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Curtain Grouting To Reduce Seepage Foundation Access Road To The Top Of The Dam At Tugu Dam

Supriono[1*], A. I. Candra[2], Y. C. S. Poernomo[3]

[1*,2,3]*Faculty of Engineering, Kadiri University.*

Email: [1*] priyo8321@gmail.com, [2] iwan_candra@unik-kediri.ac.id, [3] yosef.cs@unik-kediri.ac.id

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ABSTRACT

The construction of a complementary access road to the top of the dam is to the left of the Tugu dam pedestal. Based on geological studies, it is feared that there is a potential for seepage that passes through the left pedestal through joints, fractures, and fault areas/rock layers below the foundation surface. To anticipate this, the allowable seepage requirement is the lugeon value (Lu) < 3. This study aims to determine the geological conditions and the amount of seepage before and after foundation repairs are carried out using the grouting method. The type of this research is field research, qualitative descriptive because this research tries to collect lugeon population and cement material absorbed into the rock from water pressure test and grouting injection work by grouping each type of hole, pilot hole, primary hole, secondary hole, tertiary hole, and check hole. The study results by taking rock cores found that the constituent rocks were volcanic breccia units and colluvial rocks. Furthermore, a water pressure test before grouting with a water passing value of (k) = 6.62E-05 to 4.73E-04 cm/sec or with a lugeon value (Lu) of 5.07 to 36.21. After repairing the foundation using rim curtain grouting, the seepage that occurs decreases with a water passing value (k) = 1.96E-05 to 3.03E-05 cm/sec or lugeon (Lu) 1.50 to 2.32, so the requirements the target value of Lu < 3 was achieved with the effectiveness in the good category.

1. Introduction

The Tugu Dam in Trenggalek Regency, built on the Keser River, is part of a national strategic project to develop the potential of water resources in the Brantas River Region, namely flood control Baku water supply and potential for mini-hydropower plants[1]. With the construction of the Tugu Dam, it is hoped that it will provide benefits in the field of irrigation and the provision of clean water for the community around the dam to benefit the welfare and prosperity of the downstream community [2].

Complementary construction of the access road to the top of the dam is on the left pedestal [3][4][5]. In this regard, efforts were made to repair the foundation with the rim curtain grouting method to reduce or minimize seepage under the foundation surface through the left pedestal [6][7]. Foundations, in addition to having a role as a support for the building load and transmitting the forces or loads acting on the structure to the relatively hard subgrade, it is necessary to pay attention to the presence of joints, fractures, and fault planes/rock layers where this will reduce the bearing capacity of the foundation and affect the permeability [8][9][10].

In planning the foundation, especially dams, to get background knowledge of geological conditions, geological investigation work is carried out, namely through a full coring drilling process by taking all rock cores from the hole's surface to the planned depth. So that information/description of technical properties and rock quality designation (RQD) is obtained below the foundation surface [11][12][13][14]. The drilled holes are carried out with a passing water test to find out information about the porosity value of rocks with different lugeon values (Lu) and permeability coefficients (k) in cm/second, depending on the water flow conditions that occur in the soil or rock being tested [15][16]. While the borehole depth for curtain grouting work uses the USBR formula with d = 1/3 h + c where: d = drilling depth (m), h static water pressure height/dam height (m), and c = constant number taken between 7, 5m~25m [17].

This study aimed to repair the foundation by rim curtain grouting on constructing the access road to the top of the dam at Tugu Dam. Rim curtain grouting is applied to determine geological conditions, plan the distance between grouting holes and calculate the effectiveness of seepage before and after grouting.

2. Research Method

The scope of this research is rim curtain grouting work by taking data on the lugeon value and the use of cement material from the results of the grouting work on the foundation site of the access road to the top of the dam to the left of the Tugu Dam pedestal. The research method used is a descriptive qualitative field research method. The population and sample used are lugeon value data and cement extraction (kg/m) with the split spacing method so that the magnitude of the grouting effectiveness will be obtained by comparing the lugeon value before grouting in the pilot hole (PH) with after grouting at the check hole (CH) [5].

2.1 Population and Sample

The population referred to in this study is the data on the value of lugeon and cement take (kg/m) for water pressure test, and grouting work on rim curtain grouting work along the 150 m access road, with a split spacing method based on the type of hole, namely P.H./pilot

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hole = 45 stages, P/primary hole = 125 stages, S/secondary hole = 170 stages, T/tertiary hole = 335 stages and C.H./check hole = 45 stages so that the total data population is 720 stages [5].

This study's sample/data sample was taken during the grouting test using an equilateral triangle. The success of the distance between holes and the depth of the drill hole was carried out in the grouting test as a reference for the overall work implementation. The data taken are the depth of drilling work and water pressure test, and grouting at predetermined depths [18][12].

2.2 Instrument

The instrument in this study consisted of drilling equipment for making intermediate holes and injection equipment, namely water pressure test work to determine the porosity value of rock with units of Lu (lugeon) and k or water passing coefficient (cm/second), while the work of injection of a mixture of cement and water called grouting work, to determine the cement slurry that enters the rock (cement take) in kg/m units equipped with a pressure gauge that functions as pressure control and a flow meter to determine the amount of fluid flow discharge flowing into the cross-section of the hole [19][20]. Instruments, equipment, and grouting materials are calibrated or controlled for capacity compliance with the technical specifications of the grouting work on the Tugu Dam.

2.3 Data Collection and Analysis Methods

Data collection was carried out on all grouting holes with a predetermined depth of 25 m with a step length of 5 m and grouped by hole type according to the depth zone of the grouting hole stages.

The steps of data analysis in this study used several methods, namely:

1. Determining the rock type and the rock class's designation at the research site [21].
2. Testing of grouting materials [22][23][24].
3. Grouping lugeon and cement takes values (kg/m) based on the execution order, namely at the pilot, secondary, and tertiary, and check holes according to the depth zone.
4. Statistical analysis of lugeon prices from the spill–spacing method with :
   - Calculating the average value of the data:

     $\underline{X} = \sum_{i=1}^{n} Xi/n$ ----------> n = the amount of data.
   - Calculating Standard deviation (Sn) :

     $Sn = \sqrt{\sum_{1}^{n} \frac{(\underline{Xi})^2}{n-1}}$ ----------> with Xi = middle value to - i

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- Calculating Range (range = R)

  R = (X mak s – Xmin)

- Calculating the Coefficient of Variation ($\underline{V}$)

  $V = \frac{Sn}{x} * 100\ \%$

5. Frequency distribution polygons from the normal curve of lugeon values and the split spacing method with hole grouping.
6. Histogram and normal distribution curve of cement use/cement take (kg/m).
7. Grouting Effectiveness Method

The calculation of grouting evaluation (percentage) by comparing the permeability coefficient before and after grouting refers to the Cedergren, H.R. formula. (1967) [25] where:

$$Eefs = 100 - (KG / K) \times 100\%$$

With:

Eefs : Effectiveness of grouting (%)
K : Permeability coefficient before Grouting (Pilot Hole)
KG : Permeability coefficient after Grouting (Cek Hole)

Category Effectiveness Value:

> 90 % : *Excellent* (baik sekali)
(60 ~ 90) % : *Good* (baik)
(30 ~ 60) % : *Acceptable* (cukup)
(10 ~ 30) % : *Less* (kurang)
< 10 % : *Poor* (jelek)

3. Result and Discuss

3.1 Geological Investigation

By core drilling on hole No. PJAL-57 information on rock physical properties and permeability can be found to determine steps for foundation repair if needed. So that the drill sample is obtained, which can be described as follows:

1. Composing rocks and their physical properties
   - Depth 0.00 - 8.90 m: Coluvial, yellowish-brown, brittle, low cementation, easily broken or crushed by hand, andesite boulder found 40 cm.
   - Depth 8.90 - 25.00 m: Volcanic breccia, gray, hard - very hard, loudly struck with a geological hammer, floating fragments in the bed mass, open packed, strong cementation, compact, massive, with rock class Class Medium – Class High (CM -CH). Found stocky with a distance of 5 cm to 40 cm.

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2. The average Rock Quality Designation (RQD) value of rock is 52.40% in the category of moderate rock class rating.
3. The lugeon value obtained from the Water pressure test work is between Lu: 52.23 to Lu: 4.34, so the condition Lu < 3 has not been met.

The drill samples were taken and the pressurized water test shows that the foundation of the access road to the top of the dam at the Tugu dam needs to be repaired using the rim curtain grouting method.

3.2 Grouting test

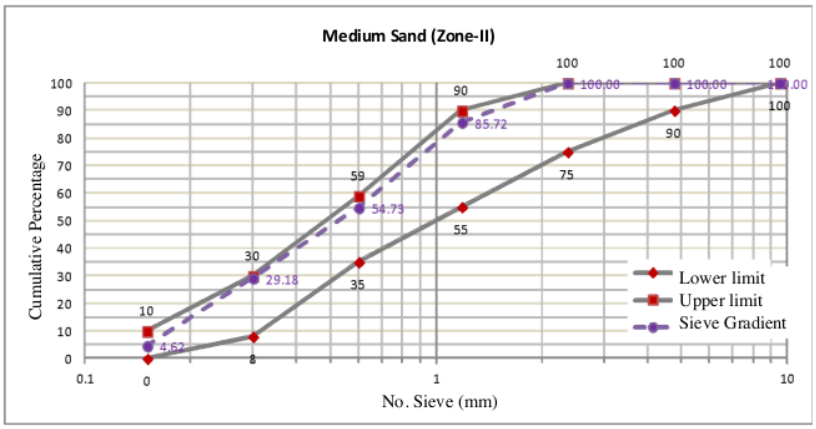
The arrangement of the holes for grouting tests on the rim curtain grouting access road to the top of the dam with the shape of an equilateral triangle, using a distance between grouting holes 2.20 m, the distance between rows/lanes 2.00 m, and the distance between the rows and the axle/centerline 1.00 m using cement grouting material Gresik OPC type – I and sand material.

The cemented material test results resume can be seen in **Table 1.** The sand material test can be seen in **Figure 1.**

Table 1. The results of grouting material testing in the laboratory.

No.	Test type	Unit	Results	Specification Technique	Information Suitable	Information Not Suitable
1	Cement Fineness	%	0,33%	< 10%	✓	
2	Cement specific gravity	gr/cm3	3,00	3, -	✓	
3	Binding time					
	Initial set	minute	126,4	49 - 202	✓	
	Final set	minute	255	185 - 312	✓	
4	Normal Consistency	%	25,3	25 - 27	✓	

Source: Testing of cement materials at the WIKA-APTA laboratory, KSO.



Source: Sand material testing at WIKA-APTA laboratory, KSO

Figure 1. Graph of fine modulus of sand grains based on the determination of the area/zone.

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Based on the fine modulus graph of the sand grains, the sand material comes from the Brantas river mining, so the sand gradation includes area/zone III (medium sand) so that the material can be used as a grouting mortar.

The data recapitulation of the implementation of the grouting test on the rim curtain grouting on the access road to the top of the Tugu Dam can be seen in **Table 2.**

Table 2. Data from the results of the grouting test on rim curtain grouting on the access road to the top of the Tugu Dam.

Sequence	Hole No.	Stage	Number of Stages	Total Lugeon	$\underline{X} = \sum_{i=1}^{n} Xi / n$	Cement take (kg/stg)	Depth (m)	Average (kg/m)
PH	P.JAL-57	1	1	42,04	42,04	915,64	5	183.13
		2	1	52,23	52,23	1385,72	5	277.14
		3	1	31,25	31,25	2595,73	5	519,15
		4	1	18,29	18,29	1533,83	5	306,77
		5	1	4,34	4,34	162,05	5	32,41
Sub Total			5			6592,97	25	263,72
P	JAR-58	1	1	45,52	45,52	2278,76	5	455,75
		2	1	10,20	10,20	1880,12	5	376,02
		3	1	31,17	31,17	2039,37	5	407,87
		4	1	2,39	2,39	0	5	0
		5	1	0,55	0,55	0	5	0
Sub Total			5			6198,25	25	247,93
S	JAR-57	1	1	6,79	6,79	297,29	5	59,46
		2	1	16,03	16,03	683,34	5	136,67
		3	1	15,50	15,50	745,23	5	149,05
		4	1	0,58	0,58	0	5	0
		5	1	0,57	0,57	0	5	0
Sub Total			5			1725,86	25	69,03
CH	CH-JA-57	1	1	1,95	1,95	0	5	0
		2	1	2,88	2,88	0	5	0
		3	1	1,91	1,91	0	5	0
		4	1	2,13	2,13	0	5	0
		5	1	1,78	1,78	0	5	0
Sub Total			5			0	25	0
Total			20			14517,08	100	145,17

Source: Implementation of rim curtain grouting on the access road to the top of the dam on the left pedestal of the Tugu Dam.

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Based on **Table 2.**, it can be concluded that the results of the rim curtain grouting test on the access road to the top of the Tugu Dam were obtained at the Lugeon Test at the pilot hole (P.JAL-57), ranging from Lu: 4.34 to Lu: 52.23. After grouting the pilot holes, primary and secondary, then carrying out a lugeon test on the check holes (CH.JA-57), the lugeon value decreases between Lu: 1.78 to Lu: 2.88, and the total cement material absorbed is 14,517.08 kg with the total length of drilling is 100 m so that the average grout take is 145.17 kg/m which is categorized as moderately high.

While the results of the calculation of the effectiveness of the implementation of the grouting test on rim curtain grouting were obtained between 59% to 95.4% or with a median of 93.9%, categorized as excellent (excellent).

The results of calculating the effectiveness of grouting before and after grouting, based on the calculation of Cedergren. HR, 1967 can be seen in **Table 3.**

Table 3. Data from the results of the grouting test on rim curtain grouting on the access road to the top of the Tugu Dam.

Stage	Depth	Pressure (kg/m)	ϕ Hole (mm)	Pilot Hole (K)		Check Hole (KG)		Effectiveness grouting
				Lugeon (lu)	Permeability (cm/det)	Lugeon (lu)	Permeability (cm/det)	Eefs = 100 – (KG / K) x 100%
1	5	1,5	73	42,04	5,49E-04	1,95	2,54E-05	95,4
2	5	3	73	52,23	6,82E-04	2,88	3,76E-05	94,5
3	5	5	73	31,25	4,08E-04	1,91	2,49E-05	91,9
4	5	7	73	18,29	2,39E-04	2,13	2,78E05	88,4
5	5	10	73	4,34	5,66E-05	1,78	2,32E-05	59,0
					Median			93,9

Source: Implementation of rim curtain grouting on the access road to the top of the dam on the left pedestal of the Tugu Dam.

The grouting test shows that the distance between the grouting holes is 2.20 m, the distance between rows/lanes is 2.00 m, and the lane distance from the axle/centerline is 1.00 m, with very good effectiveness. It is used as a reference for implementing rim curtain grouting.

3.3 Rim Curtain Grouting Work

The grouting pattern for rim curtain grouting works on the access road to the top of the dam using two paths, namely upstream and downstream lanes along 150 m. The distance between the upstream and downstream lanes is 2 m. The distance between the rim curtain grouting holes is 2.2 m, alternating between the upstream and downstream lanes and giving

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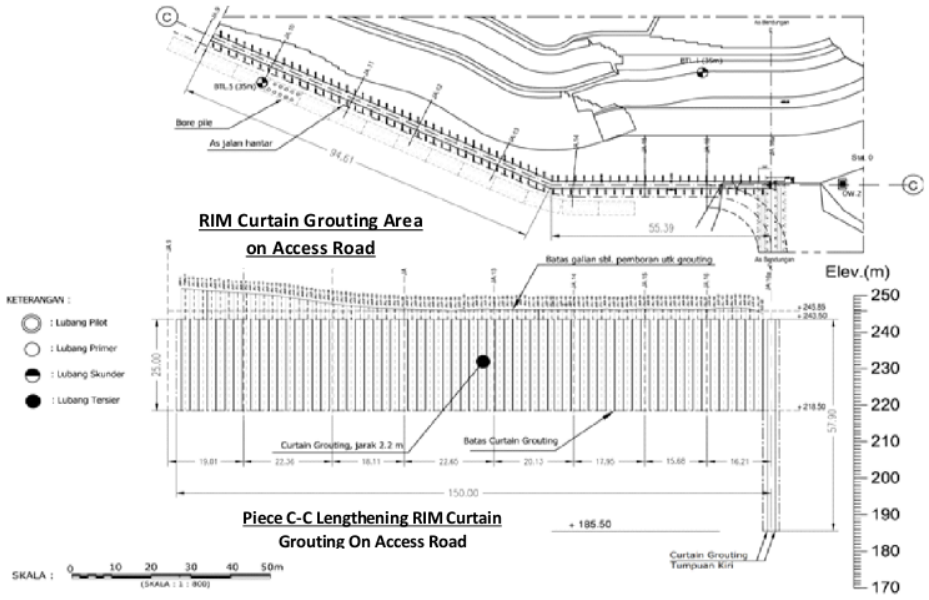
notation of rim curtain grouting holes with hole numbers JAL-1 to JAL-67 for the downstream. In contrast, the upstream part is JAR-1 to JAR-68. The grouting work begins in the downstream lane and continues in the upstream lane using the split spacing method and starts at the pilot, primary, secondary and tertiary holes. The rim curtain grouting pattern on the access road to the top of the dam can be seen in the floor plan and longitudinal sections, as shown in **Figure 2.** below:



Source : Implementation of rim curtain grouting on the access road to the top of the dam on the left pedestal of the Tugu Dam.

Figure. 2 Plans and longitudinal sections of rim curtain grouting on the access road to the top of the dam on the left pedestal of the Tugu Dam.

The results of the rim curtain grouting work carried out on the access road to the top of the dam are as follows:

3.3.1 Group Data Analysis Based on Work Sequence According to Depth Zone.

The grouping of data based on the type of hole according to the depth zone of the rim curtain grouting work on the access road to the top of the dam at the Tugu Dam can be seen in **Table 4.**

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Table 4. Grouping data based on the sequence and the depth zone of the grouting work.

Sequence	Stage	Number of Stages	Total Lugeon	$\underline{X} = \sum_{i=1}^{n} Xi / n$	Cement take (kg/stg)	Depth (m)	Average (kg/m)
PH	1	9	325,91	36,21	10590,42	45	235,34
	2	9	184,22	20,47	11690,36	45	259,79
	3	9	129,57	14,40	9023,16	45	200,52
	4	9	93,13	10,35	6151,45	45	136,7
	5	9	45,64	5,07	2686,35	45	59,7
Sub Total		45			40141,76	225	178,41
P	1	25	470,02	18,80	16011,18	125	128,09
	2	25	335,22	13,41	14302,57	125	114,42
	3	25	251,53	10,06	13810,36	125	110,48
	4	25	137,73	5,51	6958,64	125	55,67
	5	25	97,96	3,92	4474,99	125	35,80
Sub Total		125			55557,74	625	88,89
S	1	34	610,22	17,95	20564,93	170	120,97
	2	34	414,36	12,19	12400,68	170	72,95
	3	34	308,38	9,07	10396,88	170	61,16
	4	34	184,35	5,42	9574,96	170	56,32
	5	34	133,49	3,93	5748,05	170	33,81
Sub Total		170			58685,5	850	69,04
T	1	67	763,66	11,40	24196,41	335	72,23
	2	67	428,32	6,39	16588,66	335	49,52
	3	67	310,99	4,64	11011,27	335	32,87
	4	67	221,82	3,31	9295,87	335	27,75
	5	67	182,28	2,72	7502,91	335	22,40
Sub Total		335			68595,11	1675	40,95
CH	1	9	17,22	1,91	0	45	72,23
	2	9	20,92	2,32	0	45	49,52
	3	9	14,34	1,59	0	45	32,87
	4	9	14,50	1,61	0	45	27,75
	5	9	13,49	1,50	0	45	22,40
Sub Total		45			0	225	0
Total		720			222980,11	3600	61,94

Source: *Implementation of rim curtain grouting on the access road to the top of the dam on the left pedestal of the Tugu Dam.*

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The results of grouping the data obtained on the test lugeon in the pilot hole range from Lu: 5.07 to Lu: 36.21. After grouting the pilot, primary, secondary and tertiary holes, a lugeon test is carried out on the check holes. The lugeon value decreases between Lu: 1.50 to Lu: 2.32; smaller than Lu: 3 means that the lugeon value obtained after grouting work follows what is required. Meanwhile, the total cement material absorbed was 222,980.11 kg with a total drilling length of 3600 m, so the average grout take was 61.94 kg/m. can be categorized as moderate.

3.3.2 Statistical analysis of lugeon prices from the spill-spacing method

Statistical evaluation of the effectiveness of grouting with the split spacing method was carried out by grouping the data population based on the overall grouting hole sequence and sorting from the smallest data value to the largest data value. The evaluation results using statistical analysis of the normal distribution on the effectiveness of grouting with the split spacing method can be seen in **Table 5.**

Table 5. Statistical analysis of lugeon value prices using the split spacing method (split-space).

Description	Pilot hole	Primary Hole	Secondary Hole	Tertiary Hole	Check Hole	Information
Lugeon Average Price (Lu)	17.30	10.34	9.71	5.69	1.79	$\underline{X} = \sum_{i=1}^{n} Xi/n$
Standard deviation (Lu)	15.19	8.46	8.36	5.63	0.61	$Sn = \sqrt{\sum_{i=1}^{n} \frac{(Xi -}{n -}}$
Range (Lu)	0 - 17.30 = 53.33% 17.30 - 55.35 = 46.67 %	0 -10.34 = 60.80 % 10.34 - 46.15 = 39.20%	0 - 9.71 = 62.94% 9.71 - 39.9 = 37.06 %	0 - 5.69 = 64.78 % 5.69 - 38.83 % = 34.93%	0-1.79 = 44.44% 1.79-2.96 =55.56%	R = (X mak s – Xmin)
Price (lu)	42.22%	60.80 %	62.94%	87.16%	100%	range 0 s/d 10 Lu

Source: *Implementation of rim curtain grouting on the access road to the top of the dam on the left pedestal of the Tugu Dam.*

Based on the calculations in **Table 5.**, the statistical analysis results of the average lugeon price showed a significant decrease, namely the pilot hole (17.30 Lu), primary hole (10.34 Lu), secondary hole (9.71 Lu), tertiary hole (5.69 Lu) check hole (1.79 Lu) so that it can be concluded that the split spacing grouting method is effective for repairing the foundation on the rim curtain grouting of the access road to the top of the dam.

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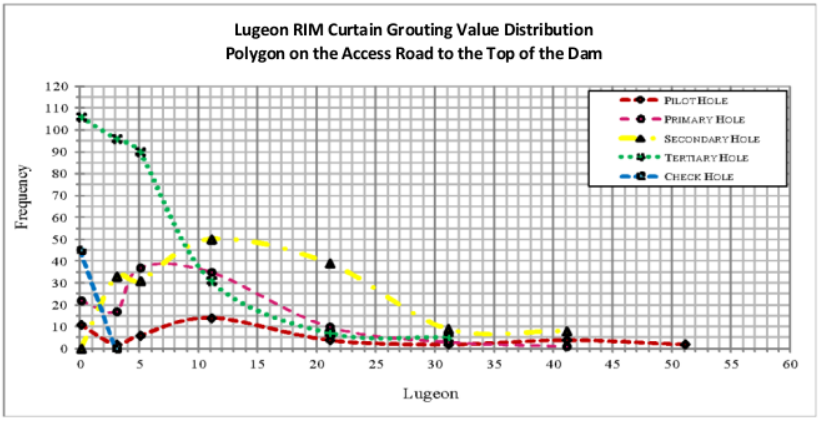
3.3.3 Frequency distribution polygons from the normal curve of lugeon values and the split spacing method with hole grouping.

The results of the water pressure test on the rim curtain grouting as a whole using the split spacing method by grouping pilot holes, primary holes, secondary holes, tertiary holes, and check holes show a tendency to decrease, as shown in the frequency distribution polygon of the normal curve of the lugeon value. As shown in **Figure 3.**

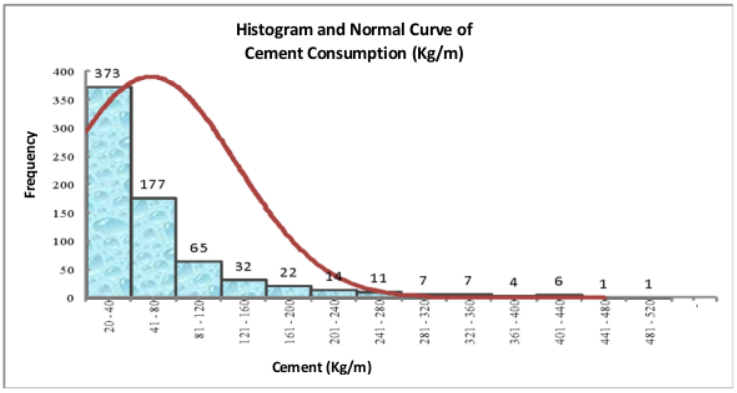


Source: Implementation of rim curtain grouting on the access road to the top of the dam on the left pedestal of the Tugu Dam.

Figure 3. Normal distribution polygon lugeon value based on the sequence grouting holes with a split spacing method.

3.3.4 Histogram and normal distribution curve of cement use/cement take (kg/m)

The use of cement/cement take (kg/m) obtained from the grouting injection job at each stage is classified ir intervals, as shown in **Figure 4.**



Source: Implementation of rim curtain grouting on the access road to the top of the dam on the left pedestal of the Tugu Dam.

Figure 4. Histogram and normal distribution of cement consumption with group classification.

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3.3.5 Effectiveness of grouting (Cendergren, H.R. (1967)

Based on the results of the calculation of the effectiveness of grouting using the Cedergren, H.R., 1967 method, the magnitude of the effect of grouting is between 70.4% to 94.7%, with a median value of 88.6%, so it is in a good category (good).

The results of the calculation of the effectiveness of grouting based on the Cedergren, H.R., 1967 equation between the permeability coefficient values before and after grouting on the complete rim curtain grouting work can be seen in **Table 6.**

Table 6. The results of calculating the effectiveness of grouting using the Cedergren, H.R 1967 method on rim curtain grouting.

Stage	Depth	Pressure (kg/m)	Hole (mm)	Pilot Hole (K)		Check Hole (KG)		Effectiveness grouting
				Lugeon (lu)	Permeability (cm/det)	Lugeon (lu)	Permeability (cm/det)	
1	5	1,5	73	36,21	4,73E-04	1,91	2,50E-05	94,7
2	5	3	73	20,47	2,67E-04	2,32	3,03E-05	88,6
3	5	5	73	14,40	1,88E-04	1,59	2,08E-05	88,9
4	5	7	73	10,35	1,35E-04	1,61	2,10E05	84,4
5	5	10	73	5,07	6,62E-05	1,50	1,96E-05	70,4
					Median			88,6

Source: Implementation of rim curtain grouting on the access road to the top of the dam on the left pedestal of the Tugu Dam.

From the rim curtain grouting work on the access road to the top of the dam in line with or following the experimental grouting/grouting test with the lugeon values before grouting ranging from Lu: 4.34 to Lu: 52.23 and after grouting between Lu: 1.78 to Lu: 2.88, smaller than Lu : 3 means that it is following the required lugeon. Meanwhile, the difference in the absorbed materials and the magnitude of the effect of grouting between this rim curtain grouting job and the grouting test is due to differences in the characteristics and depth of the constituent rocks that are not uniform at the location of the rim curtain grouting on the access road to the top of the dam at the Tugu Dam.

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4. Conclusions

Repairing the foundation using the rim curtain grouting method on the access road to the top of the dam on the left pedestal of the Tugu Dam, it can be concluded that the water pass/seepage value before grouting is (k) = 6.62 E-05 to 4.73E-04 cm/ sec or lugeon value (Lu) = 5.07 to 36.21 and after efforts to repair the rim curtain grouting work the seepage that occurs is significantly reduced with the value of water passing/seepage (k) = 1.96E-05 to 3 .03E-05 cm/sec or lugeon (Lu) 1.50 to 2.32, so that the allowable seepage requirements with a target value of lugeon (Lu) < 3 have been met with the amount of grouting effectiveness in the good category.

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