Comparative Study On Settling Rate Evaluation For Soil Particles In Reservoirs

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ABSTRACT:
This study aims to present an appropriate method on settling rate evaluation for soil particles in reservoirs. For the execution of numerical simulation on sediment in reservoirs, it is indispensable to decide the settling rate of soil particles. Laser diffraction method has been commonly used for grain size analysis and grain size is converted into settling rate by Stokes' Formula, nevertheless, it has been indicated that the settling rate calculated by this method differs from the actual one. We obtained turbid water from a river while flooding, investigated and compared settling rate distribution by settling cylinder method, centrifugal sedimentation method and laser diffraction method. Settling cylinder method could give reliable results, but it needs a plenty of turbid water and took long time to get results. Centrifugal sedimentation method could shorten time for analysis, but the equipment for this method is not disseminated. The laser diffraction method has been regarded as the standard method. We estimated that actual settling rate was slower than calculation of the Stokes' Formula because several particles formed flocks and each flocks was porous. Through this study three points were concluded. (1) Settling cylinder method was the most reliable for evaluating the settling rate of fine particles. (2) Centrifugal sedimentation method could alternate the settling cylinder method. (3) In case of using laser diffraction method, similar settling rate distribution to settling cylinder method could be obtained by ultrasonic distribution treatment.

Keywords: Reservoir, Soil Particles, Settling Rate, Settling Cylinder, Laser Diffraction Method.

1. INTRODUCTION

Sediment accumulation is one of management problems for reservoirs in Japan (Fig. 1.). Some bypass channels for releasing turbid water from upstream of a reservoir have been adopted and the effects have been highly evaluated. In case of designing specifications and practical use of sediment releasing facilities, numerical simulations for sediment accumulation in reservoirs have been conducted. For accurate simulations, the evaluation of settling rate is important matter.

This paper aims to present an appropriate method for determining settling rate of soil particles. Firstly, we collected turbid water from a site of mountainous river while heavy rainfalls and observed settling rate of particles in settling cylinder. Secondly, we analyzed grain size distribution of turbid water by using laser diffraction method and centrifugal sedimentation method. These two methods were relatively easy to get grain size distribution and then applied Stokes' Formula to the conversion from grain size into settling rate distribution. Finally, we present an appropriate method for determining settling rate distribution by comparing the results of three methods, i.e., settling cylinder method, centrifugal sedimentation method and laser diffraction method.

Figure 1. Accumulated Sediment in Nibutani Dam

2. PROCEDURE OF INVESTGATION

In the former paper, presented in ICOLD Kyoto 2012, we had reported the results of investigation by analyzing the two samples of turbid water flowing into reservoirs after heavy storm in September 2007. When we presented that paper, we got a comment that we should compare and discuss the differences of settling rate distribution of soil particles instead of grain size distribution. In this paper, we report the settling rate distributions of four samples collected in Yamaguchi River, Tonegawa River System, Ibaraki Prefecture in Japan while in heavy rainfalls in September, 2010 (Fig. 2.). The procedure of investigation will be described below.

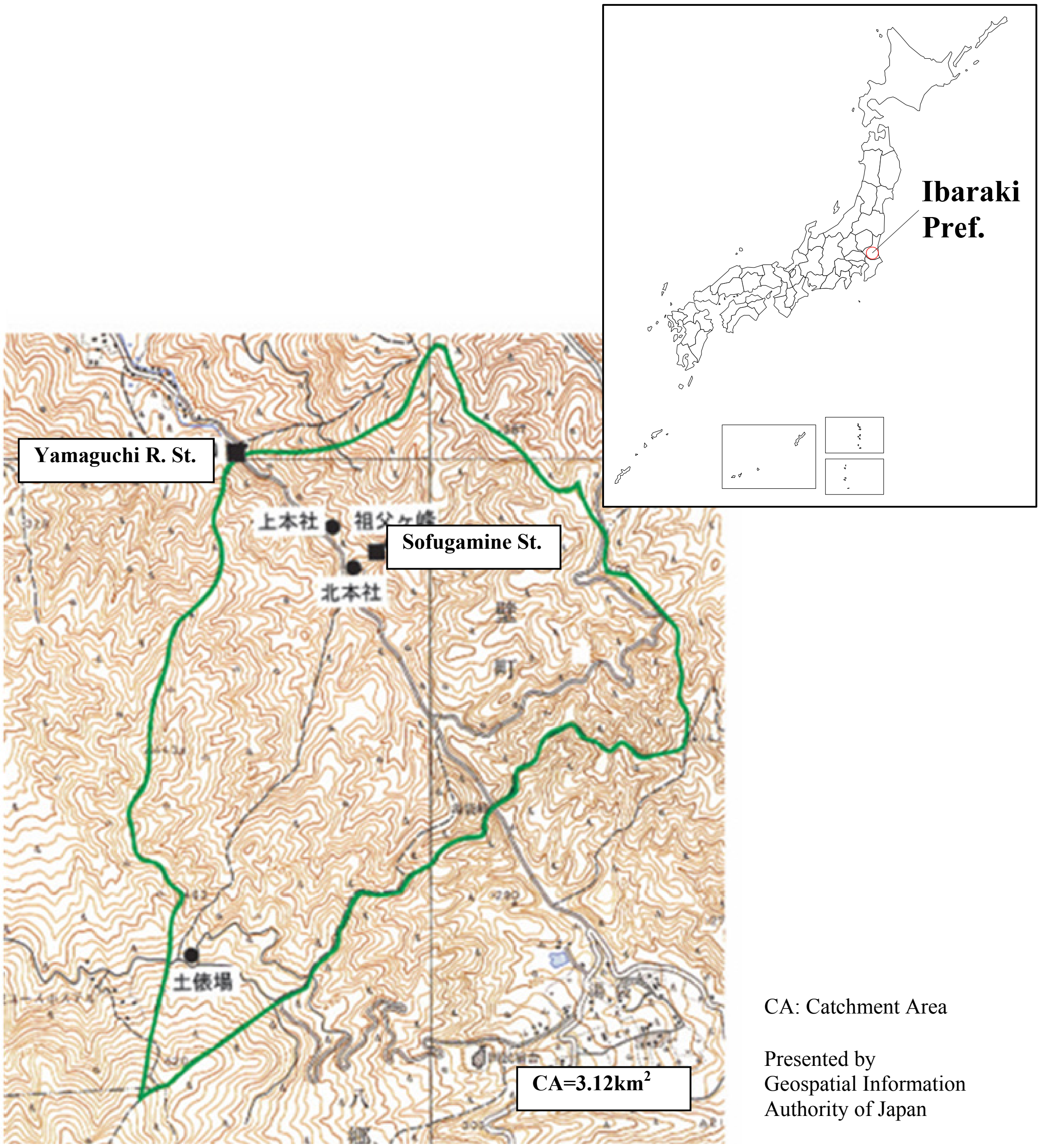


Figure 2. Location of Sampling Site

2.1. Measuring Method of Settling Rate Distribution

In case of conducting numerical simulation of sediment accumulation in reservoirs, it is necessary to determine settling rate distribution of soil particles. Laser diffraction method has been commonly used for grain size analysis of fine soil particles and settling rate is converted by Stokes' Formula because these methods do not need much effort to get result. On the other hand, an accurate data of settling rate can be given by conducting settling cylinder method, however, the size of cylinder and measurement specifications have not been standardized. In this report, we conducted three types' settling rate analysis, i.e., settling cylinder method, centrifugal sedimentation method and laser diffraction method and compared the results. The shape of settling cylinder used in this study is shown in Fig. 3. The specification of measuring method is shown in Table 1.

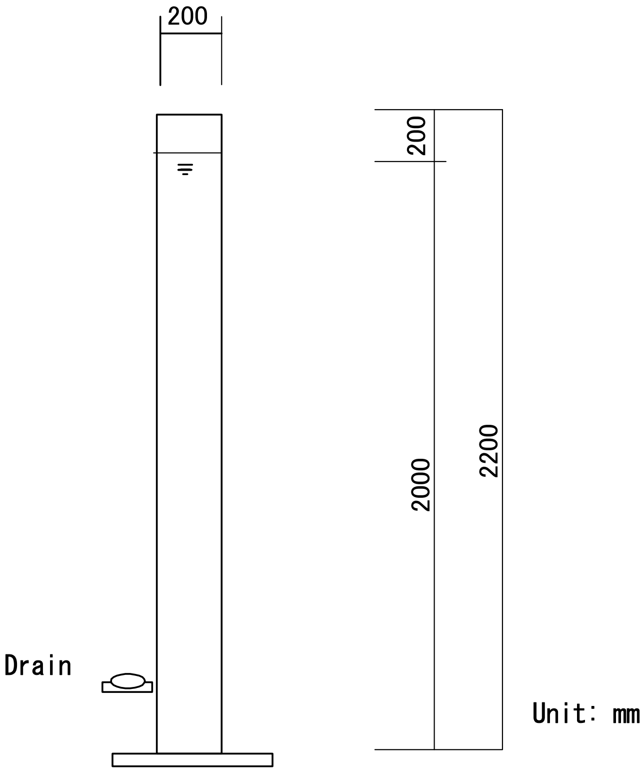


Figure 3. Shape of Settling Cylinder

Table 1. Measuring Method of Settling Rate Distribution

Measuring method	Settling cylinder method	Centrifugal sedimentation method	Laser diffraction method
Measuring instruments	Settling cylinder φ200mm× L2.2m	SKC-2000 Seishin Co.,Ltd.	SALD-3000S Shimadzu Co.,Ltd.
Measuring conditions	Constant temperature (20℃)	Range: 0.3μm～50 μm	Range: 0.05μm～3000μm
Measuring items	Water level, Suspended solids (SS), Water temperature	Grain size distribution	Grain size distribution
Measuring procedure	Pouring turbid water until 2m depth. Collecting sample water at 0.5m above bottom. Analysing SS of water.	Putting 100mL of turbid water into instrument, and then operating.	Putting 50 to 100mL of turbid water into instrument, and then operating.
Measuring intervals	13 times. (0hr, 15m, 30m,1hr, 3hr, 6hr, 12hr, 24hr, 3days, 7days, 14days, 21days, 42days)	1 time	1 time
Others	Unfixed measuring method	Not disseminated	Ordinarily adopted

The calculation method of settling rate distribution and the conversion method from grain size into settling rate are as follows:

If a particle in water is regarded to settle distance ***l*** from water surface to intake within time t, average settling rate $w(t)$ is presented as Eq.1.

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

Among time t, the share of already settled suspended solids $F_1(t)$ is equal to the difference of suspended solids between the start of 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, SS means suspended solids [mg/L].

In Eq.2, $F_1(t)$ increases gradually with time and one variation of Eq.2 is presented as Eq.3. In this equation, $F_2(t)$ gradually decreases with time and increases with settling rate. Eq.3 is corresponding with setting rate accumulation curve.

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

In condition of single globular particle's settlement, moreover, the Reynolds Number of particle ($R_e = d \cdot w_s / \nu$, ν is coefficient of kinematic viscosity of water.) is less than 1, both diameter of particle and settling rate can be converted each other.

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

In this equation, settling rate of particle is $\boldsymbol{w_s}$, diameter of particle is ***d***, gravity acceleration is ***g***, density of particle is $\boldsymbol{\rho_s}$, density of water is $\boldsymbol{\rho_w}$, and viscosity coefficient of water is $\boldsymbol{\mu}$. The diameter ***d*** is called Stokes' Diameter because it is calculated from settling rate by applied Stokes' Formula. In settling cylinder method, turbid water was poured up to the depth of 2m, then water depth variation and suspended solids were measured at predetermined intervals.

As mentioned above, in case of executing numerical simulation on sediment accumulation in reservoirs, laser diffraction method has been commonly used for grain size analysis and settling rate is converted by Stokes' Formula for fine soil particles. On the other hand, it has been indicated that the settling rate calculated by this method differs from the actual one (KASHIWAI 2006). In settling cylinder method, the settling rate distribution is directly measured by observing the variation of suspended solids with time and this method is regarded to give accurate settling rate.

2.2. Grain Size Calibration

Soil colloidal particles contained in turbid water tend to move at random affected by the interaction of surroundings. Because of this movement, soil colloidal particles happen to collide with one another and if strong attraction is acted among these particles a flock could be formed. In case of grain size analysis, a larger distribution could be obtained if flocculated particles are directly measured, so that the settling rate distribution tends to be largely evaluated.

A distribution treatment was considered for the purpose of avoiding excess evaluation of settling rate. In this study, distribution treatments were introduced in some cases of both laser diffraction method and centrifugal sedimentation method. An ultrasonic distributor FU-10C manufactured by TGK Co., Ltd. was used for the distribution treatment. The procedure of treatment was to add ultrasonic distribution by ultrasonic distributor of 60W in power and 28 kHz in frequency. The 10 minutes of ultrasonic distribution was given to 1L of turbid water to obtain enough dispersion of particles. 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 ultrasonic distribution (60W)
Laser diffraction method	Stirring by hands	10 minutes of ultrasonic distribution (60W)

2.3. Procedure of Experiment

Firstly, we collected turbid water from mountainous river during heavy rainfalls in September, 2010. The sample site was Yamaguchi River, Ibaraki Prefecture in Japan. Sampling was executed once at the time of peak discharge and three times after the peak. Sampling time and analyzed turbidities were shown in Table 3, precipitation data was in Fig. 4., and discharge was in Fig. 5.

As mentioned above, settling rates were analyzed by three methods and in some cases the ultrasonic distribution treatments were added. And then, the differences between settling rate distributions were considered.

Table 3. Sampling Time and Analyzed Turbidities

Sample No.	Sampling Date	Sampling time	Turbidity [NTU]	Suspended Solids [mg/L]
1	16 SEP 2010	10:55	787	944
2	16 SEP 2010	11:25	432	466
3	16 SEP 2010	12:35	143	189
4	16 SEP 2010	13:50	59	93

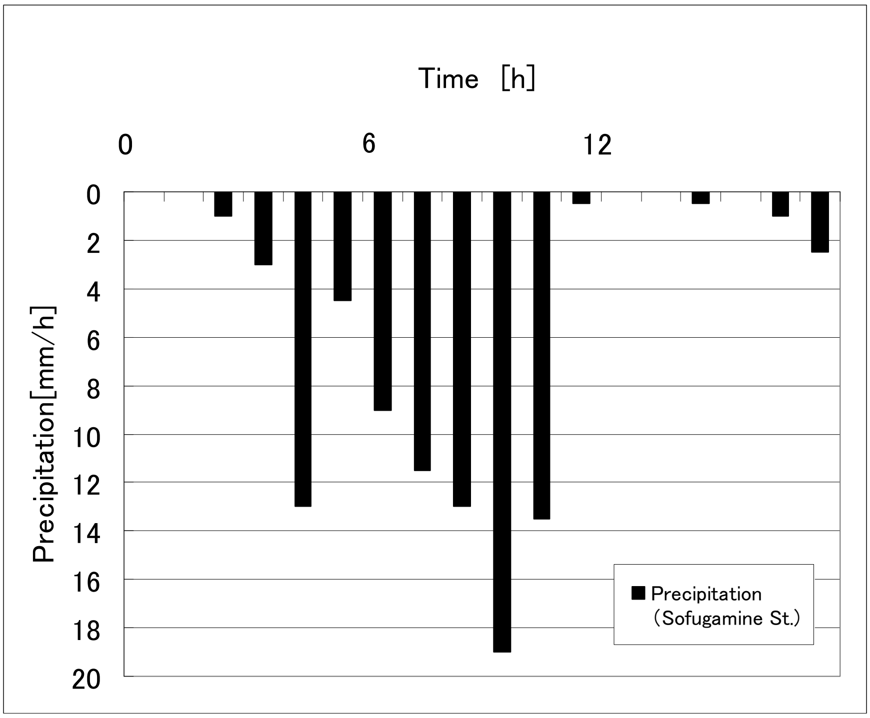


Figure 4. Precipitation on Sampling Day

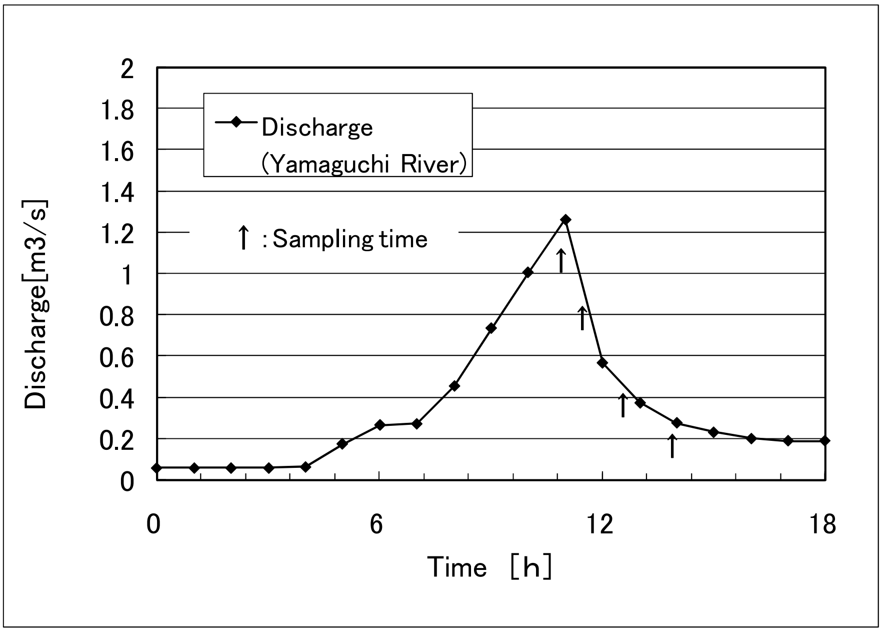


Figure 5. Discharge on Sampling Day

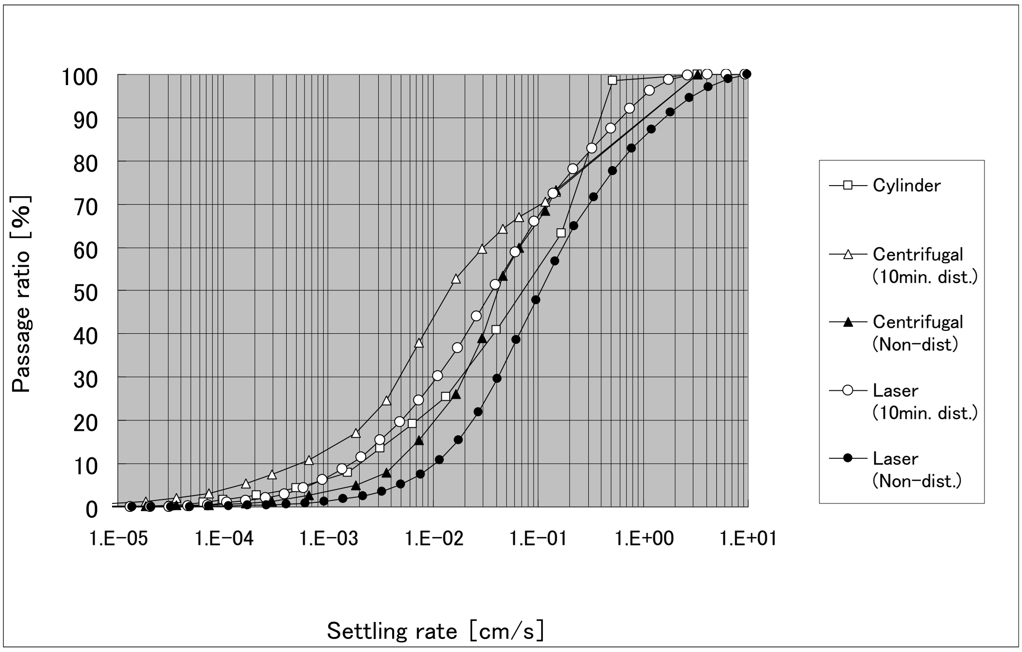
3. RESULTS

The results of experiments and analysis were shown in Fig. 6. to Fig. 9. Firstly, we consider the results of turbidity (Table 3). The Sample 1 was extracted at the time of peak discharge and it showed the highest turbidity among the four. The analyzed turbidity became lower with decreasing discharge. In this study, we could not extract samples at the phase of increasing discharge; however, preparatory standby at the sampling site should be taken for investigating turbidity change through all phases.

Secondly, we compare the results of settling cylinder method (Fig. 6. to Fig. 9.). These figure show that the particles in the residual ratio have higher rate than the certain settling rate. When we focus on the settling rate of 0.1 cm/s, 57% sediments were faster in Sample 1, 45 % in Sample 2, 33 % in Sample 3 and 22 % in Sample 4. According to the results of settling cylinder method, the settling rate became slower with time at the phase of decreasing discharge. It is regarded that the inflow discharge after the peak does less contribution to the accumulation of sediment in a reservoir; on the other hand, it may cause long-term persistence of turbid water in a reservoir after floods.

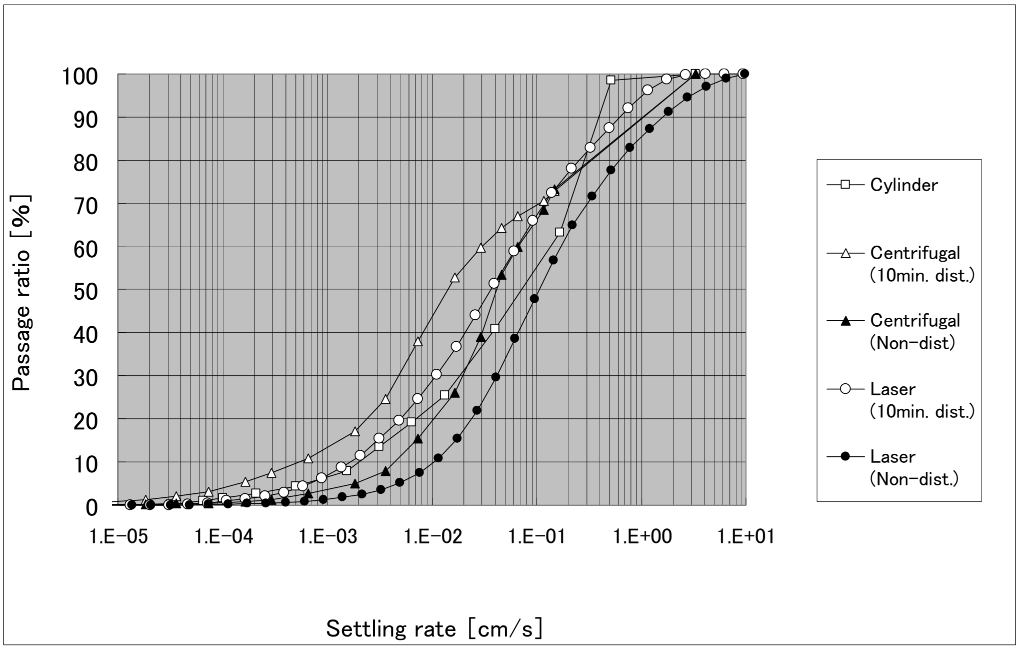
Thirdly, we take Sample 1 as an example and compare the settling rate among different analysis methods (Fig. 6.). It showed similar curve between settling cylinder method and centrifugal sedimentation method (non distribution), especially in the range of less than 0.01cm/s. On the other hand, the results of laser diffraction method (non distribution) showed relatively faster settling rate distribution compared with settling cylinder method or centrifugal sedimentation method (non distribution).

Fourthly, we consider the effects of ultrasonic distribution treatments. The purpose of distribution treatment is to avoid excess evaluation of settling rate. From the results of the Sample 1(Fig. 6.) and Sample 2 (Fig. 7.), the slower settling rates were given in both the centrifugal sedimentation method and the laser diffraction method by adding ultrasonic distribution treatment. From these results, some particles in flooding water form flocks and may cause rapid settlement in a reservoir. In Sample 2, the laser diffraction method with 10 minutes' ultrasonic distribution treatment shows relatively similar to the results of settling cylinder method.



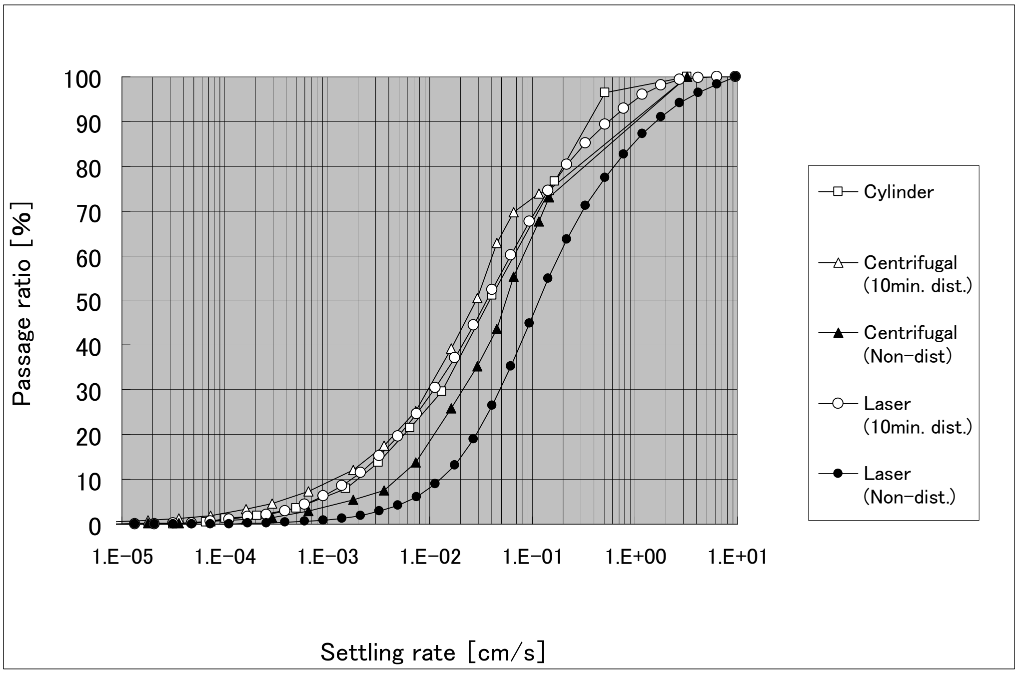
Note: dist. means distribution

Figure 6. Settling Rate Distribution (Sample 1)



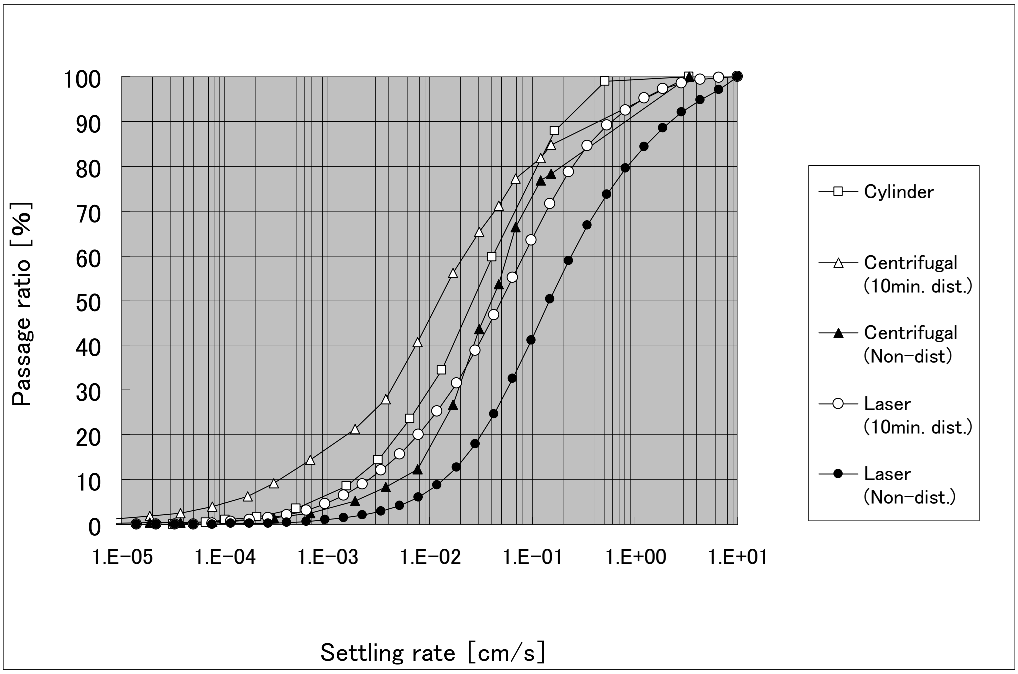
Note: dist. means distribution

Figure 7. Settling Rate Distribution (Sample 2)



Note: dist. means distribution

Figure 8. Settling Rate Distribution (Sample 3)



Note: dist. means distribution

Figure 9. Settling Rate Distribution (Sample 4)

According to the results of above mentioned examinations, it was found out that similar settling rate distribution to settling cylinder method could be obtained by conducting centrifugal sedimentation method without distribution treatment, however, the results of laser diffraction method gave relatively faster settling rate distribution especially in the slow settling rate range and differed from the results of settling cylinder method. It suggests that if we use laser diffraction method for giving settling rate distribution, it may cause the results of larger accumulation of sediment in a reservoir compared to the actual one.

4. CONCLUSION

Through this study three points were concluded. (1) Settling cylinder method was the most reliable for evaluating the settling rate of fine particles. (2) Centrifugal sedimentation method could alternate the settling cylinder method because it gave similar settling rate to the settling cylinder method. (3) In case of using laser diffraction method, grain size distribution similar to settling cylinder method could be obtained by adding ultrasonic distribution treatment.

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