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PERMEABILITY OF SAVCIBEY DAM (BİLECİK) AXIS LOCATION AND DESIGN OF GROUT CURTAIN

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Research Article

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ABSTRACT

This study comprise the design of the planned grout curtain in Savcıbey Dam (Söğüt/Bilecik) in order to provide impermeability along the dam axis. Within the context of field studies, engineering geology map was generated, ground investigation drilling was realized and permeability tests were performed. Within the field studies, the joint conditions of the geological units (Triassic aged Bozüyük Metamorphic schists) under the dam axis and its effect on permeability was observed considering the positions of the discontinuities with regard to the dam axis location. Orientation of discontinuities generally have strikes changing between N – S and NNE – SSW. 5 boreholes on dam axis, 2 boreholes on cofferdam, 3 boreholes on diversion tunnel and 2 boreholes on spillway total 245 m ground investigation borehole were drilled. In order to determine the permeability profile of dam axis and design the grout curtain, Lugeon tests in Bozüyük Metamorphic units observed in dam axis, falling head permeability tests in alluviums observed in thalveg and slope debris observed in right abutment were performed. Lugeon tests realized in Bozüyük Metamorphic units show that the unit is generally permeable and partly low permeable. Alluvium and slope debris are highly permeable. In addition, drilling works realized in dam axis shows that the augmentation of the weathering degree cause an increase of permeability in Triassic aged Bozüyük Metamorphic schists. As a result of these studies information about the permeability of Savcıbey Dam was collected and the grout curtain hole was designed. Accordingly, it is predicted that approximately 40 m depth of grout curtain from the stripping excavation with the depth of 1.50 m would prevent the possible leakages.

1. Introduction

Depending upon the population increase, dams make a significant contribution to the national economy in terms of energy need, potable water supply, agricultural irrigation, flood protection, fishery, recreation and many more purposes. Engineering geology and hydrogeology studies realized during planning stage are crucial to minimize the potential problems during construction stage and to exploit these dams safely. These constructions are studied by many researchers from different perspectives such as geotechnics, hydrogeology, landsliding, liquefaction, resistance to earthquake, etc. (Lombardi, 1985; Nonveiller, 1989; Karagüzel and Kılıç, 2000; Tunar et. al., 2013; Eryılmaz Türkkan and Korkmaz, 2015; Aldemir et. al., 2015). Lombardi (1985) studied about the cementation properties of grout and grout curtain designed for the impermeability of dams and underlined that the cohesion of the grout increase the viscosity and grout can not penetrate into the discontinuities. Nonveiller (1989) studied about the different techniques for the construction of grout curtain. Aksoy and Ercanoğlu (2006) and (2007) studied bout landsliding. Ulusay et al. (2007) studied about the liquefaction in dams and reservoirs. Tunar et al. (2013) studied about tailings dam stability. Eryılmaz and Korkmaz studied the determination of hydraulic conductivity with in-situ tests. Aldemir et al. (2015) studied about analysis techniques utilized in earthquake behaviours of concrete dams. Karagüzel and Kılıç (2000) researched the effect of alteration in permeability of an ophiolitic melange in terms of grouting efficiency and grout take amount. In addition, Karagüzel and Kılıç (2000) expressed mathematically the relation between the water loss in Lugeon test and grout take amount with the use of statistical analysis. Moreover, permeability of rock masses is analysed by many researchers (Ewert, 2003; Foyo et al., 2005; Şekercioğlu, 2007; Coli et al., 2008; Li et al., 2008; Gürocak and Alemdağ, 2012; Kayabaşı et al., 2015). Foyo et al. (2005) determined

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a secondary permeability index for the rock masses in dam foundations with Lugeon tests. Rock mass permeability properties are analysed numerically and empirically in the study realized by Gürocak and Alemdağ (2012). Kayabaşı et al. (2015) evaluated the relation between the Lugeon values and discontinuity properties of rock masses with the utilization of nonlinear regression analysis. For the determination of grout curtain depth the empiric method proposed by Şekercioğlu (2007). However, as this method is an empiric method, grout curtain depth is determined using with the engineering judgement considering the hydraulic head of the foundation rock.

The aim of this work in general is, design of the grout curtain and to determine the permeability characteristics of Savcıbey Dam axis location. For this purpose, the depth of the grouting works is determined. Project area is located in Bilecik Province, Söğüt County (Figure 1). Savcıbey Dam is planned to construct on Yol River by DSİ 3. Regional Directorate for the irrigation of agricultural lands which is approximately 164 ha and belonging to Savcıbey Village. Dam axis is located in 1/25,000 scaled Eskişehir "İ24-a2" topographic map and transport is provided by asphalt road (Figure 1).

2. Geology

This study comprises office works, site works and laboratory works. In context of office works, literature review about the study area and its near environ is done and the studies realized by General Directorate of State Hydraulic Works (DSİ) and General Directorate of Mineral Research and Exploration (MTA) are investigated. Site works are consist of geological mapping, drilling, and in-situ permeability tests. Laboratory works are performed on the core samples handled from the drilling operations. 5 boreholes and 200 m depth for dam axis, 2 boreholes and 25m depth for cofferdam, 3 boreholes and 30m depth for diversion tunnel, 2 boreholes and 20m depth for spillway, total 275m of drilling works realized within the field works. The boreholes drilled for axis location, diversion tunnel and cofferdam are shown on figure 2 and 3. The permeability characteristics of ruck units under different hydraulic heads are determined by the Lugeon tests performed in the boreholes drilled along dam axis. Hydraulic conductivity of the alluvium and slope debris is specified by the falling head permeability tests.

Dip and dip direction of the discontinuities in metamorphic rocks is the most important parameter for the permeability of dam axis location. Therewithal, infilling material, weathering degree, aperture, spacing are the factors effecting the dam permeability also. Any negative provision is detected in terms of permeability in dam axis location based on the observations realized according to the field prestudies. In addition, dip directions are generally towards upstream, even if schistosity strikes cross the dam axis with 90^0 and the discontinuities are infilled with clay. For these reasons, any permeability problem is waiting based on the observations.

Schists belonging to Bozüyük Metamorphics are dominated in project area and its surroundings but marbles of same formation crop out locally. Quaternary aged alluvium (Qal) and slope debris (Qym) overly the Bozüyük Metamorphics discordantly. Study area is located in second degree earthquake zone and approximately 50 km far from North Anatolian Fault Zone which is the one of main active tectonic fault system. Geological units of dam location and surroundings is explained below and generalized stratigraphic columnar section of study area and its surrounding is given in figure 4.

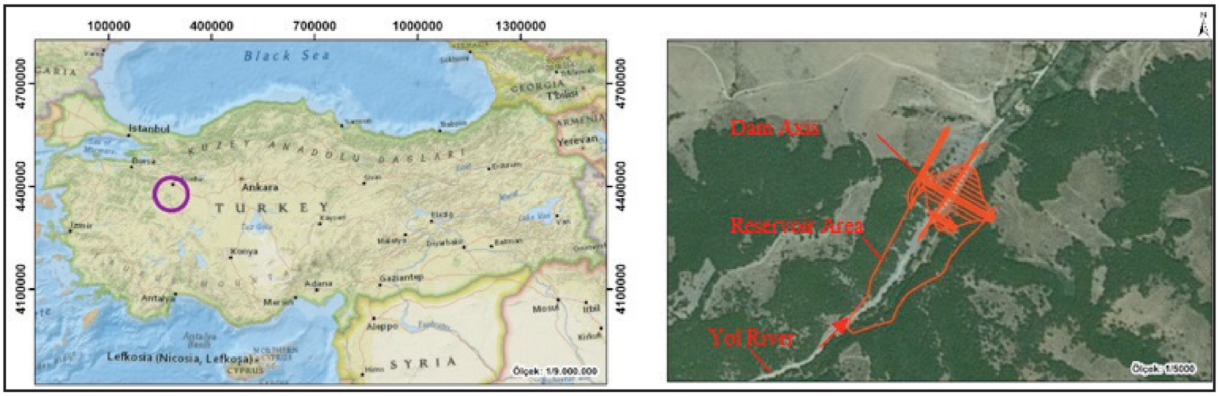

Figure 1- Site location map of study area.

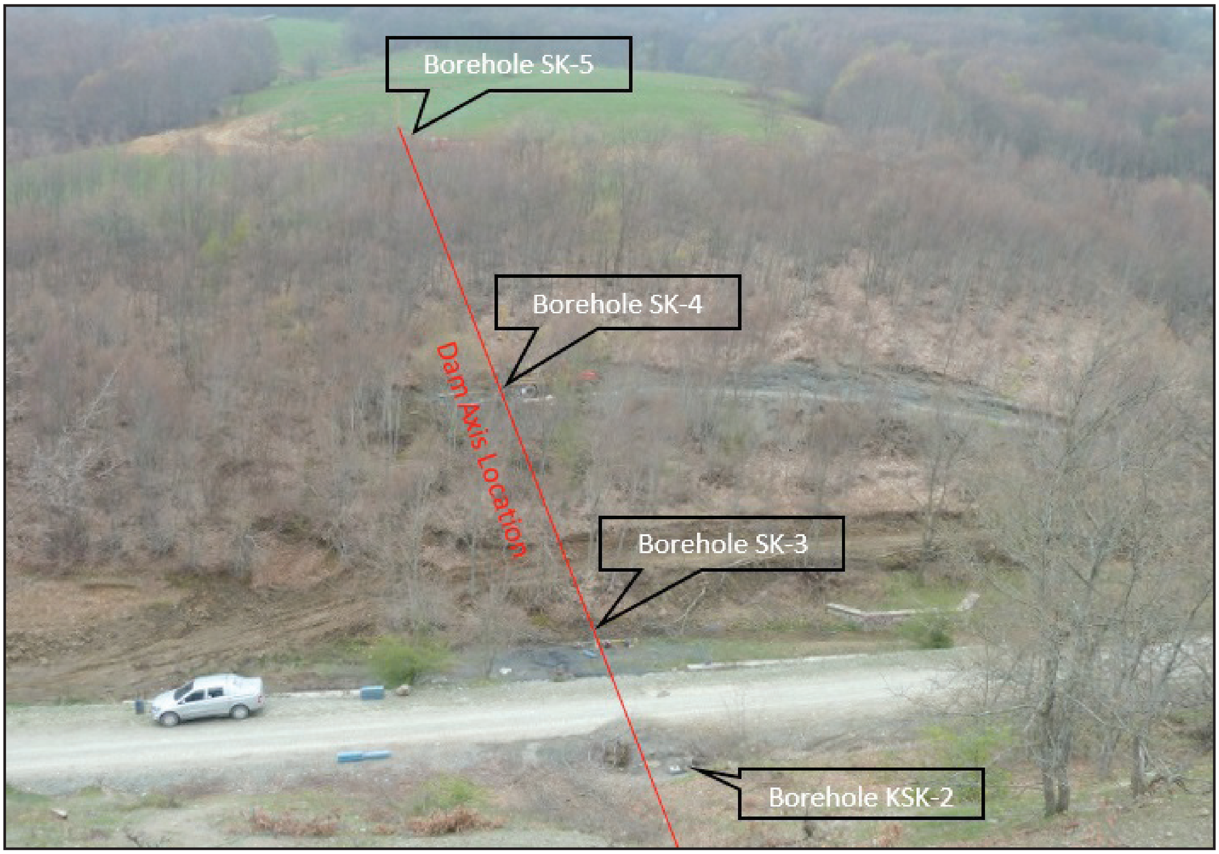

Figure 2- View to right abutment from borehole SK -1 (left abutment) in Savcıbey Dam axis location.

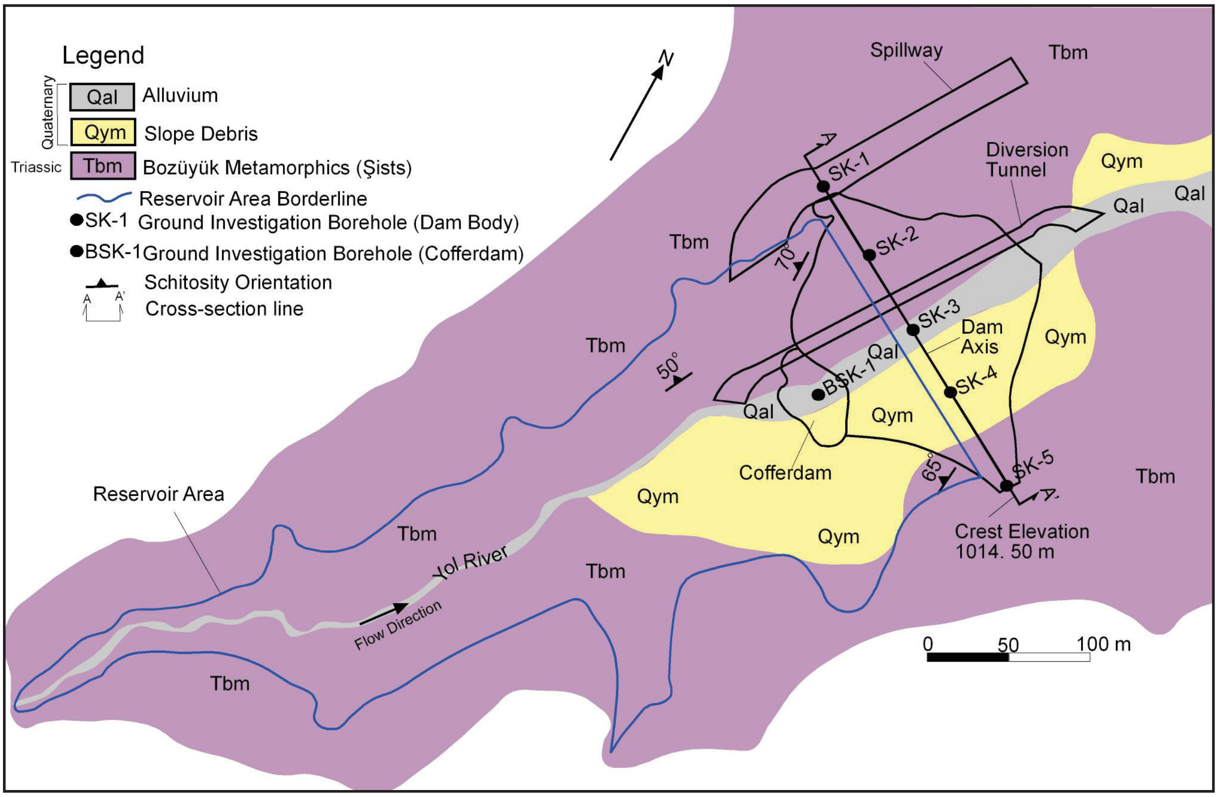

Figure 3- Engineering geology map of Savcıbey Dam axis location and reservoir area.

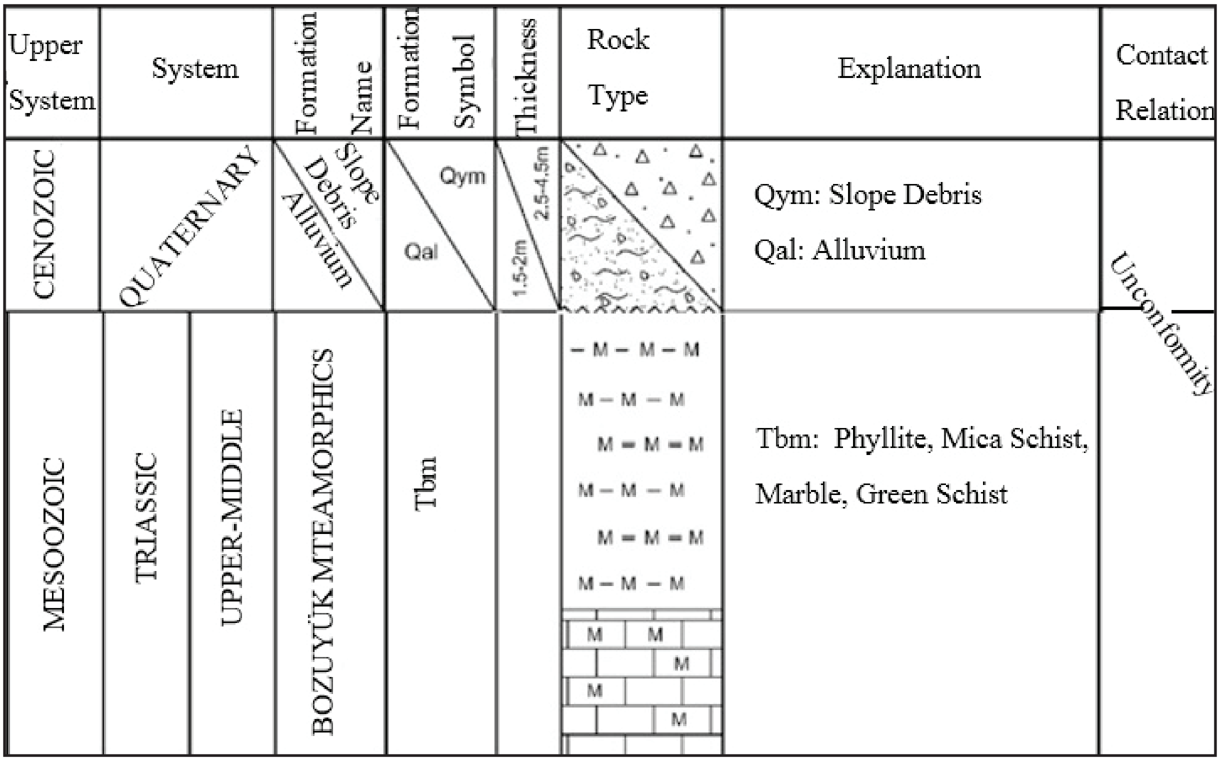

Figure 4- Generalized stratigraphic columnar section ofdam location and its surrounding.

2.1. Bozüyük Metamorphics (Tbm)

Bozüyük Metamorphics are exposed over large areas in the region. This unit is investigated by many researchers and aged as Triassic (Yılmaz, 1979; Yılmaz and Koral, 2007; Ayaroğlu, 1979; Kayadibi et al., 1994). Quaternary aged alluvium (Qal) and slope debris (Qym) overly the Bozüyük Metamorphics discordantly. Rock units of this formation are phyllite, mica schist, green schist, talk schist, chloride schist, amphibole schist, microscaled glaucophane schist, graphite schist, ortho gneiss, quartzite, marble, serpentinite, peridotite, gabbro, metadiabase and metabasalt (Yılmaz, 1979). Initially, carbonates with clay and sand sized materials and products of a granitic intrusion are effected from metamorphism of green schist facies conditions and became actual petrographic properties (Ayaroğlu, 1979). Green schists belonging to Bozüyük Metamorphics are dominated in project area and its near environ but local marble masses are also observed. However, any marble mass is encountered on the ground of dam body as seen in figure 5. However, Triassic aged this units are subjected to tectonic effect of during many geological times and due to this effect the schistosity planes have different orientations. Schistosity plane strikes are towards NE-SW direction and their dips are changing between 50^0 and 70^0 based on the orientations surveyed on the outcrops in dam axis, left and right abutments. General dip direction of schistosity planes are surveyed as NW.

First folding is started with Hersinian movement in study area and its near environ. Paleozoic aged schists are folded severely and intrusion activity is started through the faults in faulting stage. Acidic intrusives are settled into the schists during this stage. Then aplites are setteled into these intrusives trough the NE-SW directed faults. This aplite mass is transformed to E-W direction with the Alpine movements (Yılmaz, 1979). But, any of this aplites are encountered in dam location. Fracture system which are formed by the paleotectonic activities are generally infilled with clay. The mean spacing of the fractures is 2m, aperture is changing between 1 cm and 30 cm based on the information handled from the line investigation along the road cut.

Accordingly, the relation between the Quaternary aged alluvium and slope debris overlying the Bozüyük Metamorphics is shown on figure 5 with the ground investigation borehole locations which is represented with A-A’ cross section of figure 3.

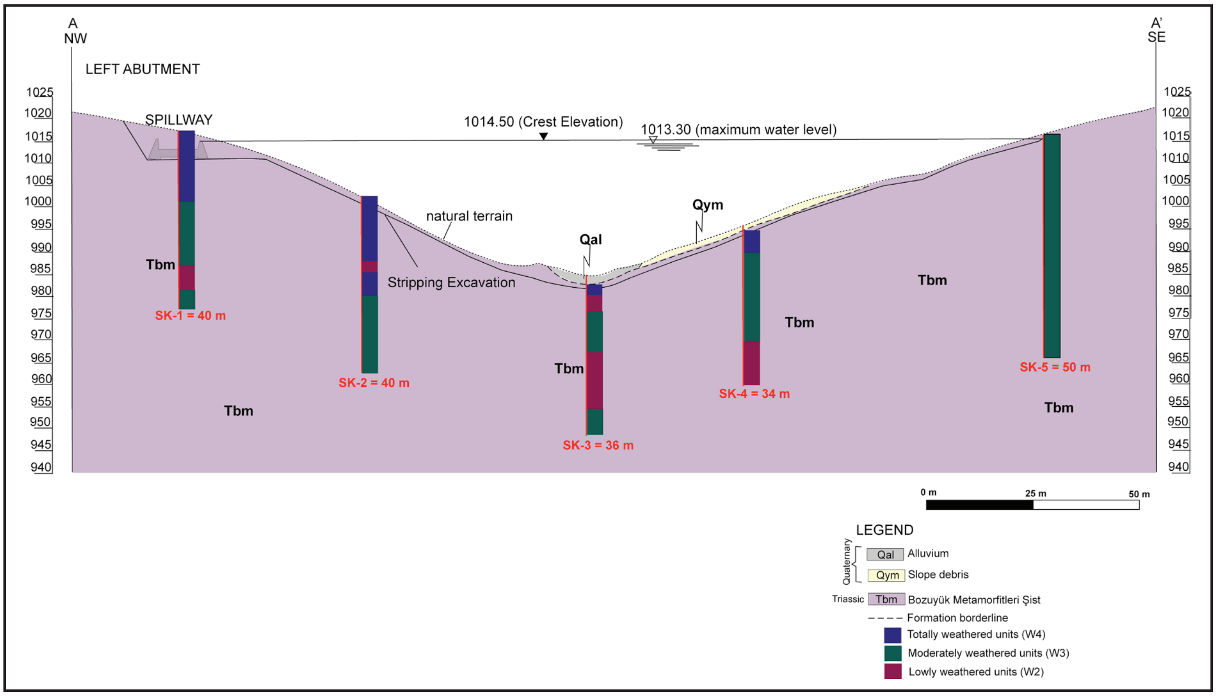

Figure 5- Engineering geology cross section of dam body (A - A' section).

2.2. Alluvium (Qal)

Quaternary aged alluviums are located along the Yol River bed (Figures 3 and 5). This unit, which is formed by erosion transportation and deposition, is constituted by gravel, sand, silt and clay sized material. According to the drilling works, the thickness of the alluvium is changed between 1.50 - 2.00 m. The width of the alluvium can be reach up to 10 m locally.

2.3. Slope Debris (Qym)

Blocky structured slope debris are formed by the weathered bedrock and transported to piedmont. For this reason slope debris is constituted by coarse gravel and clay sized material and cementation is observed. The drilling works realized in right abutment shows that the slope debris thickness can be reach up to 1.0 m.

3. Engineering Geology

Savcıbey Dam body is projected as clay cored rock-filled dam, its height from thalveg is 31.15 m and from foundation is 36.15 m. Crest length of dam body is 189.67 m, thalveg elevation is 985.64 m and minimum water elevation of reservoir is 995.75 m, maximum water elevation of reservoir is 1013.3 m. Sluice outlet is designed as concrete jacket penstock pipe type in left abutment with inlet elevation of 988.50 m and outlet elevation of 978.50 m. Spillway is projected in left abutment with water stilling basin.

According to the criteria of weathering degree of rock masses proposed by ISRM (2007), the core samples obtained from drilling works are generally totally weathered (W4) and moderately weathered (W3), but locally lowly weathered (W2) units are encountered.

4. Permeability of Dam Axis Location

The principal aim of this study is design of grout curtain and for this purpose, to determine the permeability of alluvium, slope debris and bedrock falling head permeability test and Lugeon tests have been performed. These tests are realized in ground investigation boreholes drilled on dam axis location.

Lugeon test is an in-situ test applied in a borehole with the purpose of hydraulic conductivity determination of rock masses under different hydraulic heads. This test is realized generally with test levels changing between 2 – 5 m. Test level length is designate based upon the physical and structural properties of rock mass. In an uniform and impermeable rock mass test level can be applied with 5 – 10 m test zone and in a permeable rock mass which has variable physical properties, this test zone can be reduced until 1 m (Akyüz, 2010). Test method proposed by Lugeon (1933), 1 Lugeon is defined as the water amount pumped to the 1 meter length of test zone under 10 atm hydraulic pressure in 1 minute. The pressure applying to the test zone is also specified by engineering judgement depending on the physical properties of rock but general application in Turkey is using 2, 4, 6, 8, 10 kg/cm^2 of test pressures. Each pressure stage applied to the rock during 10 minutes and the water leakages are recorded each 5 minutes. Then, 9, 7, 5, 3, 1 kg/cm^2 of test pressures are applied and water leakages are recorded.

Lugeon value (LU) is calculated by the equation below.

LU = (Q x 10) / (P x L) (equation 1)

In this expression, LU is Lugeon value (lt/min/m), Q is water amount given to the rock formation (lt/min), P is hydraulic head applied to the test zone (kg/cm^2) and L is test length (m). The permeability class corresponding to the Lugeon values is presented in table 1.

Table 1- Permeability classification based on the Lugeon values of rock masses

Lugeon Values	Permeability Class
<1 Lugeon	Impermeable
1 - 5 Lugeon	Low Permeable
5 - 25 Lugeon	Permeable
>25 Lugeon	Highly Permeable

A grout curtain is planned along the dam axis to avoid the probable leakage from Savcıbey Dam and to accumulate the water more efficiently. To design the grout curtain and to predict the approximate grout amount for each grout stage, Lugeon (1933) tests are performed in total 6 boreholes, 5 boreholes (SK-1, SK-2, SK-3, SK-4 and SK-5) drilled along dam axis and 1 borehole (BSK-1) drilled for cofferdam (Figure 3).

Under homogeneous and isotropic conditions 1 Lugeon is equivalent to a hydraulic conductivity of 1.3x10^{-5} cm/s proposed by Fell et al. (2005). In the table proposed by Fell et al. (2005), the relation between Lugeon values and hydraulic conductivity is shown on figure 6.

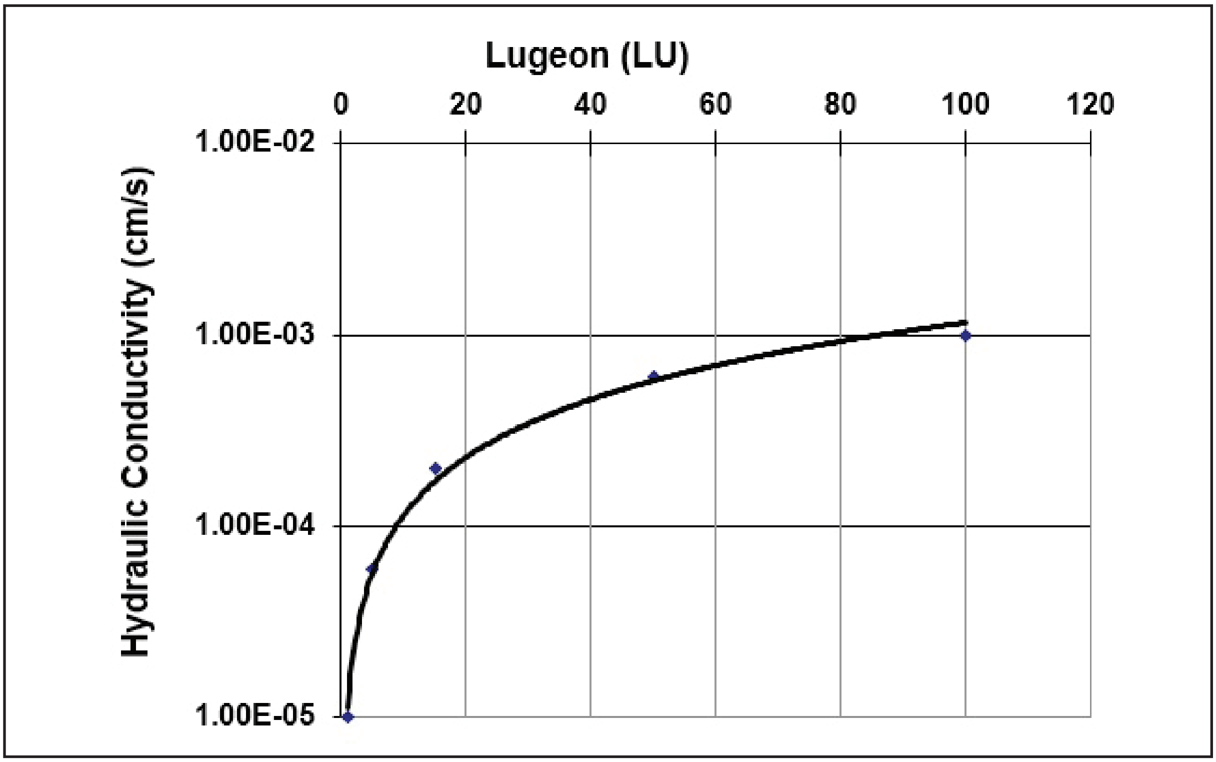

Figure 6- Relation between Lugeon values and hydraulic conductivity (modified from Fell et al., 2005).

Hydraulic conductivity values corresponding to Lugeon values of figure 6 can be represented by the expression given in equation 2.

$$K = 1 \times 10^{-5} \times (LU)^{1,0082} \qquad \text{(equation 2)}$$

The coefficient of correlation between hydraulic conductivity (K) and Lugeon values (LU) expressed in equation 2 is determined as R^2=0.9954. The coefficient of correlation converging to 1 indicates the higher relationship between the Lugeon and hydraulic conductivity values expressed in equation 2. In other words, R^2 converging to 1 shows that equation 2 reflects the reality. The Lugeon values obtained from the Lugeon tests which are performed for the determination of the permeability characteristics of Savcıbey Dam foundation under variable hydraulic heads, are transformed to hydraulic conductivity with the use of equation 2. Minimum, mean and maximum hydraulic conductivity values are shown on table 2.

In addition, the variation of Lugeon values with the depth is shown on figure 7 for the boreholes drilled in left abutment SK-1 and SK-2, thalveg SK-3 and BSK-1 and right abutment SK-4 and SK-5.

5. Falling Head Permeability Tests

Falling head permeability tests are performed in alluvium and slope debris to specify the permeability characteristics of Savcıbey Dam soil foundation. Each test stage is set as 2 m. This test is realized in weathered parts of Bozüyük Metamorphics in 0 – 4 m stage of SK-1, 0 – 2 m stage of SK-2 and alluviums in 0 – 8 m stage of BSK-1. Falling head permeability test cannot be applied to the boreholes SK-3, SK-4 and SK-5 due to the use of casing for unstable borehole walls during drilling operation. Permeability of alluvium sampled from the borehole SK-3 is predicted by the test results of the borehole BSK-1.

Falling head permeability tests realized in boreholes SK-1 and SK-2 show that the weathered and highly jointed parts of Bozüyük Metamorphics are permeable in terms of hydraulic conductivity ($K \approx 10^{-4}$ cm/s). And the falling head permeability tests realized in the borehole BSK-1 shows that the alluviums are highly permeable in terms of hydraulic conductivity ($K \approx 10^{-3}$ cm/s). Under this circumstance, excavation of alluvium units under the Savcıbey Dam axis is important with regard to the permeability and stability of dam body. Considering the groundwater level and the hydraulic conductivity of the excavated soil, it is predicted that a water income to the excavation pit with 3,2 lt/s flow rate (SuYapı, 2013). In this case, the water income to the excavation pit should be dewatered with suitable pumps.

6. Determination of Grout Curtain Depth

There are many methods for the determination of grout curtain depth (h') (Bureau of Indian Standard, 1993; Pettersson and Molin, 1999; Evert, 2003; Şekercioğlu, 2007; Schleiss and Pougatsch, 2011). This methods in which the grout curtain depth is a function of dam height (h), are expressed as equation 3, 4, 5, 6 and 7.

According to Bureau of Indian Standard (1993) $h' = \{\frac{2}{3}\} h+8$ (equation 3);

According to Pettersson ve Molin (1999) $h' = \{\frac{3}{4}\} h$ (equation 4);

According to Ewert (2003) $h' = h$ (equation 5);

According to Schleiss ve Pougatsch (2011) $h' = \{\frac{2}{3}\} h$ (equation 6);

According to Şekercioğlu (2007) $h' = \{\frac{1}{2}\} h + 15$ (equation 7);

Table 2- Minimum, mean and maximum hydraulic conductivity (cm/s) of each borehole.

	Hydraulic Conductivities (cm/s)					
	SK-1	SK-2	SK-3	SK-4	SK-5	BSK-1
Minimum	4.1E-05	4.1E-05	3.1E-05	3.6E-05	8.4E-06	8.8E-05
Mean	1.4E-04	2.2E-04	7.6E-05	1.3E-04	1.1E-04	7.5E-04
Maximum	3.6E-04	5.4E-04	1.8E-04	1.9E-04	2.3E-04	1.8E-03

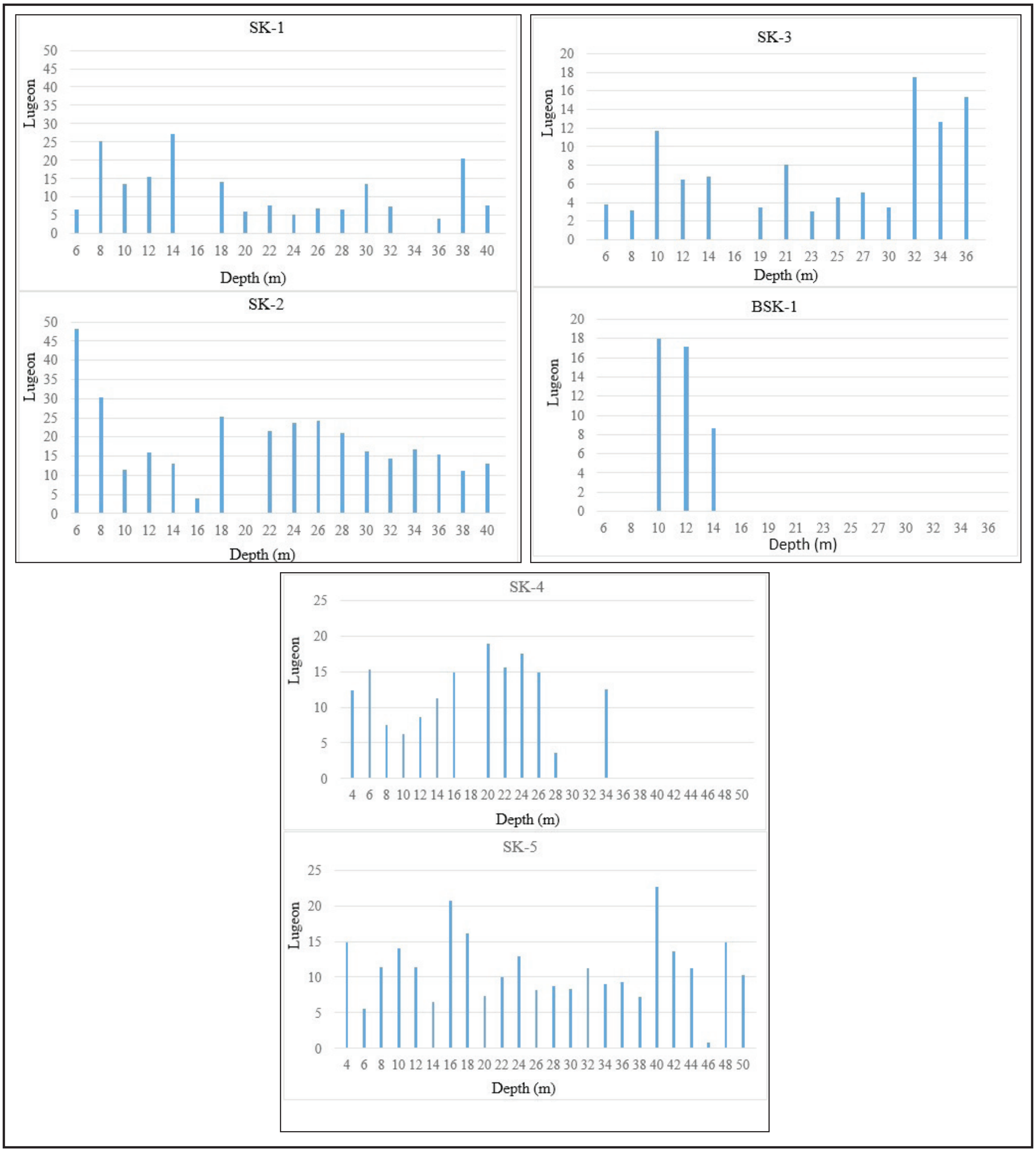

Figure 7- Lugeon value variations with depth for left abutment (SK- 1 and SK-2), thalveg (SK – 3 and BSK – 1) and right abutment (SK -4 and SK -5).

Grout curtain depth (h') calculation is compared using with the equation 3 proposed by Bureau of Indian Standard (1933) and the equation 7 proposed by Şekercioğlu (2007) for Savcıbey Dam thalveg area. Hereunder, h' is calculated 30.575 m from equation 7 and 28.77 m from equation 3. It is seen that both of methods proposed for the grout curtain depth are close. In this study, grout curtain depth for Savcıbey Dam is calculated based on the equation 7 proposed by Şekercioğlu (2007) but on behalf of to be in safe side same grout curtain depth is predicted for the abutments considering the engineering judgement.

In addition, grout curtain depth is designed considering the height of dam body from thalveg (31.15 m) and the extra hydraulic head on the bedrock of dam foundation. Moreover, grout curtain is prolonged through the reservoir area in order to avoid small-scale leakages. It is though that small-scale leakages would be avoided and impermeability would be provided by the grout curtain represented in figure 7. Groundwater Levels (GWL) and hydraulic conductivity values are considered for the design of the grout curtain. GWL surveys realized after drilling operation shows that GWL of the borehole SK-1 is 13.20 m and SK-2 is 13.60 m. GWL of the borehole SK-3 drilled for thalveg is 0 m. GWL of the boreholes SK-4 and SK-5 drilled for right abutment are 3.00 m and 0.60 m respectively. Comparison of the GWL of the boreholes drilled along the dam axis indicates that GWL movement is through river for both of abutments (Figure 8). This GWL conditions demonstrates that river is fed by both of the abutments and any of water flux trough the abutments by the river elevation.

It is aimed to avoid the potential leakages and provide the impermeability with the grout curtain represented in figure 8. Accordingly, grout curtain depth of left abutment is changing between 35 and 40 m. Augmentation of hydraulic head on the formation will also increase the hydrostatic pressure and favour the leakages. For this reason, due to the most of the hydraulic head will be on thalveg, grout curtain depth is increased approaching trough thalveg. Grout curtain depth is calculated as 40 m along thalveg. As a result of the calculations, approaching to right abutment from thalveg the grout curtain depth is 45 m from the stripping excavation due to the augmentation of permeability.

7. Results and Suggestions

The results obtained from the Lugeon tests performed in 5 boreholes drilled on dam axis and 1 borehole drilled on cofferdam are evaluated for thalveg, right abutment and left abutment separately. Evaluation is realized based on the permeability classes stated in table 1. Accordingly, permeability of the boreholes SK-1 and SK-2 drilled for left abutment are changing between permeable and highly permeable until 14 m depth. Permeability of the borehole SK-1 is changing between lowly permeable and permeable between the depths 14 – 40 m and the rock mass of the borehole SK-2 is permeable – highly permeable especially for the depths 18 – 28 m between 28 – 40 m formation is permeable (Figure 7).

Lugeon values obtained from the boreholes SK-3 and BSK-1 drilled for thalveg indicates the existence of local highly permeable levels. Due to the water income from the borehole entrance during the Lugeon test, the test is failed for the 6 – 8m and 8 – 10 m test levels considering depth of alluvium is more than 5 m in the borehole BSK-1 and the Lugeon test can be performed only in 10 – 12 m, 12 – 14 m, 14 – 16 m test levels. For these test levels rock mass is evaluated

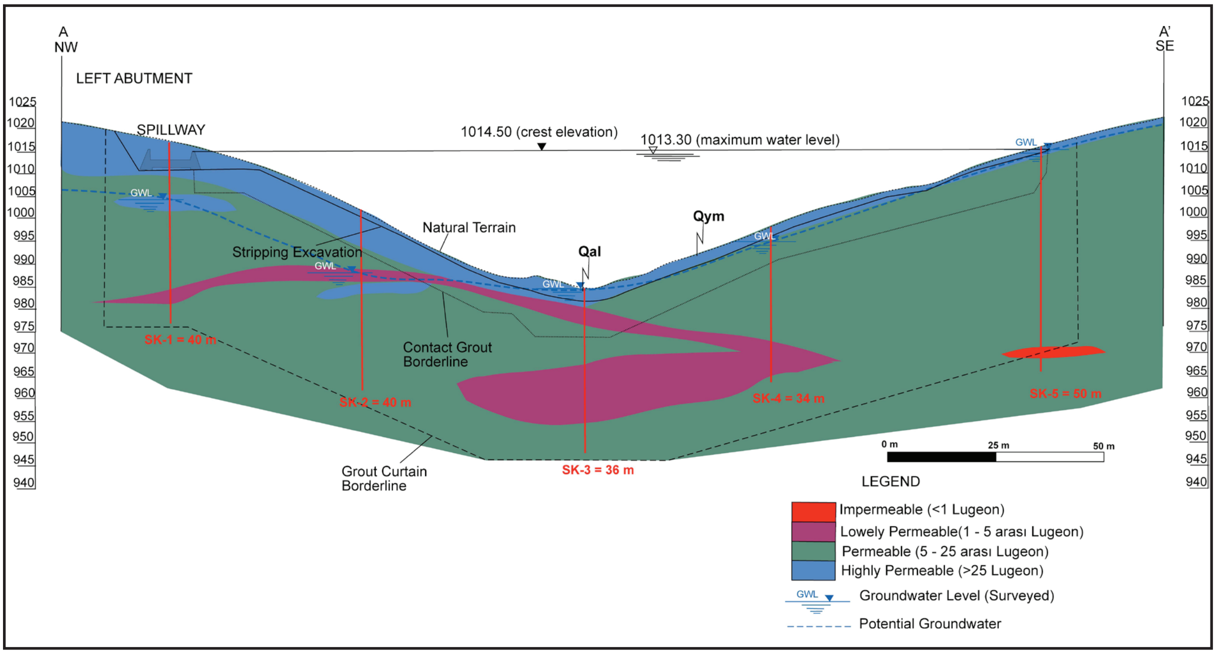

Figure 8- Microzonation of dam axis based on the Lugeon values and grout curtain borderline.

as permeable. However, 6 – 10 m and 23 – 32 m test levels of the borehole SK-3 can be evaluated as lowly permeable. The other test levels are permeable (Figure 7). The boreholes SK-4 and SK-5 drilled in right abutment are generally permeable – lowly permeable and some local impermeable levels are remarked (Figure 7).

Permeability variations based upon the depth in figure 7 is evaluated as follow considering the permeability classes corresponding to Lugeon values given in table 1;

- In the borehole SK-1, 6 – 8 m and 12 – 14 m test levels are highly permeable, 4 – 6 m, 18 – 20 m, 22 – 24 m and 34 – 36 m test levels are lowly permeable and other test levels are permeable.
- In the borehole SK-2, 4 – 8 m test level is highly permeable, 14 – 16 m test level is lowly permeable and other test levels are permeable.
- In the borehole SK-3, 4 – 8 m, 16 – 19 m, 21 – 25 m and 28 – 30 m 12 – 14 m test levels are lowly permeable and other test levels are permeable.
- In the borehole BSK-1, 8 – 14 m test levels are permeable.
- In the borehole SK-4, 26 – 28 m test level is lowly permeable and other test levels are permeable.
- In the borehole SK-5, 44 – 46 m test level is impermeable 4 – 6 m test level is lowly permeable and other test levels are permeable.

This unit can be defined as moderately (W3) – completely (W4) weathered based on the data obtained from ground investigation boreholes and the observations considering the weathering degree definition criteria of rock masses proposed by ISRM (2007). Additionally, lowly weathered (W2) units are observed during drilling operations. Comparison of the figures 5 and 8 indicates the effect of weathering degree to permeability. Accordingly, it is observed that completely weathered (W4) units are more permeable than moderately (W3) and lowly weathered (W2) units. And it is remarked that the Lugeon test levels which are failed due to the water income from the borehole entrance are completely weathered (W4). In this case, it can be said that permeability increases with the augmentation of weathering degree in Bozüyük Metamorphics.

Foundation rock unit of dam location Bozüyük Metamorphics can be evaluated as lowly permeable – permeable. It is approved that 1.5 – 2 m thick alluvium and 1 m thick slope debris existing in dam axis will be removed by stripping excavation. The results of geological observations and Lugeon tests performed in boreholes are evaluated and it is deduced that after removing the alluvium and slope debris there will not be any permeability problem except some levels in thalveg and abutments. Considering these, water movement from upstream to downstream will be avoided with the grout curtain, in other words, the targeted impermeability will be provided.

Bozüyük Metamorphics which constitute foundation rock of the dam axis location and its near environ is observed as mica schist, graphite schist and talc schist. The units belonging to Bozüyük Metamorphics observed in dam location and its near environ are generally greenish brown – grey with schistosity. Triassic aged this metamorphic units are subjected to tectonic effect of during many geological times and due to this effect the schistosity planes have different orientations. However, any negative provision is detected in terms of permeability in dam axis location due to the dip direction of schistosities are generally towards upstream. In addition, slope debris and alluvium located in dam body will be stripped and it is planned to construct the dam on the bedrock. During this operation water income to the excavation area can be awaited but discharging of this water with the suitable pumps is possible. Any stability problem is awaited for dam axis considering the stress-strain characteristics of bedrock.

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