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REHABILITATION OF DORUKHAN TUNNEL

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ABSTRACT

Dorukhan Tunnel was opened to traffic in 1976. Concrete lining and pavement were heavily damaged; illumination and ventilation systems could not be established due to the lack of waterproofing. Vertical clearance in the traffic area also was not enough. In the view of these reasons in order to improve the standard of the road, tunnel was rehabilitated. Five main criteria have been taken into account: protecting of the existing stability of the tunnel during increasing of vertical clearance by excavation at the bottom of tunnel; establishing water insulation; choosing of secondary lining considering irregularities of the tunnel cross-section; construction time and economy. In the course of this paper, during the rehabilitation of tunnel, planning and carrying out of different kind of construction works, geotechnical investigation and trials to observe performance of grouting at the bottom, waterproofing and shotcrete for secondary lining, have been discussed. Finally, it was seen that alternatives for rehabilitation at the bottom, waterproofing and secondary lining were controlled firstly by construction time and economy.

1. HISTORY OF THE TUNNEL

Dorukhan Tunnel, with 903 m length, is located on a main road which links Ankara, capital of the Turkey, to Black Sea. Construction of the tunnel was completed by conventional methods in difficult geological conditions and opened to traffic in 1976. The permanent support of the tunnel was concrete lining with a quality of BS 16. Due to lack of water insulation, there was water inflow towards the tunnel especially at the conjunction of the main tunnel and cut-and-cover section of the tunnel. Concrete lining and pavement were heavily damaged; illumination and ventilation systems could not be established (Figure 1).

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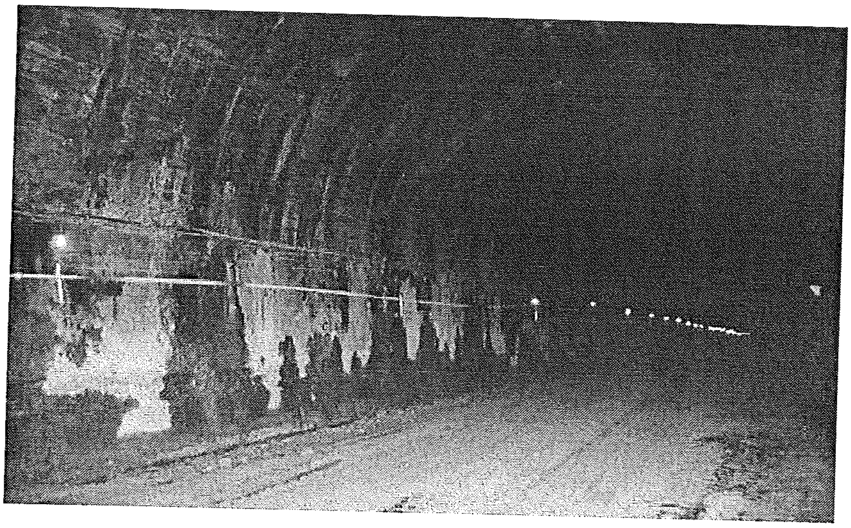


Figure 1 The Inside of the Tunnel Before Rehabilitation

According to the original design, thickness of the concrete lining was 50 cm at crest, 100 cm at sidewalls in sections of tunnel driven in granodiorite and 120 cm at crest, 140 cm at sidewalls in metasiltstone. The thickness of the pavement was 27-30 cm concrete lining overlaid by cobblestone. Vertical clearance in the traffic area, 3.60-4.00 m, was low and out of standards (Figure 2). Traffic speed was decreased up to 15-25 km/h. During the initial construction, thicknesses of the lining were revised due to problems encountered during excavation of the tunnel but there were no records about construction. Considering location of tunnel, traffic volume and length of tunnel, rehabilitation of the tunnel was a necessary.

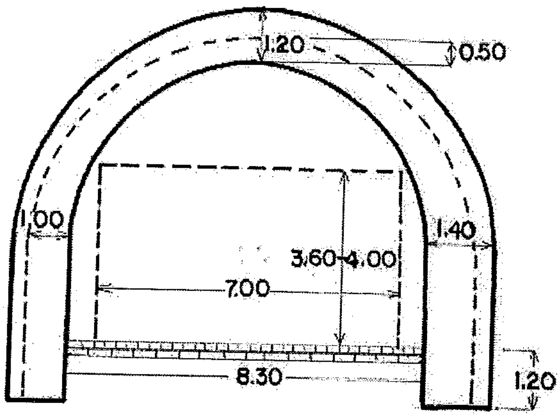


Figure 2. Crossection of the Tunnel Before Rehabilitation
(—Concrete lining in phylitte-metasiltstone, ---Concrete lining in granodiorite)

2. GEOLOGICAL AND GEOTECHNICAL EVALUATION AT DESIGN STAGE OF TUNNEL REHABILITATION

Site investigations (engineering geology, boreholes, rock mechanics tests etc.) carried out for the second tube, which is planned to construct app. 75 m near of the Dorukhan tunnel, was used in design stage of tunnel rehabilitation.

Tunnel location is near North Anatolian Fault Zone and was driven in phyllite - metasiltstone and granodiorite which are poor and weathered rock. There was fault gouge with low angle due to overlaying of granodiorite to phyllite and metasiltstone that governs tunnel geology about 350 m in length at Mengen side. This section was defined as class C2 (squeezing) and remaining 550 m in length at Devrek side was defined as class B2 (friable), according to New Australian Tunnelling Method (NATM) (Figure 3).

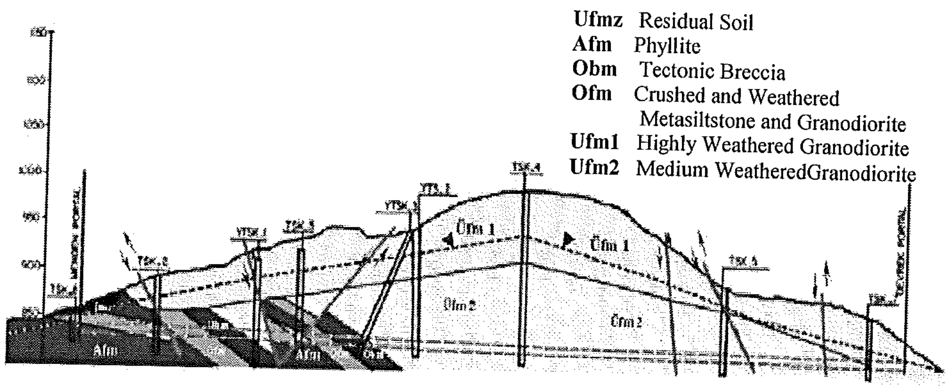


Figure 3 Geological Profile of the Tunnel

Shear fault zones directly affect the cut-and-cover part at Devrek portal of the tunnel. The Devrek entrance of the tunnel was shifted backwards because of the problems in the slopes of sides and forehead. Surface water leaked towards the tunnel because of the topographic characteristics of the site. It was observed that there was inflow in the tunnel at Devrek portal at the conjunction of cut-and-cover section and main tunnel section. It can be concluded that the water inflow can be reduced with the help of drainage.

Then, pits were dug in order to examine the pavement layer thicknesses and foundation depth in existing tunnel. Profile of the tunnel cross section was determined in 5-10 m intervals to evaluate irregularities and deformations in the tunnel lining.

One of the goal of the rehabilitation project was to increase vertical clearance in the traffic area by excavation at the tunnel bottom. To prevent causing instabilities in tunnel lining due to excavation, precautions had to be taken. To determine the type and extend of the precautions, numerical analyses were carried out. Numeric analysis of the Dorukhan tunnel was performed by 2-D Finite Element Program called Phase 2.0. Analysis was based on two types of rock conditions B2 and C2 classes.

Using the information related to tunnel geometry, back analysis were done and the rock properties around the tunnel were determined by assuming the existing tunnel was stable. Also, rock parameters were compared to the parameters from geotechnical evaluation. Then, by using these parameters (Table 1), changes in displacements, principal stresses and safety factors of concrete lining and surrounding rock with the excavation at the tunnel bottom were calculated according to Mohr-Coulomb criteria. From the results of the analysis, it is concluded that if preventive precautions will not be taken at the bottom of the tunnel, there will be increase in principal stresses, deformations and decrease in safety factors of the concrete lining.

Table 1 Rock Parameters in Dorukhan Tunnel

Formation	Granadiorite	Metasiltstone
Material Type	Elastic	Elasto-Plastic
Unit Weight (MN/m^3))	0.022	0.019
Elastic Module (Mpa)	6000	300
Poisson's ratio	0.2	0.3
Cohesion (Mpa)	0.2	0.1
Friction Angle (^{0})	35	30
Residual Cohesion (Mpa)	-	0.05
Residual Friction Angle (^{0})	-	25

3. REHABILITATON PROJECT OF THE DORUKHAN TUNNEL

Rehabilitation project of the tunnel was prepared including the following facilities.

- Surface drainage system which consists of trenches with concrete lining,
- Service road (because tunnel had to be closed to traffic during rehabilitation works in the tunnel).
- Ground improvement to increase the vertical clearance in traffic area of road by excavation in the bottom of the tunnel
- Waterproofing and groundwater drainage
- Secondary lining for protection of waterproofing
- Rehabilitation of pavement
- Illumination and ventilation systems.

3.1. Criteria Of Rehabilitation Project And Discussion Of Alternatives

There were five factors that must be taken into account. The stability of the tunnel during the excavating at the bottom of tunnel, must be maintained. Water flow through the tunnel must be prevented. The irregularities of cross-section of existing tunnel must be considered when choosing type of secondary lining. Construction time is another important factor since traffic is not allowed in the tunnel during rehabilitation so, construction time had to be optimized. Finally, processes in the rehabilitation project should be finalized regarding economy.

3.1.1. Alternatives To Maintain The Tunnel Stability During The Excavation Of Bottom Of The Tunnel

Invert could be produced by grouting in bottom of the tunnel at squeezing rock conditions. Grouting at the bottom of the tunnel walls could be performed easily and rapidly due to fair rock conditions. Another solution for this problem was to excavate the bottom of the tunnel in forms of skipping sections. But this process might cause an increase in depth of excavation at the tunnel bottom. Application was assumed to have difficulties for stability and to take long time.

3.1.2. Alternatives For Waterproofing

There were three alternatives for waterproofing system. These are grouting behind the existing concrete lining; water insulation with special materials such as epoxy (for this alternative cost, possibility of leakage at long term and probable water pressure behind concrete lining were taken in to consideration); enclosing the tunnel with protective felt and membrane (this system can be applied easily and quickly, moreover leakage at long term can be stopped with this system)

3.1.3. Alternatives For Secondary Lining

There were four alternatives for secondary lining. These are shotcrete, cast in place concrete, prefabricated concrete module and aluminum lining. Using of shotcrete was advantageous and preferable due to fast application and easy covering of irregularities of existing concrete lining. Besides, steel mesh must be used to overcome the difficulty of application of shotcrete on smooth surface of the membrane.

If it is decided to use cast in place concrete, existing lining should be re-profiled because of irregularities and deviations of tunnel axes. Then, concrete could be casted using tunnel mold. The production would be slow due to setting time of the concrete and re-profiling.

If prefabricated concrete module is used as secondary lining, re-profiling must be done in order to place the specially produced modules. There could be difficulties during placing of modules.

The last alternative is the usage of aluminum lining. Performance of aluminum lining against fire was not efficient and special production was needed.

3.1.4. Finalizing the rehabilitation project

After evaluation of the alternatives; the rehabilitation project was finalized in the following ways;

- Ground improvement at tunnel bottom was considered to be done by grouting.
- Enclosing the tunnel with protective felt and membrane for waterproofing system and shotcrete for secondary lining were chosen.

4. REHABILITATION WORKS

4.1. Surface Drainage

As it was mentioned before, there was water inflow towards the tunnel. Water inflow through the tunnel was reduced by establishing surface drainage with concrete lining trenches in portals of tunnel (Figure 4).

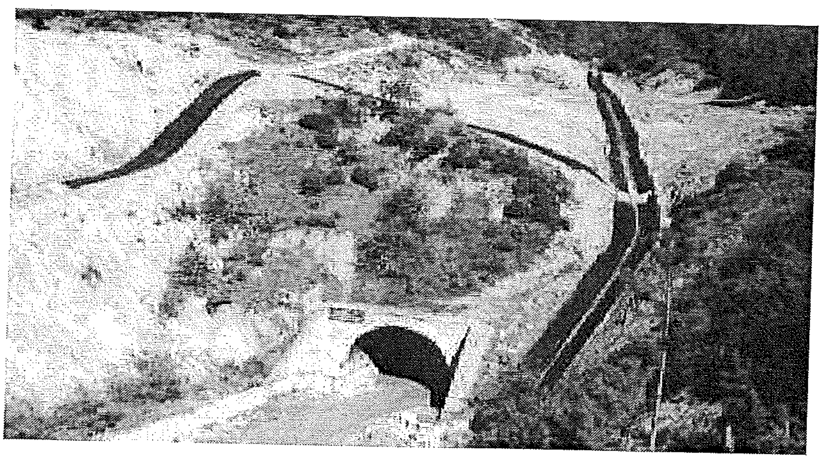


Figure 4 Surface Drainage on the Mengen Portal

4.2. Construction of Service Road

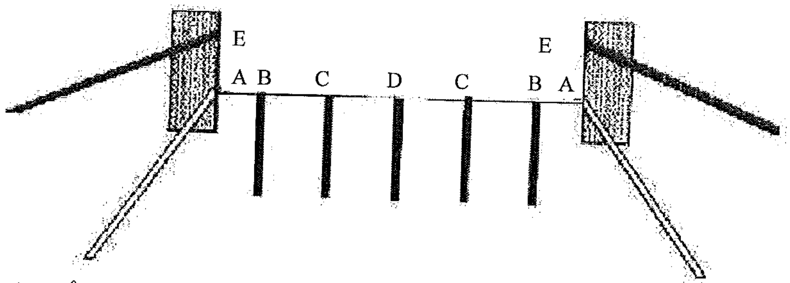
Since the tunnel had to be closed to traffic during rehabilitation, service road, which was approximately 4 km, was constructed so that the transportation from Devrek to Mengen was available.

4.3. New Boreholes at the Tunnel Bottom

Boreholes were driven at the bottom of tunnel to check the rock conditions during the rehabilitation. Since rock at the tunnel bottom was highly weathered, it was decided to form a grouted zone with a depth of approximately 2.5m at tunnel bottom along the tunnel.

4.4. Trials for Grouting and Waterproofing

In order to evaluate the performance of grouting, trial of grouting was performed in three sections having different characteristic. First part was between Km:0+000 and 0+024 and having a formation of phyllite-metasiltstone, second part was between Km:0+560 and 0+584 and having a formation of granodiorite and last part was between Km:0+850-0+874 at cut-and-cover section. Control tests were performed in order to check the results according to Specifications of State Hydraulic Works. Then, it was concluded that by grouting a reasonable improvement at the tunnel bottom could be maintained (Figure 5). The depth of the groutings (B,C,D) at the tunnel bottom was increased in order to obtain a deeper grouted ring in highly weathered rock conditions.



A Grouting 40^0 inclined from vertical, located at the bottom of the tunnel (L=4.83m)
B Grouting perpendicular to the bottom of the tunnel, located 1.0m apart from the wall of the tunnel
C Grouting perpendicular to the bottom of the tunnel, located 2.6m apart from the wall of the tunnel
D Grouting perpendicular to the bottom of the tunnel, located at the tunnel axis (L=3.1m)
E Grouting 65^0 inclined from vertical, located 50cm above the tunnel (L=4.0m)

Figure 5 Section of Grouting Holes at the Bottom

In trial application, rondela with hook was applied on membrane, steel mesh was hanged on hook and shotcrete was spread on steel mesh. After the trial, application waterproofing system was redesigned and steel bars were put in front of the steel mesh to prevent hanging down. Waterproofing and shotcrete application were performed along the tunnel according to the details given in Figure 6.

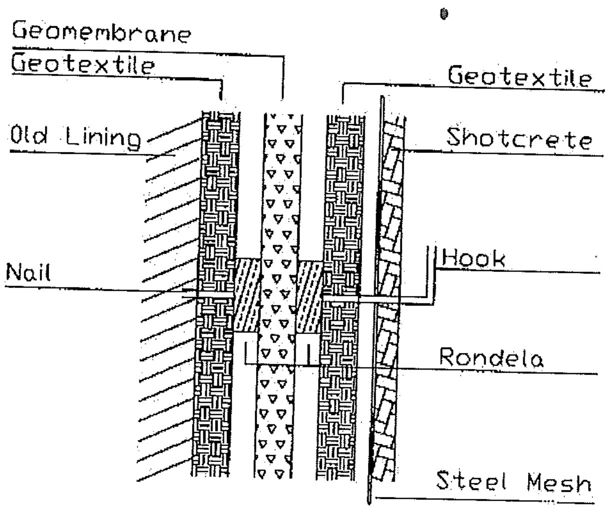


Figure 6 Waterproofing Details

Shotcrete was applied on steel mesh, which was reinforced with Ø12 bars bent in radial direction with 0.2 m spacing (Figure7).

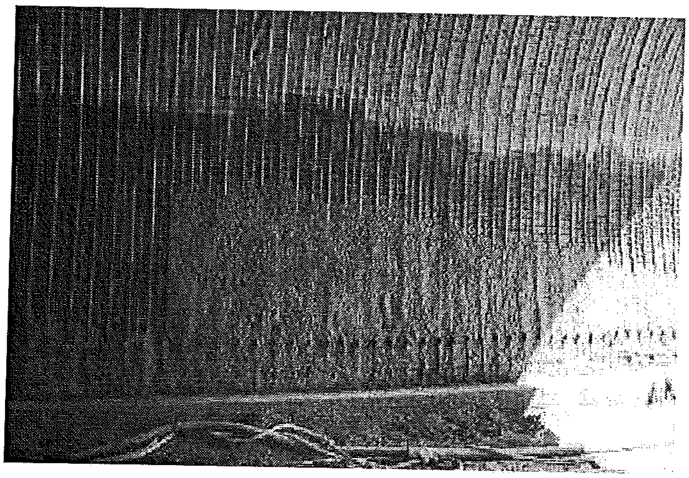


Figure 7 Steel Mesh and Shotcrete Application

4.5. Construction Stages Applied in Squeezing Rock

Drainage holes, which were 6m in length and 5 cm in diameter, were drilled in the existing lining and PVC pipes were set in these holes. After the bottom of the tunnel had grouted, the material at the bottom of the tunnel was excavated. During the excavation process, 3-D geotechnical measurements of lining were performed in order to control unexpected deformations (Figure 8).

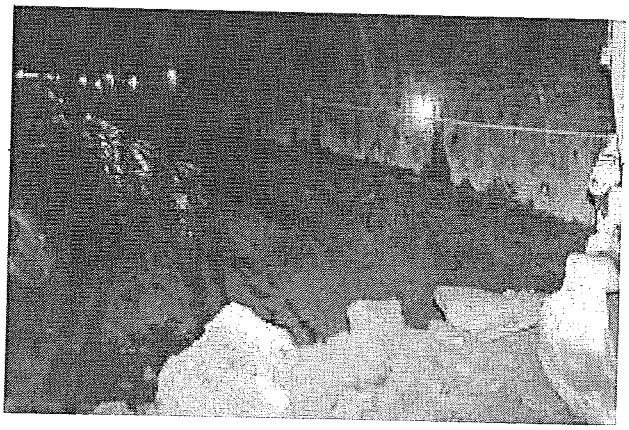


Figure 8 Excavation at the Tunnel Bottom with 3-D Measurement

In the following stage, waterproofing was applied according to revised application details (Figure 9). Steel mesh and shotcrete lining were applied (Figure 7). Before the construction of final pavement, surface drainage and cable channels were located (Figure 10).

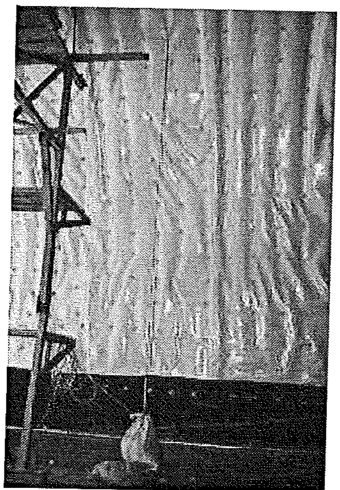


Figure 9 Application of Waterproofing

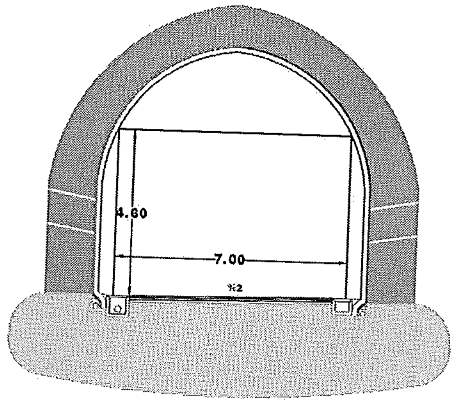


Figure10 Cross-section of Dorukhan Tunnel after Rehabilitation

5. CONCLUSION

Dorukhan Tunnel, located on the main artery, had to be opened to traffic during winter season since the service road with low geometric standards could not serve traffic. So, the rehabilitation works has been carried out for two-summer seasons. Rehabilitation of the tunnel was started on October,1998 and completed on November, 2000 (Figure 11). During rehabilitation works, 37,894 m^2 protective felt (geotextile), 18,947 m^2 membrane, 78 tones steel mesh, 185 tones reinforcement, 2,518 m^3 shotcrete, 2,118 m drainage pipe and 17,976 m^3 pavement material were used. The estimated cost was 4,692,820USD excluding service road cost. Due to auditing in construction, the final cost is reduced to 4,116,944 USD including the cost of service road.

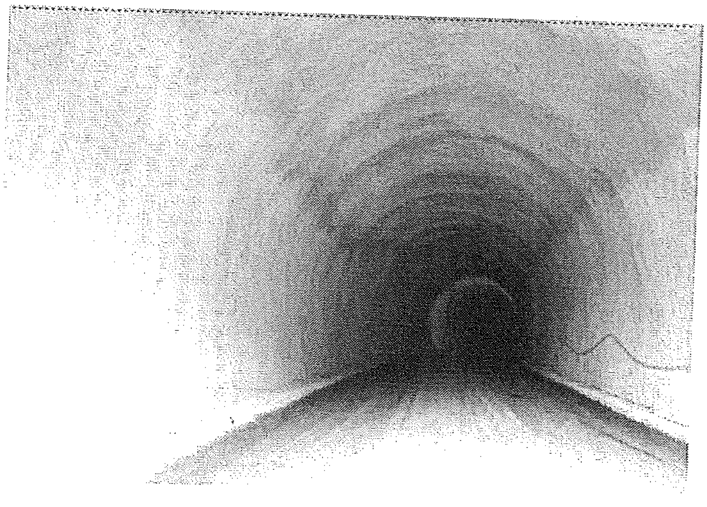


Figure 11 A View from Dorukhan Tunnel after Rehabilitation

6. REFERENCES

1. New Dorukhan Tunnel Design Reports, Su Yapı Eng. And Cons., 1999
2. Old Dorukhan Tunnel Design Reports, General Directorate of Highways, 1999