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Research Article/Araştırma Makalesi

Evaluation of Permeability in Quarry Operated below Stream Level

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Keywords
Finite element method, Permeability, Seepage analysis, Quarry.

Abstract
In this study, the permeability problem that may occur in a quarry planned as an open-pit operation under the Melet Stream (Ordu) flow level has been evaluated by numerical analysis method. The quarry, the subject of the study area, is planned to be operated at approximately 65 m from the Melet Streambed and below the water flow level (27 m). The quarry, which previously operated in the upper elevations of the Melet Stream, consists of the dacitic rock mass. The engineering properties of the rock mass were determined by the scan line survey studies on the slopes opened in the quarry, and it was determined that the rock mass was moderately permeable with the help of empirical equations using the parameters obtained. To determine the water discharges that may occur from the bottom and side surfaces of the quarry, which is thought to be operated below the Melet Stream flow level, finite element-based Seepage analysis was carried out in the RS2 computer program. Considering the water discharge values in these areas, it has been determined that the water discharges to occur at the base of the operation site (zero elevation) and the sidewall is respectively 2.33*10-12 m3/day (at the bottom), 6.12*10-12 m3/day (the sidewall of the quarry). The water discharges in the quarry area at these depths are very close to zero, and there is a distance of approximately 65 m between the quarry area and Melet Stream. In addition, the quarry means that no risk of flooding will occur during the quarry operation.

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1. Introduction

It has become a routine engineering problem from past to present to encounter flash floods and seepage during engineering structures' construction and operation processes (tunnel, subway, private underground hangars) and mines (quarry and underground gallery systems). Mainly life-threatening flash floods occur with the discharge of accumulated water in fault-controlled crush zones, underground caves where lithological karstification is intense, and previously operated and abandoned galleries. Seepage waters occurring in almost all underground structures and businesses depend on the porosity and permeability

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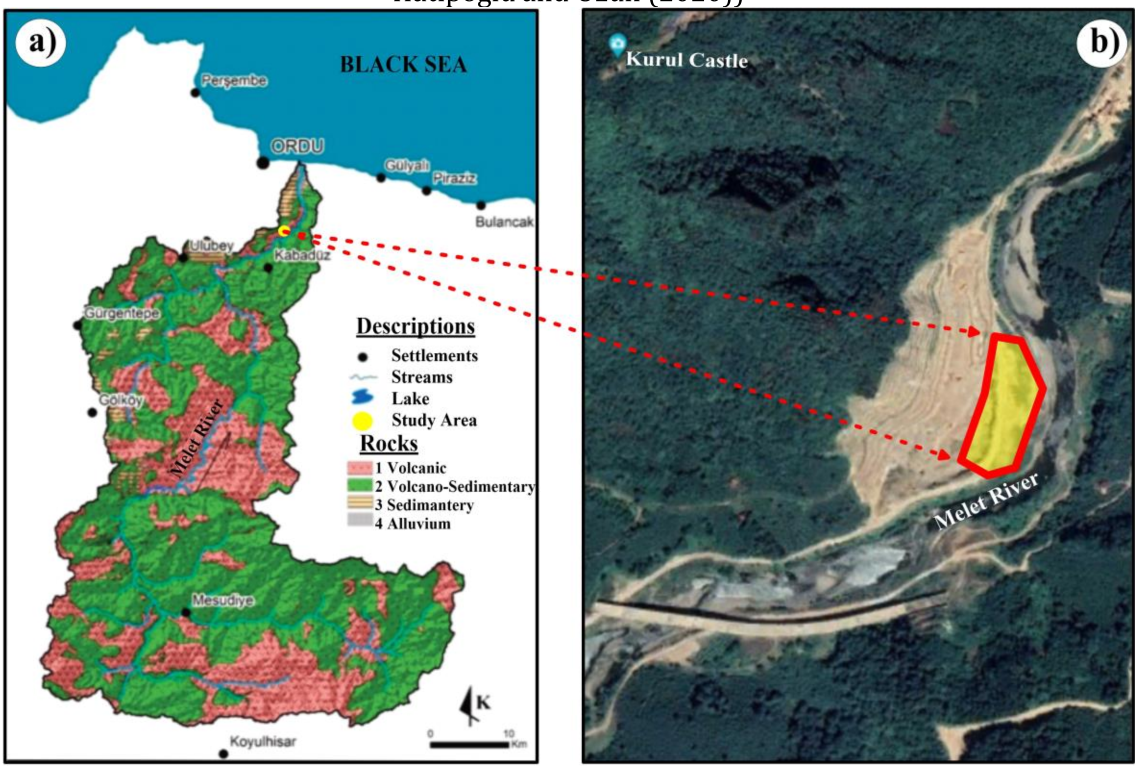
properties of the lithological units that make up the rock or soil mass. Although seepage does not pose a life-threatening threat like sudden floods, it negatively affects the construction of business and engineering structures over time. Rock mass permeability is an essential parameter for both mining operations (aboveground and underground) and rock masses that form the basis of engineering structures. Many researchers have studied it until now (Karagüzel and Kılıç, 2000; Foyo et al., 2005; Alemdag et al., 2008; Coli et al., 2008; Ersoy et al., 2008; Nandi, 2011; Gürocak and Alemdağ, 2012; Moosavi et al., 2012; Alemdağ, 2015; Kanık and Ersoy, 2019; Ersoy et al., 2019; Alemdağ and Kanık, 2020).

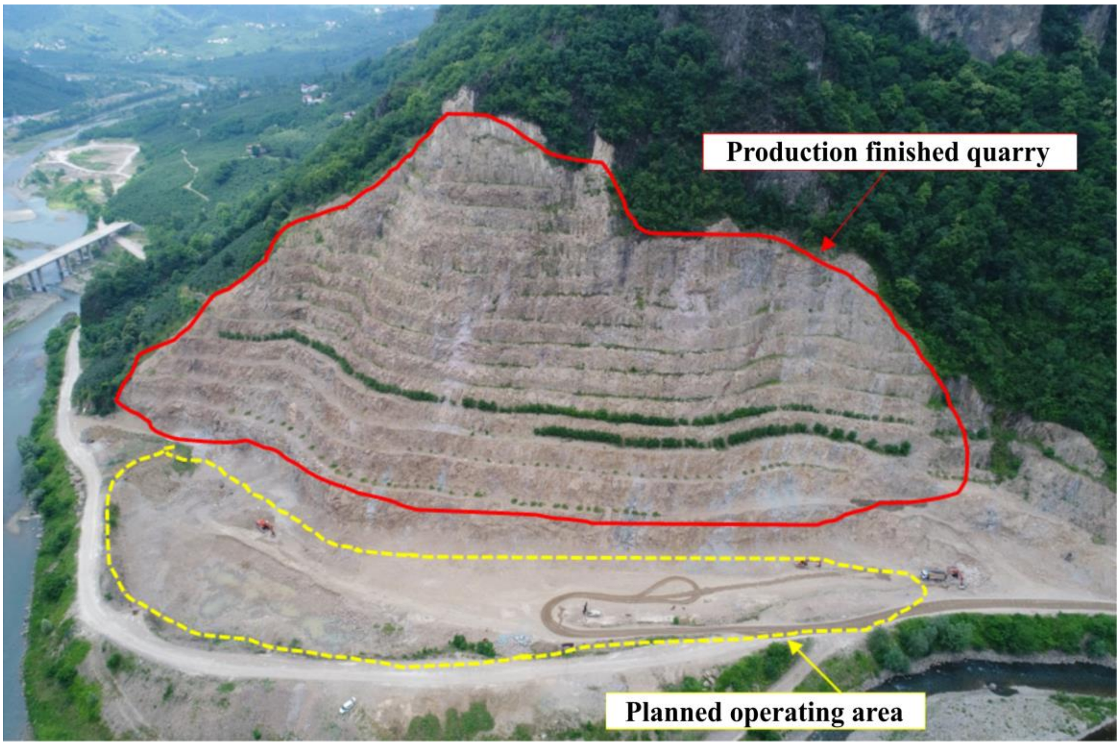
In this study, it has been evaluated whether the quarry (Figure 2), which is planned to be operated at a horizontal distance of approximately 65 m on the west side of the Melet River flow direction (Figure 1 a, b), will not be adversely affected by flooding or seepage, which may result from a possible permeability problem since it will be operated at the lower elevations of the water level.

Fig 1. Geological map (a) and satellite image (b) of the study area (modified from Hatipoğlu and Uzun (2020))



For this purpose, the permeability of the basement rock spreading in the quarry area, which is planned to be operated with the open-pit method, was evaluated using the empirical equations and numerical analysis methods used by making use of the rock mass properties examined in situ. To determine the permeability of the rock mass in the quarry area, the RQD value of the rock mass was determined using the joint density data obtained from the line survey measurements. Subsequently, Qureshi et al. (2014) and by using the empirical equations suggested by Farid and Rizwan (2017), the permeability value was determined, and this value was used as an input parameter in numerical analysis, and the permeability status of the quarry area was also numerically revealed. In addition, the amount of seepage that will occur in the discharge sections drawn on the bottom and side surfaces of the quarry area was determined with the help of the infiltration analysis made in the RS2 (Rocscience, 2019) program.

Fig 2. View of the area that has been produced and planned to be operated in the study area



2. Geology of the Study Area

It has been determined that the geological units spreading regionally in the basin, from the older to the youngest, Upper Cretaceous aged volcanic, volcano-sedimentary rocks and Quaternary aged talus and alluviums outcrop. (Fig 1a). The volcanic rocks planned to be operated in the quarry the subject of the study were defined as the Tirebolu Formation by Güven (1993). The formation's general features include light gray colored dacite and pyroclastics, and occasionally light brown colored rhyolite and rhyodacite (Figure 3). It crops out in about 3 km in width and 6-10 km in length in the southern parts of the Tirebolu and Espiye regions. It shows a columnar structure in places; it is less weathered and less cracked. Decomposition is seen in the form of marginalization and silicification. The units belonging to the formation are observed in a wide area along the Melet River valley. The age of the formation is Upper Cretaceous. In the study area, light gray-colored dacite of the formation, in places, light-brown, gaseous rhyodacite type rocks crop out. In addition, the spreading volcanic rocks present a tight-compact structure and contain unsystematic, randomly formed cracks. Separations have developed along the crack surfaces. The dissociation color is dark brown and yellow.

Alluviums consist of sandy, silty, pebbly, and blocky materials formed in large and small river valleys around the study area. It is observed most intensely in the Melet River valley. Blocks with a diameter of 25-30 cm are also frequently seen in alluviums formed by gravels with 2-15 cm diameter. Blocks and pebbles are generally round, some with blunt corners. Slope debris is located on the skirts of the slopes in the study area, and they are angular, flat, and some with blunt corners, blocks, gravel, sand, silt, and clays according to the rock types in the area where the slopes are located.

Fig 3. Field view of dacites belonging to the Tirebolu Formation.

3. Results

To determine the geotechnical properties of the units at the quarry site, the engineering properties of the discontinuities contained in the dacite rock masses were determined by considering the ISRM (2007) definition criteria and using the scanline study method (Tablo 1). In addition, to determine the geomechanical properties of rock materials in the laboratory, block samples were collected from the field and cores were prepared according to the methods recommended by ISRM (2007), and experiments were carried out. The RQD (%) values of the rock masses were calculated for the rock mass (66%) by using the discontinuity frequency parameter obtained using the scanline survey method, and their statistical distributions are given in Figure 4.

In order to determine the amount of water discharge that will occur in the quarry rock mass, Hoek et al. The numerical classification chart suggested by Hoek et al. (2013) was used. The 1.5*$JCond_{89}$ (Joint condition) values used in this classification are given in Table 1, and the RQD/2 value was determined using the average RQD values shown in Figure 4. Accordingly, the GSI value of the dacite rock mass was determined as 63 (Figure 5). The constants (mb, s, a) of the dacite rock mass were calculated using the RocLab V1.03 (2007) program, taking into account the failure criterion of Hoek-Brown (Hoek et al., 2002) (Table 2). Another parameter to be used in the seepage analysis is the permeability coefficient (K), equations 1 and 2 were used to determine this value and the average permeability coefficient was determined as $1.7x10^{-3}$.

$$K = 3447e^{-0.06\,(RQD)} \times 10^{-8} \quad RQD > 50 \qquad \text{(Farid and Rizwan, 2017)} \qquad (1)$$

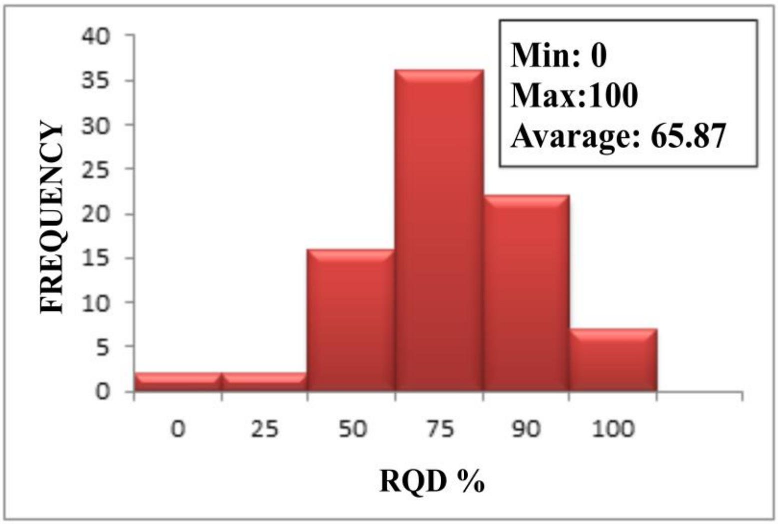
$$K = 0.01382 - 0.003\ln(RQD) \qquad \text{(Qureshi et al., 2014)} \qquad (2)$$

Table 1. Discontinuity properties of dacite rock masses

Discontinuity properties	Definition	Rating
		Dacite
Roughness	Rough	5
Weathering	Moderately degraded	3
Infilling	Clay fill thickness<5mm	2
Discontinuity	<1mm	6
Aperture	0.1 – 1 mm	4
$JCond_{89}$		**20**

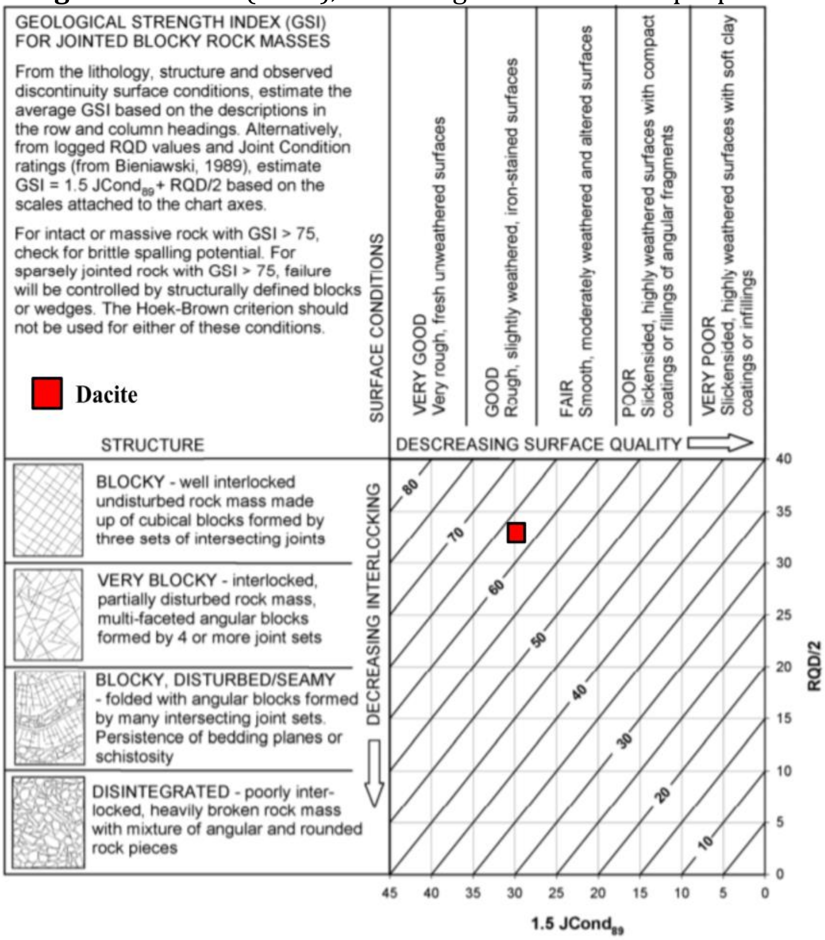
JCond89: Discontinuity scoring according to the RMR 1989 version (Bieniawski, 1989)

Fig 4. %RQD distribution histogram of dacite rock mass.



In order to determine the material properties of the investigated rock mass and determine the parameters to be used as input parameters in numerical analysis solutions, block samples were collected from the operation site. Drawings of average uniaxial strength and unit weights of aged dacites with appropriate cores according to laboratory test standards from samples from open-pit mines. Accordingly, the average uniaxial compressive strength of dacites was determined as 145MPa, and unit volume weight values were determined as 25.50kN/m^3.

Fig 5. Hoek et al. (2013), according to the GSI chart proposed.



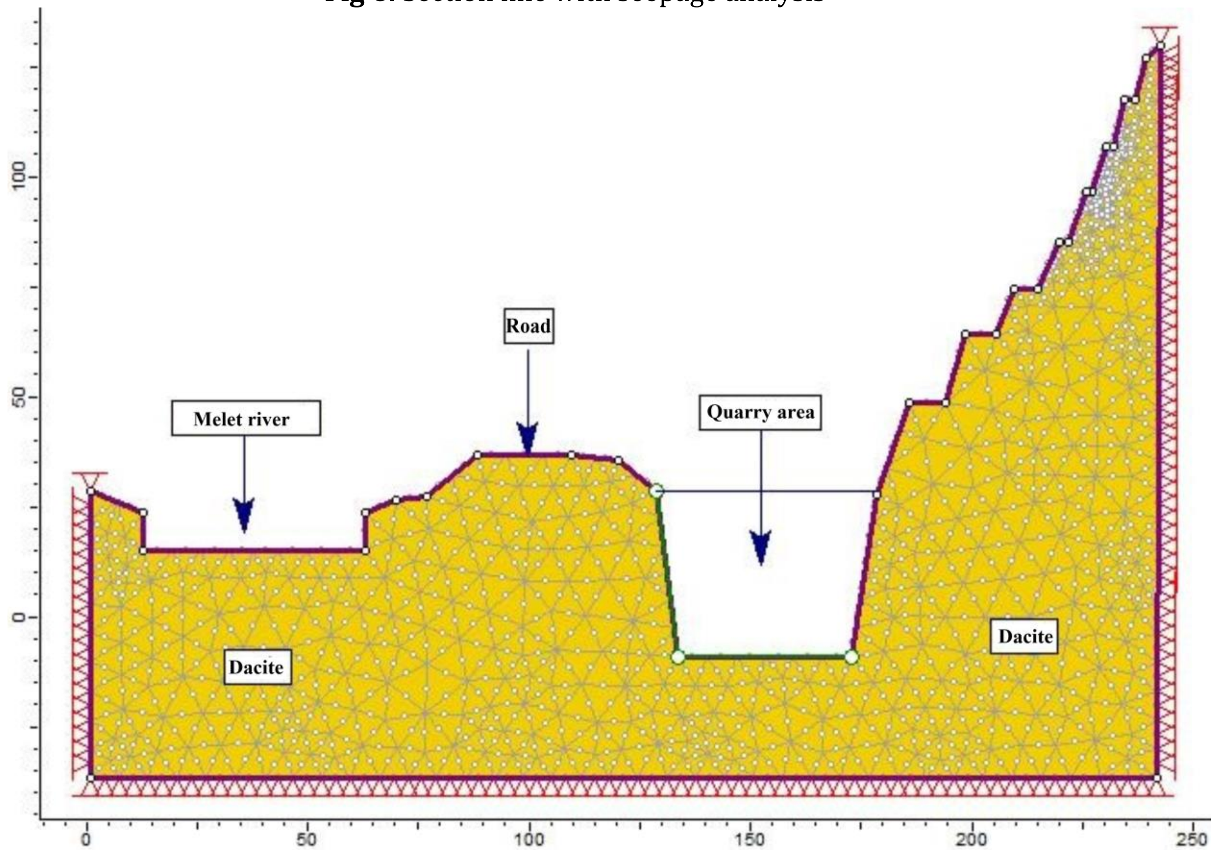
4. Seepage Analysis

As a result of the macroscopic observations made in the study area, the geological unit that spreads is composed of light gray dacite and occasionally light brown colored rhyolite and rhyodacite. The investigated unit shows a columnar structure in places. It is slightly moderately weathered and shows an unsystematic fractured system. Weathering is generally seen as argillization (Figure 3). As a result of the investigations, the dacite rock mass is not an aquifer rock, but only in the fracture zones, water outflows in the form of moistening, dripping, and infiltration were observed. To determine the water discharges that will occur in the quarry planned to be operated in the dacitic rock mass, finite element-based seepage analyzes were performed in the RS2 (Rocscience, 2019) computer program. The parameters used in the analysis model made with RS2 are given in Table 2, and a 6-node, triangular uniform mesh system is used in the model (Figure 6).

Table 2. Parameters used in numerical analysis

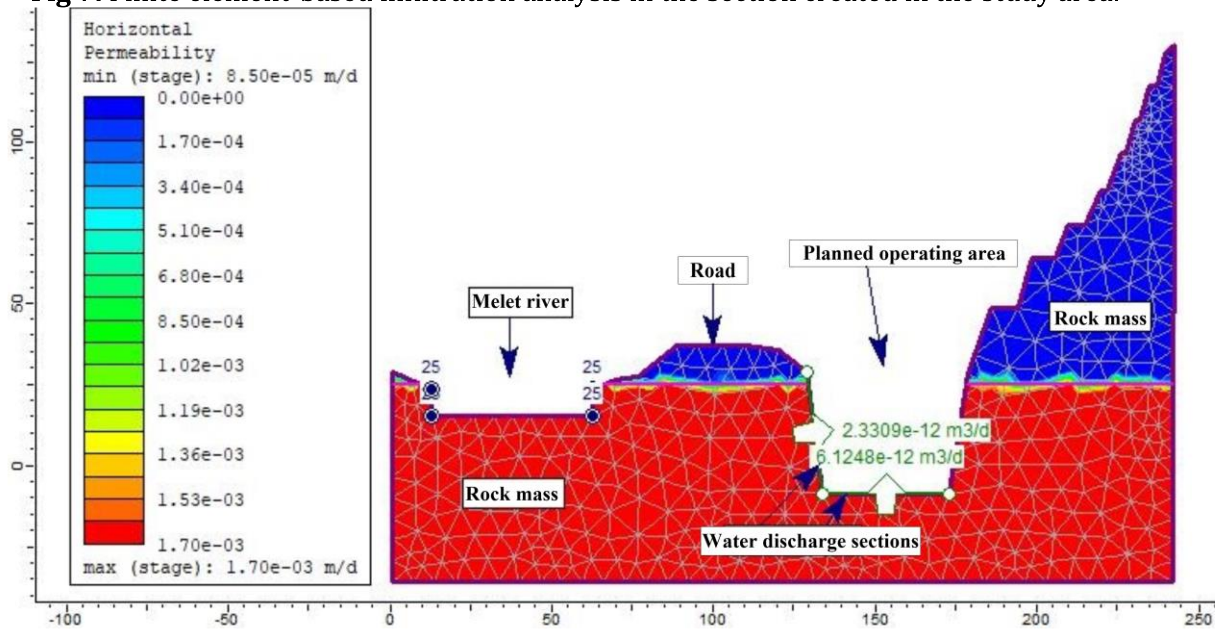
Dacite	GSI	σ_{ci} (MPa)	mi	γ (kN/m³)	υ	D	K (m/s)	E_m (GPa)	Hoek - Brown constant		
									mb	s	a
Quarry	63	145	25	25.50	0.28	0.7	1.7×10^{-3}	4.77	3.27	0.0047	0.502

Fig 6. Section line with seepage analysis



Finite element method seepage analysis was carried out using the RS2 (Rocscience, 2019) computer program to determine the possible infiltration of the Melet River and the water discharge to the operation area in the area planned to be operated. In the study area, the Melet River flows at an elevation of approximately 27 m, and the base level of the quarry area that is planned to be operated is planned as zero (0 m). In this case, there is a distance of approximately 65m between the Melet River and the quarry border to be operated (Figure 6). Since the area to be operated is planned to be opened below the flow level of the Melet River, it has been determined whether there will be water leaks on the sidewalls of the quarry and at the bottom of the quarry, and daily water discharges into the quarry area (Figure 7). Considering the water discharge values in these areas, it has been determined that the water discharges occur at the base of the operation site (zero elevation), and the sidewall is $6.12*10^{-12}$ m^3/day (at the bottom), $2.33*10^{-12}$ m^3/day (the sidewall of the quarry), respectively. As a result of the analysis, the water discharge values determined in the quarry area are very close to zero, and a distance of approximately 65 meters from the Melet River has revealed that no flooding risk will occur.

Fig 7. Finite element-based infiltration analysis in the section created in the study area.



5. Conclusions

In this study, an evaluation of a possible seepage situation at the bottom and sidewalls of the quarry, which is planned to be operated near the Melet River and below the river's flow level, has been evaluated; the results are given below.

- The dacite rock mass in the quarry area contains moderately weathered and random discontinuity sets; the discontinuities are generally closed and filled with weathering product clay. For this reason, it does not show an aquifer characteristic.
- The permeability characteristic of the rock mass has been determined by empirical approaches (K= 1.7x10-3 m/s), and it is moderately permeable.
- Seepage analysis was carried out using the finite element method on the cross-section line determined by considering the Melet River in the study area, and when the water discharge values at the bottom of the quarry and side walls are considered, respectively, 6.12 * 10-12 m3/day, 2.33 * 10-12 m3/day.

These values indicate that the water in the Melet River does not pose a risk of water discharge for the quarry to be operated, only that there will be water leaks that will not affect the operation in the area. In addition, the surface waters due to rain and snow that will accumulate in the quarry area will be discharged into the Melet River, and there is no adverse situation related to the surface waters.

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