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Case study – deformations and remedial measures for Nefise Akçelik and Asarkayası tunnels on Black Sea Costal Road Project

M. Vardar
Istanbul Technical University-Faculty of Mines, Turkey

H. Karaoğlan
Emay Int. Eng. Cons. & Trd. Co. Ltd, Turkey

Z. Etkesen & E. Akiş
General Directorate of Highways, Turkey

ABSTRACT: Nefise Akçelik Tunnel and Asarkayası tunnel are constructed in the scope of Black Sea Coastal Road Project in Turkey. Basalt agglomerates and tuffs formed as submarine volcanism along the twin tunnels alignment. For Nefise Akçelik and Asarkayasi tunnels the lengths are 3776 meters and 306 meters, along the problematic sections overburden heights are 375 meters and 110 meters respectively. After completion of excavation and installation of primary supports, high displacement occurred. The morphology is controlled by young tectonic activity and erosion. Along the fault zone there are water incomes into the tunnels. In this paper engineering geological and geomechanical reasons for deformations are described and rehabilitation design approaches are given as case studies.

1 INTRODUCTION

Both of the tunnels are constructed in the scope of Black Sea Coastal Road Project in Turkey. This coastal route project is one of the important projects as it connects northeast neighbors (Georgia, Armenia and Azerbaijan) to Turkey and Europe.

Nefise Akçelik tunnel is the longest double tube tunnel with a length of 3776 m in Turkey. Depth of the tunnel is 33 meters in portals and ranges between 75–375 meters throughout the route. The diameter of the tunnel is 12.6 meters and the cross section area after excavation is 80.96 m^2. The problematic sections, where high deformations occurred are approximately 117 meters for the left tube and 49 meters long for the right tube.

Asarkayasi tunnel has a length of 306 and 310 meters for the left and right tubes respectively. Depth of the tunnel is 20–30 meters in portals and reaches 110 meters throughout the route. The diameter of the tunnel is 12.6 meters and the cross section area after excavation is 90.99 m^2. The problematic sections are approximately 35 meters + 28 meters = 63 meters long for the left tube and 37 meters long for the right tube.

Tunnels are driven under difficult conditions due to morphology and geology. In addition to these conditions, there is water income into Nefise Akçelik Tunnel. In Asarkayasi Tunnel, there is no excessive ground water flow. The morphology on the tunnels route is controlled by young tectonic activity and erosion.

Deformations were occurred after completion of excavation and installation of primary support system of Nefise Akçelik and Asarkayasi Tunnels. Surface geology, fault systems, tunnel geological mapping, deformation records were evaluated to estimate the stress distribution and rock parameters in problematic sections.

This paper presents example of deformations occurred in tunnels through weak geological sections and summarizes the rehabilitation design approaches for problematic sections.

2 NEFİSE AKCELİK TUNNEL

Along the problematic section, according to New Australian Tunnelling Method (NATM), B2 rock support (rock bolts and shotcrete) and B3 rock support (rock bolts, shotcrete, steel ribs, without invert) had been installed in the problematic sections of left tube and right tube respectively.

Convergence measurements were recorded and geological mapping were done during construction. In May 2002, excavation and primary support of the right tube was completed. In August 2002, excavation of the left tube was done by blasting. After blasting, the shotcrete at the roof and shoulders in the right tube cracked heaved and fell Maximum deformation measured was 14 cm. As an immediate measure for this situation, after re-excavating, extra bolts (6–8 m) were installed.

The tunnel construction was stopped due to financial problems up to May 2003. During this period, deformations continued. Since the deformation rate was beyond acceptable limits, inner lining could not be constructed.

After June 2003, following investigation studies were done; surface geology and fault systems were restudied, radial deformations (24 points on one cross-section) were recorded with 2 meters intervals. Deformations are evaluated due to last 1.5 months records. According to the tunnel geological mapping (Fig. 1) (considering the fault systems, water effect, weak zones) and deformation records, the parameters of the surrounding rock types were determined by back analyses. Then, rehabilitation project was designed.

According to the studies, it was seen that the morphology on the tunnel route is controlled by tectonic activity and erosion. Because of this, the region is surrounded by steep valleys and rivers still continue to erode the valley beds. At the section, where high deformations occurred, the tunnel is driven parallel to east-west directional fault controlled valley, where the fault and tunnel crosses each other. As it can be seen on Figure 2, the tunnel is compressed by tectonic forces at this section.

2.1 *Results of investigation studies*

The tunnel route is settling along the Upper Cretaceous basaltic, andesitic lavas and pyroclasts, and overlapped by Upper Cretaceous – Eocene sediments and carbonate rocks, Brinkmann (1974). Nefise Akçelik tunnel is driven throughout volcano-clastic series. These series include basaltic lavas (basalts, diabase), basaltic pyroclasts (andesitic, basaltic tuff-agglomerate) and sedimentary rocks (claystone, mudstone, shale) as lithological units. Tunnel base map was prepared to observe the lithologies and fault direction beneath the surface.

Volcanic units are usually jointed and filling materials are calcite and clay. Fillings have a thickness ranges between 1 mm to 15 cm. Also opened cracks are common. This structure yields to the circulation of the groundwater throughout the joint systems. In the tunnel driven zone, groundwater is collected and the tunnel becomes a collector gallery. That drain system affects the clay and tuff units at the invert, and the units become softer. So that tuffs altered and clay zones become softer.

2.2 *Engineering geology and deformations of the left tube*

Clay zones are the product of basalt lavas and calcite filled basalts, altered by groundwater. Clay zones cause to excessive deformation problems at the invert. There are no displacements in clastic units (agglomerates), but also water income is excessively high in these units. Left tube is crossed by NW-SE and NE-SW directional faults. As tunnel driven, the fault systems caused to cracking and loosening strength of the volcanic units.

The last 1.5 month displacements were ~5 cm at the roof, 13 cm at side walls and 20 cm at the bottom.

2.3 *Engineering geology and deformations of the right tube*

NW-SE and NE-SW directional faults cross each other along the right tube. This structure yields to produce clay zones. The tunnel base includes clayey

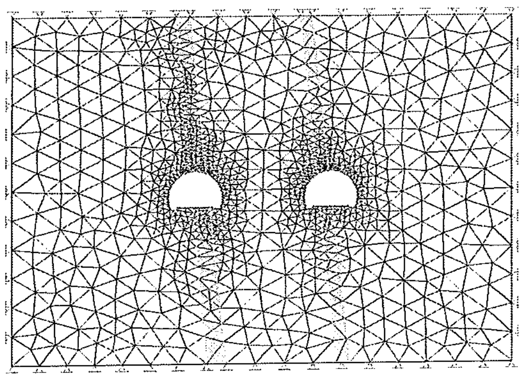

Figure 1. Geological model used for numerical analysis.

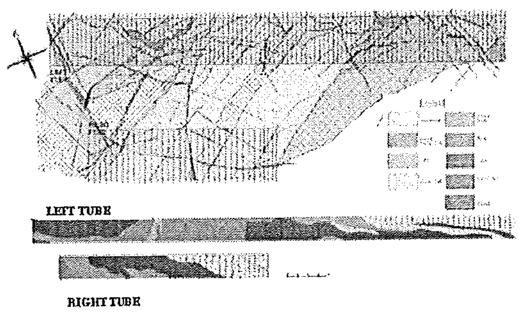

Figure 2. Tunnel level geology map and cross-section chainage 10+683.00–10+800.60 km for the left tube and 10+693.10–10+742.10 km for the right tube.

silty lithologies. Andesitic and basaltic clay layers overlap these lithologies. Andesitic and basaltic tuffs are weak between chainage in problemitic section, and separated with clayey units by NW-SE directional faults.

The last 1.5 month displacements were 5 cm at the roof, shoulders and left side wall, 9.5 cm right side wall.

2.4 *Rehabilitation project*

The rehabilitation project was consists of following steps; drainage measures, forming the ring with invert.

For right tube (from B2 to B3 rock support) excavation and construction stages: (Fig. 3a)

Top heading:
Excavation between existing steel ribs
Installation extra ribs, shotcrete and wire mesh.
Installation extra bolts (Ø28, L = 6 m)
Invert:
Invert excavation and installation of drainage system.

If required, forming the ring with installation extra bolts at toes (L = 12 m) and at the bottom (L = 6 m) of the invert.

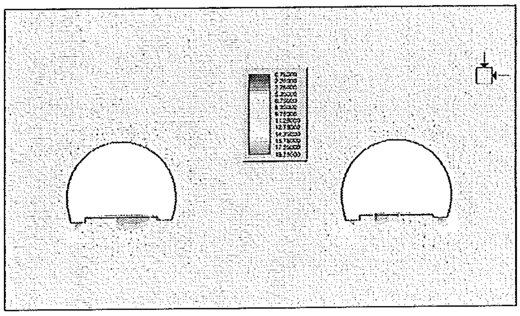

Figure 3a. Excavation and construction stages for B2 to B3 support.

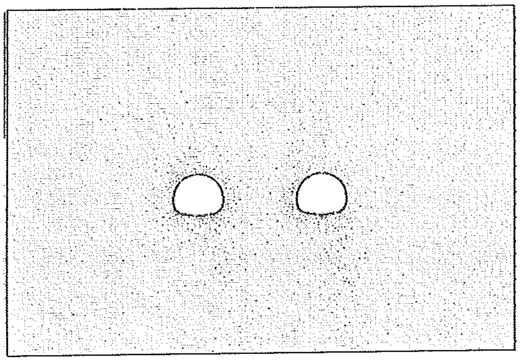

Figure 3b. Excavation and construction stages for B3 rock support.

Construction of foundations beams between foundations and inner lining.

For right tube (B3 rock support) (Fig. 3b)

Excavation of invert and installation of drainage system.

Forming the ring with installation wire mesh, shotcrete and steel ribs.

Installation of bolts at the toes (L = 8–12 m)

If required, installation of bolts (L = 6 m) at the bottom of the invert.

Construction of foundation beams between foundations and inner lining.

3 ASARKAYASI TUNNEL

NATM C2 rock support had been applied during construction since the deformations were lower than expected, the invert was not constructed.

Convergence measurements were recorded and geological mapping were done during construction. In the problematic sections over breaks on shoulders and roof stability problems at face occurred.

After completing the excavation and primary support, the inner lining and drainage system could not be constructed due to financial problems.

After two years records showed heaving and settlements at the bottom on shoulders and side walls. The deformations were acceptable but continued so the inner lining could not be constructed.

Following investigation studies were done; surface geology and fault systems were restudied, radial deformations, tunnel geological mapping (Fig. 4) (considering the fault systems, weak zones) were evaluated. Parameters of surrounding rock type were determined by back analysis. Then rehabilitation project was done.

3.1 *Result of investigation*

The morphology is similar with the Nefise AKÇELİK tunnel. During construction no excessive water income was exposed. Water was formed as dropping, seepage and small springs.

The tunnel is crossed perpendicularly by N-S directional fault. Fault zone material consists of

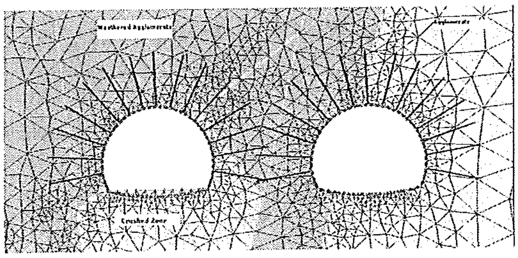

Figure 4. Geological model used for numerical analysis.

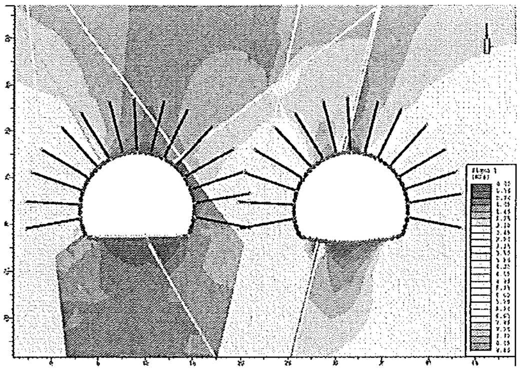

Figure 5. Analysis Results for Rehabilitation Project – Stress Distribution Around Tunnels

agglomerates volcano bres, mudstone, claystone, basaltic tuff, with very weak strength, highly weathering fractured and cracked.

3.1.1 *Left tube*

In first problematic section 35 m in length the tunnel was excavated in andesite, riyolit, riyadesit. The formation is moderately high weathered, has moderately strong-very weak strength. Because of extremely high alliterations, prophilites occured. Units have random and uncontinued discontinuities. Joint filling material is Mn0 and clay.

In second problematic section 28 m in length the formation similar with the first section. Fault zone dip direction is through the tunnel.

Fault zone materials consist of swelling clay at the bottom of the tunnel. 10 cm heaving occurred at the bottom depending on swelling clay, 3 cm convergence occurred in the tunnel.

3.2 *Rehabilitation project*

Considering geological mapping, deformations, the geological model was prepared and the parameters were determined by back analysis. Then the rehabilitation project was designed.

Since the deformations are smaller than Nefise Akçelik tunnel deformations, the lighter measurements were sufficient.

The rehabilitation project includes following stages: (Fig. 5)

- Excavation of the bottom for invert (~2 m).
- Installation drainage system at the bottom of invert.
- Forming the ring with shotcrete, wire mesh and steel ribs.
- Filling the invert with concrete.

4 CONCLUSION

Nefise Akçelik and Asarkayasi tunnels route has a morphology controlled young tectonic activity and erosion. The area crossed fault systems and geological weak zones. As a result of stopping the tunnels construction and insufficient drainage system caused the deformations in the tunnels. Deformation records related with the construction may lead the project without living that kind of problems.

According to engineering geological and geomechanical evaluations, new design projects including invert, extra supports drainage systems were applied. Deformations decreases under the limit values and inner linings were constructed.

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