CHAPTER 216

Mechanism and estimation of sedimentation in Bangkok Bar Channel

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ABSTRACT

Mechanism of sedimentation in Bangkok Bar Channel in Thailand is investigated by using the periodically measured water depth around channel, dregded volume and the relation between discharged sediment concentration and discharged velocity measured at the river mouth of Chao Praya. Simple numerical simulations for predicting sedimentation volume in the channel are also carried out. The results show that both discharged sediment from the river and sedimentation around Bangkok Bar caused by waves and current play an important role in the sedimentation in the channel.

Introduction

The city of Bangkok has been developed along the Chao Praya River. The Bangkok Harbor plays very important role in economic and social activities of Thailand. Bangkok Bar Channel is a unique approach channel to Bangkok Harbor that is the representative river port constructed along the river mouth of the Chao Praya, Thailand. Various facilities are scattered along the both sides of the river between the river mouth and the bridge located about 50km upward (see Fig.1). Due to the heavy sedimentation discharge from the river and severe sedimentation around the bar, the channel is barely maintained its fair way through the continuous dredging of about 5milion m^3/year.

Some reports have already been published about the sedimentation of the channel by NEDECO(1963), Port Authority of Thailand and so on. They reported many important and interesting phenomena and fact about hydraulics of the river mouth and characteristics of the bed material

The aim of this study is to investigate the mechanism of sedimentation in Bangkok Bar Channel and to estimate the volume of sedimentation in the channel through the statistical analysis of measured time history of river discharge, dredged volume and bottom profiles during August 1989 and August 1991 together with the results mentioned in the above-mentioned reports. In 1992, we also carried out field measurements of velocity and silt concentration at river mouth.

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For the estimation of siltation volume in the channel, we conducted some numerical simulation of non-equilibrium sediment concentration caused by waves and current that crossed the channel. It is generally recognized that there are two modes of silt transport that is transport by mud flow and that by suspension. Here, we only evaluate the sedimentation volume in latter mode.

Outline of Bangkok Bar Channel

The construction of the channel began in 1951 and was completed in 1954. The volume of capital dredging was about 16milion m^3. The length of the channel is 18km and the channel crosses Bangkok Bar, the depth of which is less than 2m at low tide. Figure 1 shows a plane view of the Bangkok Bar Channel. A mean depth of the channel is about -8.5m under the mean sea level and the width of the channel varies from 100m (at straight part) to 200m (at the bend).

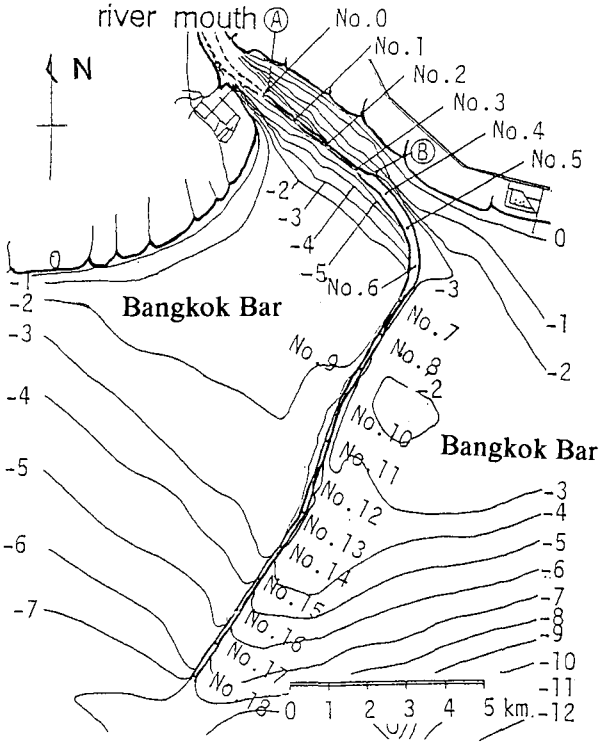


Fig.1 Plane view of Bangkok Bar Channel

There is a couple of possible causes for the sedimentation around the channel, such as sedimentation of discharged silt from the river, sedimentation caused by waves and tidal current, that caused by waves and wave-induced current around the

bank, and so on. There are also some mode of sediment transport, such as suspended sediment transport, bed load transport, mud flow, and so on. Among them, we firstly evaluated the volume of discharge sediment from the river based on the depth averaged discharge velocity and siltation concentration measured in May and in August 1991. Then, the amount of sedimentation due to suspension around the Bangkok Bar caused by waves and tidal current was predicted through the numerical simulation.

Characteristics of River discharge and Monsoon

Sedimentation around the channel seems to deeply depend on the river discharge and wind waves generated by monsoon. In usual, the maximum discharge is more than 3000m^3/s that took place at rate September to October that will be shown in Fig.5(b) later. However, in the objective period (from August, 1989 to August, 1991), the discharge was far less than the usual year as will be shown in Fig.6(b).

Figure 2 is the time series of wind direction and wind velocity measured at the Bangkok during objective period.

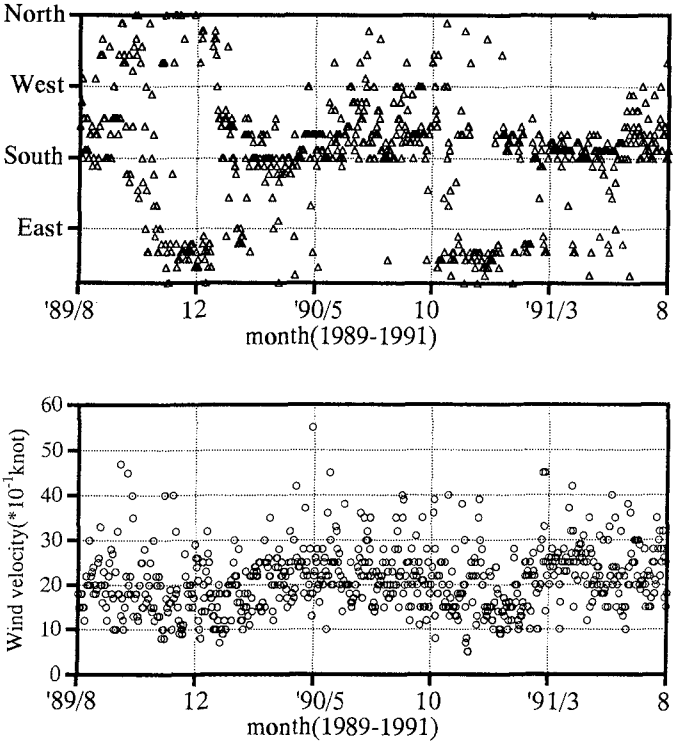


Fig. 2 Time series of wind direction and velocity during objective period

NE monsoon and SW monsoon seasons usually begin at November and May, respectively. In the objective period, each monsoon seasons began firster than usual. The mean wind velocity is about 0.5m/s to 3.0m/s and a little bit strong wind blows in SW monsoon season.

The direction that brings significant wind waves is from south to south-west. From May to July in 1990, both discharged flow from the river and wind waves caused by the monsoon might affect sedimentation in the channel. Only the discharged flow was the sedimentation agency in channel from October to December in 1989 and only waves and tidal current caused sedimentation in the channel from May to July in 1991.

Sedimentation volume in the channel

Sedimentation volume in the channel was estimated from measured channel topography and records of dredged volume. Sounding of the channel has been carrying out by Port Authority of Thailand twice a month at distances of 200m in the offshore (transversal) direction and 5m in the longitudinal direction. We express the measured depth in the following way:

$$h(x,y,t)=h(i\Delta x, j\Delta y, k\Delta t), \qquad (1)$$

x : *transversal direction*, $\Delta x = 200m, 1 \le i \le 91$

y : *longitudinal direction*, $\Delta y = 5m, 1 \le j \le 61$

$\Delta t = month/2$

Sedimentation volume was calculated by the following relation:

$$\Delta V(i,j,k) = \{h(i,j,k) - h(i,j,k+1)\}\Delta x \Delta y \qquad (2)$$

We define the total sedimentation volume ΔTV as a sum of ΔV and dredged volume ΔV_d. We obtained there data through the courtesy of the Port Authority of Thailand.

The characteristics of the time and spatial variation of the sedimentation volume is investigated by comparing the time histories of river discharge and wind data.

Figure 3 illustrates the temporal and spatial distribution of the total siltation volume of the channel. The vertical axis is the distance from the river mouth and the horizontal axis is the month.

It can be seen that dark parts centered around 3 to 8km from the river mouth. This section of the channel corresponds to the bending part. Especially, from August to October and April to July, large volume of sediment deposited. These two duration corresponds to the two peaks of river discharge (see Fig.6(b)). However, there are another dark parts in the bend during February and August in 1991 (south-west monsoon season) when there was only small river discharge.

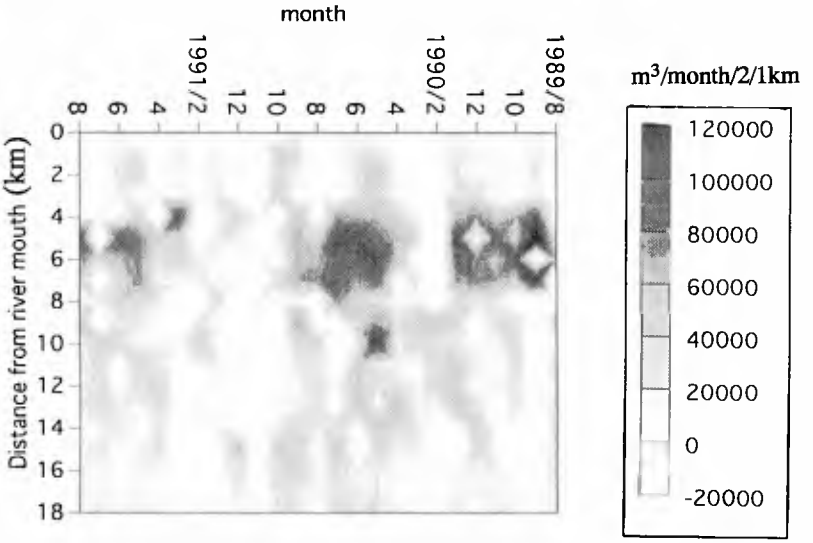


Fig.3 Temporal and spatial distribution of the total sedimentation volume

Figure 4 illustrates the variance of the change in water depth $\Delta h_{vr}(i,j)$ that means the magnitude of the topographic change in the channel.

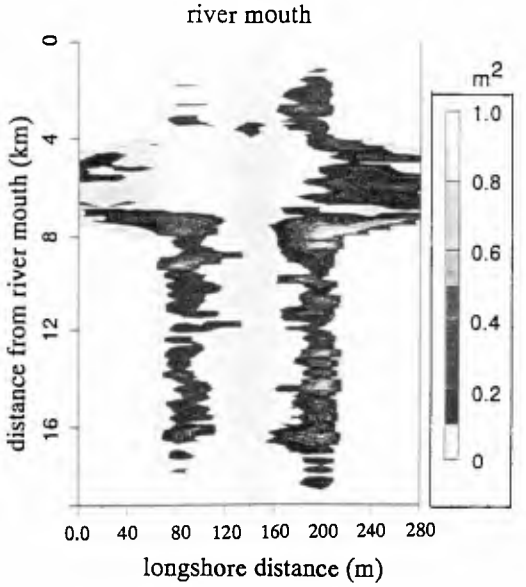


Fig.4 Variance in water depth around the channel

The variance is calculated by Eq.(3).

$$\Delta h_{vr}(i,j) = \sum_{k} \{h(i,j,k) - \overline{h(i,j)}\}^2 / 25 \qquad (3)$$

where $h(i,j)$ is the averaged water depth during the objective period.

The vertical axis is again the distance from the river mouth and the horizontal axis is the longshore distance. It is found that change in water depth is large in the bend and the slope of the channel where the non-equilibrium property of suspended sediment is strong.

Figure 5 shows the comparison of the averaged river discharge and the averaged total siltation during 1957 and 1963. The averaged total siltation volume is calculated in upper section (from 0km to 6km from the rover mouth), middle section (from 6km to 12km from the river mouth) and lower section (from 12km to 18km from the rover mouth) separately in the following way and are shown by a solid line, a dotted line and a broken line, respectively.

$$\Delta TV_l(k) = \sum_{i=(l-1)*30}^{l*30-1} \sum_{j} \Delta TV(i,j,k), \qquad (4)$$

l=1:upper section, 2:middle section, 3:lower section

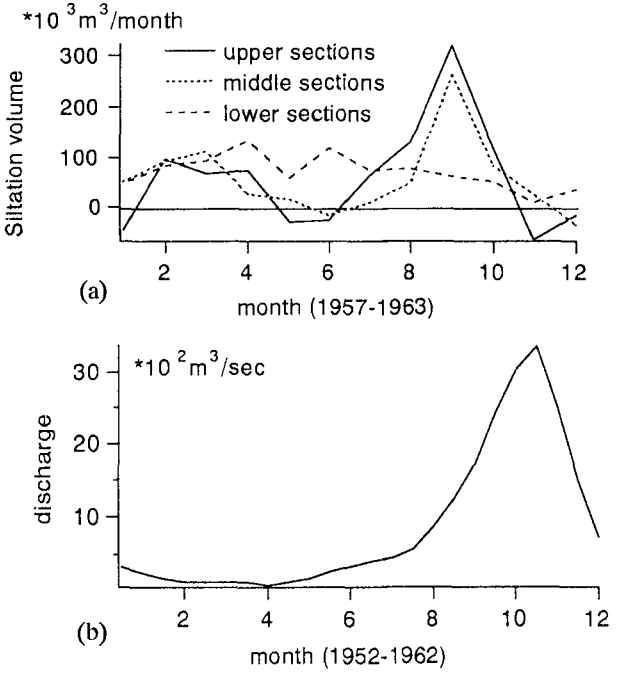


Fig. 5 Comparison of the seasonal changes of averaged total sedimentation volume and river discharge

River discharge has a peak at middle of October and the total siltation in the upper and the middle sections have peaks at middle of September that correspond to the peak of river discharge. They also indicate large values during February and April when the river discharge becomes minimum. The total siltation in the lower sections dose not show any significant seasonal change.

From these results, we can judge that sedimentation in the upper and the middle sections is mainly caused by river discharge and in the lower sections river discharge has little influence. Waves and current also play an important role in sedimentation in dry SW monsoon season in the upper and middle sections and in the lower sections they become unique agitation and transporting agency of bed material to deposit in the channel.

Figure 6 shows the comparison of time histories of the total siltation and river discharge during August 1989 and August 1991. In this duration there are three peaks in river discharge and again there are increases in the total siltation in the upper and the middle sections. However, the correspondence is not so clear as the former figure due to the scattering of the data because these are the raw and unsmoothed data.

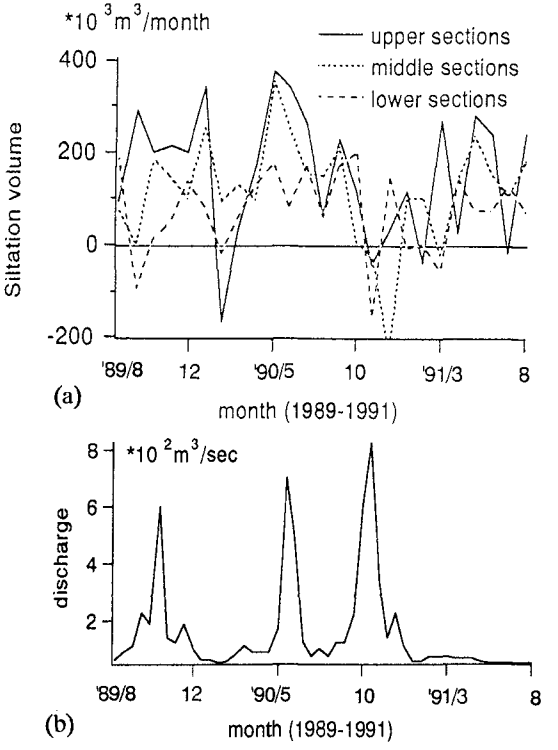


Fig.6 Comparison of time histories of total siltation volume and river discharge during the objective period

Estimation of sedimentation volume discharged from the river

We carried out field measurement of discharged velocity and silt concentration in May and August 1992 at two point near the river mouth. Here, we roughly estimated the siltation volume using the measured results. Figure 7 illustrates the relation between the mean discharged velocity and mean silt concentration presented in the report of NEDECO (1963). The open circles in the figure are the result of our measurements.

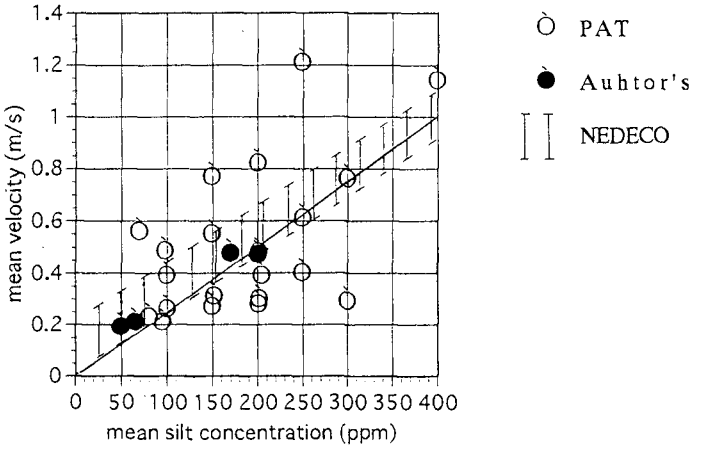


Fig.7 Relation between depth averaged discharge velocity and silt concentration at the river mouth

As you know well, the mean silt concentrations in the beginning of the discharge and in the descending period of the discharge are not the same. Generally it is lower in the later period. However, we assume that the mean silt concentration is a unique function of the mean velocity. Then we have the relation between then from the figure in the following form:

$$C[ppm] = 400U[m/s] \qquad (5)$$

Let the discharged volume and sectional area of the flow at the river mouth be Q and A, then the discharged silt volume Qs is expressed as:

$$Q_s = AUC = 400Q^2/A * 10^{-6}\left[m^3/s\right] \qquad (6)$$

Further we assume that the time history of the river discharge is expressed by the triangle with the peak value of 3000m^3/s and continues for two months as shown in Fig.8 and the sectional area of the river mouth be 2000m^2. Then the total siltation volume discharged from the river is calculated by the integration

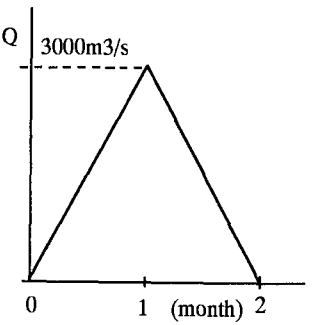


Fig.8 Assumed hydrograph

$$Q_{total} = \int_0^{two-month} Q_s dt \qquad (7)$$

that gives $1.6*10^6 m^3$/year. The value is about a half of the annual averaged total annual siltation volume.

Estimation of sedimentation volume caused by waves and tidal current

In this section, siltation volume due to waves and current, an another sedimentation agency in the channel is evaluated by a simple numerical simulation.

For the sake of simplicity, and to grasp the rough figure of the sedimentation in the channel, we assume that the waves and current cross the channel at right angle as shown in the lower figure. X-axis is taken in the direction of wave propagation and we simulate the flow and sedimentation in 2-D phenomena (see Fig.9).

In such case, sever sedimentation will take place due to the non-equilibrium suspended sediment transport caused by the existence of channel. In the numerical simulation, we have to reproduce the non-equilibrium state of the suspended sediment concentration adequately.

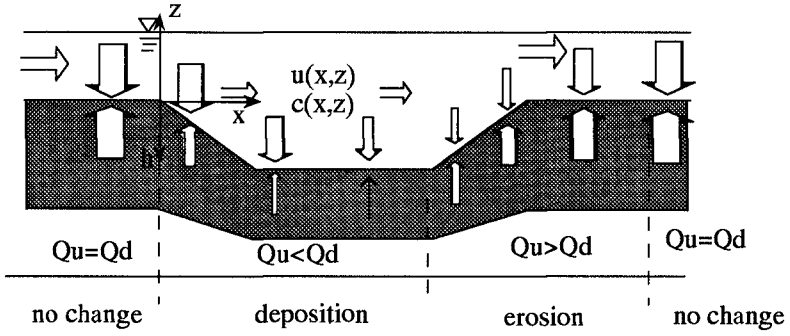


Fig.9 Coordinate system

A governing equation of suspended sediment concentration c is an advection-diffusion equation that is expressed by Eq.(8).

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} - W_f \frac{\partial c}{\partial z} = \varepsilon_x \frac{\partial^2 c}{\partial x^2} + \varepsilon_z \frac{\partial^2 c}{\partial z^2} \qquad (8)$$

where u is the mean current velocity that has a vertical distribution, ε_x and ε_z are the diffusion coefficients in x and z direction and W_f is the settling velocity of bed material.

It has been recognized that it is generally difficult to numerically solve the advection-diffusion equation with high accuracy because it contains two mathematically and physically different terms, i.e., advection term and diffusion term. Recently, highly accurate numerical procedures for solving the advection-diffusion equation have been developed by Komatsu et.al.(1985) that is called a split operator approach.

We applied two procedures to simulate non-equilibrium suspended sediment concentration. Eq.(8) is solved by using a split-operator approach in Method-1 and in Method-2, an advection-dispersion equation Eq.(9) instead of Eq.(8) is solved to obtain sediment concentration. Equation (9) is derived by taking depth average of Eq.(8).

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} + V\frac{\partial C}{\partial y} = \kappa_x \frac{\partial^2 C}{\partial x^2} + \kappa_y \frac{\partial^2 C}{\partial y^2} + \Delta Q_s \qquad (9)$$

$$\Delta Q_s = \left\{ C_0 u^* \left(1 - W_f / u^*\right) - W_f C \right\} / h \qquad (10)$$

$$\gamma = 1, \quad u^*/W_f \le 1, \gamma = 0, \quad u^*/W_f > 1$$

where U and V are the depth averaged mean current velocity in x and y directions, C is the depth averaged concentration of suspended sediment, k_x and k_y are the dispersion coefficients in x and y directions, u^* is the bottom shear velocity caused by waves and current C_0 is the reference concentration at the bottom and h is the water depth.

In Method-1, the advection-diffusion equation is split into the advection and the diffusion equations Eqs.(11) and (12).

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} - W_f \frac{\partial c}{\partial z} = 0 \qquad (11)$$

$$\frac{\partial c}{\partial t} = \varepsilon_x \frac{\partial^2 c}{\partial x^2} + \varepsilon_z \frac{\partial^2 c}{\partial z^2} \qquad (12)$$

These two equations are transformed to a pair of finite difference equations by using 6-point and 5-point methods, respectively. The difference equations are calculated iteratively at grid points. The boundary condition for concentration is given at the upstream end and at the bottom.

After obtaining the steady solution, we can evaluate suspended sediment flux (Eq.(13)) and the rate of topographic change by Eq.(14).

$$q_s(x,z) = \int c(x,z)u(x,z)dz \qquad (13)$$

$$\frac{\partial h(x,t)}{\partial t} = \frac{1}{1-\lambda}\frac{\partial q_s(x,t)}{\partial x} \qquad (14)$$

In Method-2, a depth averaged advection-dispersion equation (Eq.(9)) is solved by using an Alternating Direction Implicit method. The boundary condition for the depth averaged concentration is given at the upstream end and at the bottom. The change in water depth is calculated by using vertical sediment flux ΔQ_s as follows:

$$\frac{\partial h}{\partial t} = \frac{-\Delta Q_s}{1-\lambda} \qquad (13)$$

We have already developed this method for the simulation of topographic change in coastal region. We apply the procedure to calculate topographic change of channel section. About 20 times as much as CPU time is required in Method-1 when compared with that required in Method-2.

We carried out numerical simulations of channel topography change of two cases as shown in Fig.10. In both cases, the depth of the fairway was 8.5m. The depth at the channel approach was 3m in Case-1 and 5m in Case-2. The non-equilibrium property of suspended sediment is stronger in Case-1 than in Case-2.

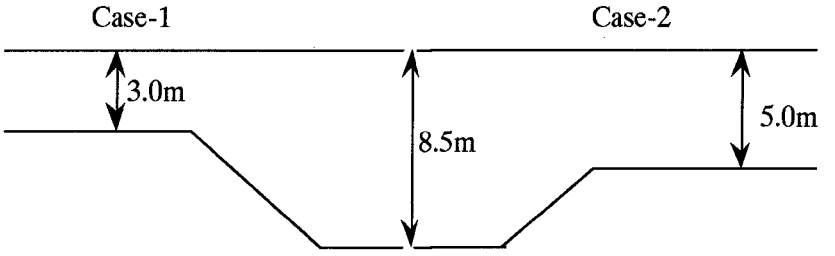
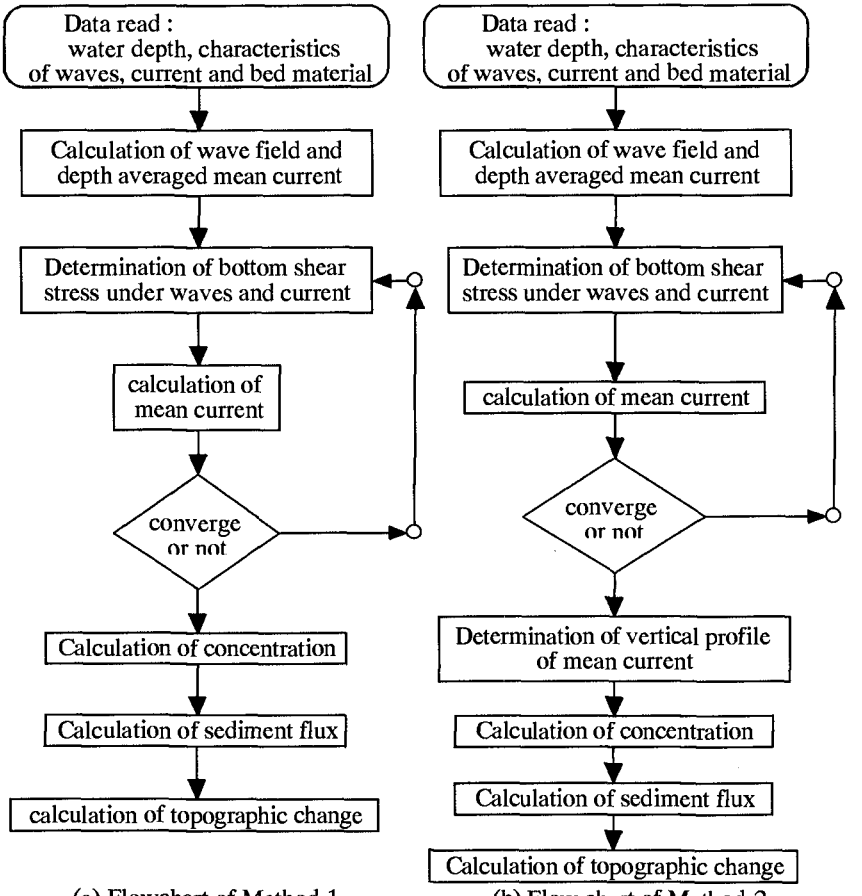


Fig.10 Channel section of numerical simulation

Height and period of incident waves were 1.5m and 6s. According to the report of the Port Authority of Thailand, waves of such magnitude would occur more than 30hrs per year. The mean current velocity was determined to be 0.3m/s that was a mean tidal current that crosses the channel. The settling velocity of bed material was 0.12cm/s that included the effect of flocculation (NEDECO, 1963).

In the numerical simulation, we first calculated waves and current based on equations of wave energy conservation and depth averaged momentum conservation where the bottom shear stress were evaluated from the turbulent boundary layer equation (Deguchi, 1995). In Method-1, the vertical distribution of mean current was determined from the depth averaged mean current velocity by using the kinematic eddy viscosity as a function of bottom shear velocity.

Figure 11 illustrates flow charts of both methods. We used the same value as the kinematic eddy viscosity for the diffusion coefficient in Method-1. The dispersion coefficient in Method-2 was given as a function of the product of the bottom shear velocity and the water depth.



(a) Flowchart of Method-1 (b) Flow chart of Method-2

Fig.11 Flow chart of numerical simulation

Figure 12 shows the comparison of predicted changes in water depth at two representative channel sections by two methods. Although there are signuficant difference between the simulated results by the two methods, we can judge that we can not neglect the effect of the waves and current in the sedimentation in channel. In Case-1 (Fig.(a)), the predicted decrease in water depth in channel by Method-1 is larger than 20cm per one hour. On the other hand, the decrease of the depth in Case-2 (Fig.(b)) is only 6cm per hour in average.

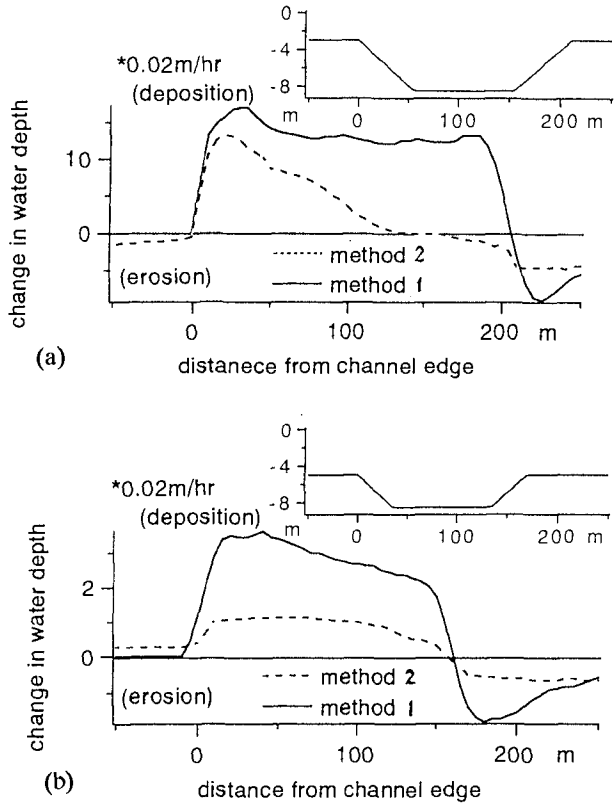


Fig.12 Change in water depth across channel
((a):Case-1, (b):Case-2)

According to the calculated change in water depth by Method 2, volumetric change per unit length per one hour of the channel is about $17m^3/m/hour$ that will be about $500m^3/m/year$. When we assume that this amount of siltation take place along the middle sections 6km (From No.6 to No.12) where the depth of approach is about 3m, the total amount of sedimentation will be $3*10^6m^3/year$ that is the same order of the siltation volume due to river discharge.

From these results the amount of sedimentation caused by waves and current is estimated to be about $3*10^6m^3/year$ that is the same order of the sedimentation volume discharged from the river.

Conclusions

Through the statistical analysis of the topographic change in the channel, it is found that sedimentation in the upper and the middle sections of the Bangkok Bar Channel is mainly caused by the river discharge. In the lower sections, the river discharge has little influence. Waves and tidal current also play an important role in sedimentation in the middle and lower sections and they become a unique agitation and transporting agency of bed material to deposit in the channel of lower sections.

From the results of simplified numerical simulation of the sedimentation in the channel, we can judge that the order of the amount of sedimentation caused by waves and current in the middle sections is almost the same as that brought about by the river discharge.

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