

CHAPTER 174

An Experiment on Clay Suspension under Water Waves

by

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SUMMARY

The physical behaviour of water waves upon the suspension of fine cohesive clay was explored experimentally in a wave channel. Results obtained from the experiment show that equilibrium concentration is reached in the wave field some time about five hours after the initiation of waves. The ratio between the mean bottom concentration and the vertical average is constant and yields almost the same value within the range 1.17 and 1.34 at equilibrium and the bottom concentration at equilibrium is linearly proportioning to the maximum bottom velocity of waves. The dimensionless transient concentration possesses a relationship also with the bottom velocity and the bottom shear stress can be related to the maximum value of the ratio between the bottom concentration and the vertical average value found within a short time after the initiation of waves.

INTRODUCTION

Tidal current, river flow, waves, longshore current and wind drifted current are those dynamic factors affecting sediment transport in a coastal region. Two kinds of the sediment; sand and clay exposed themselves to those forces differently. The loosened particles and larger densities of sand show its transport as bed load, suspended bed material load and suspended load while the cohesive property of clay and small density besides its chemical interactions shows its transport only in the form of suspension. Within the complex physico-chemical system in a coastal region various investigations were carried out under field conditions to quantify the coastal transport and relate it with the acting forces and the sediment properties.

In order to understand in particular the behaviour of waves on coastal sediment, studies were and are actively conducted also in the laboratories and theories are being developed. However, the majority of the works are concentrated on the behaviour of granular materials and sand, MONOHAR (1955) set up an oscillating plate with sand on top to investigate the vertical motion of sand under simulated water waves. Flume experiments were carried out by many investigators for example HOMMA and HORIKAWA (1963), HORIKAWA and WATANABE (1970), HATTORI (1971) and others to examine the behavior of waves on sand con-

centration. Emphasis have been made with respect to formation of ripples and evaluation of the diffusion coefficient affected by ripple dimensions. Researches on transportation of cohesive clay are mainly carried out under the two forces namely; the current and the settling. In the current system KRONE (1963) introduced a flume study to demonstrate the rheological properties of clay in the transport process METHA and PARTHENIADES (1974) clarified the physico-chemical properties of clay and the resisting shear stress in a rotating annular channel. LEE (1974) obtained the depositional characteristics of clay in different salinities. WATANABE et al (1979) showed that clay transport by tidal current can be simulated in a simplified experiment. Settling studies of clay were done for example by MALIK (1974). Information about the effect of waves upon clay were mentioned by ALLERSMA et al (1965). It is the objective of this study to determine the interaction between waves and the cohesive materials by means of an experiment

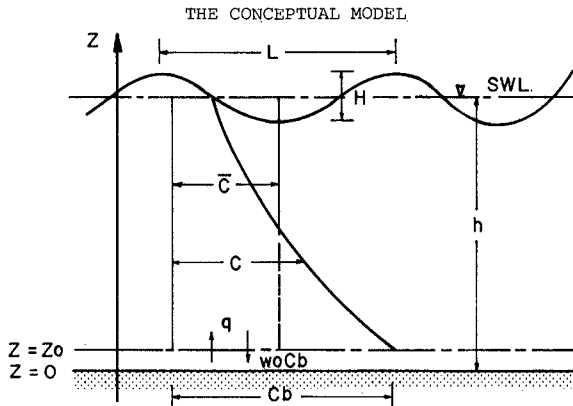


Fig. 1 Elements of Concentration Field

The concentration field under wave motion is shown in Fig.1. From the figure a level $z = z_0$ is defined as an active layer where the sediments at rest in the bottom, $z = 0$, are disturbed and entrain at the rate q into the upper layer, C_b is the concentration at this level. C is the concentration profile and $\bar{C}$ is the vertical average concentration. The wave field possesses the depth at still water level (SWL) equals to h having the wave height H with the wave length L and the period T . The settling velocity of the sediment is w_0 ,

By definition, the average concentration is:

$$\bar{C} = \frac{1}{h} \int_0^h C dz \quad (1)$$

The total concentration is:

$$\hat{C} = \int_0^h C dz \quad (2)$$

Introducing a parameter β , the dimensionless concentration as:

$$\beta = \frac{C_b}{C} \quad (3)$$

THE EXPERIMENT

The experiment was carried out in a glass walled wave channel of 40 cm wide 60 cm deep and 45 m long. It has the horizontal steel bottom. A paddle type wave generator with hinge at the bottom is incorporated at the upper end of the channel. At the lower end, the perforated sloping wave absorber is located. To minimize the under current due to rise of water level at the stagnant lee end, a 15 cm diameter pipe connected the fore bay and the far bay of the channel. Waves were measured by a capacitance type wave gauge. Samples of clay water mixture were extracted through the mine siphons of 2 mm hole. The concentration of each sample was obtained from a calibrated photo-transistor sediment meter. Fig.2 shows the definition sketch of the general set-up of the experiment.

Clay sample taken from the Samut Sakhon river mouth, an estuary in central Thailand was used in the experiment. The sizes of the particles obtained from the hydrometer analysis are between 0.001 mm and 1.0 mm with the apparent densities of 1.21-1.64 kg/lit. Prior to placing the clay into the flume, the sample was washed through the U.S. standard sieve No.200 having the opening of 0.074 mm to ensure the uniformity of the particles and to eliminate the small fraction of the non-cohesive materials. The sample was rinsed through fresh water to remove the original high saline content of the clay so that effect of flocculation is reduced. The mixture was evenly filled over the length of the channel so that after two weeks settling it showed an approximate 2.5 cm clay layer above the steel bottom with a low concentration mixture of 30 cm depth above.

Waves in the experiment are confined within the intermediate range having $1/2 > h/L > 1/20$. The reason is that effect of turbulence due to breaking waves and the strong fluctuating shear stress within a wave period are not encountered. Twenty two runs were conducted and within each test run samples were siphoned and analysed simultaneously as shown in the time steps below.

Time Step	0	1	2	3	4	5	6	7	8	9
Time Interval (min)	0	5	5	10	20	30	30	60	60	120
Elapse Time (min)	0	5	10	20	40	70	100	160	220	340

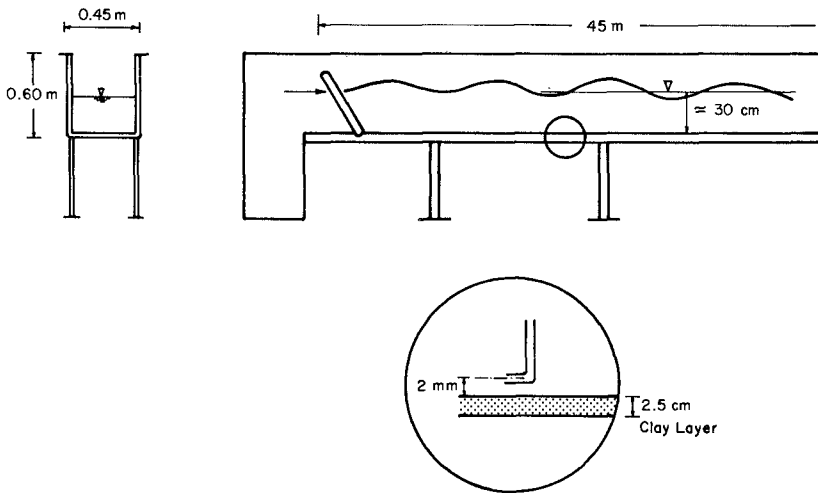


Fig. 2 The Wave Channel

Fig.3 shows the flow diagram of the experimental procedure.

THE RESULTS

The results obtained from the experiment are presented in the following manners:

i) Concentration Profiles Fig.4 shows an example of the concentration profiles which demonstrates the vertical exchanges of clay at successive time steps. It shows that there is a significant increase of the bottom concentration some time after waves were generated while the concentration in the upper layer remains unchanged. This means that the bottom clay are disturbed and entrain into the near bottom layer. At longer time concentration in the upper layer increases which shows that the sediment from the near bottom layer diffuses into the wave field.

ii) Equilibrium Concentration Time variation of the total concentration is shown in Fig.5. It shows some fluctuations at the early stages and becomes assymtote with time at a longer time period. Hence equilibrium condition is existed.

iii) The Normalized Concentration Fig.6 shows some plots of the normalized concentration, β , against time, t . Interpretation of this parameter is similar to (ii), however, with more physical emphasis. It shows the effect of bottom entrainment during the rising limb of β until it reaches the maxima (β). Follows by the diffusion process as shown by the gradual fall of β and consequently equilibrium when β is assymtotic with t . It also shows that at equilibrium β is nearly constant for all cases.

iv) Transient Concentration The characteristics of changes in the concentration can be obtained from the integrated diffusion equation which is derived from the mass conservation in the concentration field as:

$$(h - z_o) \frac{d\bar{C}}{dt} = -w_o C_b + q \quad (4)$$

and the boundary conditions at $t = 0$ when:

$$\beta_{eq} = \frac{(C_b)_{eq}}{\bar{C}} = \text{constant};$$

$$\bar{C} = \bar{C}_{(eq)}; \text{ and } \frac{d\bar{C}}{dt} = 0$$

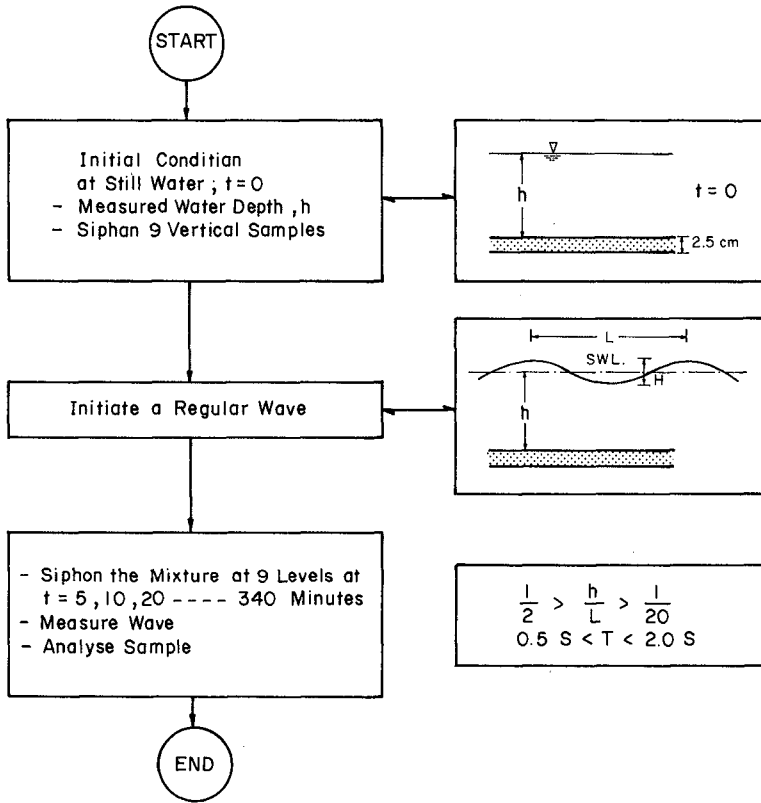


Fig. 3 Flow Diagram Showing the Procedure of the Experiment

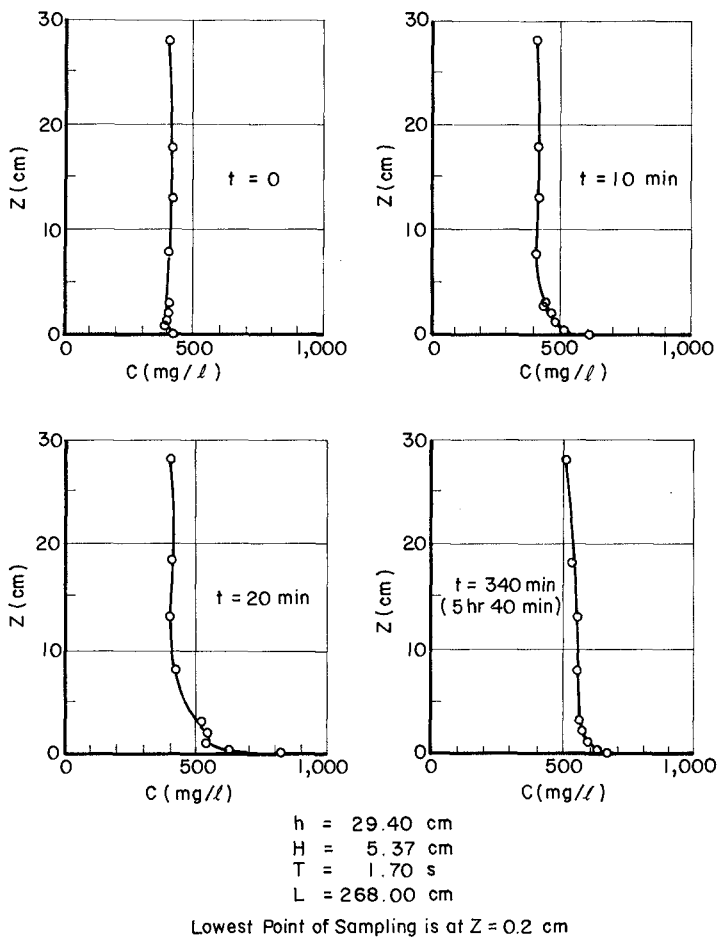


Fig. 4 An Example of Concentration Profiles

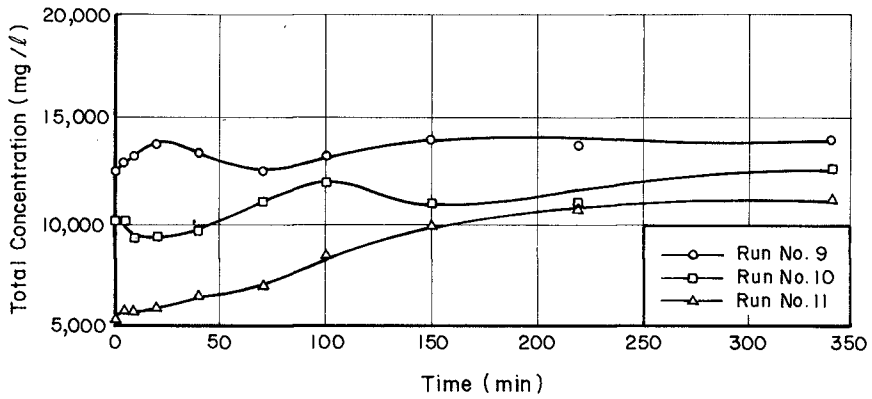
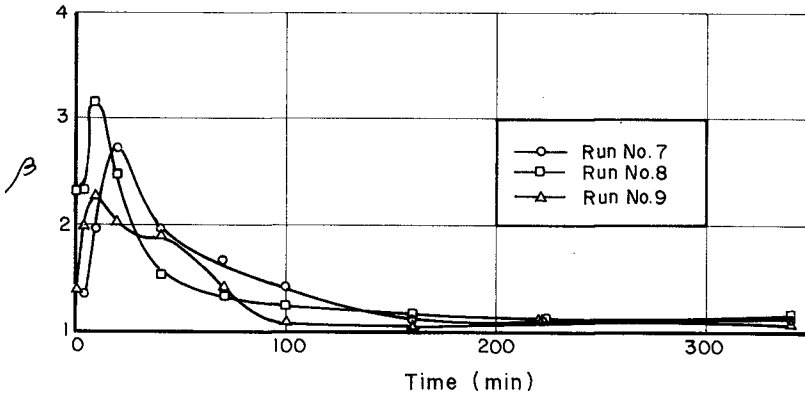


Fig. 5 Time Variation of Total Concentration

Fig. 6 The Normalized Concentration , β

At $t = 0$; $\bar{C} = \bar{C}_0$

The solution is:

$$\frac{\bar{C}_{(eq)} - \bar{C}_i}{\bar{C}_{(eq)} - \bar{C}_0} = e^{-\beta' t} \quad (5)$$

when $\beta' = \frac{\beta w_0}{h - z_0}$ (6)

Plotting $\frac{\bar{C}_{(eq)} - \bar{C}_i}{\bar{C}_{(eq)} - \bar{C}_0}$ with t the slope β' can be evaluated from the

known value of β of each run the average value of the terminal fall velocity, w_0 , is obtained which is equal to 2.15 mm/s.

v) Wave Effect on the Concentration This effect can be demonstrated by the maximum bottom velocity, $\hat{U}$, from:

$$\hat{U} = \frac{\pi H \sqrt{T}}{\sinh 2\pi h/L} \quad (7)$$

of the small amplitude wave theory and the bottom concentration at equilibrium, $C_{b(eq)}$. It was found that the two parameters give a relationship:

$$C_{b(eq)} = 191 + 47\hat{U} \quad (8)$$

Fig.7 shows the graphical relationship plotted from the data. The value 191 at the intercept is the bias concentration.

The effect of the bottom velocity can be demonstrated also by correlating it with the parameter $-\beta'$ which characterizes the transient concentration. Fig.8 shows the relationship between $-\beta'$ and $\hat{U}$ as:

$$-\beta' = 3.59(10)^{-3} \hat{U}^{0.12} \quad (9)$$

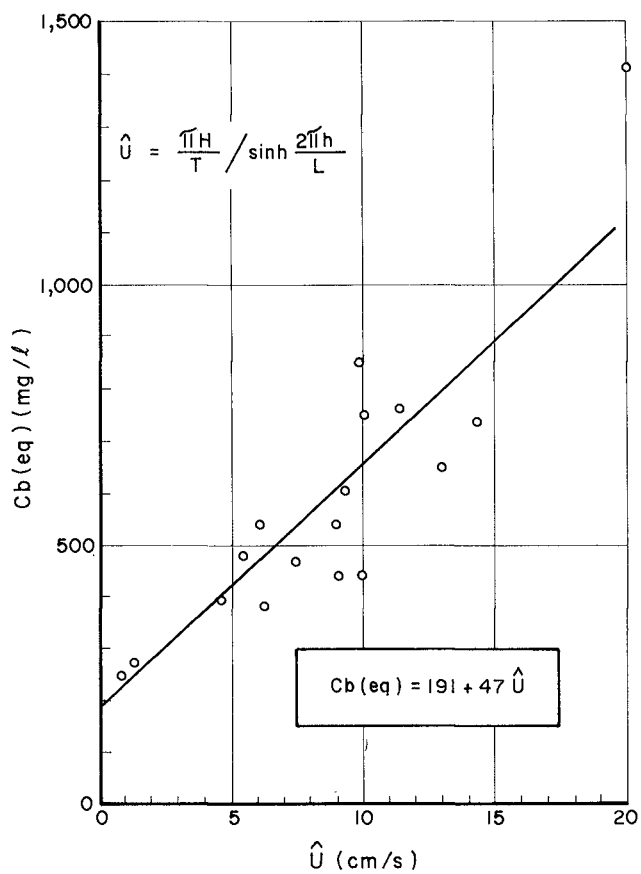


Fig. 7 Effect of Bottom Velocity, $\hat{U}$, upon the Equilibrium Concentration at Bed, $C_b(eq)$

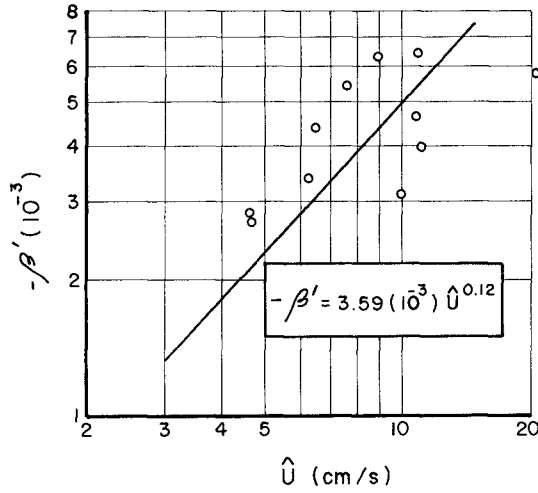


Fig. 8 Variation of Transient Concentration Parameter β' and the Bottom Velocity, $\hat{U}$

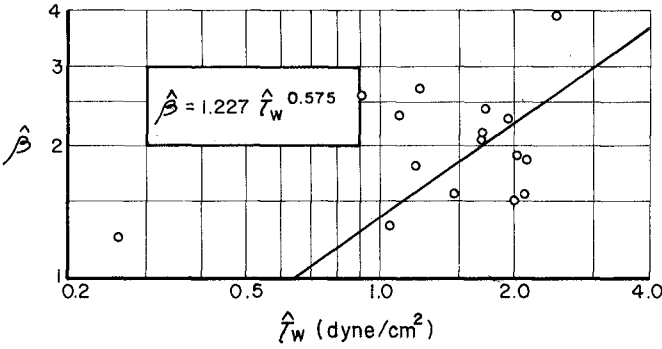


Fig. 9 Relationship between the Bottom Shear Stress $\hat{\tau}_w$, and the Maximum Normalized Concentration, $\hat{\beta}$

vi) Effect of the Bottom Shear Stress The bottom shear stress under intermediate waves is calculated using:

$$\hat{\tau}_w = f_w \frac{1}{2} \rho \hat{U}^2 \quad (10)$$

where $\hat{\tau}_w$ is the maximum bottom shear stress, f_w is the friction factor, ρ is the water density and $\hat{U}$ is the maximum oscillating velocity. It was found that the bottom shear stress can be correlated with the maximum value of the normalized concentration, β , which indicates then the effect of shear force in disturbing the bottom clay into the active layer near the bottom. Fig.9 shows that:

$$\hat{\beta} = 1.227 \hat{\tau}_w^{0.575} \quad (11)$$

CONCLUSIONS

This experiment was conducted as a preliminary stage of the investigation to determine the effect of waves on the concentration of cohesive clay. The main part of the knowledge is to identify the parameters of the acting forces, eg velocity and shear stress effecting the concentration field. Physical natures of the two regions; one in the immediate vicinity of the bed and the other in the upper region of the wave field in the disturbing process are identified. Field application cannot yet be recommended until further theoretical back up with, if possible confirmation by field data will be made.

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