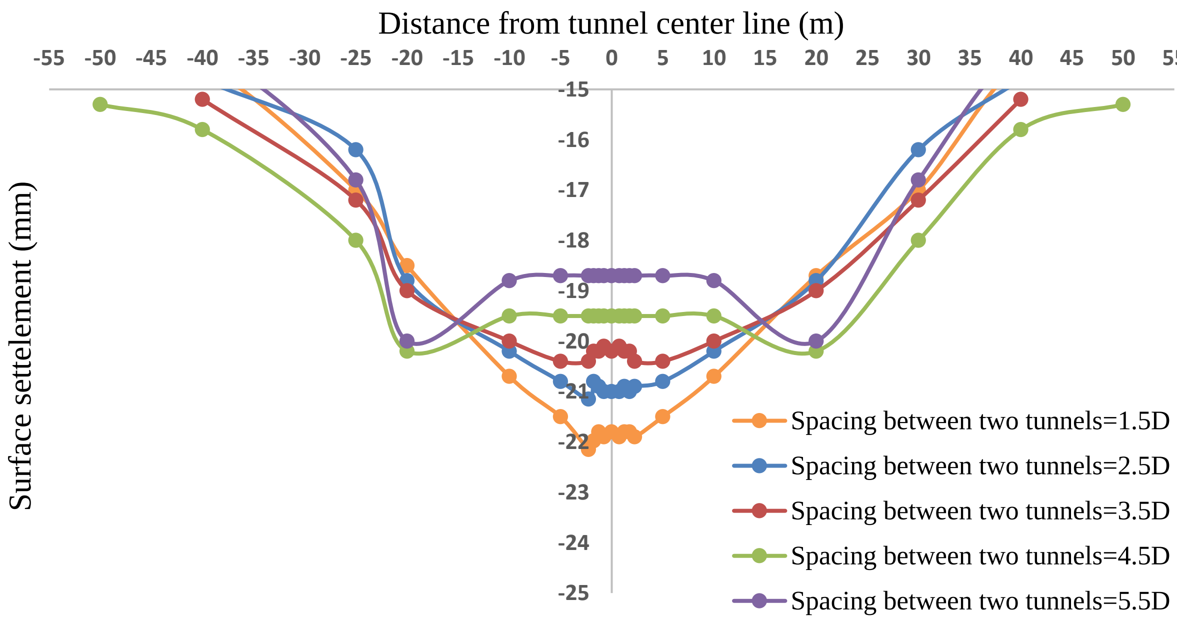

Fig.7. Relationship between Surface settlement and distance from tunnel center line with lining thickness (t) =0.025D.

From the figure it can show that:
Maximum surface settlement at spacing 1.5D&3.5D the maximum moved to the middle point between the two tunnels. with increasing spacing from 4.5D to 5.5D, was observed to be at the center of each tunnel. Increasing spacing from (1.5 to 5.5) D, the maximum surface settlement decreasing by 11%.

4.3 Lining Thickness of Tunnel:

Effect of lining thickness of tunnel on lateral deformation of tunnel and maximum vertical displacement on soil at crown of tunnel.as shown in **figs.8 to 11.** The elastic parameters of the concrete lining of tunnel were lasted in **Table 3.**

Table 3. The parameters of lining thickness of tunnel.

Parameters	Tunnel
Tunnel diameter (D) (m)	6.0
Lining thickness of tunnels (t) (m)	(0.025D, 0.045D, 0.065D, 0.085D & 0.105D)
Young's modulus (E) kN/m^2	31.30*10^6
Poisson's ratio (ν)	0.20
Ultimate unite wight (γ) kN/m^2	25

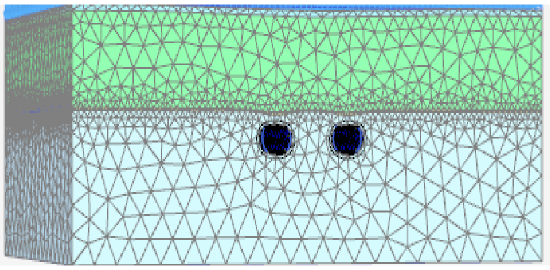

Fig.8. Deformed mesh for spacing between two tunnels =2.5D with lining thickness=0.045D.

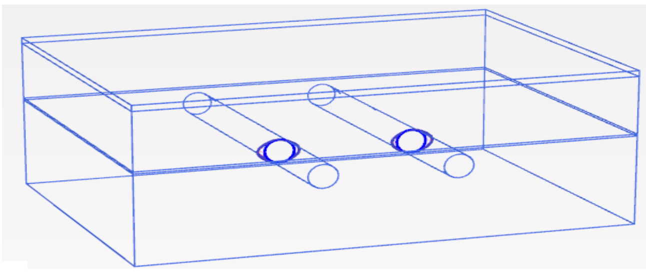

Fig.9. lateral deformation of tunnel at spacing between two tunnels 4.5D with lining thickness of tunnel=0.085D.

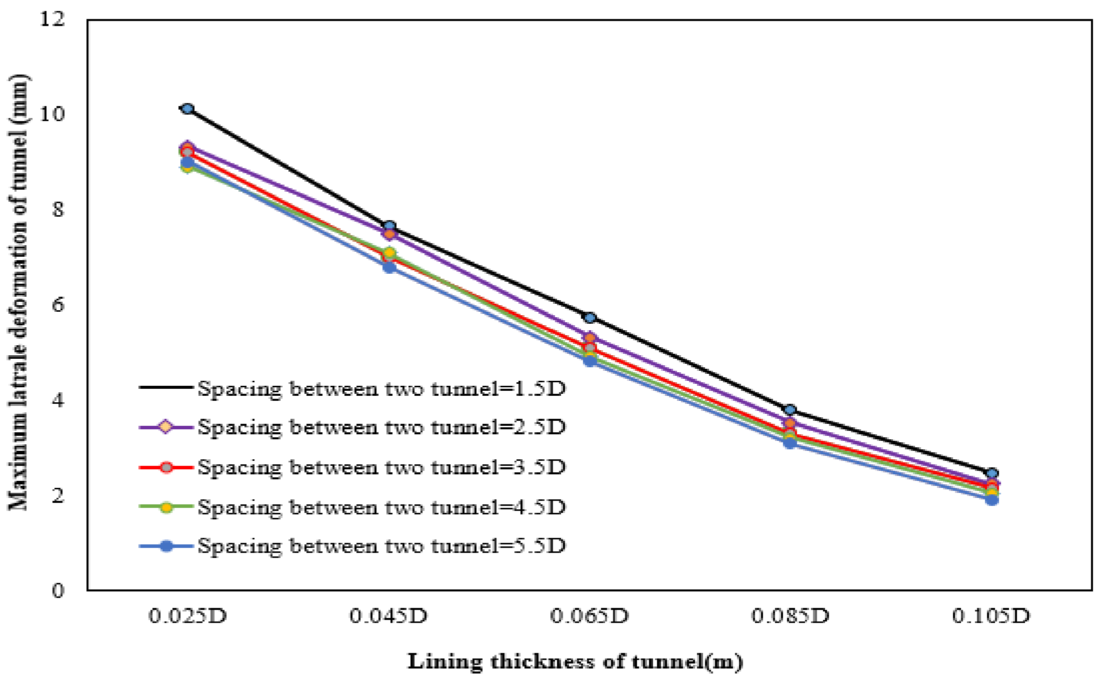

Fig.10. Relation between lining thickness and maximum lateral deformation of tunnel with spacing between adjacent two tunnels.

From **fig.10.** it can be observed that, with increasing of lining thickness the lateral deformation of tunnel decreases in semi linear relationship. Increasing lining thickness from (0.025D) to (0.105D) leads to reduction in lateral displacement by 75.3% for tunnel spacing (1.5D) to (5.5D).

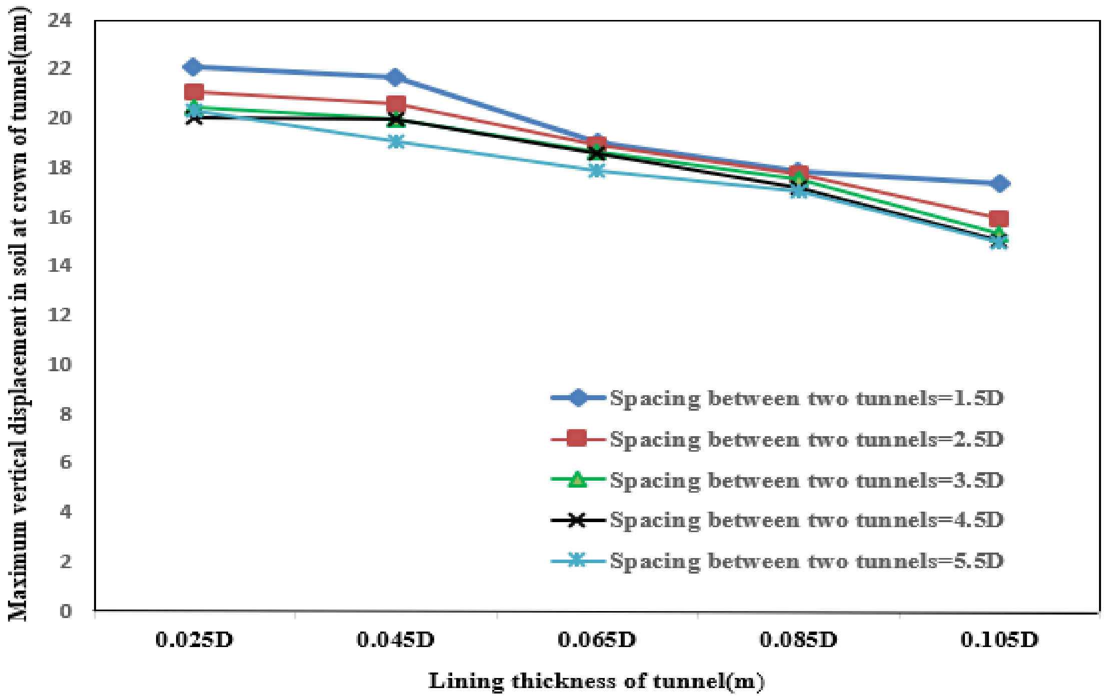

Fig. 11. Relationship between maximum vertical displacements in soil at crown of tunnel and lining thickness of tunnel with spacing between two tunnels.

From **fig.11.** it was found that: with increase in lining thickness from (0.025D) to (0.105D) the maximum displacement in soil at crown of tunnel decreased by 23% for tunnel spacing (1.5D - 5.5D).

4.4. Effect of tunnel spacing:

Effect of spacing between two circular tunnels on maximum lateral deformation and stresses in soil with different lining thickness are shown in **figs.12.** to **15**.

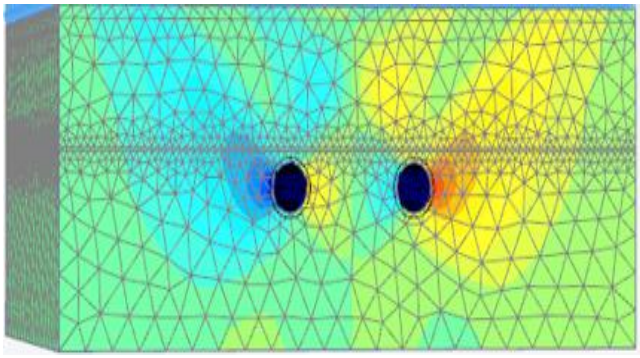

Fig.12. Maximum lateral deformation of tunnel at spacing 3.5D with lining thickness of tunnel=0.105D.

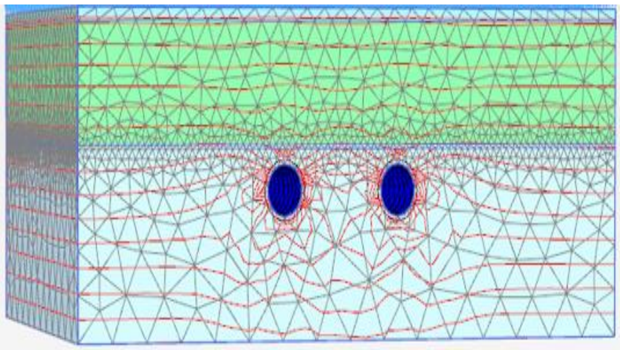

Fig.13. Total stresses in soil for spacing 2.5Dwith lining thickness of tunnl=0.045D

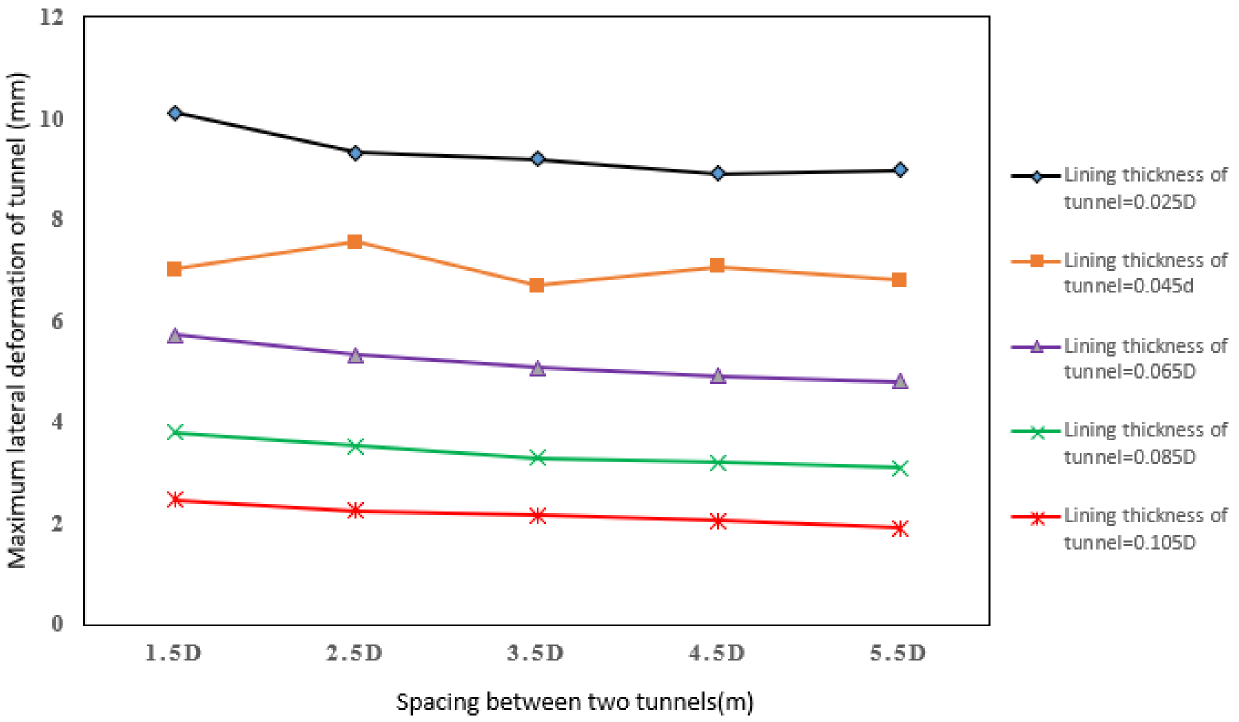

Fig.14. Effect of tunnel spacing and lining thickness on induced maximum lateral tunnel deformation.

From **fig.14.** it was found that the tunnel spacing has less significant effect on the lateral displacement compared with tunnel lining thickness.

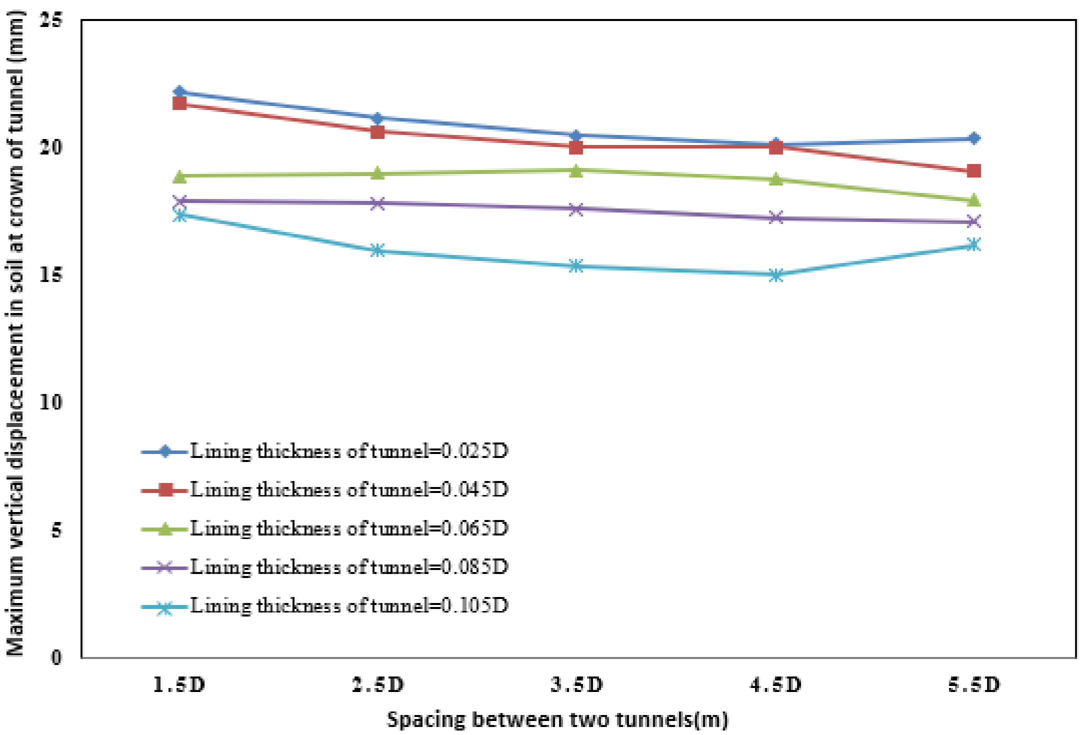

Fig.15. Effect of tunnel spacing and lining thickness on induced maximum vertical tunnel deformation.

From this figure it was found that: increasing spacing from (1.5D – 5.5D) had reduced the maximum vertical displacement in soil at crown of tunnel by 24.36% for tunnel lining thickness (0.25D – 0.105D).

4.4.1 Maximum Stress in Soil Between the Two Tunnels:

The effect of tunnel spacing and lining thickness (t) on the maximum stresses in soil. is presented in **Fig.16.**

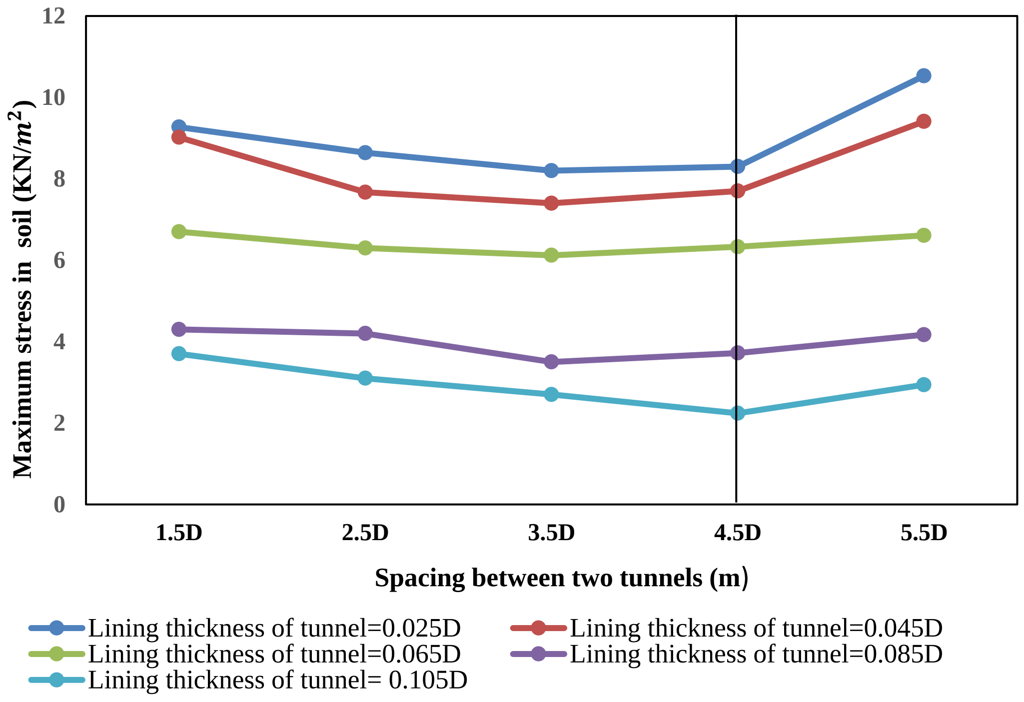

Fig.16. Effect of tunnel spacing and lining thickness on induced maximum stresses in soil.

From figure (16) it was found that, maximum stress in soil decreased by 67% with increasing spacing between twin tunnels up to 4.5D, after which the stress around tunnel increased, as each tunnel behaved as a single tunnel.

SUMARY AND CONCLUSION:

In the present study a numerical parametric study was carried out on modified verified model based on case study. Soil profile at a site from metro line No. 4. in Egypt was selected to investigate the effect of tunnel lining and spacing on the induced surface settlement, lateral tunnel displacement and soil stresses surrounding two adjacent circular tunnels. From this study, the following conclusions were drawn:

1. Maximum surface settlement at spacing 1.5D to 3.5D was observed to be located above the center of each tunnel, with increase of the tunnel spacing the maximum settlement moved to be at the middle point between the two tunnels. Increasing spacing from (1.5 to 5.5) D, had decreased the maximum surface settlement by 11%.
2. With increasing of lining thickness, the lateral deformation of tunnel decreases in semi linear relationship. Increasing lining thickness from (0.025D - 0.105D) had reduced the lateral displacement by about 75.3% for tunnel spacing (1.5D - 5.5D).
3. Increasing lining thickness from (0.025D - 0.105D) the redaction in maximum displacement in soil at crown of tunnel was by about 23% for tunnel spacing (1.5D - 5.5D).
4. The tunnel spacing has less effect on the lateral displacement compared with tunnel lining thickness.
5. Increasing spacing from (1.5D – 5.5D) decreased the maximum vertical displacement in

soil at crown of tunnel by 24.36% for tunnel lining thickness (0.25D – 0.105D).

6. Maximum stress in soil decreased by 67% with increasing distance between the twin tunnels up to 4.5D, after which the stress around tunnel increased again, as each tunnel behaved as a single tunnel.

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