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Comparative Study of Conventional Rotary and Rotary-Percussion Techniques in Grout Hole Drilling from the Perspectives of Time, Cost, and Quality

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Abstract: A dam foundation structure is usually strengthened by grouting, which begins with grout hole drilling. This paper aims to examine a comparison between conventional rotary and rotary-percussion drilling techniques in a drilling case study of the Tugu Dam Project, from the perspective of time, cost, and quality comprehensively. Primary data was obtained from the field investigation and interviews. Secondary data was gathered from available project documents of the PT Wijaya Karya-APTA KSO Project Contractor. The findings have highlighted that the implementation of the rotary-percussion technique for grout hole drilling is better than conventional rotary drilling. There are 16 days of time-saving and 3.84% cost-savings for the rotary-percussion technique, as a result of faster rate of penetration. The quality of grouting work using the rotary-percussion drilling technique tends to be of better quality, although there is a shortcoming due to the limited drilling depth of only 5m particularly.

Keywords: Drilling work; conventional rotary; rotary-percussion; time; cost; quality.

Introduction

Dams are civil engineering structures that cross the river as a barrier to the flow of river water which can raise the water level of the river to become a reservoir or lake. Dams have a very high risk because they have the potential to fail as a catastrophic type of structural failure characterized by the sudden, rapid, and uncontrolled release of impounded water, spilling a very large volume of water downstream, in the event of a dam collapse, especially the collapse of the foundation structure. Thirty to fifty percent of dam failures [1] are caused by concentrated leaks from seepage through the dam and its foundation. Under pressure, water seeps through soil or rock's expanded cracks, causing progressive erosion. Cracks in soil or rock foundation are a significant issue for dam safety. A concentrated leak from the dam and its foundations can cause the dam to breach failure. In another case of the postconstruction period, grouting is one of the few ground improvement techniques that can be used for the restoration or retrofitting of structures.

For this reason, the dam foundation structure is usually reinforced with grouting, by injecting cement slurry into rock fractures inside grout holes. Thus, artificial underground impermeable grouting curtains can be formed, cutting off waterways, inhibiting water seepage through the foundation layer, and reducing structural failures or deficiencies in the dam [2]. The grouting method has been widely applied to soil improvement and stability, including its consolidation ability, in the field of engineering geology, and is one of the most important techniques in anti-seepage and dam reinforcement [3].

The grouting work in the dam project begins with a drilling borehole which is the creation of a narrow, deep hole in the ground. In a typical drilling project for a dam, a drill bit is utilized to bore a hole in a circular cross-section of a deep hole in the earth's ground. Drilling work is the most resource-intensive aspect of grouting, which can give an immediate effect on the total cost of the whole grouting project [4], making it imperative to pay close attention to drilling techniques. In general, there are two primary drilling techniques: conventional rotary drilling and rotary-percussion drilling. The rotary drill works a high rotation and torque, the drill bit pressing, rotating rapidly at the end of the drill pipe, and boring the rocks, whereas the rotary-percussion drill utilizes the hammer impacts while simultaneously rotating the bit.

After the borehole drilling process is complete, the next step is to measure the average permeability of water in the borehole or first Lugeon test, which is expressed in terms of the Lugeon value. Lugeon value was obtained from an in-situ permeability test with a pressure of 1 MPa in the grouting hole. The Lugeon value [5] is the amount of water (liters) that enters or

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seeps into the 1-meter-long rock mass in the borehole in 1 minute (liters/minute/meter at a water pressure of 1 MPa). The first measurements of Lugeon values are considered Lugeon-I. Table 1 illustrates the conditions that are frequently linked with various Lugeon values, as well as the precision with which these values are typically reported. Due to the variability of rock and soil properties, the range of possible Lugeon values is alarmingly large among boreholes.

Table 1. Condition of Rock Mass Discontinuities Linked with Different Lugeon Values [5]

Lugeon range	Permeability range (cm/sec)	Condition of rock mass discontinuities
<1	$< 1x10^{-5}$	Very tight
1-5	$1x10^{-5}$ - $6x10^{-5}$	Tight
5-15	$6x10^{-5}$ - $2x10^{-4}$	Few partly open
15-50	$2x10^{-4}$ - $6x10^{-4}$	Some open
50-100	$6x10^{-4}$ - $1x10^{-3}$	Many open
>100	$> 1x10^{-3}$	Open closely spaces or voids

After the Lugeon-I values are obtained, the boreholes can be grouted completely. The grouting process is applying certain pressure to the grouting material in the form of liquid through a grouting pump into the borehole in order to increase the integrity of the rock and soil mass, as well as increase the seepage resistance of the dam foundation structure. After the whole boreholes have been grouted completely, there are second drilling works in order to make several new boreholes namely check holes, next to the boreholes that have been grouted. In these check holes, the water permeability test is also carried out for obtaining the second measurements of Lugeon value, namely Lugeon-II as verification of the grouting or plugging effect. The effectiveness of grouting work is measured by comparing the values of Lugeon-II and Lugeon-I, as indicators of the quality of grouting work.

Well-known studies on dam safety using Lugeon values mentioned the Tapin dam [6], the Nipah dam [7], and the Sirikit dam [1]. However, a detailed study is still limited to using the Lugeon value to measure project quality based on grouting work effectiveness [6], to calculate the composition of grouting material [7], and to explore cracking mechanism due to hydraulic fracturing [1]. In fact, major project goals are not only the quality of the project but also time and cost considerations as a key direction process for managing risks in construction projects. Generally, the construction dam projects are complex in nature and limited resources, thus it is important to consider three primary objectives in a project, in terms of time, cost, and quality [8-9]. Time reflects the amount of time available to complete the project, cost represents the amount of money or resources available, and quality accords to the fit-to-purpose that the project must achieve in order to be successful. For example, in order to reduce both cost and time, the drilling equipment must be able to be rapidly moved and transported from one hole to the next. According to the grout hole drilling, the need for an optimal decision to choose the best techniques for drilling, either conventional rotary drilling or rotary-percussion drilling has arisen due to huge competition in the drilling dam construction project.

One of the major dam projects in Indonesia was the Tugu Dam Project, located in Trenggalek Regency. The Tugu Dam was one of the 65 large dams in the strategic plan of the Indonesian Ministry of Public Work [10]. The project started with the ground breaking on January 29 2014 and was inaugurated on November 30 2021. This project took a long time, namely 7 years, due to land acquisition problems. Grouting hole drilling work began on May 8, 2017. The tight schedule for this project dictated that the grouting work had to be completed immediately first because the successor tasks, namely the core embankment work, was urged to be completed before entering the rainy season. In the early stage of grouting work, project manager decided to carry out the drilling work in the blanket section of the right abutment using five conventional rotary drilling machines. Based on the daily project work progress report, the performance and progress of conventional rotary drilling work did not satisfy the planned project schedule. In order to achieve the pre-determined targets for the project, the project manager had implemented effective risk management by accelerating drilling work. It was decided to add another drilling technique, namely rotary-percussion technique which generally had faster rate of drilling penetration. This rotary-percussion technique was to drill the grouting boreholes in the blanket section of the left abutment. Therefore, the drilling works in the right and left abutments had been carried out simultaneously. Unfortunately, there has been no in-depth study previously of the selection of these two drilling techniques from the perspective of time, cost, and quality comprehensively.

The current paper attempts to examine the comparison between conventional rotary and rotary-percussion drilling techniques in drilling work for grouting boreholes in a case study of the Tugu Dam Development Project, which includes a detailed comparative assessment of time, cost, and quality comprehensively. This research is very important in order to choose the right construction technique for drilling a grouting borehole because many dams are still in the planning stages in Indonesia for improving more resilient and sustainable community life [10]. The significance and potential impact of the reported work will make the implementation of dam construction more efficient due to the limited resources faced by the Indonesian government, and other similar countries.

Research Methods

This study has utilized primary and secondary data in accordance with the grout hole drilling on Tugu dam project as a case study. Primary data was obtained from the field investigation. Recording of cycle time data was carried out directly on-site, then synchronized with project weekly reports. Interviews were employed to collect qualitative data about time, cost, and quality of work performed and its progress. Secondary data was obtained from available project reports and documents on the PT Wijaya Karya-APTA KSO Project Contractor, such as grouting layout, borehole drilling work volume, Lugeon value, and the actual cost of work performed. The project implemented 5 drilling machines each for conventional rotary technique (right side abutment) and rotary-percussion technique (left side abutment) respectively.

There were 2 abutments, left and right sides, in the Tugu dam project and there were 3 grouting sections on each abutment: the blanket grouting, L=5m deep, the sub-curtain grouting, L=15m deep, and the curtain grouting, L=25~40m deep. This study was only focus on drilling work of blanket grouting, all with 5 metres deep. Grout holes of about 75 mm were drilled using a particular drilling method. An example of schematic layout of the grouting section in the right abutment is presented in Figure 1.

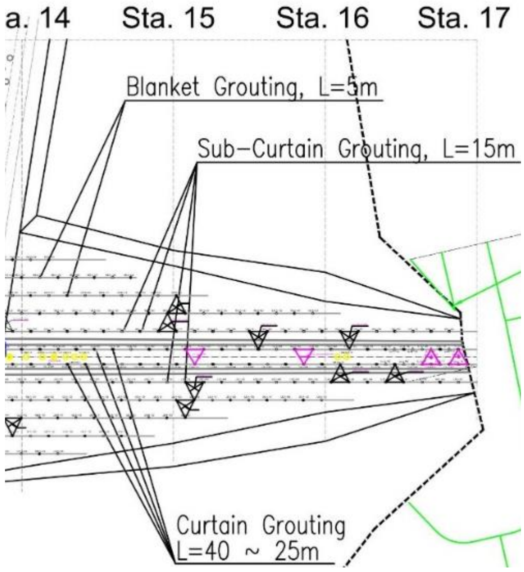

Figure 1. Schematic Grouting Layout of the Right Abutment

This study described 91 grout boreholes and 3 check holes on the blanket section of the right abutment using conventional rotary drilling, namely R.1 – R.91.

In addition, there were 91 grout boreholes and 4 check holes on the blanket section of the left abutment using rotary-percussion drilling, namely P.1 – P.91 (Figures 2 and 3). The sub-curtain and curtain drillings were not discussed further in this study because the

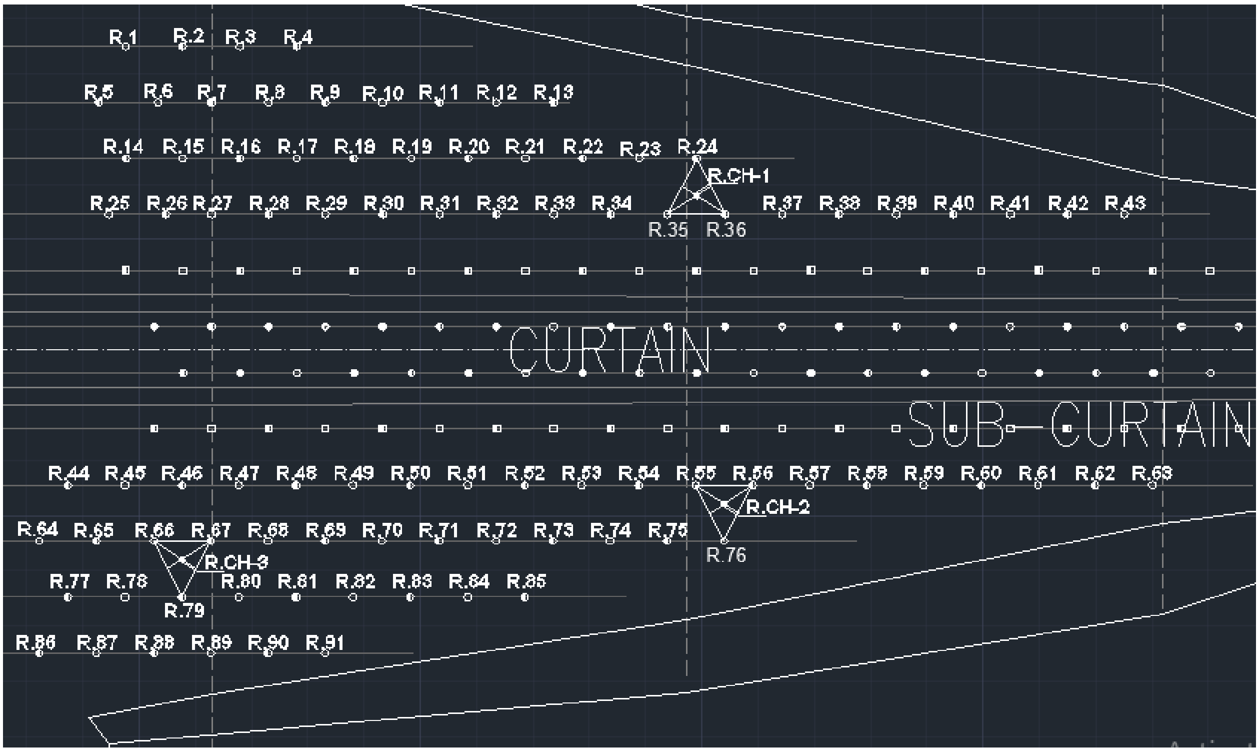

Figure 2. The Layout of Ninety-One Grouting Work and Three Check Holes on the Blanket Section of the Right Abutment using Conventional Rotary Drilling Technique (R.1 – R.91)

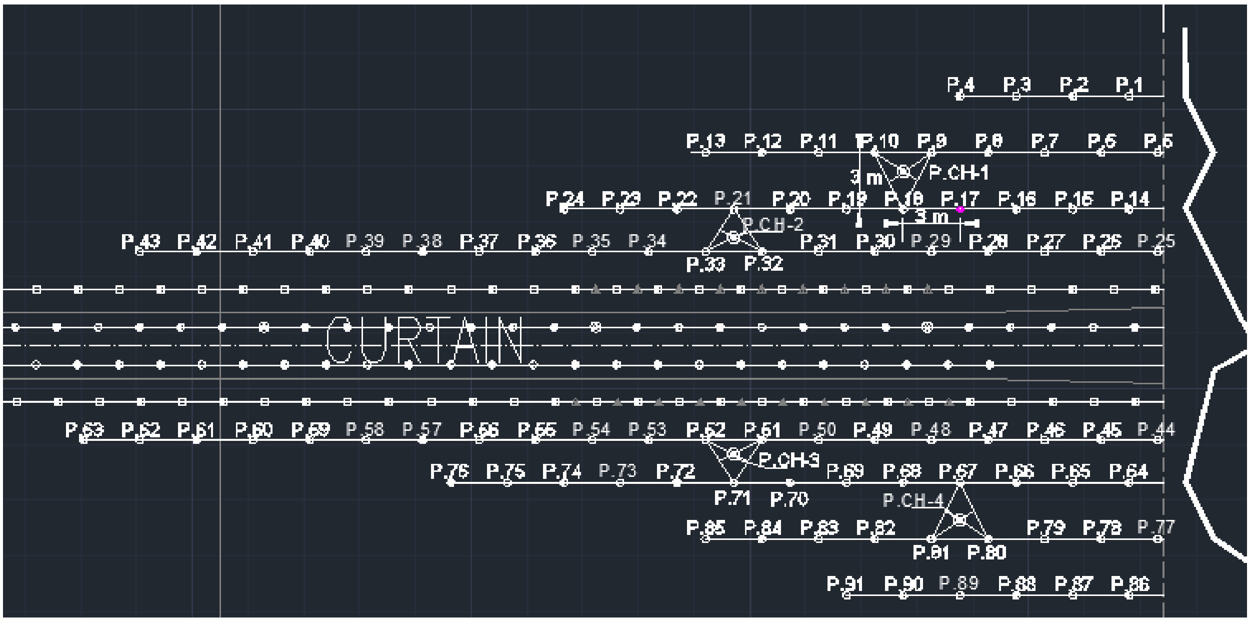

Figure 3. The Layout of Ninety-One Grouting Work and Four Check Holes on the Blanket Section of the Left Abutment using Rotary-percussion Drilling Technique (P.1 – P.91)

drilling method only used the rotary technique. Each blanket borehole had a depth of 5m, thus the total volume of work (or the total depth of the drill holes) was 5m x 91 boreholes = 455m on each abutment.

Work duration was measured by direct observation in the project site. There were 20 cycle time data in each technique. In one drilling work cycle, the cycle time (Ct) required in one cycle work [11-12] was divided into the following five elements, as described in Equation 1, namely: time of movements of equipment at the drilling workplace (Pt), time of machine installation and drilling cycle (Bt), time of up-lifting rod (At), time of connecting rod (St), and time of equipment disassembly, interruptions, and delays (Dt).

$$Ct = Pt + Bt + At + St + Dt \qquad (1)$$

Work productivity was measured by dividing the volume of work (or borehole depth, which is 5m) by the time in one drilling cycle time. In fact, work productivity at each layer of borehole depth was variably different, due to the variability of the rock formations. Therefore, this used average work productivity value. The total time for the drilling process was calculated by the total work volume divided by the average work productivity.

Project cost was measured by direct and indirect costs [13]. Direct costs were collected from the actual cost of work performed, while indirect costs were collected from the project overhead costs, summarized from the interview with five competent drilling person in the project. Overhead costs included employee salaries, general needs, electricity, water, etc.

The quality of the grouting work was measured by the magnitude of the effectiveness of the grouting work, based on Lugeon-II value in the check hole against the Lugeon-I value in the boreholes, expressed in %. The value of the effectiveness of the grouting work is calculated by Equation 2 and also presented in Table 2.

$$Efs = 100 - (KG/K) x 100 \qquad (2)$$

Where: Efs = grouting effectiveness in percent (%); KG = Lugeon-II value in the check hole; and K = average Lugeon-I value in the three boreholes next to the check hole before they are grouted

Table 2. Grouting Effectiveness [3]

Grouting effectiveness (%)	Categories
>90	Very good
60-90	Good
30-60	Fair
10-30	Poor
< 10	Very poor

Case Study Project

Grout hole drilling work in the Tugu Mini Hydropower Dam project was used in the current case study. The dam is located in Trenggalek district, East Java province Indonesia (Figure 4). The Tugu dam is located in the regional geology of volcanic breccia, andesite, and some other tuffaceous sandstone, with whitish-gray to yellowish-yellow in color. The Tugu dam has a total water storage capacity of 12.14 million m^3 with an inundation area of 41.74 Ha. The benefits of the construction of the Tugu dam include mini hydro-power, irrigation water, raw drinking water, and flood control. This ambitious aim for

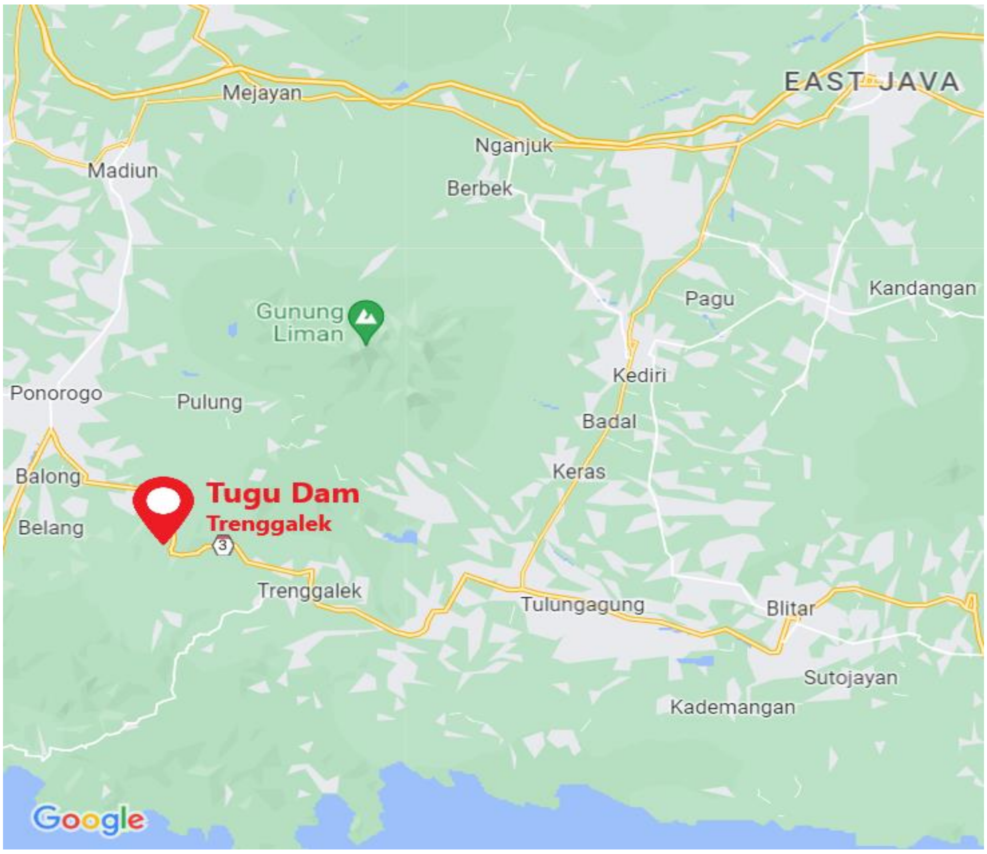

Figure 4. Study Area of the Tugu Dam

national dam projects may inspire optimism in the construction industry because it demonstrates the government's commitment to developing dams for many benefits. On the other hand, this aim increases the need for all dam project stakeholders to begin addressing and mitigating all identified difficulties.

Extracted from the construction contract agreement, the Tugu dam construction contract price for grout hole drilling on the blanket section was IDR 142,250,000 for each right or left abutment or IDR 284,500,00 for both abutments. This contract price included the direct project cost including field supervision expenses plus the indirect cost, such as markup imposed by contractors for general overhead expenses. The left and right abutment work were carried out simultaneously with a maximum contract project duration of 22 days. In relation to the indirect cost, PT Wijaya Karya as the main contractor decided to devote 4.20% of contract price for general overhead expenses or indirect cost. Therefore, the amount of indirect cost for each drilling technique was IDR 142,250,000 x 4.2% / 22 days = IDR 271,568 per day.

Drilling Techniques

Drilling is a cutting operation in which a drill bit is used to create a circular hole in a solid material. In a dam project, borehole drilling is the creation of a narrow (diameter of about 75 mm), deep hole in the ground known as a borehole. A borehole is bored beneath the ground during the course of a Geotechnical evaluation and improvement of foundation conditions. In Tugu dam project, there were two most common drilling techniques i.e. conventional rotary drilling and rotary-percussion drilling. Both were portable drilling machines, hand-held operations, and locally manufactured machines in Indonesia, as described in Figure 5. Schematic drawings of two types of drill are presented in Figure 6.

(a) (b)

Figure 5. Drilling Equipment: (a) Conventional Rotary; (b) Rotary-percussion

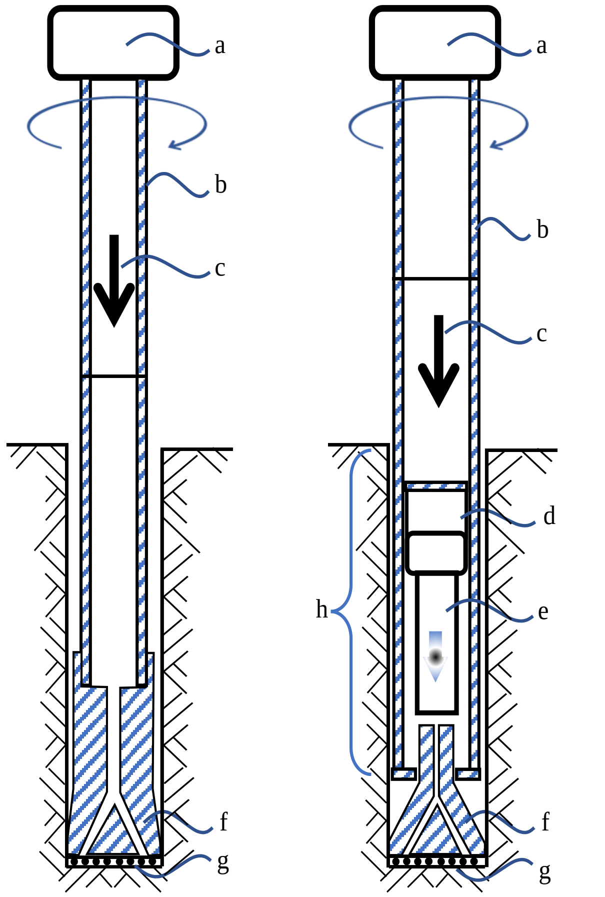

Figure 6. Schematic Drawings of Two Types of Drill: a) Rotation Mechanism, b) Drill Pipe, c) Flushing, d) Cylinder, e) Piston, f) Bit, g) Tip, h) Percussion Mechanism

Rotary drilling is well-known as a conventional drilling technique in Indonesia and frequently used in soils. Rotary drilling utilizes a high rotation and torque, the drill bit rotating rapidly at the end of the drill pipe and boring the soils or rocks. The drill bit rotates while bearing down on the bottom of the borehole, thus gouging and chipping its way downward. These drill bits come in two different varieties: roller cone bits and fixed cutter bits. Both are ideal for heavy usage in the drilling industry.

The speed of rotations and their high frequency make rotary drilling an effective means of carving through hard and soft rock formations. This is driven by a hydraulic motor with the manual gear change, providing fully controlled power and rotational speeds in forward or reverse [14]. This equipment uses water circulation to clear out the borehole, cool the drill bit, and reduce friction so that it can be operated optimally. The circulating water carries the crushed rock to the surface, so that drilling is continuous until the bit wears out. Rotary drilling rigs keep the job site clean with low environmental pollution. They generate smaller vibrations and operate with less noise.

Rotary drilling is a common drilling technique used by Indonesian people due to the cheap initial equipment cost. It is usually used in water well drilling by the Indonesian community. Water well drilling is the hole drilling process through the earth's surface for the purpose of accessing a groundwater source. Perhaps the least expensive method of drilling, the conventional rotary technique is by far the simplest and also requires low-skilled workers. Common rotary drilling techniques have enabled boreholes to be drilled to depths of about 150 meters.

The rotary drilling machine has a diesel engine as the driving force and it is attached to the main body of the rotary drilling equipment. The equipment's main body consists of a base, column, table, radial arm, and drill head. In the Tugu Dam Project, the weight of the diesel engine and the main body of the drilling machine was about 100 kg and 150 kg respectively. Because the layout of the Tugu dam project in the abutment section had a slope of about 40 degrees, there were difficulties to move the drilling equipment from one hole to the next. Due to the difficult site contour and limited budget, rotary drilling operators handled the equipment manually. For safety purposes every time during this movement, the diesel engine was released from the main body of the drilling equipment. The diesel engine were then be assembled on the main body again when the drilling equipment began to operate to the new next drilling position. This type of work process was time-consuming and required four to five worker or operators.

On the other hand, rotary-percussion drilling has widely been acknowledged for its potential to drill faster in rock due to the advantage of the hammering action, in comparison to conventional rotary drilling methods. This capability becomes apparent when drilling in heavy-stony formations such as granites, sandstones, dolomites, and limestones. Test results are clear that the rate of penetration (ROP) in hard formations when the rotary-percussion drilling method is applied, is significantly bigger. According to the drilling data with drilled formations were sandstones, limestone, and anhydrite in Tarim Basin, People's Republic of China, conventional rotary drillings were carried out with a relatively low ROP, achieving 1.67 m/hour on average, whereas rotary percussion drillings provided ROP of 4.74 m/hour on average. Rotary-percussion drilling was about 3 times faster than that of conventional rotary drilling [15]. The main problem of this type of drill was no possibility of drilling in loose formations.

In the current project site, rotary-percussion drilling had a slime/drilling residue removal system using compressed air. The depth of the drill hole with this machine was maximum only for about 5 m because the slime material in the form of soil grains and rock fragments was not easy to remove from the drill hole using only air pressure from the air compressor machine. The rotary-percussion drilling machine consisted of three components i.e. main body, electrical generator set, and air compressor machine, and they were connected either by hose or cable to each other. This modular design made the drilling machines easy to install and relocate, in turn, allowing greater operational flexibility to move it to the new next drilling position. As the machine dimensions were smaller than rotary machines, the operation and movement to the next drill only required 2-3 workers or operators. The project managers were gaining its convenience to this method in terms of saving time significantly. However, this percussion method required a high initial equipment cost. Also, it needed high durability of the drilling bits, during long runs of the drilling work. All made the process of percussion drilling increased the total cost but save time.

This case study focuses on the 5-meter-deep hole drilled in the blanket section, for which both conventional rotary and rotary-percussion drilling machines may be employed. Choosing a drilling machine in the grouting work for the dam project is a big challenge for engineers. All of the described problems generate relevant extra costs and time, which is the reason to compare the results of drilling technique when conventional rotary and rotary-percussion drilling methods are applied. Therefore it is urgent to take consideration of time, cost, and quality as the main objectives for a successful grout hole drill project.

Results and Discussion

Time Aspect

Site investigation has been carried out for cycle time data collection. Based on field observation on 20 boreholes, the cycle time data obtained for the conventional rotary drilling and the rotary-percussion technique are shown in Table 3 and 4 respectively as follows.

Each blanket borehole had a depth of 5m, and each technique operated for 91 boreholes; therefore, the total volume of work (or total depth of drill holes) for each technique was 5m x 91 boreholes = 455m. Based on Table 3 and 4, the average: cycle time (Ct), drilling speed (V), and work duration are formulated in Table 5, as follows.

It is clear that the work duration of the rotary-percussion technique is faster than the rotary and there are 16 days time-saving due to the faster ROP of rotary-percussion technique.

Table 3. Cycle Time Data for Rotary Technique

#	Time, sec				
Borehole	Pt	Bt	At	St	Dt
R.1	5420	18100	1830	3610	1830
R.8	5500	17800	1860	3580	1765
R.12	5480	17900	1780	3540	1750
R.15	5520	18000	1765	3590	1790
R.19	5535	18300	1750	3610	1810
R.23	5450	18400	1850	3605	1820
R.27	5540	18250	1835	3750	1850
R.31	5510	17200	1800	3740	1890
R.37	5570	17350	1790	3800	1920
R.43	5400	18500	1785	3570	1760
R.45	5120	18450	1810	3700	1830
R.49	5355	17400	1840	3125	1815
R.55	5190	17980	1805	3555	1795
R.61	5200	18310	1815	3640	1530
R.64	5210	18060	1685	3585	1845
R.70	5200	18090	1732	3600	1890
R.76	5390	18350	1880	3630	1740
R.78	5380	18200	1734	3670	1830
R.82	5290	18500	1750	3510	1820
R.87	5740	16860	1904	3590	1720
Average	5400	18000	1800	3600	1800

Pt = Time of movements at the drilling workplace (in second)
Bt = Time of machine installation and drilling cycle (in second)
At = Time of up-lifting rod (in second)
St = Time of connecting rod (in second)
Dt = Time of machine disassembly, interruptions, and delays (in second)

Table 4. Cycle Time Data for Rotary-Percussion Technique

#	Time, sec				
Borehole	Pt	Bt	At	St	Dt
P.1	600	3650	30	60	530
P.7	650	3580	25	60	531
P.11	620	3570	30	65	534
P.15	560	3590	30	65	527
P.19	570	3620	35	55	529
P.23	610	3610	35	55	528
P.27	605	3630	25	70	521
P.33	620	3625	32	50	522
P.37	580	3630	28	60	524
P.41	590	3615	29	60	526
P.46	550	3655	36	50	523
P.50	585	3700	30	70	528
P.56	630	3710	25	60	529
P.62	625	3645	35	60	549
P.65	605	3170	25	60	528
P.69	602	3740	31	60	530
P.73	601	3615	35	50	548
P.79	623	3783	36	50	525
P.83	606	3690	32	70	521
P.87	568	3172	16	70	519
Average	600	3600	30	60	528.6

Table 5. Formulation of Cycle Time (Ct), Drilling Speed (V), and Work Duration of Both Drilling Techniques

Drilling techniques	Average time, sec					Ct*	V**	Work duration***
	Pt	Bt	At	St	Dt	sec	m/hr	days
1. Conventional rotary	5400	18000	1800	3600	1800	30600	0.58	19.34 (rounded up to 20)
2. Rotary-percussion	600	3600	30	60	528.6	4818.6	3.73	3.05 (rounded up to 4)
						Time saving		16

*) Cycle time, Ct = Pt + Bt + At + St + Dt

**) Drilling speed, $V = \frac{5m}{Ct}$ x 3600

***) Work duration = $\frac{455m}{(5 \, x \, 8 \frac{hr}{day} x \, V)}$ (There are 8 work hours in a day and 5 machines each technique)

Table 6. Unit Prices for 1 m Drilling Depth for Conventional Rotary Technique

No	Components	Unit	Quantity	Unit price	Amount
I	Labour				
	Foreman	man/hr	0.04	IDR 85,000	IDR 3,400
	Operator	man/hr	0.20	IDR 75,000	IDR 15,000
	Operator Assistant	man/hr	0.20	IDR 72,500	IDR 14,500
	Helper	man/hr	0.60	IDR 72,500	IDR 43,500
II	Material				
	Drill bit	piece	0.03	IDR 450,000	IDR 15,000
	Gasoline	liters	1.60	IDR 10,900	IDR 17,440
	Oil	liters	0.05	IDR 25,000	IDR 1,333
	Hydraulic oil	liters	0.10	IDR 25,000	IDR 2,550
	Grease	kg	0.09	IDR 22,000	IDR 2,024
III	Equipment				
	Rotary machine	hours	1.60	IDR 67,500	IDR 108,000
				Amount of I+II+III	IDR 222,747
IV	Miscellaneous				
	Profit		10%		IDR 22,274
				Total amount	IDR 245,022

Cost Aspect

The contractor of PT Wijaya Karya which implemented the drilling work for both right and left abutment of blanket section had construction contract price of IDR 284,500,000 and 22 working calendar days. According to the requirements of the project, only certified drilling operators or technicians could operate the drilling equipment. These technicians were in charge of operating drilling equipment. They had a comprehensive comprehension of safety procedures, as well as the equipment and its operation. In addition, they were capable of resolving any mechanical or technical issues that may have arisen during drilling. These included reduced downtime resulting from equipment malfunctions and enhanced safety on the job site.

According to the project drilling cost consideration, several interviews to the competent drilling supervisors in the Tugu dam project have been carried out in order to get the actual cost of work performed for the two techniques. Some emerging data of direct cost have been revealed including: cost components, quantities, unit price per components, and amount per components. As a consequence of employing a certified operators, the unit cost of labour was greater than that of an ordinary technician, as measured by hourly wage. Detail of unit prices for the two method are described in Tables 6 and 7 for conventional rotary and rotary-percussion drilling techniques respectively. Labour cost of conventional rotary method is about two times higher than that of rotary-percussion method. Contrary, equipment cost for conventional rotary method is almost two times lower than that of rotary-percussion method.

Based on the analysis of unit prices in Tables 6 and 7, the unit prices of the rotary drilling is IDR 245,022 and the rotary-percussion drilling is IDR 245,076. There are no significance difference on unit prices between the two techniques. The total direct cost of rotary drilling is 455 m x IDR 245,022 = IDR 111,485,010. Whereas, the total direct cost of the rotary-percussion drilling is 455 m x IDR 245,076 = IDR 111,509,580.

According to the work duration, there were 20 working days for rotary drilling technique and 4 working days for rotary-percussion drilling technique. The total cost of work performed (direct + indirect cost) of rotary drilling technique was = IDR 111,485,010 + 20

Table 7. Unit Prices for 1 m Drilling Depth for Rotary-Percussion Technique

No	Components	Unit	Quantity	Unit price	Amount
I	Labour				
	Foreman	man/hr	0.02	IDR 85,000	IDR 1,4160
	Operator	man/hr	0.03	IDR 75,000	IDR 2,500
	Operator Assistant	man/hr	0.10	IDR 72,500	IDR 7,250
	Helper	man/hr	0.17	IDR 72,500	IDR 12,083
II	Material				
	Drill bit	piece	0.05	IDR 450,000	IDR 22,500
	Gasoline	liters	1.33	IDR 10,900	IDR 14,533
	Oil	liters	0.03	IDR 25,000	IDR 833
	Grease	kg	0.03	IDR 22,000	IDR 733
III	Equipment				
	Rotary-percussion machine	hours	0.27	IDR 67,500	IDR 24,394
	Electrical generator	hours	0.27	IDR 294,279	IDR 78,474
	Air compressor	hours	0.27	IDR 217,791	IDR 58,077
				Amount of I+II+III	IDR 222,796
IV	Miscellaneous				
	Profit		10%		IDR 22,274
				Total amount	IDR 245,076

Table 8. Total Cost of Work Performed and Their Savings

Drilling techniques	Construction contract price	Direct cost	Dur. (days)	Indirect cost per day	Indirect cost	Total cost of work performed	Saving	% Saving
(1)	(2)	(3)	(4)	(5)	(6)=(4)x(5)	(7)=(3)+(6)	(8)=(2)-(7)	(9)=(8)/(2)
1. Conventional rotary	IDR 142,250,000	IDR 111,485,010	20	IDR 271,568	IDR 5,431,364	IDR 116,916,374	IDR 25,333,626	13.99%
2. Rotary-percussion	IDR 142,250,000	IDR 111,509,580	4	IDR 271,568	IDR 1,086,273	IDR 112,595,853	IDR 29,654,147	20.08%

days x IDR 271,568 = IDR 116,916,374. Whereas, the rotary-percussion drilling total cost was = 111,509,580 + 4 days x IDR 271,568 = IDR 112,595,853. The difference between the two was IDR 4,320,521 (3.84%) as a result of indirect cost particularly. In relation to the construction contract price, there were savings of 13.99% and 20.08% for rotary drilling and rotary-percussion drilling techniques respectively, as formulated in Table 8. It is clear that the cost of the rotary-percussion technique is lower than the rotary because of the lower indirect cost as a result of faster ROP.

Quality Aspect

Quality of grouting work can be measured by the value of the effectiveness of grouting work, as stated in Table 2. According to the effectiveness of grouting work, there were data of Lugeon-I values and also Lugeon-II values (KG) obtained from the check hole value. As described in Figure 2, there are three triangled boreholes as check holes for the rotary technique and Figure 3 describes four triangled boreholes as check holes for the rotary-percussion technique. These Lugeon values are mentioned in Tables 9 and 10.

Table 9. Lugeon-II Value on Check Holes and Lugeon-I on Boreholes for Rotary Technique

No	Check holes		Boreholes next to Check holes	
	#Check holes	Lugeon-II	#Boreholes	Lugeon-I
1	R.CH-1	1.22	R.24	6.50
			R.35	8.84
			R.36	9.23
2	R.CH-2	1.54	R.76	7.10
			R.55	15.49
			R.56	11.27
3	R.CH-3	2.77	R.66	7.51
			R.67	34.28
			R.79	1.31

Table 10. Lugeon-II Value on Check Hole and Lugeon-I on Boreholes for Rotary-Percussion Technique

No	Check holes		Boreholes next to check holes	
	#Check holes	Lugeon-II	#Boreholes	Lugeon-I
1	P.CH-1	2.14	P.9	52.31
			P.10	30.91
			P.18	23.33
2	P.CH-2	0.87	P.21	47.71
			P.32	34.79
			P.33	21.28
3	P.CH-3	2.04	P.71	18.30
			P.52	21.23
			P.51	30.86
4	P.CH-4	2.34	P.67	7.58
			P.80	24.18
			P/81	11.82

The value of the effectiveness of grouting work, which is based on Equation 2, can be used to determine the quality of grouting work. Based on Tables 9 and 10, the effectiveness of grouting work is summarised in Table 11, as follows.

From the results above, the effectiveness of grouting work relevant to Table 2 is at the range of 80.72% - 86.36% and 83.89% - 97.49% for rotary and rotary-percussion technique respectively. The effect of grouting is in good category and good-very good categories respectively. The effectiveness of grouting work using rotary-percussion drilling technique tends to be in a better quality. Unfortunately, there are no further investigation to explain why this results took place. Indeed, the variability of rock properties between right and left abutment has been noted by the construction actor in the Tugu dam project site. This paper has only presented that both techniques is adequate to be implemented in the grout hole drilling up to 5 m depth in the blanket section with good and very good categories of grouting work effectiveness. Besides blanket section in which the drilling boreholes are deeper than 5 metres, the only viable drilling option is the conventional rotary method.

Discussion

A comparison between rotary and rotary percussion drilling techniques for grout drilling in blanket section with 5 metres deep has been elaborated. In general, rotary-percussion drilling is the fastest and most economical method for drilling grout holes in rocks. On the other hand, rotary drilling is frequently used in soils and the most widely owned and used drill machine by common people and construction professionals in Indonesia. Based on the Tugu dam drilling project on the blanket section, rotary-percussion drilling technique are capable of 16 days in time-saving rather than rotary technique due to the faster ROP. Moreover, the total cost of rotary-percussion technique is 3.84% cheaper than the rotary. According to the quality of grouting work, both techniques have provided good-very good categories in the effectiveness of grouting work based on Lugeon value. The effectiveness of grouting work using rotary-percussion drilling technique tends to be in a better quality, but this needs a further investigation why the quality of grouting work took place in relation to the heterogeneity of natural rocks or soils, the influence of the rock jointing condition, discontinuities, and variably rock formation at an alarmingly large range.

Besides some advantages of rotary-percussion drilling technique, some emerging issues have been appeared from interviews that there are shortcoming of this rotary-percussion technique, i.e. the capacity of drilling depth for only maximum of 5m, the limited number of this machines owned by Indonesian people due to the expensive investment and rare application, difficulties in available machine spare part, incapable to drill in loose formations, and limited number of

Table 11. The Effectiveness of Grouting Work

Drilling techniques	Lugeon-II	Lugeon-I				Efs*
		#1	#2	#3	Average	
(1)	(2)	(3)	(4)	(5)	(6)=((3)+(4)+(5))/3	(7)=100-(6)/(2)x100
1. Conventional rotary	1.22	6.50	8.84	9.23	8.19	85.10%
	1.54	7.10	15.49	11.27	11.29	86.36%
	2.77	7.51	34.28	1.31	14.37	80.72%
2. Rotary-percussion	2.14	52.31	30.91	23.33	35.52	93.97%
	0.87	47.71	34.79	21.28	34.59	97.49%
	2.04	18.3	21.23	30.86	23.46	91.31%
	2.34	7.58	24.18	11.82	14.53	83.89%

*) Equation 2

Table 12. Summary of the Results

Objectives	Conventional rotary drilling technique	Rotary-percussion drilling technique	Remarks
Time	Work duration is 20 days with ROP of 0.588 m/hour	Work duration is 4 days with ROP of 3.74 m/hour	There is 16 days of time saving for the rotary-percussion technique as a result of faster ROP
Cost	Total cost is IDR 116,916,374	Total cost is IDR 112,595,853	There is 3.84% cost saving for rotary-percussion technique, as a result of reduction of indirect costs.
Quality	The results of grouting effectiveness are at the range 80.72% - 86.36%, so the effect of grouting is in good category.	The results of grouting effectiveness are at the range 83.89% - 97.49%, so the effect of grouting is in good and very good categories.	The effectiveness of grouting work using rotary-percussion drilling technique tends to be in a better quality, but need a further investigation on rock formation and characteristics.

licensed operators. Therefore, the implementation of the drilling techniques has to be explored comprehensively, as a part of a conceptual effort to the engineer, to more rational and economic design. Summary of the results of comparative study of conventional rotary and rotary-percussion techniques in blanket grout hole drilling from the perspectives of time, cost, and quality is presented in Table 12.

Conclusions

These findings highlighted that the conventional rotary drilling technique required the work duration of 20 days with a drilling speed of 0.588 m/hour. The total costs of the rotary drilling were IDR 116,916,374. Also, it produced quality results with the effectiveness of grouting at 60-90%, and the effectiveness of grouting work is included in the category of good. Whereas, the rotary-percussion technique took 4 days with a drilling speed of 3.74 m/hour. The total costs were IDR 112,595,853. There are 16 days time saving and 3.84% cost saving for rotary-percussion technique, as a result of faster ROP and also reduction of indirect costs. The effectiveness of grouting work performed by rotary-percussion drilling tends to be of higher quality, but the heterogeneity of rock formation requires further investigation. Although the implementation of rotary-percussion drilling technique is the correct decision of the project manager in order to accelerate drilling work, this application is limited to a drilling depth of only 5m in blanket section only, due to the rotary-percussion machine characteristics mentioned above. For drilling boreholes deeper than 5 metres, the conventional rotary method is the only viable option.

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