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Modelling of Natori River Mouth Topography Change due to a Heavy Flood

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1. Introduction

From the viewpoint of sediment supply from a river to the coastal area the occurrence of a heavy flood is very important as it causes a considerable change in the river mouth topography. There have been a number of studies related to Natori river mouth in the past, e.g. Sato et al.(1995), Tanaka et al.(1996) and Tanaka et al.(1997). Actual flood events were considered in the later two studies and a good agreement was found between the model prediction and the field data of water level and river mouth topography. This model is equipped to handle the spiral flow occurring in the curved channel at the river outlet portion. In the present study the a fine grid spacing has been used to enhance the degree of precision of this model. Moreover, a proposal has been made to keep the water level below 2.5m which is the limit fixed by the concerning authorities in order to avoid the hazard caused by the heavy flood of 150 years return period.

2. Natori River Mouth

Natori river mouth is located in the Miyagi Prefecture, Tohoku region, Japan. The river has a length of 55km and catchment area of 939km^2. There are two jetties at the river mouth and the sand spit located near the left jetty normally remain attached to it. The usual height of this sand spit is 2.5m. In order to avoid very high water levels in the upstream areas the flushing of this sand spit is required so that the flood discharge may be passed to ocean without causing severe backwater effect.

3. Hydrodynamic and Morphological Model

The governing equations of the hydrodynamic model consist of continuity and the momentum conservation in x and y directions as follows;

$$\frac{\partial \eta}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \quad (1)$$

$$\frac{\partial M}{\partial t}+\frac{\partial}{\partial x}\frac{M^2}{D}+\frac{\partial}{\partial y}\frac{MN}{D}+gD\frac{\partial \eta}{\partial x}+\frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2}=0 \quad (2)$$

$$\frac{\partial N}{\partial t}+\frac{\partial}{\partial x}\frac{MN}{D}+\frac{\partial}{\partial y}\frac{N^2}{D}+gD\frac{\partial \eta}{\partial y}+\frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2}=0 \quad (3)$$

where η is the water level above the still water elevation, t the time, x and y the coordinate axes in horizontal plane, M and N the flow flux per unit width in x and y direction respectively, g the acceleration due to gravity, $D(=\eta+h.\,h=$ still water depth) total water level and n is Mannings roughness factor.

The bed load sediment transport is calculated by Einstein-Brown formula (Brown, 1950) along with Lane and Kalinske(1941) formula for suspended sediment. Moreover, the sediment movement caused by the secondary current is also considered following Shimizu and Itakura (1989). The bed elevation z is computed from the well known mass conservation equation of sediment as follows;

$$\frac{\partial z}{\partial t}+\frac{1}{1-\lambda}\left(\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}\right)=0 \quad (4)$$

where λ is the porosity of sediment and q_x and q_y the sediment transport rate per unit width per unit time in x and y direction, respectively.

The jetties at the river mouth have a curvature towards north which causes the spiral flow. The mathematical treatment of this phenomenon has been described by Tanaka et al.(1997). Moreover to achieve stable computation of sediment movement on a sloping bottom the method proposed by Watanabe et al.(1986) has been employed. The upstream boundary conditions are imposed on the basis of an anticipated flood discharge and the offshore boundary conditions are based on the tidal variation in the region. The governing equations have been solved by using a leap frog scheme, the detail of which is provided by Tanaka and Qin (1993). The computation domain in the present study has been shown in Fig.1, where $\Delta x=\Delta y=7.5$m. In order to have a computationally stable solution the time increment Δt is kept as 0.4sec.

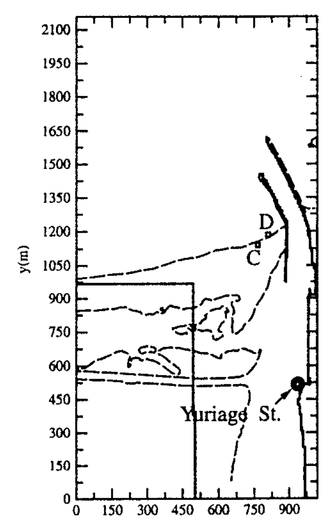

Fig.1 Computation domain

4. Results

The preliminary results comprise of the predictions by coarse grid and fine grid model. The comparison of water level at Yuriage station is presented in Fig.2. It can be observed that the fine grid model results in a smooth variation of water level under first peak of flood discharge, whereas coarse grid model shows abrupt changes at various instants. The peak water level predicted from both the grids is however same. It can be observed that at about 15 hours from the start a decrease in water level occurs till 19 hours from start. The abrupt increase in the flood discharge then causes the water level rise abruptly. A considerable erosion at about 21 hours causes the water level decrease till 22 hours from start, but the ultimate peak reaches 2.64m.

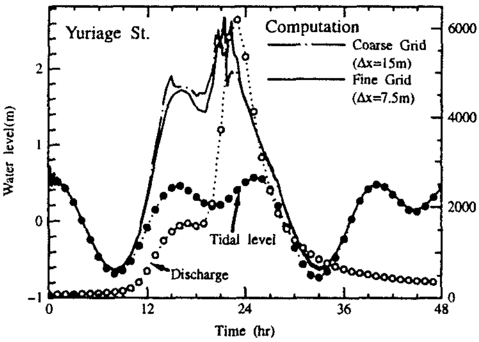

Fig.2 Water level at Yuriage Station

A comparison of the computed results for coarse and fine grid models is presented in Fig.3 where the points C and D are shown in Fig.1. These points lie on the sand spit area. It may be observed that at both the points (C and D) the fine grid model shows more erosion than the coarse grid model although the erosion starts almost the same time from start.

Considering the extreme conditions by matching the peaks of flood discharge and various tidal components as shown in Fig.4, the computation is still going on. Moreover, a flood protection embankment is being constructed along the river which would reduce the discharge carrying capacity of the channel. Therefore the bathymetry of the channel has to be modified to include the effect of this construction. On the basis of the new bathymetry under extreme conditions the prediction would be made. Those results would be used to propose a dredging or a flood protection structure in order to keep the water level below 2.5m which is the maximum value allowed by the concerning authorities.

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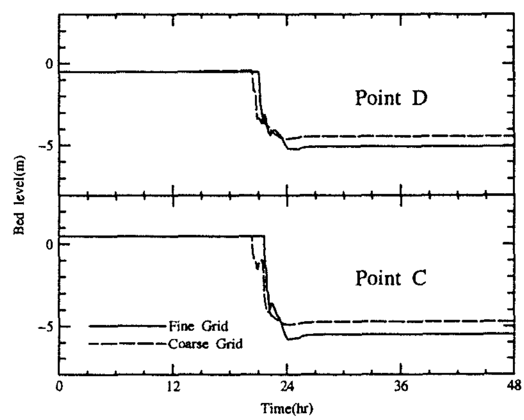

Fig.3 Bed level change on the sand spit portion.

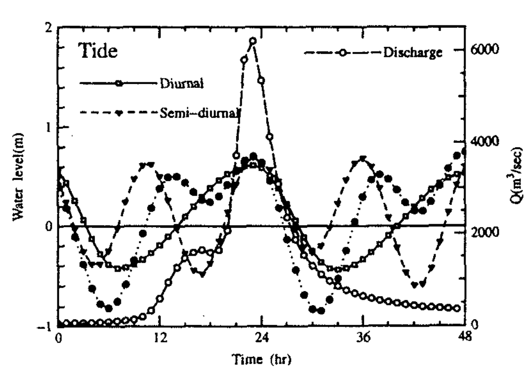

Fig.4 Most severe conditions of flow pattern.