THE KIZILAY TUNNEL – A PRACTICE IN TUNNELLING THROUGH THE ALLUVIAL DEPOSITS

Hasan ÖZASLAN[1] İsmail Hakkı BAYDUR[2] Atilla HOROZ[3]

SUMMARY

A 120 m long stretch of the Kızılay Tunnel belonging to the Ankara Light Rail Transit System (ANKARAY) is partly formed of alluvial units overlying the Ankara Clay. The alluvium is represented by varved layers of clay, silt, sand and gravel.

Jet grouting was employed in this section of the tunnel passing through the alluvial deposits below the groundwater table. In this method, periphery of the tunnel was stabilized and groundwater leakage into the tunnel was minimized by forming vertical grout columns in the crown and sidewalls of the tunnel.

It was observed that the soil parameters have been improved following the implementation according to the results of the lab testing. The grout columns taking place and spreading of the grout material particularly along the coarse grained levels of the alluvium have contributed to the tunnel stability and water tightness to a greater extent, and consequently the tunnel excavation has been completed without any significant problem.

Prior to the implementation, it was estimated that the tunneling would not interfere so much with the groundwater flow in the alluvium, which was crossed by the Kızılay tunnel longitudinally. Following the construction, results of the periodic observation of the groundwater level confirmed that the groundwater table has been maintained almost at the same level.

---

1. Geological Engineer BS, Yüksel Proje Uluslararası A.Ş., ANKARA
2. Civil Engineer BS, Yüksel Proje Uluslararası A.Ş., ANKARA
3. Civil Engineer MS, Yüksel Proje Uluslararası A.Ş., ANKARA

1. INTRODUCTION

The city of Ankara has started to face growing traffic congestion problems on its inner city roads in early 1980's. The Ankara Urban Transportation Study performed in 1980 has indicated the need to construct a network of rail transit systems considering the travel demands in different parts of the capital city. One of the anticipated systems was the Ankara Light Rail Transit System (ANKARAY), which would establish a link between the Söğütözü and Dikimevi districts in the first phase of the project (Fig.1)

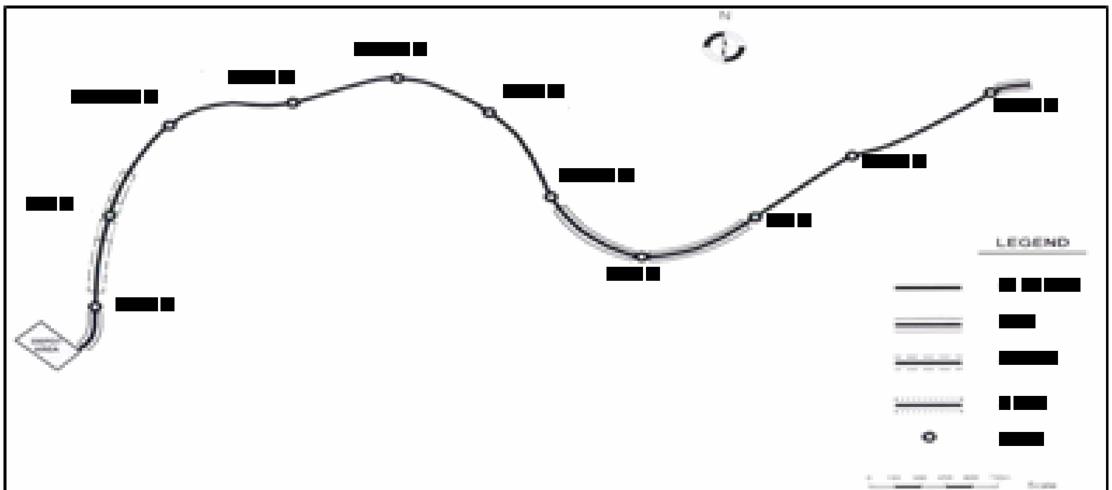

Fig.1 Location Plan of the Ankaray Route

The construction of the ANKARAY was started in 1992 and completed in 1995. The Ankara Light Rail Transit System with a total length of 9 km consists of 11 stations and is designed to carry 16000 and 25 000 passengers in each direction in 1995 and 2015 respectively.

The stations have been planned on the basis of passenger estimates and normal operation capacities. The AŞOT, Beşevler, Maltepe, Demirtepe, Kolej, Kurtuluş and Dikimevi stations are located entirely underground.

The platform and concourse floors of the Emek station are at grade and underground respectively. On the contrary, the concourse floors of the Bahçelievler and Tandoğan stations are at grade whereas the platform floors are underground. Lastly, the Kızılay station was constructed underground as a joint station also serving for the Ankara Metro System.

The lengths of the facilities belonging to the ANKARAY project with a total investment cost of 518.000.000 DM are presented below.

AŞOT Tunnel (Depot area-AŞOT st)	:	437 m
Kızılay Tunnel		
- Demirtepe-Kızılay St.	:	625 m
- Kızılay-Kolej St.	:	583 m
Dikimevi Tail Tunnel	:	132 m
Cut and Cover Sections	:	4901 m
Stations	:	1217 m
At Grade Sections	:	216 m
Depressed Sections	:	413 m

In this paper, ground profile and groundwater conditions prevailing in the Kızılay tunnel are discussed and the stages of tunneling through the alluvium are described.

2. *LOCAL GEOLOGY*

The project route predominantly consists of Ankara Clay, partly Dikmen Formation and occasionally Alluvium and Volcanic Series.

The basement rock in the region is represented by the Paleozoic-Triassic Dikmen formation (grw) mainly consisting of schists and greywackes with occasional lenses of limestone and blocks of spillite.

The Volcanic Series of Miocene age observed along the stretch between Kurtuluş and Dikimevi stations on the route are generally formed of andesite, tuff and agglomerate.

The Ankara Clay generally formed of silty clay and sandy clay comprises occasional lenses of sand-gravel and carbonate concretions.

The actual valley floors and plains existing around Ankara are covered with the alluvial deposits of the Quaternary age.

3. *GROUND PROFILE*

The subsurface investigations performed by Yüksel Proje A.Ş. as to complement the previous studies along the Kızılay tunnel route reveal that the ground profile of concerned section is formed of the made ground, alluvium and Ankara clay (Fig.2).

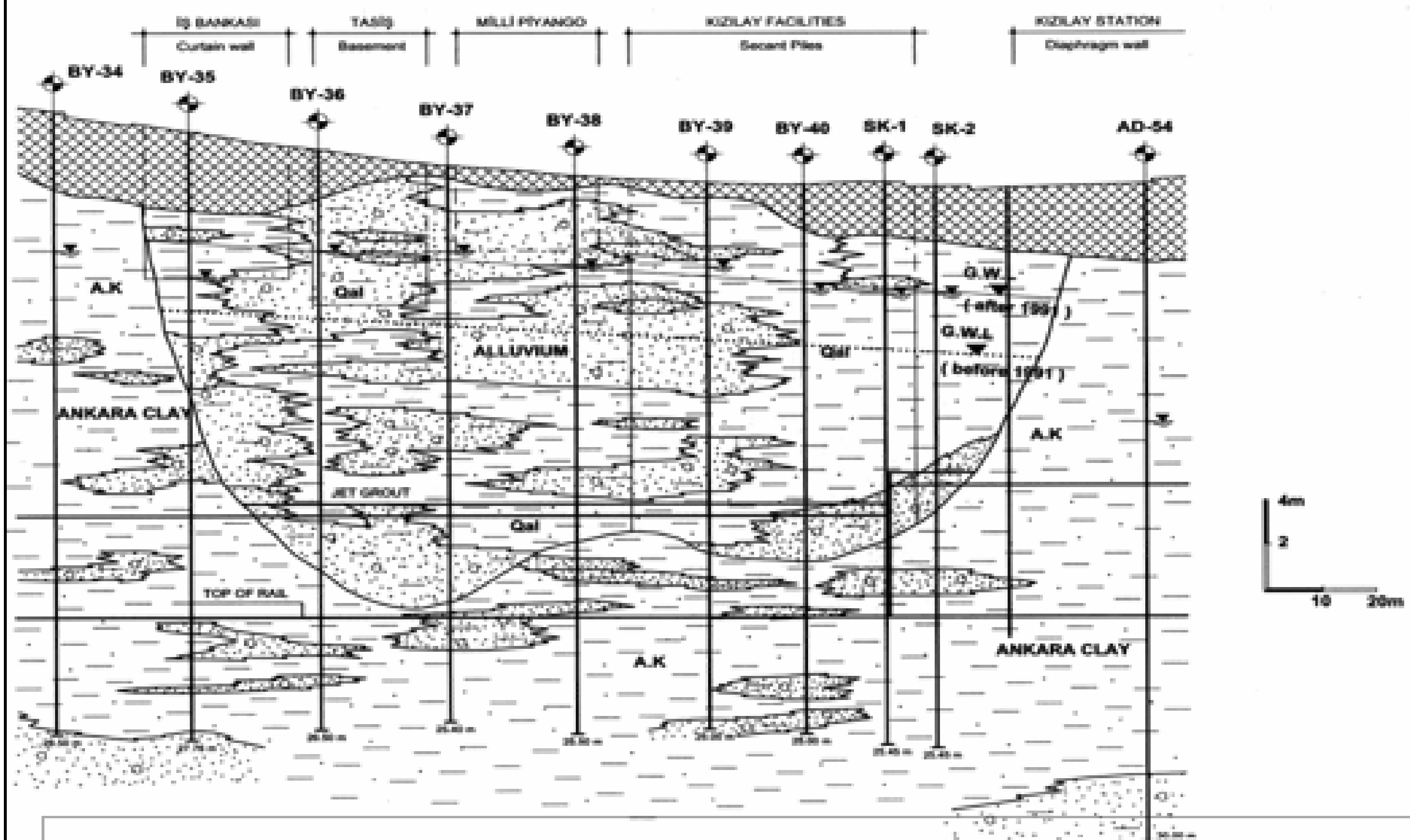

Fig.2 Geological Cross-Section of the Kızılay Area

3.1. *Made Ground*

The made ground observed on the surface is overlying the alluvium in this part of the route. It consists of compacted Ankara clay, fill material and pavement of the roads therein.

3.2. *Alluvium*

The alluvial areas existing along the route are formed of stream deposits in general. The alluvium observed in a small part of the Kızılay tunnel is represented by the mixture of greenish gray to brown, stiff to very stiff sandy clay of low to high plasticity and the lenses of clayey sand, silty sand, silty gravel and sandy gravel. The complex nature of the alluvial deposits is clearly shown on the soil profile prepared for the Kızılay tunnel (Fig.2). The alluvium is generally formed of alternating clay of low plasticity (CL) and coarse-grained soils with properties of SC, SM and SP. The typical soil properties representing the alluvial deposits are given in Fig.3.

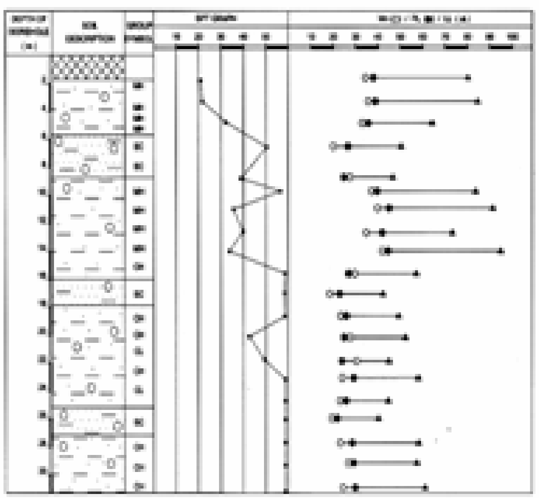

Fig.3 Typical Soil Properties of the Alluvium in the Kızılay Area

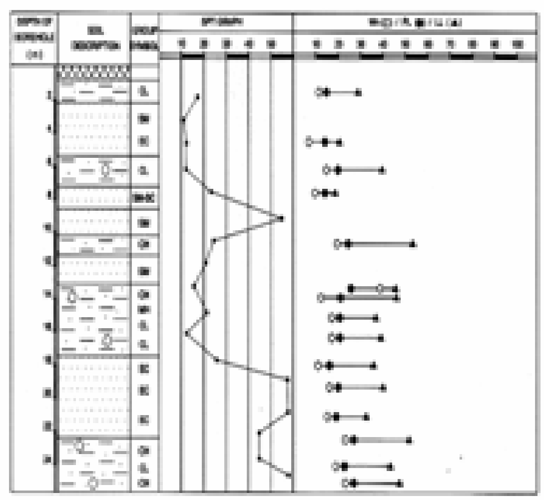

Fig.4 Typical Soil Properties of the Ankara Clay

Since the alluvial units are deposited along the valley floors, the groundwater level is relatively shallow and near the ground surface.

3.3. *Ankara Clay*

The most widespread unit existing along the Ankaray route is the Ankara clay. This unit is red, brown, beige, fissured, very stiff to hard silty clay of low to high plasticity with occasional lenses of sand - gravel and carbonate concretions.

The results obtained from a borehole drilled in the Ankara clay in the vicinity of the Kızılay station are summarized in Fig.4. The standard penetration values range from 20 to refusal in the Ankara clay whereas the liquid limit (LL) and plasticity index (PI) are around 63% respectively as per the above-mentioned results.

A typical feature of the Ankara clay is that this unit includes separate lenses of sand and gravel at different elevations. These lenses generally formed of clayey sand, silty sand and gravel are the sources of the perched water within the Ankara clay.

The Ankara clay includes different clay minerals depending on the mineralogical content of the rocks from which they were derived. It is thought that the montmorillonite and chlorite minerals most probably derived from the volcanic rocks and schist-greywacke respectively.

4. GEOTECHNICAL PROBLEMS

4.1. Soil Improvement and Tunnel Construction

A 120 m. long stretch of the Kızılay tunnel is formed of alluvial deposits represented by the mixture of clay, silt, sand and gravel. Soil improvement was recommended over this section in order to contribute to the tunnel stability through stabilizing the poor soil and to maintain safe working conditions. In this context, alternatives of ground freezing and jet grouting have been studied. The ground freezing method was not preferred due to requiring a long period and causing pollution of the groundwater. However, jet grouting was employed for soil treatment since this method was relatively rapid and practical.

Soil improvement was made in a 120 m. long stretch of the Kızılay tunnel passing through the alluvial deposits and existing below the groundwater table. In this method, the periphery of the tunnel was stabilized and groundwater leakage into the tunnel was minimized by forming grout columns in the crown and sidewalls of the tunnel (Fig.5). It has been decided to perform this method from the ground surface considering the difficulties in execution, time factor and water leakage that may originate from the probable deviation in the horizontal drilling in case of implementing this method inside the tunnel

A typical cross-section regarding this method is given in Fig. 5. The crown and sidewalls of the tunnel are stabilized by means of grout columns as shown in the related figure. Curtain walls intersecting the tunnel route at right angles were constructed at an interval of 25 meters in order to minimize the amount of water leaking from the space between the grout columns and to maintain the stability of the tunnel face (Fig. 6).

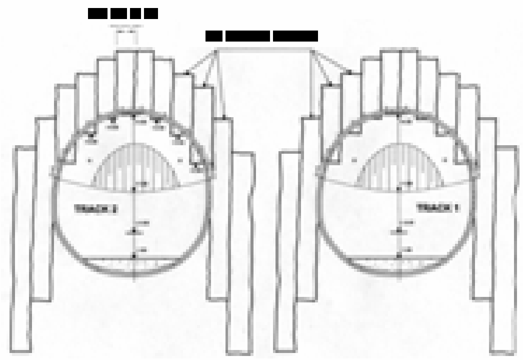

Fig.5 Soil Improvement with Jet Grouting

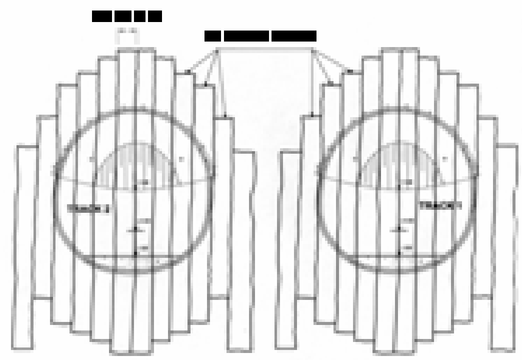

Fig.6 Construction of the Impermeable Curtain with Jet Grouting

In the jet grouting method, water/cement ratio, pressure, diameter of jetting nozzles at the tip of the bits, pulling and rotational speeds are determined depending upon the soil conditions. A series of test grouting has been accomplished for determining these parameters in the Kizilay tunnel. Following the completion of these tests, the above-mentioned parameters were modified in the following intervals and grout columns were made about 80 to 85 cm in diameter.

Water/cement ratio	W/C	= 0.7 – 1.0
Grout pressure	P	= 300-450 bar
Diameter of jetting nozzles	d	= 2.5 – 3.5 mm
Pulling speed	V	= 15 – 25 cm/min
Rotational speed	r	= 5-7 rpm
Spacing of boreholes	b	= 70-75 cm

The quality control was maintained by means of test drillings during the application of this method. Uniaxial and triaxial compressive strength tests have been conducted on the core samples, and modulus of elasticity was determined in addition to performing pressuremeter tests in the boreholes. The results obtained from these tests are summarized below.

Uniaxial compressive strength	qu	= 7.35-9.8 MPa
Natural unit weight	γ_n	= 16-18 kN/m^3
Modulus of elasticity	E_s	= 8000-10000 MPa
Cohesion	c	= 2 – 7 MPa
Internal friction angle	Ø	= $30^0 – 37^0$

The results obtained from the pressuremeter testing performed in the borehole within the grout column are as follows:

Limit pressure	P_L	= 300 – 5200 MPa
Modulus of elasticity	Ep	= 1860 – 76000 MPa

The results of the pressuremeter tests have such a wide range since it was failed to form continuous grout columns in general.

It is very difficult to change some parameters of grouting such as rotation speed, pressure and pulling speed in short intervals in accordance with the varved layers of sand and clay in the alluvium. The actual results of this application observed during the tunnel excavation show that the formation of grout columns was achieved in 30-35 percent due to the heterogeneous nature of the soil. The grout columns taking place and spreading of the grout material along the coarse-grained levels of the alluvium have contributed the tunnel stability and water tightness and consequently the tunnel excavation has been completed without any problem.

4.2. *Problems Faced in Constructing Jet Grout Columns*

The most significant problem encountered in the course of the jet grouting application is the displacement-taking place in the neighboring buildings as a result of the high pressure grouting since the tunnel route passes through densely populated areas. These displacements were observed in the walls of the excavation pits of the İş Bankası and Kızılay buildings existing 14-18 m far from the tunnel axis, on the present infrastructure box and along the Ziya Gökalp street. Heaving was observed up to 1.1 meters in height particularly along the street.

These displacements take place when the grout pressure finds a suitable path and spreads through the sandy levels within the alluvium and finally reaches some locations of porous medium, which can be controlled by no means. The jet grouting is applied through one of the three holes drilled at the corners of an equilateral triangle with sides 80 cm long. In order to avoid the displacement, two holes were drilled and left as relief holes prior to the grouting procedure. When the first displacements were observed, it was determined that the grouting procedure had been completed in 80 percent and any displacement was not recorded in the rest of the grouting operation.

4.3. *Groundwater Problems*

The alluvial deposits of the Kavaklıdere stream include a 150 long stretch from Km: 6+250 to Km: 6+400 along the Kızılay tunnel. The alluvium formed of varved layers of sand, clay and gravel reaches a depth of 20 meters occasionally (Fig.2).

The groundwater flows through the alluvium in the natural course of the stream in the S-N direction.

The groundwater flow was taking place under natural conditions where the groundwater table was 7.0 meters as per the previous borehole data. However, foundation excavations, secant piles and diaphragm walls have been made recently in the Kızılay region in connection with the Metro station and Kızılay Facilities prior to the ANKARAY project. These structures have closed a significant part of the alluvial section and consequently the groundwater level has risen up to 4.0 m. due to these obstacles as it was confirmed by the boreholes made over this area in 1991 and 1992 (Fig.2).

In addition, a curtain wall with anchors was constructed in the west side of the alluvium in the Iş Bankası area. The foundations of the Milli Piyango building situated between the pile wall and curtain wall are above the groundwater table in elevation whereas the Tasiş building partly remains in the aquifer. Under prevailing conditions, the groundwater is flowing through an alluvial section of about 17.0 m. wide between the diaphragm wall of the Metro station and pile wall of the Kızılay facilities and through the alluvial medium of 60 m. wide in-between the pile wall and curtain wall (Fig.2 and 7).

The narrowing of the sectional area formed by the above-mentioned structures causes the groundwater to rise about 3.0 meters in the upstream. According to Darcy's law, the amount of groundwater flow passing through the alluvial aquifer in the Kızılay region is defined by the following equation.

$$Q=T.i.G.$$

where ;

Q = amount of water (m^3/day)
i = hydraulic gradient
T = transmissibility (m^3/day/m) ⇨ T = k.m
k = permeability (m^3/day/m)
m = thickness of the unit (m)
G = width of the alluvium (m)

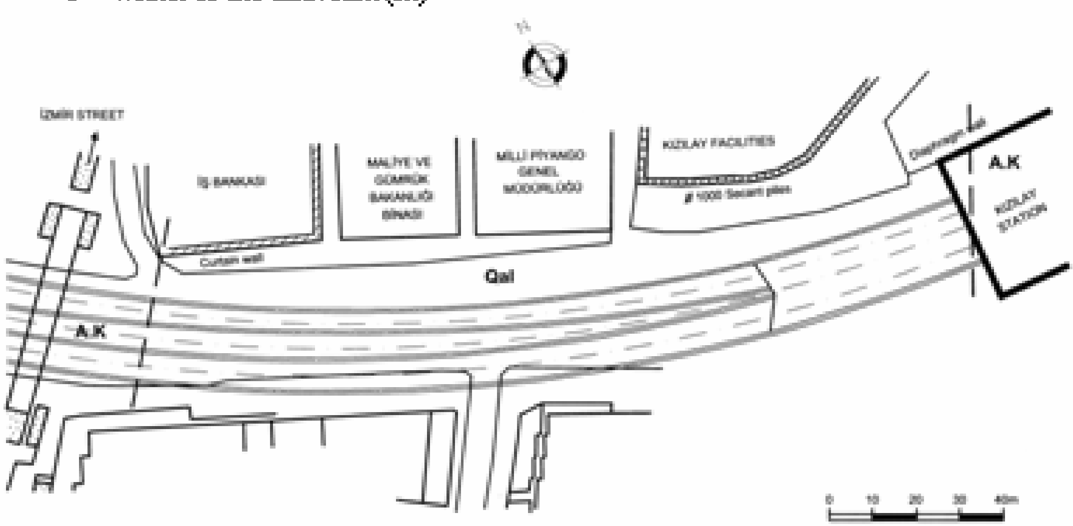

Fig.7 Plan View of the Kızılay Area

As the value of "G" (width) decreases by the foundation structures, groundwater rises about 3.0 m. in elevation and increases the value of "i" in order to maintain the same amount of groundwater flowing downstream.

Following the stabilization of the alluvial deposits along the tunnel route through employing the jet grouting method, an impermeable wall has been formed about 4.0 to 7.0 m in height from the bottom of the alluvium upwards during the tunnel construction works. The sectional area of the alluvium is about 2000 m^2 below the prevailing groundwater table. The Metro station, Kızılay facilities, Tasiş building and Iş Bankası building have already closed a sectional area of 800 m^2 in total. Thus, the groundwater is flowing through a sectional area of 1200 m^2 in the alluvium.

As a result, the particular area of about 600 m^2 obstructed by the ANKARAY project in the alluvial aquifer is smaller than the section closed by various foundation structures in the downstream of the tunnel alignment. Therefore, the prevailing high groundwater table-taking place as a consequence of the disturbed natural equilibrium is not expected to be affected more by the implementation of the ANKARAY Project.

Groundwater levels have been measured in the observation wells in the course of the jet grouting works and the relevant records have been submitted to the Client. On the other hand, irregular fluctuations of 50 cm. have been recorded in the groundwater level but the groundwater has attained its normal level parallel to the completion of the soil treatment. As a result, any drainage measure is not essential in this region since any variation in the groundwater regime has not occurred due to the tunnel construction.

5. CONCLUSIONS

The alluvial section of the Kızılay tunnel has been improved through constructing jet grout columns. Following the implementation, the tunnel was excavated in a better soil condition and it was observed that the groundwater had attained its normal level parallel to the completion of the soil treatment.

REFERENCES

1. OZASLAN, H., (1992) "ANKARAY Project – Geotechnical Appraisal Report for the Strip between Km: 6+250 – 6+400 along the Kızılay Tunnel" (Turkish), ANKARA

2. BAYDUR, I.H., OZASLAN, H., HOROZ, A., (1994) "ANKARAY Project – Geotechnical Applications" (Turkish) Proceedings of Soil Mechanics and Foundation Engineering, Fifth National Congress, Volume 3, page 961 – 1013 ANKARA