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RELATIONSHIP BETWEEN TWIN TUNNELS DISTANCE AND SURFACE SUBSIDENCE IN SOFT GROUND OF TABRIZ METRO - IRAN

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ABSTRACT: This paper presents a series of three-dimensional finite distinct element analyses carried out for line 1 of Tabriz metro tunnels. Interaction between these circular parallel twin tunnels excavated by an Earth Pressure Balance machine in a soft ground has been studied. The Influence of the distance between twin tunnels on the surface subsidence, bending moment and axial forces in the segmental lining of the first tunnel have been particularly, investigated. Advancing of the second tunnel affects the surface subsidence, bending moment and internal forces in the lining of the first tunnel. These effects relate directly to the width of the pillar separating the twin tunnels. It was found that the location of the maximum subsidence is offset from the centreline of the first tunnel. The offset increases with decrease in the distance between the tunnels. Also, moment and axial forces of the first tunnel decrease by increasing the space between the tunnels. The interaction between the tunnels has been quantified and classified in accordance with various tunnel distances.

INTRODUCTION

The use of underground spaces for transport infrastructures is required in development of large cities. In some cities, the geotechnical and underground conditions require the construction of new tunnels close to existing ones. In other cases, the solution of twin tunnels presents major advantages, such as reduction of both tunnels diameter and soil movement resulting from the tunnel construction (Chen, *et al.*, 2009).

Ground movements are an inevitable consequence of excavating and constructing tunnels. Tunnel excavation causes relaxation of *in situ* stress, which is only partially restricted by the insertion of the tunnel support. In fact it is not possible to create a void instantaneously and provide an infinitely stiff lining to fill it exactly. Hence, a certain amount of the deformation of the ground will take place at the tunnel depth; this will trigger a chain of movements, resulting in settlements at the ground surface, which are more significant at shallow tunnel depth (Moller and Vermeer, 2008).

Numerical modelling and *in situ* observations were used to analyse the interaction between twin tunnels. Results show that in some configurations, the interaction could largely affect the soil settlement and that the design of twin tunnels requires numerical analysis associated to monitoring during the design phase (Hage Chehade and Shahrour, 2008). The construction of the first tunnel may notably affect the soil conditions: reduced confinement, stress release and reduction of the strength parameters of the soils. Consequently, the second tunnel will be excavated through a different material and the induced settlements related to the second tunnel will be generally greater (Guglielmetti, *et al.*, 2007).

This paper presents 3D numerical analysis conducted to investigate the influence of twin tunnel spacing on the surface settlement and internal forces resulting from the tunnel excavation. Analysis was carried out for three different tunnel distances namely 0.5D, 1D and 1.5D where D is the tunnel's diameter.

TABRIZ METRO LINE 1

Tabriz is a large city in the north west of Iran with a population of about two million. Tabriz metro is designed in three lines. Line 1 starts at south east of the city and after passing the city centre ends at the south west. In this line two parallel circular tunnels are excavated by two EPB machines. The length of tunnels is 8 km and their diameter is 6.88 m. Figure 1 shows three lines of Tabriz metro.

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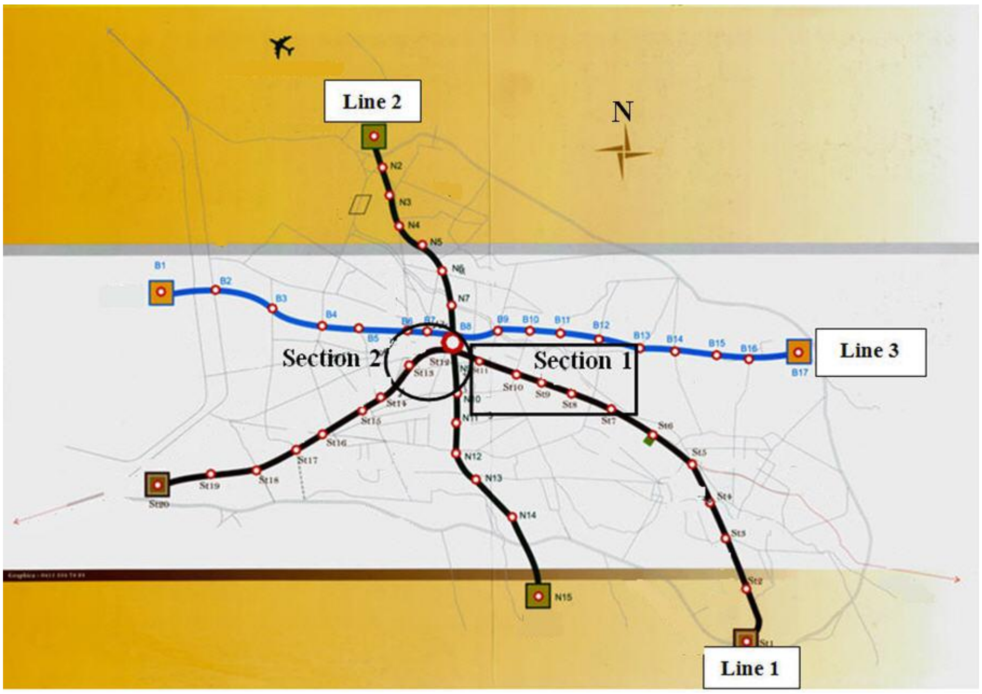

Figure 1 - Three lines of Tabriz metro

Geotechnical condition is divided into four different sections in the tunnel alignment. Analysis was carried out for sections 1 and 2 of line 1 because of the critical conditions of these parts regarding geotechnical specification, water table depth and existence of old buildings. There is one sedimentary layer in section 1 and four different layers in section 2 including two silt layers with different properties, a sand layer and a man filled layer. The properties of different layers are summarized in Table 1.

Table 1 - Properties of different layers of Tabriz metro line 1

Parameter	Section1	Section 2			
	Fine sedimentary layer	Manfilled	silt	sand	silt
Friction angle (degree)	35	5	15	33	34
Cohesion (MPa)	0	0	0.015	0	0.025
Bulk modulus (MPa)	33.34	15.62	22.3	33.34	33.34
Shear modulus (MPa)	11.12	5.6	7.4	15.4	11.2
Thickness (m)	-	5	8	15	20
Tunnel depth (m)	10	14			
Water depth (m)	20	6			

The depth of tunnels from the ground surface is 10 m and 14 m in sections 1 and 2, respectively. In section 1 ground water table is 8 m above the tunnels crown but it is below the tunnel invert in section 2 (Jahad-e Tahghighate Sahand, 2005).

THREE DIMENSIONAL MODELS

Figure 2 shows the model used for analysis of horizontally aligned tunnels with 6.88 m diameter and 7 m pillar width. The boundary of the model is extended to a distance where there is no effect of tunnel construction on the lateral border of the model. This distance is 5.5D equal to 38 m from each tunnel's centre.

The length, width and height of the model are 56 m, 90 m and 40 m, respectively. Layers of section 2 and their properties are also shown in Figure 2. The model contains 57 280 elements and 60 147 nodes. The mesh size increases gradually when the distance from the tunnel increases. The mesh size in the direction of the tunnel axis is equal to the segment length which is 1.4 m. Concerning the boundary conditions, the displacements are constrained in three directions at the bottom, while zero horizontal displacement is imposed at lateral boundaries.

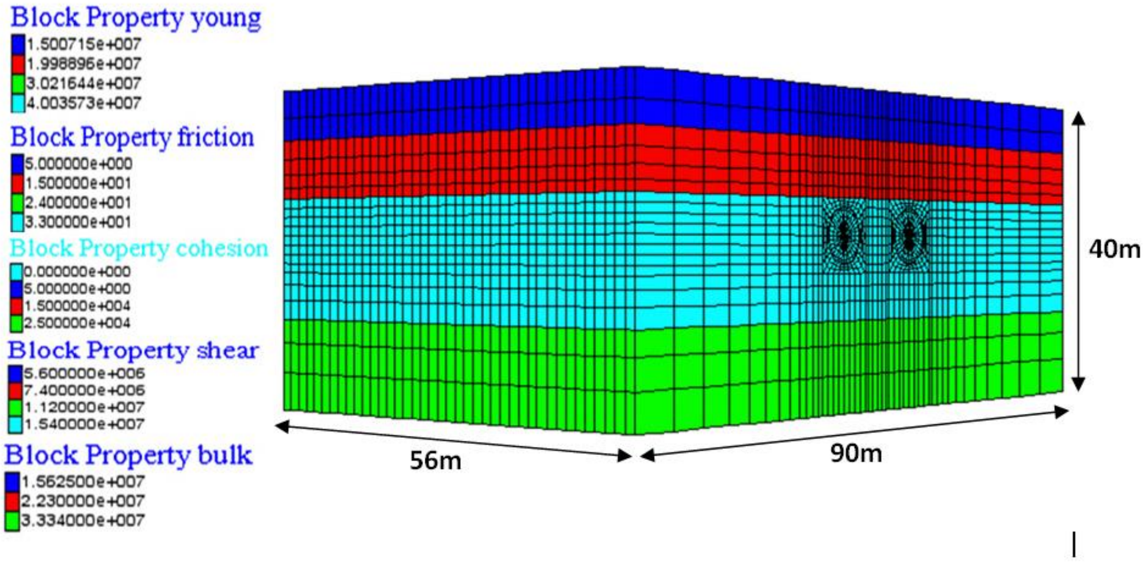

Figure 2 - The mesh used for modelling

The ratio of the horizontal to vertical stress (k) is 0.43 and 0.74, respectively for sections 1 and 2. Initial vertical stress is calculated as the weight of the layers. The stress induced by surface structures and traffic is applied as planner load on the top boundary of the model. This stress is assumed to be 24 000 N/m^2. The soil behaviour is described by an elastic perfectly plastic Mohr-Coulomb criterion.

Modelling of the twin tunnels construction is carried out in the following steps:

- Construction of the first tunnel 1.4 m, applying face pressure and installation of shield elements. This cycle is repeated till 9.8 m of the tunnel is excavated (7 cycles). There would be no lining installed up to this length.
- Continuing step one followed by installing lining elements and then injection of grout behind the shield.
- Repetition of step two till 35 m of tunnel 1 is excavated
- Starting the construction of the second tunnel in the same way performed for the first one.

The shield is modelled as a rigid cylinder by means of shell elements with external diameter of 6.86 m and length of 9.8 m. Segmental lining is modelled with shell elements with thickness of 0.3 m and internal diameter of 6 m. The behaviour of the shield and segmental lining is assumed to be linear-elastic. Properties of the shield and lining are shown in Table 2.

Table 2 - Properties of shield and segmental lining

Type of support system	Elastic modulus (Gpa)	Poisson's ratio
Shield	200	0.25
Segmental lining	25.2	0.2

Results

Analysis was conducted for three various pillar width of 3.5 m (0.5D), 7 m (D) and 10.5 m (1.5D). Figure 3 shows the surface settlement for different tunnel distances in section 1. The pattern and magnitude of the settlement depend on the distance between tunnels. Maximum settlement is about 2.65 cm, 2 cm and 1.9 cm for the pillar width of 3.5 m, 7 m and 10.5 m, respectively. By increasing pillar width from 3.5 m to 7 m, maximum settlement decreases about 25% but it decreases about 5% when pillar width increases from 7 m to 10.5 m. The maximum soil settlement is observed for tunnels with the narrowest pillar width (i.e. 3.5 m) where maximum settlement occurs in the centre part of the pillar. When distance between the tunnels increases the settlement in this part decreases because of decreasing the interaction between tunnels.

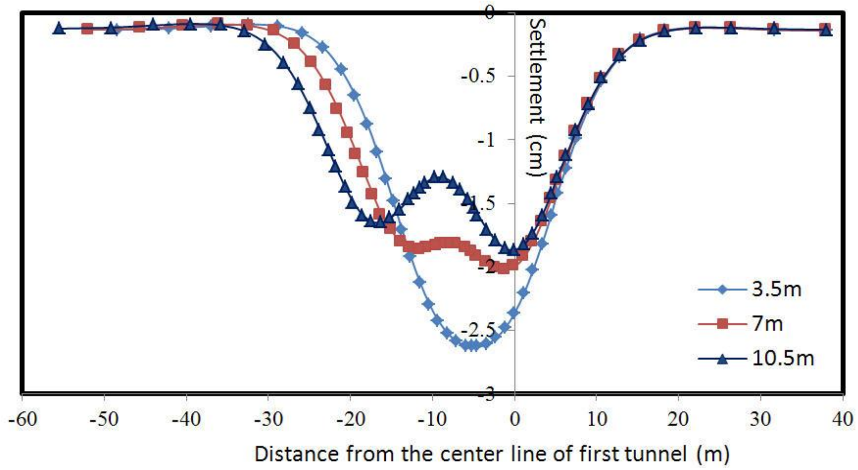

Figure 3 - Surface settlement for different pillar width between tunnels in section 1

Interaction between tunnels leads to increase in soil movement in the pillar between them. As Figure 4 shows in pillar width of less than 10.5 m maximum settlement offsets from the centre line of the first tunnel. The magnitude of offset increases when distance between tunnels decreases. In pillar width of 3.5 m maximum settlement occurs at 5.19 m far from the first tunnel axis.

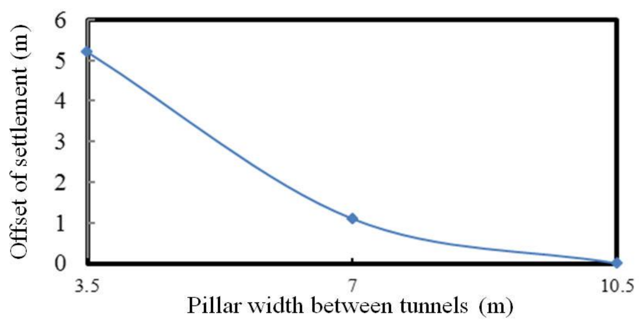

Figure 4 - Offset of maximum settlement from the center line of the first tunnel in section 1

Figure 5 shows the settlement curves in section 2. In this section, for pillar width of 3.5 m, maximum settlement doesn't occur in the central part of the pillar but is near to the first tunnel (i.e. 4.44 m from centre of the first tunnel). For the pillar width of 7 m maximum settlement is in the pillar zone with 0.75 m offset from pillar centre, but for 10.5 m pillar width maximum settlement is 3 m from the centre part of pillar (2.25m from the first tunnel wall).The shape of curve for this case shows that the interaction between tunnels decreases. Maximum settlement is 3.9, 3.5 and 2.75 cm for 3.5, 7 and 10.5 m pillar width, respectively. Therefore, increasing pillar width from 3.5 m to 7 m leads to decrease of 11% and increasing pillar width from 7 m to 10.5 m leads to another decrease of 27% in the ground settlement.

The maximum settlements estimated for pillar width of 3.5 m and 7 m are not allowable in urban area. Therefore, the pillar width of 10.5 m is suitable as it decreases the settlement to an allowable amount in section 2.

Excavation of the second tunnel changes the bending moment and axial forces in the segmental lining of the first tunnel. Tables 3 and 4 show the quantities of these parameters for various tunnels distances. As shown in these Tables, for lowest distance, the bending moment increases 17% and 11.5% and axial force increases about 6.5% and 9.5% in sections 1 and 2, respectively. Bending moment and axial forces in the lining of the first tunnel decrease when the distance between tunnels increases. In both sections the effect of advancing of the second tunnel on the lining of the first tunnel is negligible for 10.5 m pillar width.

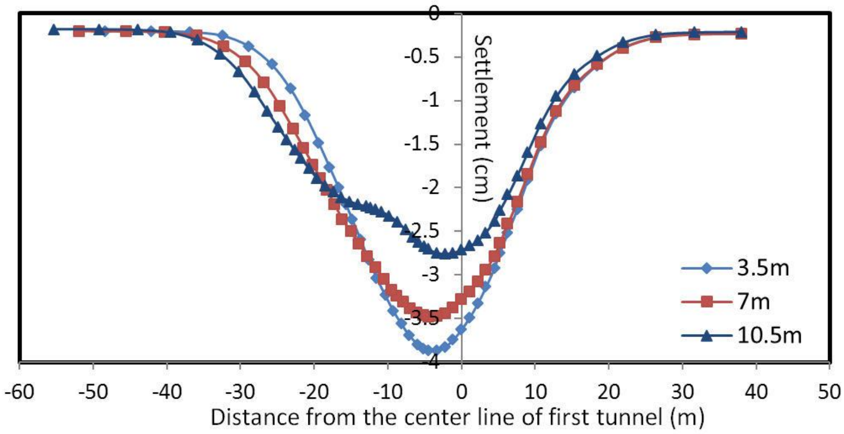

Figure 5 - Surface settlement for different pillar width between tunnels in section 2

Table 3 - Bending moment on the lining of the first tunnel after excavating the second one

Pillar width (m)	Section 1		Section 2	
	Moment in segments (KN-m)	Changes compare to single tunnel (%)	Moment in segments (KN-m)	Changes compare to single tunnel (%)
3.5	0.884208	17	2.13057	11.5
7	0.831688	10	1.99667	6.5
10.5	0.781443	3.5	1.94025	1.5

Table 4 - Axial forces in the first tunnel lining after excavating the second one

Pillar width (m)	Section 1		Section 2	
	Magnitude of forces (KN)	Changes compare to single tunnel (%)	Magnitude of forces (KN)	Changes compare to single tunnel (%)
3.5	664.94	6.5	1222.2	9.5
7	644.45	3	1152.6	3.5
10.5	625.84	0.06	1127.4	1.1

CONCLUSIONS

The following conclusions can be drawn from this numerical study:

- Settlement decreases with increasing the distance between the tunnels for both sections. In section 1, the magnitude of settlement is 2.65, 2 and 1.9 cm for pillar width of 3.5, 7 and 10.5 m, respectively. In section 2, settlement changes from 3.9 to 2.65 cm when pillar width change from 3.5m to 10.5 m;
- Offset of maximum settlement from the centre line of the first tunnel decreases by increasing the tunnels' distance. It is 5.19m and 4.44 m for section 1 and section 2, when the pillar width is 3.5m. The offset reaches zero for pillar width of 10.5 m;
- The moment in the segmental lining of the first tunnel decreases by increasing the distance between the tunnels. In section 1, it increases 17% for pillar width of 3.5 m while it increases 3.5% for pillar width of 10.5 m. These amounts are 11.5 and 3.5% for section 2;
- The axial force decrease by increasing of tunnels distance. It changes 6.5% and 9.5% for section 1 and section 2 when the pillar width is 3.5 m. These changes are 0.06% and 1.1% for pillar width of 10.5 m.

- In section 1, interaction between tunnels is negligible for pillar width of 7 m (D) and further.
- In section 2, interaction between two tunnels is negligible for pillar width of 10.5 m (1.5D) and further.

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