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Fluctuation Monitoring System for Grain Size Distribution of Cemented Sand and Gravel Materials using Digital Image Analysis

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ABSTRACT:
In construction work, such as a fill dam, where fill materials are used, management of the grain size distribution of materials is the basis of quality control. In order to monitor fluctuation trend of the grain size distribution, the authors have developed a new system to analyze fill materials characteristics using digital image analysis. In addition, this system was applied to the Tobetsu dam of trapezoidal cemented sand and gravel (CSG) dam for rationalization of the quality control during construction. In this paper, the overview of the new system and the application results to the Tobetsu dam are reported together with the development plan in the future of the new system.

Keywords: digital image analysis, grain size distribution, quality control, CSG method

1. INTRODUCTION

In construction work utilizing fill materials, such as for an earth and rock-fill dam, management of grain size distribution is the basis of quality control. In recent years, the CSG method has been adopted in construction projects in Japan. In this method, the strength of the CSG is defined as the grain size distribution of the rock-based CSG material and the range of unit water content, which are prescribed in accordance with the "diamond-shape theory (The Japan Dam Engineering, 2007)". Here, the grain size of the raw CSG material is adjusted to be less than a specific maximum grain diameter.

For quality control of construction using the CSG method, it should be verified that the grain size distribution of CSG material is within a specific grain size range. Since the CSG method is based on mass rapid sequential construction, a quality control method that is quicker and more continuous is required.

Focusing on the digital image analysis technique that has made dramatic progress in recent years, we developed a novel system, called Fluctuation Monitoring System for Grain Size Distribution using Digital Image Analysis, that quickly monitors the fluctuation trend of grain size distribution by analyzing the images of fill materials taken with a digital camera. The system was introduced at the construction site of the Tobetsu Dam in Japan, which is situated in the lower course of the Ishikari river and the first full-scale construction of a trapezoidal CSG dam, and rationalized quality control for the manufacture of CSG was achieved (Ueno et al, 2010).

This paper outlines the newly developed system as well as the application results and successful rationalization of quality control at the construction site of the Tobetsu Dam.

2. OUTLINE OF FLUCTUATION MONITORING OF GRAIN SIZE DISTRIBUTION USING DIGITAL IMAGE ANALYSIS

2.1. Original concept of the development

Engineers who are involved in construction projects, such as for earth and rock-fill dams, assess the grain size of fill materials such as crushed stones used on site as "coarse" or "fine" by observing the surface conditions. This visual evaluation often matches the results of test methods for grain size distribution.

Thus, it was considered that the grain size distribution could be evaluated based on the surface conditions of the fill materials in two dimensions, assuming that the surface conditions could be quantified, and we decided to develop the system.

2.2. System configuration and measurement procedure

The system was designed to be simple without any black box factor. It mainly consists of a common digital camera offering about 12.2 million pixels, a Personal Computer (PC) and a 0.8 m x 1.2 m tray for the material.

The measurement process starts with spreading the material in thin layer on the tray and follows these steps. Step 1: Take the image of the spread material with digital camera, Step 2: Import images to the PC, Step 3: Analyze the image, identify contour of each grain and extract grains by monitoring the grain diameter (e.g., 40, 20, and 10 mm) and Step 4: Calculate the grain size index *Ii* for each monitored grain diameter. This is a specific index obtained through quantification of the two-dimensional image information. A series of image analyses (from Step 2 to Step 4 of Fig. 1) using a dedicated program is generally completed in 10 to 20 seconds.

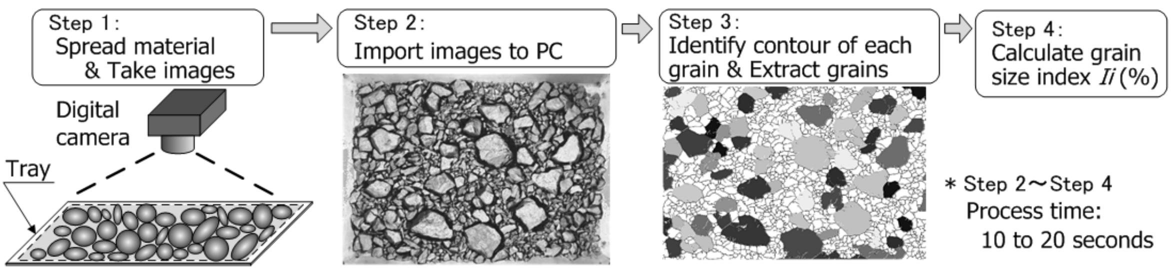

Figure 1. Procedure for new system

2.3. Examples of obtained images and results of image analyses

Fig. 2 shows the examples of obtained images and the results of image analyses of CSG material, whose maximum grain diameter is 80 mm. These images and analysis results are for the coarsest grain material and the finest grain material of certain CSG materials (The Japan Dam Engineering, 2007). The two images show a clear difference in grain size. If an image of a material is quantified and compared with these two images, it can be determined whether the grain size of the material is within the prescribed range.

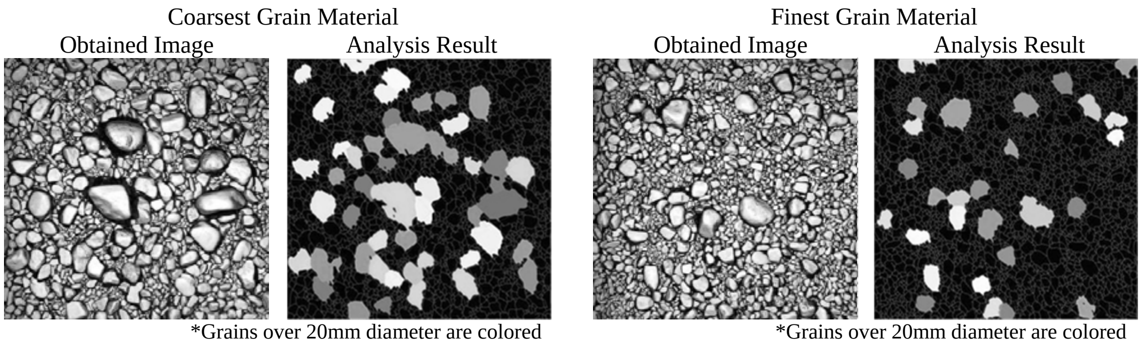

Figure 2. Example of obtained images and digital image analysis results of CSG material

2.4. Grain size index

In the early stage of developing this system, we studied quantification indexes for two-dimensional image information. Using each 30 grain of CSG material with a diameter of 10 mm or greater, we compared the projected area of the grains obtained by image analyses and the dry weight of the grains obtained from the test method for bulk density of rock authorized by the Japanese Geotechnical Society (JGS). The results of the comparison revealed a high correlation, as shown in Fig. 3. This correlation suggests that when the rock quality of CSG material is the same, then the shape and absolute dry specific gravity of grains within the same size range are also equivalent. Therefore, it was judged that the dry weight of the grains could be estimated based on the projected area of the grains obtained by image analyses.

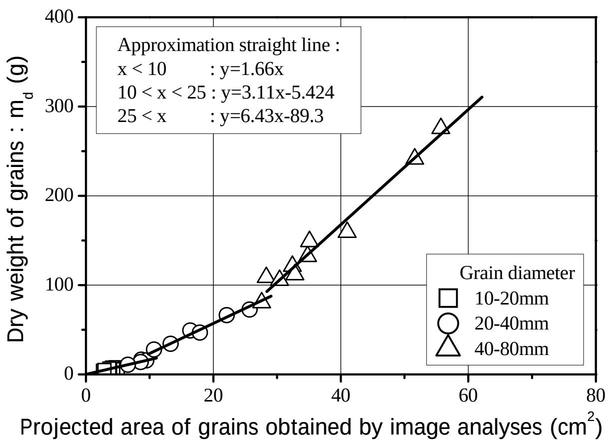

Figure 3. Correlation between projected area and dry weight with single grain of CSG material

Considering that the material actually have a mix of various-sized grains, the cumulative projected area of grains by each monitored grain diameter was normalized to the entire photographed area, as shown in Eq. 1, and this was defined as grain size index *Ii*.

$$Ii = \frac{\sum S_d}{A} \qquad (1)$$

where,

A : Entire photographed area of the material for measurement

S_d: Projected area of grains with a monitored grain diameter of (d) or greater

It was also assumed that the percent passing has a high correlation with the grain size index *Ii* because its value is obtained by normalizing the cumulative dry weight by monitored grain diameter compared with the total dry weight of the sample. Therefore, it was decided to use grain size index *Ii* as the quantification index.

2.5. Relationship between grain size index and percent passing

Fig. 4 shows an example of the relationship between the grain size index *Ii* of monitored grain diameters and percent passing with each grain diameter. As seen in the figure, a high correlation was found. Therefore, by using correlation equations that approximate this relationship, the percent passing can be estimated from the grain size index *Ii*.

Fig. 4 shows an example in which correlation equations were set by monitored grain diameters (40, 20 and 10 mm), aiming for sensitive detection of grain size fluctuations. Although there is some variability in percent passing against grain size index in Fig. 4, the influence of such variability would be reduced by estimating the percent passing by each of the different monitored grain diameters. Accordingly, it is highly possible to determine whether the CSG material matches the prescribed grain size range based on the "diamond-shape theory."

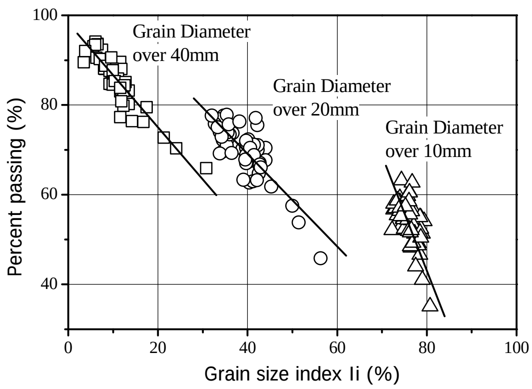

Figure 4. Correlation between grain size index and percent passing

2.6. Estimation example of grain size distribution curve

Fig. 5 shows an example of a comparison between the grain size distribution curve estimated by the system and that obtained by the simple test method with water rinse, using the same sample. Additionally, Fig. 6 shows the implementation status of the simple test method with water rinse at the Tobetsu Dam.

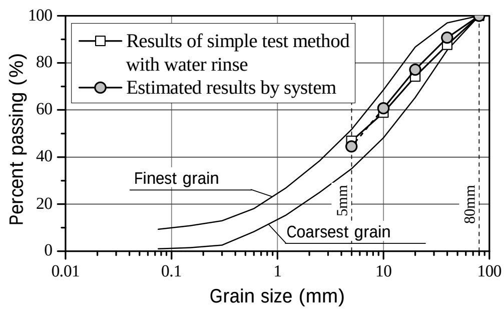

Figure 5. Comparison of grain size distribution curves

Figure 6. Implementation status of simple test method with water rinse at Tobetsu Dam

The resolution for grain identification with the system is about 3 % of the maximum grain diameter (80 mm x 0.03 = 2.4 mm). The identification accuracy for grain diameter of 5 mm or less, however, was lower than that for other grain diameters (40, 20 and 10 mm). Hence, a minimum monitored grain diameter was set to 10 mm with consideration for the estimation accuracy.

On the other hand, it was necessary to use the system for estimating percent passing for a diameter of 5 mm because of its considerable effect on the surface water of CSG material. As a result, it was decided to presume the percent passing for a diameter of 5 mm through Eq. 2 below using the percent passing for diameters of 40, 20 and 10 mm estimated by the system, as shown in Fig. 7.

$$y = ax_1 + bx_2 + cx_3 + d \qquad (2)$$

where,

y: Percent passing for a diameter of 5 mm
x_1, x_2, x_3: Percent passing for diameters of 40, 20 and 10 mm, respectively
a, b, c, d: Coefficients

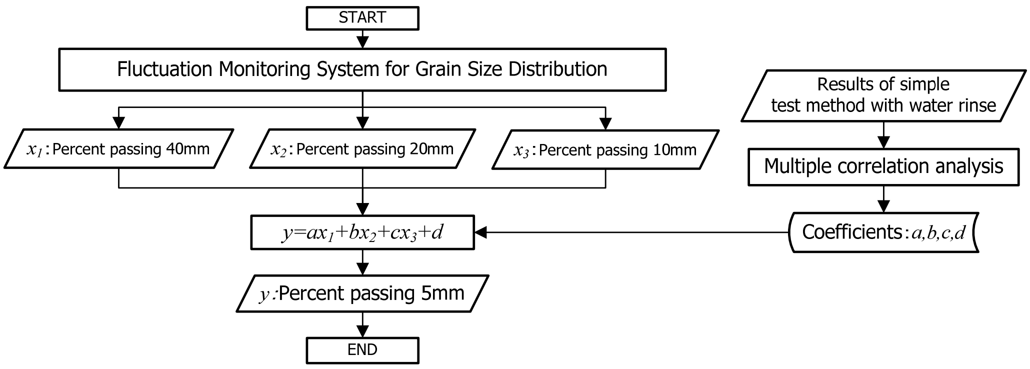

Figure 7. Flow diagram of surmised percent passing with a diameter of 5 mm

The coefficients a, b, c and d in Eq. 2 are set through multiple correlation analysis on actual data at the Tobetsu Dam. Table 1 shows an example of the multiple correlation analysis results.

Table 1. Multiple correlation analysis result

y	Coefficients				R
	a	*b*	*c*	*d*	
Percent passing 5mm	-0.087	0.273	0.437	3.245	0.917

The grain size distribution curves obtained by different methods matched well, as shown in Fig. 5. Thus, the system could accurately estimate that the grain size distribution of CSG material with the grain diameters ranging from 5 to 80 mm was roughly equivalent to that of the simple test method with water rinse.

3. APPLICATION RESULTS AT TOBETSU DAM

The Tobetsu Dam is the trapezoidal CSG dam with a height of 52 m, length of 432 m, and dam body volume of 813,000 m^3 (Ueno et al, 2010).

3.1. Application situation

The system was introduced on a full scale for monitoring the grain size fluctuation trend of the CSG material for quality control in the manufacture of CSG. Fig. 8 shows the digital-image shooting hut placed beside the CSG manufacturing plant, and Fig. 9 shows the conditions for shooting images of the CSG material.

In addition, to reduce variations in the shooting condition due to sunlight and construction light, the shootings were conducted in a space surrounded by blackout curtains, as shown in Fig. 9.

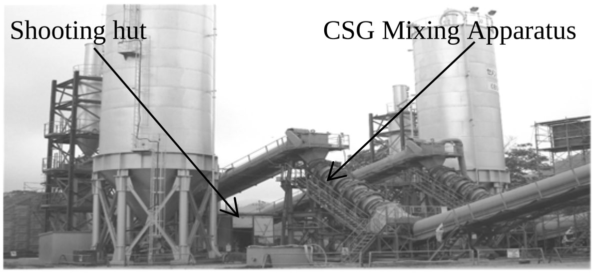

Figure 8. CSG manufacturing plant and shooting hut

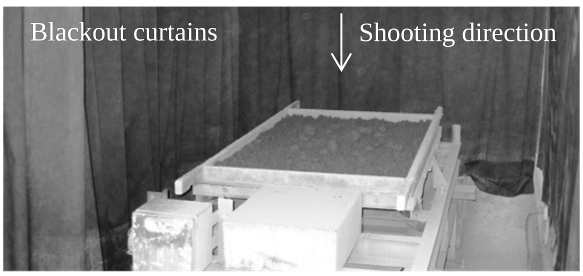

Figure 9. Shooting condition of CSG

3.2. Examples of fluctuation monitoring results for CSG material gradation

Fig. 10 shows the results of grain size fluctuation monitoring for CSG material using the system, focusing on specific monitored grain diameters of 40, 20, 10 and 5 mm, and Fig. 11 shows the results of the grain size distribution curve. In particular, Fig. 10 shows the actual outcome of CSG construction work for three days. In this regard, CSG manufacturing was implemented only at night. During the CSG manufacturing, monitoring with the system was conducted once every 15 minutes, and the simple test method with water rinse was conducted once every 2 to 4 hours.

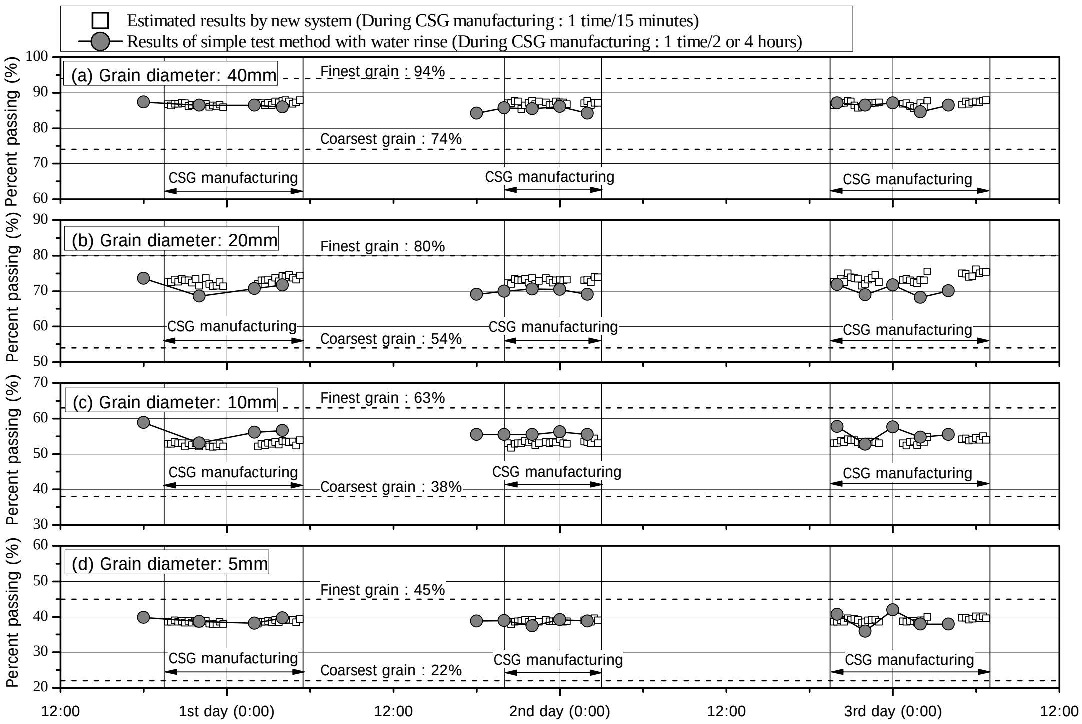

Figure 10. Results of grain size fluctuation monitoring for CSG material

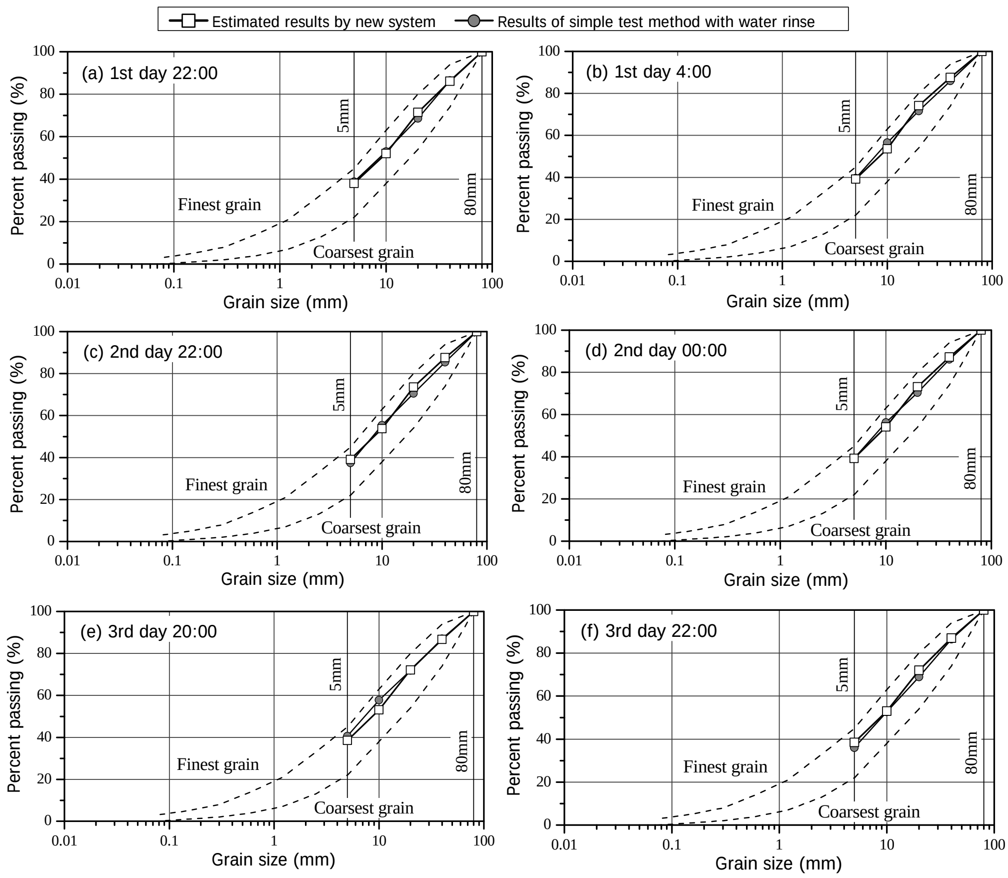

Figure 11. Grain size distribution curves of CSG material estimated by new system

As can be seen in Fig. 10 and 11, the percent passing estimated by the system and the results of the simple test method with water rinse matched well, and hence the system could successfully monitor whether the grain size of the CSG material matches a given grain size range.

3.3. Rationalization of quality control at the time of CSG construction

At the Tobetsu Dam, in addition to utilizing the system to monitor the fluctuation trend of water content of CSG material using a radio isotope moisture meter, called Fluctuation Monitoring System for Water Content of CSG Materials using Radio Isotope Moisture Meter (Ueno et al, 2011), shown in Fig. 12, was introduced for rationalizing quality control in the manufacture of CSG.

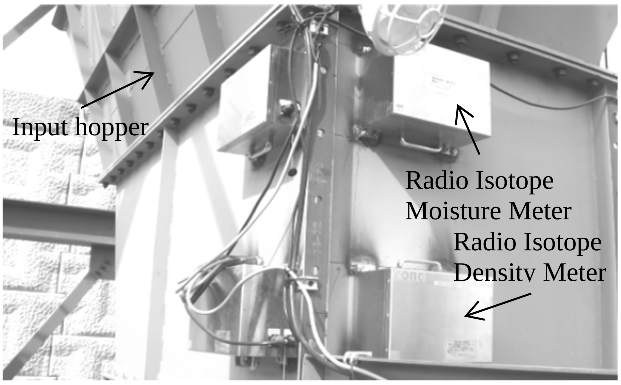

Figure 12. Radio Isotope Moisture Meter at bottom of input hopper for CSG material

Before introducing the two systems, a simple test method for grain size and water content had been implemented once every 2 hours, regardless of the quality fluctuation of CSG material as to the grain size or surface water.

After introducing the systems, however, a new quality control flow for CSG material in conjunction with real-time monitoring for variability in quality was established, as shown in Fig. 13, and subsequent quality control was performed following this flow.

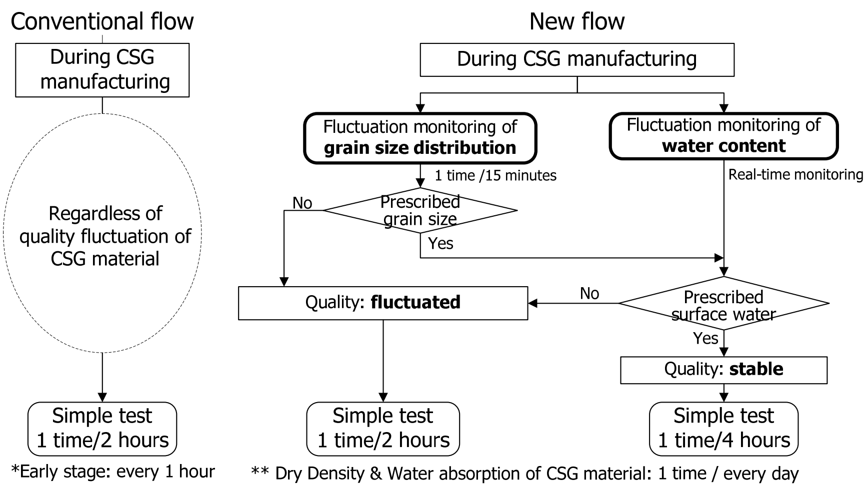

Figure 13. Flow diagram of quality control of CSG material at predefined frequency

The new quality control flow requires the simple test method once every 4 hours while the quality of CSG material is stable, but once every 2 hours when quality fluctuation is detected.

As a consequence of introducing this new quality control flow, the number of quality control tests such as simple test method on CSG material could be reduced by about 40% at the Tobetsu Dam. Both systems aimed at monitoring for variability in quality of CSG material, and water supply at CSG manufacturing was set based on the results of the simple test method. Similarly, after introducing real-time monitoring for variability in quality, the use of both system enables not only that the frequency of quality control tests was reduced, but also that a new quality control system can respond to quality fluctuation of CSG material. Moreover, compared with the traditional quality control that was previously implemented at a fixed time or at a predefined frequency, the new systems can detect sudden fluctuations in the quality of CSG material. All these have contributed to ensuring the quality of CSG.

4. FUTURE DEVELOPMENT

Material management and construction method management are inseparable for ensuring quality in the construction of civil engineering structures including dams.

In construction method management, the real-time management in construction has been achieved due to the recent progress in construction techniques aided by information and communication technology (referred to as ICT construction techniques). By contrast, in material management, traditional sampling inspection plan at a fixed time or at a predefined frequency is still principally used (KUSAKA et al, 2011). However, the Fluctuation Monitoring System for Grain Size Distribution is applicable for real-time monitoring of variability in quality for material management By using this system, real-time material management that is equivalent to ICT construction techniques in construction method management becomes possible, and the system contributes to the sophistication and rationalization of quality control in the construction of not only dams but also other civil engineering structures, as shown in Fig. 14.

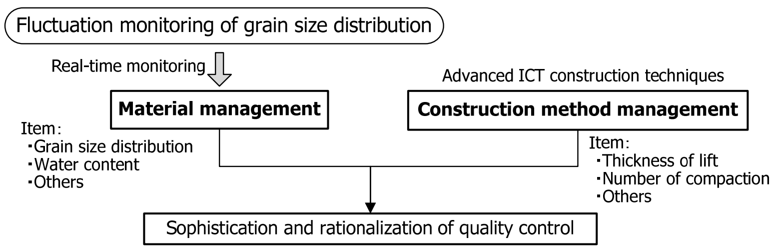

Figure 14. Future development of system

5. CONCLUSIONS

In construction work using fill materials, such as for an earth and rock-fill dam, the management of grain size distribution is the basis of quality control. Given that the CSG method is based on mass rapid sequential construction, the quicker and more continuous quality control method is required.

We have developed the Fluctuation Monitoring System for Grain Size Distribution using Digital Image Analysis aiming at the sophistication and rationalization of quality control for earth and rock-fill dams and trapezoidal CSG dams, and the system was introduced at the Tobetsu Dam.

The findings from the development of the system and its application to the Tobetsu Dam are as follows.

1) The system quickly monitors the fluctuation trend of grain size distribution by analyzing the images of fill materials taken with a digital camera.

2) The system was introduced at the Tobetsu Dam as a method for monitoring fluctuations in grain size distribution at the time of CSG construction, and was used for real-time monitoring of variability in quality of CSG material, in conjunction with the Fluctuation Monitoring System for Water Content of CSG Materials using Radio Isotope Moisture Meter.

3) A new quality control flow for CSG material in conjunction with real-time monitoring for variability in quality was established and quality control was conducted following this flow. As a consequence, the number of quality control tests on CSG material could be reduced by about 40 %. This not only reduced the frequency of quality control tests but also rationalized quality control considering fluctuations in the material quality.

4) Applying the system to material management will enable real-time material management to be equivalent to construction management by ICT construction techniques. As a result, the system contributes to the sophistication and rationalization of quality control in the construction of civil engineering structures.

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