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Influence of Relative Position of the Tunnels: A Numerical Study on Twin Tunnels

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INFLUNCE OF RELATIVE POSITION OF THE TUNNELS A NUMERICAL STUDY ON TWIN TUNNELS

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ABSTRACT

The development of cities requires the use of underground area for the construction of transportation infrastructure facilities. Construction of twin tunnels or new tunnel close to the existing ones may be done horizontally, vertically or in inclined manner. In the case of horizontal tunnels the distribution of tunnel load will be more in lateral direction. Since cities are densely concentrated with tall structures, laterally distributed loads will induce settlement in the foundation of the structures. For a particular orientation of tunnels, the soil movement and internal forces in the lining will be affected by both the relative position of tunnels and the construction procedure. Hence the study on influence of these factors on the tunnel design gains importance.

In the present study a numerical analysis has been carried out to evaluate the relative position of the twin tunnels in three directions in layered soil. The direction considered are horizontal alignment, vertical alignment and inclined alignment. Model twin tunnels have been constructed using numerical code Plaxis based on finite element analysis. Settlement analysis has been carried out for the different loading conditions on the tunnels in the selected directions. The results are presented in the form of surface settlement, bending moment and stresses in the lining of the tunnels for different orientation of tunnels. The construction of upper tunnel at first leads to both higher settlement and bending moment. The highest soil settlement is obtained for vertical aligned tunnels, while horizontal aligned tunnels cause the lowest settlement.

INTRODUCTION

The demand for construction of eco-friendly Heavy Rail Mass Transit System is increasing due to limitation of space for surface transport in the urban areas. The construction of metro system in highly congested areas demands strict ground control measures to be adopted during the construction unlike tunneling in green-fields, for the purpose of protection of existing services, buildings, monuments, transport systems, viz. Railways and airports, where surface settlements are required to be restricted within few millimeters.

Generally, constructions of the Metros are carried out by shallow tunneling that comprises of either bored or cut and cover tunnels. Simulation of ground structure interaction for cut and cover construction is simpler as primary support system is commissioned well in advance before excavation unlike the bored tunnels where primary support system commissioning follows the excavation. In case of bored tunnels, the magnitude of the secondary stress developed after the excavation is governed by variety of factors such as size of tunnel, in-situ stress field and properties of continuum (physical, elastic and strength). The several approaches for the analysis of induced stress and displacements around tunnels are available in the literature. The application and the feasibility of appropriate analysis can be judged by keeping in view the method of construction and material behavior under different stress state.

At present, the standard practices is predict the ground surface settlement for urban tunneling, which has been constructed by using EPBM, Slurry shield and TBM, based on peck's (1969) recommendations. These recommendations are based on extensive field data from urban tunneling carried out by

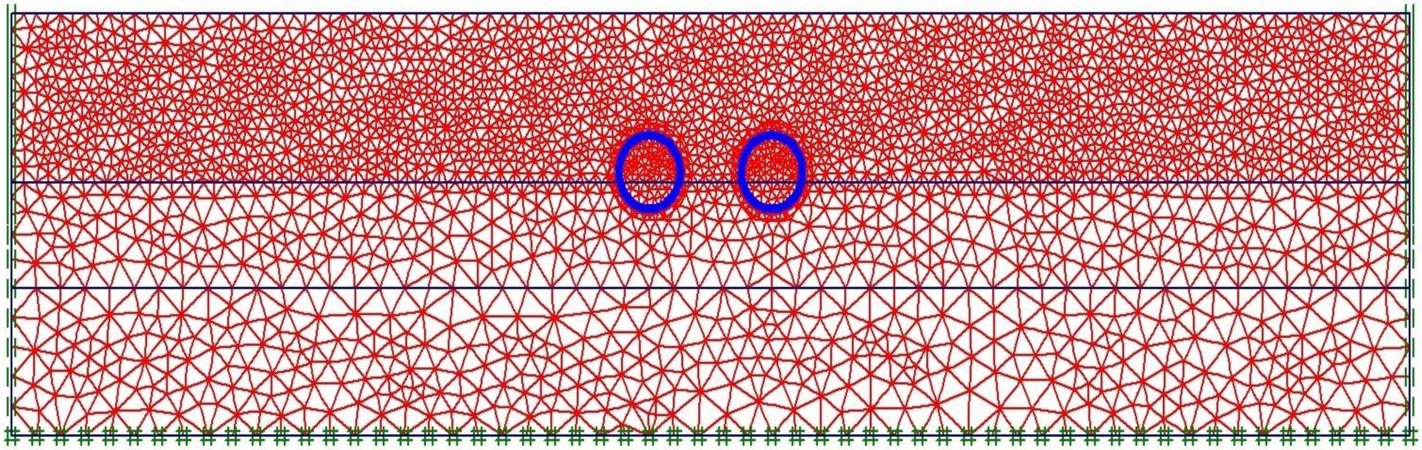

Fig. 1. *Mesh used in the analysis of tunnels with horizontal alignment*

EPBM. The prediction by this method is basically made on the basis of face loss. But the prediction of settlement due to peck (1969) does not explicitly reflect the contribution of geological medium with respect to strength and deformational behavior and is not able to distinguish for the medium having different satisfaction thickness above and below the tunnel axis. The over-Excavation due to improper operation of machine and insufficient grouting is represented in terms of percentage of the theoretical excavation required and is termed as face loss. Tunneling generally termed as good, poor and bad with respect to face loss occurred during tunneling (Bickel et al., 1977).

Greenwood.J.D (2001) conducted three dimensional analysis of surface settlement in soft ground tunneling. Wang et al in (2003) carried out the analysis for twin tunnel induced ground settlement; they studied the interaction of twin tunnels through both numerical analysis and superposition of analytical solutions. Hage Chehade et. al (2008) studied the numerical analysis of the interaction between twin-tunnels. They presented successively the numerical model for homogeneous and analyzed for three configurations of the twin-tunnels: aligned-horizontally, vertically and inclined.

In highly developed urban environments, tunneling-induced soil movements such as ground settlements and lateral movements are important to the safety of existing structures around (Boon 2009).

TUNNEL MODELLING

Analyses are conducted using the finite element method. The Young's modulus of the soil E is supposed to increase with depth and it can be calculated by using following expression:

$$E(z) = E_0 (P_m/P_0)^{0.5} \tag{1}$$

Where P_m denotes the mean stress at the depth z; E0 is constitutive parameter, which corresponds to the Young's Modulus at the mean pressure $P_m = P_0$. This expression takes into account the variation of the Young's modulus with the mean pressure, which increases with depth due to the soil self-weight. The behaviour of the lining is assumed to be linear-elastic. In a twin-tunnel modelling, the tunnels are constructed using finite element method and the procedure is as follows:-

(i) Construction of the first tunnel using the convergence-confinement method with a stress release factor $\beta = 0.5$. This factor corresponds to the ratio of the stress release before the lining installation.

(ii) Construction of the second tunnel using also the convergence - confinement method, as for the first tunnel with a stress release factor b = 0.5. This factor is applied to the stresses exercised around the tunnel after the excavation of the first tunnel.

Finite element analyses were conducted using the finite element program PLAXIS. Fig. 1 shows the mesh used for the analysis of horizontally aligned tunnel with a ratio spacing Sx/D = 2(D, Sx denote the tunnel diameter and the distance between tunnel axes, respectively). It contains 6068 triangular 15-nodes elements. The soil contains three distinct layers, for the the analysis propose we considered the soil thickness as 8D (Depth H = 8D). The lateral extension of the soil mass is equal to 20D. This extension ensures the absence of lateral boundary effect on the numerical modeling of the tunnel construction.

Concerning the boundary conditions, the displacements are constrained in both directions at the bottom, while zero horizontal displacement is imposed at lateral boundaries (Fig. 1).

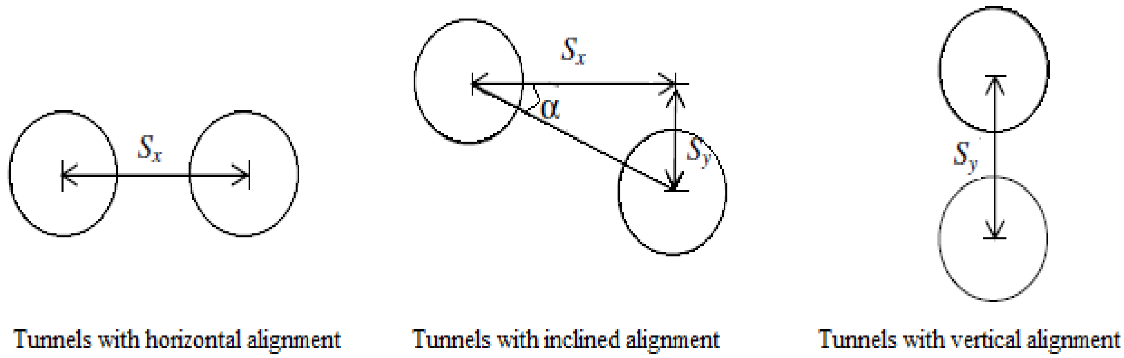

Fig. 2. *Tunnel alignment and there relative position of tunnels*

In this paper the analysis were made between two newly constructed tunnels with three different alignments. That is,

- ✓ **Tunnels with horizontal alignment,**
- ✓ **Tunnels with vertical alignment, and**
- ✓ **Tunnels with inclined alignment.**

The orientation of these three alignments for two newly constructed tunnels is shown in Fig (2).

Tunnels are constructed often for transportation by metro rail. BMRCL projects also undertake such projects. These are constructed at close spacing and at shallow depth. Hence it becomes necessary to find the probable settlement that may arise because of tunneling. Suitable measures need to be adopted if the predicted settlement exceeds the permissible limits.

In the present analysis the location chosen is near Central College at K.R. Circle junction opposite to mechanical department (Bangalore, Karnataka). As shown in Fig (3).

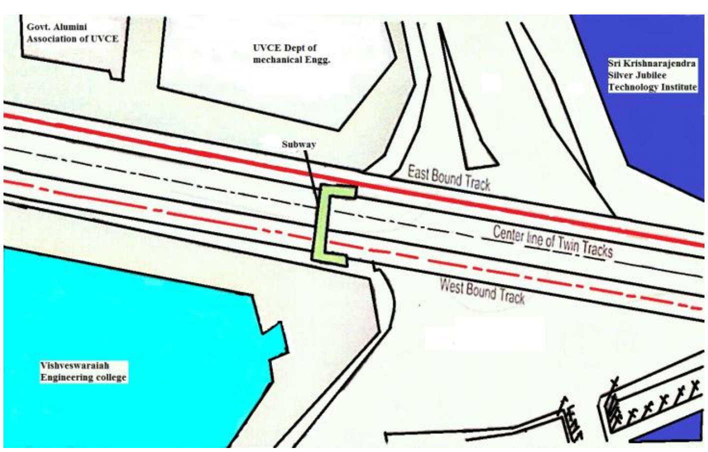

Fig. 3. *Plan of K.R. Circle Junction*

Tunnel is excavated by slurry shield TBM machines. It is proposed that the tunneling is consists of twin bore tunnels that will become eastbound tunnel (EBT) i.e., tunnel-1 and westbound tunnel (WBT) i.e., tunnel-2 respectively; for the analysis purpose, a 6.45m excavated diameter has been assumed for all bored tunnel elements

The mechanical Engineering building is located on the proposed eastbound tunnel. At this location tunnel axis depth is approximately 14.2m below the ground level. The water table is at 5m below the ground level.

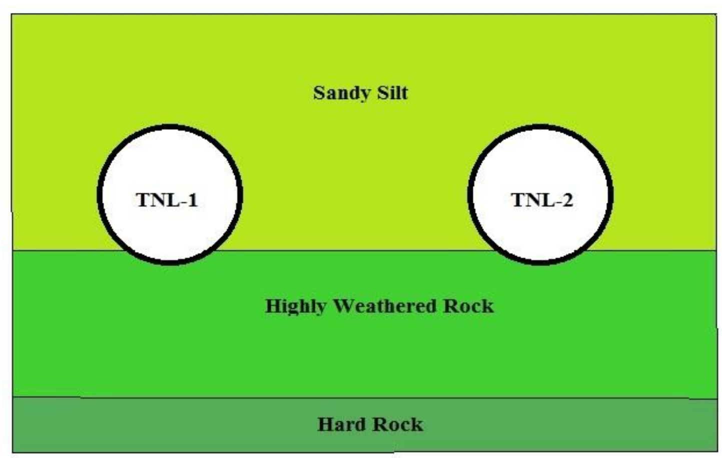

Fig. 4. *Shows the soil profile with the tunnel alignment*

The construction of new underground structure may cause damage to the adjacent building. Based on studied geological condition of the region including shallow water table (5m), low cohesion medium density materials, it is of great importance to study the probable settlements. The acceptable/Design settlement range is about 25mm and

Settlements exceeding this limit may leads to aesthetic (Superficial damage to the structures without structural consequences) and structural damages. (Damage to structures

Table 1 and Table 2 summarises the characteristics of the soil and the lining used for the analysis. The thickness of the lining is equal to 0.5 m.

Table.1 Material specifications used for soil layers of the model

Parameter	Sandy Silt	Highly weathered Rock	Hard Rock	Unit
Thickness of layer	16	10	4	M
Dry unit	15.6	19	25	(kN/m^3)
Saturated unit weight	16.9	19	25	(kN/m^3)
Young's modulus	10000+ 3000*Z	100000 (Constant)	900000 (Constant)	(kPa)
Poisson's ratio	0.3	0.3	0.3	-
Cohesion	3	0.1	0.1	(kPa)
Angle of internal friction	25	30	40	○
Permeability	$8.64*10^{-3}$	$3.456*10^{-2}$	$8.64*10^{-8}$	m/day

Where Z is depth measured from the ground level in meters (From equation 1)

Table.2 Material Properties of the precast concert segments lining.

Parameter	Name/Symbol	Value	Unit
Type of behaviour	Material type	Elastic	-
Normal Stiffness	EA	$9.898*10^6$	kN/m
Flexural rigidity	EI	$6.470*10^4$	kNm^2/m
Weight	W	4.34	kN/m/m
Poisson's ratio	V	0.2	-

and pipes). The left tunnel wil be represented as West Bond Tunnel (WBT) and the right one as East Bond Tunnel (EBT).

RESULTS OF ANALYSIS

Analysis is done in three main headings.

I. Tunnel with horizontal alignment.

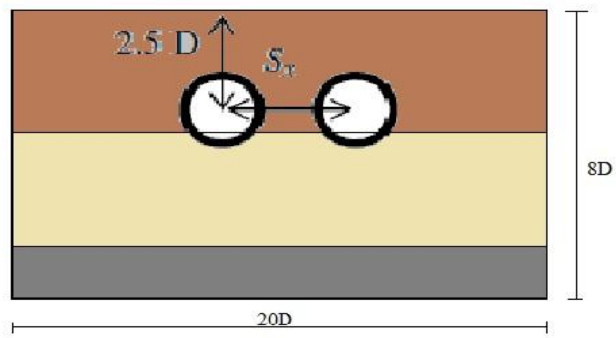

Fig.5. *Geometric configuration*

Analyses were conducted for six values of the tunnel spacing ration Sx/D (2, 3, 3.5, 4, 4.5 and 5). It shows that both the settlement pattern and amplitude depend on the distance between tunnels. The maximum soil settlement is observed for the configuration with close tunnel (Sx/D = 2).

In this case, the maximum soil settlement is induced between the two tunnels, it attains about 43 mm. The increase in the distance between tunnels induces a decrease in the settlement in the central part of the twin tunnels and leads to a stabilization in the settlement above each tunnel. Beyond the distance (Sx = 3.5D), the construction of the first tunnel does not affect the second one.
Individual settlement pattern for the six tunnel spacing ratio

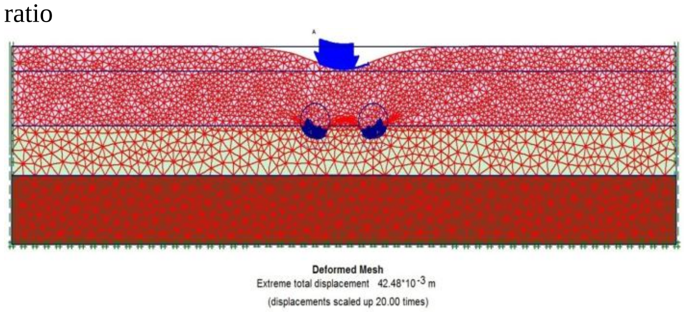

Fig 6. *Settlement pattern for 2D spacing (Horizontally aligned tunnel)*

In the case of horizontally aligned tunnels, the tunnels with minimum spacing have got maximum settlement. This is because, when the spacing between tunnels is less more overlapping of stress occurs and hence more settlement is

Observed at the surface. The maximum soil settlement observed at the surface induced between the two tunnels is attained 43mm. As the distance between the tunnels increases, overlapping of stress will get reduces, therefore interaction of two tunnels will be less. And hence soil settlement in the central part of two tunnels will get reduces. Beyond the spacing S_x = 3.5D, the construction of first tunnel does not have any influence on the second tunnel. Surface soil Settlement observed there after gives the vales less than 10mm, which is much lesser than the maximum allowable settlement for the tunnels.

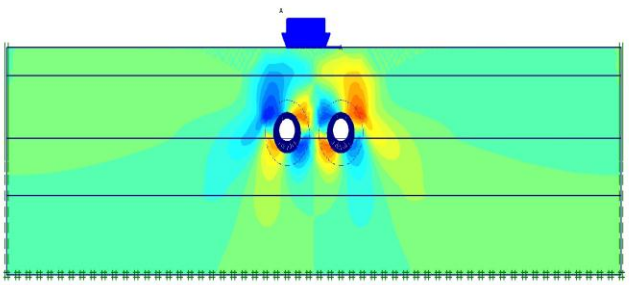

Fig 6. *Effective stress distribution for 2D spacing (Horizontally aligned tunnel)*

Also it is observed that both tunnel spacing and construction procedure does not have any influence on the internal forces in the tunnel.

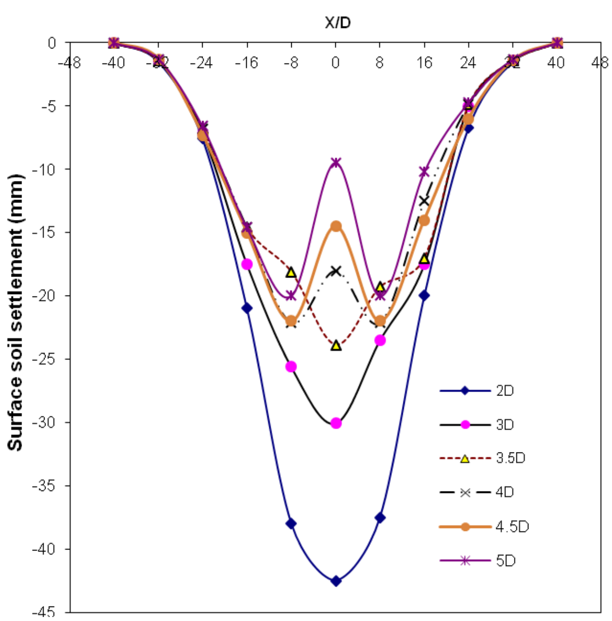

Fig. 7. *Comparison of surface soil settlement for various tunnels spacing ratio (Horizontally aligned tunnel)*

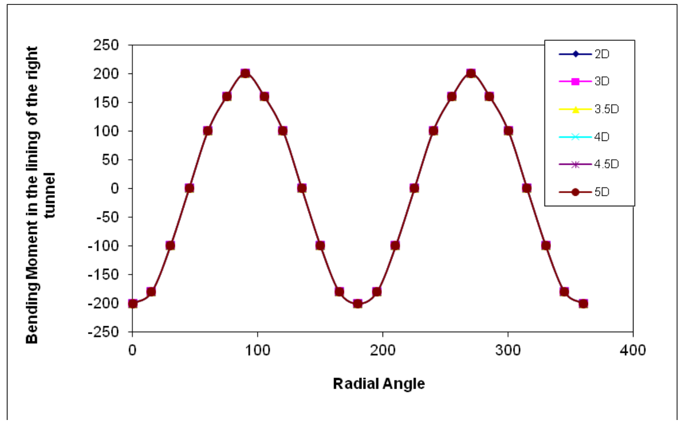

Fig. 8. *Bending moment in the tunnel lining (Horizontally aligned tunnel)*

From the above graph it is observed that bending moment curve which is drawn for the various tunnels spacing for a horizontal aligned tunnels is almost following the same path. Hence, from this graph we can conclude that the both the tunnels spacing and construction do not affect the internal forces in the tunnel.

II. Tunnels with vertical alignment

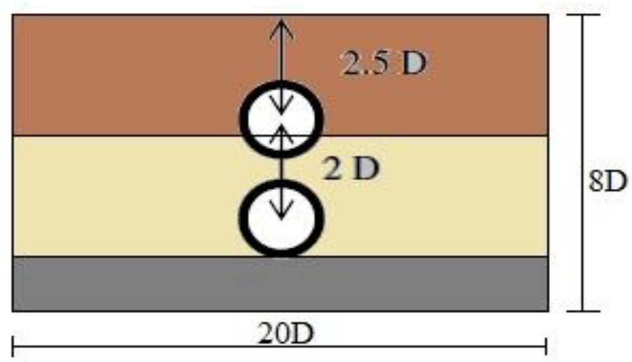

Fig.9. *Geometric configuration*

Analyses were conducted for four values of the tunnel spacing ration Sx/D (1, 1.5,2 and 2.5). The geometric configuration for vertical aligned tunnels is as shown in Fig (9). The upper tunnel canter is located at 2.5D below the soil surface and the distance between the tunnel axes is varied from 1D, 1.5D, 2D and 2.5D. In the analysis of vertical tunnels, the construction procedure is varied. And two analyses were made for a particular spacing of two vertical tunnels. In the first case, upper tunnel is constructed at first and that case is called as *reference case,* while in the second analysis lower tunnel is constructed at first and that case is called *inverted case.*

Analysis were done for two cases for particular spacing and it as observed that construction of upper tunnel at first leads to higher soil settlement than the constructing lower tunnel at first. The surface soil settlement in the reference case is about 15.5% higher than inverted case Fig (12) while the bending moment in the first case is about 23% higher than that induced in the second case. And it is showed in the Fig (13).

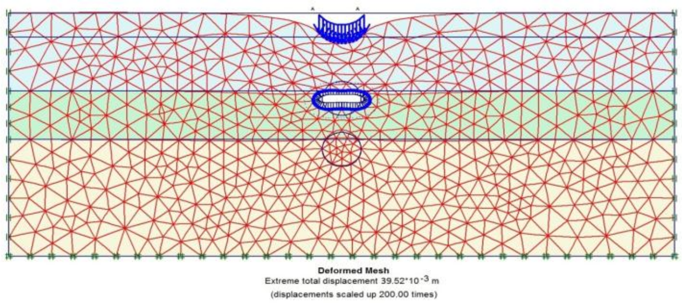

Fig. 10. *Settlement pattern observed when upper tunnel constructed first for the tunnel spacing 1D (Vertical Aligned Tunnels)*

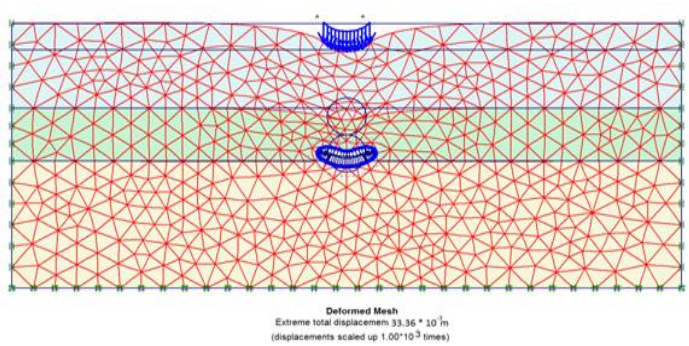

Fig. 11. *Settlement pattern observed when Lower tunnel constructed first for the tunnel spacing 1D (Vertical Aligned Tunnels)*

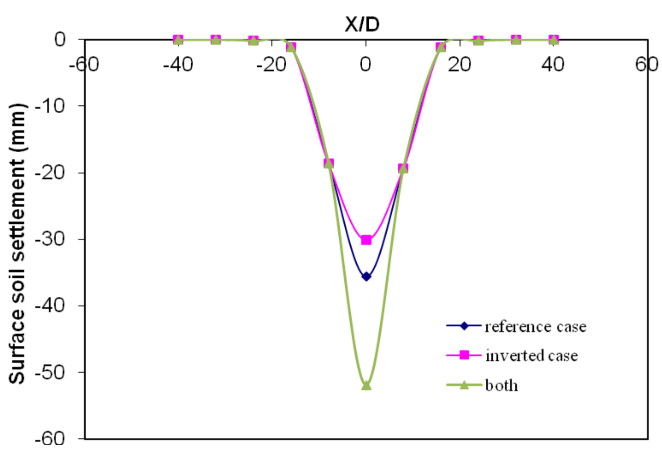

Fig. 12. *Comparison of surface soil settlement for varied construction procedure for the tunnel spacing 1D (Vertical Aligned Tunnels)*

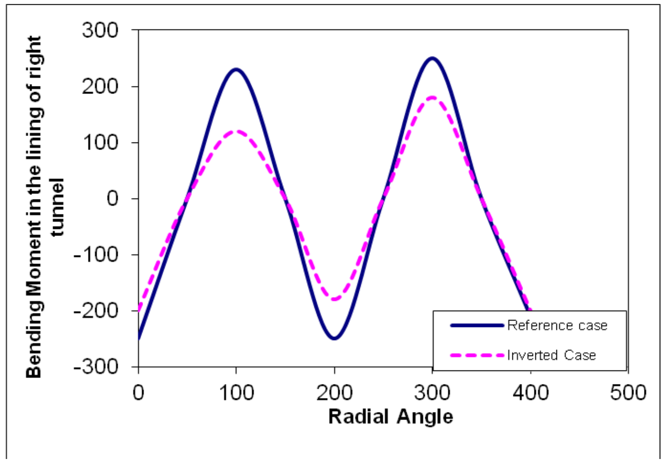

Fig.13. *Bending moment in the tunnel lining (Vertical Aligned Tunnels)*

III. Tunnels with inclined alignment.

Two configurations were analyzed. One such configuration is as shown in Fig 14. The vertical distance between the tunnel axes is equal to Sy = 2D. In the first configuration, the 5); in the horizontal distance between the tunnel axes is equal to Sx = 2D (α = 4 second configuration Sx = 2.5D (α = 39). Figs. 17 show the influence of both the tunnel configuration and construction procedure on the soil settlement and internal forces in the upper tunnel. It can be observed that the construction of the lower tunnel at first (inverted case) leads to higher soil settlement than that induced when the upper tunnel is first constructed Fig. 18. This result is similar to that obtained with vertical aligned tunnels. The bending moment in the upper tunnel are moderately affected by the order of construction of the tunnels.

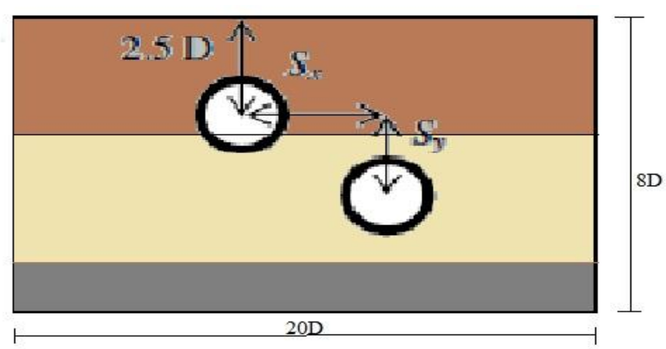

Fig.14. *Geometric configuration*

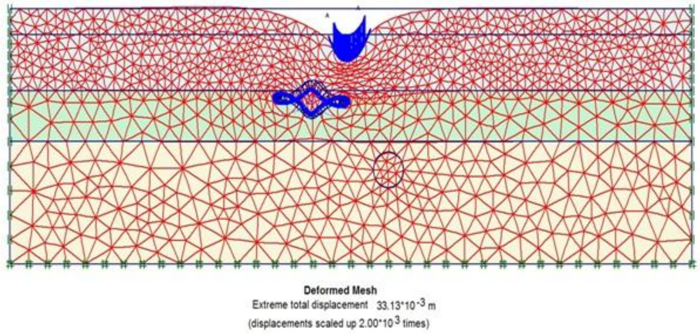

Fig.15. Settlement *pattern observed when upper tunnel constructed first for the tunnel angle α = 39⁰ (Inclined Aligned Tunnels)*

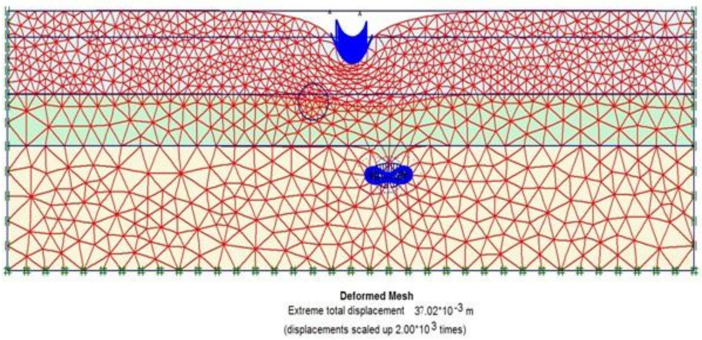

Fig.16. *Settlement pattern observed when Lower tunnel constructed first for the tunnel angle α = 39⁰ (Inclined Aligned Tunnels)*

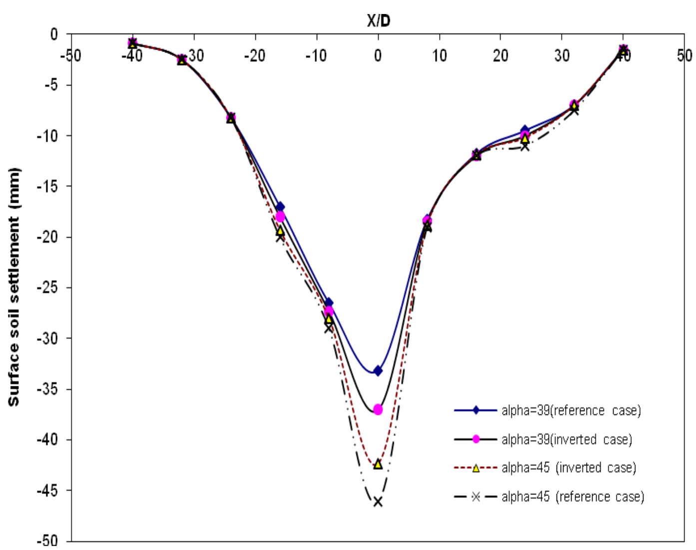

Fig.17. *Comparison of surface soil settlement for varied construction procedure (Inclined Aligned Tunnels)*

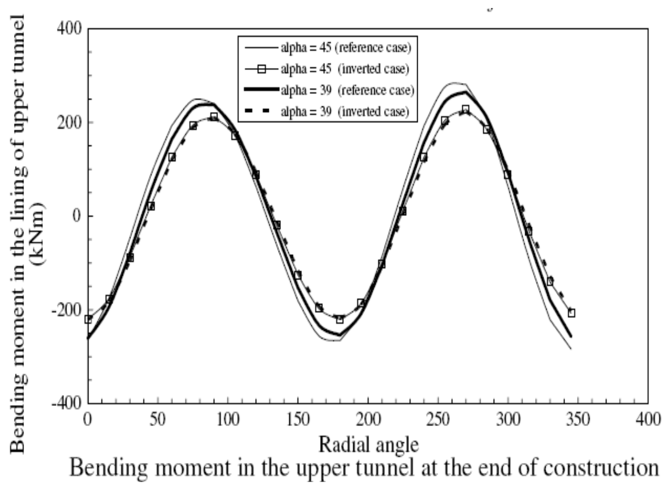

Fig.18. *Bending moment in the tunnel*

From the analyses it is observed that construction of lower tunnel at first (i.e., Inverted case) leads to the higher soil settlement than that induced when the upper tunnel is first constructed (i.e., reference case) and it as shown in Fig (10). From the results of these analyses, it can be observed that there is a considerable influence of both the tunnel configuration and construction procedure on the surface soil settlement and the internal forces in the tunnels. Bending moment in the tunnel is moderately affected by the order of construction of the tunnels Fig (11). Also it is observed that, as the angle between the tunnels Increases with respect to horizontal axis, the surface soil settlement will also get increases.

CONCLUSION

In this paper it is mainly concentrated on the interaction of two tunnels with a particular focus on the Geometric configuration and construction procedure on the surface soil settlement and internal forces due to tunnel construction by numerical method.

In the case of horizontal tunnel analyses (i.e., Stage. 1 analyses) it is observed that as the distance between the two tunnels increases, the surface soil settlement will get reduces. Beyond the distance (s_x = 4D) the construction of first tunnel does not affect the second tunnel.

In the case of vertical tunnel analyses (i.e., Stage. 2 analyses), construction of upper tunnel at first (reference case) leads to the higher soil settlement than the construction of lower tunnel at first (inverted case).

The surface soil settlement in the reference case is about 15.5% more than that induced in the inverted case. While the bending moment in the first case is about 23% higher than that induced in the second case.

The highest soil settlement is obtained for vertical aligned tunnels, while horizontal aligned tunnels cause the lowest settlement, but with a larger lateral extension of the settlement.

In the case of inclined tunnel analyses (i.e., Stage.3 analyses), it is observed that construction of lower tunnel at first leads to higher soil settlement that that induced when the upper tunnel is first constructed.

Also it is observed that as the angle between the tunnel increases with respect to horizontal axis, the surface soil settlement will get increases. And bending moment is moderately affected by the order of construction of the tunnels.

REFERENCES

1. Jedediah Greenwood. “3D analysis of surface settlement in soft ground tunnelling,” Ph.D. Thesis, University of Minnesota, 2001.

2. F. Hage Chehade, I. Shahrour (2008). Numerical analysis of the interaction between twin-tunnels: Influence of the relative position and construction procedure. Tunnelling and Underground Space Technology 23 (2008) 210–214.

3. Wang J.G., Kong S.L and Leung C.F., “Twin tunnel induced ground settlement in soft soils,” In Proceedings of the SINO-JAPANESE symposium on geotechnical engineering, Beijing, China, 2003, pp. 29-30

4. Shahrour, I., Moue, H., 1997. Three-dimensional non linear analysis of a closely twin tunnels. In: Sixth International Symposium on Numerical Models in Aeromechanics (NUMOG VI), vol. 2. Montreal, Quebec, Canada, pp. 481–487.

5. Soliman, E., Duddeck, H., Ahrens, H., 1993. Two and three-dimensional analysis of closely spaced double-tube tunnels. Tunnelling Underground Space Technol. 8 (1), 13–18.

6. Yamaguchi, I., Yamazaki, I., Kiribati, K., 1998. Study of ground-tunnel interactions of four shield tunnels driven in close proximity, in relation to design and constructions of parallel shield tunnels. Tunnelling Underground Space Technol. 13 (3), 289–304.