II-129 Falling velocity in grid generated turbulence

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INTRODUCTION

This study is a first step in the problem of sedimentation of cohesive soil in estuaries. The main purpose is to derive some neccessary information in a dispersion model. Those are the relationships between falling velocity of cohesive material and salinity and turbulence. Although these have been investigated by several authors, the empirical formulae obtained are merely expressed by bulk falling velocity and total concentration which are applicable case by case. An explicit explanation of the effect of turbulence and salinity for an individual particle is still not feasible. The purpose of the present study is to clarify this point, keeping the basic concept in mind that the dependence of falling velocity on concentration is caused by both hindered settling and flocculation. Hindered settling effect is found to reduce falling velocity of each individual particle. The analytical expression of this effect has been formulated by (1) and (10) under certain special conditions. On the other hand, flocculation effect is reported to increase mean falling velocity by (2) but its effect to individual particle falling velocity has not been confirmed yet. An attempt has been done for the better understanding of this measuring concentration profile for low concentration condition and the result is analyzed by a differential equation for the motion of an individual particle.

EXPERIMENTAL SET UP

The experiment was carried out in an oscillating grid tank of the same dimension as that used in (11). Experiments were done in still fresh water, in still various saline water and in fresh water with various intensity of turbulence. The size of kaolinite selected to represent a cohesive material was in the range of 3-20 μm. Actually, the concentration for each size could not be measured directly. Information on the size distribution was obtained by measurements by a microscope. At each level and each time step, samples were taken randomly and the number of kaolinite particle of each size was counted in photographs taken through the microscope. The concentration of each size is determined by the fraction of the number of each size to the total number. The density difference of each size turned out to be negligibly small. Falling velocity was calculated by a transport equation in vertical direction shown below:

$$\frac{\partial C}{\partial t} + W\frac{\partial C}{\partial z} = D_z\frac{\partial^2 C}{\partial z^2} \qquad \cdots\cdots(1)$$

where C = concentration of kaolinite of each size, t = time, W = falling velocity, z = vertical coordinate and D_z = dispersion cofficient whose value is taken from (7). Velocity scale measured by a laser droppler anemometer was found to be in the range of 1 cm/s.

THEORETICAL APPROACH

A particle motion equation developed in (6) is shown as follow:

$$\frac{\pi}{6}d^3\rho_p\frac{dU_p}{dt} = \frac{C_d}{2}S\rho_p(U_f-U_p)^2 + \frac{\pi d^3}{6}\rho_f\frac{dU_f}{dt} + \frac{\pi d^3}{12}\rho_f\left(\frac{dU_f}{dt}-\frac{dU_p}{dt}\right) + B + Fe \ldots(2)$$

where ρ_f,ρ_p = density of fluid and particle, respectively, d = diameter of particle, U_f,U_p = velocity of fluid and particle, respectively, C_d =

drag coefficient, S = cross sectional area of particle, B = Basset term and Fe = gravity force. Interacting force is discarded owing to low concentration condition.

Velocity of fluid and particle are assumed as in (3) that

$$U_f = \int_0^\infty (\alpha \cos\omega t + \beta \sin\omega t) d\omega \quad \cdots\cdots (3)$$

$$U_p = \int_0^\infty (\gamma \cos\omega t + \delta \sin\omega t) d\omega + \text{const.} \quad \cdots\cdots (4)$$

For the case that $R_e < 1$, the drag coefficint is $C_d = 24/R_e$ and B is negligible, where R_e = relative Reynolds number = $(U_f - U_p)d/\nu$. Linear solution of Eq.2 is obtained as

$$\bar{U}_p = \text{Const.} = Fe/a \quad \cdots\cdots (5)$$

where $\bar{U}_p$ = average particle velocity and $a = 36\mu/(2\rho_p + \rho_f)d^2$.

For the case that $R_e > 1$, Eq.2 becomes nonlinear and some simplifications are needed for analytical and numerical solutions ((4),(5),(8),(9)). A solution based on the concept utilized in (5) is found as

$$C_d S \rho_p (\text{Const.} + \int_0^\infty ((\gamma - \alpha)\cos\omega t + (\delta - \beta)\sin\omega t) d\omega)^2/2 = Fe \quad \cdots\cdots (6)$$

where Const. is interpreted as mean falling velocity of particle, and can be solved numerically for some given condition of fluid velocity.

All results from the analysis and experiment are shown in Fig.1.

CONCLUSION

Salinity has little direct effect on falling velocity of each individual particle or floc as shown in Fig.1, but it has indirect effect through formation and increase of the number of floc as can be seen in Fig.2. This can be explained by chemical potential theory and evaluated in term of collision efficiency (2).

Turbulent intensity has almost no effect on falling velocity of each individual particle or floc when $R_e < 1$ as shown in Fig.1. The deviation from the theoretical prediction is attributed to the unspherical shape of the particle and the error of the parameters used. But it does when $R_e > 1$. This can be interpreted that in small relative Reynolds number, R_e, range, flow pattern around a particle is laminar and there is almost no effect from fluctuation of turbulence. In other word, in high R_e range, flow pattern becomes turbulent and drag force is no longer viscous drag.

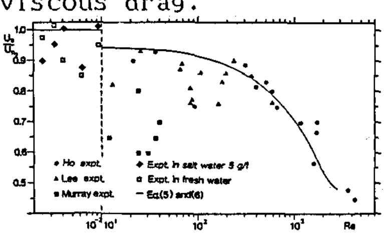

Fig.1 Relationship between relative Reynolds number and ratio of falling velocity to terminal falling velocity.

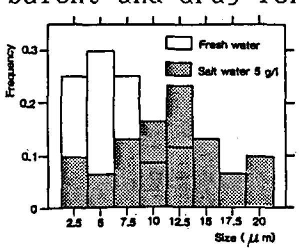

Fig.2 Size distribution of particles. at level 15 cm from bottm.

References

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