Curtain Grouting Effectivity Analysis On Foundation Rocks In Blocks 37 – 40 In The Body Of Randugunting Dam, Blora Regency, Central Java

Dian Agus Widiarso [1]*, *Tieties* Firman [1], and *Jenian* Marin[1]

[1]Diponegoro University, Geological Engineering Department, Semarang 50275, Indonesia

Abstract. Blora Regency is a barren area in Indonesia and has drought disaster potential, to address those problems Indonesian Governments launched Randugunting Dam's construction program. The research area was located at Block 37 – 40, Radugunting Dam, Japah District, Blora Region. Dam as a water retention building should have foundation rocks that are resistant towards seepage potential, therefore curtain grouting was conducted to seal geological fractures on the foundation rocks. The purpose of these research was to understand the seepage potential on foundation rocks, foundation rocks curtain grouting requirement, and curtain grouting effectiveness. Research method used were water pressure test (WPT) data analysis, in the form of water flow discharge data processed through calculation to produces Lugeon value (Lu). The Lugeon value (Lu) would be further analyzed to determine the curtain grouting effectiveness value. The result of the analysis shows that around 18.15% of the research area have seepage potential that was shown by medium (3 < Lu < 10) – high (Lu > 10) Lugeoun (Lu) value. After the curtain grouitng was conducted, it effectiveness value on Block 37 was 88.34% (good), on Block 38 was 81.43% (good), on Block 39 was 70,62% (good), and on Block 40 was 79.41% (good).

1 Introduction

Water is one of the most important element for human, it was used for consumption, tourism, construction, irigation, and etc [1]. Drought potential could disturb the public water fulfillment. Drought itself was a condition where water supply couldn't fulfill the public/environment needs on a certain period of time [2]. Drought ccould occured on several climate zone, such as areas with low rainfall levels and most likely associated with precipitation amount reduction at a period of time [3]. Blora regency is one of the areas that are prone towards drought disaster. These area was formed by limestone mountains, therefore most of it areas has limestone lithology/soil. Those condition causes Blora regency to become barren area especially on dry season, where some of it areas having trouble to fulfill public clean water needs nor irigation [4].

* Corresponding author: dianagus@lecturer.undip.ac.id

Indonesian government attempts to fulfill public water needs through dam construction. Dam is a building that restrict or redirect water flow generally on river, and usually produce reservoir or lake for irigation, flood control, fisheries activities, tourism, and etc [5]. The government launched 65 new dams construction on 2014 – 2019, as an attempt to fulfill water, food, and energy needs [6].

Randugunting dam located at Japah District, Blora Regency, Central Java, is a part of 65 new dams construction by Indonesian government [7]. Geological condition on the dam foundation tends to be complex because of numerous fractures, voids, and weak beds under the foundation. Fractures or voids potentially become seepage path that would endanger the dam foundation, therefore it is important to strengthen the dam's foundation rocks condition [8]. Established dams has damage potential such as collapse, if the foundation is not handled properly. It was happened at Malpasset Dam, France, where the dam's foundation rocks contains fractures, joints, faults, and etc [9]. To solve those problems geotechnical engineering fabrictaions could be applied, on several cases these fabrications were applied to solve geological conditions which endanger construction. One of those geotechnical engineering fabrications is grouting, it was a process where fluids (usually in the form of cement) were injected towards a fracture [10].

Grouting on dam's foundation is a process where geological fractures were sealed to lessen the seepage and/or strengthen the foundation itself [11]. As a water rentention building, Randugunting Dam should have seepage resistant foundations, therefore grouting were conducted towards its foudantion's rocks. Water pressure test (WPT) analysis was conducted to understand the effect of grouting on Randugunting dam in the form of Lugeon (Lu) value. Those analysis result indicates the foundation's rocks seepage potential, foundation rocks curtain grouting requirement, and curtain grouting effectiveness on Randugunting Dam.

2 Geological Condition

Blora regency is a part of Rembang Anticlinorium Zone, where these zone covers North Java Coast and strecth eastward along Tuban, Lamongan, Gresik, and almost all of Madura Island [12]. Rembang Anticlinorium Zone was formed predominantly by carbonate rocks. These area was formed by 3 morphological settings which are plain, hilly undulating, and hilly rolling morphological units [13]. The research area is formed by several geological formations as shown by Figure 1.

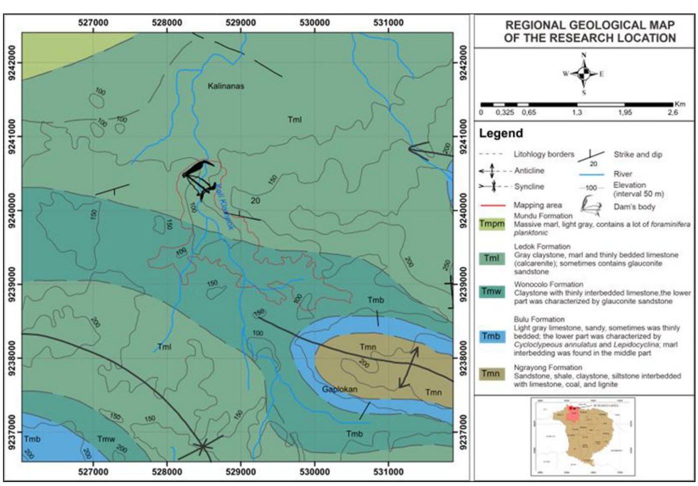

Fig. 1. Regional Geological Map of Rembang Area [15] with modifications

- Ngrayong Formation (Tmn) was formed on Middle Miocene (Tertiary), it contains sandstone, shale, claystone, siltstone interbedded with limestone, lignite, and coal.
- Bulu Formation (Tmb) was formed on Middle Miocene (Tertiary), it contains light gray limestone, sandy, generally thinly bedded; the lower part was characterized by abundant number of *Cycloclypeous annulatus* (MARTIN) and *Lepidocyclina;* meanwhile the middle part contains thinly interbedded marl.
- Wonocolo Formations (Tmw) was formed on Middle Miocene (Tertiary), it contains claystone thinly interbedded with limestone, and the lower part characterized by glauconite sandstone. There are unconformity that separates Wonocolo and Ledok Formations.
- Ledok Formations (Tml) was formed on Late Miocene (Tertiary), it contains gray claystone, marl, thinly bedded calcarenite limestone, and sometimes found glauconite sandstones.

Rembang Zone is formed by anticlinorium mountains that stretched with west – east direction from the northern part of Purwodadi through Blora. Jatirogo, Tuban, and ended on Madura Island [14]. Rembang zone was formed on two time periods, thus relative direction on magmatic trace or changes on tectonic pattern was formed [12] :

- Paleogene Era (Eocene – Oligocene), with north east – south west direction cause the northern part of East Java Basin contains strain tectonic regime. It was indicates by Pretertiary bedding that shows acretion pattern with north east – south west direction in the form of faults orientations, that were found on bedding, horst, and graben.
- Neogene Era (Miocene – Pliocene), there were changes in the tectonic regime in the form of compression at eastern – western area, causing geological structure to folds, faults, and the northern part of East Java Basin uplifted. Folds at the northern part of East Java Basin generally have west – east direction, meanwhile the faults generally have north east – south west direction, and there are severals reverse faults with east – west direction.

3 Grouting

Grouting is a grout (cement) injection process towards rocks fractures using external forces such as hydraulic or air forces [16]. Another opinion stated that grouting is an injection process towards fractures or pores, where the fluids were able to physically/chemically hardened, with prsessure adjusted to water pressure test (WPT) [17]. There are several types of grouting that were commonly used on dams construction such as consolidation grouting, contact grouting, curtain grouting, and penetration grouting [18].

3.1 Curtain Grouting

Curtain grouting is an effective grouting method to handle geological disaster problems and abble to increase the rocks strength and permeability [19]. These method was done by laying columns of cement next to each other, in attempts to create curtains of grout [20]. Curtain grouting could be done by one row, but this method is less effective to solve seepage problem or strengthening the dam's foundation. Thus, current curtain grouting was designed to have multiple row (2 rows or more), this type of curtain grouting focused on the downstream row as its main parameter. This was done so that when the injection is conducted, the cemnet were able to spread into all parts of the line, and force it into (upstream flow).

3.2 Water Pressure Test

Water pressure test was conducted using particular pressured waters towards grouting intended rocks. These test were done to understand the fractures condition before and after grouting was conducted. The test was done towards every stages and Lugeon value calculations were carried out according to its standard [21].

3.2.1 Lugeon Value (Lu)

Lugeon value (Lu) is founded by Murice Lugeon on 1993 [23]. 1 lugeon value shows that 1 liter of water was used on 1 meter of test within 1 minute, with 1 Mpa pressure [23]. Lugeon value was calculated using this equation [23] :

$$Lu = \{10 \times Q\}/\{p \times L\} \text{ or } Lu = \{10 \times V\}/\{p \times L \times t\} \quad (1)$$

Where Lu is Lugeon value, Q is Water discharge (L/min), p is Pressure of the test (Kg/cm^2), L is Length of the tested part (m), V is Injected water volume and t is Time (min)

Lugeon values that were obtain before grouting was conducted could be classified by Table 1**.**

Table 1. Lugeon value (Lu) and grouting requirements relations [24] with modification.

Lugeon Value	Description
1	The foundation’s permeability is rigous and there is no grouting required.
3	The foundation’s requires a little grouting, piping tends to occured but there is no need to stop it.
5	The foundation’s requires grouting, especially for embankment dam.
10	The foundation’s requires grouting, applicable for all type of dam.
20	The foundation’s contains joints, with small fractures.
100	The foundation’s contains joints, with rough fractures or infrequent joints with large fractures.

Lugeon value (Lu) analysis is used to understand grouting effectiveness on Tapin Dam [23], understand the influence of grouting test on Gongseng Reservoir [25], and in attempt to solve seepage problems on Kalecik Dam [26], and etc.

3.2.2 Grouting Effectiveness

Lugeon value (Lu) was further analyzed to produce grouting effectiveness percentage. Grouting effectiveness percentage could be produced by this equation [23] :

$$Efs = 100 - \{[K\text{-}Kg] \times 100\} \quad (1)$$

Where Efs is Grouting effectiveness (%), K is Water passed (Lugeon value) before grouting was conducted and Kg is Water passed (Lugeon value) aftergrouting was conducted

The grouting effectiveness percentage could be classified based on Table 2.

Table 2. Grouting effectiveness [23] with modification.

Grouting Effectiveness (%)	Grouting Effect
> 90%	Very Good
60% - 90%	Good
30% - 60%	Medium
10% - 30%	Bad
< 10%	Very Bad

4 Result and Discussion

4.1 Lugeon Value (Lu) Calculation Before Grouting Was Conducted

Water Pressure Tests were conducted on 4 pilot holes at Block 37 – 40. The lugeon value analysis could be seen at Table 3

Table 3. Pilot hole's Lugeon value (Lu) at Block 37 - 40

Stage	Depth (m)	Lugeon Value (Lu)			
		Block 37 (DC-P53-P)	Block 38 (DC-P55-P)	Block 39 (DC-P57-P)	Block 40 (DC-P59-P)
1	0 – 5	29	39	1	4
2	5 – 10	40	6	11	19
3	10 - 15	17	2	2	15
4	15 - 20	16	2	12	10
5	20 – 25	1	1	2	1
6	25 – 30	1	5	1	5
7	30 – 35	2	6	13	9
8	35 – 40	2	2	2	2
9	40 – 45	1	3	2	2
10	45 – 50	1	2	5	2

According to Table 3 the Lugeon value (Lu) on Block 37 – 40 classified as low – high. 'Low' Lugeon value (Lu) (Lu < 3) indicates that the amount of water debit that were able to flow through rocks fractures were low and did not required grouting treatment. 'Medium' Lugeon value (Lu) (3 < Lu < 10) indicates that the amount of water debit that were able to flow through rocks fractures were increasing to medium. 'High' Lugeon value (Lu) (Lu > 10) indicates that the amount of water debit that were able to flow through rocks fractures were high. Both the 'medium' and 'high' Lugeon value area required grouting treatment [24]. and did not required grouting treatment [24]. 'Medium' and 'high' Lugeon value (Lu) on Block 37 – 40 are around 18.15% of the total area.

4.2 Lugeon Value (Lu) Calculation After Grouting Was Conducted

Water Pressure Tests were conducted on 4 check holes at Block 37 – 40. The lugeon value analysis could be seen at Table 4.

Table 4. Check hole's Lugeon value (Lu) at Block 37 - 40

Stage	Depth (m)	Lugeon Value (Lu)			
		Block 37 (CCH-36)	Block 38 (CCH-37)	Block 39 (CCH-38)	Block 40 (CCH-39)
1	0 – 5	2	2	1	1
2	5 – 10	1	1	2	1
3	10 - 15	2	2	1	1
4	15 - 20	2	2	2	2
5	20 – 25	1	1	2	2
6	25 – 30	1	1	2	2
7	30 – 35	1	1	2	2
8	35 – 40	1	1	1	2
9	40 – 45	1			3
10	45 – 50	1			

According to Table 4 the Lugeon value (Lu) on Block 37 – 40 classified as low. 'Low' Lugeon value (Lu) (Lu < 3) indicates that the amount of water debit that were able to flow through rocks fractures were low and did not required grouting treatment [24].

4.3 Grouting Effectiveness Calculation

Grouting effectiveness calculation was carried out using pilot hole's and check hole's Lugeon value (Lu). The calculation result was shown by Table 5.
Grouting effectiveness value at Block 37 – 40 were classified as 'Good'. The average grouting effectiveness value at Block 37 – 40 was 77.58%, it also classified as 'Good'. Based on the calculation result, the curtain grouting that was conducted at Block 37 – 40 is 'effective'. The grouting effectiveness also shown by comparison between Lugeon value (Lu) correlation before and after curtain grouting was conducted. The comparison could be seen at Figure 2.

Based on Figure 2, it could be seen that the Lugeon value (Lu) correlation before curtain grouting was conducted that there are several stages color. Yellow and red color represents the area with 'Medium' and 'High' Lugeon value (Lu), and required curtain grouting treatment. Meanwhile, the Lugeon value (Lu) correlation after curtain grouting was conducted was prdominantly by green color. Green color represents the area with 'Low' Lugeon value (Lu), and does not required curtain grouting. It could bee seen that after curtain grouting was conducted, the area that requires grouting and has 'Medium' – 'High' Lugeon value (Lu) shows changes as it does not requires grouting anymore and has 'Low Lugeon value (Lu). Therefore, this changes shows that the curtain grouting at Block 37 – 40 ia effective.

Table 5. Grouting effectiveness value at Block 37 - 40

Grouting Location	Lugeon Value (Lu)	Pilot Hole	Check Hole	Grouting Effectiveness Value (%)	Category	Grouting Effectiveness Average Value (%)
Block 37	Maximum Value	1.00	1.00	88.18	Good	77.58 (Good)
	Minimum Value	40.00	2.00			
	Average Value	11.00	1.30			
Block 38	Maximum Value	1.00	1.00	79.78	Good	
	Minimum Value	39.00	2.00			
	Average Value	6.80	1.38			
Block 39	Maximum Value	1.00	1.00	68.14	Good	
	Minimum Value	13.00	2.00			
	Average Value	5.10	1.63			
Block 40	Maximum Value	1.00	1.00	74.24	Good	
	Minimum Value	19.00	3.00			
	Average Value	6.90	1.78			

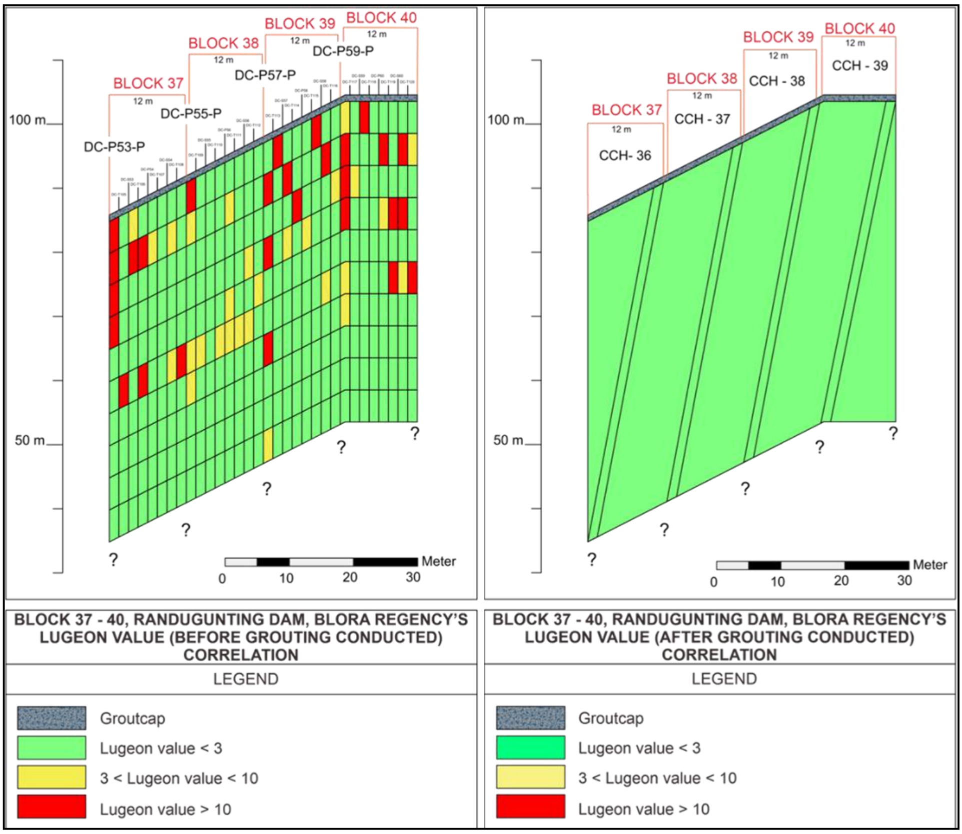

Fig. 2. Underground condition comparison between Block 37 – 40 before and after curtain grouting was conducted

5 Conclusion

Lugeon value analysis before grouting was conducted shows some area with 'Medium' (3 < Lu < 10) – 'High' (Lu > 10) Lugeon value (Lu). Areas with 'Medium' – 'High' Lugeon (Lu) value shows the amount of water debit that able to flow through fractures, and has seepage potential. This area covers around 18.15% from the total grouting area at Block 37 – 40. It could be concluded that around 18.15% area of Block 37 – 40 Randugunting Dam has seepage potential. 'Medium' (3 < Lu < 10) and 'High' (Lu > 10) Lugeon (Lu) value area requires curtain grouting treatment to lessen the seepage potential on those area, meanwhile area with 'Low' (Lu < 3) Lugeon (Lu) value are the area that does not requires grouting and does not have seepage potential. It could be concluded that around 18.15% areas at Block 37 – 40 Randugunting Dam requires curtain grouting treatment. Grouting effectiveness value at Block 37 is 88.18% (Good), Block 38 is 79.78% (Good), Block 39 is 68.14% (Good), and Block 40 is 74.24% (Good). The average grouting effectiveness value at Block 37 – 40 is 77.58% (Good). Grouting effectiveness value that classified as 'Good' shows that curtain grouting treatment that was conducted is effective.

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