KSCE Journal of Civil Engineering (2016) 20(4):1323-1328

DOI 10.1007/s12205-015-0055-3

Geotechnical Engineering

pISSN 1226-7988, eISSN 1976-3808
www.springer.com/12205

Criteria for the Selection of Construction Method at the Ovit Mountain Tunnel (Turkey)

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Received January 19, 2015/Accepted April 29, 2015/Published Online July 17, 2015

Abstract

The Ovit Mountain Tunnel (OMT) is an highway tunnel under construction at Mount Ovit between Ikizdere (Rize) and Ispir (Erzurum) in NE Turkey. It will be the country's longest tunnel about 14700 m long in twin tubes. This paper compares and assesses tunnel excavation by Tunnel Boring Machine (TBM) excavation or drill and blast method for the OMT. Rock mass and material characteristics were evaluated to identify the excavation method. The rock mass classification of the tunnel grounds was performed by utilizing the Rock Mass Rating (RMR), Q system and New Austrian Tunnelling Method (NATM) which was followed by a geotechnical investigation along the tunnel. Twelve boreholes with a total length of 1116.5 m were drilled to assist and verify rock mass classifications. Seventy five rock samples were obtained for mechanical test. TBM method was selected at preliminary design stage of the OMT. But now, the OMT is driven by drill and blast method, using hydraulic excavators and the support is based on the principles of the NATM. The selection of this tunnelling excavation method was decided by morphological site conditions, geological, geotechnical site conditions, time and economic criteria.

Keywords: *site investigations, construction, tunnels, rock mechanics*

1. Introduction

Construction of tunnels will be either by TBM or by drill and blast method. Several advantages and disadvantages are associated with both methods, and they have been competing for more than 30 years (Hagen, 2012). While drill and blast method is more exible, the TBM will normally have better progress if the equipment is specially designed for the job. However, time and design for mobilization is longer for the TBM and TBM is more vulnerable to unexpected geological conditions and requires a higher effort for ground investigations during the planning stage (Maidl *et al*., 2008). Several conditions have to be established and evaluated before a decision can be taken on the excavation method, but often as in most other manufacturing the most cost effective is the preferred one. There are some related technical or economical regards (Golestanifar *et al*., 2011). Ehrbar *et al.* (2011) studied on selection of tunnelling methods at the Gotthard Base Tunnel (Switzerland). They explained that, the selection of tunnelling method was therefore decided by economic criteria as the result of competition among international bidders in the tendering phase. Karlbauer (2012) emphasized final dimensions and construction material specifications in compliance with the applicable constraints and the structural and economic requirements at Eierberge Tunnel (Germany).

Nowadays, drill and blast method that are very popular in highway tunnel are utilized in Turkey like the OMT (Rize-Erzurum), Dallıkavak Tunnel (Erzurum), Sabuncubeli Tunnel (Manisa). This study is about selecting the tunnel excavation method for the OMT. The TBM method was evaluated at preliminary design stage of the OMT (TTS, 2013a). After which, the drill and blast method was selected for the OMT because of the morphological site conditions, geological and geotechnical site conditions, as well as time and economic conditions.

2. General Information About the OMT

Transportation is one of the serious difficulties in the Eastern Black Sea region because of the irregular geomorphology. In addition to various road improvement projects along the route, the OMT is the key element in the new highway system. It comprises two 14700 m long tubes and, on completion, will be the longest tunnel in Turkey and the fourth longest globally. The tunnel runs NW - SE through the Ovit Mountain. The elevation of the entrance portal is about 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 plan is mainly straight with slight curves at each end to reach the optimum portal positions. The two bores are connected by crosscuts at intervals of 250 m to

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Fig. 1. General View of the OMT Portal

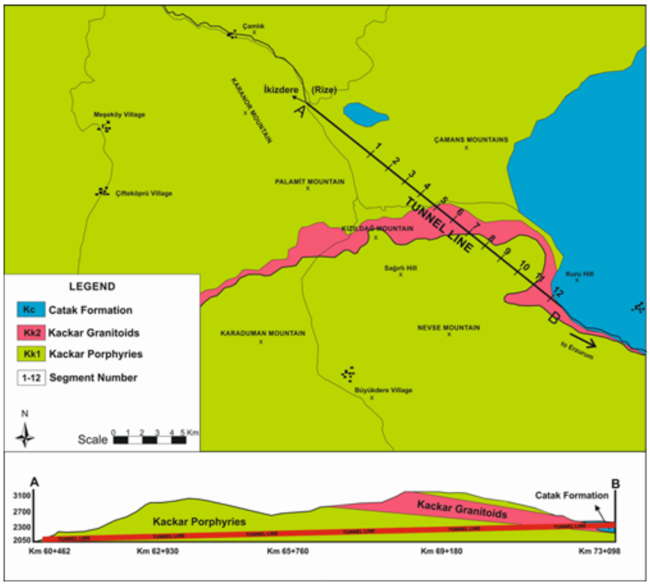

Fig. 2. Geological Map and Cross-section of the OMT (modified from TTS, 2013a)

enable escape routes and to provide accommodation services. In profile, there will be a grade, chiefly to facilitate drainage of 3.5% for the first 7 km from the main northwest portal, and of 1.0% for 5.5 km from the other portal. At the high point, 2500 m above sea level, there will be a 1700 m long drive, 8 m square in order to facilitate emergency egress and ventilation. This replaces the original plan for an access shaft as it was decided this would be too deep and difficult to access high up in the mountainous terrain.

Construction facilities and tunnel construction began in October 2012 and it will be opened to traffic by the end of 2015. Engineering studies continue in the tunnel on a 24 hour basis. The OMT bores are two lane tunnels with 8.0 × 5.0 m clearance and the excavation cross-sectional area varies from 88.72 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 m. General view of the OMT portal is shown in Fig. 1.

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 fore poling 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 method in hard rock conditions and impact hammer in softer ground.

3. Geological Setting

In general, the eastern Black Sea was formed by the intercalation of Upper Cretaceous basic and acidic volcanic rocks and their pyroclasts (agglomerate and tuff), which are the products of subduction zone in the island arc volcanism related with the tectonism of the region. The volcano-sedimentary and pelagic units were formed during the dormant periods of volcanism in the region (Akin, 1979; Okay and Sahinturk, 1997; Robinson *et al*., 1995; Sengor and Yilmaz, 1981; Yilmaz *et al*., 2003; Sopaci and Akgun, 2008; Akgun *et al*., 2014). The oldest volcanic rocks in the region are the lower basic series and the youngest volcanic rock is the acidic biotite bearing dacite. The other units observed in the region are deep intrusive rocks such as diorite, quartz diorite, granodiorite, basaltic dykes and sedimentary units including sandstone and limestone (Boztug *et al*., 2006). The region is under the influence of the eastern Black Sea tectonism, related to island arc volcanism. Tectonism developed in the northeast, northwest and east-west directions. The general orientation of the discontinuities in the region is NE and NW. No active fault capable of creating a destructive earthquake exists along the project path and vicinity in the Province of Rize. The nearest fault system to the study area is the North Anatolian Fault Zone which is located at 150-200 km distance. Similarly, the Erzurum Fault Zone capable of 2nd degree damage is located 100-150 km away.

The tunnel lies within three main geological formations (Fig. 2). The Kackar Granitoids are massive, homogenous and jointed rocks. In total 5 sample points were measured in Kackar granotoids. Discontinuity systems of Kackar granotoids were statistically analysed with RockWorks 2006 trial version. The determined dominant discontinuity sets are illustrated in Fig. 3. These Mesozoic rocks are grey in colour; unweathered, 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 formation in many locations. Catak Formation, located on the SE section of the tunnel, consists of basaltic lavas

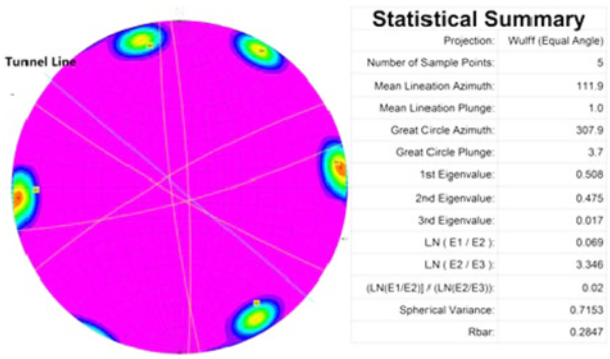

Fig. 3. Stereographic Projection of Joint Sets in the Kackar Granitoids

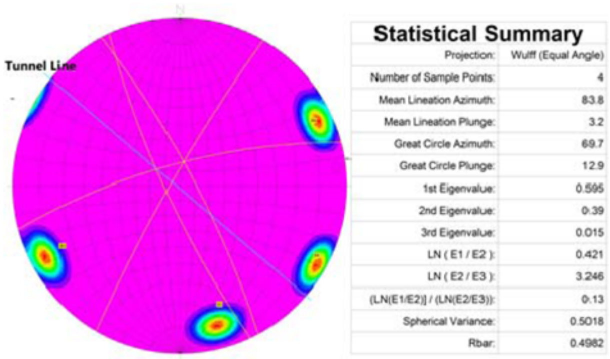

Fig. 4. Stereographic Projection of Joint Sets in the Catak Formation

and pyroclasts. The formation is cut by sediment rock layers like claystone, marl and siltstone (Tuysuz, 2012; TTS, 2013a). In total 4 sample points were measured in Catak Formation. Discontinuity systems of the formation were statistically analysed with RockWorks 2006 trial version (Fig. 4)

4. Geotechnical Studies

Geotechnical studies were studied according to ISRM (1981), drilling (ASTM D2113, 2008; ASTM D5079, 2008), in situ and laboratory testing (ASTM C88, 1999; ASTM C127, 2001; ASTM C131, 2003; ASTM D2113, 2008; ASTM D5079, 2008). A detailed study of the drilling, geotechnical properties of the tunnel alignment was performed, the stability was evaluated and a rock support design was proposed. For this purpose, lithological properties of rocks along the tunnel alignment were evaluated during drilling. During drilling, discontinuities in the rocks were studied for such as dip direction, roughness, infilling and spacing according to ISRM (1981). The data required for the design came from in-situ testing and failure analysis of the excavated materials. These data show the physical and mechanical properties of the rock zones, including joint sets and discontinuities. Based on these data, the values of RQD and RMR class of rocks were determined. Finally, a stability analysis was conducted, and appropriate supports were suggested for the tunnel using geomechanical classification systems. Laboratory tests were performed on core samples in order to determine the intact rock parameters. Laboratory test results are shown in Table 1.

According to the geotechnical investigations, the 14700 m long tunnel route was classified into 12 homogenous sections. Rock mass classes along the relatively uniform segments were determined according to the Austrian Standard ÖNORM B2203 specifications during the tunnel excavation. With respect to ÖNORM; 6 different NATM rock support categories varying between A2 to C2 were assigned to the sections.

4.1 Assessment of the TBM Excavation for Tunnel Alignment

Geotechnical assessment of the tunnel alignment was executed as surface, subsurface and laboratory studies. A total of 12 points were drilled from the surface for the OMT alignment. The length of the drill was 1116.5 m with an average depth of 93 m per borehole. Rock mass parameters, which could be estimate by empirical rock mass classification systems depending on the geotechnical descriptions of rock masses (Hoek, 1997; Hoek *et al*., 2002). Detailed geotechnical evaluation of the rock masses

Table 1. Summarized Mean Values of Laboratory Test Results for Tunnel Alignment

Borehole No	Sample Depth (m)		Unit Weight (kN/m^3)		UCS (MPa)		Elasticity (GPa)		Poisson Ratio		Point Load (I_{50})		Sample Description
	min	max	min	max	min	max	min	max	min	max	min	max	
SK-1	12.89	20.00	28.00	28.30	166.50	193.22	52.54	-	0.26	-	-	-	Andesite
SK-2	16.00	19.55	-	-	77.60	223.60	-	-	-	-	3.88	11.18	Granite
SK-3	15.50	50.00	26.00	26.50	31.61	72.54	21.78	26.02	-	-	-	-	Granite
SK-4	10.50	49.40	26.20	27.50	78.46	209.68	37.84	58.11	-	-	-	-	Andesite
SK-5	20.00	35.00	26.10	26.70	52.38	90.47	-	-	-	-	-	-	Granite
SK-6	17.35	62.70	26.30	27.80	47.26	211.17	-	-	-	-	-	-	Andesite
SK-7	23.50	44.20	26.10	27.30	34.57	125.03	-	-	-	-	-	-	Andesite
SK-8	404.00	604.35	25.50	28.20	17.01	259.47	54.08	71.43	0.21	0.27		-	Basalt
SK-9	38.15	52.12	27.50	28.30	115.20	168.00	70.81	-	0.22	-	6.17	-	Diabase
SK-10	32.15	48.75	27.10	27.60	32.26	110.60	25.41	42.72	0.28	-	5.53	-	Basalt
SK-11	30.50	36.50	27.20	27.30	137.35	151.85	42.66	51.68	0.25	0.26	-	-	Basalt
SK-12	28.80	34.70	27.20	28.30	119.07	130.40	45.79	-	0.22	-	6.52	-	Basalt

Table 2. Distribution of Averaged Utilization, and Advanced Rate for Each Homogenous Section

Tunnel sections	Length (m)	RMR	Rock properties	Q	Q_{TBM}	Operation Time (h)	ROP (m/h)	AR (m/h)
Km 58+210 - Km 58+300	90	42.5	Moderate	2.933	0.1378	27	7.43	3.34
Km 58+300 - Km 59+370	1070	48.1	Moderate	7.333	1.0309	1067	4.97	1.003
Km 59+370 - Km 59+420	50	24.5	Weak	0.074	0.0006	13.1	22.29	3.818
Km 59+420 - Km 61+140	1720	50.1	Moderate	11.733	3.4161	2697	3.91	0.608
Km 61+140 - Km 61+420	280	24.5	Weak	0.074	0.0009	4307	20.21	0.065
Km 61+420 - Km 62+420	1000	52.1	Moderate	13.689	5.9239	1539	3.50	0.650
Km 62+420 - Km 62+460	40	24.5	Moderate	0.074	0.0016	12.2	18.23	3.279
Km 62+460 - Km 66+440	3980	52.1	Moderate	1.825	0.5303	6729	5.68	0.650
Km 66+440 - Km 67+060	620	55.8	Moderate	1.564	0.0475	208.13	9.20	2.979
Km 67+060 - Km 69+470	2410	52.1	Moderate	1.825	0.5279	3423	5.68	0.704
Km 69+470 - Km 72+720	3250	56.5	Moderate	1.4667	0.0723	2107	8.46	1.542
Km 72+720 - Km 72+910	190	39.5	Moderate	0.367	0.0032	47.8	15.73	1.773

along the OMT with an alignment of N 110-140°E was made. OMT was excavated by utilizing the geotechnical rock mass classification systems such as RMR (Bieniawski, 1989) and Q System (Barton *et al*., 1974). Although rock mass classification systems are useful during the preliminary design stage, they cannot adequately calculate stress distributions, support performance and deformations around the tunnel (Genis *et al*., 2007). Therefore empirical methods should be augmented by numerical methods (Sari and Pasamehmetoglu, 2004; Basarir, 2006). Since rock mass strength parameters are essential input parameters for the numerical methods, a number of studies were performed to estimate these parameters by means of rock mass classification systems. In this study, rock mass strength parameters were obtained by means of RMR and Q systems. Detailed information of the tunnel such as operation time, Average Rate of Penetration (ROP) and Advance Rate (AR) of different rock mass units are shown in Table 2.

The geotechnical properties of the sections were assessed using three empirical rock mass classification systems, namely the RMR method, Q system and NATM by using correlations with the RMR and Q systems. Operation with TBM method will approximately take (924 day) to be completed in 2.5 yr.

4.2 Application of the Drill And Blast Method at the OMT

The drill and blast method is still the most typical method for medium to hard rock conditions. It can be applied to a wide range of rock conditions. Some of its features include versatile equipment, fast start-up and relatively low capital cost tied to the equipment. On the other hand, the cyclic nature of the drill and blast method requires good work site organization. The two tunnels are actually being driven as four drives with two partial faces in each. The full excavation dimensions of each horse-shoe shaped drive are 8.4 m height and 11.78 m width (Figs. 5 and 6).

First, a top heading is driven to a height of 5.9 m followed by a bench of 2.5 m height, a contractual distance of 250 m behind. A ramp between the two facilitates access for the drill-rig and mucking out (Fig. 7). Most of the tunnelling was executed by drill and blast method using four rigs with standard manual controls, one for each of the current main tunnel excavation drives. However, the rigs also carried out necessary rock bolting and excavation of crosscuts between the two bores.

Fig. 5. Prepared Site for Tunnel Excavation

Fig. 6. The Placement of the Steel Wire After the Excavation Process

4.3 NATM Construction

At the OMT, NATM (Rabcewicz, 1964) A1 and B1 categories are flexible and light support classes, used in hard rock conditions. Category B2 was applied to the transition zones from

Fig. 7. Wheel-mounted Drilling Rig

Fig. 8. Support Installation in the OMT

stiff to soft rock. Conversely B3 and C2 categories consist of stiff and heavy support, which were applied in the weathering zones. These zones carry groundwater into the tunnel. Crushed, granular cohesionless rock forms the weak zones at the OMT (MAKYOL, 2013). In both the flexible and rigid tunnel support, 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 (ϕ 6/150 grid 221 mm^2/m) mesh reinforced with 10 cm C30/37 shotcrete in combination with 6 or 7 SN type 4.0 m (ϕ 28) 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 (Fig. 8).

NATM Class C1 was 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 (ϕ 10,5/150 and ϕ8,5/150) mesh (TTS, 2013b; Eryigit *et al*., 2014; Guner *et al*., 2014). Additionally, OMT tunnel structure waterproofed for highest safety comprising a membrane (Fig. 9).

As for other major tunnelling projects, rapid tunnelling under safe conditions is the primary goal and the OMT was no

Fig. 9. Waterproofing Installation at OMT

different. In order to increase the construction speed, attempting to minimize the time spent installing ground support is crucial. The tunnel using drill and blast method will be excavated in (1837 days) 5 yr time.

5. Conclusions

Selecting the tunnel excavation method requires multiple evaluations of site specifics as well as the project requirements. A huge investment and limitation on the ground condition in tunnelling projects often put the decision makers in irreversible and critical situations where qualitative measurements and uncertainties trigger complex problems. In most cases, there would probably be ground conditions feasible for both TBM and drill and blast method. Unless there are other essential factors specific to the project (vibration limitation requirements, geometry, accessibility), which exclude one method or the other, the selection of tunnelling method should be left to economic criterion. This means that both TBM tunnelling and the drill and blast method have to be fully tendered with equal weight in order to obtain comparable bids. At the OMT, these considerations were purposefully put into practice. With hindsight, it can be stated that the principle described above proved successful on every section and the optimal tunnelling methods for the overall project were used. Operation with TBM method will approximately take (924 days) to be completed in 2.5 yr. The same tunnel using drill and blast method will be excavated in (1837 day) 5 yr time. However, according to contractor the structure will be completed in 4 yr.

Acknowledgements

The author wishes to express his deep gratitude to the Turkish General Directorate of Highways managers, SIAL and MAKYOL Eng. Co., and site engineers for their help and permission to write this paper. I express also my thanks to the anonymous reviewers for their constructive comments which have helped to improve this manuscript.

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