INTERNATIONAL SYMPOSIUM ON
DAMS FOR A CHANGING WORLD
-Need for Knowledge Transfer across the Generations & the World
Kyoto, Japan June 5, 2012

A Comparative Study on Grain Size Analysis for Sediments Flowing into Reservoirs

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ABSTRACT:
The objective of this study was to present an appropriate method for grain size analysis of sediments flowing into reservoirs. In the numerical simulation of reservoir turbidity, it is important to have accurate data on the particle settling rate. Laser diffraction is typically used for grain size analysis and the settling rate is converted by Stokes formula; however, it has been indicated that the settling rate calculated by this method differs from the actual rate. We conducted grain size analysis using three different methods, i.e., settling cylinder, centrifugal sedimentation and laser diffraction. A comparison of the results led to the following conclusions: (1) Settling cylinder was the most reliable method for obtaining the settling rate of fine particles. (2) Centrifugal sedimentation was a viable alternative to the settling cylinder method. (3) Laser diffraction provided grain size distribution similar to the settling cylinder method by applying supersonic distribution treatment.

Keywords: numerical simulation of turbidity, grain size analysis, settling cylinder method, centrifugal sedimentation method, laser diffraction method

1. INTRODUCTION

Long-term persistence of water turbidity is a water quality problem for reservoirs in Japan. Various countermeasures have been adopted, including the installation of selective intake facilities and fences to control the diffusion of turbidity (Fig. 1). Bypass channels for releasing clear water from the upstream of a reservoir have also been adopted with highly effective results. For the preparation of design specifications and practical use of these facilities, the turbidity and temperature of the reservoir water are numerically simulated, which requires accurate data on the particle settling rate.

The objective of our study was to present an appropriate method for determining grain size distribution, which is necessary for obtaining the settling rate of soil particles for numerical simulation of reservoir turbidity. First, we collected samples of turbid water from two reservoirs after a heavy storm and observed the settling rate of particles in a settling cylinder. The Stokes formula was used to convert the settling rate to grain size for analysis of grain size distribution. Second, we analyzed the grain size distribution of turbid water by using laser diffraction and centrifugal sedimentation. In both methods the grain size distribution was easily obtained. Lastly, we compared the results of the three analysis methods, i.e., settling cylinder, centrifugal sedimentation and laser diffraction to present an appropriate method for determining grain size distribution.

Figure 1. Long-term persistence of turbid water at Kawaji Dam (December 2007)

2. INVESTIGATION PROCEDURE

In preparation for the experiment, we collected samples of turbid water flowing into two reservoirs after a heavy storm in September 2007. The collection sites were the Kawaji Dam reservoir in Tochigi Prefecture and the Shimokubo Dam reservoir in Saitama Prefecture. The investigation procedure is described below.

2.1. Measuring Method of Grain Size Distribution

To conduct a numerical simulation of reservoir turbidity, it is necessary to determine the settling rate distribution of soil particles. Grain size analysis is typically done by laser diffraction or centrifugal sedimentation and the settling rate is converted by Stokes formula. Both methods easily handle the task. On the other hand, the settling cylinder method gives a more accurate settling rate; however, the cylinder size and measuring specifications are not standardized. In this study, we conducted grain size analysis by settling cylinder, centrifugal sedimentation and laser diffraction, and then, compared the results. A diagram of the settling cylinder used in this study is shown in Fig. 2. The specifications of the measuring methods are listed in Table 1.

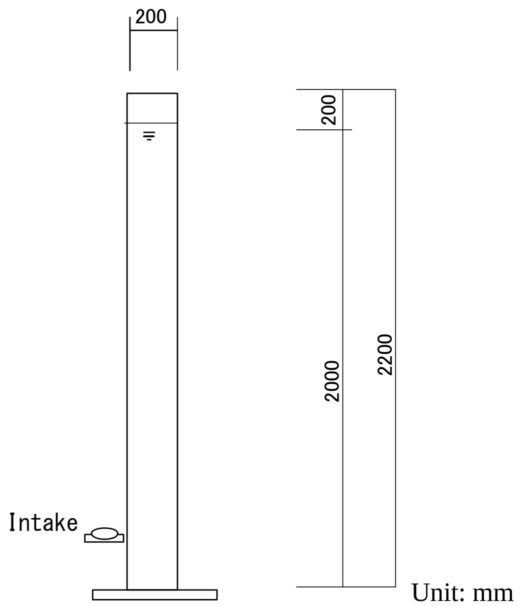

Figure 2. Diagram of settling cylinder

Table 1. Specifications of Measuring Methods

Measuring method	Settling cylinder	Centrifugal sedimentation	Laser diffraction
Measuring instruments	Settling cylinder ϕ200mm× L2.2m	SKC-2000 Seishin Co.,Ltd.	SALD-3000S Shimadzu Co.,Ltd.
Measuring conditions	Constant temperature (20℃)	Range: 0.3-50 μm	Range: 0.05-3000μm
Measuring items	Water level, Suspended solids (SS), Water temperature	Grain size distribution	Grain size distribution
Measuring procedure	Turbid water is poured to a depth of 2m. Water sample is collected from 0.5m above the bottom. SS of water is analyzed.	100mL of turbid water is placed in the device, and then the device is operated.	50 to 100mL of turbid water is placed in the device and then the device is operated.
Measuring intervals	11 times. (0, 1, 3, 6, 12, 24 hours, then 3, 7, 14, 21, 42 days)	1 time	1 time
Others	Unfixed measuring method	Few instruments	Ordinarily adopted

The conversion method from settling rate to grain size is as follows:

If a particle in water is considered to settle at distance l from the water surface to the intake within time t , the average settling rate $w(t)$ is given by:

$$w(t) = \frac{l}{t} \tag{1}$$

Among time t, the share of already settled suspended solids $F_1(t)$ is equal to the difference in suspended solids between the start of the experiment ($t = 0$) and t, so that $F_1(t)$ is presented as Eq.2.

$$F_1(t) = \frac{SS_{t=0} - SS(t)}{SS_{t=0}} \tag{2}$$

In Eq.2, $F_1(t)$ gradually decreases with time and one variation of Eq.2 is presented as Eq.3. This equation corresponds to the grain size accumulation curve and gradually increases with time.

$$F_2(t) = \frac{SS(t)}{SS_{t=0}} \tag{3}$$

Under conditions of single globular particle settlement, moreover, where the particle Reynolds number ($Re = d \cdot w_s / \nu$) is less than 1, the particle diameter and settling rate can be mutually converted.

$$w_s = \frac{d^2 g(\rho_s - \rho_w)}{18\mu} \tag{4}$$

In Eq.(4), w_s is particle settling rate , d is the particle diameter, g is the gravity acceleration, ρ_s is the particle density, ρ_w is the water density, and μ .is the viscosity coefficient of water. The diameter d is referred to as the Stokes diameter because it is calculated from the settling rate by applying the Stokes formula. In the settling cylinder method, turbid water was poured up to a depth of 2m, and then water depth variation, water temperature and suspended solids were measured at predetermined intervals.

2.2. Determination of Settling Rate

As mentioned earlier, in a numerical simulation on reservoir turbidity, grain size analysis is typically done by laser diffraction and the settling rate is converted by Stokes formula; however, it has been indicated that the settling rate calculated by this method differs from the actual rate. In the settling cylinder method, the settling rate distribution is directly measured by observing the variation in suspended solids with time, which is considered to give an accurate settling rate. To ensure clarity, grain size distribution rather than settling rate distribution is compared in the following section..

2.3. Grain Size Calibration

Soil colloidal particles contained in turbid water tend to move at random and are affected by interaction with the surroundings. Soil colloidal particles can collide with one another and a strong attraction among particles can result in the formation of flock. In grain size analysis, a larger distribution could be obtained if flocculated particles are directly measured, leading to the overestimation of settling rate distribution.

To avoid an overestimation in this study, distribution treatment was applied to experimental cases for both laser diffraction and centrifugal sedimentation. An FU-10C supersonic distributor manufactured by TGK Co., Ltd. was used for the distribution treatment. The predetermined duration of supersonic distribution at 60W, 28kHz was applied to 1L of turbid water. The method of distribution is shown in Table 2.

Table 2. Distribution of Soil Particles in Turbid Water

Measuring method	Distribution methods	
	Non-distribution	With distribution
Centrifugal sedimentation method	Stirring by hands	10 minutes of supersonic distribution (60W)
Laser diffraction method	Stirring by hands	10 minutes of supersonic distribution (60W)

2.4. Experimental Procedure

First, we collected samples of turbid water flowing into the Kawaji Dam reservoir and Shimokubo Dam reservoir after a heavy storm in 2007. Suspended solids were 1,160 and 42 mg/L at the Kawaji and Shimokubo reservoirs, respectively. The turbid water sampled at the Shimokubo reservoir was relatively clear. Grain size distribution of the samples was analyzed by settling cylinder, centrifugal sedimentation and laser diffraction, and in some cases, supersonic distribution treatment was applied. In addition to the grain size analysis, the grain shapes were examined through a microscope. Lastly, the difference in grain size distribution among the threemethods was assessed. The experimental cases are shown in Table 3 and Table 4.

Table 3. Experimental cases (1)

Case No.	Sample	Measuring method	Distribution treatment	Result
1	Kawaji Dam	Settling cylinder	Without distribution	Figs. 3,4.
2	Kawaji Dam	Centrifugal sedimentation	Without distribution	Fig.3.
3	Kawaji Dam	Centrifugal sedimentation	With distribution	Fig.3.
4	Kawaji Dam	Laser diffraction	Without distribution	Fig.4.
5	Kawaji Dam	Laser diffraction	With distribution	Fig.4.

Table 4. Experimental cases (2)

Case No.	Sample	Measuring method	Distribution treatment	Result
6	Shimo-kubo Dam	Settling cylinder	Without distribution	Figs. 5,6.
7	Shimo-kubo Dam	Centrifugal sedimentation	Without distribution	Fig.5.
8	Shimo-kubo Dam	Centrifugal sedimentation	With distribution	Fig.5.
9	Shimo-kubo Dam	Laser diffraction	Without distribution	Fig.6.
10	Shimo-kubo Dam	Laser diffraction	With distribution	Fig.6.

3. RESULTS

3.1. Comparison of Grain Size Distribution

The results for the Kawaji Dam reservoir are shown in Figs 3 and 4, and those for the Shimokubo Dam reservoir are shown in Figs. 5 and 6. The results for the Kawaji showed good correspondence between the settling cylinder method and centrifugal sedimentation method (without distribution), especially in the range of less than 2 μm. On the other hand, the results of the laser diffraction method (without distribution) showed a relatively larger size distribution compared with the settling cylinder and centrifugal sedimentation methods.

The results for the Shimokubo reservoir also showed good correspondence between the settling cylinder method and centrifugal sedimentation method (without distribution), especially in the range of less than 5 μm, which is a wider range compared to that of the Kawaji.

In the experimental cases with supersonic distribution treatment, we obtained the following results. For the Kawaji reservoir, the difference in grain size distribution was small for the two methods, i.e., with and without distribution (Figs 3 and 4). However, for the Shimokubo reservoir, the difference was larger (Figs 5 and 6). Moreover, the centrifugal sedimentation method with supersonic distribution treatment showed finer grain size distribution compared with the settling cylinder method.

The results of the above investigation and experiments revealed that grain size distribution similar to that in the settling cylinder method could be obtained by using the centrifugal sedimentation method without distribution treatment; however, the laser diffraction method gave a relatively large grain size distribution especially in the fine particle size range and differed from the results of the settling cylinder method.

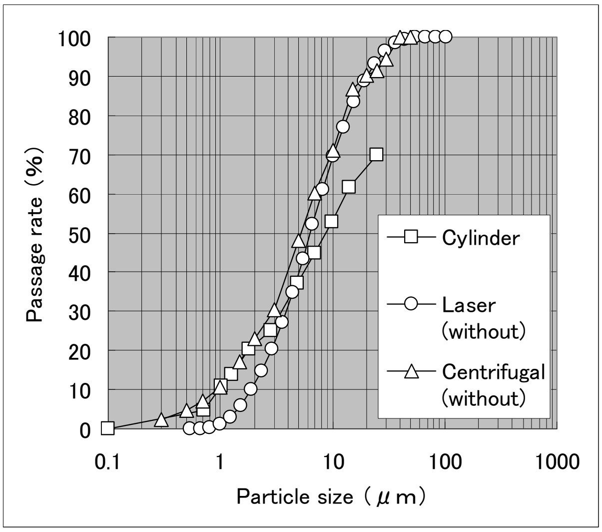

Figure 3. Grain size distribution at the Kawaji Dam (1)

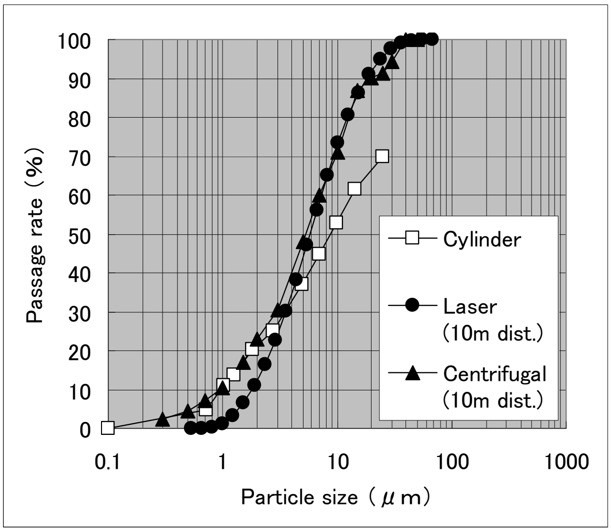

Figure 4. Grain size distribution at the Kawaji Dam (2)

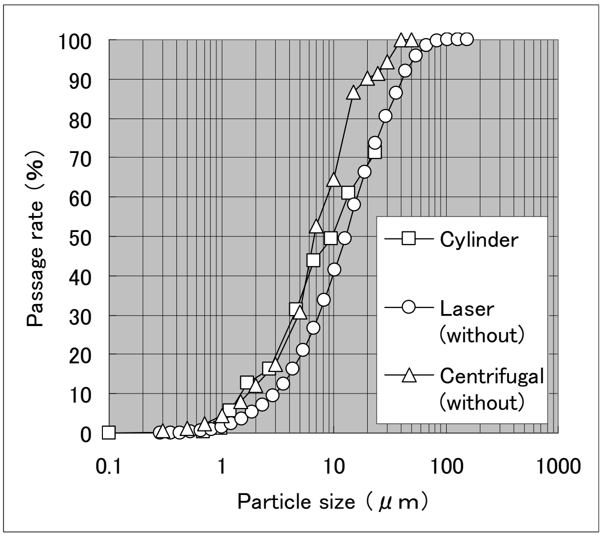

Figure 5. Grain size distribution at the Shimokubo Dam (1)

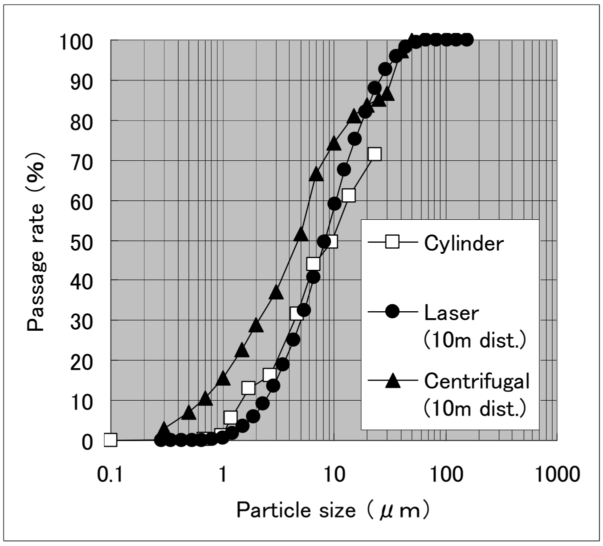

Figure 6. Grain size distribution at the Shimokubo Dam (2)

3.2. Observation of Grain Shapes

The shapes of grain particles were observed through a microscope as seen in the images in Figs 7 and 8. The Kawaji photo shows several particles of 10-20μm composed of planar pieces and angular shaped particles. The Shimokubo photo shows numerous planar pieces of 5-10μm and some fragment particles of more or less than 7μm. Our observation of grain shapes revealed that turbid water flowing into both reservoirs was mainly composed of thick and planar shaped particles.

In the laser diffraction method, the particle size was converted to diameter of spherical particles. If particles were planar shaped, observations by the laser diffraction method could give a faster settling rate than the actual one. On the other hand, the settling cylinder method gave an accurate settling rate since it is based on direct measurement.

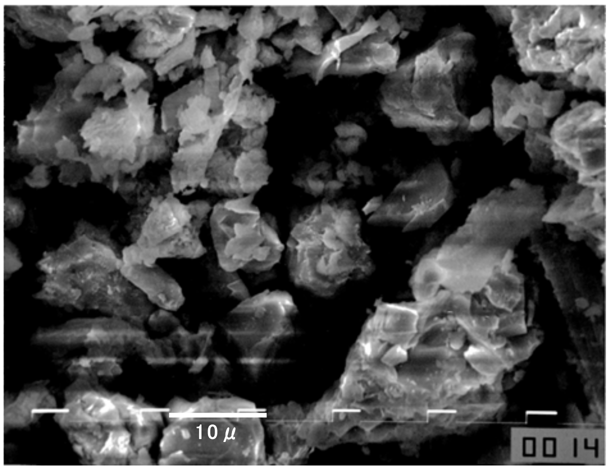

Figure 7. Shape of particles in Kawaji Dam (×2000)

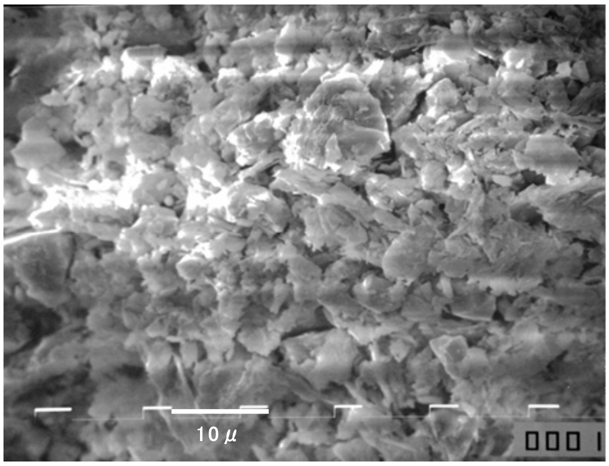

Figure 8. Shape of particles in Shimokubo Dam (×2000)

4. CONCLUSIONS

The following three conclusions were drawn from the results of this study; (1) The settling cylinder method was the most reliable approach for obtaining the settling rate of fine particles; (2) Centrifugal sedimentation was a viable alternative to the settling cylinder method; and (3) Laser diffraction obtained a grain size distribution similar to that of the settling cylinder method by applying supersonic distribution treatment.

ACKNOWLEDGEMENT

We were able to obtain sample water and hydraulic data with the kind cooperation of the Kawaji Dam Branch Office of MLIT and the Shimokubo Dam Management Office of JWA. We express our sincere thanks to both organizations.

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