PROCEEDINGS OF THE THIRD INTERNATIONAL CONFERENCE ON ESTUARIES AND COASTS

ICEC2009

SEPTEMBER 14-16, 2009

SENDAI, JAPAN

VOLUME 1

Edited by

Department of Civil Engineering

Tohoku University

BED MATERIAL STRUCTURE AND SAND TRANSPORT BY FLOOD FLOWS IN THE ESTUARY OF THE CHIKUGO RIVER

Kenta SUZUKI
Graduate School of Sience and Engineering, Chuo Universuty, 1-13-27,Kasuga,Bunkyo-ku Tokyo,Japan
E-mail: kenta-s@civil.chuo-u.ac.jp
Shoji FUKUOKA
Research and Development Initiative, Chuo University
Kazumi MATSUO
Chikugo River Office, Kyushu Reginal Development Bureau, Ministry of Land Infrastructure and Transport

Abstract: It has been said that sand composing of Ariake sea bed is gradually decreasing due to insufficient supply from the Chikugo river. The river bank of Chikugo river estuary in the ordinary flow condition is seen to cover with fine sediment such as silty clay called 'gata-soil '. But it remains unproved that the sand is transported by a little amount from the Chikugo river to the Ariake sea because of very few investigations of sediment transport in the Chikugo river. In this study, we analyzed river bed material structure and bed variation using core sample survey and supersonic echo sounder in the estuary area of the Chikugo river and Ariake sea. From the result of these investigations, we proved the presence of sufficient sands on the river bed. Furthermore, to make clear bed deformation and sediment transport process during a flood, the authors observed temporal changes in water surface profiles of the flood flow and applied unsteady 2D flow analysis using observed temporal changes in water surface profiles. The result of analysis indicated that the shear stress intensity of river flows was large enough to make sand movement and flood flows transported a certain amount of sands from the Chikugo river into the Ariake sea.

Keywords: Estuary, Tidal level, Flood flow, Unsteady 2D flow analysis, Temporal changes in water surface profiles, Sand, River bed variation

1. INTRODUCTION

The Ariake sea which located in Kyushyu district in Japan has a large tidal level change (Maximum 6m, Average 4m in height). Therefore, the fine sediment such as silty-clay called 'gata-soil' which is broadly present in the Ariake sea area is brought to Chikugo river estuary with the flood tide. This is one reason that the bed of the Chikugo river is believed to be covered with Gata Soil. But it remains unproved that the sand is transported by a little amount from the Chikugo River to the Ariake sea because of very few investigations of sediment transport in the Chikugo river. The paper aims to make clear the existence of sand in river channel and its characteristic behavior during flood flow by using field data which have been taken in the Chikugo River and Ariake sea(Irie et al.,2009). The plan form of the study area from Ariake sea to Chikugo-Ozeki barrage (23.0km from river mouth) is shown in Fig. 1. All of this area is strongly affected by tidal level change of Ariake sea. The Hayatue river is a tributary bifurcating at the section of 6.0km from the river mouth. There is a training jetty made by Johannis de Rijke to prevent sediment deposition on river bed from 0.0km to 6.2km .

2. CHARACTARISTICS OF RIVR BED MATERIALS

2.1 Structure of river bed material

To identify characteristics of river bed materials, the river bed survey had been conducted in 2002 at the sections of filled square shown in Fig.1. This survey is able to define what kind of materials exists and how much depth of each bed material layer by using different frequency of supersonic echo sounder. Fig.2 shows the structure of river bed layer. Fig.2 (a) shows the result of 0.0km station installing a training jetty of the river. Fig. 2 (b) shows 10.0km station from river mouth with no training jetty. At the center of the 0.0km and 10.0km river channel sections where the lateral bed slope is mild, the bed surface layer is mainly composed of the sand. On the other hand, the river bank area where the lateral bed slope is comparatively steeper than the centre of river channel is covered with silty-clay. The boundary between sand and silty-clay almost corresponds to low tidal level as shown in Fig. 2 (a). The silty-clay which comes from Ariake sea on the flood tide deposited on river bank in a stage of falling tide.

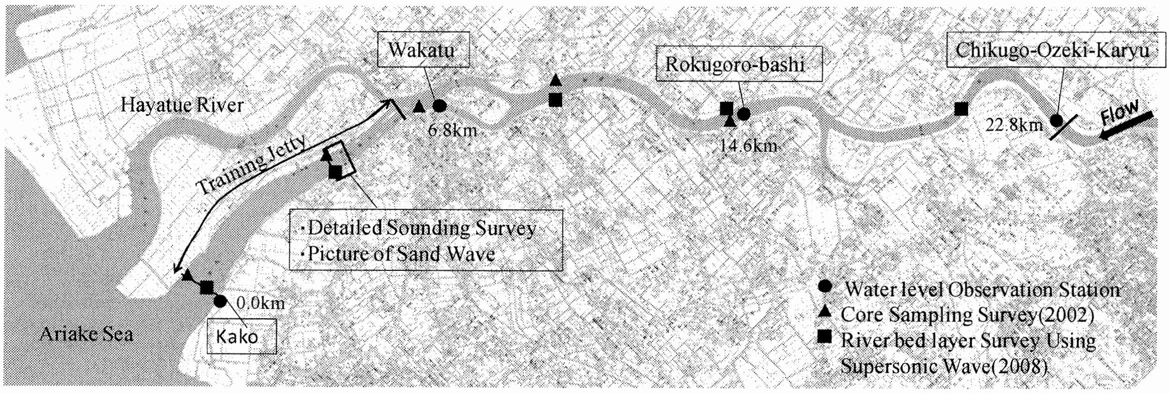
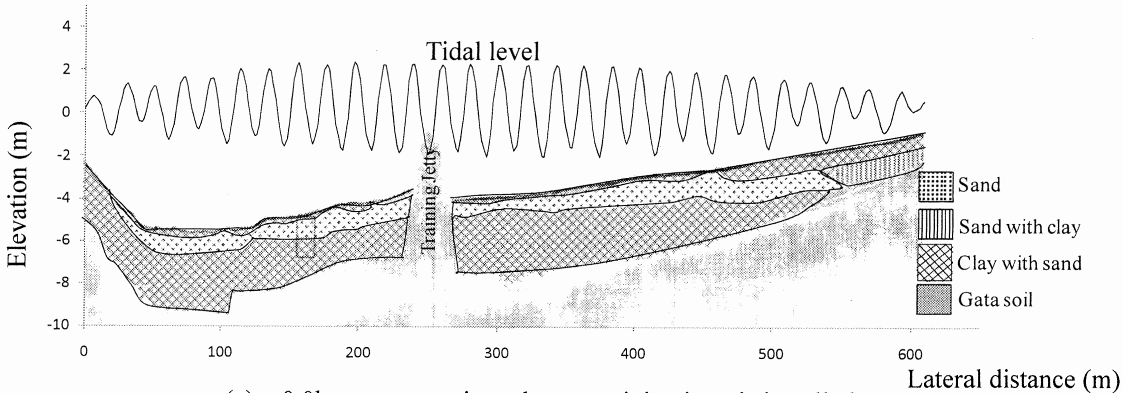
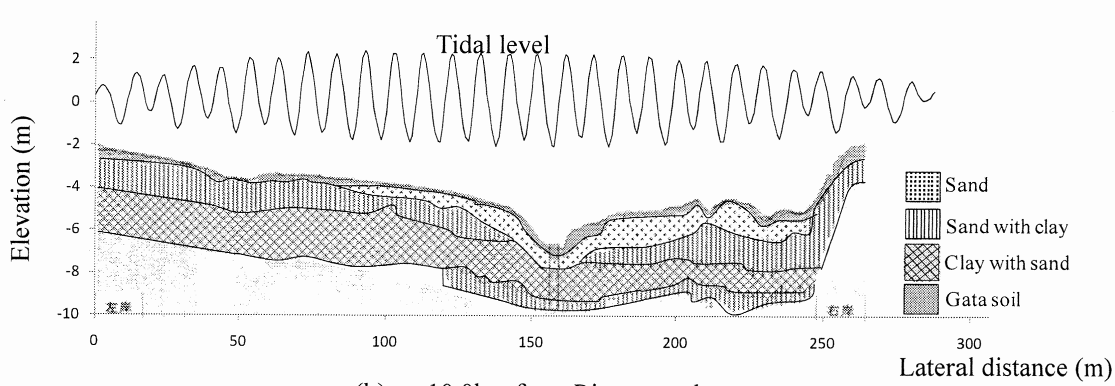


Fig. 1 Plan form of the study area of the Chikugo river and Ariake sea



(a) 0.0km cross-section where a training jetty is installed



(b) 10.0km from River mouth

Fig. 2 Structure of river bed layer and its materials (2008)

2.2 Result of core sample survey

The core sample survey had been conducted in 2002 at the sections of filled triangle shown in Fig. 1. At each section, sample has been taken at 3 positions (Left side, Centre, Right side). The result of core sample survey is shown in Fig. 3 which shows widely distributed sands in river channel. Especially, the ratio of sand relative to bed materials at the 0.0km through 10.0km is higher than 14.0km. Fig. 4 demonstrates grain size distribution curves with respect to depth from the river bed at the section of 10.0km . The sand exists at the depth of 0.4m though 0.9m from river bed , its d_{60} size is about 0.8mm.

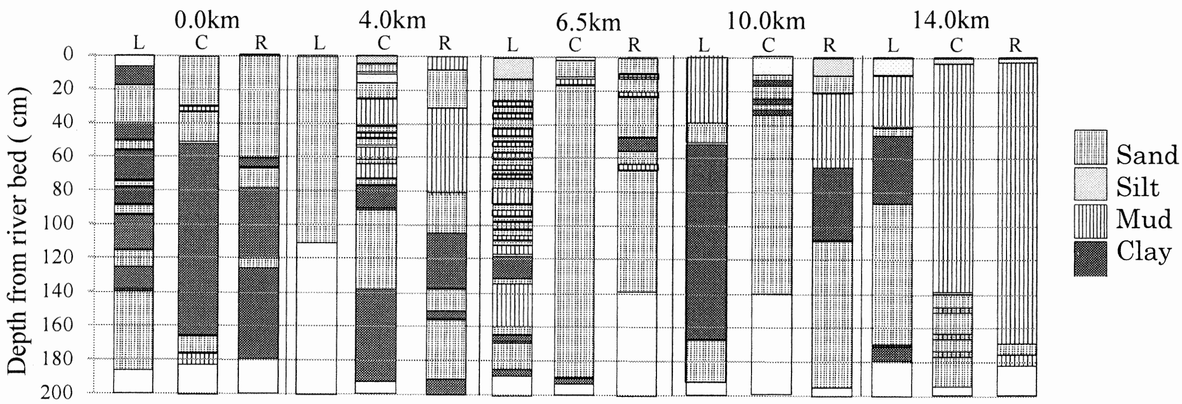


Fig. 3 Vertical profiles of river bed material

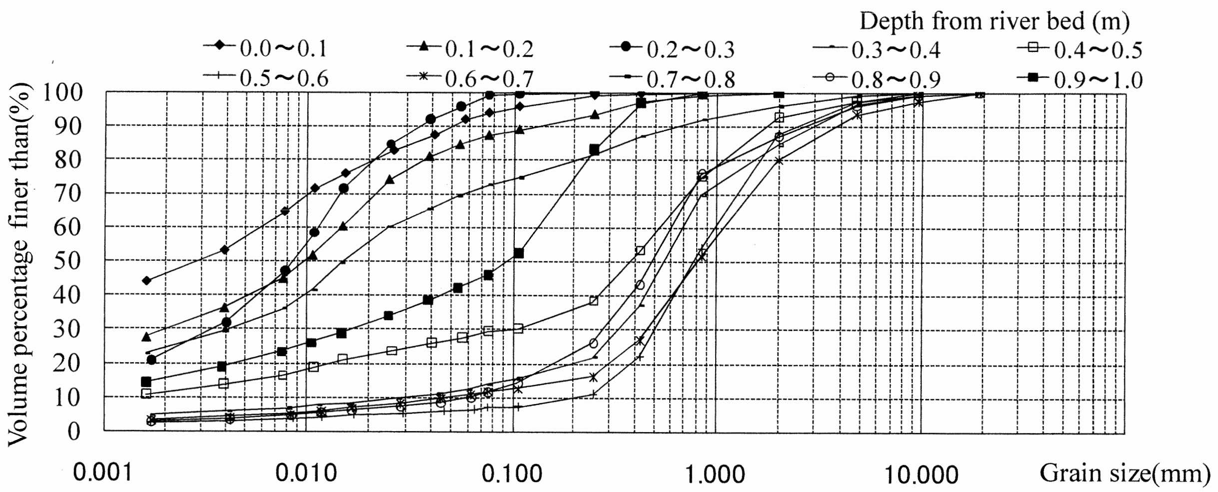
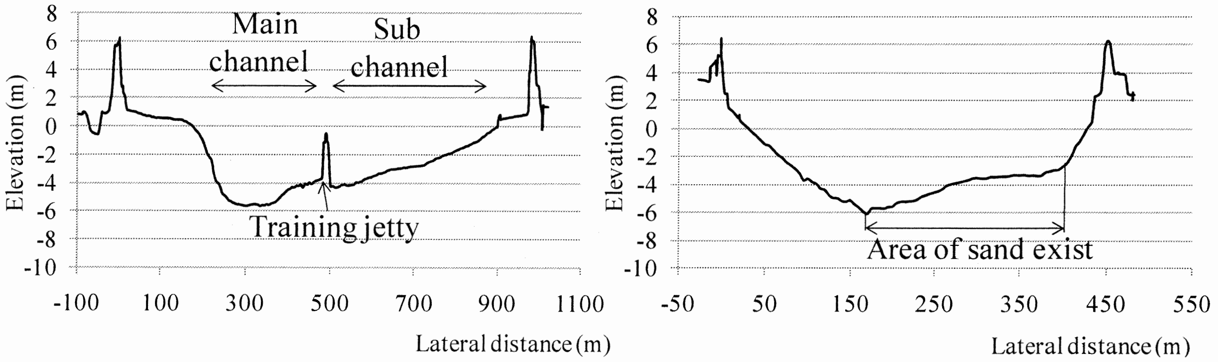


Fig. 4 Grain size distribution respect to depth from river bed surface at 10.0km

2.3 Change in average river bed elevation before and after the flood

A large flood occurred in the Chikugo river in July 2007. In order to compare river bed elevation before and after the flood, the authors investigate the longitudinal change in average elevation of river bed. Average bed height is determined from the bed elevation of the center area of the river cross-section where the existence of sand is assured in 2.1. Fig. 5 shows the calculation method of average bed elevation. At the section of 0.0km through 6.2km where a training jetty has been installed, flows with different behavior arise from difference of river bed elevations between right side and left side of the jetty. We call left side the main channel and right side the sub-channel. The elevation of the main channel is comparatively lower than that of the sub-channel as shown in Fig. 5(a). Fig. 5(b) is the way to calculate at the section with no training jetty. The comparison of average elevation of river bed before and after the flood is shown in Fig. 6. Solid line indicates bed elevation of the main channel before the flood, solid line with filled mark the main channel after the flood, broken line sub-channel before the flood and broken line with filled mark sub-channel after the flood. Fig. 6 indicates that river bed degradation occurred after the flood. From these results, we can say with fair certainty that the sand was transported to the Ariake sea during the 2007 flood.



(a) 0.0km cross-section where the training jetty has been installed

(b) 6.5km cross-section with no training jetty

Fig. 5 Example of way of calculate average elevation of river bed

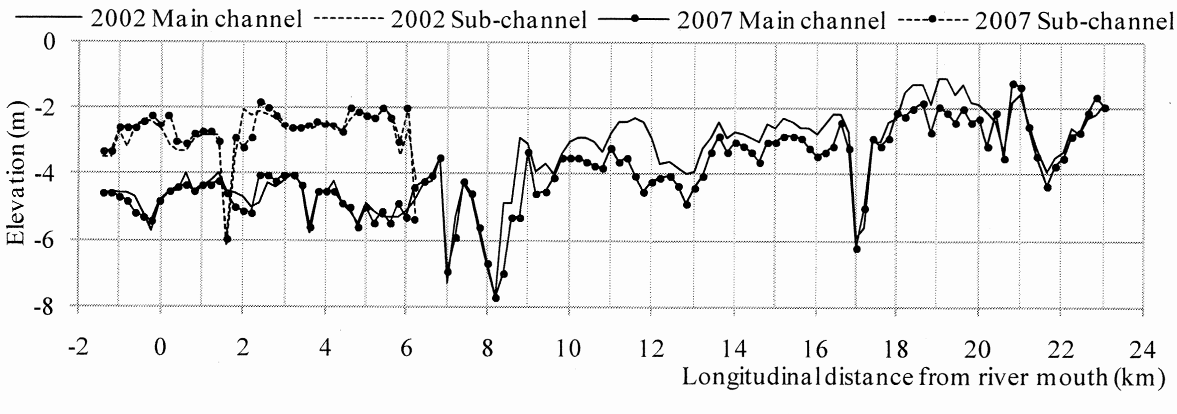


Fig. 6 Average elevation change before and after 2007 flood

3. UNSTEADY 2D FLOW ANALYSIS USING OBSERVED WATER SURFACE PROFILES

3.1 Method of analysis and analytical results

To clarify characteristics of the flood flow and sand transportation during 2007 flood, we applied the unsteady planar two-dimensional flow analysis using observed temporal changes in water surface profiles. The analysis is conducted based on the method of Fukuoka and Watanabe et al. (2002, 2004). Equations of motion and equation of continuity based on the general coordinate system are described by

$$\frac{\partial}{\partial t}\left(\frac{Q^{\xi}}{J}\right)+\frac{\partial}{\partial \xi}\left(\frac{UQ^{\xi}}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{VQ^{\xi}}{J}\right)-\frac{M}{J}\left(U\frac{\partial \xi_x}{\partial \xi}+V\frac{\partial \xi_x}{\partial \eta}\right)-\frac{N}{J}\left(U\frac{\partial \xi_y}{\partial \xi}+V\frac{\partial \xi_y}{\partial \eta}\right)$$
$$=-gh\left(\frac{\xi_x^2+\xi_y^2}{j}\frac{\partial z_s}{\partial \xi}+\frac{\xi_x\eta_x+\xi_y\eta_y}{J}\frac{\partial z_s}{\partial \eta}\right)-\frac{\tau_b^{\xi}}{\rho J}+\frac{\xi_x^2}{J}\frac{\partial}{\partial \xi}(-\overline{u'^2h})+\frac{\xi_x\eta_x}{J}\frac{\partial}{\partial \eta}(-\overline{u'^2h})$$
$$+\frac{\xi_y^2}{J}\frac{\partial}{\partial \xi}(-\overline{v'^2h})+\frac{\xi_y\eta_y}{J}\frac{\partial}{\partial \eta}(-\overline{v'^2h})+\frac{\xi_x\eta_y+\xi_y\eta_x}{J}\frac{\partial}{\partial \eta}(-\overline{u'v'h})+\frac{2\xi_x\xi_y}{J}\frac{\partial}{\partial \xi}(-\overline{u'v'h}) \quad (1)$$

$$\frac{\partial}{\partial t}\left(\frac{Q^{\eta}}{J}\right)+\frac{\partial}{\partial \xi}\left(\frac{UQ^{\eta}}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{VQ^{\eta}}{J}\right)-\frac{M}{J}\left(U\frac{\partial \eta_x}{\partial \xi}+V\frac{\partial \eta_x}{\partial \eta}\right)-\frac{N}{J}\left(U\frac{\partial \eta_y}{\partial \xi}+V\frac{\partial \eta_y}{\partial \eta}\right)$$
$$=-gh\left(\frac{\xi_x\eta_x+\xi_y\eta_y}{J}\frac{\partial z_s}{\partial \xi}+\frac{\eta_x^2+\eta_y^2}{J}\frac{\partial z_s}{\partial \eta}\right)-\frac{\tau_b^{\eta}}{\rho J}+\frac{\xi_x\eta_x}{J}\frac{\partial}{\partial \xi}(-\overline{u'^2h})+\frac{\eta_x^2}{J}\frac{\partial}{\partial \eta}(-\overline{u'^2h})$$
$$+\frac{\xi_y\eta_y}{J}\frac{\partial}{\partial \xi}(-\overline{v'^2h})+\frac{\eta_y^2}{J}\frac{\partial}{\partial \eta}(-\overline{v'^2h})+\frac{\xi_x\eta_y+\xi_y\eta_x}{J}\frac{\partial}{\partial \xi}(-\overline{u'v'h})+\frac{2\eta_x\eta_y}{J}\frac{\partial}{\partial \xi}(-\overline{u'v'h}) \quad (2)$$

$$\frac{\partial}{\partial t}\left(\frac{h}{J}\right)+\frac{\partial}{\partial \xi}\left(\frac{Uh}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{Vh}{J}\right)=0 \quad (3)$$

This method has proved to explain temporal characteristics of flood flows by determining Manning's roughness coefficient so as to minimize difference between observed and calculated temporal changes in water surface profiles(Fukuoka,Watanabe.2002,2004). In 2007 flood, water level was observed at 4 observation stations, Chikugo-Ozeki-karyu (22.8km), Rokugoro-basih (14.6km), Wakatu (6.8km) and Kako (0.0km) shown in Fig. 1. Fig. 7 shows water level hydrographs at each station. The flood peak at the Chikugo-Ozeki karyu(22.8km) occurred at 8 o'clock when the tidal level of Ariake sea was lowest. At the peak of the flood, water levels of Rokugoro-bashi and Wakatu were strongly affected by the tidal level change of the Ariake sea. We gave the river bed topographic data which had been measured in 2002 for the 2007 flood analysis of the Chikugo river. The analysis area of flood flow and sand transport was taken from Chikugo-Ozeki-karyu(22.8km) to the Ariake sea(-5.0km). The upstream boundary condition is observed water level hydrograph of Chikugo-Ozeki karyu(22.8km). The down stream boundary condition is controlled automatically so as to minimize the difference between observed and calculated water level at Kako station (0.0km) considering travel time lag of water level from -5.0km to 0.0km . The Manning's roughness coefficient is determined so as to minimize the difference between observed and calculated water level hydrographs from Rokugoro-basih (14.6km) to Wakatu (6.8km). The calculated and observed temporal changes in water surface profile are shown in Fig. 8 and Fig.9. Fig. 8 shows water surface profiles in the rising period and the peak discharge. Fig. 9 in the falling period of flood flow. In each stage, calculation results coincide well with observed temporal changes in water surface profiles. This means that calculated velocity distributions and water levels of the flood flow seem to provide fairly good explanation with those of the 2007 flood. Fig. 10 shows calculated discharge hydrograph at the section of the Chikugo-Ozeki karyu(22.8km). This indicates that the peak discharge was over 4000m^3/s.

Fig. 11 shows the distribution of non-dimensional shear stress (τ_*) at full tide of the Ariake sea (1 o'clock July 7th 2007) and Fig. 12 at the time of peak flood discharge (8 o'clock July 7th 2007). Shear stress is calculated by the unsteady planar 2D flow analysis. Non-dimensional critical shear stress which designates the critical state of sand movement is τ_{*C} =0.05. The intensity of shear stress at full tide is enough to transport the sand, although the longitudinal slope of water surface is very mild. The flood peak discharge occurred at the time of the lowest tidal level of the Ariake sea. Longitudinal water surface profile is steep as shown in Fig. 8. The shear stress at the peak discharge is enough to make transport of the sand in a wide area of the Chikugo river and Ariake sea.

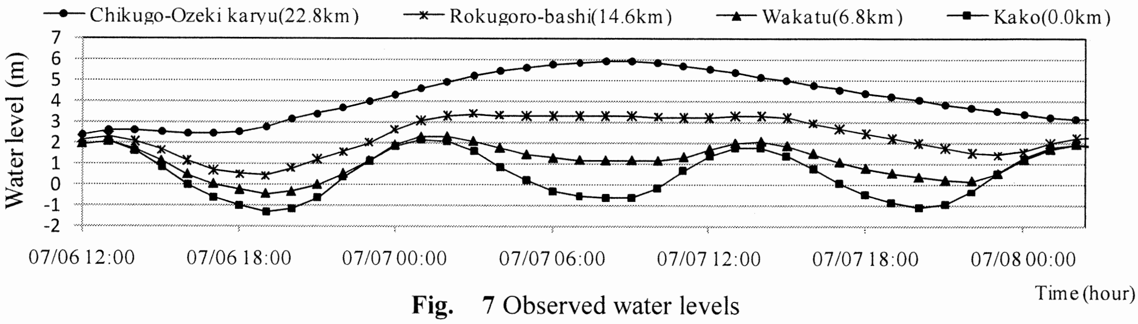


Fig. 7 Observed water levels

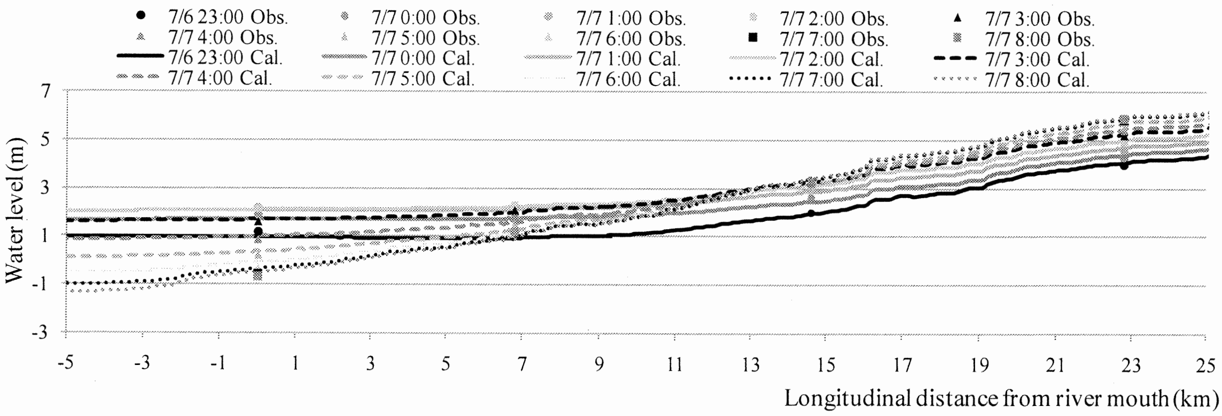


Fig. 8 Observed and calculated water surface profiles in the flood rising period and the peak discharge

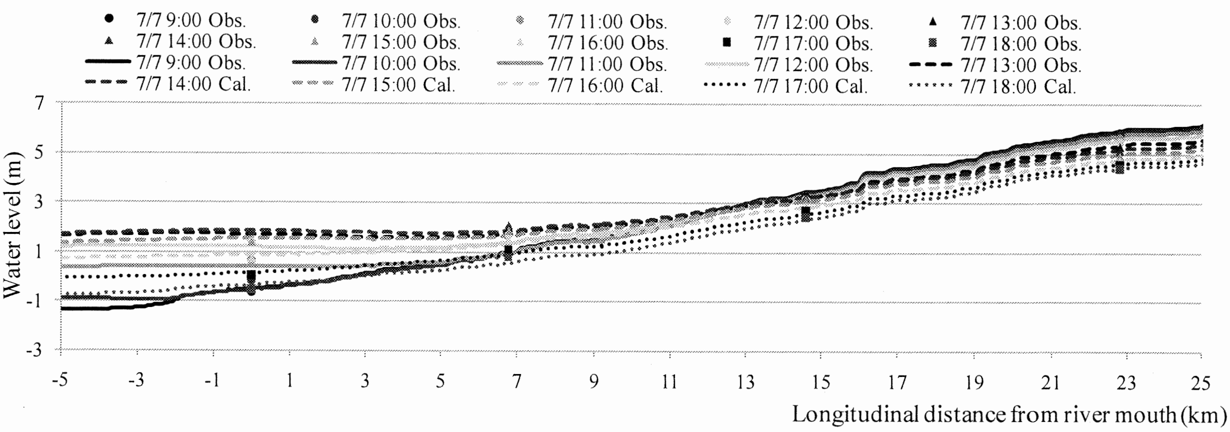


Fig. 9 Observed and calculated water surface profiles of flood falling period

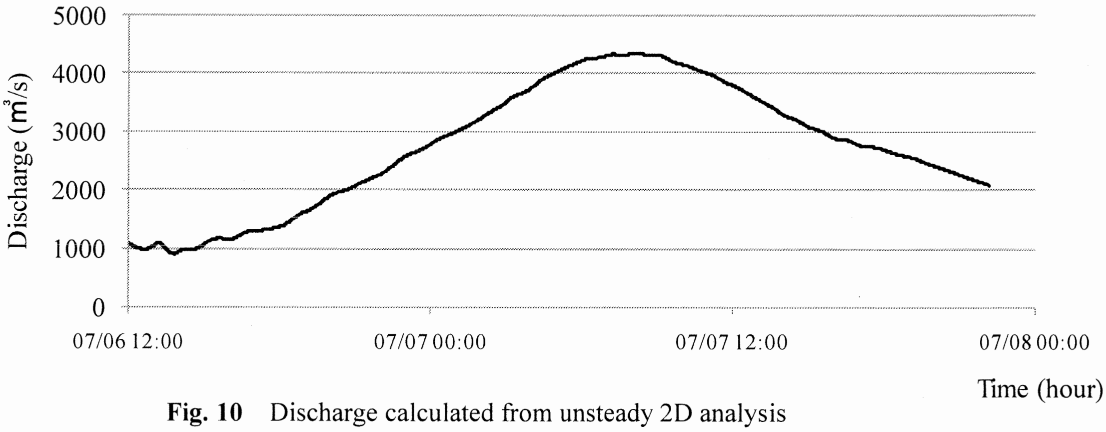


Fig. 10 Discharge calculated from unsteady 2D analysis

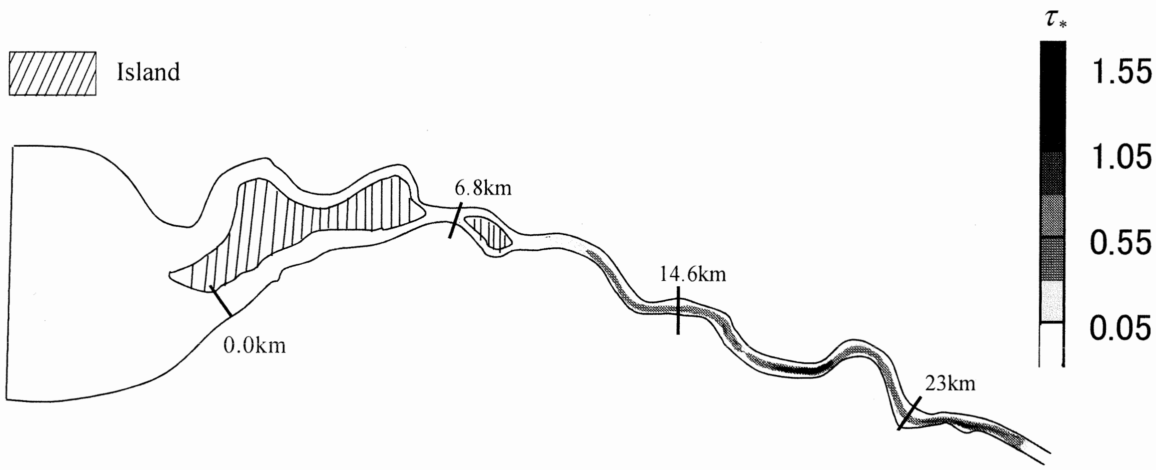


Fig. 11 Contour diagram of non-dimensional shear stress when tidal level of the Ariake sea was highest (1 o'clock, July 7th 2007)

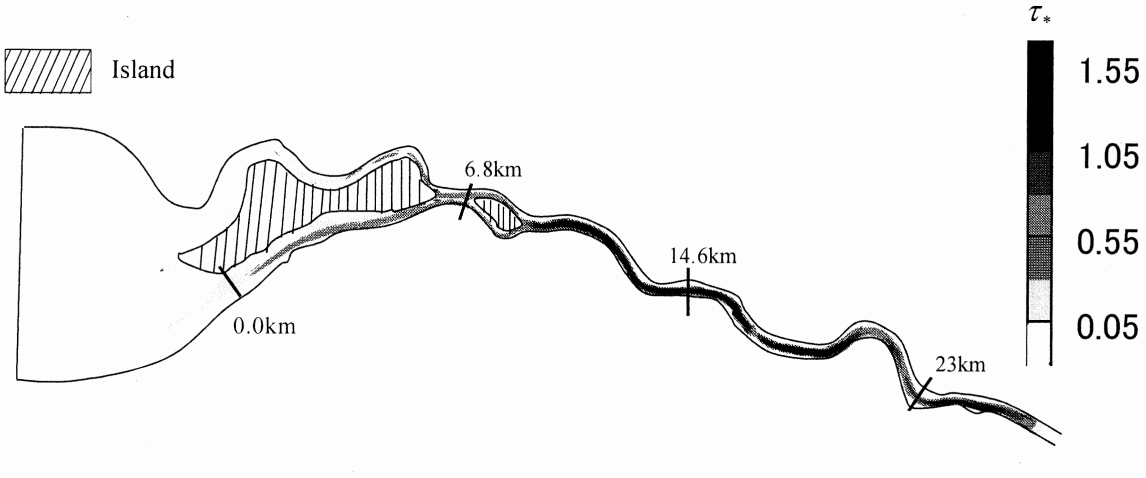


Fig. 12 Contour diagram of non-dimensional shear stress of the peak discharge (8 o'clock, July 7 2007)

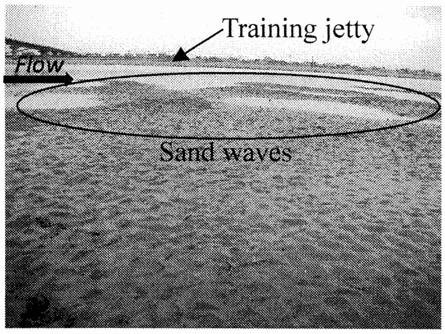


Photo 1 Sand waves at 4.3km from river mouth

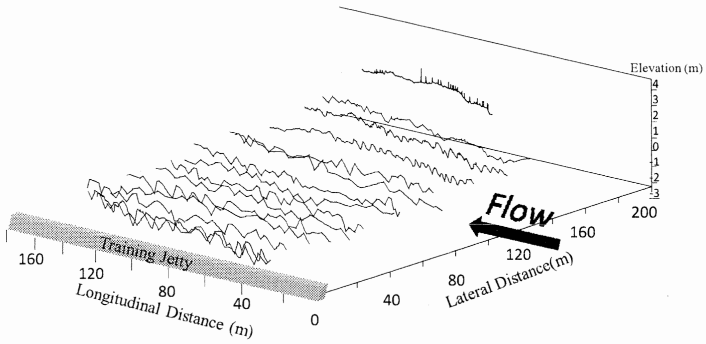


Fig.13 River bed shape at the right side of training jetty of 4.3km from river mouth

5.RIVER BED FORM DURING THE FLOOD

Photo 1 shows the picture of river bed shape which was taken at 4.3km from river mouth. Fig. 14 demonstrates bed forms by detailed echo sounding survey of the river bed conducted after 2007 flood. Around lower bed elevation near the training jetty, sand waves are seen in a continuous manner whose wavelength is about 20m and wave height is about 2m. These river bed form tells us that the sand is moving down with the form of dune and large amount of sand flows out to the Ariake sea from the Chikugo river during floods.

6. CONCLUSIONS

The authors investigated the structure of bed materials on the basis of core sample survey and river bed structure survey in the Chikugo river estuary to make sure of research results that the sand is transported a little from the Chikugo river to the Ariake sea. Temporal water surface profiles of a flood were also measured in the river. Unsteady 2D flow analysis using measured temporal changes in water surface profiles was carried out in order to make clear flood flow characteristics and sand transportation due to the flood.
Main conclusions were drawn as follows.

(1) It was ascertained that the sand existed in the bed layer over wide area of the Chikugo river estuary.
(2) Unsteady planar 2D flow analysis using observed temporal changes in water surface profiles demonstrated that the non-dimensional shear stress was enough to make transportation of the sand to the Ariake sea during floods.
(3) Large sand waves generated at the river bed in a continuous manor. The sand is thought to move with the form of sand waves.

REFERENCES

Fukuoka, S. and Watanabe, A., 2002, Estimating Channel Storage and Discharge Hydrographs of Flooding, *5th International Conference on Hydroscience & Engineering (CD-ROM).*

Fukuoka, S. Watanabe, A. Hara, T. Akiyama, M.2004, Highly accurate estimation of hydrograph of flood discharge and water storage in rivers by using an unsteady two-dimensional flow analysis based on temporal change in observed water surface profiles, *Journal of hydraulic, coastal and environmental engineering*, JSCE, No.761/II-67, pp.45-56, 2004.5.

Irie, Y., Ishikawa, H., Maeda, A., Yamaguchi, H., Sakamoto, T., Fukuoka, S., Watanabe, A., 2009, Flood flow and sand transport in the estuary area of the Chikugo River, *Advance in River Engineering*, (in press).