Development of Embankment Material Grading Control Continuous Management System Using Three-dimensional Image Processor

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ABSTRACT:
In dam construction, grading control of embankment material is of vital importance in quality control. The conventional practice is to take samples and carry out sieve analyses at regular intervals, which is both labor- and time-consuming. When constructing a trapezoidal dam with cemented sand and gravel, it is standard practice to produce embankment material by mixing locally available earth material such as riverbed deposits and excavated material with cement and water. In order to achieve the required strength of embankment material, therefore, grading control checks need to be made to ensure that its strength is kept within the allowable range. The authors have developed a new continuous grading management system using three-dimensional image processing technology. The newly developed system makes real-time monitoring of grading possible by irradiating line laser light onto the material on the conveyor, calculating the volume of particles of each size from the image data continuously acquired with a digital camera and thereby determining particle size distribution. The usefulness of the system has been verified by using it for a countermeasure against landslide in which cemented sand and gravel embankment material was used. This paper introduces the new system and reports the field verification results.

Keywords: *three-dimensional image analysis, liner laser, real-time management, particle size distribution, CSG method*

1. INTRODUCTION

In recent years, productivity improvement and labor-saving efforts in dam construction projects have brought about dramatic changes in construction methods. With the evolution of construction methods from the block construction method to the RCD (Roller Compacted Dam-concrete) method and then to the cruising RCD method, the resulting rationalization and mechanization of construction have greatly contributed to the achievement of a shorter construction period and a lower construction cost.
Efforts to improve construction materials have led to the development of trapezoidal CSG (cemented sand and gravel) dams so that concrete dams can be built mostly by use of heavy construction equipment. Improvements have been made in the area of fill dams, too, through the improvement of construction equipment performance, the development of larger construction equipment, and the mechanization of finishing works of excavation and treatment of rock-embankment contact zone. The increasing use of information and communication technology (ICT) has also accelerated construction rationalization through labor saving and automation.
With the progress of construction efficiency improvement and mechanization, new technologies are being introduced in the area of construction management, too.
By improving the image processing technology (Fujisaki et al. 2013; Eda et al. 2014) which has made a remarkable progress in recent years to the extent of being put to practical use in various applications, the authors have developed a continuous grading management system using a three-dimensional image processing system, which is a completely new type of grading management system designed for higher-accuracy real-time management of grading control (hereinafter referred to as the "new system"). The newly developed method aims to manage particle size measurement and control on the basis of the image volume ratio instead of the image area ratio as in the conventional management method. This paper briefly describes the new system and reports the results of the field tests conducted to verify the usefulness of the new system used for the CSG countermeasure against landslide at Asakawa Dam.

2. OVERVIEW OF THE NEW SYSTEM

2.1. Background of development

Embankment material called CSG commonly used for the construction of the main structures of dams is produced by mixing locally available earth material with cement and water without making grading adjustments or washing. Grading control, therefore, is important in order to attain the required strength of CSG mixes. To this end, sieve analysis is carried out manually every one or two hours to check whether the particle size of CSG is within the diamond-shaped area on the strength–unit water content chart. In order to achieve speedy high-volume

placement of CSG mixes, it is necessary to develop a technique for real-time management of quality control.
To achieve this goal, a new method for continuous CSG grading management by use of a three-dimensional image processing system has been developed. The system is capable of automatic measurement of CSG grading by applying the image processing technology (see Fig.1) used in various applications such as completion inspection of automotive parts. The system was in-situ test in the CSG embankment work at Asakawa Dam.

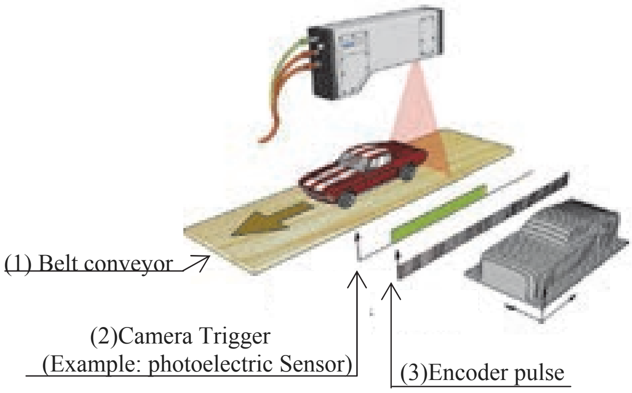


Figure 1. Line laser camera used in a production line

2.2. Image processing technology: challenges and solutions

Processing of digital image data involves processing the image data obtained from an input device such as a camera or a scanner to extract desired image information. To do that, a number of problems had to be solved:

① Since clear images are needed, there is a need for photography techniques, including lighting and shooting techniques, that make it possible to obtain clearly defined images of each particle.
② There is a need for an image processing technology to remove unnecessary image elements (dirt) from the recorded images.
③ There is a need for an image processing (edge processing) technology that makes it possible to recognize, from image data, each of a number of particles in contact with one another as an individual particle.
④ The number of particles recorded in a single image is too small for grading measurement.
In order to separate individual particles from a conglomerate of particles in recorded image data, it is necessary to perform edge processing (e.g. binarization with a Laplacian filter, wavelet transform) of two-dimensional image data. It was known, however, that real-time grading control by that method was not possible because the computing capability required was not available.
As the first step, therefore, a study was conducted to determine how the test sample can be mechanically dispersed so as to shorten image processing time and improve the accuracy of analysis. The previously developed method of dropping the sample was tested, but the method turned out to be inadequate because of problems such as low image quality (poor focusing), inadequate dispersion of fine particles and long image acquisition time. It was necessary, therefore, to come up with a completely different approach to sample dispersion. As a result, it was decided to disperse the sample by use of the velocity difference between the belt feeder and the belt conveyor.
The image processing method was determined by searching for a method that does not require edge processing as part of two-dimensional image processing. For real-time grading measurement of CSG, the author turned attention to a three-dimensional (3D) line laser camera (3D smart camera) system used for such applications as the completion inspection of automotive parts. In view of the fact that the 3D line laser camera system is capable of instantaneously measuring the volume of CSG by continuously acquiring three-dimensional surface profile data, the authors decided to use the system, thinking that it would probably make real-time grading management possible.

2.3. Preliminary experiments with 3D line laser camera

An experiment using a 3D line laser camera system was conducted by using the setup shown in Fig. 2.
The experiment was conducted by using the optical cutting method in which three-dimensional measurement can be made by combining a two-dimensional digital camera and a line laser system.
Fig.1 illustrates the principle of three-dimensional imaging. As shown, line laser is irradiated to the sample (in the illustration, the automobile) on the moving table (for example, a belt conveyor), and the image of the laser light striking the surface of the sample is recorded with a diagonally positioned two-dimensional digital camera.

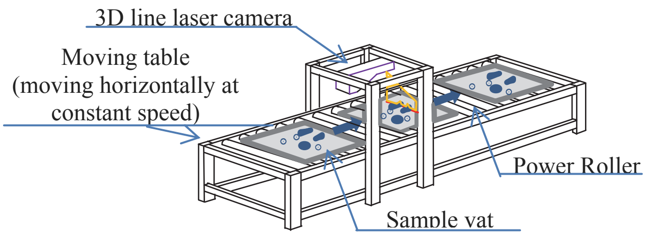


Figure 2. Preliminary experiment apparatus using 3D line laser camera

The images thus obtained are turned into profile data and converted to three-dimensional data on the computer. The locus of points lit up by the laser light is recorded, and three-dimensional images are generated from continuously recorded images. In short, the principle is the same as mathematical integration for volume calculation. High-speed image analysis is made possible by extracting only height information from the profile data in the camera and reducing the extracted information to single-line data.

In the three-case experiment using the apparatus mentioned above, the degree of dispersion and arrangement of CSG samples on the moving table were varied. Although the results in the three cases should have been identical, the measurement results showed errors but they were within 1.5% (Table 1). Thus, it has been shown that the measuring system excels in reproducibility (see Fig. 3).

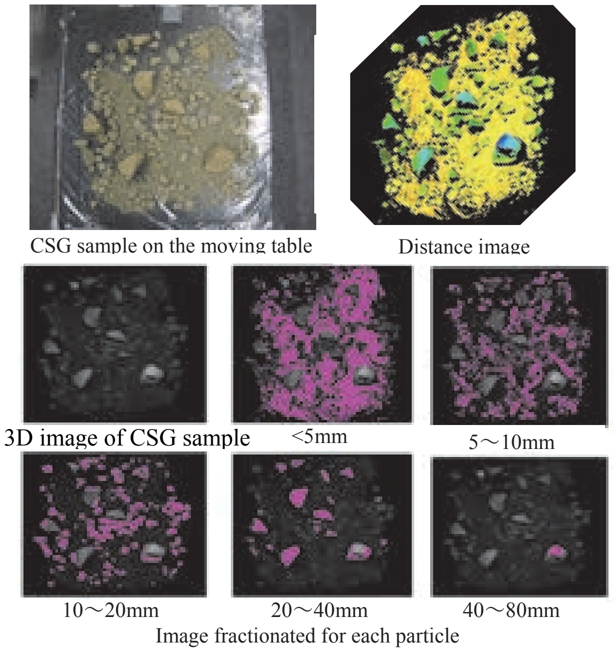


Figure 3. Images from preliminary experiment conducted by using 3D line laser camera

Table1. Results of preliminary experiment using 3D line laser camera (particle size content based on image analysis)

Particle size	<5mm	5-10mm	19-20mm	20-40mm	>40mm
case1	24.17	10.52	8.75	4.06	0.24
case2	25.71	10.93	8.59	3.39	0.27
case3	24.50	10.66	8.83	3.74	0.42
max-min(%)	1.54	0.41	0.24	0.33	0.18

3. SYSTEM CONFIGURATION

In view of the results of the preliminary experiment, a particle size measuring system for in-site test was developed. As shown in Fig. 4, the new system consists of a feeding hopper, a belt feeder, a belt conveyor and a 3D line laser camera (see Figs.4 and 5).

3.1.1. Dispersion device

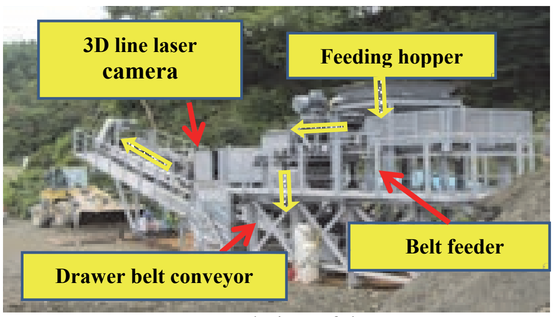
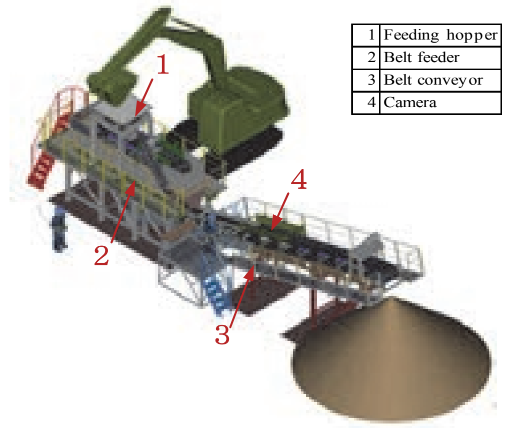


Figure 4. General view of the system

The velocity difference between the belt feeder and the belt conveyor was used as a dispersion method by which to recognize individual particles more accurately at the image processing stage. The effectiveness of the dispersion device was checked in advance, and the belt feeder speed and the belt conveyor speed were set to 1 m/min and 75 m/min, respectively. As a result, the CSG mix fed by the belt feeder onto the belt conveyor in the form of a 10-centimeter-thick layer was dispersed to a thickness (theoretical) of 1.3 mm.



view of dispersing device

3.1.2. 3D Line laser camera system

As an image acquisition device, a 3D line laser camera designed for the optical cutting method was used. The camera was set so as to acquire 800 profiles (3D profiles of the CSG mix moving on the belt conveyor) per second. This means that if the belt conveyor speed is 75 m/min, 0.16-centimeter-wide profiles are acquired (Fig. 6). The camera was installed in a darkroom so that the reflected light can be seen clearly.

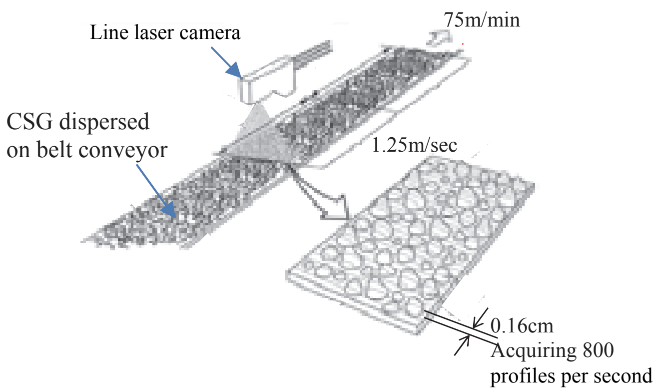


Figure 6. Optical cutting method using line laser camera

equipment were kept apart, and impact bars were installed to the belt conveyor so as to keep the distance between the conveyor surface and the camera unchanged and keep the surface flat.

3.2. Overview of system performance verification

3.2.1. Material used

The material used for the system performance verification was the same as the CSG mix used for the countermeasure against landslide at Asakawa Dam. The material was smaller-than-80-mm andesite (Neogene volcanic rock) particles obtained by using a mobile screen.

3.2.2. Verification method

Fig.7 illustrates the flow of the verification process.

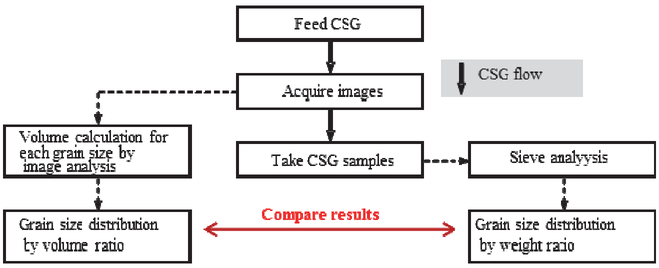


Figure 7. Field verification flow**Figure 5.** Schematic

To evaluate the influence of differences in the condition of the CSG mix, samples were taken at different locations and verification tests were conducted on different days. Ten samples were measured on each day, and a total of 30 samples were used.

Thirty kilograms or more of each sample was used, and, by using all samples collected (about one minute), comparisons were made between the particle size distribution calculated through image processing (a volume ratio based on the height from the belt conveyor surface determined by analyzing the entire image was taken to be the particle size ratio) and the particle size distribution determined through sieve analysis (simplified manual sieve analysis) (see Figs. 8 and 9).

3.3. Field verification result

3.3.1. Grading comparison: image processing vs. sieve analysis

Fig.10 shows the test results of comparison of grading by image processing and sieve analysis. The Case 1 to Case 3 results show the averages of the values obtained from a total of 10 samples in each case. The solid lines show sieve analysis results, and the dotted lines represent volume ratios determined through image processing.

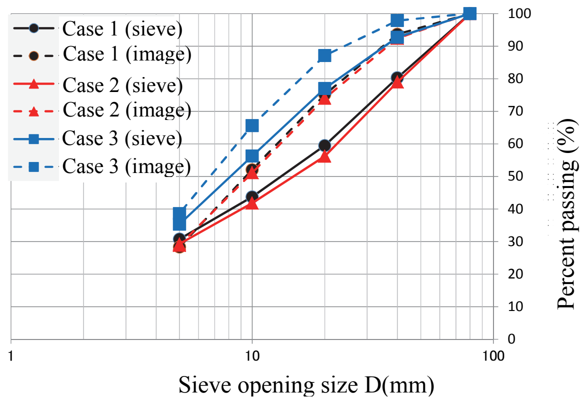


Figure10. Comparison of particle size distribution determined through image processing and sieve analysis

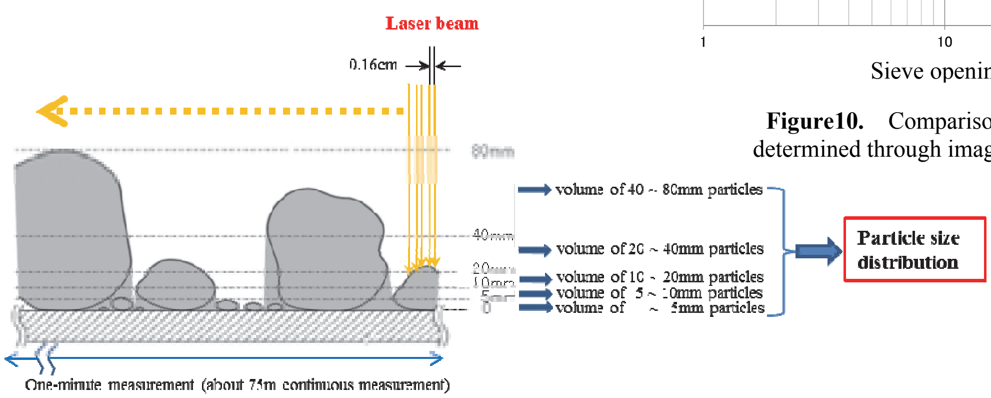


Figure 8. Schematic view of particle size distribution by volume ratio through image processing

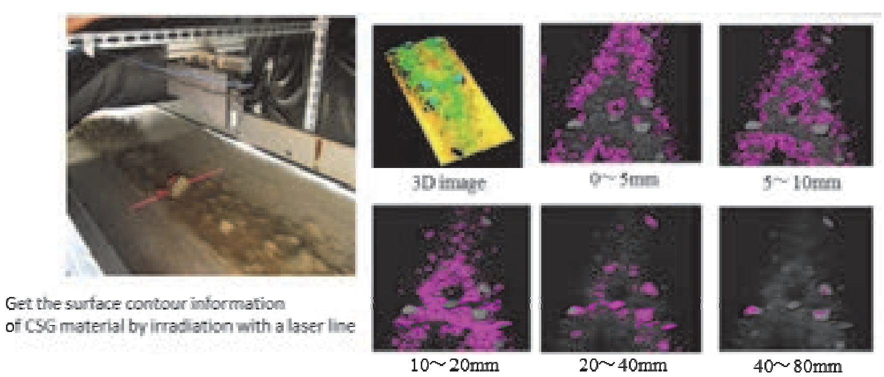


Figure 9. Slice images showing particles of different sizes acquired with the line laser camera

The particle sizes determined through image processing were obtained by calculating the volume ratio, by equating the distance (height) from the belt conveyor surface with the sieve opening size (5, 10, 20 and 40 mm) used in sieve analysis, from the three-dimensional model obtained through image processing and converting the volume ratio to particle size distribution.

As shown in Fig. 10, the volume ratios obtained through image processing differed considerably from the weight ratios determined through sieve analysis.

The authors thought of the possibility that the density differences among different particle sizes caused the differences mentioned above. Comparison was made, therefore, with the weight ratios obtained by calculating the weight per unit image volume for each particle size category and using the weight thus determined as a coefficient to be multiplied by the volume ratio. The comparison revealed, however, that the differences remained unchanged.

3.3.2. Volume ratio correction based on optimum threshold

The authors then thought that the particle size differences shown in Fig. 10 were attributable to oblateness of CSG particles and decided to make threshold-based corrections when classifying three-dimensional models obtained through image processing.

The reason why the authors thought so is that particle size differences will naturally result if the height from the belt conveyor surface is assumed to be equal to particle size because image acquisition was made when the particles were in a stable condition. To be more specific, the authors thought that if the particles are oblate in shape as shown in Fig. 11, the intermediate edge length *b* should be used as the particle size of the circumscribed rectangular parallelepiped, but actually the shortest edge length *c* was used to determine particle size distribution.

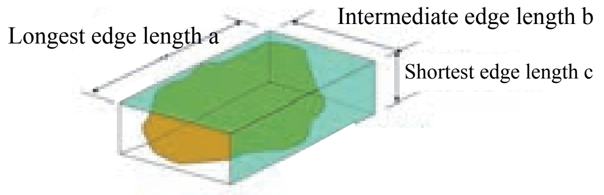


Figure 11. Circumscribed rectangular parallelepiped

Hence, the authors decided to find the threshold that makes the relation "volume ratio = weight ratio" hold true. Although the 30 samples used in the verification experiment had different thresholds, it was decided to use common values (thresholds) obtained through statistical processing. The optimum thresholds used for the verification experiment were 0, 5, 8.5, 14 and 27 mm, while the particle size thresholds used for the sieve analysis were 0, 5, 10, 20 and 40 mm. Fig. 12 compares the volume ratios calculated by using the optimum thresholds and the weight ratios determined through the sieve analysis. As shown, the curves, which showed significant differences in shape in Fig. 12, now show smaller differences.

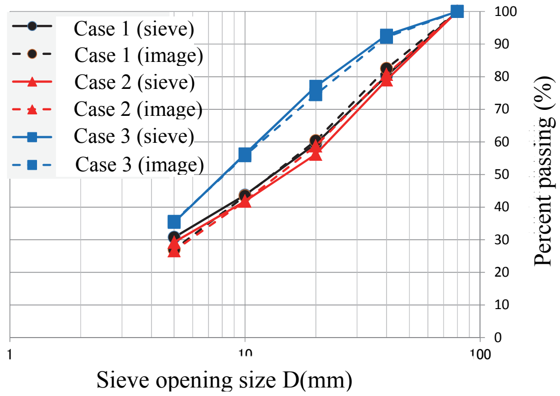


Figure12. Relationship between the optimum threshold-based volume ratio and the weight ratio

Fig.13 shows the cumulative percentages of different particle sizes determined through sieve analysis (weight ratio) and through image processing (volume ratio). The differences were within about ±5%.

The optimum thresholds were calculated as follows. The volume ratio was calculated in steps of 0.5 mm in the height from the belt conveyor surface. Then, a threshold histogram corresponding to the sieve analysis results (weight ratio) was produced, and an optimal value close to the median was taken as the optimum threshold.

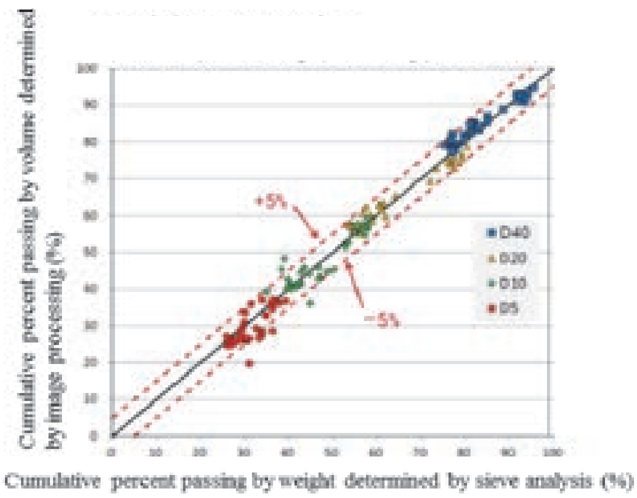


Figure 13. Comparison of particle size distributions: sieve analysis (weight ratio) vs. image processing (volume ratio)
(Cumulative percent passing: sieve analysis vs. image processing (Cases 1 to 3))

4. FUTURE OPERATIONAL

There has been growing demand in recent years for labor saving in public works projects because of the shortage of construction workers, as well as for the reduction of cost and environmental stress. In the area of quality control, too, there is a growing need to make redoubled efforts to make automatic instrumentation and real-time management possible.

To meet these needs, the authors have developed a new method for continuous particle size measurement of CSG mixes by use of a three-dimensional image processing system so as to automate particle size measurement and reflect measurement results in construction work in real time.

The newly developed technology makes high-accuracy measurement possible by performing the simple and easy-to-understand task of calculating the volume of mechanically dispersed earth material by use of a commercially available camera and processing the obtained results statistically.

Since the profile of irradiated line laser light is recorded with a 3D line laser camera, measurement results are not affected by such factors as background color, lighting conditions, the color and shade of the subject, and sticking dirt.Particle size measuring systems using conventional image processing technology are not capable of real-time measurement because edge processing is time-consuming. The new system performs all processing tasks from 3D surface profile data acquisition to the conversion from particle size–volume data based on optimum thresholds and the calculation of particle size distribution (weight ratio) in several seconds.

The authors believe that the technology can be applied to not only the CSG method but also other construction methods that use mixtures of ordinary earth materials and cement.

The new system has made it possible to monitor particle size control, which at present can only be performed after placement, in real time. The method of facilitating the management of the moisture content of embankment material by using such instruments as nuclear gauges has already been put to practical use. The authors believe that since particle size and moisture content can be controlled in real time, it is now possible to automatically adjust the quantities of cement and water to be added to the mix being used according to the measured weight of the material on the belt conveyor. It is hoped that the newly developed method is utilized to make fully automated production of cement-based mixes possible.

5. CONCLUSIONS

The knowledge gained from the development of the new system and the field test conducted at Asakawa Dam in connection with countermeasure against landslide using CSG:

(1) Application to various sites and materials made possible by simple image acquisition settings.

Measurements can be obtained simply by dispersing the CSG mix by use of a belt feeder (1 m/min) and a high-speed belt conveyor (75 m/min).

(2) Speedy data acquisition without using sophisticated analysis program (image analysis based on the volume ratio instead of the area ratio).

It is now possible to acquire data in one minute and output particle size distribution measurement results in real time.

(3) Continuous 100% measurement

The new system determines particle size distribution from the volume of all CSG mix put into the testing apparatus. The quantity of samples analyzed, therefore, is always greater than the minimum quantity of samples that need to be taken. As a result, measurement results are free from the influence of uneven sampling and sample quantity, and measuring accuracy is improved (the system is capable of measuring 100 kg or more per minute of CSG mixes).

(4) Simple calibration

In preparation for measurement by use of the new system, image volume is determined in steps of 0.5 mm in the height from the belt conveyor surface from the three-dimensional surface profile of the CSG mix passing in the specified time period (one minute), and the obtained values are compared with the measured values (particle size data) obtained in advance through sieve analysis. The heights thus determined as the values closest to the particle size distribution are regarded as optimum thresholds. In about one day prior to system operation, optimum threshold heights can be determined by carrying out calibration for about 30 samples. Since the differences between the measurement results obtained from the new system and the measurement results obtained through sieve analysis are within about 5%, the proposed method can be used as a particle size measuring method in place of sieve analysis.

(5) Quality control through real-time particle size measurement.

The new system is capable of converting one-minute measurement results in a short period of time (about one minute) for comparison with the specified range. Particle size management can be performed in real time instead of in an ex post facto manner. If particle size distribution is likely to deviate from the specified range, the quality control manager is automatically notified in real time so that corrective action can be taken in a timely manner.

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