DEVELOPMENT OF BLASTING MANAGEMENT SYSTEM AND ITS APPLICATION TO VERIFICATION OF GROUND EVALUATION USING LOGGING-WHILE-DRILLING

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Abstract: Concrete aggregate production in dam construction is planned according to the distribution of good quality rocks estimated by preliminary surveys such as borehole exploration and geophysical survey. The accuracy in estimating the distribution of good quality rocks depends on the quantity of sur- vey and is generally low. This may lead to a limited enhancement in the aggregate production efficiency. To resolve the problem, we developed a rock blasting management system, which consists of a rational construction technique with an information and communication technology (ICT), and a demonstration experiment at a dam site. In this report, we will describe the overviews of the aggregate production work at the Gokayama Dam and the developed rock blasting management system with the results of a verification experiment on the drilling survey and a demonstration experiment at an aggregate production site.

Keywords: dam concrete aggregate production, ICT, crawler drill, machine guidance, drilling survey

1 INTRODUCTION

Concrete aggregate production in dam construction is planned according to the distribution of good quality rocks estimated by preliminary surveys such as borehole exploration and geophysical survey. The accuracy in estimating the distribution of good quality rocks depends on the quantity of survey and is generally low. This may lead to a limited enhancement in the aggregate production efficiency. To resolve the problem, we developed a rock blasting management system named “T-iBlast DAM”, which consists of rational construction techniques with an information and communication technology (ICT), and a demonstration experiment at the Gokayama Dam aggregate production work site ordered by the Fukuoka prefecture of Japan. The “T-iBlast DAM” consists of two subsystems, which are named “the intelligent crawler drill system (ICDS)” (Figure1) and “the ground evaluation system (GES)”. ICDS has a logging- while-drilling and the drilling guidance functions. The former function can estimate rock quality using specific drilling energy during drilling works of a crawler drill used for blasting, while the latter function can guide drilling position, orientation and depth using the Global Navigation Satellite System (GNSS). GES can manage rock quality information in three dimensions. The method of applying the drilling logging results to the informational construction has already been verified in a large-scale underground cavern [1]. The method was then referred to in our research. In this report, we describe the overviews of the aggregate production work at the Gokayama Dam and the

T-iBlast DAM with the results of a verification test on the logging-while-drilling function and a demonstration experiment conducted at the dam site. If the rock quality inside the quarry can be evaluated, it will be possible to collect good rock aggregates with higher precision. In addition, if the management of accumulated survey data is integrated in three dimensions, it is possible to reduce not only waste rock materials, but processing loss in the entire construction work. At the end of the report, we present a rationalization technique using an ICT in future dam aggregate manufacturing work combined with an "on-site analysis method" which is separately under development [2].

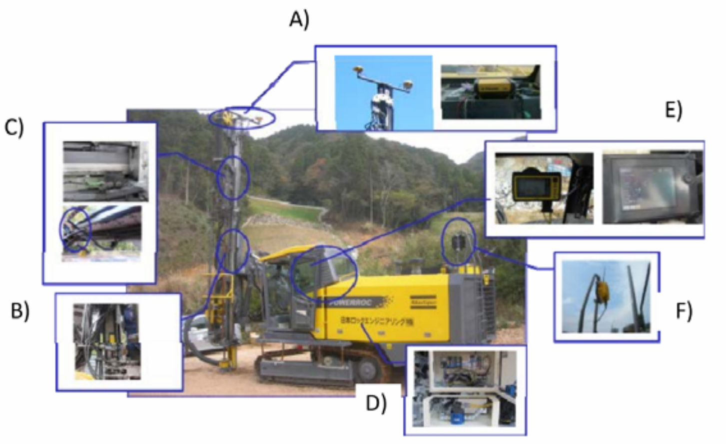

Figure 1: Intelligent crawler drill (Details of each part will be described in 3.1.1)

2 AGGREGATE PRODUCTION WORK OF THE GOKAYAMA DAM

2.1 Overview

The Gokayama Dam is a concrete gravity dam in Fukuoka prefecture, constructed for flood control and secure water supply (Figure2). Distributed rocks are biotite granite. In terms of the rock classification for aggregates, the target rock materials are Ⅰ-1 (class B-CH) and Ⅰ-2 (class CH-CM), while the waste rock materials are Ⅱ (class CL) and Ⅲ (class D) (Figure3).

Figure 2: Location of Gokayama Dam

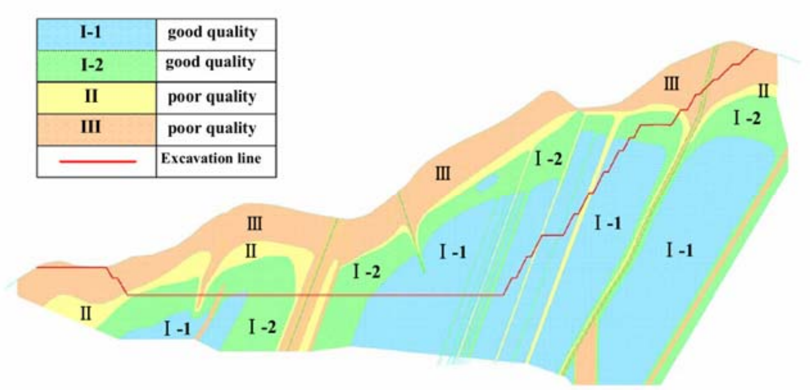

Figure 3: Rock classification of Gokayama Dam (sectional view)

2.2 Work flow

The work flow of the aggregate production work is as follows:

A) Removal of topsoil (soil and sand) accumulated on the rock
B) Rock excavation by blasting in the bench cut method
C) Classification of rock quality
D) Collection and loading the rock material

2.3 Separation of good rock aggregates from waste rock materials [3]

At the Gokayama Dam, the poor-quality rock which had previously experienced weathering and hydrothermal alteration existed in good-quality rock. It was impossible to separate them before blasting. There was concern that the amount of waste rock materials would increase because poor-quality rock would be mixed with good-quality rock due to blasting. Therefore, instead of classifying rock materials into target (good) rock and waste (poor) rock only, we classified the rock material into three groups of good quality rock, poor quality rock, and intermediate rock (mixture of good- and poor-quality rocks) to be further processed. Generally poor-quality rock is weaker than good-quality rock, and the former tends to become pulverized more finely than the latter during blasting and subsequent works such as material collection and transportation using heavy machinery. Using this tendency, the intermediate quality rock was further processed first by the grizzly equipment (Figure4), then by the screening bucket (Figure5). This way, we could retrieve good-quality rock and reduce the amount of waste rock materials. Nevertheless, it was anticipated that transport cost would increase with the increase in the intermediate rock group. So, it was desired to evaluate the inside of the rock mass before blasting, to be able to apply different blasting scheme in good-quality rock from that in poor-quality rock.

Figure 4: Grizzly equipment [3]

Figure 5: Screening bucket [3]

2.4 Background for development of blasting management system

Rock quality is classified based on the results of visual observation on blasted rocks distributed near the ground surface. Since it is impossible to inspect inside the quarry, the accuracy in estimating the rock quality is therefore also limited. In addition, transport costs will increase with the increase in the intermediate quality rock. As mentioned above, it is desired to evaluate the inside of the rock mass before blasting, to be able to apply different blasting scheme in good- quality rock from that in poor-quality rock. Furthermore, works related to drilling for blasting such as determination of the drilling positions and borehole lengths are normally carried out manually. Under these conditions, a labor-saving means by mechanization is strongly desired. The outline of the T-iBlast DAM and a demonstration experiment at the Gokayama Dam aggregate production work site will be reported in the following section.

3 T-i Blast DAM

ICDS and GES which constitute the T-iBlast DAM are described below.

3.1 ICDS

3.1.1 System overview

This system is a fusion of positioning guidance technology using a GNSS surveying system (Trimble DPS 900 Nikon Trimble Co., Ltd.) and rock quality evaluation technology with the use of drilling energy. Drilling work is usually performed at an interval of about 3 m, so high accuracy rock quality determination can be expected from the acquisition of high-density rock quality information. The main components mounted on the crawler drill and their roles

are listed below and are shown in Figure1

A) GNSS antenna and Receiver: Acquisition of coordinate and orientation

B) Inclinometer: Measurement of tilt angle of the mast

C) Leach sensor: Measurement of drilling length

D) Hydraulic force meter: Calculation of drilling energy

E) Tablet PC: Monitoring for guidance and rock quality determination

F) Radio equipment: Real Time Kinematic Positioning and Receiving GNSS correction information

Table 1: Comparison of ICDS with the conventional work flow

	Worker	Position measureme	Guidance	Drilling	Checking
ICDS	Operater:1	No need	Display on monitor in the operator room	Display on monitor in the operator room	No need
onvention al work	Operater:1 Assistant:1	Using measurement instrument and marking	Visual confirmation	Drilling by sense of operator	Using measurement instrument

3.1.2 GNSS machine guidance function

Bench drilling creates a drilling surface in a staircase shape, and natural grounds are blasted so that the elevation of the bench surface becomes uniform in the blasting operation. It is necessary to drill to the same elevation to keep a constant slope grade in the same direction. We compared the conventional construction method with that used in the workflow of this function (Table1). The greatest feature of this function is that the crawler drill itself has the function of surveying , so it is possible to omit the procedure such as "measurement" and "examination". Moreover, setting the "elevation of the end point" instead of the "drilling length" to a certain value, even when the undulation of the current bench surface is large, the elevation of the hole bottom can be kept constant, and the bench surface can be easily aligned horizontally. Another feature is the direction and angle guidance function. If it is possible to always arrange the crawler drill facing the inclination direction of the hole, it could be adjusted by the inclinometer guide attached to the crawler drill and by the assistant worker. In reality, it is difficult to adjust the crawler drill. On the other hand, regardless of the direction of the crawler drill, this function enables to guide the drilling rod to the hole bottom at desired position and inclination that match the designed drilling plan (Figure6).

3.1.3 Logging-while-drilling function

Drilling by a crawler drill is performed with a hydraulically driven rock drilling machine. The drill bit penetrates the rock with rotational, hammering and feeding pressures (last being the force to press the drill bit against the rock) applied to it through the rod. The logging-while- drilling function can calculate the drilling energy which is defined as the rotational and hammering pressures and the drilling rate to drill a unit of volume. Investigating the correlation between the drilling energy and rock class in advance, it becomes possible to classify the rocks according to their drilling energy. In addition, an operator can evaluate the rock condition in real time. Figure7 shows an example of the logging-while-drilling function in the operator's room.

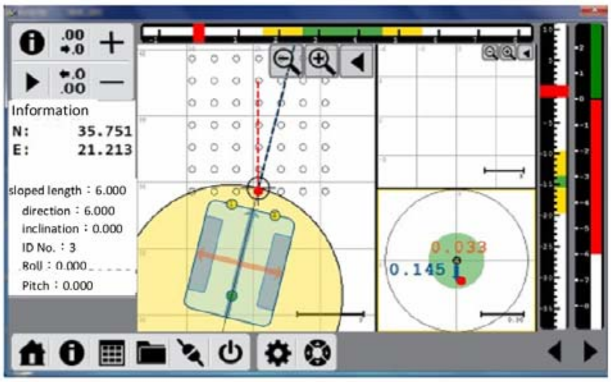

Figure 6: Machine guidance monitor in the operator room

Figure 7: Drilling survey monitor in the operator room

3.2 GES

Using Geo-Graphia (GEOSCIENCE Research Laboratory) which is a three-dimensional integrated visualization software, it is possible to display the result of the logging-while-drilling as 3D contour display using geo-statistics method, and volume ratio for each rock class.

4 VERIFICATION EXPERIMENT ON LOGGING-WHILE-DRILLING FUNCTION

Prior to evaluation of relationship between specific energy while drilling by crawler drill and rock classification, a fundamental verification experiment was conducted by drilling layered concrete with known strengths.

4.1 Outline of experiment

To evaluate the logging-while-drilling function, a concrete block cast in four layers as an artificial rock was drilled. Every layer comprised 50 cm thick, 200cm long and 200cm wide. The concrete strengths were respectively 50, 100, 30 and 50 N/ mm2 from the bottom layer. The reason for setting the bottom and the top layers to 50 N / mm2 is to confirm the reproducibility of the data. The layered concrete block was drilled after backfilling with soil and sand to simulate the conditions at the real drilling site (Figure8, Figure9).

4.2 Experimental results

The experimental results are shown in Figure10 and Figure11. The relationship between specific drilling energy and compressive strength was recognized as given by (Equation. 1).

$$\text{Compressive strength} = 0.0862\times(\text{specific drilling energy})\ 1.56 \qquad (1)$$

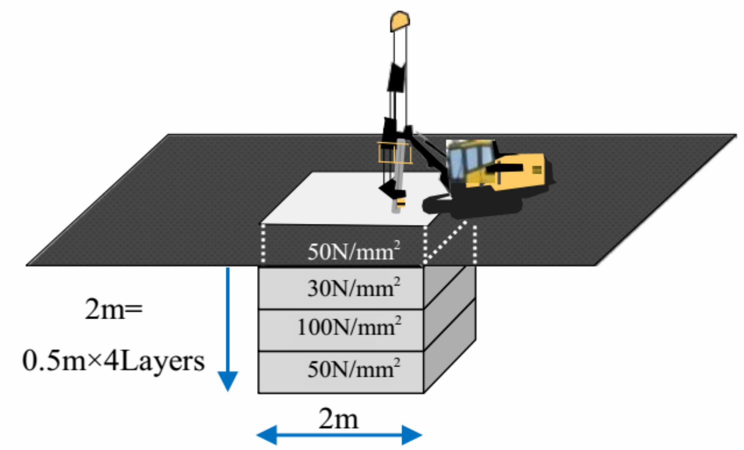

Figure 8: Schematic chart of the drilling survey for a layered concrete block

Figure 9: Experimental condition of a layered concrete block

（left:test block, right:drilling state）

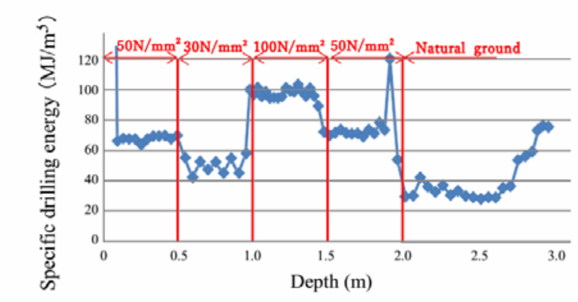

Figure 10: Experimental result of specific drilling survey for a layered concrete block

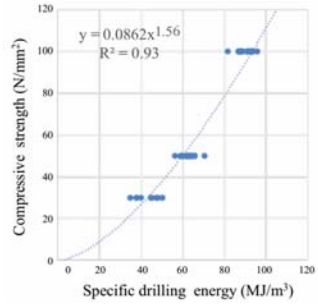

Figure 11: Schematic chart of the drilling survey for a layered concrete block

Since the compressive strength of medium hard rock (equivalent to rock class CM) is approximately 30 N/mm2, this function is conclusively possible to determine which portion of rock can be used for concrete aggregate.

5 DEMONSTRATION EXPERIMENT ON T-iBlast DAM

We conducted a demonstration experiment to confirm the effectiveness of the system at the Gokayama Dam aggregate production work site ordered by the Fukuoka prefecture. The outline of the experiment will be reported below.

5.1 Outline of experiment

The T-iBlast DAM was applied to one cycle of the blasting work, the ground condition was evaluated and the test results were verified.

5.1.1 Threshold setting

To set the threshold value for separating good rock from waste rock materials using the specific drilling energy obtained by logging-while-drilling, we performed the experiment at a position 50cm away from where a core drilling had already been drilled during the preliminary investigation. From the relationship between drilling energy and rock class at the corresponding depth, distributions of frequency for each rock class were created (Figure12), and the specific drilling energy at which each rock class was dominant was set as the threshold values. As a result, class D or CL was less than 35 MJ/m3, class CM was between 35 and 70 MJ/m3, and class CH more than 70 MJ/m3 (Figure13).

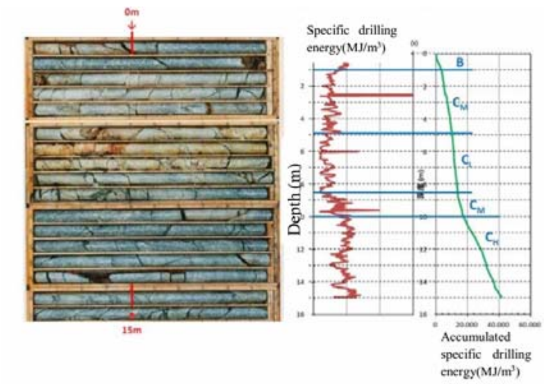

Figure 12: Correspondence between specific drilling energy and rock classes

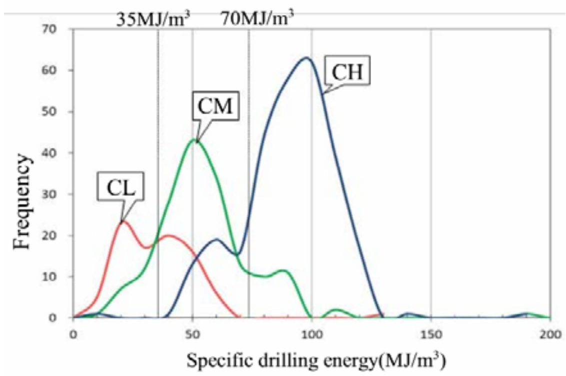

Figure 13: Frequency distribution of specific drilling energy and determination of threshold for each rock class

5.1.2 Data acquisition by logging-while-drilling function

At a bench section scheduled to be blasted on the following day at noon, the logging-while- drilling was carried out in 15 places (drilling length of 11 m with an interval of 4 m) by the intelligent crawler drill from the afternoon on that day to the time for blasting in the following day.

5.1.3 Analysis by ground evaluation system (GES) (Figure14)

Using a three dimensional visualizing software, we showed the color-coded specific drilling energy data by the threshold values first. Using the geostatistical method, we then showed the zones in colored contours and created the main sectional views (front, middle and back sections). This way, we could confirm the distribution profile of the waste rock materials. Observation of the cross sections before blasting confirmed good rock materials (classes CM to CH) at the front section, whereas waste rock materials (class CL or poorer) could be assumed in the middle and back cross sections inside the blasting target block.

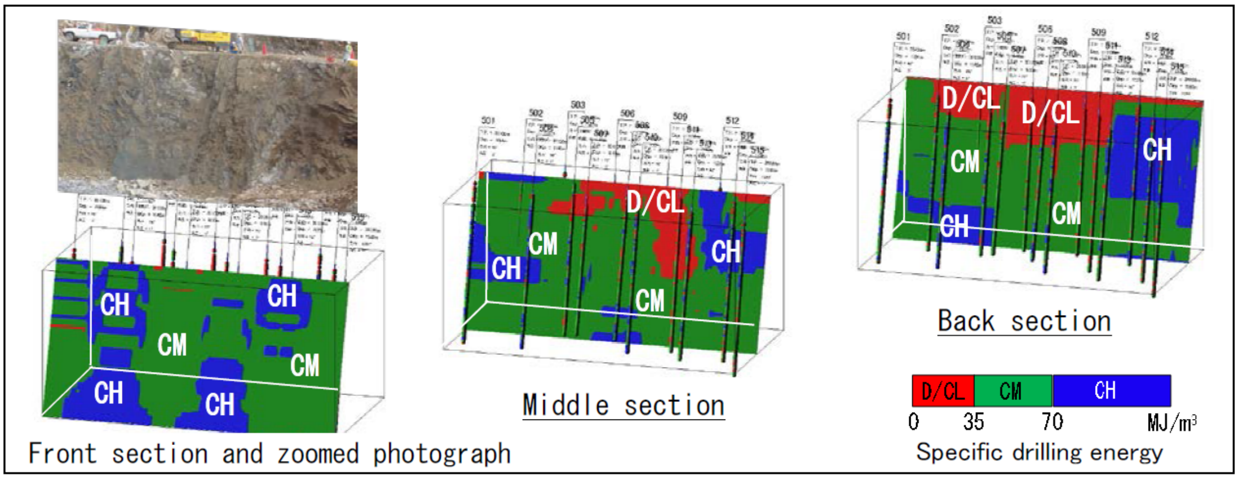

Figure 14: Analysis results of the drilling survey

（from left to right, face section and zoomed photograph, middle section and back section）

Figure 15: Verification result of the waste rock area estimated by the drilling survey

Figure 16: Verification result of the good rock area estimated by the drilling survey

5.1.4 Verification of results

After blasting, we confirmed the distribution of the waste rock materials inside the blasted block. It was possible to confirm the waste rock materials which deteriorated due to hydrothermal alteration at the expected position. Rocks are so soft that can be broken by a light blow of a hammer (Figure15). Likewise, high quality rocks of class CM could be confirmed at the expected position next to the waste rock materials. Rocks are hard, so can be broken by a strong blow because of non or week alteration (Figure16).

5.1.5 Future study

In addition to the TiBlast DAM reported here, we are developing a method of evaluating rock materials easily and quickly at dam construction site. In this method, the rock material is quantitatively evaluated from correlation of dry density with moisture content using a portable susceptibility meter, colorimeter, fluorescent X-ray analyzer (on-site analyzer)). Figure17 shows a rationalized construction plan using an ICT in the dam aggregate production work that integrates T-iBlast DAM together with an evaluation method using on-site analysis devices.

6 CONCLUSION

We developed a rock blasting management system named "T-iBlast DAM", which consists of rational construction techniques with an ICT. Using machine guidance function, we could reduce monitoring time and human cost necessary for adjusting drill positions. Regarding the logging- while-drilling function, we could obtain the correlation between concrete strength and specific drilling energy. In addition, as a result of applying the T-iBlast DAM to the aggregate production work site, it was found possible to evaluate the inside of the rock block to be blasted, which could not be evaluated by the conventional visual observation method. If this evaluation is given to work related persons before blasting, it is possible not only to grasp the amount of the waste rock materials in advance but also to reduce transport costs by blasting good rocks separately from poor-quality rock, based on the evaluation results. Moreover, accumulating such results every time will be very useful for management of aggregate production. From these experiments, we confirmed the validity of the T-iBlast DAM.

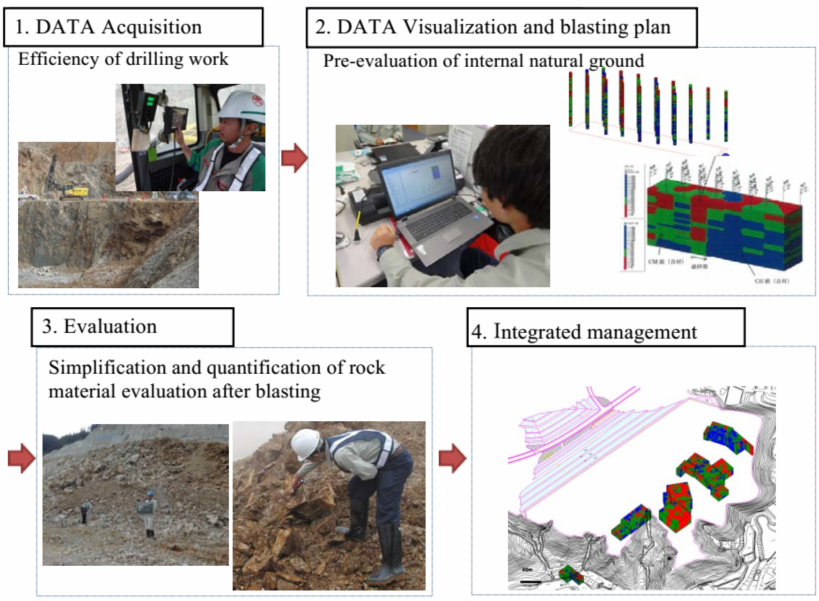

Figure 17: Flow of intelligent construction procedure with ICT for dam concrete aggregate production in the future.

REFERENCES

[1] Takeda N., Nishimura T., Yamagami M. (2012). Applicability of drilling survey for informative construction on the underground excavation (in Japanese). Electric power civil engineering, No.359.

[2] Ichiki T., Yamagami M., Takemoto T. (2015). Simple and quick field evaluation of rock material quality for dam construction-examples of granite and andesite (in Japanese). Report of taisei technology center No.48., 26.

[3] Nishiyama Y., Sumiyoshi M., Toyomasu T., Nakamori H., Kawamura A., Ujitugu T., Nishi T., Oukouchi M., and Takayanagi A. (2016). On-site reporting Effective utilization of aggregation material sampling using screening equipment at the Gokayama dam (in Japanese). Engineering for dams, vol.353, pp.72-86.