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Engineering Geology 87 (2006) 141 – 148

ENGINEERING GEOLOGY

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Engineering geological assessment of the Obruk dam site (Corum, Turkey)

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Received 26 August 2005; received in revised form 31 March 2006; accepted 6 April 2006
Available online 8 September 2006

Abstract

Engineering geological properties of rock masses, such as discontinuities, degree of weathering, strength and hydraulic conductivities along the dam axis, and the excavatibility of diversion tunnels, power tunnels and spillways, were investigated in order to determine probable problems and necessary precautions to be taken prior to construction. In this study, the Obruk dam site, constructed on the Kızılırmak River to the north of Çorum, central Anatolia, was investigated from the standpoint of the aforementioned engineering geological aspects. Quaternary alluvium at the dam site has a thickness of about 65 m and overlies the Eocene basalt basement. Diversion and power tunnels were constructed in the basalts. In order to determine the distribution of the basalt, both horizontally and vertically, core samples were collected from preliminary geotechnical boreholes drilled by the General Directorate of the State Hydraulic Works (DSI), and the depth to groundwater was measured in these boreholes. The geological and geomechanical properties of the basalt are controlled by tectonism and weathering, and these properties vary over short distances. The mineralogical, petrographical, and geomechanical properties of the basalt core samples were determined. Based on these test results, the rock mass cropping out at the dam site has been classified for tunneling, and possible support systems suggested.

Keywords: Basalt; Obruk dam; Rock mass classification; Support type

1. Introduction

The principal factors that constrain the geomechanical properties of rocks are geological structure, mineralogical composition, discontinuities, and degree of weathering. Accordingly, the geological and geotechnical properties of rocks that comprise the basement to major engineering structures (such as dams) should be determined in the field and in the laboratory prior to construction. Axis locations, the excavatibility of rocks underlying the projected traces of spillways, diversion tunnels and power tunnels, grouting conditions and the determination of support systems for tunnels are also significant from the standpoint of optimal project design. Engineering geological investigations and rock mechanics studies mainly include discontinuity surveying, core drilling in-situ testing (Özsan and Akın, 2002).

In the present study, the basalts that represent the basement to the Obruk dam — constructed on the Kızılırmak River approximately 50 km NW of Çorum in central Anatolia — were investigated from an engineering geological perspective (Fig. 1). This dam, which is of the earth-fill type and intended for energy production and irrigation, is situated 67 m above the thalweg, with a height of 126 m from base to top and a 12,000 hm^3 body

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doi:10.1016/j.enggeo.2006.04.005

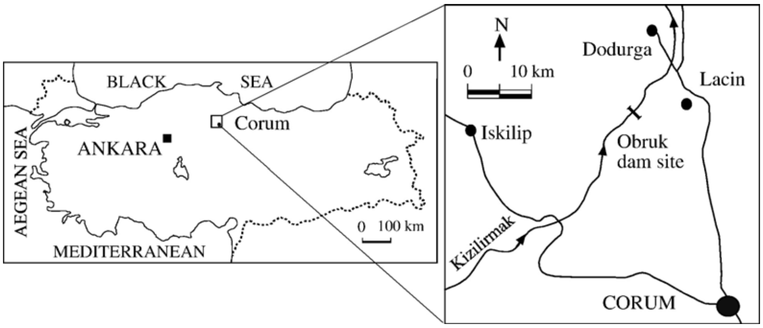

Fig. 1. Location map of the study area.

volume, and was planned to have 203 MW of power with an annual energy production of 473 GWh. In 1979 and 1983, within the framework of the Lower Kızılırmak Project, General Directorate of the State Hydraulic Works (DSI) prepared engineering geological planning reports on the basis of exploratory drilling in the area of the initial axis of the Obruk dam (DSI, 1979, 1983). Kılıç (1999) studied the geomechanical properties of the basalts in the area of the planned initial axis of the Obruk dam, and divided these rocks into five groups on the basis of degree of weathering. Koçbay (2003), through study of the characteristics and degree of basalt weathering in the Osmancık–Çorum area, proposed a classification related to decomposition. Further, Koçbay and Kılıç (2003) investigated the possible use of these basalts as a natural building material.

Because there is an active landslide located approximately 500 m on the source side of the initial axis area for the Obruk dam, it was relocated. Thus, the present study deals — from an engineering geological perspective — with the second axis area chosen. In order to study vertical and lateral variations in the basalts and take core samples thereof, do Lugeon tests in order to determine the coefficient of hydraulic conductivities, and to determine the ground-water level, we benefited from 17 basement-investigation drill holes that were drilled by the General Directorate of the State Hydraulic Works (DSI) at construction sites for the dam project. These 17 drill holes had depths between 40 and 160 m and a total depth of 1512 m. Furthermore, the predominant strike and dip directions of joints in the basalts were determined, and representative block samples were taken from outcrops.

After initially determining the mineralogical, petrographic and chemical characteristics of the samples, the samples were grouped on the basis of degree of weathering. Subsequently, the physical and geomechanical characteristics of 172 samples were ascertained. Using these data, an engineering geological map and sections for the traces of 1) the new axis location for the Obruk dam and 2) power and diversion tunnels were prepared. On the basis of all of these characteristics, the rock mass was classified from the perspective of tunneling.

2. Geology of the dam site

The Lutetian Bayat formation, comprising volcanites and flysch interbeds, crops out in the study area (MTA, 1975). In the vicinity of the dam site, the Bayat formation is widespread, and the predominant lithology is basalt. The basalt consists of a fine-grained dark matrix, medium-sized plagioclase crystals, relatively coarse-grained pyroxene and olivine phenocrysts, and opaque minerals. Locally, pyrite is present within the opaque phases. Chloritization is widespread in glassy rock flour and in pyroxenes, while plagioclases have been altered to clay. Carbonatization, silicification, chloritization and argillization increases in relation to degree of hydrothermal alteration. Alteration is more intense along discontinuities, and gypsum fillings occur in fractures. At the top of the sequence is Quaternary alluvium made up of block, gravel, sand, silt and clay-sized materials (Fig. 2).

The study area — located approximately 35 km from the North Anatolian Fault Zone (NAFZ), one of the most important tectonic features of Turkey — has been strongly affected by tectonism. Numerous NE–SW- and NW–SE-trending normal faults at varying scales occur to the right and left of the dam axis. The effects of tectonism and the development of joints are obvious. An engineering geological map of the dam site, diversion and power tunnels, spillway area, and right and left slopes, and sections thereof, are given in Figs. 2 and 3, respectively.

3. Mineralogical and chemical characteristics

During the course of our field work, samples were taken from surface exposures and from drill holes, and by determining primary and weathering-induced

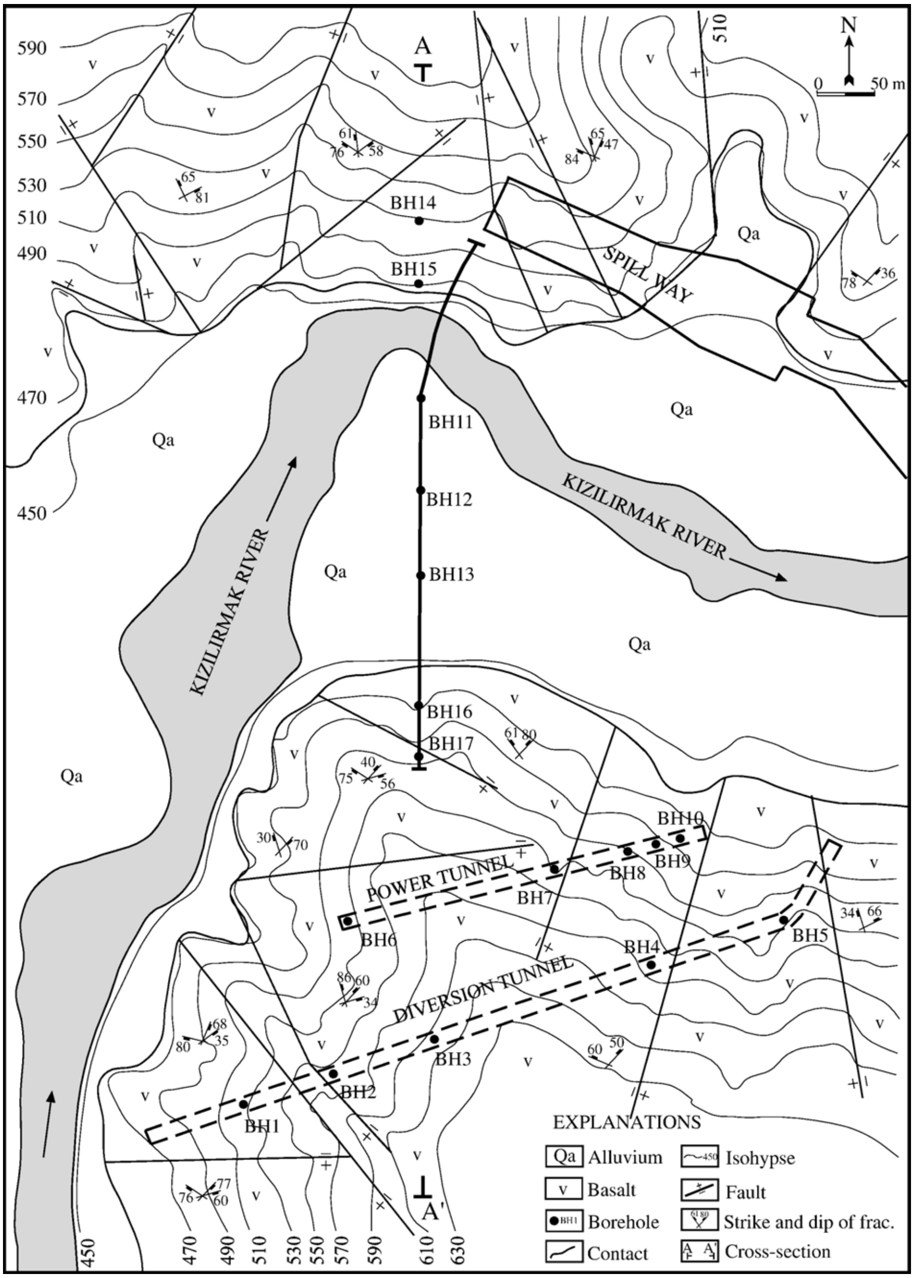

Fig. 2. Locations of the boreholes, main structures, and engineering geological map of the Obruk dam site.

secondary minerals and their textural relationships, rock descriptions were made. On the basis of petrographic studies, it was ascertained that the volcanic rocks at the dam site comprise basalt and minor amounts of andesitic basalt; both rock groups consist of plagioclase (oligoclase, andesine and some labradorite), amphibole and augite. In addition to these, other secondary components include biotite, apatite, pyrite and opaque minerals. The glassy material of the basalt has been altered to sericite and chlorite as a function of the degree of weathering. Furthermore, sericite, chlorite, calcite, clay and gypsum occur as joint fillings.

Toward the goal of identifying minerals that, due to alteration, could not be identified under the microscope, 10 basalt samples were analyzed via X-ray diffractometry (XRD). On the basis of XRD patterns, smectite, kaolinite, dolomite and hematite were identified, in addition to those already recognized microscopically. It is likely that kaolinite and smectite formed via weathering of feldspar and plagioclase, respectively, and increase in their abundances are controlled by depth. Similarly, because amorphous material is present in samples taken from depth, the peaks of some crystals are masked. It has also been ascertained that hydrothermal solutions derived from depth were rich in silica — in places suddenly solidifying to form tridymite and amorphous materials such as opal, while elsewhere coarsely crystalline quartz with comb structure developed.

In order to investigate the chemical characteristics of the basalt and to determine the variation of these characteristics with degradation and depth, 20 core samples were taken from various depths, and three samples were taken from the surface. Analyses were performed on powders using ICP-MS by Acme Analytical Laboratories Limited (Canada), and the results of the chemical analyses are given in Table 1. It is noted that these values — both for the core samples and for the samples taken from the surface — differ greatly from the major-oxide and trace-element compositions of normal basalt; this difference is attributed primarily to the action of hydrothermal solutions derived from depth. Consequently, assignment of rock names was not done on the basis of these values.

Table 1
Results of chemical analyses for basalts

Chemical composition	Min. (%)	Max. (%)	Mean (%)
SiO_2	39.39	53.71	46.55
Al_2O_3	12.18	19.92	22.14
Fe_2O_3	5.90	9.29	7.60
MgO	3.06	10.90	6.98
CaO	1.03	9.43	5.23
Na_2O	0.25	3.00	1.63
K_2O	1.12	4.20	2.66
TiO_2	0.56	0.94	0.75
P_2O_5	0.21	0.41	0.31
MnO	0.08	0.19	0.14
Cr_2O_3	0.04	0.09	0.06

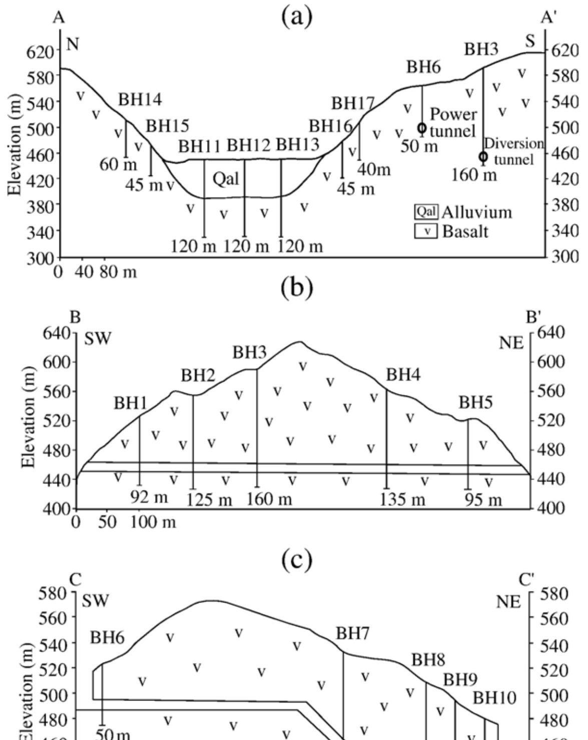

Fig. 3. Engineering geological cross-sections of the (a) dam axis, (b) diversion tunnel and (c) power tunnel.

4. Characteristics of discontinuities

In the study area, many fissures and fractures with varying orientations developed in response to tectonism. The orientations of the fissures, their degree of openness, frequency, filling or lack thereof and its characteristics (where present), directly influence the characteristics of the rock mass. The strikes and dips of 3139 joints — 1715 on the right shore of the dam, and 1424 on the left shore — in basalt outcrops were measured. These measurements were evaluated using the “DIPS” program, which is based on the stereographic projection technique, of Diederichs and Hoek (1989). On the right shore, the predominant strikes and dips are N75W/75SW, N37W/66SW and N57E/62SE, while on the left shore are N32E/46NW and EW/21N.

The discontinuities are 1 mm to 5 cm in thickness, and are filled by gypsum, clay, calcite and silica. It is noted that in some sections, the clay and gypsum fillings have been leached by surface waters. The thickness of the fillings, the type of filling material, the distribution of grain size, hydraulic conductivities, the irregularity of the surface of the discontinuity, and the fracture and rupture characteristics of the rock all influence the degree of weathering. High-strength minerals such as calcite, quartz and pyrite positively affect rock strength. It should be noted that, in sections with gypsum fillings, the sulphate concentration of the waters increases, negatively affecting proximal structures. Classification of the apertures of fractures in the basalts (Deere, 1963) and the distance between fractures and abundance of fractures over 1 m (ISRM, 1981) are given in Fig. 4 as percentages. It has been established that, from the standpoint of rock quality, basalts in the axis area of the

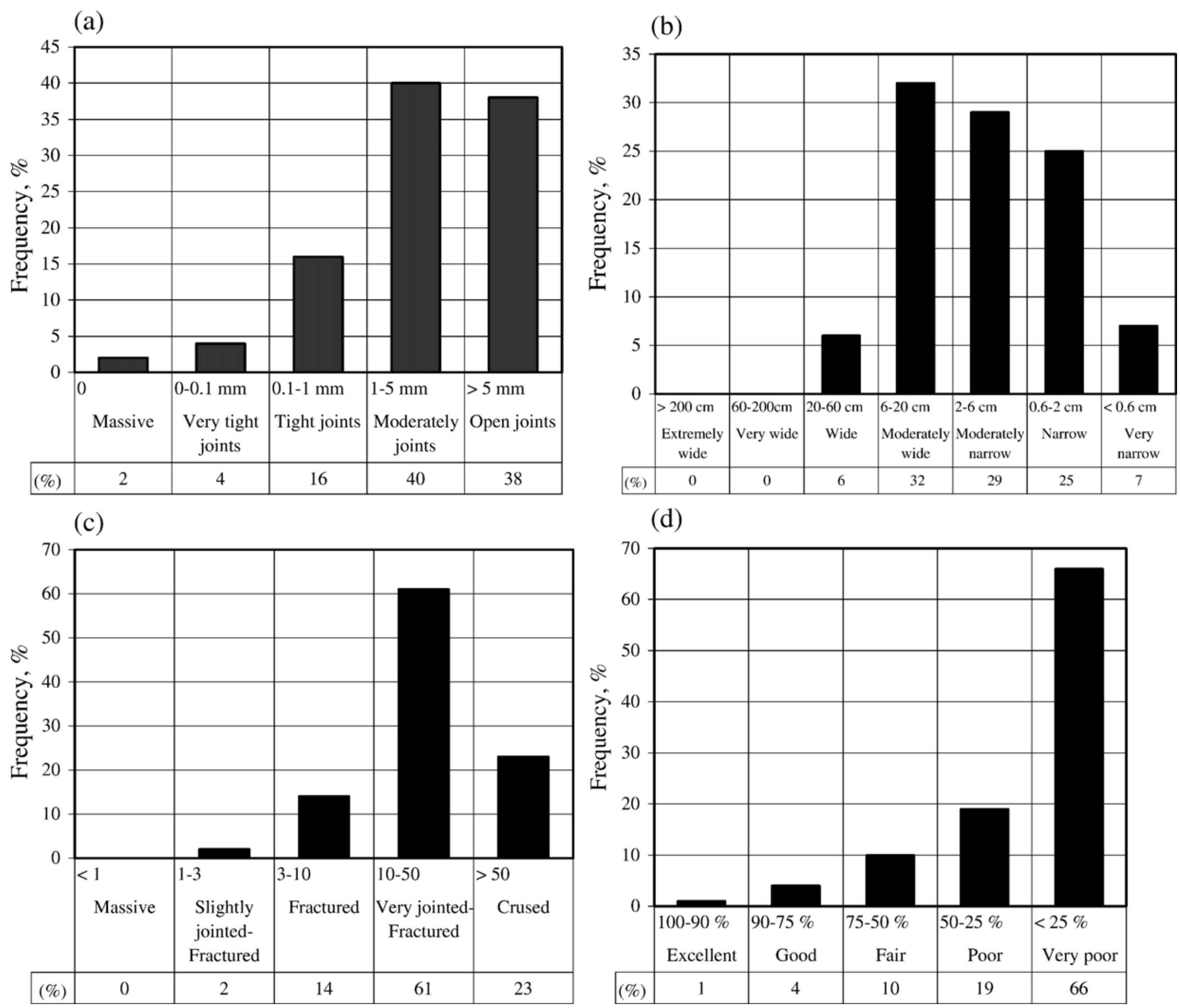

Fig. 4. Histograms showing percentage distribution and classification of basalt (a) based on fracture spacing (Deere, 1963), (b) distance between fractures (ISRM, 1981), (c) frequency of fractures in 1 m (ISRM, 1981) and based on RQD (Deere, 1963).

dam and along the traces of the diversion and power tunnels are of very poor and poor quality. As degree of weathering in the basalts increases, the RQD values decrease (Koçbay, 2003). Classification and distribution percentages on the basis of RQD values are given in Fig. 4.

5. Physical and geomechanical characteristics of the basalts

Geomechanical characteristics of a total of 172 54-mm core samples of basalt — 105 samples from various depths from drill holes for the diversion tunnel, 23 from drill holes for the power tunnel, and 44 from the axis area — were determined in the Engineering Geology Research and Application Laboratory of Ankara University and in the Concrete and Materials Laboratory of the State Hydraulic Works (DSI) Technical Research and Quality Control Office.

The dry unit weights, saturated unit weights, weighted water absorptions, volumetric water absorptions, permeabilities, specific gravities, point-load strength indices, uniaxial pressure strengths, velocities of P and S waves, dynamic and static elasticity modules, and Poisson ratios for the basalts were determined on the basis of ASTM (1980, 1996) and ISRM (1978, 1981, 1985). Minimum, maximum, mean, standard deviation and standard error values for these parameters are given in Table 2.

The specific gravity of the basalts varies between 2.80 and 3.04, and is elevated because the rock contains certain dark-colored minerals, such as pyrite. In

Table 2
Statistical evaluation of index and geomechanical properties of the basalts in the study area

Properties	Number of sample	Min.	Max.	Arithmetic mean	Standard error	Standard deviation
Saturated unit weight, γ_d (kN/m^3)	172	23.23	28.42	26.01	0.07	0.92
Dry unit weight, γ_s (kN/m^3)	172	22.25	28.32	25.71	0.08	1.02
Water absorption by weight, A_a (%)	172	0.14	5.30	1.20	0.08	0.98
Water absorption by volume, A_h (%)	172	0.40	12.80	3.07	0.18	2.41
Porosity, n (%)	172	2.10	14.90	7.17	0.19	2.56
Spesific gravity, G_s	172	2.80	3.04	2.88	0.004	0.05
Poisson ratio, v	172	0.21	0.43	0.33	0.002	0.032
P wave velocity, C_p (m/s)	172	3088	6985	4997	62.56	820.44
S wave velocity, C_s (m/s)	172	1576	3495	2525	28.48	373.49
Point-load strength index, Is_{50} (MPa)	149	1.15	15.10	6.27	0.23	2.82
Uniaxial compressive strength, σ_c (MPa)	114	9.80	130.20	52.57	2.24	23.89
Static elasticity modules, E_s (GPa)	99	8.92	89.08	39.25	1.73	17.17
Dynamic elasticity modules, E_d (GPa)	172	159.67	856.61	451.64	10.55	138.33

classifications based both on point-load strength index (Deere and Miller, 1966) and uniaxial compressive strength (ISRM, 1981), it was determined that the basalt is of high and medium strength (Fig. 5).

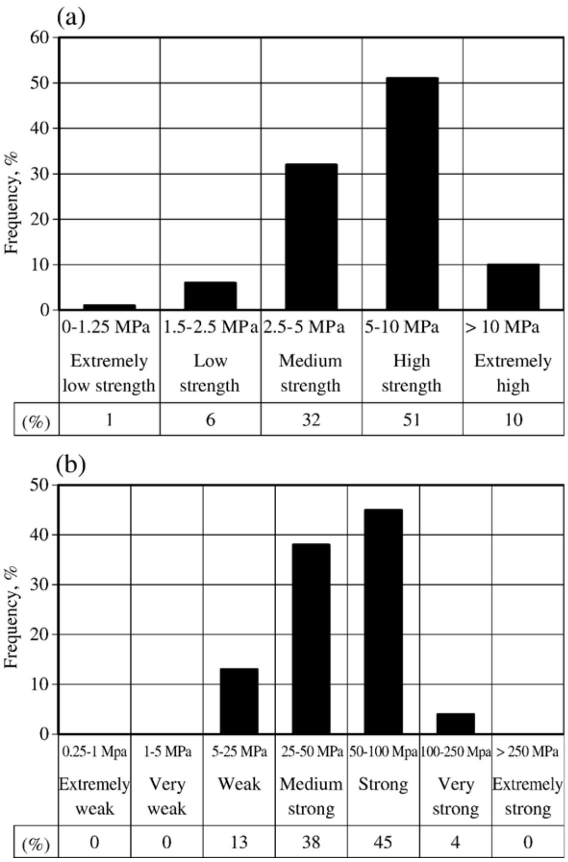

Fig. 5. Histograms showing percentage distribution and classification of basalt based on (a) point-load index (Deere and Miller, 1966), and uniaxial compressive strength (ISRM, 1981).

During drilling along the dam axis and the traces of diversion and power tunnels Lugeon tests were performed, in order to determine hydraulic conductivities and it was ascertained that most of the basalts are impermeable or only slightly permeable (Fig. 6). In spite of the fact that discontinuities within the basalt are closely spaced, the low hydraulic conductivities can be explained by the filling of fractures with clays produced during weathering.

6. Engineering classification of the rock mass

The basalts were classified according to the RMR (Bieniawski, 1989) and Q (Barton et al., 1974; Barton, 2002) systems in order to determine what kinds of support systems should be used in the diversion and power tunnels. RMR values, the parameters used in rock-mass classification and corresponding point totals for best- and worst-case scenarios, are given in Table 3.

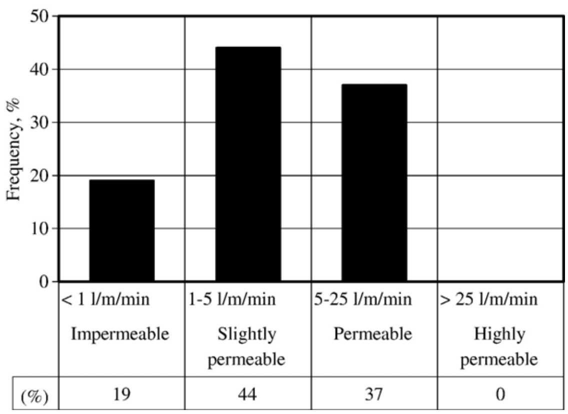

Fig. 6. Histograms showing percentage distribution and classification of basalt based on the Lugeon unit (Lugeon, 1933).

Table 3
Classification of the basalt at the dam site based on RMR system

Parameters	Parameters rating or description			
	Min.	Rating	Max.	Rating
Uniaxial compressive strength, (MPa)	9.80	2	130.20	12
Rock Quality Designation (%)	20	3	80	17
Spacing of discontinuities (mm)	<60	5	>180	15
Condition of discontinuities				
Continuity (m)	>20	0	<1	6
Spacing (mm)	>5	0	None	6
Roughness	Polished	0	Smooth	1
Filling	None	6	Hard	2
Weathering degree	Highly	0	Slightly	5
Groundwater conditions	Wet	7	Dripping	4
Orientation of discontinuities	Unfavourable	−10	Unfavourable	−10
RMR		13		58

The RMR value determined for worst conditions is 13. Accordingly, the basalt is placed in the "very weak rock (V)" group. For the rock mass in this group, advance should be made uniformly on the floor and roof, and support should be installed simultaneously with each 0.5–1 m of advance in excavation; furthermore, shotcrete should be utilized immediately after blasting. On wire-mesh walls and arches, 1–1.5-m spaced, 5-m long systematic bolts, and on the roof arches 150–200 mm, on the lateral walls 150 mm, and on the mirror 50 mm of shotcrete, and steel-shored, 0.75-m spaced medium-heavy traverses should be used. For optimal conditions, the total numerical value is 58. Thus, this basalt is placed in the "medium rock (III)" group. For the rock mass in this group, advance should be made from the roof arches and floor and, on the roof, complete support should be installed for up to 10 m to the mirror by advancing the excavation by 1.5–3 m. On the wire-mesh walls and arches, 1.5–2-m spaced, 3–4-m long systematic bolts, and on the roof arch and lateral walls, 50–100 mm and 30 mm, respectively, of shotcrete, should be used.

Parameters used in the Q rock-mass classification, and corresponding values for best and worst conditions, are given in Table 4. Based on the Q values calculated here and on the computational procedure revised by Grimstad and Barton (1993), support types were determined for the 10-m diameter diversion and 8-m diameter power tunnels. For the worst conditions, the obtained Q value is 0.02; thus, the basalt falls into the "extremely weak rock" group. In the support system recommended for the rock mass in this group, the rock should be bolted, steel-shored, mesh-reinforced and should use a 15–25-cm thickness of shotcrete. The Q value obtained for optimal conditions is 3.52 and, thus, the basalt falls into the "weak" group. In the support system recommended for rock in this group, systematic rock bolts and shotcrete 4–5- cm thick should be used.

Table 4
Classification of the basalt at the dam site based on Q system

Parameters	Rating	
	Minimum	Maximum
Rock Quality Designation (%)	20	80
Joint set number (J_n)	20	6
Joint roughness number (J_r)	2	1
Joint alteration number (J_a)	4	1
Joint water reduction factor (J_w)	0.33	0.66
Stress reduction factor (SRF)	10	2.5
Q	0.02	3.52

7. Results and recommendations

The physical and geomechanical characteristics of the Eocene basalts in the axis area and diversion and power tunnels for the Obruk dam constructed on the Kızılırmak River were determined in the field and laboratory. The results of this investigation and our recommendations are summarized below.

The abundant basalts exposed in the study area have hyalopilitic and hyalopilitic porphyritic textures. Argillization, silification, chloritization, carbonatization and iron-oxide alteration are widespread, and weathering of the basalts is profound.

On the right and left shores of the dam's axis area, random joints — in addition to the joint sets with three different orientations mentioned above — are present. The basalt is in the "moderately open fractured", "closely spaced" class. According to the rock-quality designation (RQD), the basalt in the axis area, and along the traces of the diversion and power tunnels, is of "very poor quality" and "poor quality". Furthermore, on the basis of the point-load strength index and uniaxial pressure strength, the basalt is "medium-high strength" and "strong-moderately strong".

It was determined that basalt in the dam axis area and along the traces of the diversion and power tunnels is impermeable to slightly permeable. In spite of abundant discontinuities, the reason for the decrease in hydraulic conductivities is the filling of fractures by clays that developed during weathering. However, in order to obtain complete impermeability in the dam axis area and to increase stability in the tunnels, it would be appropriate to use injection. Because of gypsum fracture fills, a sulphate-resistant cement should be used in the reinforced-concrete structures of the dam. In the RMR rock-mass classification, the basalt falls into the "very weak rock (V)" and "medium rock (III)" groups, while in the *Q* rock-mass classification, it falls into the "extremely weak" and "weak" groups.

Acknowledgments

The support for the project (97K12080) by State Planning Organization and Ankara University Science Research Foundation is gratefully ackknowledged. The authors would like to thank the General Directorate of the State Hydraulic Works (DSI). The authors would also thank Dr.Yusuf Kaan Kadioglu and Dr. Koray Sözeri for their mineralogical and petrographical determinations of rocks.

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