Site investigations and convergence measurements for a twin metro tunnel driven in Ankara clay, Turkey

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Abstract: Over population and increase in the traffic congestion in urban areas have led to an inevitable rise in the construction of underground structures. Therefore, a project consisting of 9325m twin metro tunnel construction has been planned by the Greater Municipality of Ankara in order to help to ease transportation problems in Ankara, Turkey. This paper presents the geotechnical properties along the tunnel route, and construction of the Middle East Technical University (METU) twin metro tunnel between 2.720 and 4.000 km as a part of Ankara project III. The twin metro tunnel runs mainly through Ankara Clay above this is artificial fill material. Each tunnel has approximately 38 m^2 cross-sectional area and is excavated in two stages in accordance with New Austrian Tunnelling Method (NATM). There have been several drilling holes conducted to investigate groundwater levels and engineering properties of the host medium; these will be examined in the paper. In order to monitor the amount of tunnel closure, convergence measurements taken during construction of the tunnel will be presented and discussed.

Résumé: Augmentation des populations et de traffics in villages ont conduit a' construire des structures de subsurfaces. Ainisi, la construction des tunnel jumeaux de metro de 9325 m longue a été decidée par la Municipalité de Mairied'AnkaraPour resoudre le probleme de transport. Cet article presente des caracterer geotechniques du trajet du tunnel et ceux de metro jumeaux de METU entre 2.720 et 4.000 km qui font partie d'Ankaray Project-III. Le metro jumeaux est sur les argiles d'Ankara qui sont des materiaux de remplissage. Chaque Tunnel posséde une superficie de 38 m^2 et est creusé par le method NATM. Pour evaluer le niveau de l'eau dans la zone du travil, plusieurs.Logs de sondage ont été realisés et les propriétés genie civil des materiaux ont été examinées dans cet article. Pour determiner les quantités de curvature du tunnel, des mesures convergentes ont été prises durant de construction du tunnel et ces données seront discutées pendant la representation

Keywords: Tunnels, site investigation, in situ tests, monitoring

INTRODUCTION

Underground facilities in urban areas such as tunnels have a significant importance on the daily life of commuters as they provide fast and safe transportation services. Therefore, the construction of metro tunnels has escalated in recent years all over the world. Constructing multiple tunnels provides increased engineering challenges e.g. excavation of twin metro tunnels side by side or piggyback (Addanbrooke et al., 2001) requires much more attention rather than a constructing single tunnel. Therefore, the geological settings along the tunnel routes have to be investigated thoroughly and the stand-up time of the ground as well as tunnel face stability must have be determined. Ground movements due to excavation of a second tunnel in a close proximity to the existing tunnel should also be found in order to understand interactions between them. In this study geological and geotechnical properties along the tunnel route and tunnel closure during the excavation of METU twin tunnels are been presented.

Convergence of a tunnel, which is the amount of closure on the tunnel diameter, is a significant sign of deformation. In order to maintain stability, the closure amount should be precisely measured and the necessary support measures should be determined accordingly. Kovari and Amstad (1993) pointed out that the closure of a tunnel is related to the deformation and an important factor for tunnel stability. In fact, convergence is the most vital indication of stability of any underground structures. Therefore, in order to inspect deformation rates and changes in the theoretical tunnel geometry a short-term convergence measurement programme was undertaken between 25-07-2003 and 22-08-2003 for each tunnel. Most of the in situ measurements as well as laboratory tests were carried out by YUKSEL Project International during the METU twin tunnel construction (Yuksel project report, 2003). Convergence measurements were carried out after the shotcrete was applied to the tunnel periphery before the permanent 400 mm concrete lining was installed. Topographical measurements techniques were utilised to monitor convergence of the tunnel. Convergence pins attached to the tunnel walls sustained some damage due to the working equipment in the tunnel during measurements. Also, locally trapped water in the clay caused swelling which led to changes in pin locations from time to time. Therefore, some measurements can be erroneous.

GEOLOGY AND GEOTECHNICAL PROPERTIES AT THE CONSTRUCTION SITE

The basic formations around Ankara consist of the Dikmen Formation, the Volcanic Series, the Akhöyük Formation, the Ankara Clay and alluvium. The Ankara Clay and alluvial deposits are on the tunnel route. Location of the constructed tunnels is given in Figure 1. The soil profile for the tunnel route contains artificial fill and Ankara Clay as shown in Figure 2. The artificial fill, which is not compacted and brown in colour, is composed of blocky, gravel with rubble and sandy clay. The thickness of artificial fill ranges from 1.40 m to 5.60 m.

Figure 1. Location map for the tunnel

Ankara Clay is brown to reddish brown in colour and composed of mainly silty, sandy clay with clayey silt. Finer reddish-brown material consisting of a high amount of clay are also defined as Ankara Clay (Ordemir et al., 1965).

Ankara Clay is locally found to be at shallow depths with very thin lime layers, nodules and concretions appearing within the clayey levels as lenses with no lateral continuity (Erol, 1973). The sandy and gravelly layers vary in thickness in the Ankara Clay. As the Ankara Clay is impermeable, there is no certain water level. However, water is found in sandy gravelly layers. According to the drilling logs, the water table on the METU twin tunnel route is given in Table 1. The mineral composition of the Ankara Clay indicates smectite group (e.g. montmorillonite) clay minerals and illite (Ordemir et al., 1977; Erguler and Ulusay, 2003). This fissured clay has a swelling potential due to the montmorillionite and illite content. According to the Unified Soil Classification System (USCS), Ankara Clay exhibits high plasticity clay (CH),m and highly compressible inorganic silt and organic clays (MH).

Table 1. Water table measured from boreholes

Borehole No.	Depth (m)	Borehole Elevation (m)	Water table depth (m)
AK-ST-05	26.00	874.366	4.30
AK-BT-05	22.95	876.951	4.75
AK-BT-06	16.95	878.826	4.45
AK-CT-08A	15.45	878.060	7.50
AK-CT-09	46.79	878.322	14.80
AK-CT-10	18.45	870.299	2.20
AK-CT-11	15.45	857.411	3.15

Permeability tests have also been conducted on samples from the drill holes. As indicated earlier Ankara Clay is impermeable. However a 7.52576 x 10^{-06} m/s permeability value was found only in borehole AK-CT-08A as shown in Figure 2.

Standard Penetration Tests, which aim to determine the SPT N value, giving an indication of the soil stiffness, were carried out during the twin metro tunnel excavation and the test results are given in Table 2. Laboratory tests carried out on undisturbed (UD) soil samples taken from the MTA twin tunnel route and soil properties are given in Table 3.

Table 2. Standard penetration test results for Ankara Clay at the METU tunnel route

Depth, m	Very soft N*=(0-2)	Soft N=(3-4)	Firm N=(5-8)	Stiff N=(9-15)	Very stiff N=(16-30)	Hard N>30
0-10	-	-	-	8	33	59
10-20	-	-	-	-	-	100
20-30	-	-	-	-	50	50
30-40	-	-	-	-	-	100
40-50						100

*N=Number of blows

Overburden thickness over the METU tunnel ranges from 9.00 to 37.00 m. The undrained shear strength of Ankara Clay at between 0 and 20 m depth is found to be 200 kPa which means tunnel face can be stable before the installation of required support elements. One of the difficulties faced with soft ground tunnelling is low strength parameters with high deformation characteristics. Change in water content, however, can lower the undrained shear strength of the soil leading to tunnel instability.

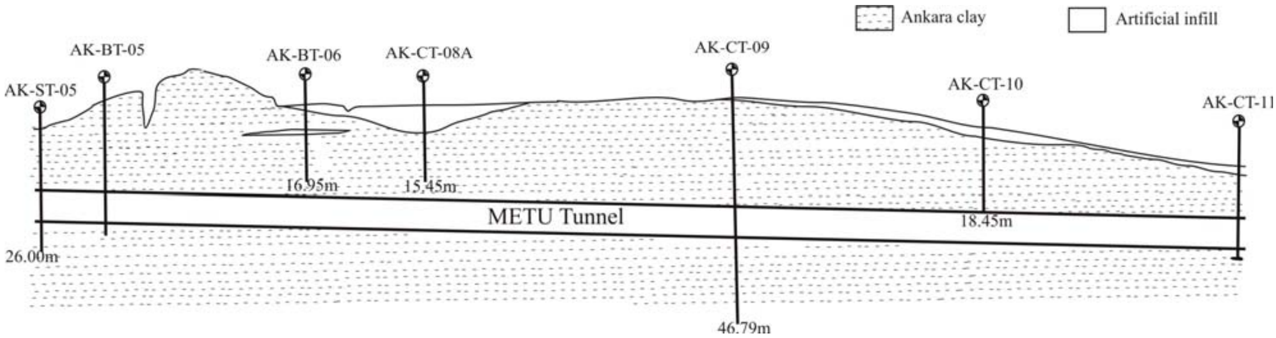

Figure 2. Soil profile along METU tunnel route and borehole places

During the excavation of the tunnel, stability is mainly affected by the soil properties in which tunnel runs, the excavation techniques adopted and support systems used. In order to determine an appropriate support systems soil and/or rock mass classification has to be determined.

The undrained shear strength, S_u, of Ankara Clay varies with depth (z). The following relationship can be used to estimate S_u with depth;

$$S_u = 5z + 150 \text{ (kPa)}$$

Table 3. Ankara Clay soil properties

Parameters, Symbols, unit	Values
Natural unit weight, γ_n, kN/m^3	18.10
Effective cohesion, c$'$, kPa	25
Undrained shear strength, S_u, kPa	$S_u = 5z + 150$
Effective friction angle, ϕ', degree	24
Elasticity modulus, E, MPa (0-20m)	60
Elasticity modulus, E, MPa (20-40m)	90
Moisture Content, w, %	31
Liquid Limit, LL, %	68
Plastic Limit, PL, %	35
Plasticity Index, PI	33
Unified Soil Classification System (USCS)	MH, CH
Void ratio, e	1.04

The Ankara Clay tends to swell and expand causing the opening of fissures during excavation due to stress relief. This can result in a decrease in the shear strength of the soil. Therefore, a tunnel face stability problem, as shown in Figure 3, has to be examined before excavation begins. Tunnel face stability in clay was investigated by Broms and Bennermark (1967) and they proposed a face stability index (*N*), which is the ratio between the difference of the natural pressure and the pressure applied to the tunnel face, and the undrained shear strength, to analyze tunnel face stability. It was suggested that the tunnel face would be stable when the stability ratio is less than six. The face stability index is given by;

$$N = \frac{\sigma_s + \gamma H - \sigma_T}{S_u}$$

where;

σ_s = surface surcharge
S_u = undrained shear strength at tunnel axis
σ_T = tunnel support pressure
H = depth of tunnel axis (C+D/2)

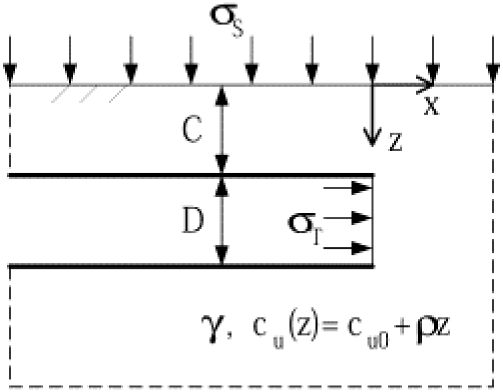

Figure 3. Face stability problem (After Augarde et. al., 2003)

In the case of METU twin tunnel construction, face stability index (*N*) was found to fall in the range 1 to 4 in terms of the soil properties measured at the site. The face stability index found suggests that tunnel face is stable during installation of support elements.

TUNNEL CONSTRUCTION AND CONVERGENCE MEASUREMENTS

The tunnel shape is near circular, having a cross sectional area of around 38 m^2. The approximate radius of the tunnel is 6.70 m. Figure 4 illustrates the constructed tunnel geometry. The Pillar left in between tunnel centrelines is approximately 15 m. A sequential excavation technique rather than full face excavation has been devised to provide stability. Therefore, excavation was carried out in two stages. In order to inspect for potential trapped water and provide drainage before excavation started, 6-8 m long drainage holes of 50 mm diameter were drilled. Just after the excavation of the upper part of the left tunnel, indicated as first stage of excavation in Figure 4, a 30 mm thick layer of instant shotcrete was applied. Following this wire mesh with lattice girders and rock bolts were emplaced, where required, and a 170 mm thick layer of shotcrete was applied. The total shotcrete thickness used was 200 mm. An unsupported span was kept within 1.00-1.50 m and after 6 m advance of upper part of the tunnel, excavation of lower part was carried out. The same support procedures used for the upper part was also used for second stage of excavation, that is, the invert of the tunnel. Following completion of shotcreting of the entire tunnel, a 400 mm final concrete lining was used to finalise construction.

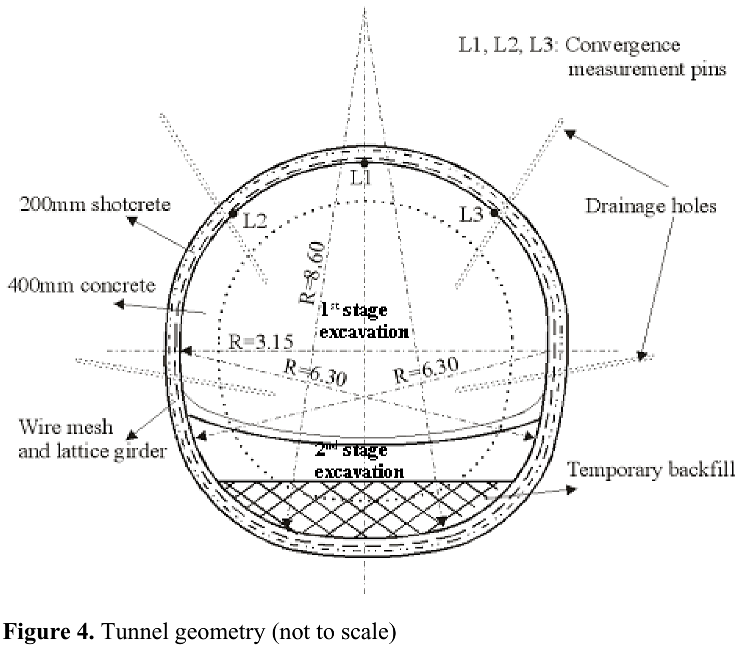

Figure 4. Tunnel geometry (not to scale)

The construction of the left tunnel was followed by excavation of the right tunnel, with the same excavation and support procedures. Convergence measurements pins were installed at 1-2 m back from the face. At chainage 3745.30 m the maximum convergence of 4mm occurred at stations L1-L2 (Figure 5a). As can be seen from Figure 5b the maximum decrease in the size of the theoretical cross section of left tunnel was 11mm. Apparently convergence stops at this level. Between stations L1 and L2 there were nearly no closures, unlike between stations L1-L3 of the left tunnel. Convergence measurements at the right tunnel are given in Figure 6a and Figure 6b. The distance between measurements stations in the left and right tunnesl was approximately 15 m. Thus, the right tunnel suffered less deformation than the left tunnel (Figure 6a and Figure 6b).

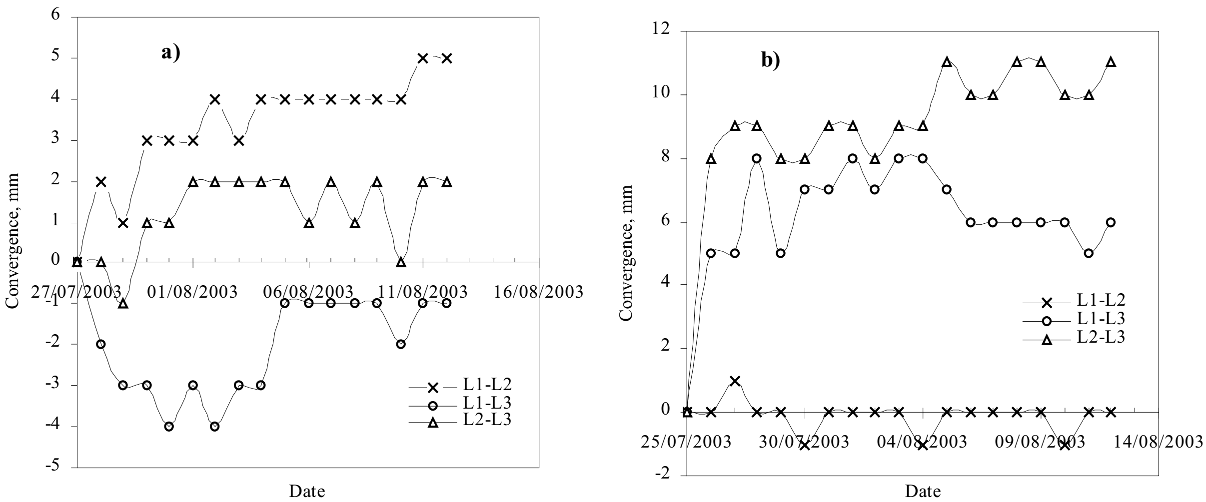

Figure 5. Convergence of left tunnel **a)** chainage of 3735.30m **b)** chainage of 3747.60m

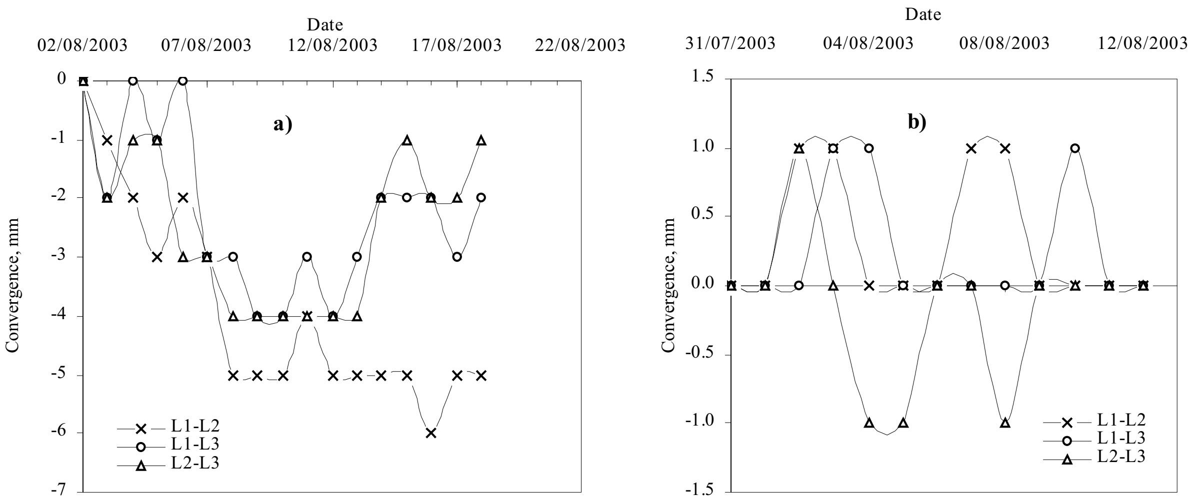

Figure 6. Convergence of right tunnel **a)** chainage of 3720.10m **b)** chainage of 3731.80m

DISCUSSION

In order to make a robust judgement on the deformation characteristics or convergence profiles of the twin tunnels, the lower sections of the tunnels had to be measured as well. In addition, deformation between the stations in the upper and lower sections of the tunnels needed to be measured. However, the data provided here only covers the upper section convergence measurements and thus there cannot be a certain conclusion made over the stability of entire tunnel. On the other hand, numerical modelling can be used to examine the stability and interactions of these twin tunnels. Therefore, a two-dimensional finite element analysis can be carried out provided that reliable geotechnical data are used. In METU twin tunnel construction, as one tunnel was excavated and supported after the other, three-dimensional FE analysis would provide a better solution for future investigation of deformation, tunnel face stability and tunnel convergence.

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