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The Geological Strength Index Chart Assesment For Rock Mass Permeability

Jeolojik Dayanım İndeksi Tablosunun Kaya Kütle Geçirimliliği İçin Değerlendirilmesi

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ABSTRACT
Determination of permeability of rock masses without testing is very chalenging due to the presence of complex discontinuity patterns in rock masses. Many empirical approaches were proposed in the literature for estimation of rock mass properties. However, approaches based on rock mass classification systems in determination of rock mass permeability in the literature are rarely encountered. Considering this lack in the literature, in this study, the use of the Geological Strength Index (GSI) chart which is one of the input parameters of the Hoek-Brown empirical failure criterion has been assessed for rock mass permeability. In this study, 365 lugeon test results were used. These data were obtained from various dam sites and a coal mine in Turkey. Firstly, lugeon test results were plotted on the quantitative GSI chart by considering the Surface Condition Rating (SCR) and Structure Rating (SR). Then, different permeability regions on the GSI chart were defined for the rock mass permeability. In this study, the data were obtained from granite, diorite, volcanic breccia, andesite and agglomerate type of rock masses. The proposed rock mass permeability (RMP)- Geologic Strength Index (GSI) chart needs development with other study supports. Morever, RMP-GSI chart should not be used for rock types having a soluble character such as limestone and gypsum since they may include karstic zones.

Keywords: Permeability, GSI, Rock mass, Lugeon.

ÖZ
Kaya kütlenin geçirimliliğini deney yapmadan belirlemek, karmaşık süreksizlik yapıları nedeniyle, hemen hemen olanaksızdır. Kaya kütlenin özelliklerini belirlemek için literatürde pek çok görgül eşitlik önerilmiştir. Bununla birlikte kaya kütle sınıflandırma sistemlerini temel alan ve kaya kütle geçirimliliğini belirleyen görgül eşitlikler yok denecek kadar azdır. Bu eksikliği göz önüne alarak, bu çalışmada Hoek-Brown yenilme ölçütü girdilerinden biri olan GSI abağı, kaya kütle geçirimliliğinin tahmini anlamında değerlendirilmiştir. Bu çalışmada, 365 adet lüjyon deneyi sonucu kullanılmıştır. Bu veriler Türkiye'deki değişik baraj yeri ve bir kömür madeni çalışmalarından derlenmiştir. Öncelikli olarak süreksizlik yüzey koşulları (SCR) değerleri ve yapısal özellik değerleri (SR) hesaplanmış ve bu değerlere karşı gelen lüjyon değerleri rakamsal GSI abağının üzerine işlenmiştir. Daha sonra değişik geçirimlilik bölgelerinin sınırları belirlenmiştir. Bu çalışmadaki veriler granit, diyorit, volkanik breş, andezit ve aglomera kaya kütlelerine aittir. Önerilen kya kütle geçirimlilik (RMP)- Jeolojik Dayanım İndeksi (GSI) abağının diğer çalışmaların desteğiyle geliştirilmeye ihtiyacı vardır. Buna ilave olarak, RMP-GSI abağı kireçtaşı ve jips gibi karstik zonlar içerebilen, eriyebilen litolojilerde de kullanılmaması önerilmiştir.

Anahtar Kelimeler: *Geçirimlilik, GSI, Kaya kütlesi, Lüjyon.*

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INTRODUCTION

In rock mechanic practice, the empirical approaches to estimate various rock mass and intact rock properties have been proposed by various researchers (Kayabasi et al., 2003; Cevik et al., 2011). One of the rock mass properties is permeability. For this reason, estimation the rock mass permeability is important subject for engineering projects. Although there are various methods for evaluating rock mass permeability, most of them are time consuming. Also, there isn't any method or chart that helps to predict rock mass permeability for preliminary studies. The main aim of this paper is to prepare rock mass based permeability chart by utilizing rock mass properties. For this purpose the quantitative Geological Strength Index (GSI) chart was selected as a tool to prepare rock mass permeability chart. The GSI was defined firstly by Hoek et al (1992) and Hoek et al (1995) for determination of rock mass properties and to collect data for Hoek-Brown failure criteria. GSI chart was developed and modified later by various authors; (Hoek and Brown, 1997; Marinos and Hoek, 2001), (Figure 1). The GSI chart was originally unquantitative. Investigators observed the rock mass properties, especially joints, blocks and defined the GSI value. Disadvantage of this method was being subjective and unmeasurable. In other words, without using any numerical data or parameters of rock mass, determination of GSI with this way may result in different GSI values for the same rock mass by different investigators. In order to eliminate these disadvantages, Quantitave GSI table was suggested by Sonmez and Ulusay (1999) and modified by the same authors (Sönmez and Ulusay, 2002). Quantitative GSI chart, comprises two new input parameters; Structure Rating (SR) which is derived from volumetric joint count, and Surface Condition Rating (SCR) (Fig.1) derived from the Weathering Rating (Rw), Roughness Rating (Rr) and Infilling Rating (Rf) of the rock mass which has the same input parameters used in the Geomechanic Classification-RMR (Bieniawski,1989).

In this study, Quantitative GSI chart were utilized according to lugeon test results in order to estimate permeability of rock masses.

ROCK MASS PERMEABILITY

Permeability is a measure of transmissibility of a fluid (water) through a porous medium e.g., soil and rock. The basic law hydraulic conductivity was defined by Darcy (1856). It states that the rate of flow (Q) per unit area of an aquifer is proportional to the gradient of the potential head (i) measured in the direction of flow:

$$V=Ki \text{ (m/sn)} \tag{1}$$

K (m/sn) is the hydraulic conductivity. For a particular aquifer or a part of an aquifer of area (A) (m^2) and flow rate, Q;

$$Q=vA=AKi. \text{ (m}^3\text{/sn)} \tag{2}$$

Intact or massive rocks are mainly impermeable but rock masses having discontinuities can be permeable depending on their discontinuity properties. Increase in discontinuity systems results in flow of water as in a channel. According to Serafim (1968), a rock mass intersected by a system of paralel sided joints with a aperture (e) seperated by a distance (d), hydraulic conductivity could be defined as in the following equation;

$$K=(e^3.\gamma_w)/12d\mu \tag{3}$$

where γ_w is the unit weight of water and μ is the viscosity.

Equivalent hydraulic conductivity of parallel jointed platforms were studied by Huitt (1956), Snow (1968), Sharp (1970), and Maini et al (1971). Investigators proposed the following equation;

$$K=(e^3.q)/12d\upsilon \tag{4}$$

where q is the gravitional acceleration (981 cm/sn^2), υ is the kinematic viscocity coefficient (equal to 0.0101 cm^2/sn at 20° for pure water)

Louis (1969) suggested the equation 5 for the laminar flow and paralel beddings of the joint sets for a capillar flow. If the flow is a laminar flow and the joint system is full with water, the hydraulic conductivity of rock mass can be determined with this equation;

$$K=(e/b).k_f.k_r \tag{5}$$

where k_f is the hydraulic conductivity constant for fill material, k_r is the hydraulic conductivity constant of unweathered intack rock material.

Lugeon (1933) developed a method, named as the lugeon test, which determines the transmissivity of rock. The test is based on pressurizing water in a borehole opened in a rock mass and recording loss water in a time interval. One lugeon (L) is equal to one liter of water per minute injected into 1 meter of

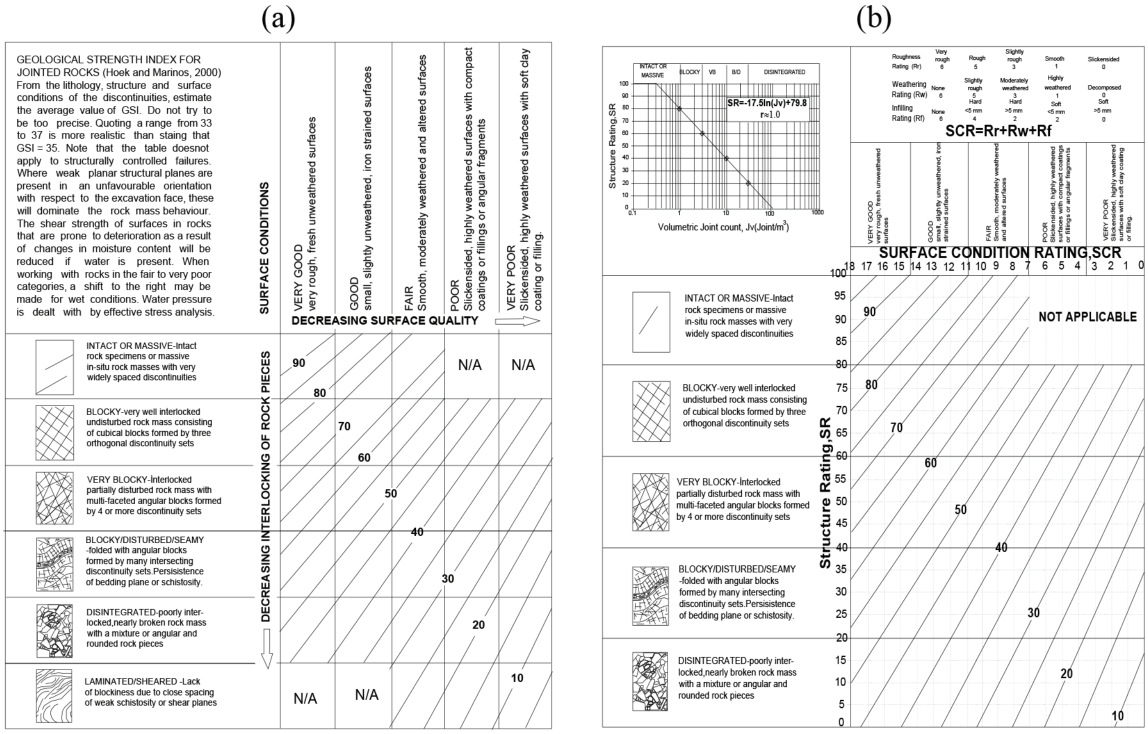

Figure 1. GSI charts a) defined by Hoek et al (1997), b) developed by Sönmez et al. (1999).

Şekil 1. GSI abağı a) Hoek et al (1997) tarafından önerilmiş b) Sönmez et al.(1999) tarafından geliştirilmiş.

borehole under 10 atmosphere pressures. If the test results in less than 1 lugeon, rock mass is impermeable, 1-5 lugeon means rock mass slightly permeable, 5-25 lugeon means permeable and >25 lugeon means highly permeable. A lugeon is accepted as 10^{-7} m/sn. Lugeon test is a widespread testing method for determination of rock mass permeability especially in dam investigations and grouting projects.

Terzaghi and Peck (1967) and International Society of Rock Mechanics (1981) proposed tables classifying rock mass permeability based on spacing of discontinuities. These tables show similarities and can be summarized as in Table 1.

Lee and Farmer (1990) suggested a simple method for estimating fracture porosity and permeability based on empirical relations between fracture aperture, Joint Roughness Coefficient (JRC) and Joint Compressive Strength (JCS). A valid approximation of fracture porosity and permeability from conducting aperture, e_c, JRC and JCS could be made from idealized structure. Porosity, n, and permeability coefficient, k, can be defined in terms of e_c an spacing of discontinuites, S.

Barton (2002) correlated The Rock Mass Rating (Q) system with P-wave velocity, static modulus of deformation, support pressure, tunnel deformation, Lugeon-value and cohesive and frictional strength of rock masses, undisturbed or affected from excavation process. Author suggested that the normalized rock mass rating (Qc) is inversely related with lugeon value and proposed the following equation;

$$L \approx 1/Qc \quad (6)$$

The values of this study were tested with Eq. (6). Meaningful results were not determined.

The relationships between rock mass properties, permeability and grouting have been studied by numerous researchers. Gürocak et al. (2012) evaluated the permeability of dam site lithologies and the maximum depth of grout injection using the Kiraly (1969, 1978, 2002) and Hoek and Bray (1981) methods based on the values obtained from Lugeon tests. Uromeihy et al (2012) studied groutability at the Kamal-Saleh dam. They compared rock mass rating (RMR) and geological strength index (GSI) systems with Lugeon tests. They also suggested that rock quality designation values (RQD) had a direct rela-

Table 1. Permeability values for jointed rock masses, Terzaghi and Peck 1967; ISRM 1981).
Çizelge 1. Eklemli kaya kütleleri için geçirimlilik değerleri, Terzaghi and Peck 1967; ISRM 1981).

Rock mass Description	Permeability Degree	Permeability Constants k, m/s)
Very closely spaced joints	Highly permeable	$1\text{-}10^{-2}$
Closely to Moderately spaced closely	Medium permeable	$10^{-2}\text{-}10^{-5}$
Widely to very widely Spaced	Slightly permeable	$10^{-5}\text{-}10^{-9}$
Unjointed, massive	Impermeable	$<10^{-9}$

tionship with Lugeon values. Sadeghiyeh et al (2013) compared permeability and groutability of the Ostur dam site rock mass for a grout curtain site. Investigators correlated secondary permeability index, rock quality designation and cement take at the dam site and suggested that the areas with diverging trends required no treatment and that those with converging trends required heavy treatment. Kayabaşı et al (2015) produced ANFIS (Adaptive Neuro-Fuzzy Inference System) modeling to determine rock mass permeability. A dataset including 365 cases with Lugeon test results and corresponding RQD (Rock Quality Designation), spacing of discontinuities and SCR (Surface Condition Rating) properties is employed. ANFIS is a more successful tool than NLMR (Nonlinear Multiple Regression Model). These results show that the models developed are reliable enough and, if there is no direct test result, these models can be used in engineering projects.

All of the previous investigators except for Lugeon (1933), studied the permeability of rock masses having one or two discontinuity sets. Rock masses having three or more discontinuity sets as in blocky disintegrated rock masses, the question of how permeability can be assessed with a practical way using a chart constitutes the main purpose of this study.

REGIONING GEOLOGICAL STRENGTH INDEX (GSI) CHART FOR PERMEABILITY ASPECTS

All of the rock classification methods especially Rock Mass Rating (RMR) (Bieniawski, 1979; Bieniawski, 1989) uses rock properties as distinquishing parameters. The main input parameters to classify rock masses are the uniaxial compressive strength of rock material, Rock Quality Designation (RQD) (Deere, 1964), spacing of discontinuities, condition of discontinuities, groundwater conditions and orientation of discontinuities.

Rock mass permeability is determined by discontinuity conditions (length (persistence), aperture, roughness, infilling and weathering condition) and spacing of discontinuities (Table 2). These parameters are the input parameters of RMR classification system. Except for discontinuity length and aperture, the rock mass properties determining rock mass permeability are the same with rock mass properties that are input parameters for quantitative GSI calculations. Combination of surface condition rating (SCR) and structure rating (SR) parameters of a core run with corresponding lugeon values can be used for regioning of the GSI chart for permeability aspect.

The lugeon test results from five dam sites and a coal mine were used for this study (Table 3, Fig. 2). The dam sites were projected on Çoruh river on northeast of Turkey. The coal mine locates on northwest of Turkey.

Volcanic breccia outcroppes at Laleli dam axis is projected on Çoruh river near Ispir province of Erzurum city (Bayram, 1989). Eocene volcanic breccia is known as Laleli volcanites. It is grayish, pinkish and greenish colored, diameters of grains are nearly 10 cm, and cornered. The joints are unweathered to slightly weathered and very widely spaced (ISRM, 1981). The joint surfaces are very rough to rough, thin calcite and silt filled, oxited and persistence of the joints is very high. Intact rock is strong according to uniaxial test analyses. Rock mass quality (RQD) of Laleli dam sites ranges from fair to excellent rock mass types (Table 4).

Aglomerates of Eocene Laleli volcanites outcrops at Ispir dam axis and its environment (Oguz, 1989). Aglomerates are divided as andesitic aglomerates and basaltic aglomerates according to thin section

Table 2. Quantitative GSI input parameters and rock mass permeability determining rock mass properties.
Çizelge 2. Numerik GSI parametreleri ve kaya kütle geçirimliliğini belirleyen, kaya kütle özellikleri.

Rock mass properties for determining rock mass permeability	Rock mass properties that are used Calculation of quantitative GSI	
1-Discontinuity length and aperture	Surface Condition rating, SCR)	1-Discontinuity roughness
2-Discontinuity infilling		2-Discontinuity filling
3-Weathering condition		3-Weathering condition
4-Spacing of discontinuities	Structure rating, SR)	4-Block dimension, Jv)
		5-Rock quality designation, RQD)

Table 3. Information about the dam sites and coal mine.
Çizelge 3. Baraj yerleri ve kömür madeni hakkında bilgiler.

Study Sites	Borehole number	Type of the lithology	Number of permeability (lugeon) test
Laleli dam, Çoruh River/ERZURUM)	4	Volcanic breccia	66
Altıparmak dam, Barhal river/ARTVİN)	9	Granite	124
Deriner dam, Çoruh river/ARTVİN)	7	Quartzdiorite	67
Arkun dam, Çoruh river/ARTVİN)	17	Andesite	107
Ispir dam Çoruh river/ERZURUM)	12	Aglomerate	53
Coal mine, Çan/ÇANAKKALE	5	Aglomerate	38
Total	54		365

Table 4. Rock mass quality distribution of the study sites.
Çizelge 4. Çalışma alanlarında kaya kütle kalitesi dağılımı.

RQD	Rock mass quality	Laleli dam , %)	Altıparmak dam , %)	Deriner dam , %)	Arkun dam , %)	Ispir dam , %)	Can coal mine , %)
0<25	Very poor	0	1	31	2	2	11
25-50	Poor	11	11	15	13	9	11
50-75	Fair	39	18	28	34	12	39
75-90	Good	25	38	19	33	28	13
90-100	Excellent	25	32	7	18	49	26

analyses. They are mainly, dark brownish, greenish colored, flowish structured, moderately widely spaced jointed according to the classification recommended by ISRM (1981). The joint surfaces are rough, wavy, calcite filled, rarely siliceous filled, unweathered or slightly weathered. Persistence of the joints is very high and intact rock is very strong according to uniaxial test analyses. Rock mass quality (RQD) at Ispir dam sites ranges from fair to excellent rock mass types (Table 4).

Arkun dam is projected on Çoruh River close to Artvin city. Upper Createcous Berta formation andesites outcrop at dam axis (Ökten, 1989). They are gray, dark gray, green, and dark green colored, porphyrtic textured, rarely flow structured, moderately widely-widely space jointed. The joints are very narrow apertured, slightly weathered. The joints surface are rough, stepped, oxited, and the joints are thin siliceous infilled. Persistence of the joints is very high and intact rock is very strong to strong according to uniaxial test analyses. Rock mass quality (RQD) at Arkun dam sites ranges from poor to excellent rock mass types (Table 4).

Quartzdiorites of İkizdere Magmatites outcrop at Deriner dam axis projected on Çoruh River close to Artvin city (Kayabasi et al., 2003). They are light gray, pinkish colored, moderately wide jointed. The joints are very narrow apertured, fresh-slightly weathered. The joint surfaces are rough and oxited and persistence of the jonts is very high. The intact rock is very strong according to uniaxial test analyses. Rock mass quality (RQD) at Deriner dam site ranges from very poor to good rock mass types (Table 4).

Altıparmak Dam is projected on a Barhal Stream which is a branch of Çoruh River. Granites of Ikizdere magmatites outcrop at dam sites of Altıparmak dam (Adiguzel, 2002). The granites are dark gray, pinkish colored, fresh-slightly weathered. The joints are wide-very wide spaced, very narrow apertured, rough surfaced, without infillig. The persistence of joints is medium and intact rock is very strong according to uniaxial test analyses. Rock mass quality (RQD) at Altıparmak dam site ranges from poor to excellent rock mass types (Table 4).

Çan coal mine locates at Çan/Çanakkale (Kayabasi, 2009). Thick aglomerate beds cover clay and coal beds. Aglomerates are pinkish, grayish, reddish colored, weathering changes from slightly to highly weathering. The joints are very closely spaced, rough, and slickensided surfaced, without infilling or very thin calcite stained. The apertures are very narrow to moderately narrow. The persistence is very high and intact rock is weak to moderately strong according to uniaxial test analyses. Rock mass quality (RQD) at Çan coal mine site ranges very poor to excellent rock mass types (Table 4).

According to lugeon test results, permeability of the study sites can be summarized as following; The rock masses of Laleli dam site, Altiparmak dam site and Çan coal mine are impermeable-slightly permeable since more than 75 % of lugeon test results are between <1 and 1-5 lugeon range (Table 5), More than 75 % of the test results are in slightly permeable-permeable range at Altıparmak and Ispir dam sites. The lugeon test results of Deriner dam site show a widespread distribution that is why all of the permeability ranges are represented at Deriner dam site.

RQD values may give an idea about permeability but this approach may not be valid for every situation. If a rock mass have one or two sets of discontinuity patterns, RQD may be high, but low persistency and disconnected discontinuities will cause decrease in permeability, otherwise rock mass with high RQD would be permeable. Very blocky and disintegrated rock mass means low RQD value and rock is permeable with fresh discontinuity surfaces, but weathered rock mass with soft filling material may be impermeable because of closing of apertures with filling material due to testing pressure. RQD frequency of the boreholes drilled at Çan coal mine and average lugeon test results did not gave a meaningfull histogram for the RQD-Lugeon relationship (Figure 3). Similar result can be said for Ispir dam site. Increase in RQD frequency causes rock mass impermeability at Laleli, Arkun, Altıparmak and Deriner dam sites.

Evaluation of RMP-GSI chart

The first step of present study is determination of RQD value of a core run and carrying out a lugeon test at the same core run depth interval. RQD is used to determine volumetric joint count (Jv) that gives the structure rating (SR) data (Figure 4). Jv is calculated with equation derived by Palmstrom (1974);

$$RQD=115-3.3Jv \qquad (7)$$

The percentage of Jv values of the dam sites and the coal mine are given in Table 6. Small blocks were dominating at Arkun, Laleli, Deriner and Çan coal mine; medium sized blocks were dominating at Altıparmak and Ispir dams. All of the study sites were forming blocks from medium sized to small and very small blocks according to ISRM (1981) blocksize classification of rock masses.

Determination of the Structure Rating (SR) was carried out according to the following equation;

$$SR=-17.5\ln(Jv)+79.8 \quad (r \approx 1) \text{ (Sonmez et al.,2002)} \qquad (8)$$

Table 5. Lugeon test values of study areas.
Çizelge 5. Çalışma alanları lüjyon deneyi değerleri.

Lugeon	Permeability description	Laleli dam , %)	Altiparmak dam , %)	Deriner dam , %)	Arkun dam , %)	Ispir dam , %)	Çan coal mine , %)
<1	Impermeable	45	47	18	10	25	34
1-5	Slightly permeable	32	42	24	44	42	55
5-25	Permeable	21	3	34	38	32	8
>25	Highly permeable	2	8	24	8	1	3

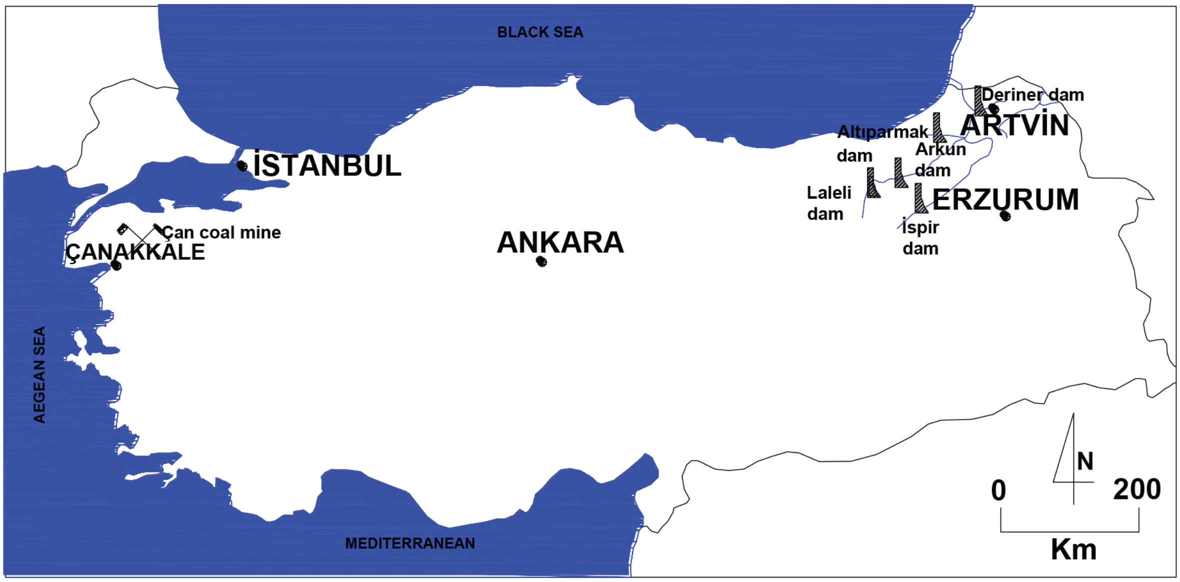

Figure 2. Location map of the dam sites and the coal mine.
Şekil 2. Baraj yerleri ve kömür madeni lokasyon haritası.

The second step is the determination of Surface Condition Rating (SCR). The total of the rating values of discontinuity roughness, weathearing and fillings gives the SCR. Rating values are the same as in the RMR rating system. SCR is the other input parameter of the GSI chart. Later, GSI is determined from SCR (horizontal line) and SR (vertical line) values on quantitative GSI chart. The last step is the conciding the lugeon value and the GSI value of rock mass on quantitative GSI chart. An example for these steps from Arkun dam site is given in Table 7, Table 8 and Figure 4.

The range of the SR, SCR and the GSI values are summarized at Table 9. All of the study sites have blocky, very blocky, blocky disturbed and seamy character. Discontinuity surfaces of all of the study sites have mainly very good, good and fair surfaces; Deriner and Çan coal mine have poor and very poor discontinuity surfaces besides other type of surfaces. Intact/massive, disintegrated, laminated type rock masses were not determined from the dam sites and the coal mine during inspections.

GSI value of rock mass and the corresponding permeability value were determined and quantitative GSI charts with permeability values were prepared for all of the investigated locations. Range of the lugeon values was represented with symbols and they are given at Table 10.

The symbols of the lugeon test results for all of the sites are shown on quantitative GSI chart and GSI chart and borders of the same symbols are drawn

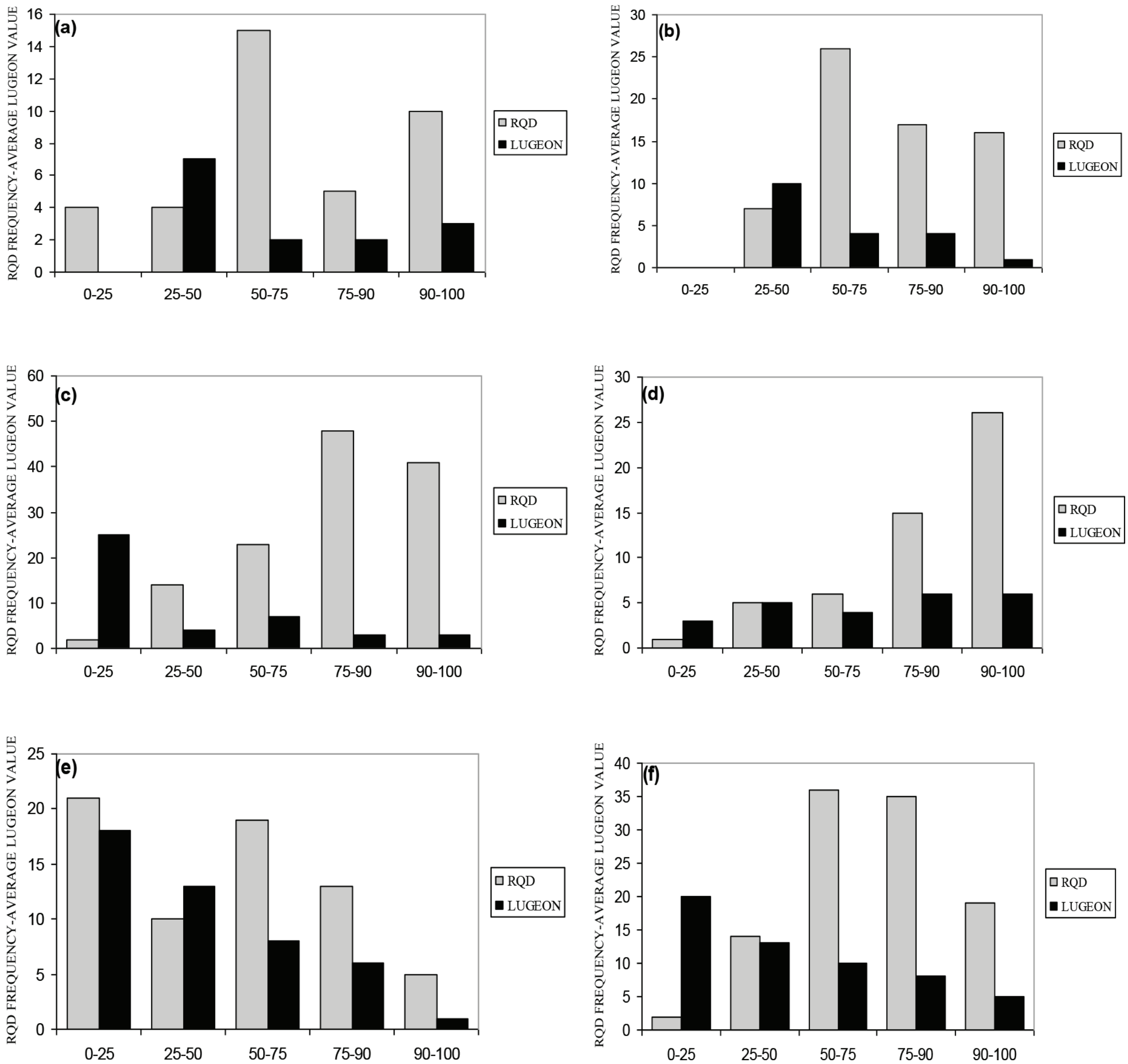

Figure 3. Distribution histograms of RQD-Average results of lugeon tests a) Çan coal mine, b) Laleli dam site, c) Altıparmak dam site, d) Ispir dam site, e) Deriner dam site, f) Arkun dam site.

Şekil 3. RQD-Lüjyon deney sonuçları ortalamaları grafiği a) Çan kömür madeni, b) Laleli baraj yeri, c) Altıparmak baraj yeri, d) İspir baraj yeri, e) Deriner baraj yeri, f) Arkun baraj yeri.

and the permeability regions of the GSI charts were evaluated for six differrent sites and litologies (Figure 5 (a) and Figure 5 (b)) and Rock Mass Permeability (RMP)-Geologic Strength Index (GSI) chart were prepared (Fig. 6). These derivations could be made for the rock mass permeability from RMP-GSI chart; when GSI value is equal/greater than 60, rock mass is impermeable/slightly permeable. If GSI value of rock mass equal or less than 20, rock mass is permeable/highly permeable. If GSI values are between 20 and 60, permeability of rock mass must be determined from RMP-GSI chart. Engineers must determine surface quality and the blockiness of the rock mass visually and determine GSI value and permeability of rock mass from RMP-GSI chart.

SUMMARY AND CONCLUSIONS

The aim of this study is to assess the use of the Geological Strength Index (GSI), which is one of the input parameters of the Hoek-Brown empirical failure criterion, for the estimation of rock mass permeability.The quantitative GSI parameters and properties

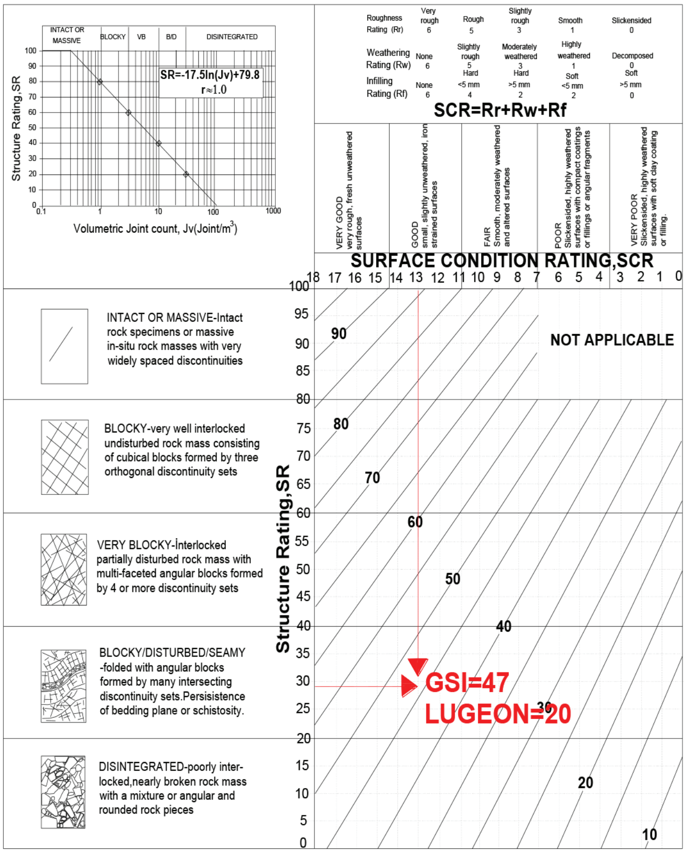

Figure 4. An example about coinciding GSI and Lugeon values on Quantitative GSI chart.
Şekil 4. Numerik GSI abağında GSI ve lüjyon deneyleri çakıştırma örneği.

Table 6. The range of the block sizes, Jv)
Çizelge 6. Blok boyutu aralığı, Jv)

Jv (Joints/m³)	Description	Laleli Dam, (%)	Altıparmak Dam, (%)	Deriner Dam, (%)	Arkun Dam, (%)	Ispir Dam, (%)	Çan Coal mine, (%)
<1	Very large blocks	0	0	0	0	0	0
1-3	Large blocks	0	0	0	0	0	0
3-10	Medium-sized blocks	42	61	16	25	66	31.5
10-30	Small blocks	56	37	58	72	34	60.5
>30	Very small blocks	0	2	26	3	0	8

determining rock mass permeability were collected from five dam sites projected on Çoruh river at north-east of Turkey and a coal mine site at northwest of Turkey. Rock quality designation (RQD), weathering degree, discontinuity roughness, discontinuity fillings of core runs were determined from drillings and corresponding lugeon tests were performed. The surface condition ratings (SCR) and structure rating values (SR) were defined and the GSI values of rock masses were determined. The quantitative GSI chart was regioned with corresponding permeability values. Rock Mass Permeability (RMP)-Geologic Strength Index (GSI) chart was prepared. Totally 365 lugeon tests from 54 boreholes were selected for

Table 7. An example for calculating discontinuity Structure Rating (SR) from borehole 2 at Arkun dam site
Çizelge 7. Arkun baraj yeri 2 nolu sondajda süreksizlik Yapısal özellik değerlendirmesi (SR) hesaplanmasına bir örnek.

Core run(m)	Rock Quality Designation (RQD, %)	Volumetric Joint Count (Jv)	Structure Rating (SR)
30.00-33.00	40	25	29

Table 8. An example for calculating discontinuity Surface Condition Rating (SCR) from borehole 2 at Arkun dam site
Çizelge 8. Arkun baraj yeri 2 nolu sondajda süreksizlik Yüzey Koşulları Değerlendirmesi (SCR) hesaplanmasına bir örnek.

	Roughness	Rating value
Core run (m) 30.00-33.000	Rough	5
	Infill	Value
	Calcite fill-closed	2
	Weathering	Value
	Unweathered	6
	Surface Condition Rating, (SCR)	13

Table 9. Information about Geologic Strength Index properties of study sites.
Çizelge 9. Çalışma alanlarında Jeolojik Dayanım İndeksi özellikleri hakkında bilgiler.

Study site	Lithology	Surface conditon Rating (SCR)		Structure Rating (SR)		Geologic Strength Index (GSI)		Notes
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	
Laleli dam	Volcanic breccia	17	10	68	28	66	38	SR:Blocky,very blocky,disturbed seamy.SCR:Very good, good.
Altıparmak dam	Granite	17	10	69	18	69	42	SR:Blocky,very blocky,disturbed seamy.SCR:Very good, good, fair.
Deriner dam	Quartzdiorite	16	1	62	21	58	15	SR:Very blocky,disturbed seamy.SCR:Very good, good, fair, poor
Arkun dam	Andesite	17	6	62	27	72	31	SR:Blocky,very blocky,disturbed seamy.SCR:Very good, good, fair, poor
Ispir dam	Aglomerate	15	12	69	25	71	46	SR:Blocky,very blocky,disturbed seamy.SCR:Very good, good.
Çan coal mine	Aglomerate	16	3	67	24	72	31	SR:Blocky,very blocky,disturbed seamy.SCR:Very good, good, fair,poor,very poor

SCR:Surface condition rating, SR:Structure rating

Table 10. Symbols for Lugeon test value ranges
Çizelge 10. Lüjyon deneyi değer aralıkları sembolleri.

Symbol	Lugeon value	Description
●	<1	Impermeable
▲	1-5	Slightly permeable
■	5-25	Permeable
+	>25	Highly permeable

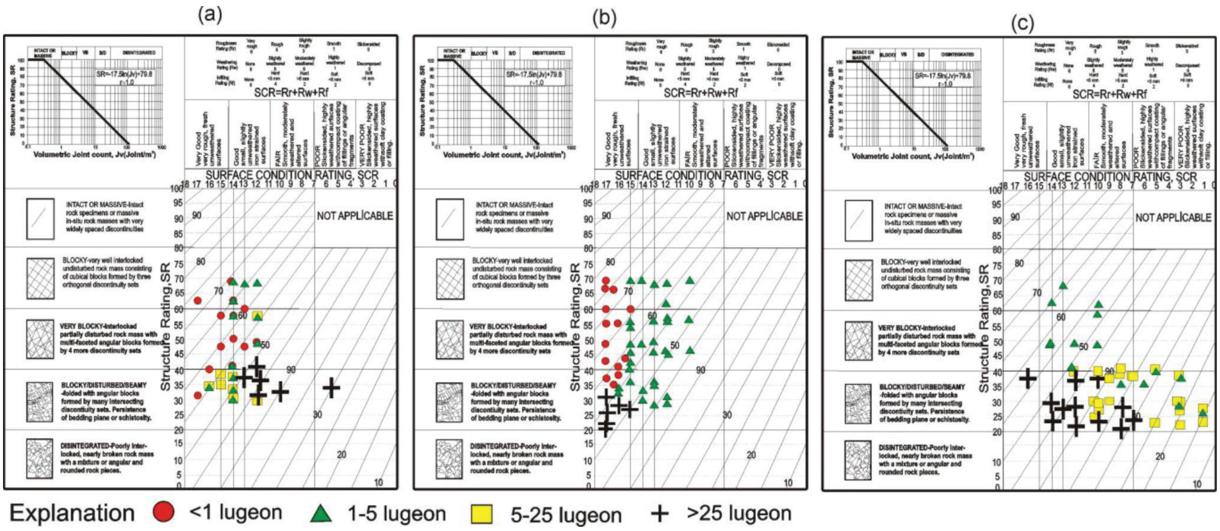

Figure 5(a). Lugeon test results and GSI values of the study areas a) Laleli dam site, b) Altıparmak dam site, c) Deriner dam site, d) Arkun dam site, e) Ispir dam site, f) Çan coal mine.
Şekil 5 (a). Çalışma alanları lüjyon deneyi sonuçları ve GSI değerleri a) Laleli baraj yeri, b) Altıparmak baraj yeri, c) Deriner baraj yeri.

this purpose. From the RMP-GSI chart, the following derivations could be made for the rock mass permeability; when GSI value is equal to or greater than 60, rock mass is impermeable/slightly permeable, if GSI value of rock mass equal or less than 20, rock mass is permeable/highly permeable. If GSI values are between 20 and 60, permeability of rock mass must be determined from RMP-GSI chart. Engineers must determine surface quality and the blockiness of the rock mass visually and GSI value and permeability of rock mass from RMP-GSI chart. The study sites are blocky, very blocky and blocky disturbed/seamy and show all types of surface conditions. Decrease in surface rating could be interprated as increase in permeability according to this study. Blocky disturbed/seamy and disintegrated rock masses are permeable. Better surface conditions rating between 15 to 17 for rock masses with blocky-very blocky are slightly permeable or impermeable, worst surface conditions rating between 0-3 are also slightly permeable or impermeable for blocky-very blocky rock masses. There are not any data for massive or intact rock masses in this study, but these types of rock masses are impermeable as it is shown on the RMP-GSI chart. The GSI permeability chart could be helpful during first reconnaissance studies for estimation of rock mass permeability during construction of engineering structures such as dams, tunnels and roads.

This study is a preliminary step for defining rock mass permeability from a chart. Limited number of lugeon test data and the GSI value were used in pre-

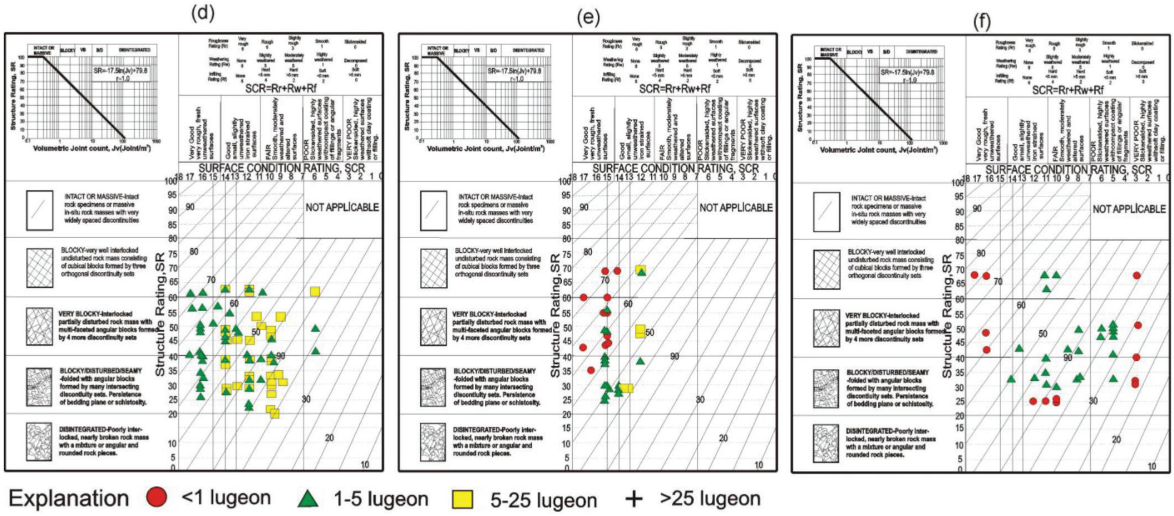

Figure 5 (b). Lugeon test results and GSI values of the study areas: d) Arkun dam site, e) Ispir dam site, f) Çan coal mine.

Şekil 5 (b). Çalışma alanları lüjyon deneyi sonuçları ve GSI c) Deriner baraj yeri, d) Arkun baraj yeri, e) İspir baraj yeri, f) Çan kömür ocağı.

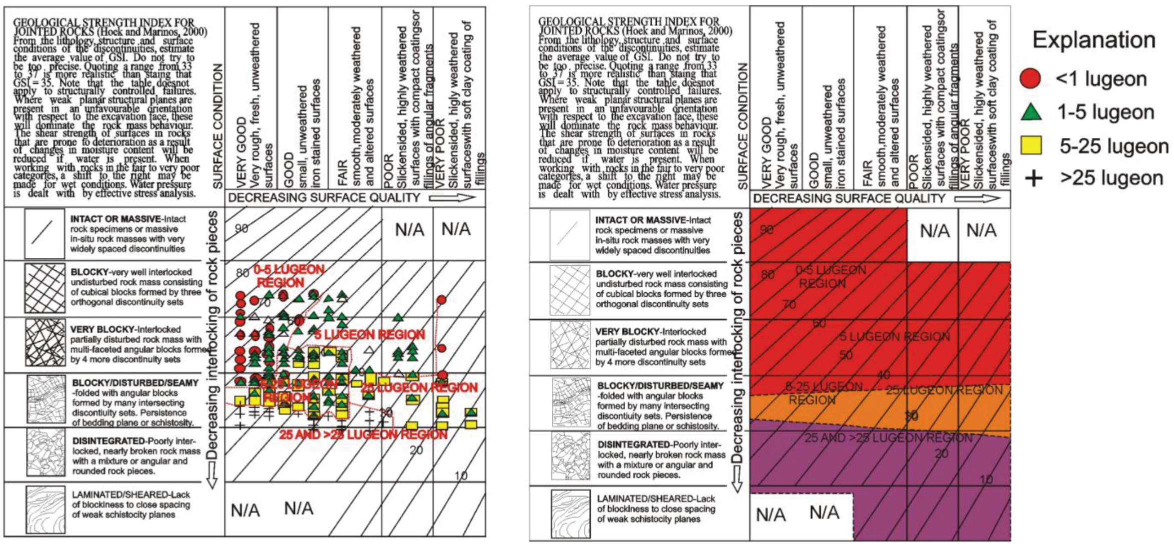

Figure 6a).Coinciding lugeon test results of the study sites on GSI chart b) Determined permeability regions on GSI chart.

Şekil 6a). Çalışma alanlar GSI abağında lüjyon deneyi sonuçlarının gösterilmesi b) GSI abağında belirlenen geçirimlilik bölgeleri.

sent study. Suggested chart should be developed with additional studies. The data used from mostly volcanic rocks, so some other testing results from geological features e.g. beddings, faults, sedimentary structures should be used for deveoloping RMP-GSI chart. There are several disadvantageous points for using RMP-GSI chart. Anisotropy of the rock mass is the main problem in geotechnical investigation studies. This may cause the determination of different GSI value for different directions for the same rock mass. This would cause estimation of different permeability values for the same rock mass. Detailed geological surveying should be performed in order to determine GSI value of rock mass also. Another main disadvantage of the RMP-GSI chart is the determination of lugeon values under 10 atm pressures, since the RMP-GSI chart represents the permeability of rock masses under 10 atm. Investigators must deliberate projecting on limestone, gypsum and clay bearing rock masses since they may have huge covered solution cavities.

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