AN OVERVIEW OF THE CONSTRUCTION OF TURKEY'S LONGEST ROAD TUNNEL FOCUSING ON GROUND SUPPORT USING MACRO SYNTHETIC FIBERS AS SHOTCRETE REINFORCEMENT

P. Guner
Unitek Insaat San. Ve Tic. A.S., Istanbul, Turkiye.

H. A. Eryigit
Mak-Yol Insaat San. Tic. Ve Tur. A.S., Istanbul, Turkiye.

A. Sayin
Turkish Ministry Of Transportation Highway Authority 10th Regional Management, Trabzon, Turkiye.

B. Kocak
TTS International Engineering and Architecture, Istanbul, Turkiye.

ABSTRACT: Mount Ovit Tunnel (Turkish: Ovit Dağı Tüneli), is a highway tunnel under construction through Mount Ovit which is 2600 m in height and 12.6 km in length. Initially the project faced many problems caused by highly unstable portal batters, and fault zones with high water inflows and difficult rock conditions. Macro synthetic fiber reinforced shotcrete FRS lining was considered to use instead of steel mesh to increase the excavation speed of the NATM tunnel so as to form a fast shotcrete lining and keep tunnel deformation within the specified limits. This paper examines the design of macro synthetic FRS lining for the projects different NATM support categories, FRS quality control test result including EFNARC plates, convergence monitoring, together with the back calculations and their analysis. A comparison between the advance speeds of the excavation for each of the trial tubes using different reinforcement methods will be analyzed.

1 INTRODUCTION

1.1 *Project Overview*

The Ovit tunnel between Rize (İkizdere) – Erzurum (İspir) regions, is a twin bore highway tunnel with an approximate length of 12.6 km. At the western end of the tunnel, an approximately 1.4 km long avalanche tunnel, with the same, closed cross section as the underground tunnel is added. The total length of one tube of the entire tunnel is 14 km and at is expected to become the world's 4th longest road tunnel. It is planned that the tunnel will be opened to traffic in 2015. When the project is completed the travel time between the south eastern province of Mardin and the Black Sea province of Rize will drop to just 4.5 hours from the current 10-11 hours. The tunnel will enable the transport of crops and goods all year round between Rize and Erzurum. The current passage over the mountains is mostly closed during winters due to risk of avalanches and heavy snow.

The project is being constructed by Turkish Contractor Makyol Construction at an estimated cost of USD 350 million (800 million Turkish Liras). Construction facilities and tunnel construction begun in October 2012 and it is planned that the tunnel will be opened to traffic in 2015.

The Ovit tunnel bores are two lane tunnels with 8.0 m x 5.0 m clearance and the excavation cross sectional area varies form 88.72 m^2 to 115.97 m^2. The width of the final lining is 10.60 m at springline and the width of the excavation at springline varies between 11.94 and 12.5 meters. Figure 1 shows a typical cross section of the tunnel with and without an invert (TTS, 2013).

The tunnels are currently being excavated and supported utilizing the New Austrian Tunneling Method (NATM) and the technical codes of the General Directorate of Highways of Turkey (Karayolları Teknik Sartnamesi-KTS, 2006).

The initial support utilizes shotcrete, reinforced with wire mesh and rock bolts for rock reinforcement. In difficult ground conditions, additional support is provided by IPN type steel ribs and forepoling piles with a varying diameter of between 50.80 – 88.90 mm. The tunnels are driven from four faces. Excavation is being done by drill and blast in hard rock conditions and impact hammer in softer ground.

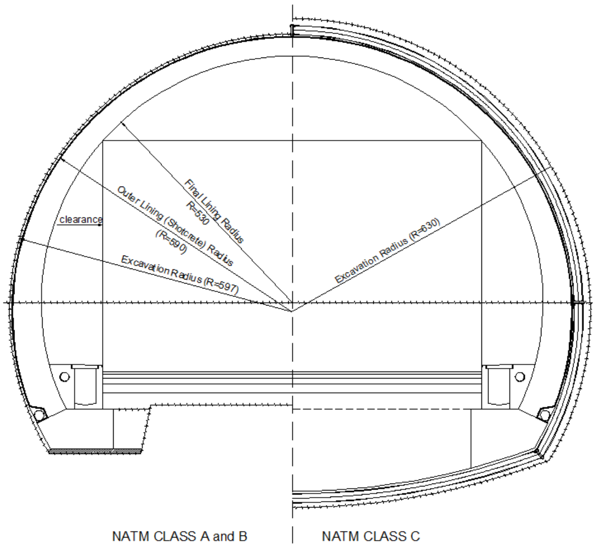

Figure 1. Ovit Tunnel typical cross section

There were many difficulties during the excavation of the 1000 m tubes including highly unstable slopes, many fault zones with high water inflows and difficult weather conditions. Figure 2 shows the type of winter weather conditions that the Ovit Tunnel is subjected to.

Figure 2. Ovit Tunnel Winter, 2013

These difficulties hindered the excavation work causing the project to fall behind schedule. Unfortunately the geology of the twin tube tunnel only allowed excavation at four faces of the twin tube tunnel with no opportunity to increase excavation rates with an approach tunnel. The use of steel mesh reinforcement in the shotcrete lining also presented safety issues and relatively slows application. Macro synthetic fiber reinforcement was considered because of its advantages over conventional steel mesh reinforcement and the project undertook a detailed review to prove up this potential. Consequently a full design review was undertaken followed by field and laboratory testing.

1.2 *Geological Setting*

The tunnel runs Northwest – Southeast through the Ovit mountain. The elevation of the entrance portal is about at 2050 meters and roughly one third of the tunnel is sloped 1.1% in the opposite direction. At the southeast portal, the elevation reaches up to 2260 meters. The overburden of the tunnel is about 850 – 900 m maximum, and 400 – 500 m on average.

The tunnel lies within three main geological formations. The Kackar Granitoids are massive, homogenous, jointed rocks. These Mesozoic aged rocks are grey in color; fresh with good quality rock and high rock mass strength. The second formation, Kackar porphyries are more fractured compared to the granitoids. Dikes, sills and hydrothermal weathering zones are the main structures of the porphyries and granitoids which are cut off by this geologic formation in many locations. Catak formation, located at the southeast section of the tunnel, consists of basaltic lavas and pyroclasts. The formation is cut by sediment rock layers like claystone, marl and siltstone (TTS, 2013).

Figure 3 shows the geological plan and simplified longitudinal section of the Ovit tunnel (Tüysüz & Genç, 2012). According to the engineering geological, geomechanical and geotechnical investigations, the 12.6 km long tunnel route was classified into 27 homogenous sections. With respect to Önorm B2201 and KTS; 6 different NATM rock support categories varying between A2 to C2 were assigned to the sections.

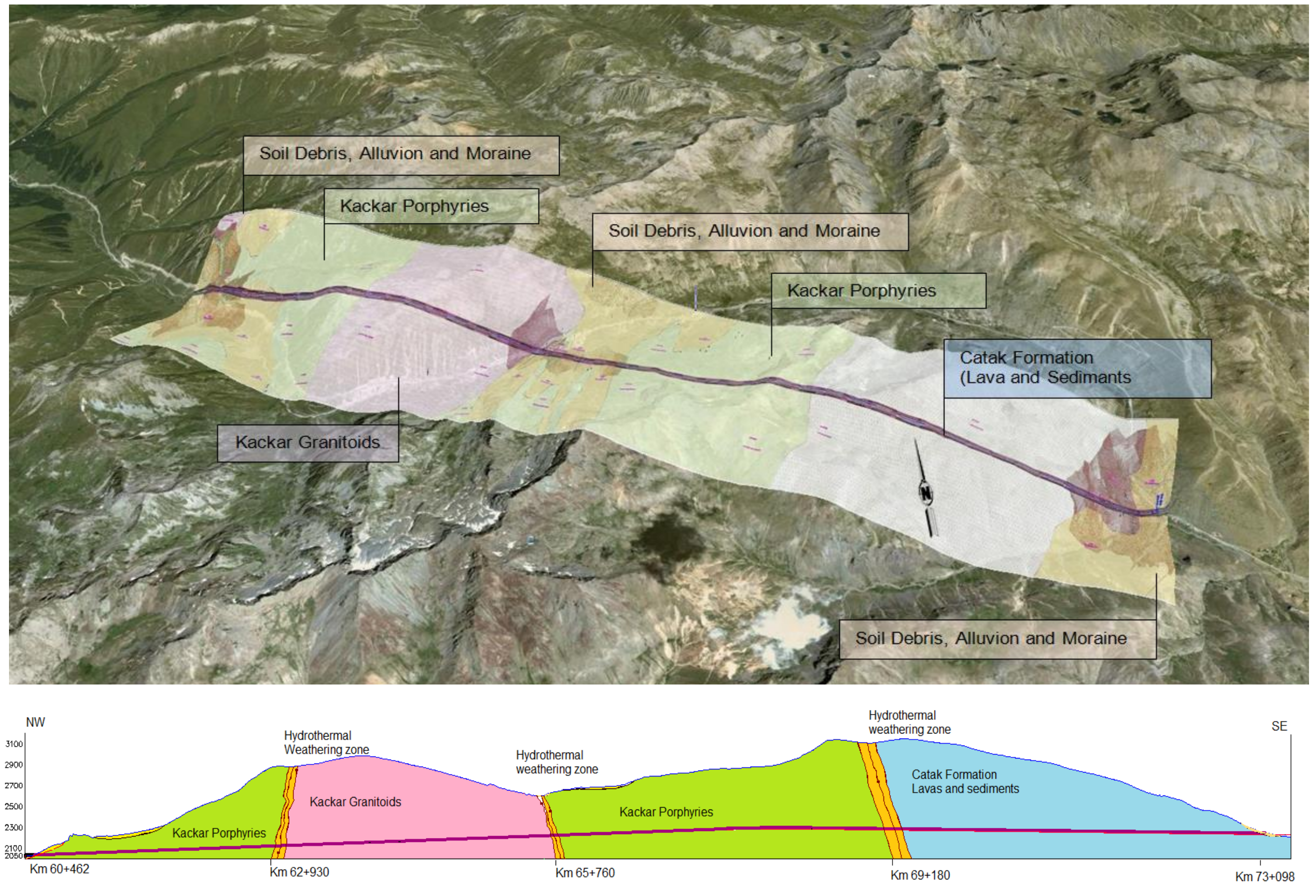

Figure 3. Geological plan and longitudinal section of the Ovit tunnel

1.3 *NATM Construction*

At the Ovit tunnel, NATM A1 and B1 categories are flexible and light support classes, used in hard rock conditions. Category B2 is applied in transition zones from stiff to soft rock or conversely B3 and C2 categories consist of stiff and heavy support which is applied in weathering zones. These zones carry groundwater into the tunnel. Crushed, granular cohesion-less rock forms the weakness zones at the Ovit tunnel.

In both the flexible and rigid tunnel supports, all NATM classes were designed to use welded wire mesh for primary shotcrete lining reinforcement. Wire mesh was chosen because in Turkey the use of this type of conventional reinforcement is very common. Class B1 includes a single layer of Q221/221 (Φ6/150 grid 221mm^2/m) mesh reinforced with 10 cm C30/37 shotcrete in combination with 6 or 7 SN type 4.0 m (Φ28) rock bolts; for categories B2, B3 and C2 a double layer of Q221/221 mesh was specified with an increased shotcrete thickness and between 16 and 22 rock bolts per round incorporating steel ribs of either IPN 160 mm or IPN 200 mm. NATM Class C1 is used in deep tunnel sections driven through massive granite where rock burst problems occur. This NATM class was designed to use a double layer of Q589/378 (Φ10,5/150 and Φ8,5/150) mesh (TTS, 2013).

As for other major tunneling projects rapid tunneling under safe conditions is the primary goal and the Ovit tunnel was no different. In order to increase the construction speed, attempting to minimize the time spent installing ground support is crucial. Therefore, using fiber reinforcement instead of welded wire mesh for the shotcrete reinforcement was investigated. The Turkish Highway Authority’s 10th Regional Management was keen to increase the speed of excavation of the twin tube tunnel and at the same time provide a safe shotcrete lining which performed the same or better than the current mesh reinforcement and so macro synthetic fiber reinforced shotcrete lining was chosen to replace the steel mesh reinforcement. Significant trialing in May 2013 led to the change to the highly durable macro synthetic fiber to replace the mesh which has since proven to show a much safer and more efficient form of ground support.

2 MACRO SYNTHETIC FIBER REINFORCED SHOTCRETE LINING OF THE OVIT TUNNEL

2.1 Macro synthetic fibers

The use of macro synthetic fiber reinforced shotcrete in tunnels is not very common in Turkey due to lack of FRS design codes, practices of designers and contractors. Therefore, conventional welded wire fabric reinforcements are preferred. However, the General Directorate of Highways (KGM) and many contractors are aware of the advantages and applicability of FRS, and the recent works of KGM smoothed the way for the adoption of fiber reinforcement on this and other projects in Turkey. Synthetic fibers were also defined in the KGM's technical specifications (KTS, 2006).

The British Tunneling Society (BTS) specifies the use of fiber reinforcement for shotcrete reinforcement and this was taken into consideration when choosing the synthetic fibers (BTS, 2010):

- Structural macro synthetic fibers shall be in accordance with BS EN 14889-2. Only Class II fibers shall be used where fibers are incorporated for structural purposes,
- The minimum tensile strength for steel fibers is 800 MPa and for macro-synthetic fibers 500 MPa.

Moreover, aside from the fibers material characteristics the surface embossing of the synthetic fiber is also important to its performance in the shotcrete. According to the Barton, '*Dramix steel fibers and the best BarChip polypropylene (surface-roughened) fibers are equally acceptable for their fracture energy enhancement of the S(fr). Smooth floor-slab fiber qualities should not be used in tunnels'* (2012).

The main advantages of macro synthetic fiber reinforced shotcrete in tunneling over wire mesh reinforcement can be summarized as (EPC Tunneling Booklet):

- No steel fixing - therefore safer working conditions during excavation and an increase in construction speed;
- Higher quality can be obtained for shotcrete applications;
- Reduced voids and better contact between shotcrete and rock wall;
- Synthetic fiber does not corrode;
- Increase in the shotcrete's performance characteristics because the reinforcement is throughout the entire thickness and in all directions (3D);
- Synthetic fibers do not damage the equipment and provide much safer working conditions than the steel fibers.

2.2 Specification of the FRS lining

The design of macro synthetic fiber reinforced shotcrete is done using empirical methods based on case histories as well as by capacity limit curves that are based on equivalency considerations of a steel mesh reinforced shotcrete section.

At the Ovit tunnel, expected deformations vary between 30 mm to 100 mm. NATM categories B1 and B2 have deformation tolerances up to 50 mm, where the displacements are expected to be limited and decreasing with time. In NATM categories B3 and C2, deformation tolerances were 100 mm. At the Ovit Tunnel 95 % of the remaining excavation the ground conditions are expected to be in fair and good rock qualities which are defined in B1, B2 and B3 categories. According to the Q Barton Chart (Barton & Grimstad, 2004), FRS lining specified flexural toughness requirement is 700 Joules at 28 days according to EN 14885 - 5 (testing sprayed concrete part 5: determination of energy absorption capacity of fiber reinforced slab specimens) EFNARC plate test (2006).

Ground support elements such as shotcrete thickness, rock bolts and the IPN type steel ribs remain the same as the existing design. Especially in poor and very poor ground conditions including fault zones with high water content, using hybrid reinforcement as 1 layer steel mesh reinforcement with FRS shotcrete application has been specified. Moreover, in the same fault zones where there is a danger of collapse it has been suggested to use both a double layer of steel mesh with FRS to increase the ductility of the shotcrete and prevent the risk of damage due to the failure of the weak ground while placing the steel mesh. Shotcrete thickness of the each category is given in Table 1 (TTS, 2013).

Table 1. Shotcrete thicknesses of the NATM categories.

NATM	Flash (cm)	1st App. (cm)	2nd App. (cm)	Total (cm)
A2	-	7	-	7
B1	5	5	-	10
B2	5	15	5	25
B3	5	15	10	30
C1	5	15	10	30
C2	5	20	15	40

Laboratory test results from a macro synthetic fiber has been provided to evaluate its applicability in the Ovit tunnel. The performance of the macro synthetic fiber reinforced shotcrete was measured in the field by laboratory tests and convergence measurements. These results will be discussed in the next sections. Fiber properties are as follows (EPC catalog):

Base Resin: Modified Olefin
Length: 54 mm
Tensile Strength: 580 MPa
Surface Texture: continuously embossed
No. of fibers: 37000 pieces/kg
Specific Gravity: 0.90 – 0.92 gr/cm^3
Young's Modulus: 12 GPa
Melting Point: 159 – 179 ^{o}C
Ignition Point: over 450 ^{o}C

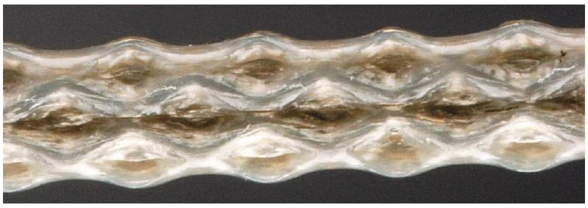

Figure 3. Microscopic view of a macro synthetic fiber showing the highly engineered embossing.

2.3 *Quality control testing program of FRS*

Quality control tests of the macro synthetic fiber reinforced shotcrete have been determined in accordance with the requirements of KGM's technical specifications for sprayed concrete. These requirements are similar with the European specification for sprayed concrete and according to the frequency of the control tests of FRS which is given in the table 2, the normal type of control has been determined. (Efnarc, 1996).

Table 2. Frequency of control testing

Type of Control	Minor (m^2)	Normal (m^2)	Extended (m^2)
Compressive Strength	500	250	100
Flexural Strength	-	500	250
Residual Strength	-	1000	500
Energy Absorption	-	1000	500
Bond	-	500	250
Fiber Content	-	250	10

However, in practice it has been recognized that performing the normal control test frequency in the construction site laboratories will be very difficult. Therefore, similar worldwide past project experiences and test programs for FRS were taken into consideration and the quality control tests types reduced. Core compressive strength test EN 4012, energy absorption EFNARC plate test EN 14488-5 test and thickness control were specified for the quality control tests of the macro synthetic fiber reinforced shotcrete. The performance control of the FRS lining has been supported with convergence monitoring and back analysis. According to the project design compressive strength specification of the wet mix shotcrete class is C30/37. Average core compressive strength test results of the shotcrete are given in the table 3.

Table 3. Average core compressive shotcrete strength

Days	Average Core Compressive Strength to the date, MPa
1	15
7	26
28	33

3. PERFORMING EFNARC PANEL TEST AND THE RESULTS

Energy absorption tests performed according to the EN – 14488-5 (testing sprayed concrete part 5: determination of energy absorption capacity of fiber reinforced slab specimens). Due to the location of the Ovit Tunnel, it was difficult to spray the test panels and then transport them to a university laboratory so EFNARC plate testing equipment were set up at the construction site's quality laboratories. For the first time in Turkey the plate tests were performed at both tunnel sites.

Steel specimen molds were prepared (600 x 600 x 100 mm) which are shown in figure 5. All the mold angles had a 45 degree angle to allow the wet mix rebound to out of the mold and they were cured in the onsite laboratories' curing tanks until the testing date. Special care has to be taken in how the test specimens are handled from spraying in the tunnel to transporting to the laboratory to ensure that they are not damaged.

Figure 5. 600x600x100mm dimensions panels

The following precautions should be applied to the preparation of test specimens (Decker, 2010):

- The panels sprayed in the tunnel should be in a location where they will not impede production and will not be disturbed;
- If the panels are handled too early during the curing process, the result can be drastically reduced;
- Attention must be given to the means of transporting specimen to limit disturbance and to limit the possibility of a panel falling or striking any personnel,
- The panels also need to be stripped, the stripping process can lead to sample disturbance as well,
- The accelerator dosage, closeness of nozzle to panel and finishing of panel have a big effect on the results.

3.1. *EFNARC Plate Test Results*

EFNARC plate tests were tested with a semi-automatic machine in the site laboratories. The load was measured by a manometer and the displacements measured by a 50 mm comparator (Figure 6). The tests were performed at 7 and 28 day on cured test specimens but it was found that keeping the very big test specimens in the laboratory pools caused difficulties therefore the tests at 28 days were not cured beyond 7 days.

Figure 6. Efnarc plate test system and cracked specimen

The average total energy absorption of the 28 day specimens of the macro synthetic fiber reinforced shotcrete was 900 Joules at 25 mm displacement and 7 day cured specimens have over 700 Joules energy absorption at 25 mm displacement. Figure 7 shows the 28 day test result typical load displacement curve. The monthly 7 day cured specimens average energy absorption test results are given in the figure 8 (Ovit Tunnel monthly activity report, 2013).

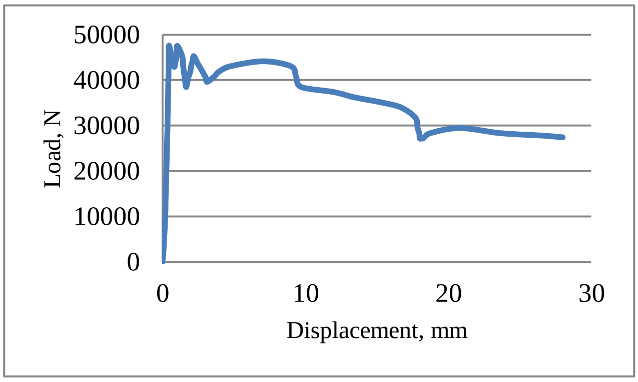

Figure 7. Typical load – displacement curve of the 28 day cured test specimen

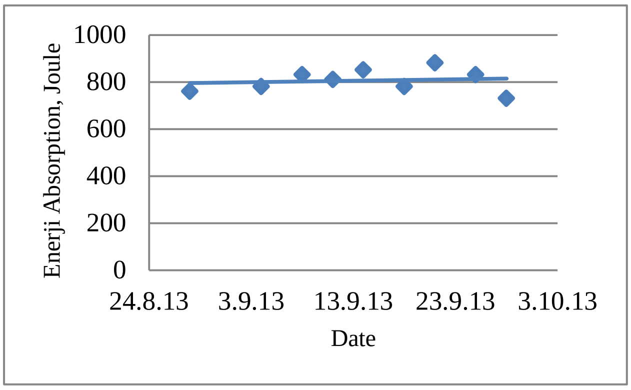

Figure 8. 7 day total energy absorption test results from the monthly activity report of Ovit Tunnel.

4. BACK ANALYSIS

The Ovit tunnel implemented an extensive convergence monitoring program together coupled with regular visual observation of the lining. The convergence readings were evaluated and a back analysis performed to ensure the shotcrete met the performance criteria. For this paper, a back analysis was performed based on the convergence readings, measured at the heading station Ch 71+926 (referred to as sol 49), which was chosen as an example section. The excavation and support is NATM Class B1 where the measurements were taken after the top heading support. The back analyse were used to estimate the sectional forces by the shotcrete lining after the stabilization of any settlement. Figure below shows the convergence readings, used in the back analysis. The deformation stabilizes after

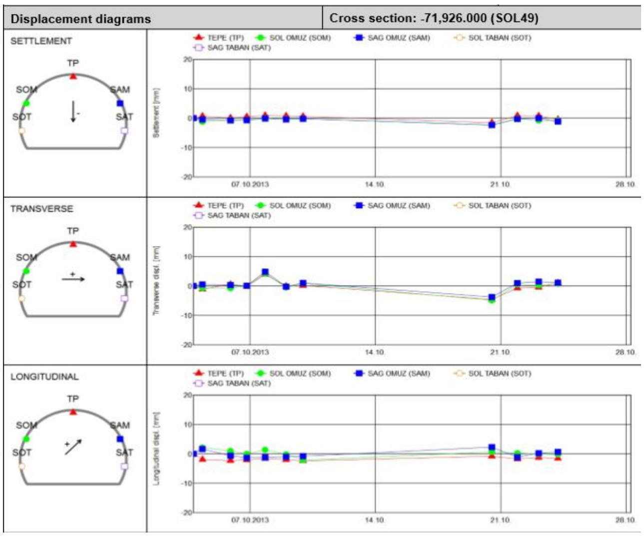

Figure 9. Convergence measurements after top heading support, Ch 71+926 – NATM Class B1

the installation of support and vertical and lateral displacements are limited between 2 – 5 mm.

The back analysis was performed utilizing Phase2 v 8.0.18, using the 2D finite element analysis method. The model was created using a plain strain analysis with the generalized Hoek and Brown method. To model the 3D effect stages were used along with the internal pressure reduction approach. To model the disturbed zone around the tunnel due to blasting and excavation a 1.5 - 2.0 m thick zone and a disturbance factor of D = 0.3 was used.

Stages defined in Phase 2 are as following:

a. In-situ stress state prior to excavation;
b. Internal pressure reduction of the top heading of the left tube tunnel by means of relaxing internal pressure on the tunnel boundary from a value equal to the applied in-situ stress to zero;
c. Full excavation of top heading and installation of tunnel support. Shotcrete lining is assigned with early strength parameters;
d. Relaxing the internal pressure of the invert,
e. Excavation and support of invert;
f. Hardening the shotcrete properties for both top heading and invert;

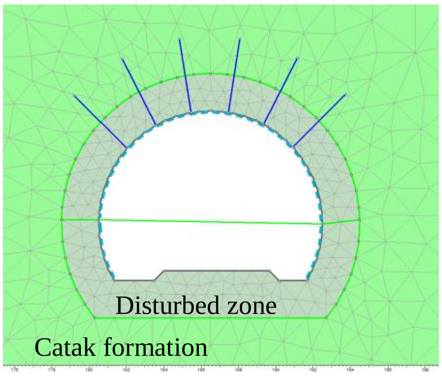

Figure 10. Excavation and support of final phase for single tube

The rock type in the area of the convergence was in Catak formation; rock consisting of basaltic lavas and pyroclasts. The formation is cut in several sections by sediment rock layers like claystone, marl and siltstone. The overburden in the area of the measured convergence was 372 meters. Because the section was in homogenous ground conditions, the model was simplified and no different material properties were defined above the tunnel.

The table below shows the shotcrete properties used in the plastic model. The early strength represents the 3-day strength of shotcrete, where the final strength is the 28-day strength. The early strength was chosen based on the timing of the support installation.

Table 4. Shotcrete Liner Properties

c	Early	Final
E (GPa)	7	21
ν	0.2	0.2
σc, MPa	13.5	30
σt, MPa	1.28	1.9

The results showed that the final deformations on the crown were 4.80 mm. The displacement after excavation was 2.80 mm, which increased 2.0 mm after the installation of the ground. The lateral deformation on the side wall was calculated 2.10 – 2.25 mm, in the location of the convergence points. The calculated values lie within the limits of convergence measurements and the figure below shows the stress trajectories and displacements around the tunnel.

The FRS liner axial forces and bending moments computed in the back analysis are as follows. The computed maximum axial load was N = 0.91 MN per unit width and maximum moment M = 0.0010 MNm per unit width.

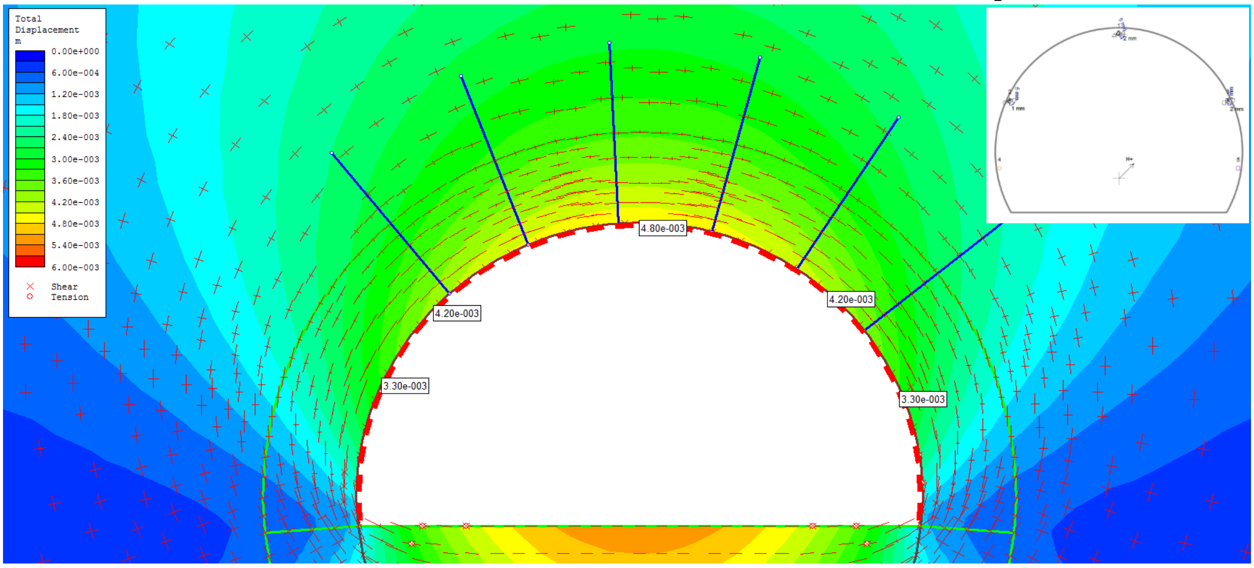

Figure 11. Back analysis result after top heading support

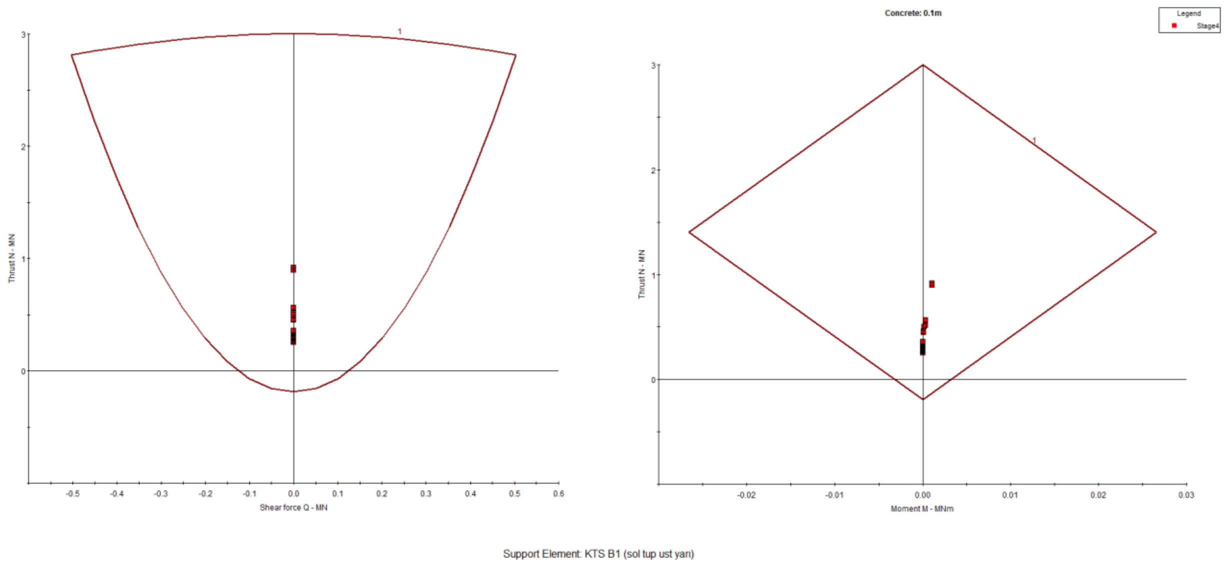

Figure 12. M-N chart for the FRS top heading lining showing the axial forces and bending moments

Using the early strength of shotcrete, the liner was able to withstand the loads acting on the support system. During construction, no visual signs of liner yielding were observed.

5 COMPARISONS OF STEEL MESH APPLICATION VS SYNTHETIC FRS LINING

The use of macro synthetic fiber reinforcement instead of steel mesh commenced at the Northwest (entrance) excavation of the twin tube tunnel which was at 61.522 m and the Southeast (exit) was at the 72.065 m. Before the introduction of the FRS application, steel mesh was used which took significant time and labor for its application in the shotcrete lining. According to the excavation records of the Ovit tunnel for the B1 category where the steel rib was not installed and steel mesh used it took 30% of the excavation cycle time. For the other categories it was 14% mainly because placing the steel mesh on the steel rib is much easier. In all the support classes 5 laborers worked just to install the steel mesh at each face of the tunnel. Moreover, steel mesh fixing causes safety problems from the falling small rock pieces. Using FRS lining eliminates labor costs and steel mesh fixing times have been eliminated.

To date four faces of the twin tube tunnel have been going forward to date in B1 NATM category by drill and blast, in which FRS lining application has started. The average excavation advance speed increased from 7.10 m/day to 9.0 m/day with synthetic FRS application. Currently there has been a 25% time saving using FRS lining. Overall calculations show that the Ovit Tunnel’s excavation will be finished 106 days sooner with FRS lining opposed to using steel mesh reinforced shotcrete lining offering the project substantial cost savings.

Although the use of FRS lining is much easier than the steel mesh reinforced shotcrete lining to increase excavation speed, planning and the quality of the wet mix shotcrete is very important. A homogenous fiber distribution has to be provided otherwise the fibers can block the spraying machine. Also the training of the nozzleman is a key factor to prevent the high rebound and provide the shotcrete thickness and quality as specified by the design requirements.

Figure 13. B1 Class - FRS Lining of Ovit Tunnel

6 CONCLUSION

The Ovit Tunnel’s laboratory and field tests show that the macro synthetic fibers have been successfully applying instead of the steel mesh reinforcement of the shotcrete lining. The core compressive strength tests and the flexural toughness tests results of the FRS are in accordance with the project design requirements. The deformation measurements of the FRS lining are in the contract limits and the back analysis show that the liner is able to withstand the loads acting on the support system. According to the Ovit Tunnel’s excavation records, synthetic FRS lining application has provided minimum 25% time saving than steel mesh application and it has been recognized that with a better planning, the excavation speed can be increased more.

Due to its importance, the Ovit tunnel is planned to be completed quickly. Synthetic FRS application has proven its advantages on time saving by eliminating the steel mesh fixing. It has been experienced that FRS lining will be the best and the safest solution for improving tunneling advance excavation speeds.

REFERENCES

Barton N., Grimstad, 2004 *The Q-system following thirty years of development and application in tunneling projects* E. EUROCK 2004 & 53rd Geomechanics Colloquium. Schubert (ed.), VGE

Barton N., 2012, *Defining NMT as part of the NATM SCL debate*, International tunnelling consultant, Oslo/SãoPaulo.

Decker J. B., Madsen P.H. and Gall V., 2010 *Examination of shotcrete liner at Devil’s slide tunnel utilizing ASTM 1550 field test results and back analysis*, Arma 10-402, *Salt Lake City, UT.*

EFNARC, 1996, *European specification for sprayed concrete.*

Elasto Plastic Concrete Company, *EPC Tunneling Booklet.*

Elasto Plastic Concrete Company, *EPC BarChip 54 catalog.*

Mak-Yol İnSaat San. Tic. Ve Tur., CMA Ovit, 2013, *Ovit Tunnel Monthly Activity Report.*

Ozben et al, 2006, *Karayolları Teknik Sartnamesi (Technical Specification of Highways),* Ankara, T.C. Cevre ve Sehircilik Bakanligi Karayollari Genel Mudurlugu, 753.

The British Tunnelling Society and the Institution for Civil Engineers (ICE), 2010, *Specifications for tunneling third edition.* London: Telford T., 200.

TTS Muhendislik ve Mimarlık Ltd. Sti. 2013.. *Ovit Tunnel final project geological and geotechnical report (Ovit Tüneli kesin proje jeolojik ve jeoteknik raporu),*

TTS Muhendislik ve Mimarlık Ltd. Sti. 2013, *Ovit Tunnel final project tunnel calculation report (Ovit Tüneli kesin proje tünel hesap raporu),*

Tuysuz O., Genç C., 2012, *Ovit dağı Tünel güzergahlarının jeolojik etüdü (Geological etudes of the Mount Ovit tunnel route),* Istanbul Technical Universtiy.