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The Relation of the Method Used in Tunneling Operations with the Geological Structure Example of the Black Sea Coastal Road

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Abstract: Transportation tunnels are the most preferred method to facilitate transportation in mountainous and rough terrains. The excavation method and the choice of fortification tools in tunnel construction depend on the geological structure of the tunnel route. Correct formation determination and determination will reduce the cost and eliminate many risks. The Black Sea region has a very mountainous and rugged terrain. The most obvious method used to overcome rough terrain is road tunnels. The rock classification of the tunnel route and the support to be formed accordingly are very important in the selection of the method to be applied in the highway tunnel constructions. Within the scope of this study, Trabzon-Akyazı region, which is an important part of the Black Sea coastal road, was studied. The geological formations on the route of the 3-lane and double-tube tunnel with a length of approximately 2476 meters, which is planned to be built within the highway passing through this region, were examined and the method used in the tunnel construction was determined. As a result of the analyzes and calculations, it has been determined that the dominant unit along the tunnel routes is the agglomerate of the Beşirli formation and the New Austrian Tunneling (NATM) method is applicable. The rock classes found were determined to be B3 and C2 classes according to NATM. Excavations in the tunnel were carried out by drilling and blasting method in the form of the upper half and the lower half.
Keywords: Tunneling; NATM; Geological formation; Geotechnical design.

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1. Introduction

With the developing technology and population in regions with geographical difficulties, the need for tunnels and similar structures is increasing day by day. In order to meet this increasing need, there is a need for strong, durable structures that will be built as soon as possible. The most important parameter to meet these conditions is the excavation method to be used.

The tunneling method is determined by evaluating parameters such as the topography of the route to be tunneled, ground conditions and the geometry of the tunnel to be opened.

Depending on the innovations in construction technologies, 4 different tunneling methods are used today [1-3].

1) Tunnels built with the cut-and-cover method,
2) Tunnels built with the classical method
3) Tunnels built with TBM Tunnel Boring Machine
4) Immersed Tunnel method

In tunnels opened in rock environments, many problems may develop due to the geology of the region, such as physical and mechanical properties of the rock unit, discontinuity properties (faults, folds, etc.), weathering, magmatic intrusions, groundwater and natural stresses. In order to eliminate or prevent these problems, the loads to be transferred to the geological structure should be determined with sufficient sensitivity in the design of the planned underground engineering structures. After the insufficient determination or transfer of the geological structure, the risks that the geological structure may pose during the excavation (slope slip, tunnel collapse, excessive deformation and settlement in deep excavation pits, excessive water development, etc.) should be minimized [4,5]. In addition, the geological structure is one of the important parameters for the timely and successful opening of the tunnel in tunneling operations.

All these methods, which have a common denominator with the effect of technological developments, have tried to classify the behavior of the rock mass in which excavations are made.

The two methods that make rock mass classification and are used most in today's applications are; There are NATM (New Austrian Tunnelling Method) and ADECO-RS (The Analysis of Controlled Deformation in Rocks and Soils). Both methods categorized the rock mass behavior in various ways.

The tunnels to be built within the scope of this project are planned to be constructed according to the NATM system. The determination of the excavation method for each structural region along the tunnel route is possible by individually classifying the rock mass on the route where the tunnel excavation will be made, taking into account various engineering properties [6,7].

The NATM approach is to mobilize or maintain the existing resistance of the rock surrounding the tunnel, thereby making the country rock substantially self-supporting. NATM is a method of using a thin shotcrete layer, suitably reinforcing with rock studs, and using reverse arch concrete placed as close to the excavation as possible [6]. In the project to be carried out within the scope of the study, 4 tunnels will be opened. The first of the tunnels to be opened, the Akyazı Tunnel with a length of approximately 2476 meters, with 3 lanes and double tubes, will be examined within the scope of this research. In addition, there is a 2 lane, approximately 616 m long connection tunnel at the project site, which separates at approximately 2540 m of the Akyazı tunnel and connects to the main road [8].

The Akyazı tunnel, which is planned to be opened on the project route, has double tubes and its left tube is between 0+760.00km and 3+180.00km; the right tube is located between 0+760.00km and 3+242.00km. It enters the tunnel at an elevation of approximately 9.07 at 760m on the project route and exits the tunnel at an elevation of approximately 9.80 at 3242m with an inclination of 0.64%.

Akyazı Tunnel and Connection Tunnel, which will be opened within the scope of Trabzon City Pass Kanuni Boulevard Project, are within the borders of the 10th Regional Directorate of Highways (Trabzon). 1/25000 and 1/1000 scaled topographic maps were used in the field studies. Field studies were carried out in June 2013. As a result of these studies, the geological model of the area was created and the lithological contacts of the units, fault, crush zone etc. It was elaborated on the geological plan in detail. During the field studies, discontinuity measurements were taken along the tunnel route, as a basis for the geotechnical parameters of the tunnel, and the Geological Strength Index of the unit encountered with the geological data was determined.

In the study, the tunnel route was determined by using the RMR and Q rock classification system, and NATM was determined and a blasting design suitable for this method was proposed.

2. General geology of the study area and surroundings

Trabzon is located in the northeast of the Eastern Pontide Tectonic Unit. This tectonic unit; It forms a metallogenic belt, approximately 500 km long from the Kızılırmak valley in the west to the Georgian border in the east, and approximately 50-75 km wide from the Black Sea coast in the north to the North Anatolian fault in the south. In a broad sense, it is a part of the island arc sequence developed in the Jurassic-Pliocene time interval due to the Alpine mountain formation. The "Pontids", in which Trabzon is located, were affected by the Austric phases of the early Alpine period, the Anatolian of the middle Alpine period and the Attic tectonic phases of the late Alpine period. Especially after the Attic phase, which affected the region, the units folded and surfaced and were eroded. As a result of this period, Sandstone - Claystone - Conglomerate, basaltic agglomerated pebbly sedimentary levels were formed especially in the coastal areas (Akçaabat-Yomra). During and after this period, the rising movements on the land continued and marine terraces were formed [9].

Tholeiitic and calc-alkaline rocks belonging to the Mesozoic and Cenozoic periods are observed in Trabzon province and its surroundings. The Mesozoic period begins with Liassic volcanics and continues with Upper Jurassic-Lower Cretaceous shallow platform carbonates. The Upper Cretaceous period is a period of intense volcanic activity. This activity continued its development with acid and basic periods. Towards the end of the Upper Cretaceous, volcanic activity usually ceases. In this phase, turbiditic deposits continue uninterruptedly until the end of Paleocene.

The volcanic activity, which started in the Liassic and continued its development in periods until the end of the Upper Cretaceous, is in the form of submarine volcanism, and they are stacked with sedimentary intercalations. Pillow lava structures were generally formed in the lavas.

During the late Paleocene, granitoid emplacement developed with orogenic activities (Kaçkar Granitoid -I). In the Eocene period, the reactivated volcanism continues effectively. Due to spreading in the submarine environment, a Volcano-Sedimentary sequence has developed. Granitoid settlements continued in the Eocene period (Kaçkar Granitoid-II).

Tholeiitic and calc-alkaline rocks belonging to the Mesozoic and Cenozoic periods are observed in Trabzon province and its surroundings. The rock units within the study area are described below (Fig. 1).

3. Material and method

Determining the character of the rock mass excavated; The geological, hydrological and geotechnical information that forms the basis of the project should be compared with the information obtained from the geological mapping made during the excavation of the tunnel. Mainly, it should be checked whether the rock formation, lithology and rock units envisaged in the project are encountered.

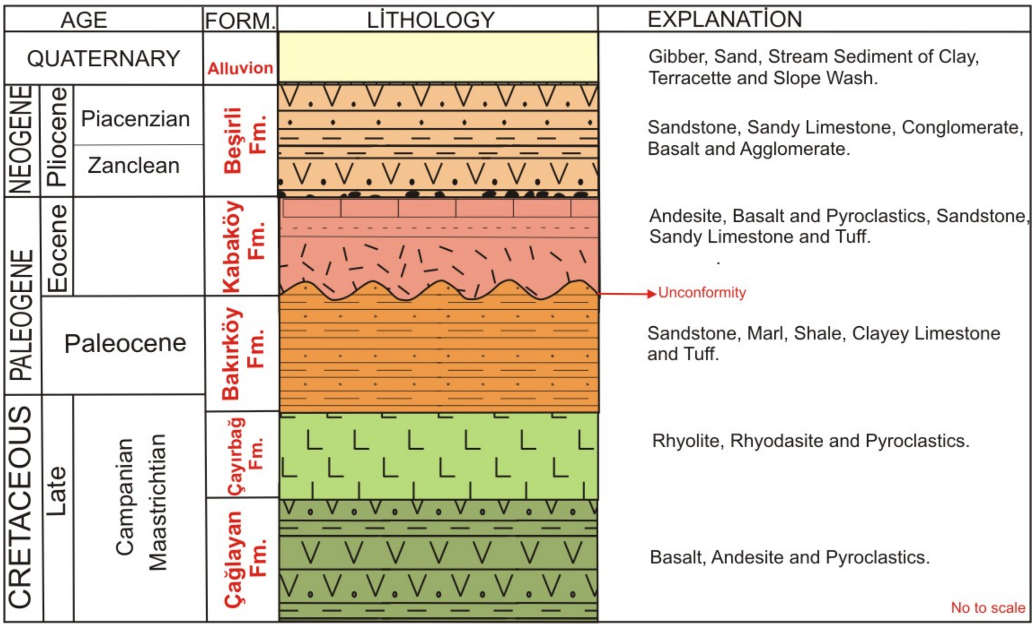

Figure 1. Generalized stratigraphic strut section of Trabzon province and its surroundings.

Determination of rock mass type during excavation; Interpretation of the behavior of the excavated rock mass using information such as discontinuity obtained during geological mapping, the nature of the fill between discontinuities, water leaks, weathering degrees, strength of the rock, excessive dismantling, the location of faults relative to the tunnel section and the impact area, and accordingly the interpretation of the rock type from three main groups A (stable), B (brittle), C (printed) should be determined.

The dominant unit along the routes of the double tube Akyazı tunnel to be opened within the scope of the project and the connection tunnel that separates from this tunnel and joins with the main road is the agglomerate of the Beşirli formation.

As a result of the outcrop studies carried out in the field, it has been determined that this unit is slightly - moderately weathered, very weak - moderately strong rock. In addition, tuff intermediate levels with a thickness of approximately 1 m at km:1+000 and approximately 3 m thick at km:1+700 were observed on the Akyazı tunnel route. In addition to these two units, slope debris was also encountered in the project area.

During the geological mapping, a total of 9 different locations were studied and measurements could not be taken in 1 location because massive agglomerate was encountered, and discontinuity measurements taken at the remaining 8 locations are shown on the stereo-net projection (Fig. 2). The dominant discontinuities in this unit are crack sets.

Major joint sets measured at each location were determined on the stereo-net projections above. The slope direction/tilt angle, spacing, continuity, surface properties and roughness of these joint sets are summarized in Table 1 below.

3.1 Geotechnical design parameter

The tunnel will be opened within the Beşirli formation, which is dominated by the agglomerate unit in the project area. During the geological mapping, exposure studies were carried out in 9 different locations in the project area and the geological strength index for the encountered unit was determined according to the modified GSI system proposed by Sönmez and Ulusoy [10]. According to this approach, the GSI parameter is a function of the structural properties of the rock mass and the discontinuity surface properties (Fig.3).

Geotechnical design parameters were determined by Hoek and Brown fracture criteria and the values used for this purpose are GSI (Geological Strength Index), UCS (Uniaxial compressive strength of rock material) and Mi constant (Dimensional material constant of rock material).

The GSI parameters were determined for the unit encountered along the tunnel and are summarized in Table 2 below. GSI values for the unit encountered during geological map studies were assigned for 9 different locations. Accordingly, it has been determined that the GSI values for the unit encountered in the project area vary between about 40 and 60 (Table 2).

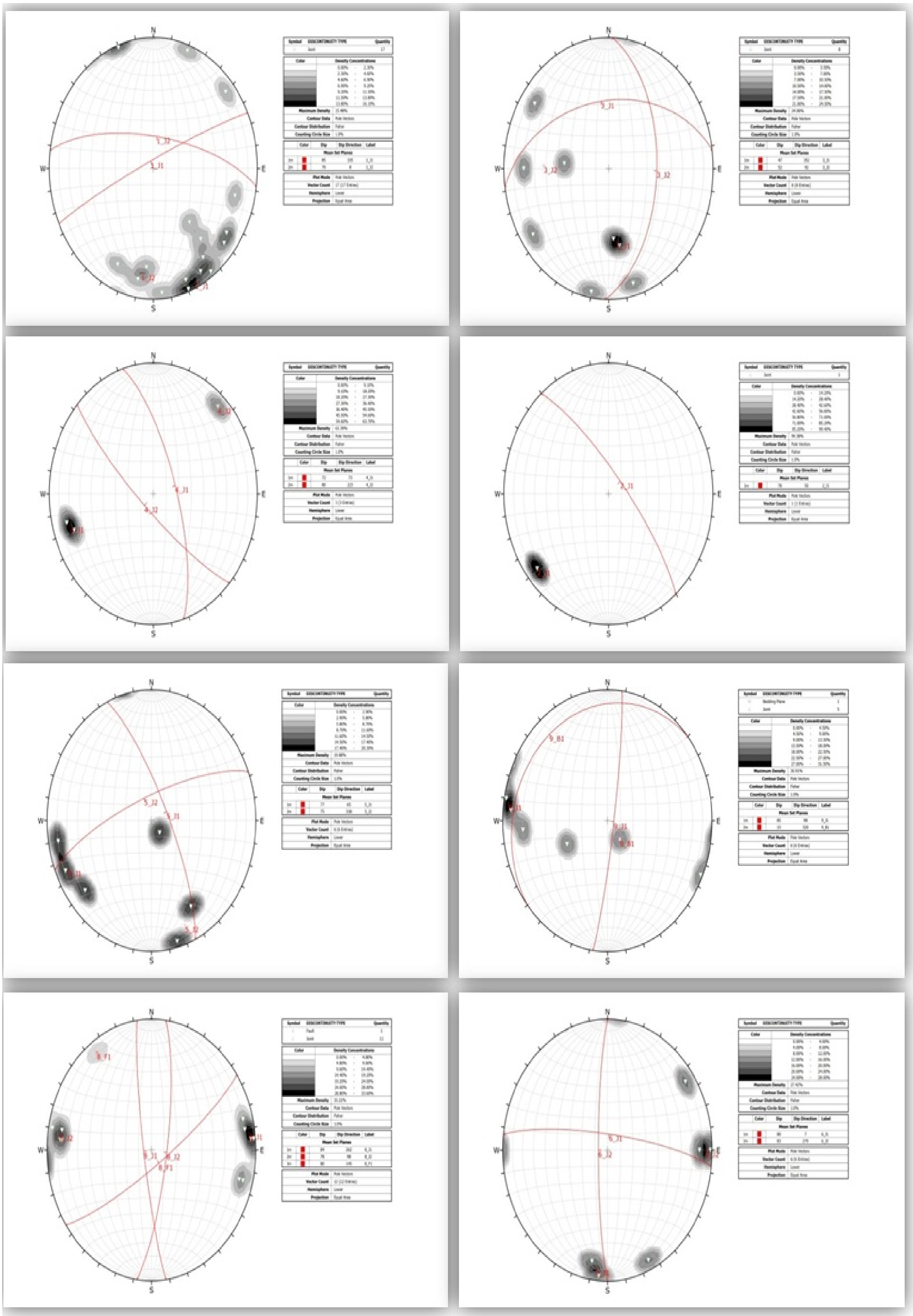

Figure 2. 1-9 on the Project route. main joint sets of discontinuities measured within the agglomerate unit at their locations

Table 1. Surface properties and roughnesses.

Location Number	Discontinuity Type	Range (m)	Continuity (m)	Discontinuity surface weathering and fill type	Roughness	Slope /Tilt Direction
1	Joint 1	0,6 – 2	10 – 20	Very weathered, filled (hard fill>5mm)	Less rough	85 / 355
1	Joint 2	0,6 – 2				70 / 008
2	Joint 1	0,2 – 0,6				78 / 050
3	Joint 1	0,6 – 2	3 - 10			47 / 352
3	Joint 2					52 / 092
4	Joint 1	0,2 – 0,6	3 - 10	Very weathered, filled (hard fill<5mm) Iron oxide coated	Less rough	72/073
4	Joint 2	0,2 – 0,6	3 - 10	Very weathered, filled (hard fill<5mm) FeO coated	Less rough	80/223
5	Joint 1	0,2 – 0,6	3 - 10	Very weathered, filled (hard fill<5mm) Iron oxide coated	Less rough	77 / 065
5	Joint 2					75 / 338
6	Joint 1	0,2 – 0,6	10 – 20	Moderately weathered, filled (hard fill<5mm)	Less rough	80 / 007
6	Joint 2					83 / 270
8	Joint 1	0,6 – 2	10 – 20	Moderately weathered, filled (hard fill<5mm) Iron oxide coated	Less rough	84 / 262
8	Joint 2	0,6 – 2	10 – 20			78 / 098
8	Fault	>6	>20			80 / 145
9	Joint 1	0,6 – 2	3 - 10	Very weathered, filled (hard fill>5mm) Iron oxide coated	Less rough	85 / 98
9	Joint 2					15 / 320

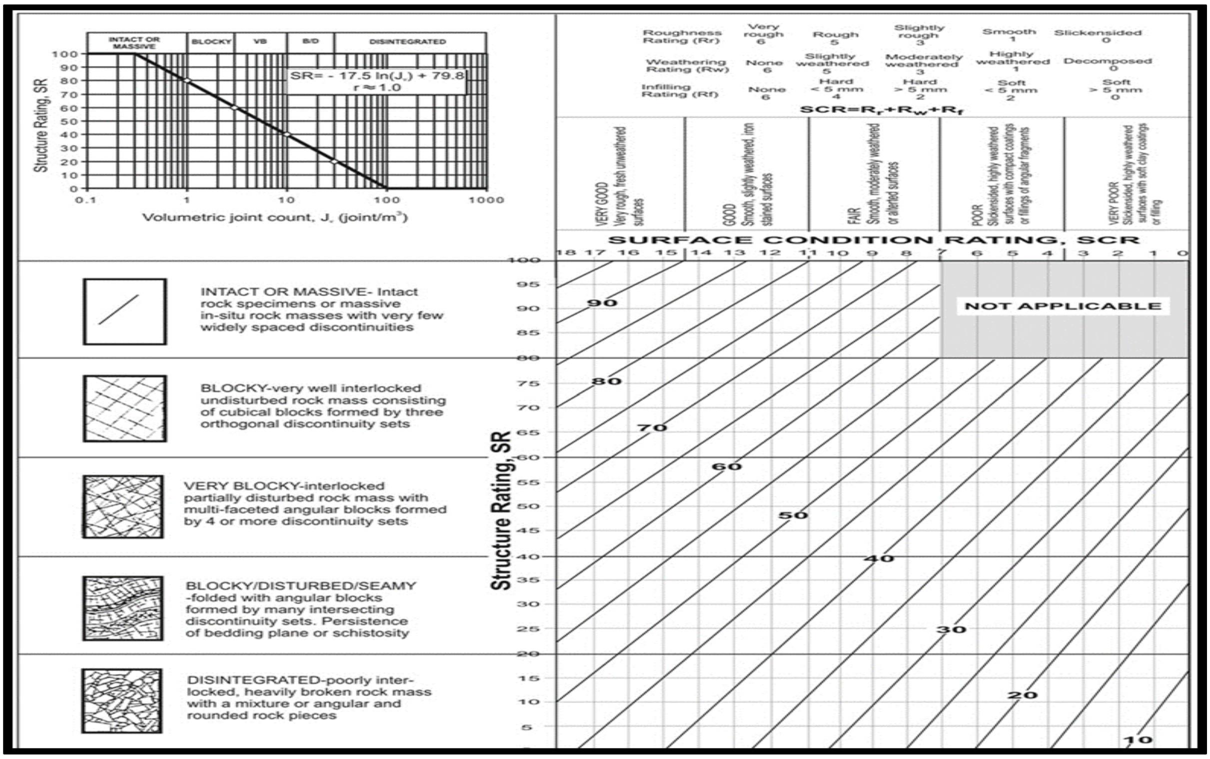

Figure 3. Geological Strength Index (GSI) determination for the unit encountered at 1,2,3,4,5 and 9 locations along the tunnel route as indicated in table 1 [10].

Depending on the NATM classification, 2 different rock classes are encountered along the route of the Akyazı Tunnel. B3 and C2 rock classes were made depending on the rock appearance, experience and observations, geotechnical measurement results and deformations in similar rock conditions before the start of the excavation sequence.

Table 2. GSI value of Beşirli formation encountered in 9 different locations in the project area

Location Number	Number of volumetric joints (Jv) *(1/x+1/y+1/z)*	Structural feature scoring (SR) *(-17,5xlnJv+79,8)*	Surface properties (SCR) *(Rr+Rw+Rf)*	GSI
1	1/0,6+1/1=**3**	**61**	(Rr=3+Rw=1+Rf=2) = **6**	**43** (40 recommended on the safe side.)
2	1/0,3=**3**	**61**	(Rr=3+Rw=1+Rf=2) = **6**	**43** (40 recommended on the safe side)
3	1/0,6+1/1=**3**	**61**	(Rr=3+Rw=1+Rf=2) = **6**	**43** (40 recommended on the safe side)
4	1/0,5+1/0,5=**4**	**56**	(Rr=3+Rw=1+Rf=4) = **8**	**45**
5	1/0,5+1/0,5=**4**	**56**	(Rr=3+Rw=1+Rf=4) = **8**	**45**
6	1/0,5+1/0,5=**4**	**56**	(Rr=3+Rw=3+Rf=4)= **10**	**52** (50 recommended on the safe side)
7	-	-	-	The GSI value of the massive unit is estimated to be around 40.
8	1/1+1/2+1/10=**1,6**	**72**	(Rr=3+Rw=3+Rf=4)= **10**	**60**
9	1/0,6+1/1=**3**	**61**	(Rr=3+Rw=1+Rf=2) = **6**	**43** (40 recommended on the safe side.)

The portal class rock mass is essentially independent of the geotechnical properties of the rock mass and includes the studies that need to be done to meet the horizontal pressures as well as the vertical pressures at the entrance and exit parts of the tunnel. The amounts of different types of rock classes in the Akyazı tunnel are given in Table 3 and Figure 4.

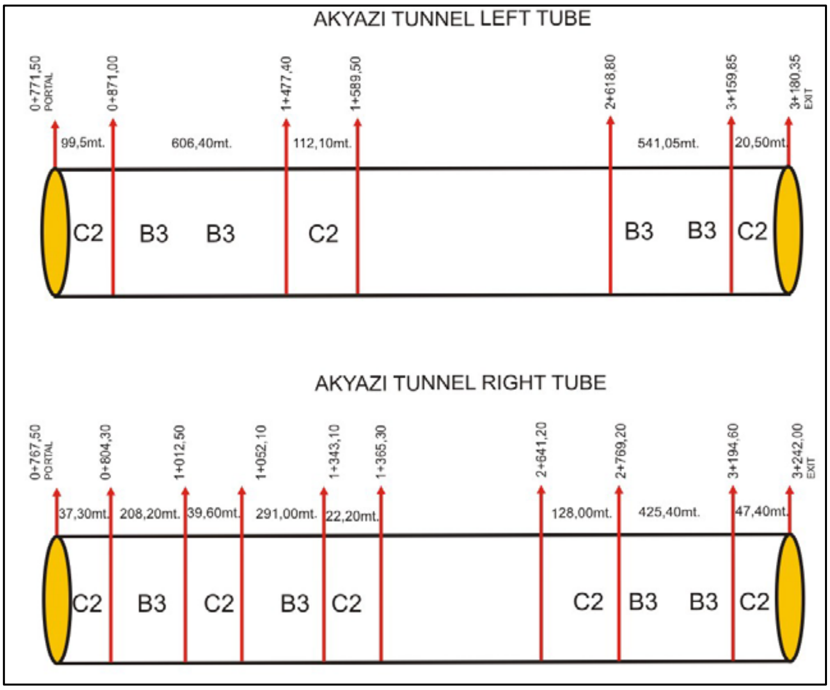

Figure 4. Schematic representation of rock classes and lengths in the Akyazı tunnel.

Table 3. Rock class and lengths of Akyazı tunnel

Rock grade	Range (m)		Total length (m)
	Right tube	Left tube	
B3	924,6	1027,35	1951,95
C2	124,3	120	244,3

3.2 Excavation and drilling blasting design

Excavations in the Akyazı tunnel in the study area are carried out by the New Austrian Tunneling Method (NATM). In this method, after the holes in the excavation mirror are drilled with a drilling Jumbo machine, explosive charging, blasting, ventilation, shell removal, rust transport and fortification are carried out [11-14]. These works in the tunnel continue in a cycle (Figure 5).

As the explosive material used in the tunnel, only a cap sensitive explosive, a non-electrical delayed system, an electrical capsule and a detonating cord are used with a combined design. Holes are drilled on the mirror surface in a V-CUT pattern, and non-electric and delayed in-hole detonators are placed together with detonator sensitive explosives. Capsule ends remaining on the mirror surface are connected to each other with a wick, the detonating cord to which the delayed capsular ends are connected is connected to the electrical detonator, and the mirror is made ready for firing by connecting the bell wire and the electrical detonator.

As explosive; Superpower 90 capsule sensitive (emulsion-cartridge) explosives, Supremedet non-electric (delayed) detonators, Supreme electric detonators and Solarcord detonating roving materials are used. In Figure 6, the amount of advance, hole sizes, number of holes and specific charge amounts for each rock class are given.

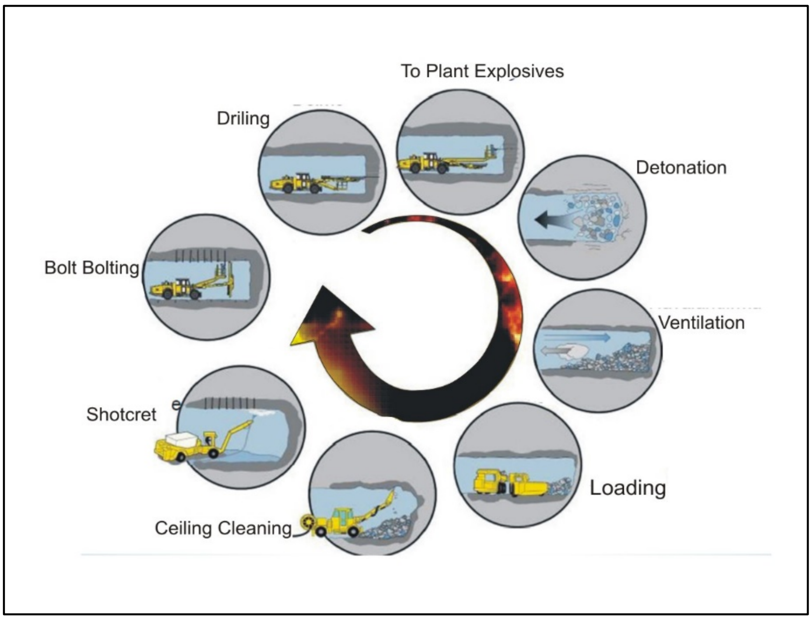

Figure 5. General duty cycle in NATM tunnels

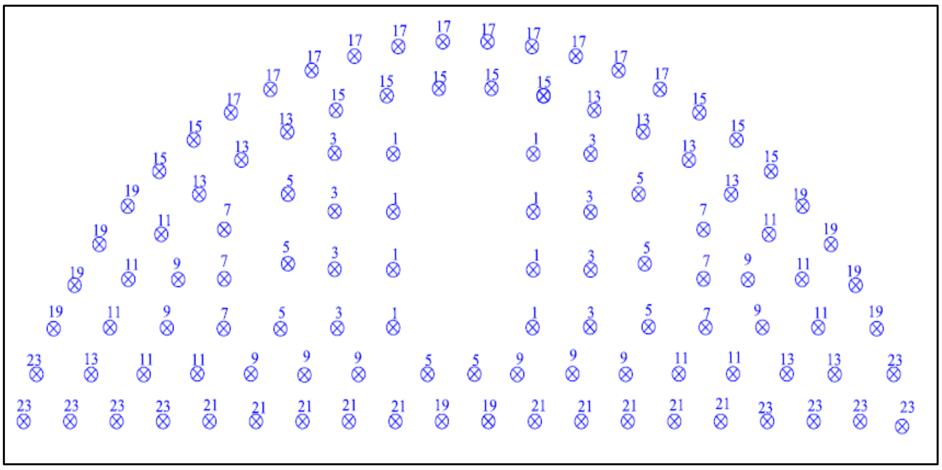

Figure 6. Explosion design used in Akyazı tunnel

This cycle is completed in 9 hours in total. The procedures and their durations are summarized in Table 4.

Table 4. Operations and their durations in the Akyazi tunnel

Action Taken	Time (Hours)
Drilling	2
Filling	1,5
Ventilation	0,5
Discharge to Pass	2
Ceiling Screening Wire Mesh Binding	2
Shotcrete	1
Total Time	9

Shotcrete in Akyazı tunnel is designed in BS20 (C/20-30) concrete class and is applied as a wet mix. The wet shotcrete prepared outside the tunnel is brought into the tunnel by transmixers and applied with the help of Tünelmak Adroit 430 and Adroit 230 (Fig. 5). Shotcrete should be applied perpendicular to the surface and from a distance of approximately 70 cm. In order to provide the early carrier function of the shotcrete, 5% of the cement weight is added to the mixture as a set accelerator additive [15-18].

4. Conclusions

The Akyazı tunnel, which is located in the Black Sea coastal road project, was found to be approximately 2476m in length after the examinations and calculations, and a progress of 1050m in the right tube and 1150m in the left tube was achieved during the study period. Along the tunnel route, 2 different rock classes were determined for the purpose of excavation based on the New Austrian Tunneling (NATM) method. These rock classes; B3 is (244,3m), C2 (1951,9m). Excavations in the tunnel were carried out by drilling and blasting method in the form of the upper half and the lower half. Different hole charges were used in each rock class in order to prevent excessive dismantling, breaking and cracking around the tunnel, and to prevent the studs and shotcrete placed close to the tunnel excavation bee from being damaged by the vibrations caused by blasting.

It has been determined that it will be opened within the Granites belonging to the Çatak Formation and that the tunnel entrance and exit portal excavations remain within the weathered altered granites. The tunnel was divided into five sections and examined as the entrance portal, axis I, Axis II, Axis III and exit portal. RMR and Q classifications were made and it was stated that the NATM support class tunnel would be passed with the B3 support system in the entrance portal, axis I, Axis III and Exit portal, and with the B2 support system in the Axis II Section.

Depending on the different rock classes and deformation properties in the tunnel, the type, amount and placement times of the support elements used in the tunnel also differ. With the completion of the project, it is thought that traffic will be relieved, an important time will be gained and the risk of accidents will be reduced. It should not be ignored that the measurements taken on the tunnel route are made from the surface, and discontinuities should be checked during construction in places where slipping is possible.

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