CHAPTER 117

# Effects of structure on deposition of discharged sediment around rivermouth

by
Ichiro Deguchi* and Toru Sawaragi**

## ABSTRACT

The influence of coastal structures on a discharged flow and a depositional pattern of discharged sediment from a river are investigated experimentally. It is found that a pair of offshore detached breakwaters, as well as a pair of jetties, had a little influence on them. The offshore detached breakwater has also a function to prevent rivermouth from filling up with depositional sediment by waves. A numerical procedure for the prediction of depositional pattern of discharged sediment is developed based on the experimental results. The proposed numerical procedure is shown to reproduce depositional patterns around a rivermouth without structures and a jetty-protected rivermouth satisfactorily. However, the flow pattern around the offshore detached breakwater-protected rivermouth can not be reproduced.

## INTRODUCTION

Until now, jetties have been widely used to protect a rivermouth from blockage. This is because a jetty possesses an effective function to trap sediment transported in the longshore direction. However, this function of jetty produces an abrupt discontinuity of sediment transport and consequently brings erosion of a coast around a rivermouth. The decrease of discharged sediment due to constructions of dams and improvements of river channels accelerate the erosion.

Therefore, to deal with rivermouthes by constructing coastal structures successfully, it is required that such structures have functions not only to prevent the rivermouth from blockage but also not to bring an extreme discontinuity of sediment transport in the longshore direction. It is also desired that the discharged sediment from the rivermouth should be fed back effectively to the beach around the rivermouth.

*Associ. Prof., Dept. of Civil Engineering, Osaka University
**Prof., Dept. of Civil Engineering, Osaka University
Yamada-oka, Suita-city, Osaka 565, Japan

The authors have been conducting a series of investigations to establish the optimum design method for rivermouth treatments. This study is a part of the investigations in which the effects of jetties and offshore detached breakwaters, which will be one alternative of jetties, on the behavior of discharged sediment from the river are discussed based on the experimental results. A numerical model for predicting the depositional pattern of discharged sediment is also proposed and the applicability of the model is verified through experiments.

## EXPERIMENTS ON THE DEPOSITIONAL PATTERN OF DISCHARGED SEDIMENT

The effects of jetties and offshore detached breakwaters on the discharged flow from the river and depositional patterns of discharged sediment were first investigated by conducting three-dimensional experiments in a wave basin of 5m wide, 15m long and 0.6m deep. A sketch of the wave basin and the model river constructed in it is shown in Fig.1 together with the coordinate system and symbols used in the following descriptions.

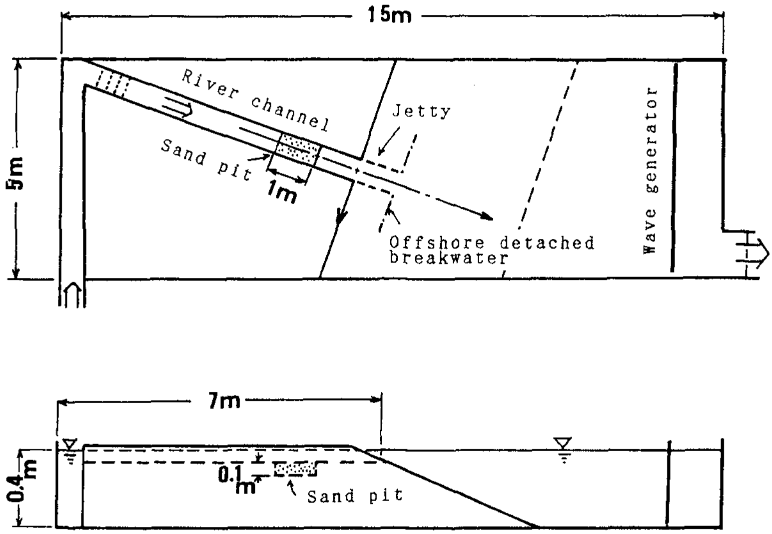


Fig.1 Sketch of wave basin and model rivermouth

A width of the model river channel,B, was 0.5m and a depth at the rivermouth ,$h_0$ ,defined at X=0 in the figure was 6.5cm. A river discharge,$Q_r$ ,in the experiment was kept constant to be 11700cm$^3$ /sec and a mean discharged velocity at the rivermouth,$U_0$, was 45-47cm/sec.

Two kinds of sand of mean grain size $d_{50}$ =0.15mm(fine sand) and 0.35mm(median sand) were used as a bed material of the river and were discharged from a pit by feeding sand into the pit so that a volume of sand in the pit became almost constant. A depth and a length of the pit was 10cm and 1.0m. Fine sand was easily brought into suspension by currents and median sand was mainly transported as bed load.

Jetties and offshore detached breakwaters of different length, the dimensions of which are given in Table 1, were used. The locations of these structure are illustrated in Fig.1.

Table 1 Dimension of structure

| Structure | | Length:Ls(m) | Ls/B | Ls/Lo |
|---|---|---|---|---|
| Jetties | I | 0.5 | 1.0 | 0.5 |
| | II | 1.0 | 2.0 | 1.0 |
| Offshore detached | 1 | 0.8 | 1.6 | 0.8 |
| breakwater | 1I | 1.2 | 2.4 | 1.2 |

Lo:the wave length in deep water

A mean water depth of the wave basin was 30cm and a bottom slopes of the river channel and beach were 1/100 and 1/10, respectively.

After measuring velocities and surface displacements around the rivermouth on a fixed bed, sand was discharged. Depositional patterns were measured after 2 hr's sediment discharge with a resistance type bottom profiler. The velocity was measured with a 2-component electromagnetic current meter in the middle layer and capacitance type wave gauges were utilized to measure surface displacements. Trajectories of tracers thrown into the river and around the rivermouth were also recorded by a video-camera to analyze flow patterns.

A deformation of depositional pattern caused by waves was measured by generating waves obliquely to the shore line for one hour. A height and a period of incident waves were 4cm and 0.8sec and an angle of wave incidence was 20°.

The effects of jetties and offshore detached breakwaters on the discharged flow and depositional patterns of discharged sediment were investigated based on the experimental result.

Figure 2 shows the effects of coastal structures on the velocity,U, of the discharged flow and the mean water level, E, along the center line of the river channel(Y=0).

The discharged velocity and the mean water level measured in the jetty-protected rivermouth shown by open circles do indicate almost the same values as the results obtained in the case where there was no coastal structure which are illustrated by closed circles.

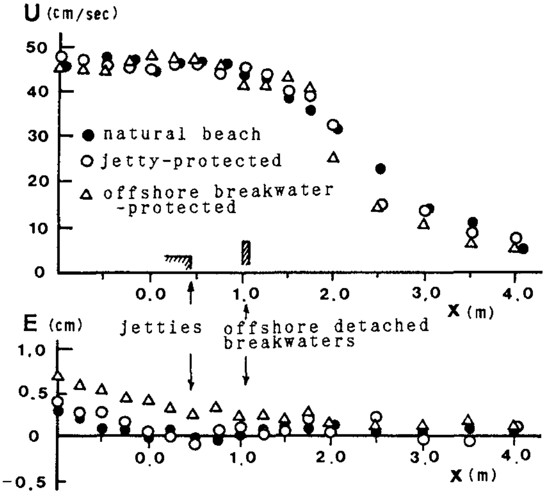


Fig.2 Effects of coastal structures on the discharged velocity and mean water level

When the offshore detached breakwaters were constructed, the rise of mean water level behind them became conspicuous when compared with other two cases shown in the figure. However, the corresponding difference in the discharged velocity in that region can not be found. Although the discharged velocity decreases a little in the region of $2m<X<3.5m$ $(4<X/B<7)$, it recovers to the same velocity as other two cases.

Figure 3 shows examples of discharged flow patterns. Figures (a) is the case of natural rivermouth without structures. Figures (b) and (c) correspond to the cases of jetty-protected rivermouth and offshore detached breakwater-protected rivermouth.

In the case of natural rivermouth, the discharged flow did not spread in the longshore direction and an entrainment of surrounding water can be seen in the wide region.

In the case of jetty-protected rivermouth, the entrainment of surrounding water took place no sooner than the discharge flowed out of the jetties. Of course, strong divergence can not be found.

On the other hands, at the rivermouth where the offshore detached breakwaters were constructed, the remarkable entrainment took place within a narrow region near the shoreline and the discharged flow diverged outwards behind the breakwaters. However, in the offshore of the breakwater, a small volume of surrounding water was again entrained and the discharged flow did not diverged significantly.

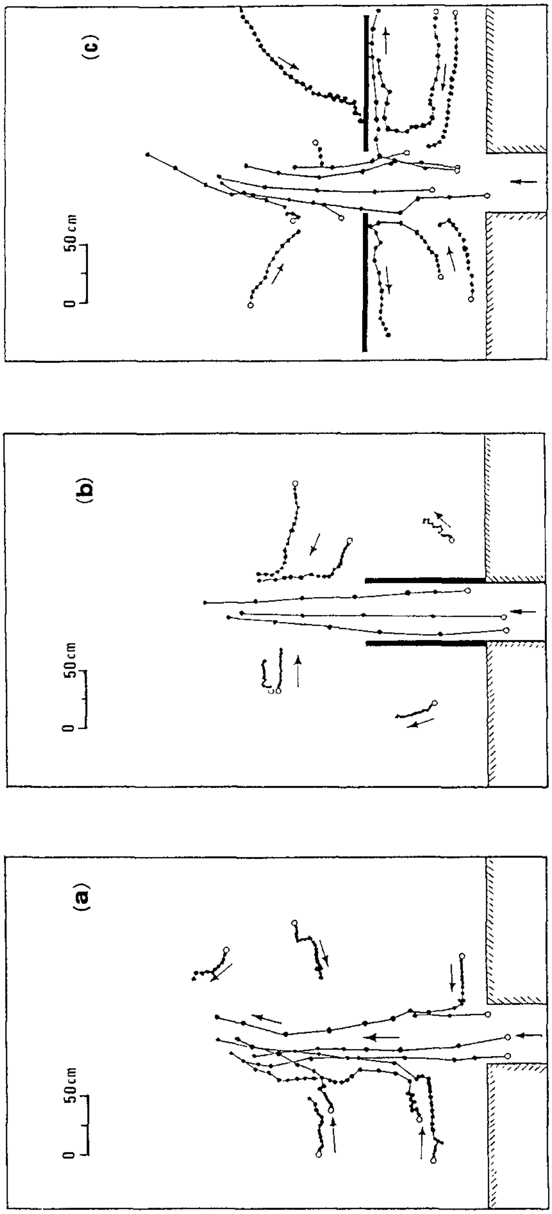


Fig.3 Flow patterns around rivermouth

Figures 4 to 6 illustrate the depositional pattern of discharged sediment(Fig.(a)) and the deformation of depositional pattern due to waves(Fig.(b)). The bed material of these cases was median sand which was mainly transported as bed load by the discharged flow and wave action. Fine solid lines in Fig.(a) indicate contours of the change of water depth took place within 2hrs and those in Fig.(b) give contours of deposited sand after 1hr wave generation.

Fig.4 is the case of natural rivermouth and Figs.5 and 6 are the results of jetty-protected and offshore detached breakwater-protected rivermouth. When we compare Fig.(a) of these figures, the following facts can be found out:
1)The maximum deposition takes place at about X=1.5m(X/B=3) regardless of the existence of the coastal structures and this point corresponds to the place where the decrease of discharged flow began in Fig.2.
2)Discharged sediment did not spread in the longshore direction. These results agree with those obtained by Butakov(1971), Suga et al.(1986) and so on. However, behind the breakwater which is shown in Fig.6, a small portion of discharged sediment was trapped. These depositional pattern correspond well to the flow patterns shown in the former figures.

As mentioned before, fine sand was easily brought into suspension by currents and waves and the direction of net cross-shore sediment transport by waves was in the offshore On the other hands, median sand was transported as bed load by currents and waves and the direction of net cross-shore sediment transport by waves was in the onshore.

When compared Fig.(a) with Fig.(b) of Fig.4, it is found that the depositional pattern of discharged sediment was flattened by wave action and a part of deposited sediment was transported in the longshore direction in the breaker zone around the rivermouth. The same deformation as this was observed around the rivermouth protected by short jetties.

Any longshore movement can not be seen around rivermouth protected by long jetties shown in Fig.5 because the length of the jetty was longer than the breaker zone. Further, a signifi- cant part of deposited sediment was transported in the onshore direction and redeposited between the jetties. As the results, the sectional area of discharged flow decreased.

Around the rivermouth protected by the offshore detached breakwaters given in Fig.6, the depositional pattern was also flattened by waves and a small portion of the deposited sand in the offshore of the breakwater was carried through the gap of the breakwaters and redeposited behind the breakwater. However, the sectional area of the discharged flow was not reduced by these sand movement.

In the cases of fine sand, decrease of sectional area by wave action did not take place even in the case where the long jetties were constructed.

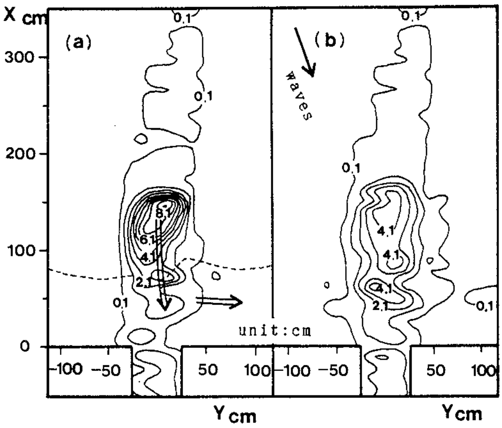


Fig.4
Depositional pattern of discharged sediment (without structure)

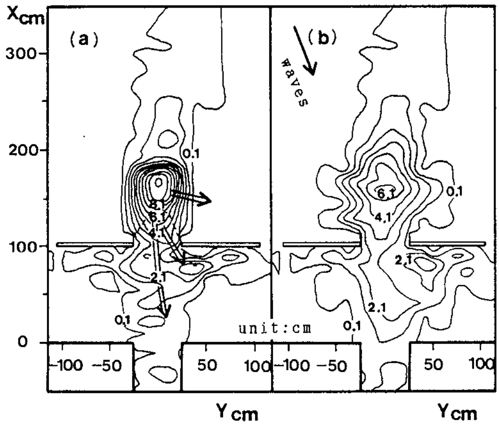


Fig.5
Depositional pattern of discharged sediment (with jetties)

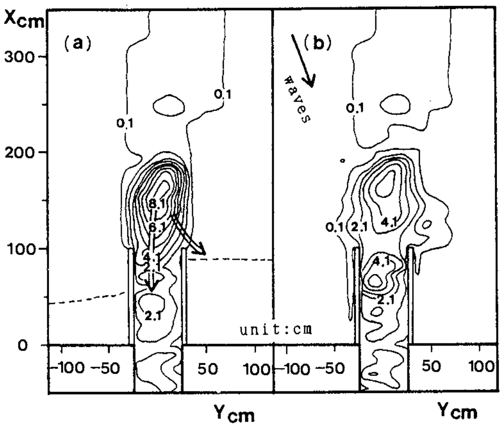


Fig.6
Depositional pattern of discharged sediment (with offshore detached breakwaters)

From these results, we can conclude that coastal structures used in the experiments do not affect the river discharge significantly. Depositional patterns of discharged sediment are also not deeply influenced by the structures. However, when the grain size of discharged sediment is coarse enough so that it is transported in the onshore by waves, a special consideration has to be paid in the planning of rivermouth treatments. Further, the offshore detached breakwater is shown to be an alternative of the jetty.

## NUMERICAL PROCEDURE FOR PREDICTION OF DEPOSITIONAL PATTERNS OF DISCHARGED SEDIMENT

Generally, the change of water depth is expressed by the following equation in the coordinate system given in Fig.7:

$$\frac{\partial h}{\partial t} = \frac{1}{1-\lambda}\left(\frac{\partial}{\partial x}\int U_s \overline{C}\, dz + \frac{\partial}{\partial y}\int V_s \overline{C}\, dz + \Delta Q_s\right) \qquad (1)$$

where $\lambda$ is the void ratio of sediment, $\overline{C}$ is the concentration of sediment, ($U_s$, $V_s$) are the sediment migration speed in x- and y-direction and $\Delta Qs$ is the vertical sediment flux.

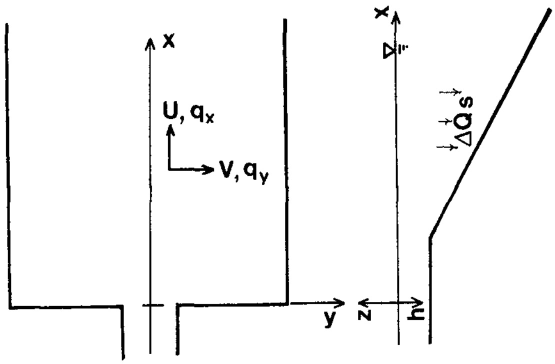


Fig.7 Coordinate system

Based on Eq.(1), some numerical procedures for the prediction of topographic change in the coast have already been proposed and practical simulations in the fields were carried out. The authors also proposed a numerical model for predicting topographic changes around the rivermouth (Sawaragi et al.(1985)). However, in the model, the contribution of discharged sediment from the river was not taken into account.

In this study, we constructed a numerical model for predicting depositional patterns of discharged sediment from the river in the coastal region. The numerical model consists of three parts as shown Fig.8.

First of all, the flow fields around the rivermouth was calculated based on vertically and temporally averaged mass and momentum conservation equations. Then, the horizontal flux and the vertical flux of sediment are estimated and finally, the change of water depth around the rivermouth is calculated from Eq.(1).

1)Calculation of the flow fields
U, V, E

↓

2)Estimation of sediment fluxes
horizontal fluxes : $q_x$ and $q_y$
vertical flux : $\Delta Qs$

↓

3)Calculation of topographic change
Eq.(1)

↓

out put

↓

Fig.8 Flow of the numerical model

1) Calculation of the flow fields
Fundamental equations for the calculation of flow fields are

$$\frac{\partial E}{\partial t}+\frac{\partial}{\partial x}U(h+E)+\frac{\partial}{\partial y}V(h+E)=0 \tag{2}$$

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}=-g\frac{\partial E}{\partial x}-\frac{Tx}{\rho(h+E)}+L'\nabla^2 U \tag{3}$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}=-g\frac{\partial E}{\partial y}-\frac{Ty}{\rho(h+E)}+L'\nabla^2 V \tag{4}$$

where U and V are the vertically averaged cross-shore and longshore velocities of discharged flow, E is the surface displacement from the still water, Tx and Ty are the time averaged bottom shear stresses in the x-(cross-shore) and y-(longshore) direction and L' is the horizontal mixing coefficients. In the present numerical model, following expressions for (Tx,Ty) and L' are used:

$$(Tx,Ty)=\rho f_w Fc(U,V)/2,\quad Fc^2=(U^2+V^2)$$
$$f_w=(2g/100)/\{18\log(12R/k_s)\}^2 \tag{5}$$

$$L'=0.01(h+E)\sqrt{g(h+E)}/\tan\theta \tag{6}$$

where R is the hydraulic radius, $k_s$ is the equivalent roughness height and $\tan\theta$ is the bottom slope.

These equations are transformed into finite difference equations at homogeneous grid points and solved by so-called ADI method. A homogeneous grid system of a distance $\Delta S$=20cm was used and a time increment $\Delta t$ was 0.15sec.

A boundary condition for the discharge of the river was given as a surface elevation,$E_0$, at the upstream end of the river channel. By preliminary calculations, $E_0$ was determined to be 0.8cm to give the discharge of 11.7 l/sec at the rivermouth whose depth was about 6.5cm.

2) Horizontal and vertical flux of sediment

When the sediment concentration is in equilibrium , a formula of sediment transport rate in a steady state can be applied to the horizontal sediment flux,ie, the 1st(=$q_x$) and 2nd(=$q_y$) terms in the right hand side of Eq.(1). In this study, the authors apply the following Rijin's formula (Rijin(1985)) to estimate the horizontal sediment flux:

$$\vec{q} = (q_x, q_y) = \vec{q_b} + \vec{q_s}$$
$$\vec{q_b} = C_b \delta_b \vec{U_{sb}}, \quad \vec{q_s} = F d C_a \vec{U_{ss}} \tag{7}$$

In these equations, $C_b$ and $C_a$ are the sediment concentration in the bed load layer and the reference level, $\delta_b$ is the thickness of bed load layer, $U_b$ and $U_s$ are the migration speeds of sand in the bed load layer and suspended load layer and F is the vertical distribution function of the concentration of suspended sediment. These are given by the following equations:

$$C_b = 0.18\, C_0 T / D_* \quad (C_0 = 0.65), \quad C_a = 0.015 (d_{50}/z_a)(T^{1.5}/D_*^{0.3})$$
$$|\vec{U_{sb}}| = 1.5 T^{0.6} \{(\rho_s/\rho - 1) g d_{50}\}^{0.5}, \quad \vec{U_{ss}} = \vec{U}$$
$$\delta_b = 0.3 d_{50} D_*^{0.7} T^{0.5},$$
$$F = \{(z_a/d)^{z'} - (z_a/d)^{1.2}\} / (1 - z_a/d)^{z'} (1.2 - z')$$

in which, $T = (u_*^2 - u_{*c}^2)/u_{*c}^2$, $u_*^2 = g/Cz^2 (U^2 + V^2)$, $Cz = 18\log(12R/Ks)$, $d = h + E$ , $D_* = d_{50}[(\rho_s/\rho - 1) g/\nu^2]^{1/3}$, $z' = W_f/\beta K u_* + 2.5 (W_f/u_*)^{0.8} (C_a/C_0)^{0.4}$, and $\beta = 1 + 2(W_f/u_*)^2$.

$W_f$ and K in the above expressions are the settling velocity of sand and Karman's constant and $z_a$ is the height of the referent level of suspended sediment. In the calculation, $z_a$ is assumed to be 0.01*d. $u_{*c}$ is the critical shear velocity for the sand movement. The authors apply $u_{*c}$ on the horizontal bottom proposed by Iwagaki(1956). The effect of bottom slope on $u_{*c}$ is taken into account as the influence of the gravity at the critical stage of the sand movement.

In the Rijin's expression, the suspended load was formulated by giving the bed load as a boundary condition. Therefore, to reproduce depositional patterns observed in the experiments numerically, a special technique was used which will be mentioned afterward.

On the other hands, various expressions for the vertical flux $\Delta Qs$ in Eq.(1) have been proposed(for example, Sawaragi et al.(1985), Hosokawa et al.(1986)). In this study, $\Delta Qs$ was defined as the volume of settling sediment which entered the calculation region from the upstream boundary of the river channel and was determined from the convection diffusion equation:

$$\Delta Qs = +\bar{C} W_f \tag{8}$$

$$\frac{\partial \bar{C}}{\partial t} + U\frac{\partial \bar{C}}{\partial x} + V\frac{\partial \bar{C}}{\partial y} = \frac{\partial}{\partial x}\left(Ksx\frac{\partial \bar{C}}{\partial x}\right) + \frac{\partial}{\partial y}\left(Ksy\frac{\partial \bar{C}}{\partial y}\right) + \frac{1}{d}\left(Ksz\frac{\partial \bar{C}}{\partial z} + W_f \bar{C}\right)_{z=-h} \tag{9}$$

where Ksx and Ksy are the diffusion coefficient of suspended sediment and are estimated by the following expression (Murray(1968)):

$$Ksx = Ksy = 0.15\, Fc\, d \qquad (10)$$

Eq.(9) is solved numerically at the same grid points as the calculation of flow fields to determine the vertical flux of Eq.(8) with the boundary condition at X= Xstart as

$$C = Cor = \frac{1}{d}\int q_x\, dz \qquad (11)$$

3)Calculation of the change of water depth
Change of water depth, that is, the depositional patterns of discharged sediment from the rivermouth was calculated from Eq.(1).

The topographic change took place within a unit time $\Delta t$ is expressed by the sum of those caused by vertical flux $\Delta h_v$ and horizontal flux $\Delta h_h$ as follows:

$$\frac{\Delta h}{\Delta t} = \frac{1}{\Delta t}(\Delta h_v + \Delta h_h)\ , \quad \frac{\Delta h_v}{\Delta t} = \frac{1}{1-\lambda}\Delta Qs\ ,$$

$$\frac{\Delta h_h}{\Delta t} = \frac{1}{1-\lambda}\left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y}\right) \qquad (12)$$

The change of water depth caused by $\Delta Qs$ is easily estimated provided that $\Delta Qs$ is given. However, it is required a special treatment to reproduce depositional pattern brought about by the horizontal flux in the experiments. Because in the experiments, sediment was discharged from the sand pit to the river channel of the fixed bed where there is no source of suspended sediment.

Therefore, in the calculation of the change of water depth, the following procedure was employed:
For the simplicity, consider the phenomena in one-dimension and let $\Delta x$ and $\Delta t$ be the space and time increments as shown in Fig.9.

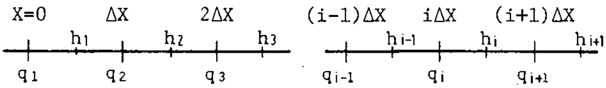


Fig.9 Descritization scheme for the calculation of topographic change due to the horizontal sediment flux

Then, during $t=0\sim\Delta t$, only $q_1$ at $x=0$ takes place. During time $t=\Delta t\text{-}2\Delta t$, $q_1$ and $q_2$ occur at $x=0$ and $\Delta x$. During $t=(n-1)\Delta t\text{-}n\Delta t$, sediment movement tale place in the region $x<(n-1)\Delta x$. At this time, the change of water depth $\Delta h_i$ at $x=i\Delta x$, can be expressed by

$$\Delta h_i = \{(n-i+1)q_i - (n-i)q_{i+1}\}(\Delta t/\Delta X)/(1-\lambda) \qquad (13)$$

In the calculation of $\Delta h$ we used this procedure in both x- and y-direction.

## APPLICABILITY OF THE NUMERICAL MODEL

Figure 10 illustrates calculated and measured flow patterns in the case where there was no coastal structures. Calculated results is shown by the velocity vectors and measured result is illustrated as the trajectories of floats.

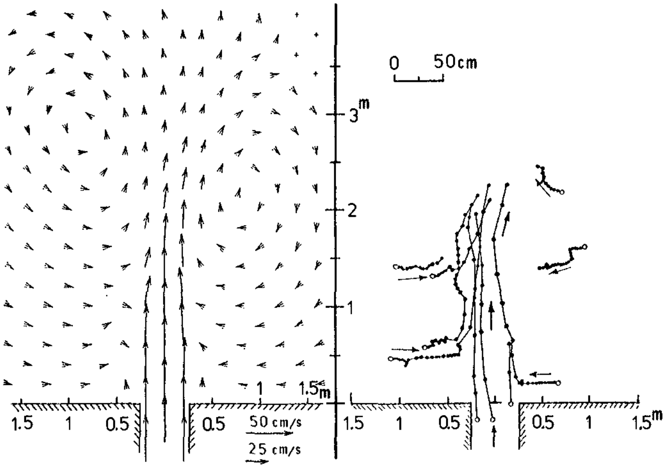


Fig.10 Calculated and measured flow pattern around river-mouth without structure

Figure 11 shows the comparison of measured and calculated discharge velocity U and mean surface displacement E along the center line of the river channel.

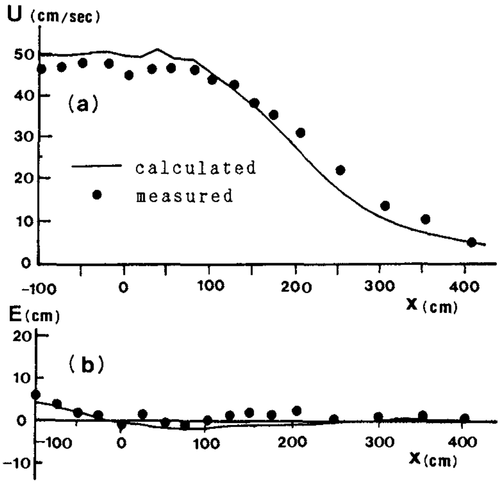


Fig.11 Comparison between calculated and measured discharged velocity and mean water level along a center line of the river channel

These results show that the present numerical procedure for predicting flow field is adequate.

Figure 12 illustrates the comparison of measured and calculated depositional profiles along the center line of the river channel. Fig.(a) is the case of fine sand and (b) is the case of median sand.

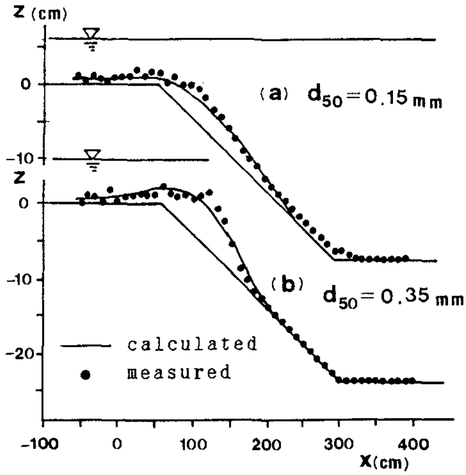


Fig.12 Comparison between calculated and measured depositional profile along a center line of the river channel

From the figure, it can be seen that the depositional profiles of discharged sediment can be predicted by the present model accurately regardless of the grain size of discharged sediment.

Figures 13(a) illustrates the depositional pattern of discharged sediment in the case of fine sand without structure which corresponds to Fig.12(a). Figure 13(b) shows the predicted depositional pattern. When compared with these figures, it is judged that depositional pattern can also be predicted fairly well by the present model.

In Figs.(c) and (d), changes of water depth caused by vertical sediment flux $\Delta Qs$, bed load and suspended load are shown separately.

Although the effects of $\Delta Qs$ extended till X>3m, the amount of the topographic change is small. Change of water depth caused by bed load did not expand beyond X=2.0m which coincides with the critical depth where the bottom shear stress exceeded the critical shear of the sediment movement shown by the arrow in the figure. On the other hands, deposition due to suspended load extended far beyond this critical depth.

The same degree of agreements can be seen between measured and predicted depositional patterns in the cases of jetty-protected rivermouth. However, when the offshore detached breakwaters were constructed, discharged flow pattern in the experiments can not be reproduced by the present model. Therefore, there is some room for further improvements of the model.

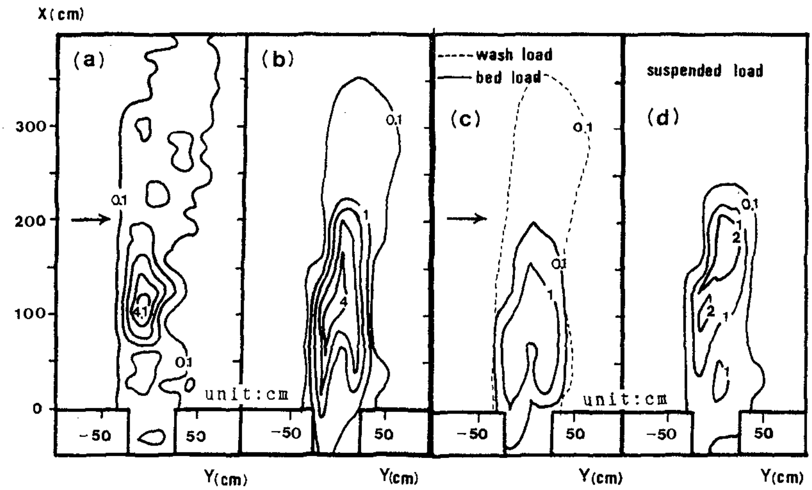


Fig.13 Depositional pattern of discharged sediment in the case of fine sand

## CONCLUSIONS

The effects of coastal structures on the discharged flow and depositional patterns of discharged sediment from the river were investigated through experiments. A pair of offshore detached breakwaters is shown to be one alternative of a pair of jetties which have been commonly constructed as a countermeasure against a blockage of rivermouth.

A numerical procedure is also developed for predicting the depositional patterns of discharged sediment. The depositional patterns measured around the rivermouth without structures and around the jetty-protected rivermouth can be reproduced by the numerical procedure precisely. However, the flow pattern measured around rivermouth protected by the offshore detached breakwater can not be reproduced exactly.

## REFERENCES

Butakov,A.N.(1971) : Study of development and deformation of mouth bar, Proc. 14th Conf. on IAHR, Paris, pp.95-102.

Hosokawa,Y., N.Tanaka, M.Kudaka and K.Sato(1986) : Method for forecasting quantity of sedimentation in trenches and its application in the field, Proc. 33rd Japanese Conf. on Coastal Engineering, pp.312-316(in Japanese).

Iwagaki,Y.(1956) : Basic study on the critical shear stress for sand movement in the open channels, Proc. JSCE, Vol. 41, (in Japanese).

Murray,S.P.(1968) : Simulation of horizontal turbulent diffusion of particle under waves, Proc. 10th ICCE, pp. 446-466.

Rijin,L.C.(1985) : Sediment transport, Delft Hydraulic Labo. Publication No.334.

Sawaragi,T., J.S.Lee and I.Deguchi(1985) : A new model for a prediction of beach deformation around a rivermouth, Proc. Int'l. Sympo. Ocean Space Utilization '85, Vol.2, pp.229-236.

Suga,K., T.Ishikawa, K.Nadaoka and H.Tanaka(1987): Formation of sand terrace in front of a river mouth and its decline, Technical Note in Proc. of the Japan Society of Civil Engineers, No.381/II-7, pp.227-230(in Japanese).