International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:8, No:1, 2014

Construction Procedures Evaluation of Three Adjacent Tunnels and Excavation Step Effects

M. Mahdi, N. Shariatmadari

***Abstract*—**Since, both the relative position of tunnels and the construction procedure affect the soil movement and internal forces in the lining, it is of major concern to study the influence of these factors on the tunnel design. Construction procedures of tunnels have considerable effects on the magnitude of surface movements and lining stresses. This paper describes numerical analysis of construction procedure of a three adjacent shallow tunnels at high groundwater levels using the commercial finite difference software (FLAC-3D). The aim of this study is to determinate the most suitable construction procedure for the three tunnels and the optimum excavation step in Tehran Metro tunnels in order to optimize the surface settlements and lining stresses.

***Keywords*—**Shallow tunnel, multiple tunnels, construction procedure, surface movement, numerical modeling.

I. Introduction

The need for tunnel design and construction in urban areas, mainly for transportation purposes, has increased markedly in recent years, especially in Tehran city. New tunnels are often required in close proximity to the existing ones and construction must be carried out without damage either to the buildings above the excavation field or to the subsurface infrastructures. During the design stages it is therefore necessary to predict possible interaction effects.

Due to the high interaction between tunneling and existing structures in urban areas, tunneling operations in urban areas draws much attention. This paper describes a thorough analysis of the tunneling influence in soft soils on surface settlements. A combination of in situ observations and numerical modeling was previously adopted to analyze such problem.

The surface settlements, S above a single tunnel constructed in soft ground are usually assumed to follow an inverted Gaussian curve, i.e.

$$S = S_{\max} \exp(-y^2 / 2i^2) \quad (1)$$

where S_{max} is the maximum settlement (over the tunnel axis), y is the vertical distance from the tunnel axis and i is the width of the settlement trough [1].

The source of these settlements is the “volume loss” which occurs at the tunnel. It is defined as the additional volume of soil which is excavated over the volume required to house the final lining. As excavation proceeds, the soil ahead of the face is unloaded so it tends to move inwards. Losses also occur behind the face due to the nature of the shield in which the excavation is being carried out.

Many field studies have confirmed (1) to be acceptable for green field sites [2]-[5] while, for structures in urban situations, (1) is no longer valid.

For multiple tunnels, settlements from each are calculated according to (1) and then added up to give the resultant. This however ignores the interaction between tunnels during their construction. It is clear that the disturbance associated with tunnel construction will change the properties of the surrounding soil, and hence alters the effect of a subsequent tunneling operation through that zone of soil.

Consider a multiple tunneling scheme of two parallel tunnels. Due to construction of the second tunnel, the first tunnel and the surrounding soil may move as a rigid body. The redistribution of stress results in an effect which is known as “arching” around the second tunnel. Arching has a consequence of tunnel load removal, in other words, a reduction in earth pressure [6]-[8]. Furthermore, if the second tunnel is in the close proximity of the first one there will be lining distortion and displacements towards the first tunnel. The minimum distance between the tunnels, so as to avoid the interaction effects, clearly varies according to the position and the soil properties.

Recently, researchers have used both physical and numerical models to study tunnel interaction. Reference [9] performs a series of two dimensional finite element (FE) analyses of multiple tunnels using a linear elastic soil model. It reports that interaction effects are small at a pillar width (i.e. the clear space between the outside of two tunnels) of one tunnel diameter (1D). However, at a pillar width greater than 2D there was no apparent interaction. Hence, the tunnels of this case could be considered independent and the settlements would be calculated accordingly. It also find that the surface settlements stemmed from the excavation of the second tunnel are higher than those resulted by the first.

Reduced-scale physical model testing of parallel tunnels is performed in [10]. For pillar widths greater than 1.5D the interaction effects were found to be small. Two-dimensional FE analysis of multiple tunnels using a non-linear elastic-perfectly plastic soil model is performed in [11]. In this paper it is concluded that in side-by-side tunnels, just for a pillar width greater than 7D interaction effects became negligible. On the other hand, for the “piggy-back” situation (where the tunnels axes are vertically aligned) the pillar width at which

M. Mahdi is with the Department of Civil Engineering, University of Tabriz, Tabriz, Iran, (e-mail: m.mahdi@tabrizu.ac.ir).
N. Shariatmadari is with the Department of Civil Engineering, Iran University of Science and Technology, Tehran, Iran, (e-mail: shariatmadari@iust.ac.ir).

interaction ceased was 1D. However, when the second tunnel was driven below the existing tunnel, interaction always occurred, regardless of the depth of the former. Recent experimental data from a three station tunnel construction close to the existing tunnels on the Piccadilly line in London indicated no interaction for pillar widths beyond 6D and 7D [11].

The development of transportation systems in Great Tehran city requires the construction of metro tunnels. In this way, Tehran metro project is being extended from Mirdamad station to Tajrish station. In u1 station three adjacent shallow tunnels are being constructed (Metro principal tunnel, Rectifier tunnel and ventilation tunnel) as shown in Fig. 1.

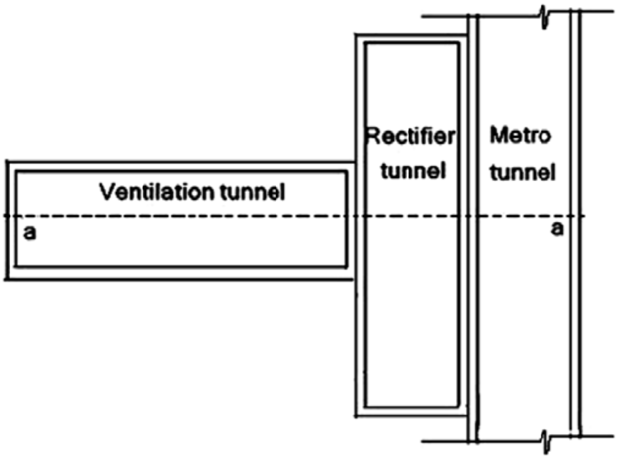
Construction of the third tunnel adjacent to the previous two ones will change the interaction between them. Existence of local groundwater also is another problem for performing. Using vertical and horizontal boreholes, the ground-water level will be dropped under the tunnels bench level. Since there is no space between the tunnels, Construction sequence should be considered to optimize the tunnels interactions.

For interaction analysis between these three adjacent shallow tunnels in Tehran metro, a 3D model has been produced using finite difference software FLAC-3D. The 3D model shows effects of the third dimension and excavation step.

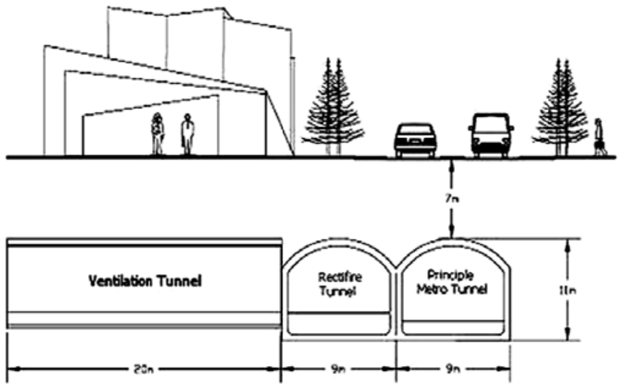
II. Geometry Analysis

Using in situ construction procedures, at first the head of the main tunnel with the step of 1 meter is excavated. Having shotcreted the head, the bench excavated (with step of 1 meter), shotcreted and finally lined with reinforced concrete. After the main tunnel completion, the rectifier and ventilation tunnel will be constructed as well as the main tunnel consecutively as shown in Fig. 2. For all cases, the tunnels are assumed to be straight and like the one represented in Fig. 2.

The soil stratigraphy modeled in this study was kept constant throughout the analysis which is shown in Fig. 3. The axis depth is 30m.



(a)



(b)

Fig. 1 Arrangement of tunnels: a) plan, b) section a-a

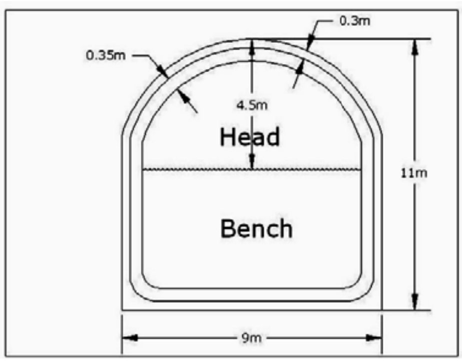


Fig. 2 Tunnel geometry

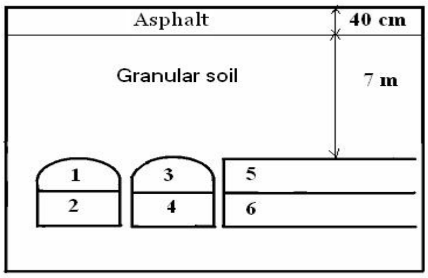


Fig. 3 Soil stratigraphy and filed construction procedure (method A)

III. Modeling with FLAC-3D

Section a-a (Fig. 1) is the critical section, for intersection of three tunnels lies in this section. Therefore in modeling attempted to dimensions so select that be coefficient space from section a-a (at least 2D, D= tunnels diameter).

Fig. 4 shows the mesh used for the tunnels analysis. Concerning the boundary conditions, the displacements are constrained in three directions at the bottom, while zero horizontal displacement is imposed at the lateral boundaries.

International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:8, No:1, 2014

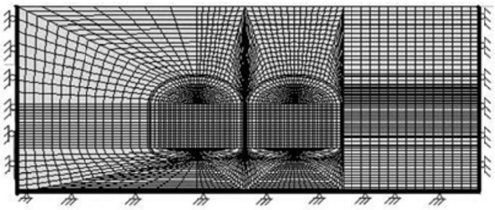


Fig. 4 Mesh used in the analysis of tunnels

Table I summarizes the properties of the soil and the lining used in this study. The soil corresponds to GW-GM. The coefficient of the lateral stress (K0), thickness of the shotcrete, thickness of the lining and thickness of the asphalt are equal to 0.5, 0.35m, 0.30m and 0.40m, respectively.

In all calculations, drainage analysis was performed, meaning that no excess pore water pressures were generated. Consequently, strength parameters based on effective stress were used as indicated in Table I. The results therefore represent the settlements likely to occur over a long period of time.

In all calculations, the analysis procedure began with the definition of initial effective stresses prior to tunnel construction, using ratio value of effective horizontal to vertical stress, K_0 equal to 0.5.

TABLE I
PROPERTIES OF THE SOIL RATIO, SHOTCRETE, LINING AND ASPHALT MATERIALS

Material	E0 (MPa)	ν	C(kPa)	φ, deg	Dilatancy Angle, deg	Unit Weight (kN/m3)	Type of Behavior
Soil	125	0.3	30	40	5	20	Mohr Coulomb
Shotcrete	20000	0.25	-	-	-	24	Linear Elastic
Lining	26000	0.25	-	-	-	25	Linear Elastic
Asphalt	20000	0.25	-	-	-	24	Linear Elastic

So, seven load stages are accounted as below:

1. Construction of the first tunnel head, simulated by activating the tunnel shotcrete and deactivating the soil elements inside the first tunnel head.
2. Exertion of volume loss and activating the tunnel shotcrete for the first tunnel head.
3. Construction of the first tunnel bench, simulated by the tunnel shotcrete activation, and deactivating the soil elements inside the first tunnel bench.
4. Exertion of volume loss and activating the tunnel shotcrete for the first tunnel bench.
5. Activating the first tunnel lining.
6. Repeating of steps 1 - 5 for the second tunnel.
7. Repeating of steps 1 - 5 for the third tunnel.

Each load stage was carried out using standard nonlinear solution techniques available in FLAC.

IV. VARIOUS CONSTRUCTION PROCEDURE MODELING

The field construction procedure (method A) illustrated in Fig. 3. In addition to field construction procedure previously modeled, four other procedures are shown in Figs. 5 to 8.

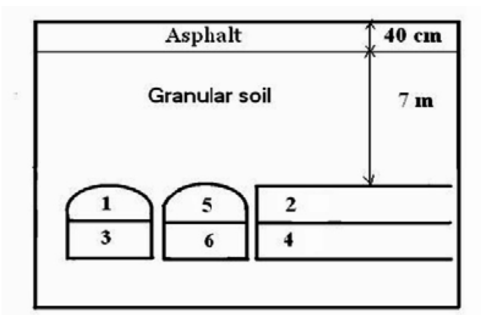


Fig. 5 Construction procedure B (Method B)

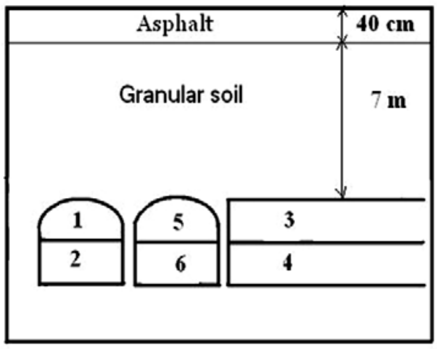


Fig. 6 Construction procedure C (Method C)

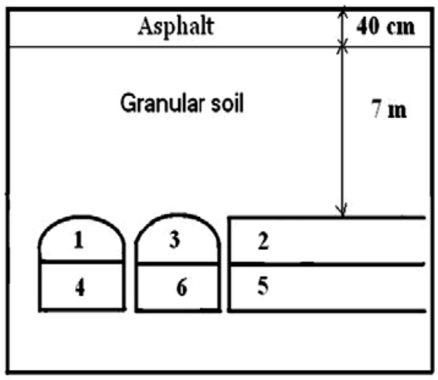


Fig. 7 Construction procedure D (Method D)

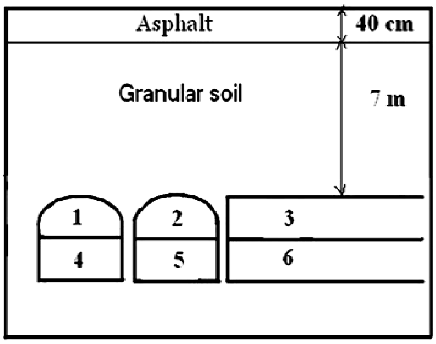


Fig. 8 Construction procedure E (Method E)

All of these construction procedures modeled as explained in part 3.

Besides, various construction procedures that shown in Figs. 5 to 8, various excavation steps modeled in method B as well. In this way, steps of 1.5, 2 and 3 meters are applied.

V. Results

In previous parts, different construction procedures modeled. Modeling Results show that construction procedure has a little effect on the amount of lining and shotcrete stresses which might be due to surface tunneling. Latter studies show that surface tunneling criterion for planning is surface movements. Table II shows the results of different construction procedures. Fig. 9 shows the surface settlement profiles.

Table II shows, applying method B, instead of method A (in situ construction procedure), the maximum surface settlement 15% (3mm), the maximum pressure stress 6% (0.5 MPa) and the maximum tension stress 25% (0.25 MPa) decrease; while the maximum shear stress 22% (0.56 MPa) increases. Therefore using method B, in construction of tunnels we can reduce the surface movements.

TABLE II
Comparison of Results in Various Construction Procedures

Construction procedure	Surface settlement on the metro tunnel (mm)	Surface settlement on the rectifier tunnel (mm)	Surface settlement on the ventilation tunnel (mm)	Maximum shear stress in shotcrete (MPa)	Maximum pressure stress in shotcrete (MPa)	Maximum tension stress in shotcrete (MPa)
Method A	14.02	19.50	13.06	2.14	3.72	1.00
Method B	13.50	16.50	13.00	2.88	6.58	1.00
Method C	14.50	18.01	15.02	2.70	6.20	1.20
Method D	15.02	18.50	15.12	2.71	6.40	1.30
Method E	15.06	18.02	14.50	2.55	6.41	1.45

The measured results in modeling show that shotcrete stresses is very less than allowed concrete stresses. So we can reduce the shotcrete thickness. The results of various excavation steps using method B as an optimum method for tunnels construction, is shown in Table III. Here it is assumed that the allowed surface settlement for field can be 20mm.

Since the allowed surface settlement assumed to be 20mm, and the surface settlement using excavation step of 2 meters is 19.3mm, therefore we can use it as an optimum excavation step for method B. In method A, since the maximum surface settlement is 19.5mm, hence we can say that the optimum excavation step is 1 meter (with appearance to allowed field settlement).

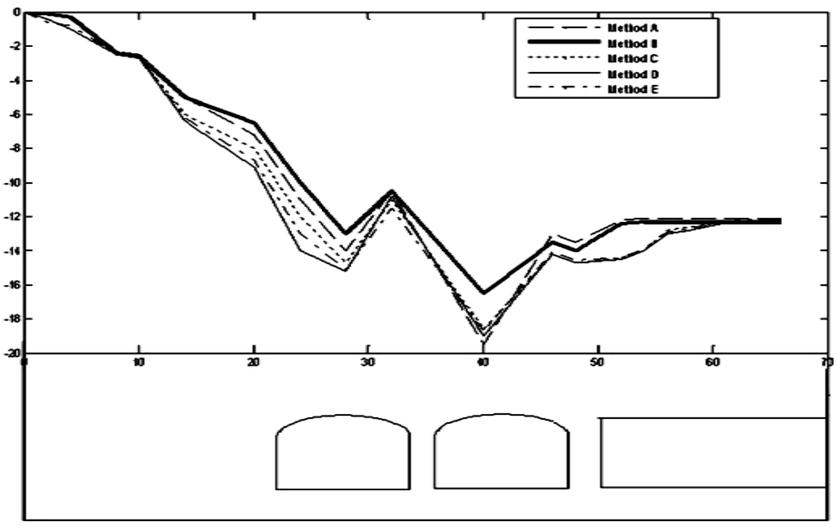


Fig. 9 Comparing surface settlement under asphalt layer in various methods

TABLE III
RESULTS OF VARIOUS EXCAVATION STEP MODELING

Excavation step (m)	Maximum surface settlement (mm)	Maximum shear stress in shotcrete (MPa)	Maximum pressure stress in shotcrete (MPa)	Maximum tension stress in shotcrete (MPa)
1.5	18.01	3.00	5.95	1.00
2	19.30	3.55	6.05	1.20
3	25.02	3.87	6.50	1.20

VI. CONCLUSIONS

Analysis and assessment of built tunnel models showed that, changing construction procedure make it possible to reduce the ground surface settlements and control the amounts of shotcrete stresses. Also the excavation step has an important effect on the amounts of ground movements. So we can find the optimum construction procedure and excavation step, in order to control the ground movements and shotcrete stresses.

The modeling showed that in shallow tunneling, the important criterion of planning is ground surface movements; because its magnitude, especially in soft ground, is usually a high amount which will be a problem in urban areas. But amounts of shotcrete and lining stresses, was very smaller than its allowed magnitude. So we can here reduce the shotcrete thickness.

REFERENCES

[1] F. Prinzl & A.R.A Gomes “The requirement of Protective measure for building affected by ground movements due to shield Tunneling in soft ground” Proc. Tunnels and Metro Polises Edited by A.Negro Jr & A. A. Ferreira , vol.2 A. A. Balkema 1998.
[2] D.K. Koungelis & C.E. Augarde “Interaction between multiple tunnels in soft ground” .School of Engineering, University of Durham, UK 2004.
[3] D.N. Chapman, S.K. Ahn, and D.V.L. Hunt" Investigating ground movements caused by the construction of multiple tunnels in soft ground using laboratory model tests " , Canadian Geotechnical Journal, volume 44, Number 6 jun 2007, ISSN 1208-6010 , Pages 513-523.
[4] F. Hage Chehade and I. Shahrour, “Numerical analysis of the interaction between twin-tunnels: Influence of the relative position and construction procedure ", Tunneling and Underground Space Technology, Volume 17, Issues 2-3, Jun.2007, Page 213.
[5] D. N. Chapman, S. K. Ahn, D. Hunt and A. Chan, “The use of model tests to investigate the ground displacements associated with multiple tunnel construction in soil”, Tunneling and Underground Space Technology, Vol. 21, Issues 3-4, May-July 2006, Page 413.
[6] M. Marata , T. Okazawa “shallow twin tunnel for six lanes beneath densely residential area” Proc. North American Tunneling, Edited by Levent Ozdemir, A. A. Balkema, 1996.pp 371-380 .
[7] X. Guogang, M. Guoyan, L. Qingbo and C. Zhifang, “Predicting the settlements above twin tunnels constructed in soft ground”, Tunneling and Underground Space Technology, Volume 19, Issues 4-5, July-September 2004, Page 378.
[8] M. Karakus and R. J. Fowell, “Effects of different tunnel face advance excavation on the settlement by FEM”, Tunneling and Underground Space Technology, Vol. 18, Issue 5, November 2003, Pages 513-523.
[9] G. N. Pande, J. R. William “Numerical Methods in Rocks Mechanics” John Wiley and Sons Ltd 1990.
[10] B. M. New and M. P. O’Riely “Tunneling induced ground movements-Predicting their magnitude and effects” Ground movements and structures vol. 4, Edited by James D.1991.
[11] C. T. Chang, M. C. Lee and P. C. Hov “Design of twin–tube tunnel through soft rock” Geotechnical Aspects of Underground Construction in soft Ground. Balkema, Rotterdam, 1996, pp. 251-255.