II－14 SETTLING VELOCITY OF NATURAL FINE PARTICLES

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1. INTRODUCTION

The rate at which a particle falls through static or very slowly moving fluid has long been studied. Although it has been well known that the settling velocity of solid particles depends on the density and viscosity of fluids and on physical properties of particles, the accuracy of the prediction for natural particles is still limited. Little information is available describing its characteristics whereas most of the information pertains to coarse particle, which is spherical, smooth, much heavier and bigger than the fine suspended particles we are dealing with.

In this study the natural fine particles, which is 0.5 μm – 1 mm in size, is used in the experiments in order to obtain the information on its size and density and to evaluate the settling velocity in quiescent water.

2. METHODOLOGY

The experiments were performed using sediments in the Nanakita river. Sediment samples were collected with core samplers of 7 cm inner diameter. Samples were horizontally sliced. The surface layer, 0-1 cm, from 3 core samplers was put into an 11 cm cylinder, then added with tap water and strongly mixed for 30 seconds. Slurries that consist of water and resuspendable fine particles were once taken immediately and 2, 5, 10, 30, 60 and 180 minutes later. Particle size distributions of resuspendable fine particles in slurries were analysed by Microtrac HRA x 100 Automated Small Volume Recirculator.

Dietrich's empirical equation (1982) is used in this study to predict the settling velocity of solids regarding to the effects of size and density, shape and roundness of the particles. The density of the natural fine particles is also evaluated based on the experimental results.

3. DIETRICH'S EMPIRICAL EQUATION

Dietrich developed an empirical equation based on data from previous settling velocity experiments. He provided equation that accounts for the effects of size, density, shape, and roundness. It can be written as

$$W_* = R_3 10^{R_1+R_2} \tag{1}$$

where R_1, R_2, R_3 are the fitted equations for size and density, shape, and roundness, respectively.

$$R_1 = \log\left(1.71 * 10^{-4} D_*^2\right) \quad \text{for } D_* \le 0.05 \tag{2}$$

$$R_1 = -3.76715 + 1.92944(\log D_*) - 0.09815(\log D_*)^2 - 0.00575(\log D_*)^3 + 0.00056(\log D_*)^4 \quad \text{for } D_* \le 0.05 \tag{3}$$

where D_* is a ratio of gravitational force acting on particle to the viscous resistance of fluid. It can be written as

$$D_* = \frac{(\rho_s - \rho) g D_n^3}{\rho \upsilon^2} \tag{4}$$

D_n is the nominal diameter, which is the diameter of a sphere of the same volume, V, of the particle, ρ_s and ρ are the densities of the grain and fluid, respectively, g is the gravitational acceleration, υ is kinematic viscosity of the fluid. In this experiment the temperature is 20°C, so that ρ is 998.2 kg/m^3 and υ is $1.003*10^{-6}$ m^2/s.

$$R_2 = \left(\log\left(1 - \frac{1-CSF}{0.85}\right)\right) - (1-CSF)^{2.3} \tanh(\log D_* - 4.6) + 0.3(0.5 - CSF)(1-CSF)^{0.2}(\log D_* - 4.6) \tag{5}$$

$$CSF = \frac{c}{(ab)^{\frac{1}{2}}} \tag{6}$$

where CSF is called shape factor. a, b, c are the largest, intermediate, and shortest axis of the particle, respectively. It is assumed to be 0.2 in this paper.

$$R_3 = \left[0.65 - \left(\frac{CSF}{2.83} \tanh(\log D_* - 4.6)\right)\right]^{(1+(3.5-P)/2.5)} \tag{7}$$

where P is the Power value of roundness. It varies from 2.0 for the crushed grains to 6.0 for the smooth particles. It is assumed to be 6.0 in this calculation.

The settling velocity, w_s, of the particle is finally calculated from

$$W_* = \frac{\rho w_s^3}{(\rho_s - \rho) g \upsilon} \tag{8}$$

4. RESULTS AND DISCUSSION

4.1 Density of Settling Particle

The results of particle size distribution in slurries revealed that the resuspendable fine particles available in the Nanakita riverbed ranges from 0.8 to 300 μm in size. Assuming that fine particles were well mixed throughout the cylindrical column at the 0th minute, the loss of particles from water column as time passed is due to the settling. Figure 1 shows the particle size distribution of the particles in slurries that collected at the 0th, 2nd, 5th, 10th, 30th, 60th and 180th minute.

Figure 2 shows the predicted particle size distributions at various values of particle density compared with the results of slurries collected at time 30, 60 and 180 minutes. The prediction of the suspended particles is based on the number of particles that existed in water column just after mixed.

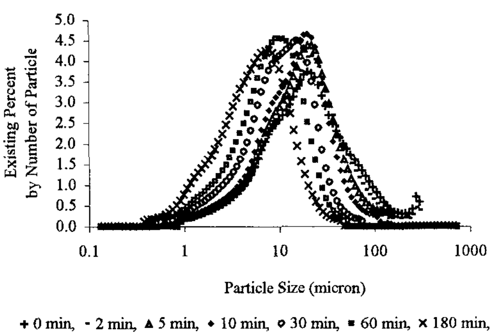

Fig.1 The particle size distribution of particles in slurries collected at different time after mixing

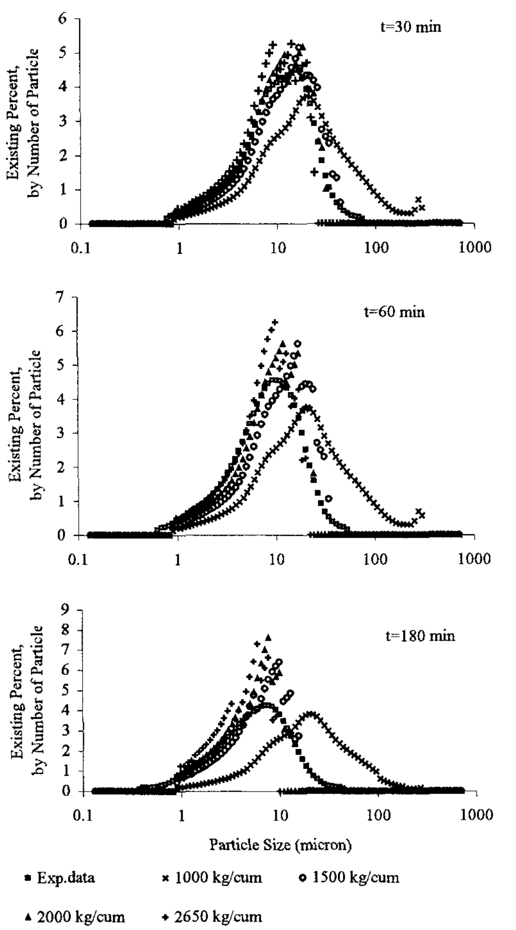

Fig.2 Comparison of particle size distribution between the predictions and experimental results of slurries that collected at time 30, 60, 180 minutes.

It can be seen that the density of fine particle is much lower than sand particle, 2,650 kg/m^3. The predictions show good agreement with the experimental results when density is 1,500 to 2,000 kg/m^3.

The density of particle is assumed to be uniform for all grain sizes. It was tested in various values from 1,000 kg/m^3, which is close to the density of water, to 2,650 kg/m^3, which is the density of sand.

It is found that the predictions of small size particles become zero after 30 minutes while it existed in reality. This can be caused by our assumption of uniform density, i.e. there might be some range of density for different particle size. However it is rather difficult to get the accurate value of the density of each particle size.

4.2 Settling Velocity of Particle

Microtrac presents the particle size distribution in the unit of percentage of number, so the density of particle was assumed in calculating the settling velocity of these fine grains based on the mass of each particle size. Figure 3 shows the settling velocity of fine natural particle at various input densities.

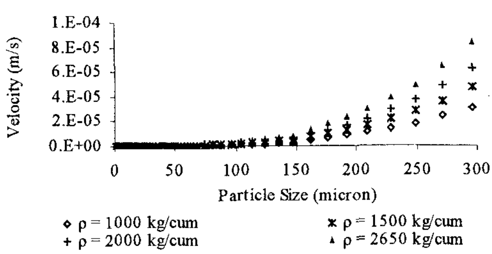

Fig.3 Settling velocity of fine particles at different value of density, base on experimental result

The quartz grain, which the density is 2,650 kg/m^3, has the settling velocity ranged from $8.30*10^{-5}$ to $3.40*10^{-13}$ m/s for 300 to 1 μm particles. It is higher than the settling velocity of fine natural particles, which the density is 1,500 to 2,000 kg/m^3. The settling velocity of the 300-μm fine particles varies from $4.7*10^{-5}$ to $6.26*10^{-5}$ m/s while the settling velocity of 1-μm particles varies from $1.93*10^{-13}$ to $2.60*10^{-13}$ m/s. It indicates that the size and density of fine natural particle strongly influence its settling velocity.

5. SUMMARY

Settling velocity of sediment particles through quiescent water can be predicted by a number of models, but the accuracy is still limited for the natural fine particles due to the deficiency of its physical properties information. From this study we found that the natural fine particle that can be resuspended ranges from 0.8 to 300 μm in size where the density is much lower than quartz grain. Though we cannot obtain the accurate density of each particle size, we found that the density of natural fine particle is approximately 1,500-2,000 kg/m^3.

The settling velocity of fine particles varies from $1.93*10^{-13}$ to $6.26*10^{-5}$ m/s for the particle 1-300 μm. It is lower than the settling velocity of quartz grain due to the influence of density difference.

REFERENCES

1) Dietrich ,W.E."Settling Velocity of Natural Particles", *Water Resource Research.*Vol.18, No.6: 1615-1626,1982.