SHORELINE CHANGE MODELING COMBINED WITH THE RIVER MOUTH MODEL

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ABSTRACT

The shoreline change around river mouth was examined by means of frequently aerial photographs. The natural evident show that the river mouth influence to the surrounding shoreline has form in sediment supplier and river flow. The influence is an obstruction to the long-shore sediment transport, which makes an accretion and erosion on both sides of river mouth. The shoreline change modeling was developed and combined with the reservoir and river mouth model to consider the river mouth influence. The model shows the simulation of sand terrace existence gives better improvement than the simulation of river mouth width in the shoreline change model around river mouth. The modeling improvement was hoped will give benefit to the coastal and river management plan.

1. INTRODUCTION

Many research focused on river mouth morphology, which is influenced by sediment source on upstream or by tide & wave. The construction of dam or land use change in the watershed area may reduce the sediment yield into the river and influence the river mouth morphology. The delta formation and sand spit development was influenced by wave and tide current (Wright et al., 1980). Some research also discusses the influence of river mouth as sediment supplier to surrounding beach. The existence of delta formation or sand terrace in front of river mouth makes accretion or erosion in surrounding beach. The natural river mouth seems have similar condition with perpendicular structure. The river water usually flow to the sea in perpendicular direction depending on the course of river mouth. The perpendicular of water flow may also able to obstruct the long-shore sediment transport like jetty or groin.

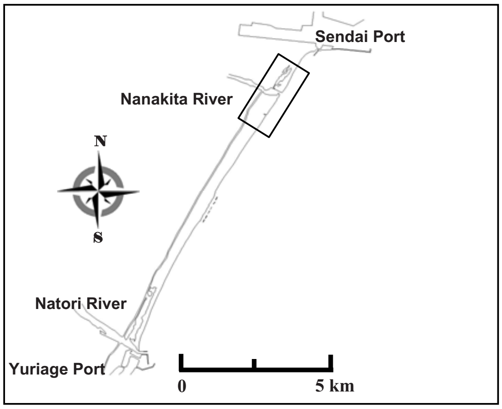

Fig. 1: *Study area*

This study attempts to investigate the shoreline condition around river mouth especially at Nanakita River Mouth. The shoreline change was investigated from bi-monthly aerial photograph and correlated with the natural data such as wave and river discharge. Then, the shoreline change model was developed by considering the existence of sand terrace and river mouth width change. The simulated shoreline was verified by shoreline data also from aerial photograph.

The Sendai Coast is sandy beach and stretch about 12 km from Sendai Port at north until Natori River at south (Fig.1). At north border, there is Sendai Port with its 2 km long of breakwater. Going to south, there is Nanakita River mouth and Gamo Lagoon. About 1 km from the Nanakita River mouth, there is water outlet belongs to waste water treatment facility of Sendai City. Natori River mouth border the Sendai coast at south. However, the object of this study is only about 4 km shoreline around the Nanakita River mouth.

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2. MODEL DEVELOPMENT

Reservoir Model

In tidal inlet, many morphological features exist inside and outside of inlet such as flood and ebb shoal. The sediment is possible to move cyclically around the inlet, which is influenced by wave action and tidal current, such as back and forth between the flood and ebb shoals or around the ebb shoal; down-drift bypassing bar; beach; channel; and back again to the ebb shoal. Kraus (2002) simulated that process in tidal inlet by analogy to a series of reservoirs or beakers. The volume of sediment in the shoal (reservoir) can increase until it reaches an equilibrium volume V_{Ee} (the subscript *e* denoting equilibrium) according to the hydrodynamic conditions. Sediment may leaks to adjacent reservoir with assumption the leaving transport rate (Q_{Eout}) is proportional with the filling transport rate (Q_{Ein}) multiply by a ratio between instantaneous volume inside reservoir (V_E) and equilibrium volume of reservoir (V_{Ee}). When the equilibrium volume is achieved (the reservoir is full), the sediment, which goes to the full reservoir, will bypass that reservoir in the direction of transport at the particular time.

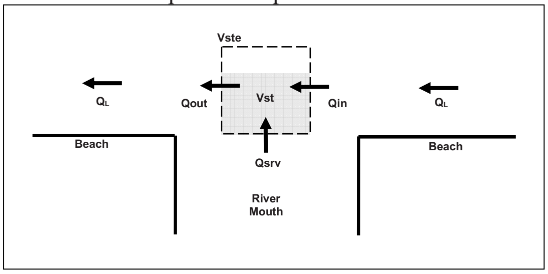

Fig. 2: *Sketch of sand terrace simulation*

The reservoir model, which is introduced by Kraus (2002), is suited to simulate the emerging of sand terrace and bypassing process in river mouth. This study used that model with some adjustment by disregard the initial purpose and application of reservoir model, which is for simulating tidal inlets behavior. The existence of sand terrace, the component and pathway of sediment transport in river mouth is depicted in Figure 2. It shows sketch of river mouth situation with the simple case of long-shore sediment transported from right to left. The Q_L is sediment transport rate induced by wave along the shoreline on both sides of river mouth. The Q_{in} is the long-shore transport rate from up-drift beach side, which enters the river mouth or sand terrace area. The Q_{out} is the long-shore transport rate, which leave out the river mouth or sand terrace area and go to down-drift side. The Q_{srv} is sediment transport rate induced by river water discharge and fill in the sand terrace area. The volume of sand terrace area at any given time is V_{st} with the corresponding equilibrium value of V_{ste}.

As same assumption with the reservoir model, the rate of sediment transported out is specified as:

$$Q_{out} = \frac{V_{st}}{V_{ste}}(Q_{in} + Q_{srv}) \qquad (1)$$

The mass conservation equation for the sand terrace is:

$$\frac{dV_{st}}{dt} = Q_{in} + Q_{srv} - Q_{out} \qquad (2)$$

where *t* is time. With the initial condition $V_{st}(0) = 0$, the Equation 2 can be solved analytically become:

$$V_{st} = V_{ste}(1 - e^{-\alpha t}) \qquad (3)$$

where:

$$\alpha = \frac{Q_{in} + Q_{srv}}{V_{ste}} \qquad (4)$$

The ratio between instantaneous volume and equilibrium volume of sand terrace can be used to simulate the bypassing factor (*Byp*):

$$Byp = 1 - \frac{V_{st}}{V_{ste}} \qquad (5)$$

River Mouth Model

Ogawa et al. (1984) have proposed the mathematical model for simulating the fluctuation of river mouth width. The model assumed that the wave component is responsible for development of sand spit and the river discharge flush out the sediment from the mouth as seen in Figure 3. The governing equation is expressed as follows:

$$\left(1-\lambda\right)L\,h\frac{dB}{dt}=e_r q_r B-e_w\left(1-\lambda\right)Q_w \tag{6}$$

where λ is porosity of sand, L is width of sand spit, h is the depth of river mouth, B is the width of river mouth, q_r (or Q_{srv} in sand terrace model) is river discharge, Q_w (or Q_L) is wave long-shore transport, e_r is the efficiency of flushing out by river flow and e_w is the efficiency of sand spit development by wave motion. When the sand spit development reach the equilibrium condition (the narrowest width of river mouth), the river flow passing the mouth obviously interrupt the long-shore transport. Therefore, the bypassing factor can be expressed in ratio of instantaneous and maximum river mouth width as:

$$Byp=\frac{B}{B\max} \tag{7}$$

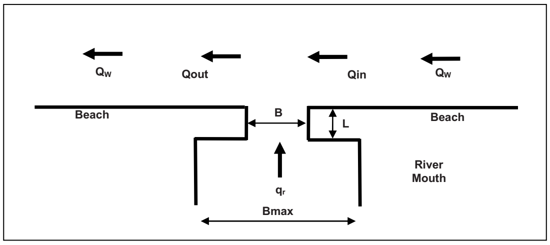

Fig. 3: *Sketch of river mouth simulation*

In this study, the river flux was estimated by using MPM Formula for bed load transport, which is expressed in river discharge as: (Meyer-Peter, 1951)

$$q_s=\sqrt{(s-1)\,g\,d_s^3}\left(\frac{4n^2 q_r^{\,2}}{(s-1)\,d_s\,h^{7/3}B^2}-0.188\right)^{3/2} \tag{8}$$

where q_s is sediment discharge per unit width, s is relative density, g is gravity acceleration, d_s is sediment size, n is Manning coefficient, ρ is water density. The long-shore sediment transport induced by wave was calculated by the CERC Formula:

$$Q_w=K(EC_g)_b\sin\alpha_b\cos\alpha_b \tag{9}$$

where E_b is wave energy at breaking position and C_{gb} is wave group celerity also at breaking position, α_b is wave breaking angle and K is empirical coefficient.

Shoreline Change Model

Total shoreline around the Nanakita River mouth for simulation is about 4,000 m. The shoreline stretches from Sendai Port breakwater until position x = 4,000 m on the right of river mouth. The Nanakita River mouth was simulated with 180 m width in open condition. The spatial step of shoreline was set at 30 m and coincided with spatial step of bathymetry. Therefore, the wave parameters also coincided with shoreline spatial step because calculation of wave deformation was based on bathymetry. The simulation was performed in interval 1994 until 2009. The calculation of wave deformation was conducted in daily interval, but the shoreline change simulation was run in two minutes interval (120 s) because the stability problem. The sand terrace and river mouth simulation were also conducted in shorter interval (hours).

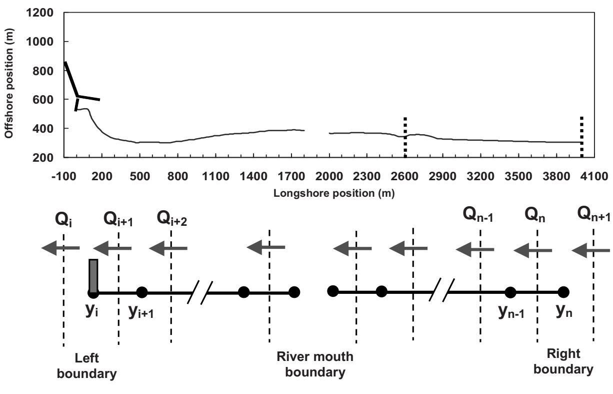

Fig. 4: *The boundary and model of shoreline around the Nanakita River mouth*

There are three boundaries exist in the model, i.e. left, right and river mouth boundary. The left boundary represented the Sendai Port breakwater, which completely blocked the long-shore sediment transport. It is obviously the left boundary can be set by:

$$Q_1 = 0 \tag{10}$$

The right boundary was determined as fixed boundary because the shoreline is relatively in stable condition and set as:

$$Q_{n+1} = Q_n \tag{11}$$

In this boundary the long-shore transport still passing but has no differences with up-drift or down-drift cell and moreover makes no shoreline change. This position is also far enough from the influence of river mouth. The river mouth boundary was sketched in Figure 5 with simple case that long-shore transport from right to left. The long-shore transport component of Q_3, Q_4, Q_7, Q_8 were calculated from wave parameter. The long-shore transport components at river mouth boundary (Q_5 and Q_6) were important to simulate the river mouth influence. These components were determined based on how the river mouth will be modeled. This study setup the shoreline change model with four different conditions in river mouth boundary. These are for examining the improvement in shoreline change model by incorporating the influence of river mouth in more detail. The conditions are follows:

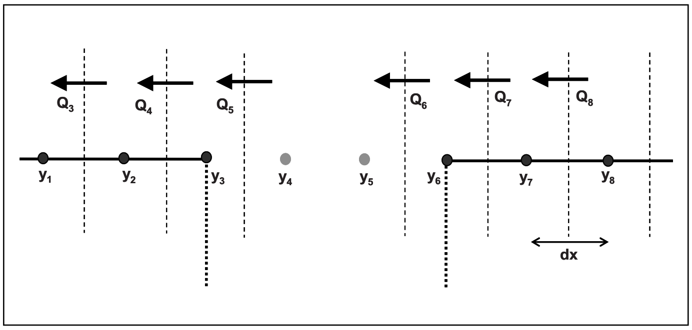

Fig. 5: *Sketch of river mouth boundary*

<u>Model 1</u>

First model simulate the condition without considering the river mouth influence. The river discharge was assumed no exist. The long-shore sediment transport components at both sides of river mouth boundary were determined as follows:

$$Q5 = Q4, \ \ Q6 = Q7 \tag{12}$$

<u>Model 2</u>

Model 2 simulate the Bypassing coefficient which was controlled by the existence of sand terrace in front of river mouth. The sand terrace was simulated by applying the principal of reservoir model (Kraus, 2002). The transport components at river mouth boundary can be determined as follows

$$Q5 = Q6 = Byp \times Q7 \tag{13}$$

The bypassing coefficient was calculated by Equation 5. In this model the flushing out sediment from sand terrace was assumed loss to the offshore.

<u>Model 3</u>

Model 3 simulate the bypassing coefficient which was controlled by the width of river mouth. The width of river mouth was calculated by applying the river mouth model (Ogawa et al., 1984). The transport components at river mouth boundary were determined as same as Equation 13 and the bypassing coefficient was calculated by Equation 7.

3. RESULTS AND DISCUSSIONS

Figure 6 shows the morphology process around Nanakita River mouth in 1997. Figure 6.g shows the river discharge, Figure 6.h shows the wave height condition, and Figure 6.i shows the direction of incoming wave. In January (Fig.6.a), the river mouth was in process of sand spit development because the river discharge was in low condition. The shoal was not emerge, which means the long-shore transport fully compensate the development of sand spit. In March (Fig. 6.b), the river mouth was in equilibrium condition i.e.: the river mouth width in narrowest condition. The shoal was emerge on both sides of river mouth which means the river flow give blocking effect to the long-shore sediment transport. The picture also shows cloudy area on tip of flow which may show the existence of sediment bypassing river mouth in this time. Figure 6.j shows the shoreline position 100 m on left and right side of river mouth. In this month, the right shoreline was more advances than left position. In May (Fig. 6.c), the river mouth was still in equilibrium condition because the river discharge was still low (Fig.6.g). The shape of sand spit is slightly going into river because the wave direction is in almost perpendicular condition (Fig.6.i). In June (Fig.6.d), the river discharge is usually going high (summer season), the river mouth become wide because the sand spit is flushed out by flood. In this time, the sand terrace may emerge in front of river mouth to store the river flux and the flush out sediment from sand spit. In September (Fig.6.e), the remains of sand terrace from previous flood event still appear. The wave action spreads the sand terrace to both sides of river mouth which is depend on the wave direction. In November (Fig.6.f), the river mouth is in stage to reach the equilibrium condition again. The sand terrace is slowly decreased and goes to diminish.

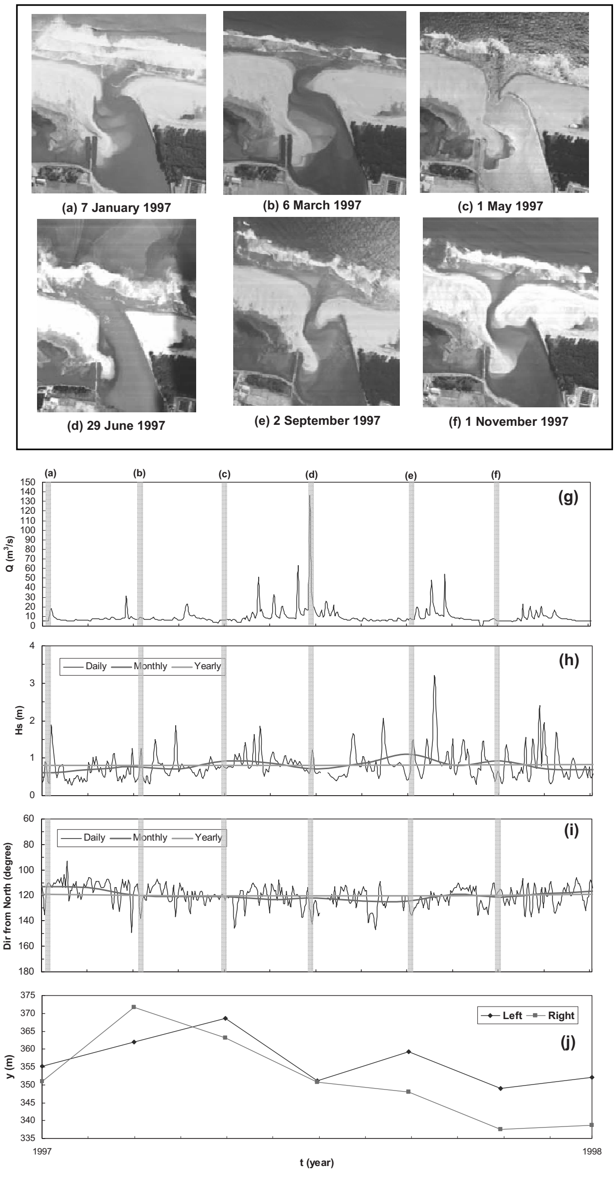

Fig. 6: *Seasonal variation of river mouth behavior*

The simulation result of all model were presented in Figure 7. There are still big discrepancy between measured and simulated in area from Sendai Port breakwater until section 2000. It is caused by the problem in wave ray modeling, which make the shoreline near break water was eroded and deposited in the area of advance shoreline. For the right side, the calculated shoreline is in well agreement with the measured one. Considering the river mouth only influence the surrounding area, Figure 8 shows the detail in 500 m around river mouth. Model 1 is over estimate on the left side but perform well on the right side. Model 2 shows good agreement with measured shoreline both on left and right side. Model 3 is under estimate on the left side and over estimate on the right side. This mean the inclusion of sand terrace model gives better improvement to the shoreline change model. The calculation of root mean square error (RMSE) gives value 16.1 m, 6.9 m and 21.2 m for Model 1, 2 and 3 respectively. It shows the smallest error of sand terrace model compare than other model.

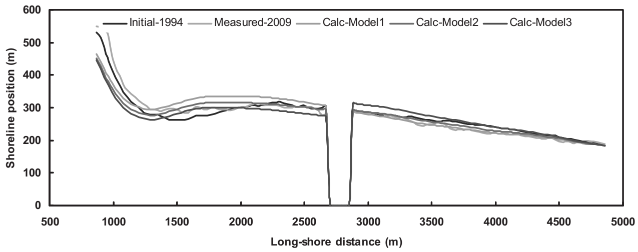

Fig. 7: *Results of shoreline change model*

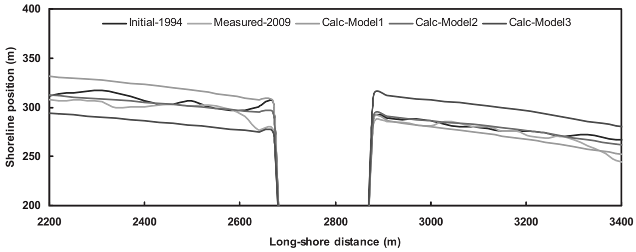

Fig. 8: *Comparison in 500 m around river mouth*

4. CONCLUSIONS

The natural evidence from aerial photograph and others data have shown the influence of river mouth to the surrounding shoreline in seasonal time scale. The existence of sand terrace and the equilibrium of river mouth give obstruction to the long-shore transport. The combination of reservoir model and river mouth model in the shoreline change model were performed to simulate those influences. The reservoir model gives better improvement to the shoreline change model around river mouth, which was showed by the smallest error. The river mouth model still needs modification for giving better improvement.

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