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Research Article

THE STUDY OF CEMENT GROUTING ON THE IMPROVEMENT OF DARBAND DAM STRUCTURE OF BOJNORD-IRAN

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ABSTRACT
Grouting is a method of injecting grout materials to improve geo-materials (soil and rock). In this method, the grout materials are injected into void and pore spaces in order to reduce permeability, correct faults and improve deformability of rocks. This paper examines the hydraulic features of geological formations of the left abutment of Darband Earth Dam before and after the pumping of grout materials into three boreholes of total length of 270 m. The results of permeability tests showed that the average depth of Lugeon which has been 23 m prior to injection has decreased to less than 2 m after grouting. Moreover, the findings showed a significant increase in quality indexes of rock formations after the performance of grouting.

***Keywords**: Injection, Geotechnic, Dam, Lugeon*

INTRODUCTION
Darband is a soil-filled earth dam situated in NE of Iran 35 km away from provincial capital of Bojnord in the vicinity of Jajarm City lying at 56^0, $58^{/}$ east longitude and 37^0,$36^{/}$ degree north latitude (Fig.1). The height of the dam from the river bed is about 70 m and its crest is 120 m long and during wet seasons, its reservoir can store up to 25.5 million m3 water. In order to improve the dam foundations and prevent the water seepage through its geological formations, compaction grouting was put high on the agenda by the authorities. Injection of grout materials in soils can fill the pore spaces and rocks' fractures, thus it can reduce the permeability and strengthen the resistance characteristics (Ghafouri and et al, 2010). Permeability is also considered as a major factor in the design of grouting curtain to prevent water seepage through foundation and control the adverse impact of water drainage through the foundation materials(Turkmen,2003). Permeability is much higher in bedding surfaces, fractures, cracks compared with the permeability of the rocks, so it can be claimed that water seepage only takes place through rock unconformities (Verfel,1989).This paper aims to study and compare the impact of cement grouting on Darband Earth Dam rock formations before and after the grouting works.

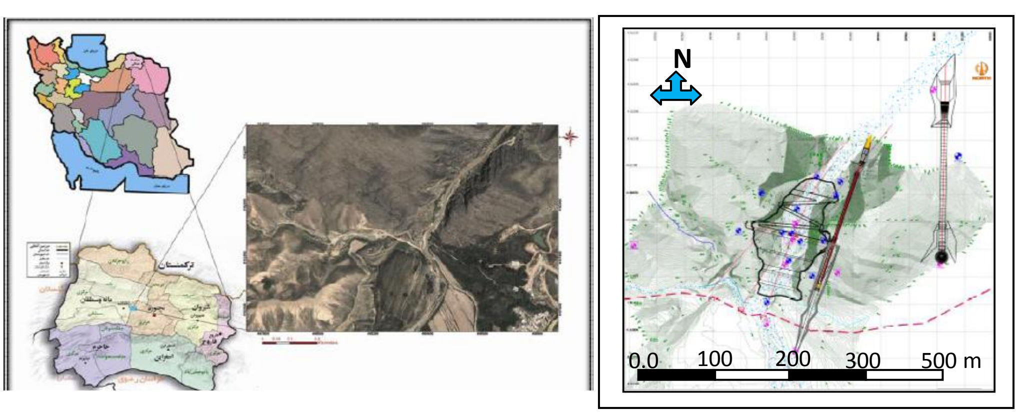

Figure1: Location map of the Darband dam site

Site Geology

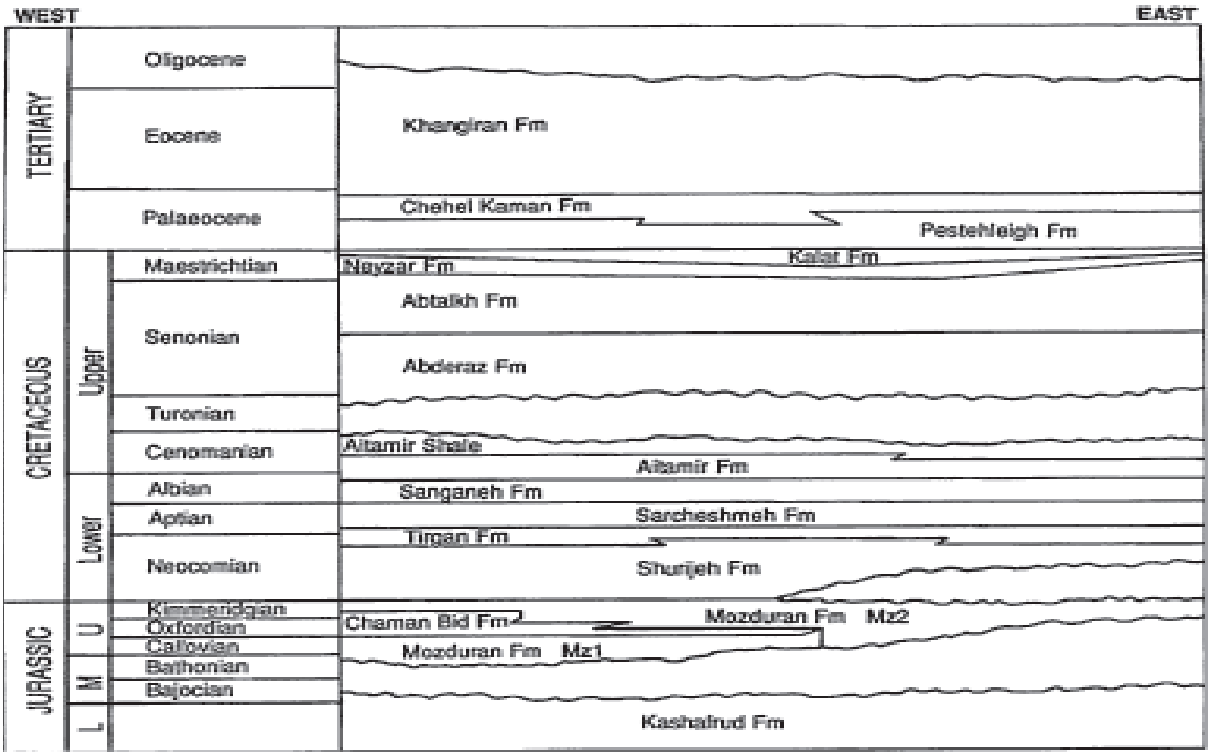

figure2: General Stratigraphy of the Kopet-Dogh basin

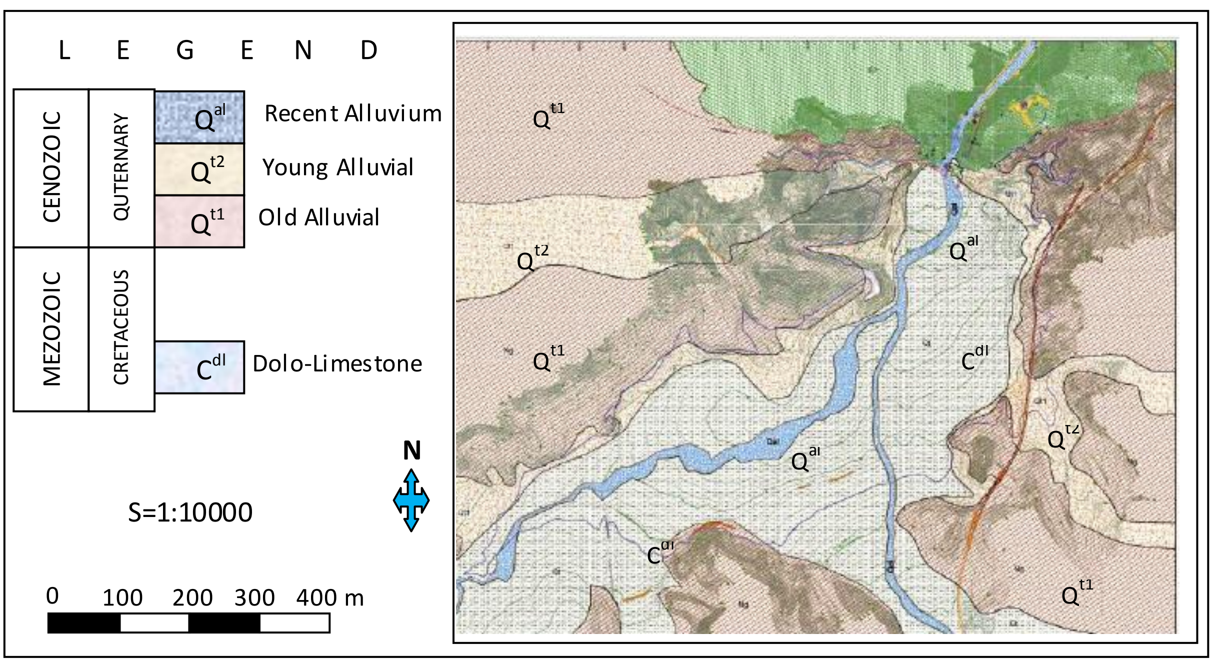

Figure3: Geological Map of Darband Dam Site

The regional and local engineering geology have played a major role in the planning, design, construction and preference of the dam in Kopet-Dagh basin(Lashkaripour & Ghafouri,2002). In terms of geological and structural zoning, Nabavi(nabavi,1975) maintains that Darband Dam is situated in Kopet-dagh Sedimentary Zone. The Kopet-Dogh formed as an intercontinental basin in NE Iran and SW Turkmenistan(berberian & king,1981 and Alavi and et al, 1997), and contains more than 6,000 m of Mesozoic and Cenozoic marine and fluvial sedimentary rocks(Afshar-Harb,1994).The general stratigraphy of the Kopet-Dogh comprises 15 formations from mid Jurassic to Oligocene age is shown in Fig.2. The rock masses found in the foundation of the dam are of gray Dolo-Limestone of Tirgan Formation where numerous fractures have appeared under the impact of tectonic factore in depth while the top layers exposed to environmental factors have been greatly damaged and crushed (Fig.3).

Permeability Characteristics of the Rock Masses of the Site

Water seepage measurement is carried out at a given section of a borehole at pressurized cracks and fractures depending on the joints distribution or their cutting by the bedding(Feder,1993). Since in grouting operations, radial flow is of significance, certain tests need to be administered in order to determine the permeability in which water flow is radial inside the cracks and fractures. Lugeon test is widely used to measure the amount of water injected into a segment of the bored hole under a steady pressure(Lugeon,1933). In this paper, in order to determine water permeability and identify the hydrological characteristics of bedrocks beneath the dam foundation, 50 water pressure tests or Lugeon Tests were conducted at the time of digging the test boreholes at 5 m depth. The tests were carried out at 5 stages (minimum pressure, medium pressure, maximum pressure, medium and minimum pressures). Based on the finding of the boreholes, the average Rock Quality Designation(RQD) at the BHDG1, BHDG2 and BHDG3 boreholes dug on the left side of the dam were 75, 64.5 and 76 percent respectively.
Based on the findings of permeability tests and evaluation of RQD, it can be concluded that the bedrocks at the left abutment are rather fractured and have a high permeability (Table 1). The results of Lugeon Tests also showed that the rock masses at surface areas up to a maximum depth of 50 meters had a high permeability whereas in deeper layers this permeability lowered.

Table1: Average Permeability at rock masses of the Dam

Borehole Number	**RQD(%)**		**Lugeon**	
	<50m	**>50m**	**<50m**	**>50m**
BHDG1	65.1	87.3	40	10
BHDG2	71.4	78.5	35.5	14.5
BHDG3	58.3	87.5	18.2	3.5

Table 2 displays the Lugeon values obtained for boreholes at the dam's left abutment. As can be seen, the average values for boreholes up to 50 m deep is 31 Lugeon while for boreholes deeper than 50 meters it is 9 Lugeon.

Table 2:
Lugeon with Depth in Borehole

BH.	Lugeon & Depth(m)																	
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90
BHDG1	30	26	42	38	50	47	30	42	39	32	13	2	17	25	14	7	10	2
BHDG2	32	31	29	38	42	51	29	38	16	36	40	39	17	1	1	12	3	3
BHDG3	7	5	28	25	20	23	18	5	34	6	6	5	5	1	4	3	3	1

Test Injection Operations

Three boreholes of 90 m deep were dug at the left abutment of the dam in a triangular shape at 12 m distance from each other. Injection was carried out at 5 m sections in a down/up manner (DU) with a minimum 4 and a maximum 14 bar pressure. It needs to be noted that because the injection pressure should be less than the maximum rock compressive strength to prevent the hydraulic fracturing of the rocks (Majdi and et al, 2004). The determination of an appropriate injection pressure especially in rocks such as shale type found in Darband Dam structure is of paramount importance.

The role of rock unconformity in groutability

Rocks are often subject to tectonic forces causing folding, faulting, cracks and fractures in them. Such unconformities constitute the rock porosities through which water infiltrates and makes them impermeable (Ghafouri and et al,2004). The orogenic movements at the dam site have led to the formation of fractures and cracks in the bedrock in different directions. In order to identify the engineering characteristics of the bedrock fractures at the study site, Brunton Compass and Dip/Dip Direction method were used to take samples(ISRM,1981). Based on the unconformities observed at the dam site, three joint systems namely (J1, J2 and J3) could be mentioned.

Accordingly, the J1 joints were of transverse and shear joints constituting the majority of joints in both abutments whereas the J2 joints were of cross and tension type with a slope of about 87 degree, and finally the J3 joints were of longitudinal and compressional type. Table 3 represents the engineering characteristics of the joints and Figure 4 displays the stereography of the joints created by Rocscience Dips 5.103 software program.

Table 3: Engineering characteristics of the in-situ joints at the dam site

Location	Length (cm)	opening (cm)	Number of joints in each unit	spacing (cm)	Filling
Right side	5>	1 to 2	2 to 3	50 to 80	Clay-lime.
Left side	3>	<3	1 to 2	150 to 200	Clay-lime.

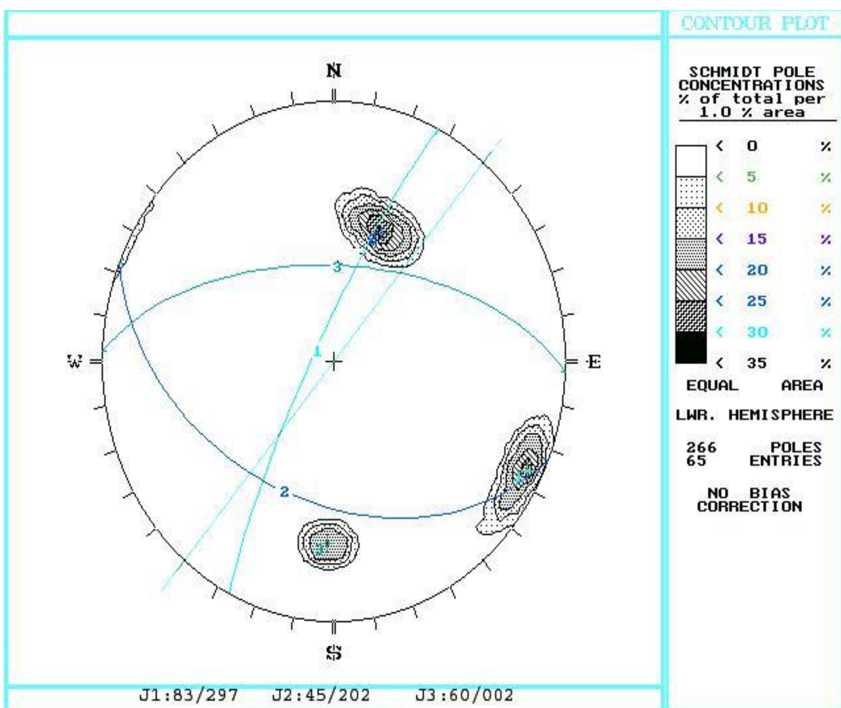

Figure 4: Joints stereography

To design the grouting (injection) curtain and the configuration of injection boreholes, it is needed not only to determine the rock mass impermeability but also obtain the engineering characteristics of the joints, their number, spacing, length, openness, and filling prior the injection operations.

Making use of the criteria listed in table 4 and knowing the characteristics of the rock mass joints, it is almost possible to have an initial pattern for grouting curtain and obtain the necessary data for its design such as injection boreholes, their spacing and depth.

Table 4: Grouting (injection) curtain design pattern by joints characteristics

No	Joints characteristics	Description
1	Length	Joints of more than 3 m long increase the permeation of the slurry
2	Joints spacing	For longer spacing, the boreholes of the first stage should be executed, whereas for close spacing, boreholes should be dug in several stages (2nd, 3rd).
3	Opening	For openings of more than 6 mm, injection should be carried out in several stages.
4	Joints filling	In case the filling is of clay type, injection should be done in several stages
5	Joints direction	Joints with a slope of 30 to 60 degree will be easily injected by vertical boreholes.

Analysis of the test injection results

By making use of test injection results, it is possible to determine the design parameters for the grouting (injection) curtain and obtain the radius of slurry penetration (grouting), cross spreading of the injection curtain, injection maximum and minimum pressure, slurry spreading angle, and the composition of the slurry to some extent [4].

To evaluate the groutability, Deere and Lombardi classifications presented in table 5 was used (Deere and Lombardi,1985).

Table 5: Grouting Classification by Deere & Lombardi

Groutability (kg/m)	Description
>400	Very high
201-400	High
101-200	Fairly high
51-100	Medium
25-50	Fairly low
<25	Low

Table 6 displays the relationship between the groutability, Lugeon value and RQD with depth of injection test boreholes. Generally speaking, up to a depth of 50 m, groutability varies from relatively high to high whereas at the depth of more than 50 m, it is estimated to be at a medium rate.

Table 6: Groutability, Lugeon value, and RQD proportionate to the Boreholes depth

Depth (m)	RQD(%)	Lugeon	Groutability (kg/m)
5 to 10	50.7	40.7	1176
11 to 20	63.7	35.3	969
21 to 30	71.2	33.3	897
31 to 40	64.5	27	513
41 to 50	73.8	25.2	433
51 to 60	79.2	17.5	119
61 to 70	83.1	11	50
71 to 80	83.3	6.8	48
81 to 90	90.4	3.2	32

Figure 5 displays the comparison of permeability and Groutability values for injection boreholes.

Referring to the following figures and the analyses conducted, it seems that there is a positive relationship between the groutability and hydraulic conductivity. There were few cases where there was high hydraulic conductivity but lower groutability, an issue which can be attributed to the presence of narrow joints. There were also few opposite cases which can be attributed to rocks hydraulic fracturing, as a result of which the joints have been opened by the injection pressure and consequently groutability has significantly increased.
Based on the results of Lugeon tests, groutability rate and RQD of rock masses, it can be concluded that permeability can act as a criterion for deciding whether there is a need for grouting or not? However, it is unlikely to determine the rocks groutability on the basis of permeability rates.
Because water cohesion is zero and according to equation 1(Lombardi.1985) in a water pressure test (Lugeon) water flow does not stop in a continuous joint or even in a rock of much wider fracture due to c=0 and R_{max}=00, but a stable grout (slurry) which is adhesive always stops when it reaches a maximum distance. Moreover, regardless of the number of joints, Lugeon tests may produce similar permeability rates. Therefore, not only it is necessary to determine permeability of rock masses, but also it is vital to know the number of joints, and the openness for grouting operations.

Equation (1) $$R_{\max} = P_{\max} . t/c$$

In which R_{max} stands for maximum radius of water permeability c refers to cohesion and t to size of the discontinuity opening and P_{max} to maximum pressure.

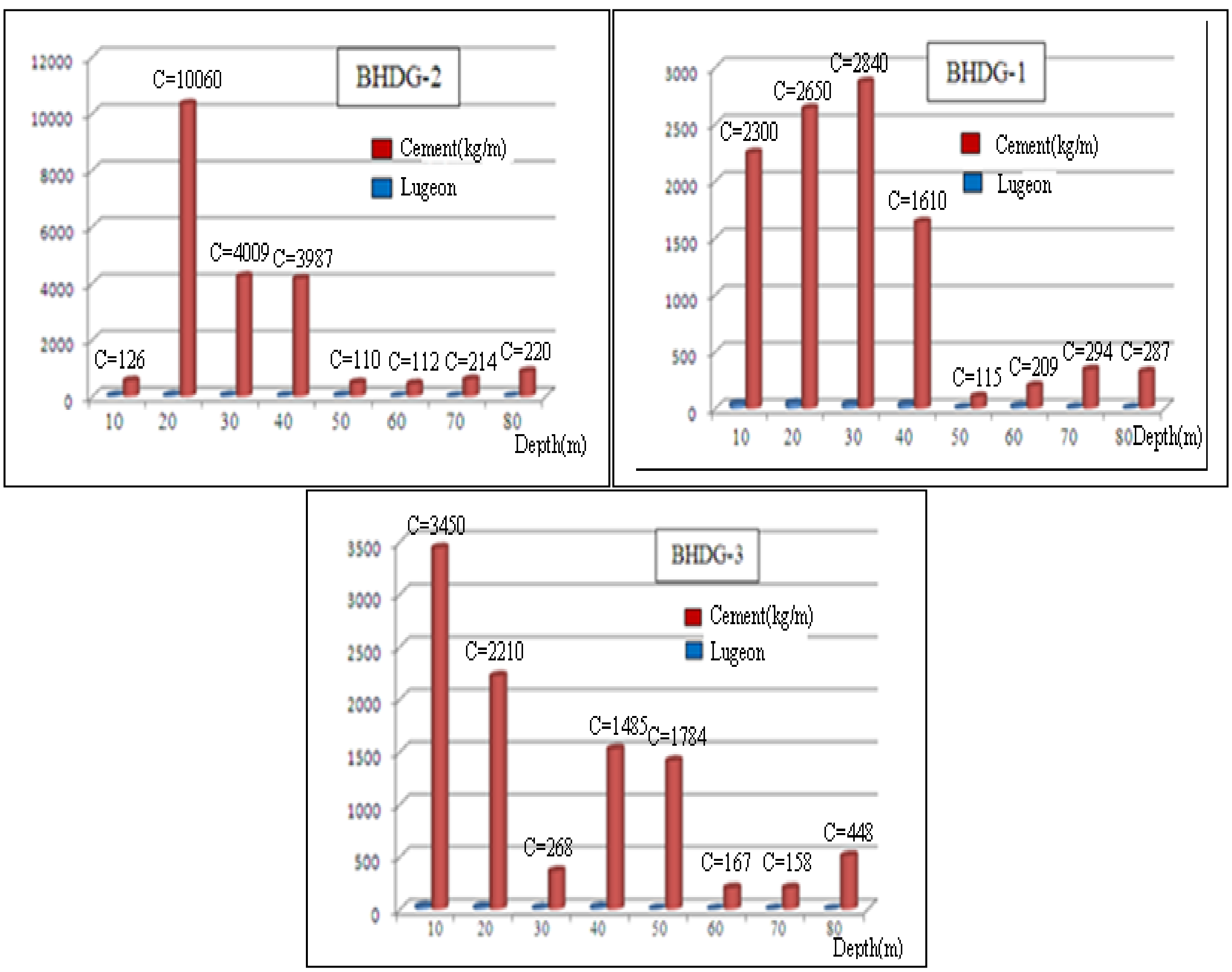

Figure 4: comparison of groutability and hydraulic conductivity proportionate to boreholes' depth

CONCLUSION

The tests conducted in the boreholes at the left abutment of the dam showed that rock masses up the depth of 50 m have an average RQD equal to 65% and with the increase of the depth, the average RQD rate got to 85% an issue which indicates that rock quality increases in deeper layers. The analysis of Lugeon tests revealed that most flows are of turbulent type an issue which can be attributed to rocks hydraulic fracturing. Considering the groutability rate and the depth, it can be concluded that due to rocks crushing near the top layers and surface areas, groutability has been high, which shows that there is a positive relationship with the RQD of rock masses in that site. In a Lugeon test, no matter how much water is pumped into the earth, water counter keeps running and it seems that water flow would continue forever. The said point based on Lombardi Equation can be attributed to zero cohesion (c=0) of water. But since cement is cohesive, after a while its particles start adhering to each other and this stops the grouting, in other words rock is sealed off or in places far away from the injection spot, stone particles may get stuck in the joints or larger particles stick to each other and block the passage of the grout, all of which result in the loss of groutability of the borehole. Generally speaking, it can be said that Lugeon Tests cannot be used as the only parameter for the design of injection curtain, and other parameters such as the joints' characteristics, and rocks compressive strength need to be known. Based on the findings of Lugeon tests before and after test injection, it can be concluded that Lugeon values decreased after injection and reached 3.5 Lugeon, moreover the RQD increased after injection and increased to more than 98%.
These figures show that cement grouting easily infiltrates into the joints and rock fractures leading to a significant improvement in the dam's stability.

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