Special Contributions, Geophysical Institute, Kyoto University, No. 6, 1966, 127-133

SOME EXPERIMENTS ON THE SEDIMENTALION IN ESTUARIES WITH DENSITY STRATIFICATION

By

Seiichi KANARI

(Received November 7, 1966)

Abstract

For the study of coloid chemical and hydrodynamic effects on estuarine sedimentation, the settling processes in salt wedges were investigated by flume experiments. The results of experiments show that strong turbulence in a thin layer on the interface between fresh and salt waters controls the settling process and cations can not directly increase the settling rate owing to weak mixing between solid particles and cations across the stable interface.

1. Introduction

In oceanography and hydrology it is important to study how the suspended silt particles are settled and distributed on the floor of the estuary where the river water makes contacts with sea water.

Concerning this problem, it has been reported that the settling velocity of suspended silt particles is increased considerably if a small quantity of salt is added to the water. The mechanism of such coloid-chemical processes was studied by Hurst [1929], Nomitsu and Takegami [1940], and they showed that the settling velocity of silt particles suspended in salt water is influenced by such cations as Mg, Ca, Na, and K.

However, the settling process will be influenced not only by the coloid-chemical conditions but also by the hydrodynamic conditions of the flow system, especially the turbulent structure.

In estuaries, salt wedges are often formed by the intrusion of sea water under the river water, and a stable interface between sea and river waters brings about a special distribution of flow and salinity. Therefore, in such a region with density stratification, the settling process of silt particle takes a different form from that in homogeneous fresh or salt water, owing to the special pattern of the turbulent zone and the cation distribution.

Concerning the two layered model of an estuary, Kaneko [1949] has conducted a flume experiment and discussed qualitatively the varying behavior of channels in a river mouth. In his paper he has pointed out that turbulence within fresh water of the river goes into decay when the fresh water flows over the salt wedge, and eddy diffusivity which indicates the degree of mixing between the fresh water and salt water decreases, and he concludes that the suspended material picked up from the river bed will be dumped on the floor of the estuary through the salt wedge, but he did not examine the real turbid water flow.

In this paper, three layered model experiments, in which a highly concentrated mud flow penetrates along the interface between fresh water and salt water, are described.

2. Experimental procedure

The experiments were carried out in a flume which consisted of a sea section (3m×3m×0.5m) and a river section (7m×0.5m×0.5m) as shown in Fig. 1. Siliceous sand with a uniform size of about 0.3cm dia. was placed along the floor of the river section with a slope of 1/26, and after the salt water, which was a solution containig Na^{+}, Cl^{-}, Mg^{++} and So_4^{--} with a ratio similar to sea water and was coloured with Fuchsin, was stored in the form of a wedge on the slope of the flume, the fresh water was allowed to flow onto it without disturbing the salt wedge. In each experiment, some combinations of the fresh water discharge, Q and the salinity of the salt wedge, S were selected from $Q=2.5m^3/h$, $5.0m^3/h$, $7.5m^3/h$ and $S=0‰$, 17.5‰, 35.0‰. After the flow of the fresh water and the intrusion of salt water had reached a state of equilibrium, in which the location of the head of the salt wedge was maintained at the section No. 7, turbid water with the silt concentration of 30g/1 was poured at a flow rate of $0.25m^3/h$ into

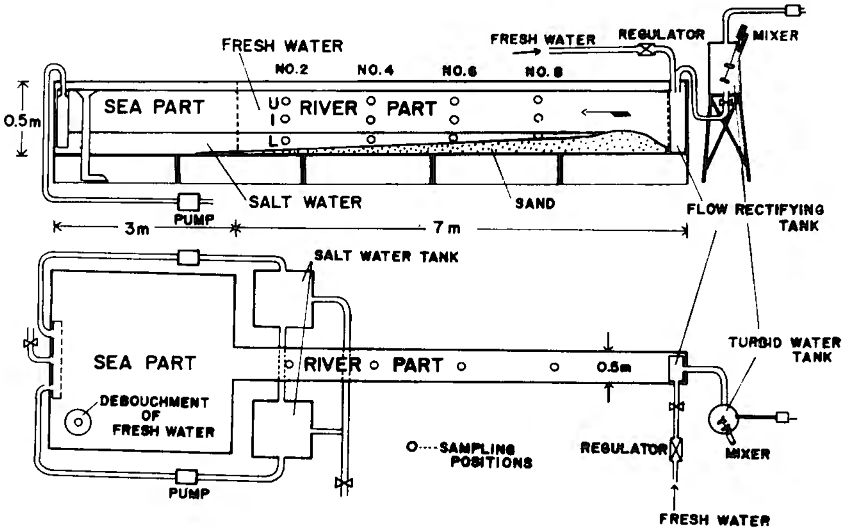

Fig. 1. Experimental flume.

the rectifying tank, therein mixd with the fresh water and then allowed to flow out into the river section. The turbid water inflow continued for 7 minutes at an almost constant discharge rate.

During each experiment the fresh water level was kept at constant by the overflow.

Fig. 2. shows the accumulated weight frequency curve of the silt particles suspended in the turbid water tank. The median diameter of the particles is 55 microns, which corresponds to the settling velocity of 0.61cm/sec in still water. The above cumulative curve shows that if there is no turbulence in the fresh water flow with a mean velocity of 4 cm/sec, 90% of the suspended particles must be settled on the floor of the river section of the flume within about 3 minutes.

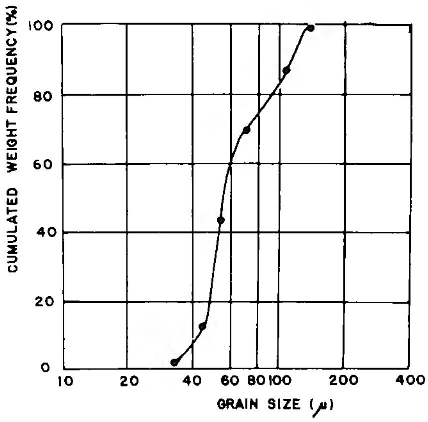

Fig. 2. Grain-size accumulation curve of suspended silt particles.

Water sampling of each of the three layers was carried out at the sections No. 2, No. 4, No. 6 and No. 8 by means of the siphon method every minute after the front of the turbid water had passed on, and silt concentration of each sample were measured by weighing. Measurements of the vertical distribution of velocity and the front speed of turbid water were also taken.

3. Result and discussion

As the turbid water moves down the river section, it tends to converge upon the interface between the fresh water and the salt water (Photo. 1, a and b), and flows down the river section with a higher velocity than that of the fresh water as a mud flow (Photo. 1, c and d).

A few typical velocity distributions observed at section No. 6 before the mud flow injection was performed, are shown in Fig. 3, in which $\Delta\rho$ denotes the density difference between fresh water and salt water, and Re denotes the Reynolds number in the fresh water flow without the mud flow injection. These velocity distributions were obtained from the sinking traces of small particles of Water Blue.

Fig. 4. shows the change of the front speed of the mud flow along the river section. The mean velocity of fresh water is also shown in this figure. As seen in Fig. 4, the front speed exceeds the mean velocity of fresh water, therefore the velocity distribution may change as shown schematically in Fig. 5 when the

a
b
c
d

Photo. 1. Four pictures showing the turbid water movement. a : 20 sec, b : 40 sec, c : 60 sec, d : 80 sec after discharge of turbid water.

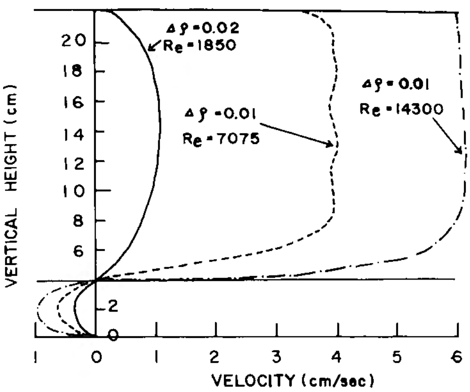

Fig. 3. Vertical distribution of velocity before discharge of turbid water.

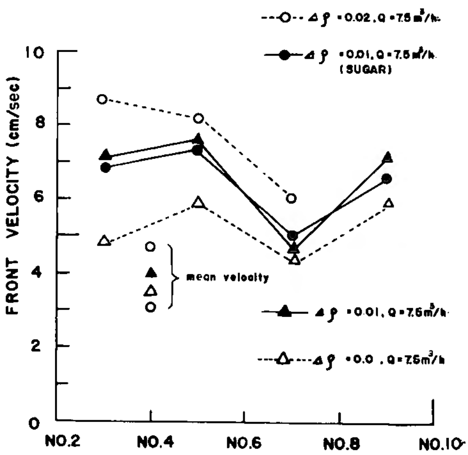

Fig. 4. Variations of front speed of the mud flows along the river part.

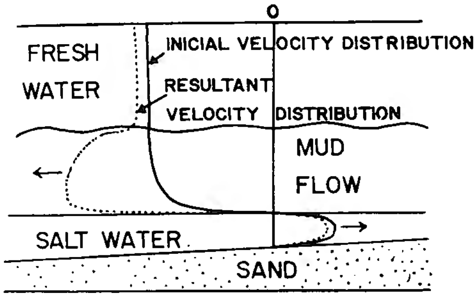

Fig. 5. Schematic sketch of vertical distribution of flow velocity. Solid line shown distribution before discharge of turbid water, and broken line shows the velocity distribution after mud flow injection occured.

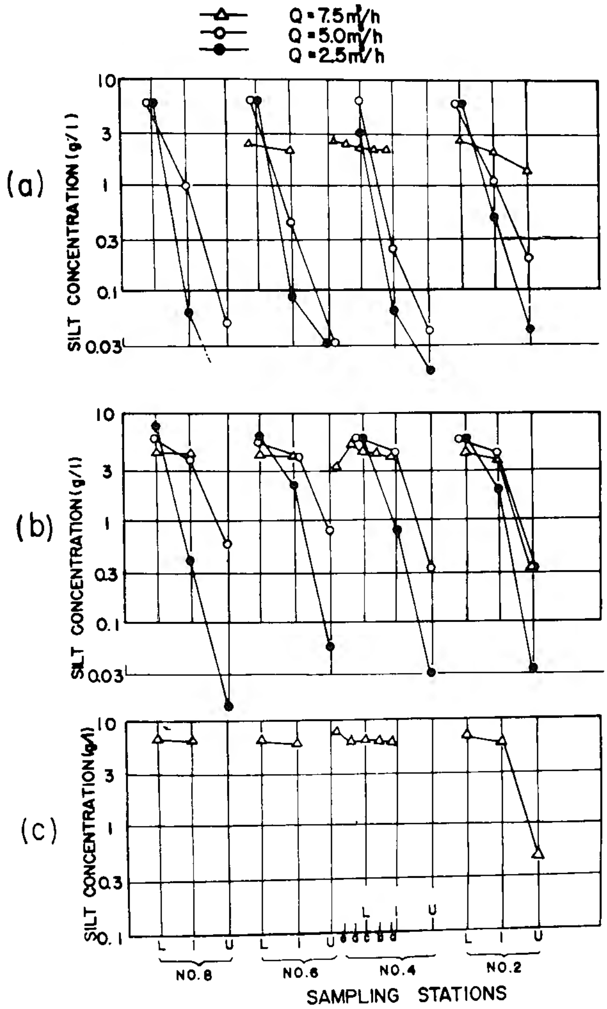

Fig. 6. Vertical distributions of silt concentration in each sections.

mud flow injection occures.

The vertical distributions of silt concentration at each sampling section are shown in Figs. 6 (a), (b), (c). In this figure, the symbols of U, I and L denote the upper layer, the intermediate layer and the lower layer respectively. At sampling section No. 4, especially five layer sampling was carried out at intervals of every 2 cm below the position of I. Fig. 6 (a) shows the silt concentration in the case where there is no salt wedge, and Fig. 6(b) shows it in the case where there is a salt wedge.

In order to examine the effect of cations in salt water, a contrast was made, in which the salt wedge was replaced by the wedge of a sugar solution. The distributions of silt concentration for the sugar wedge is shown in Fig. 6 (c).

In the case of a small discharge of fresh water ($Q=2.5m^3/h$) where there is no salt (or sugar) wedge, the vertical gradient of the distributions of silt concentration is steep, and high concentration is confined to the lower interface. This means that in the case of laminar flow, the settling process of the silt particles advanced without any obstruction of turbulence. As the flow becomes turbulent, the distribution approaches uniformity and the settling process of the silt particles is disturbed by the turbulent motion. In this case, it appears as a bending point on the vertical gradient of the distribution of silt concentration, in other words, the vertical gradient of the silt concentration is steep in the upper layer and a nearly uniform distribution is formed in the lower of the mud flow.

The same explanation will be permitted in the case of the sugar wedge, because there is no remarkable difference in the distribution of silt concentration between a salt wedge and a sugar wedge.

In order to discuss the problem described above quantitatively, we computed the eddy diffusivity in the upper layer from vertical distributions of silt concentration.

Designating by w_0 the settling velocity of a given size of particle, the product w_0c will then indicate the rate at which the particles settles across the unit horizontal area, where c represents the particles per unit volume of the water-silt mixture. If a state of equilibrium is attained, this rate of settling must be exactly equal to the rate at which the particle is transported upward by the turbulence ; thus

$$w_0 c = -\eta \frac{dc}{dz} \tag{1}$$

where z is the vertical coordinate, and η is the eddy diffusivity. Solving the equation (1) in respect of η, we obtain

$$\eta = -\frac{w_0}{\dfrac{d}{dz}(\log c)} \tag{2}$$

Now we calculate eddy diffusivity in the upper and the lower layer from $\dfrac{d(\log c)}{dz}$ between U and I, and between I and L respectively, as follows

$$\eta_U = -\frac{w_0}{\left(\dfrac{d}{dz}\log c\right)_{UI}} \tag{3}$$

$$\eta_L = -\frac{w_0}{\left(\dfrac{d}{dz}\log c\right)_{IL}} \tag{4}$$

The calculated values of η_U and η_L in the equations (3) and (4) are shown in Fig. 7 as a function of Reynolds number, in which the value of

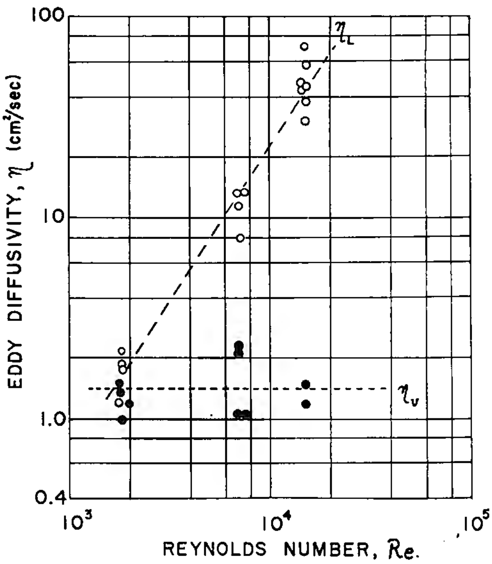

Fig. 7. Eddy diffusitity, calculated from eqs. (3) and (4).

the settling velocity w_0 was taken as 0.61 cm/sec for the particle of median diameter.

As shown in Fig. 7, the value of η_U is almost constant and is independent of the flow condition, but the value of η_L increases with the Reynolds number. This shows that the lower layer is very turbulent and the turbulence concentrated in this layer obstructs the settling of the silt particles and sustains the mud flow over a long distance. However, at the present stage we can not explain why the turbulence in the mud flow does not immediately diffuse into the surrounding water and thereby dissipate itself in a short period.

4. Conclusion

In most cases, the bulk of the sediments in estuaries or mouthes of rivers consists of silt particles transported by floods. In such conditions, it had been supposed that the settling processes of suspended silt particles would be influenced directly by coloid-chemical conditions. However, the flume experiments showed that a strong turbulence existing in a highly concentrated mud flow which may arise during a flood period, controls the silt distribution, and it seems that the coloid-chemical effects do not play a dominant role in sedimentation in the estuaries with sharp density stratification because their stable interface prevents the contact of cations with solid particles.

Further studies are necessary on the estuaries with strong vertical mixing, where no stratification is found and a high concentration of cations may directly affect the settling process.

Acknowledgements

The author wishes to thank Dr. S. Hayami, former professor of Kyoto University, and Dr. S. Okuda, professor of Kyoto University for their cordial advice and encouragement.

References

Hurst, H. E., 1929; The suspension of sand in water, Proc. Roy. Soc. London, A, 124.

Kaneko, Y., 1949; Sedimentation and coastal errosion in Niigata Harbor, Tech. Rep. Niigata, Harbor, No. 1 (in Japanese).

Nomitsu, T. and T. Takegami, 1940; A study of marine sediment. I, Tikyubutsuri (Geophysics), 4, 1–22 (in Japanese).