CHAPTER 220

Siltation Study in a Long Approach Channel on Large Scale Muddy Tidal Flat

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Abstract

Siltation mechanism in a 14km long approach channel on large scale muddy tidal flat is studied based on field investigations and numerical simulation. Natural conditions such as river discharge, waves, tides, tidal currents, and bed materials were measured over one year. The morphological change shows some relations with the grain size distribution of bed materials and current flow patterns. The net movement pattern of bed materials in the muddy tidal flat is given by the analysis of the field data. From the numerical simulation, it is revealed that the resuspended bed materials by waves from the surrounding tidal flat play an important role in the siltation process of the approach channel.

1. Introduction

Many riverine ports in Asian countries have long approach channels which connect the river mouth with offshore through a muddy flat. The study on the transport mechanisms of fine sediments in estuaries is important to develop measures for the reduction of siltation releasing a port management body from high maintenance dredging cost. In the world, there are many estuaries and ports which suffer from siltation, and field investi-

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gations have been conducted to understand the mechanism of high concentration mud movement (e.g., *Leussen and Velzen* 1989, *Costa and Mehta* 1990). Typical field investigations have been made for the siltation mechanisms in a monsoon-dominated coasts (*Terwindt et al.* 1987, *Hoekstra et al.* 1988).

In the present study, systematic field investigations were conducted in the port of Banjarmasin in South Kalimantan of the Republic of Indonesia.

The siltation mechanism on a large scale muddy tidal flat is investigated based on the field data. A numerical simulation is used to obtain detailed information on external forces which govern the siltation and the sources of materials deposited in the channel. A practical method to estimate the annual amount of deposition volume is also presented.

2. Natural Conditions

Field investigation was conducted from 10th September, 1988 to 10th September, 1989. **Figure 1** shows the map of the

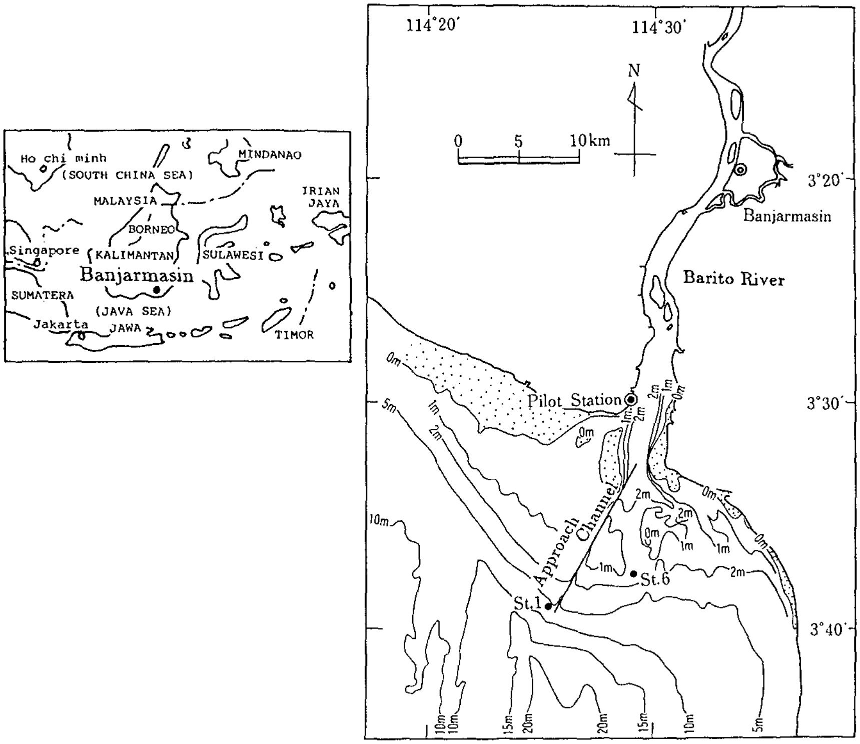

Fig.1 Map of Investigation Site

Table 1 Averaged Wave Conditions

Season	H(m)	T(s)	Direction
Rainy	0.58	4.0	S15° W
Dry	0.43	3.5	S10° W
85days	0.41	3.5	S15° W

investigation site. The port of Banjarmasin locates 26km upstream from the mouth of the Barito River. The size of the approach channel is 14km in length and 60m in width. In spite of the annual dredging (2~3 million m^3/y), the planned water depth 6m is scarcely maintained. The river mouth is characterized by the formation of the large fine sand deposits on both sides of the approach channel. Waves, tides and winds were measured for one year. Measurements of tidal currents, saline wedge, turbidity, river discharge, etc. were also conducted.

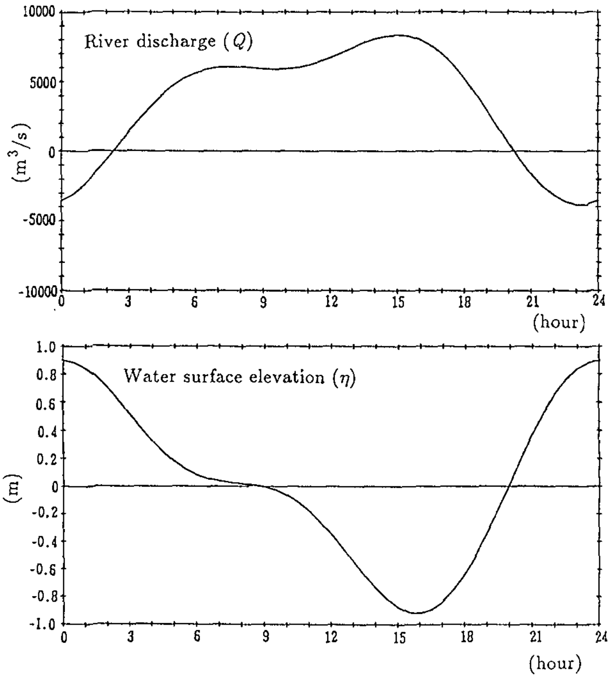

Fig.2 Time Variation of River Discharge and Water Surface Elevation at Pilot Station

From the measurements of river discharge, it can be said that the river discharge in the dry season (from April to September) is less than 1,000 m^3/s and in the wet season (from October to March) is more than 4,000 m^3/s.

Waves were measured at St.1 near the entrance of the approach channel at the water depth of 6m for 1 year continuously at every 2 hours with an ultra-sonic wave gauge. The wave directions were determined by wind directions measured at the pilot station for wave periods less than 3 seconds, and by water particle movement directions for wave periods longer than 3 seconds. The averaged significant wave heights, wave periods and energetically weighted wave directions in each season are summarized in **Table 1.** In the table, the "85 days" shows the intermission period of dredging during which the actual deposition rate in the channel is estimated for the calibration of the numerical simulation of siltation.

Tide is a basic factor in determining water level changes and currents in an estuary or coastal area. A tide gauge was set at the pier of the Pilot Station. According to the harmonic analysis of tides, the diurnal component K_1 is the largest, and the semidiurnal component M_2 is the second largest. In the numerical simulation of deposition, the tidal level which is composed of K_1 and M_2 components is taken as the representative value. In the calculation, it is assumed that the periods of K_1 and M_2 components are just 24 hours and 12 hours, respectively. A typical time variations of the river discharge and the water surface elevation in a day is presented in **Fig.2**.

Tidal current observations were carried out at eleven stations with electro-magnetic current meters. The measuring stations are expressed in **Fig.9** which will be shown later.

Another current observations were carried out by tracking the movement of drogues. This method is convenient to grasp the flow pattern briefly. Several drogues were released at the river mouth at high tide, then the observers follow each drogue position from the boat. The measured results will be shown in **Fig.11**. These current data are used for the calibration of tidal current simulation.

Bed material samplings were carried out in and around the approach channel. The total number of sampling points are 26. An example of the composition of bottom materials is shown in **Fig.3**. In the figure, bottom materials are classified into gravel (d>2mm), sand (0.074<d<2mm), silt (0.005<d<0.074mm), and clay (d<0.005mm).

At stations C, H, L, O and Q, the bottom sediments mainly

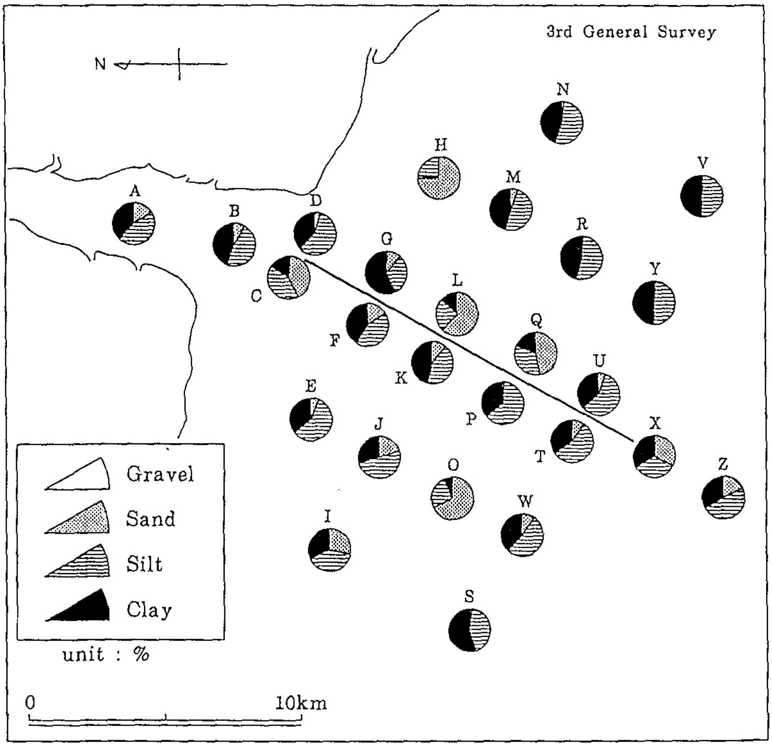

Fig.3 Composition of Bottom Materials

consist of sand and silt, and the sand content is nearly 50% or more than 50%. At other stations, the bottom sediments mainly consist of clay and silt. From the results of field observations, bottom sediments around the approach channel are generally composed of fine silt materials, except at the tidal flat near the river mouth (Sts. C and H), and other three offshore areas beside the approach channel (Sts. L, O and Q).

3. Numerical Simulation

3.1 Grid Arrangement

A three dimensional eight-layered level model with nested grids is used in the calculation (*Tsuruya et al.*, 1990). The area for calculation is 40 km×50 km. The width of the approach channel in the present condition is 60 m. The length of it, on the other hand, is 14 km which is about 230 times greater than the width. For the accurate estimation of the deposition rate in the approach channel, the small grid size is preferable. In the direction of the width, at least two grids must be placed in the approach channel. We can then set the transverse grid size as 30 m. As the square grid is unrealistic because of the requirement of tremendous number of grids, the longitudinal size is set to be ten times greater than the transverse grid size. Moreover, the area for calculation is divided into three areas with respect to grid sizes, that is 270×2,700m, 90×900m, and 30×300m for each area from the first to the third, respectively. In the calculation the water depth is vertically divided into eight layers.

3.2 Tidal Currents

An example of the calculated tidal current distribution for the first layer (from -0.5m to 1.6m measured from the datum level) of the second and the third area is shown in **Fig.4**. The time is 18 hour from the high tide as shown in **Fig.2**. The current vector distributions can be understood that the reproduction of current patterns in the numerical model is well in terms of the S-shaped bend of ebb currents (also see **Fig.11**).

3.3 Deposition Rate during Intermission Period of Dredging

The actual deposition rate in the approach channel can be estimated from the siltation volume measured with an echo-sounder. Dredging works were stopped from February 28th to May 24th 1989 for the measurement of natural mud deposition in the channel. Soundings were performed in the narrow area surrounding the approach channel. The duration of the intermission period of dredging was 85 days.

The measured volume of deposition in the channel within this period is shown in **Fig.5** for both frequencies 210 kHz and 33 kHz. The Spot number 0 corresponds to the offshore side of the channel. The volume in the figure are not directly related to the substantial deposition volume to be dredged because the measured depth by echo-sounder varies considerably with the frequency adopted and density of the fluid or mud.

The substantial deposition rate in dry weight of materials per unit area is necessary in comparing the actual and calculated deposition rates. Therefore, the vertical distribution of water content of mud which was estimated by sampling is related to the echo-sounding and lead tests to get the substantial deposition rate. **Figure 6** shows the measured and assumed vertical distribution of water content. The percentage of water content 110% corresponds to the bulk density about 1.45g/cm^3. The water content near the bed which was detected by 33kHz echo-sounder was 110.3% and the level here was almost coincident with that measured by the lead. Around the level measured with the 210kHz echo-sounder, the sample showed high water content at 1,260.4%. At the end of the intermission period of dredging, the level which was detected by 33kHz echo-

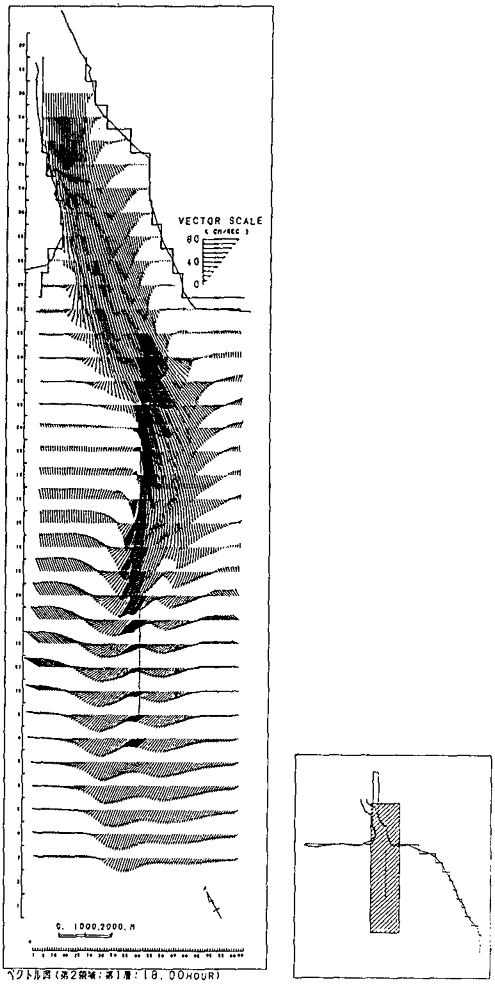

Fig.4 Current Vector Distribution (at 18:00, 1st layer)

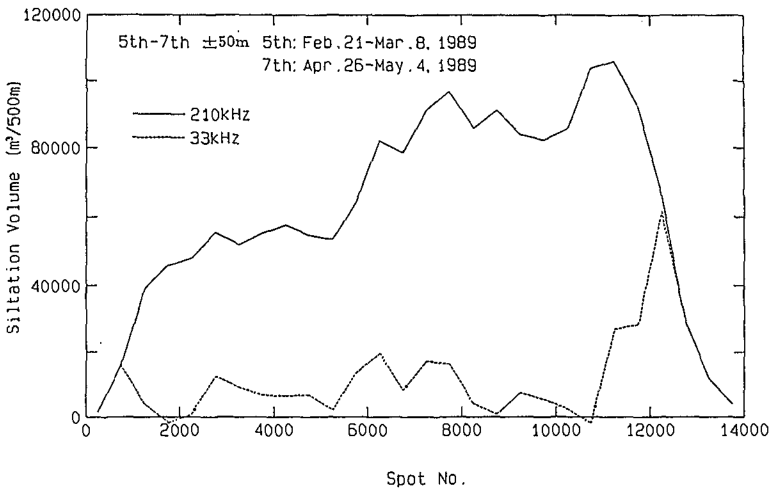

Fig.5 Apparent Siltation Volume along Channel Axis (width ±50m)

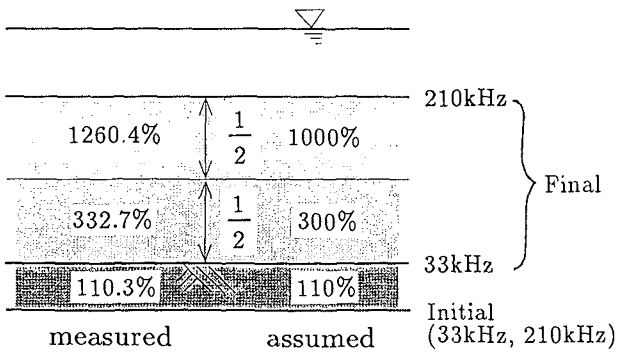

Fig.6 Measured and Assumed Water Content of Mud

sounder increased from the initial level. This means the substantial bed shoaling. Based on the data stated above, we assume the vertical distribution of water content W (%) in the approach channel as shown in the right hand side of **Fig.6**. From the assumption we can estimate the substantial deposition rate. The estimated substantial amount of deposition during the intermission period of dredging (85days) is shown in **Fig.7** as a histogram. The measured deposition volume is converted to that having the water content of 110%. For this value, the wet bulk density of soil is 1.45 t/m^3 which is the same as that of the in

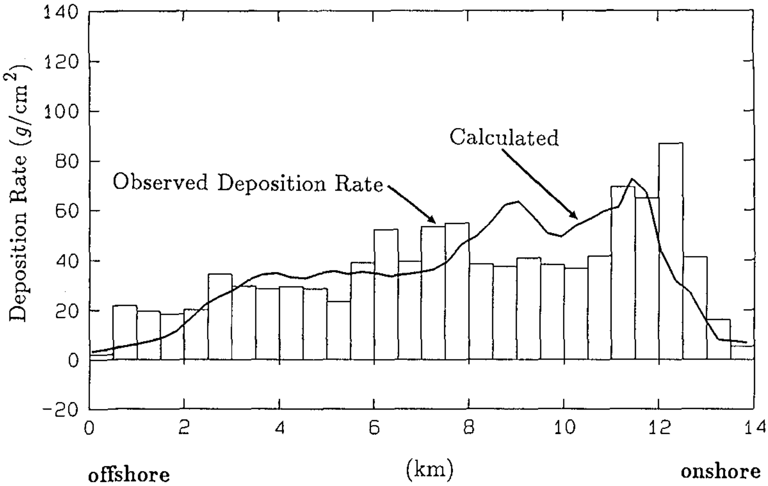

Fig.7 Observed and Calculated Deposition Rate

situ dredged soil. The total amount of deposition in 85 days thus estimated is 733,000 m^3.

To calibrate the model, the deposition rate in a day is calculated with a super-computer under the measured natural conditions such as the river discharge ($3{,}500m^3/s$), concentration of suspended solids of the river water ($50mg/l$), waves ($H_{1/3}$=41cm, $T_{1/3}$=3.5s), etc. The calculated deposition rate in 85 days is obtained by multiplying 85 by the calculated deposition rate in a day. It can be directly compared with the measured one as shown in **Fig.7**. Their distribution patterns agree well each other.

4. Results and Discussion

After the calibration of the present model is completed, the deposition rates during the rainy and dry seasons can be estimated with the corresponding natural conditions. Wave direction, significant wave height and period are statistically analyzed for the rainy and dry seasons as already shown in **Table 1**. The river discharge is given by the field observation as $5{,}000m^3/s$ for the rainy season and $1{,}500m^3/s$ for the dry season. The thick line which is illustrated as "Total" in **Fig.8** shows the calculated deposition rate for the rainy season of which duration is 182 days.

To investigate the source of deposited materials in the channel, the direct contribution from the river is estimated by simulation under the assumption of the fixed bed condition in the tidal flat and the approach channel, so that only the sediments from the river are the source of deposited materials. As no erosion in the approach channel is allowed in the calculation of the fixed bed condition, the deposition rate on the onshore side at 13 ~14km is larger than that of the total deposition rate. Although the rate of deposition is not a linear function of the concentration of mud for the free settling region, the difference between two curves in **Fig.8** approximately correspond to the settled mud which is resuspended by waves from the surrounding tidal flat. From **Fig.8**, it can be concluded that the direct contribution from the river is not large except near the river mouth and the resuspended bed materials by waves from the surrounding tidal flat play an important role in the siltation process of the approach channel which is constructed in a large scale muddy tidal flat.

The hodographs of tidal currents in terms of the mean velocity and K_1+M_2 components (50cm above the sea bed) are shown in **Fig.9**. The numbers of the hodographs correspond to the time from the high tide. The tidal current vector in the west flat (west of the main stream) rotates clockwise and the hodographs show round shapes. In the east flat, on the other hand, they rotate anticlockwise and show long and narrow

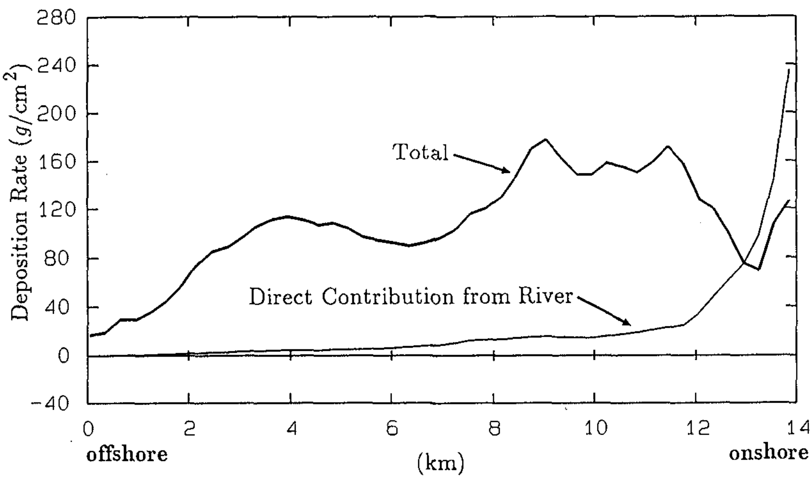

Fig.8 Calculated Deposition Rate for Rainy Season

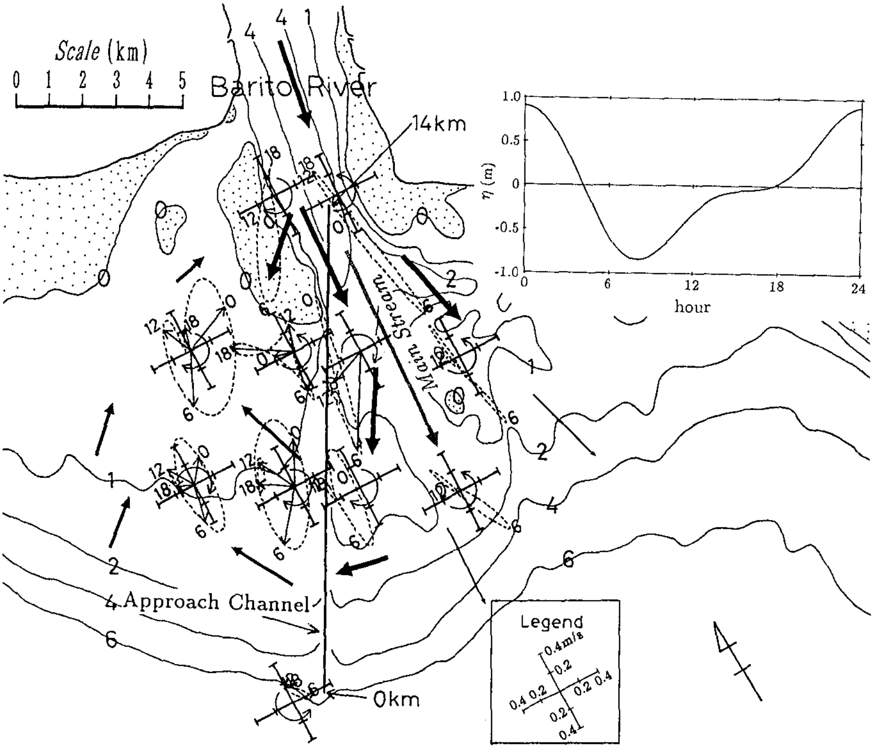

Fig.9 Hodographs of Tidal Currents and Sediment Movements

shapes. As the diurnal constituent K_1 is dominant here, the surface elevation η varies with time as schematically shown in **Fig.9**. The tidal level given here is somewhat different from that in **Fig.2**. In general, when η is low or during low tide (5~18hr), the sea bed in the tidal flat is influenced considerably by waves because of the high orbital velocity and the rate of erosion from the bed is larger than that of the high tide. The tidal currents during the low tide in the west flat are dominated by westward currents, whereas during the high tide that are dominated by eastward currents as shown in **Fig.9**. As a result, the net transport of sediments in the middle part of the west flat is from the south-east to the north-west according to the current direction. The dominant wave direction is south-west and the sediment movement in the west flat is directed to the north-east direction because of the mass transport by waves and asymmetric characteristics of tidal currents. The directions of the net transport of bed materials expected from the above consideration are shown in **Fig.9** as the arrows with the thickness roughly showing the transport quantity.

Morphological change during 84 years is analyzed by comparing the Chart around 1905 with the surveyed sounding data in 1989. In **Fig.10**, accretion and erosion areas more than 60cm are shown as the thin contour lines. Near the river mouth, typical accretion can be found in the west side of the channel. In the east side near the river mouth, on the other hand, erosion is dominant. At the offshore side of the channel, erosion also can be found in the west side of the channel. In the east side near the river mouth, on the other hand, erosion is dominant. At the offshore side of the channel, erosion also can be found in the west bank. The thick contour lines in the figure show the horizontal distribution of the median diameter of bed materials. There are four distinct peaks for the median diameter contours. In the west bank of the approach channel, there are two peaks and the maximum values are greater than 1000μm. In the east bank, on the other hand, the maximum values (940μm and 510μm) are slightly smaller than that of the west bank. **Figure 11** shows the loci of drogues which represent the surface current and calculated velocity distribution at the third layer (from 1 to

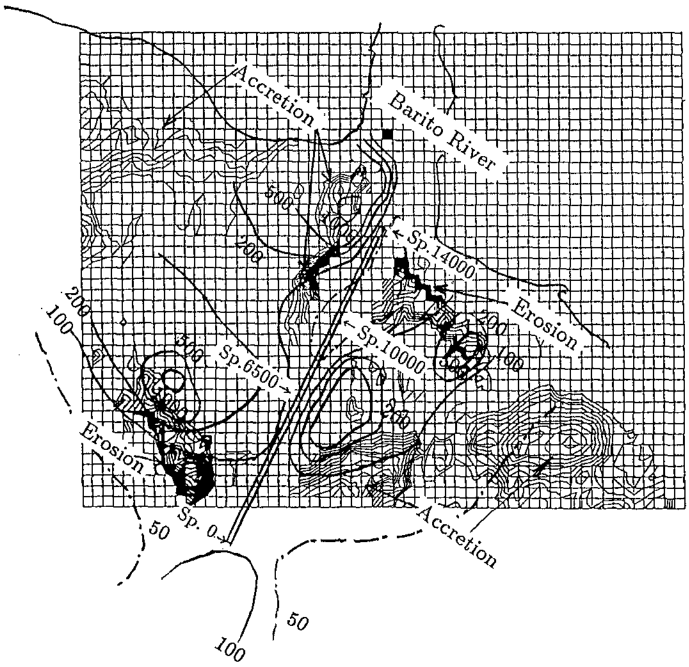

Fig.10 Morphological Change and Grain Size Distribution

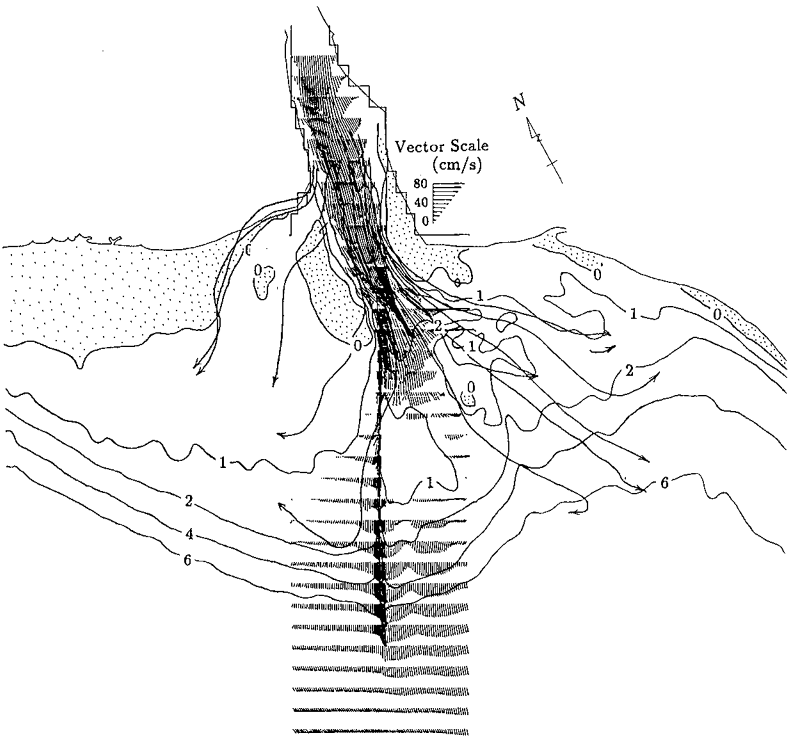

Fig.11 Measured Loci of Drogues and Calculated Flow Pattern

1.5m below the datum level) at an ebb tide. The loci of drogues are shown as thick solid arrows. From **Figs.10** and **11**, it can be thought that the west bank near the river mouth is formed by deposition of coarse sand which is carried from the river because of the sudden decrease of the current speed in this area and of the eastward longshore sand transport due to waves attacking from the dominant SW direction. The eroded area in the east part of the river mouth is formed by the strong current which is directed to the east direction from the river mouth, and only coarse sand which resist the strong tractive force can exist in this area. The accretion areas, therefore, are formed offshore side in the east bank. The erosion area in the west offshore side will be formed by the continuous wave attack.

5. Conclusions

The substantial transport direction of fine sediments on the large tidal flat was investigated based on the field data and numerical simulations. The net transport of sediments is from the south-east to the north-west in the middle part of the west flat. Finally, the sediment movement in the west flat is directed to the north-east direction because of the mass transport by waves and asymmetric characteristics of tidal currents.

From the numerical simulation, it is revealed that the resuspended bed materials by waves from the surrounding tidal flat play and important role in the siltation process of the approach channel.

Current velocity and waves play an important role in the formation of large scale muddy tidal flat.

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