

Topographic changes of tidal flats in the Ota River estuary by flood flows

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ABSTRACT: In the Ota River estuary, there are tidal flats along the riverside in the Ota River floodway. Since emergency transportation road along the riverside is to be constructed on the tidal flats, a part of the tidal flats will be lost by the road constructions. Therefore, understanding bed variations on the tidal flats by flood flows is important for minimizing loss of the tidal flats. So, we investigated changes over time in bed profiles of tidal flats by using surveying data. The observed data indicates that the tidal flat elevations become lower due to alternate bar movements and a series of flood events. We estimated effects of floods and the road constructions on temporal and spatial changes in bed profiles of the tidal flats by applying numerical model for flood flows and bed variations. Finally, this study gives the concept of riverside design to preserve tidal flats in the floodway.

1 INTRODUCTION

In the Ota River estuary, the Ota River floodway and other five branched rivers compose a channel network on the Ota River delta in Hiroshima City (Fig. 1). The floodway directly connects to the Hiroshima bay where the tidal level changes are relatively large (Maximum difference of tidal levels is about 4 m). The construction of the Ota River floodway for protecting Hiroshima City from flood disasters was begun in 1934 and finished in 1967 after 2 years suspension by the IIInd World War. Nowadays, the Ota River floodway has tidal flats along the riverside which provides habitats for many creatures in brackish rivers.

However, since there is a plan to construct an emergency transportation road along the riverside to prepare for an earthquake disaster, a part of the tidal flats will be lost by the road construction. Therefore, a project to restore and preserve the ecosystem of estuarine tidal flats is now in progress. In the project, an artificial tidal flat was already constructed on the riverside of the left bank at 0.1 km.

For the construction of emergency transportation road along the riverside, it is necessary to evaluate the effects of the road constructions on temporal and spatial changes in bed profiles of the tidal flats in the Ota River floodway.

The first objective of this study is to investigate changes in the bed profiles of the tidal flats since

the floodway had constructed. The second objective is to estimate the effects of the emergency transportation road constructions on temporal changes in bed profiles of the tidal flats along the riverside by developing the numerical model for

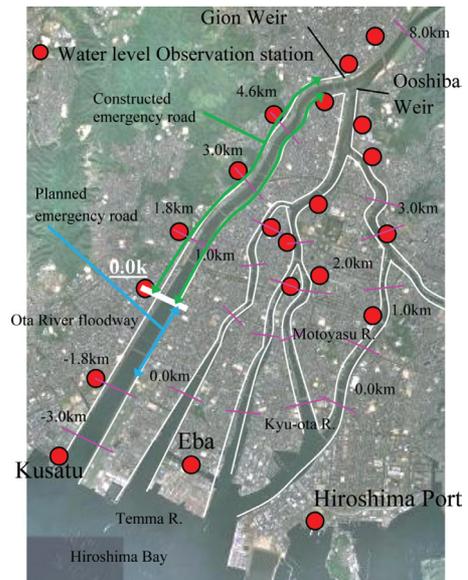


Figure 1. Air photograph of the Ota River delta in 2007 and July 2010's flood observation system.

flood flows and bed. This study's final goal is to give the concept for riverside design to preserve the tidal flats in the Ota River floodway.

2 OBSERVED TEMPORAL CHANGES IN BED PROFILES IN THE OTA RIVER FLOODWAY

2.1 Characteristics of the Ota River floodway

Figure 1 shows the air photograph of the Ota River delta in 2007 and observation system in July 2010's flood. The Ota River bifurcates to the Ota River floodway and the Kyu Ota River at 6.0 km. And, the Kyu Ota River divides into other four branched rivers which are the Kyo-basi River, Temma River, Motoyasu River and Enkou River. These rivers compose the channel network on the Ota River delta.

At the bifurcation section of the Ota River floodway and the Kyu-Ota River, Gion Weir is located at the side of the Ota River floodway and consists of a movable weir with three gates. These gates are fully opened in a flood period. Oshiba Weir is located at the side of the Kyu-Ota River and consists of a fixed weir and a movable weir with the three gates. Oshiba Weir controls inflow discharge of flood flows to the Kyu Ota River by operating the three gates.

The Ota River floodway is composed of compound cross-sectional channel from 5.8 km to 0.2 km and simple cross-sectional channel from 0.2 km to -3.4 km. The channel widths of the floodway are about 400 m.

Figure 2 shows the air photograph of the Ota River delta in 1939 when the floodway was under

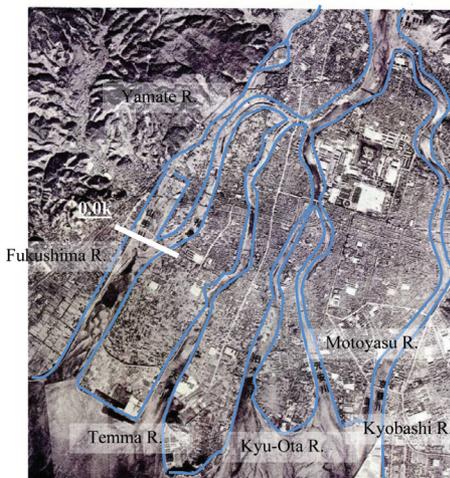


Figure 2. Air photograph of the Ota River delta in 1939.

construction. Around that time, there were extensive tidal flats around the river mouth on the delta. Nowadays, since land reclamations had been conducted around the river mouth until 1979, the tidal flats are remained only along the riverside of the Ota River floodway and the five branched rivers. The Ota River floodway was constructed by dredging of the Fukushima River and by excavating of the Yamate River (Fig. 1 & Fig. 2). Since the floodway were designed as compound cross-sectional channels in the first Ota River improvement planning which was made in 1933, the main channel was dredged at the sections downstream of 0.0 km (Fig. 3). But, the bed near the riverside of the floodway was not dredged as shown Figure 3. So, the tidal flats are remained along the riverside in the downstream of 0.0 km in the Ota River floodway (Fig. 4).

In the sections upstream of 0.0 km, flood plains are located at intertidal zone which are under water at high tide and above the water at low tide. Therefore, the flood plains have important functions as tidal flats (Fig. 5). The stability of the tidal flats in this section against the erosion and scouring is kept due to ripraps installed in front of the tidal flats (Onuma et al. 2010).

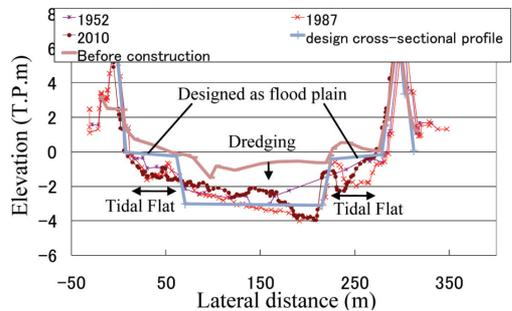


Figure 3. Designed cross-sectional profile at 0.0 km.



Figure 4. Tidal flats along the riverside at the section of downstream of 0.0 km in the Ota River floodway.

Around 2003, emergency transportation roads were constructed along both riversides at the section of 0.2 km to 5.4 km in the floodway. Moreover, the emergency transportation road of the left bank is planned to build an extension to -1.5 km



Figure 5. Tidal flats along the riverside at the section of upstream of 0.0 km in the Ota River floodway.

from 0.2 km (Fig. 1). So, a part of the tidal flats on the riverside of the left bank will be lost by the constructions of the emergency transportation road. Therefore, it is important to evaluate the effects of the emergency transportation road constructions on the temporal changes in the bed profiles of the tidal flats.

2.2 Changes in bed profiles of the tidal flats in the Ota River floodway since the completion of the floodway

Figure 6 shows the contours of the observed bed profiles in 1987, 1994, 2001, 2005 and 2010 in the Ota River floodway. We define -1.6 (T.P.m) as the lower limit of tidal flats elevations on which clams can inhabit. From this figure, it is found that the alternate bars with about 1 km wavelength are formed in the main channel of the Ota River floodway from these figures. The alternate bars move about 50~100 m to the downstream with keeping stable bed profiles by flood flows. Since maximum

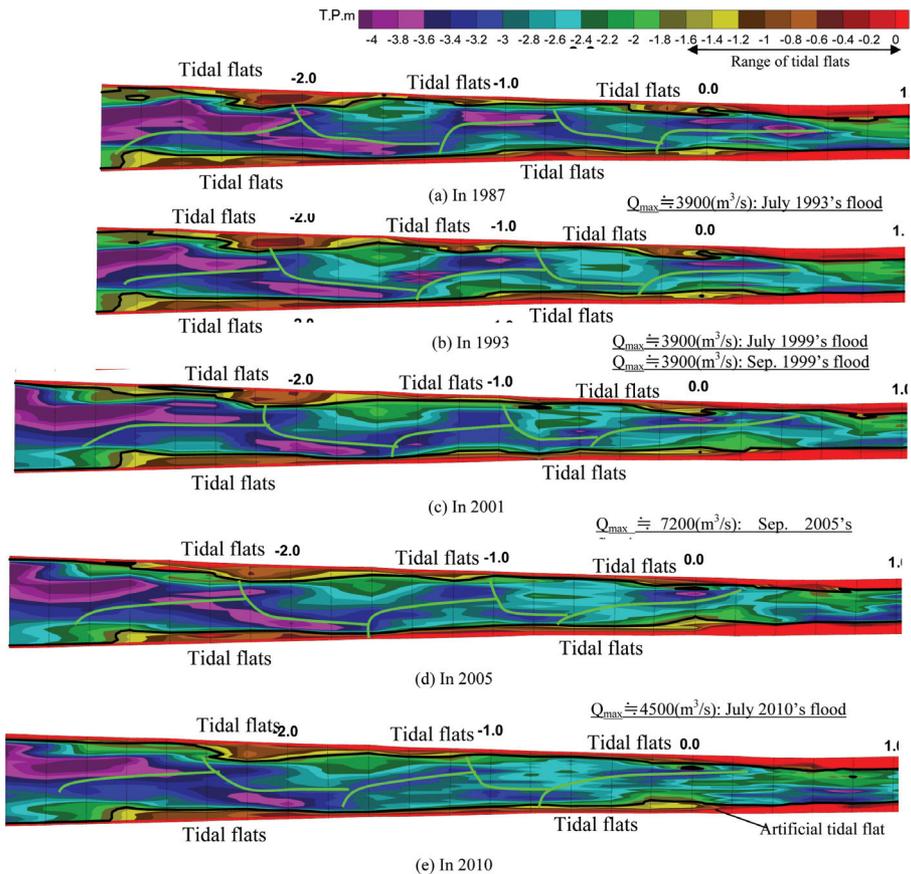


Figure 6. Contour of the observed bed profiles in the Ota River floodway.

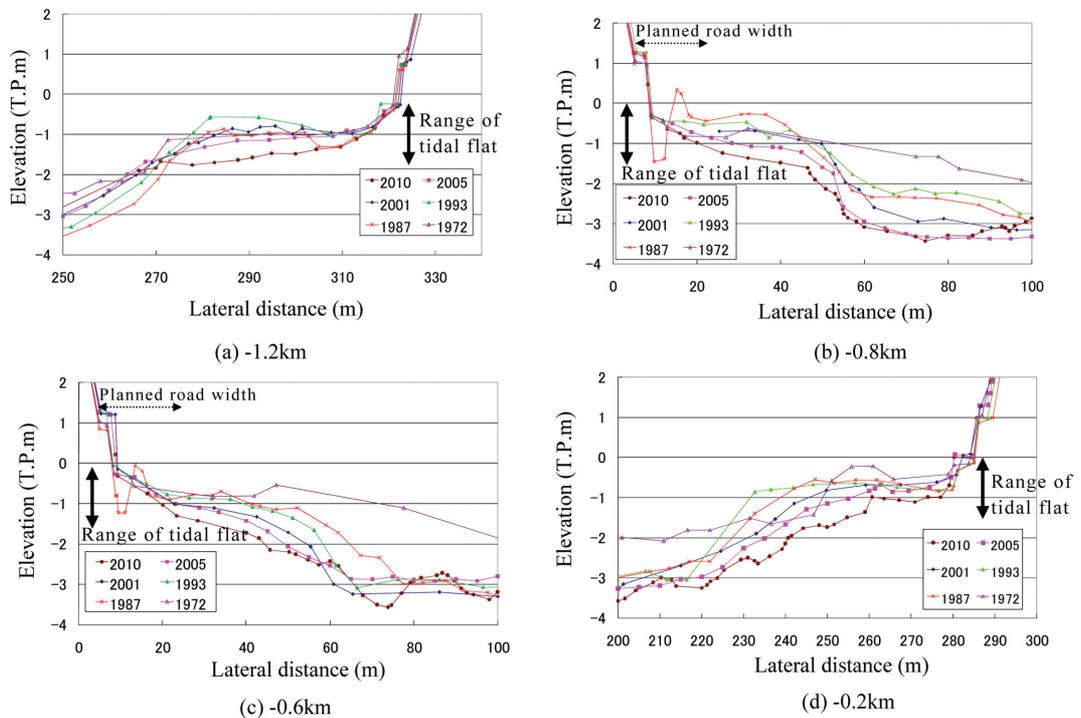


Figure 7. Cross-sectional profiles of the tidal flats.

elevation of the alternate bars is lower than low tide level which is about -2.0 (T.P.m), the alternate bars are under water even at low tide. Tidal flats in the downstream of 0.0 km are remained along the riverside.

Figure 7 shows the observed bed profiles of channel cross sections at -1.2 km, -0.8 km, -0.6 km and -0.2 km where pools of the alternate bars are located. The elevations of the tidal flats along the riverside in the downstream of 0.0 km tend to become lower over time by the flood flows. These surveying data indicate that the bed scouring on the tidal flats is associated with the alternate bars movements. In the following paragraph, we explain the above phenomena in detail.

From Figure 6(a), a pool of alternate bars was formed at left bank around -0.4 km in 1987. After that, the alternate bars moved to the downstream by July 1993's flood. In 2001 (Fig. 6(c)), the pool of alternate bars moved to around -0.6 km by July and Sep. 1999's floods. Therefore, the tidal flats around -0.6 km at the left bank lowered due to 1999's floods (Fig. 7(c)). Moreover, since the pool of the alternate bars moved to -0.8 km by Sep. 2005's flood as shown Figure 6(d), the bed scouring of tidal flats developed to -0.8 km from -0.6 km (Fig. 7(b)). Since the alternate bar elevations in the main channel are 1.0 m lower than the

tidal flats elevations, the most of bed material load in the main channel can't be transported to the tidal flats near the riverside. Therefore, once the tidal flats in the downstream of 0.0 km are scoured by flood flows, the tidal flats will not be able to naturally recover.

It is important to evaluate the effects of the emergency transportation road constructions on temporal and spatial changes in bed profiles of the tidal flats along the riverside. In the following section, we develop the calculation method of bed variations in the floodway with tidal flats by flood flows.

3 BED VARIATIONS ON THE TIDAL FLATS ALONG THE RIVERSIDE IN THE OTA RIVER FLOODWAY

3.1 Calculation method for flood flows and bed variations with tidal flats on the Ota River floodway

The Ota River floodway and other five branched rivers compose the channel network on the Ota River delta (Fig. 1). For understanding the bed variations in the Ota River floodway with tidal flats, it is necessary to evaluate the inflow discharge hydrograph which are boundary conditions of

upstream end of the floodway. Author et al. (2011) have developed the calculation method for flood flows and bed variations in the channel network on the Ota River delta. In the channel network, it is difficult to determine channel resistances and discharge through each channel, since flood flows in each channel have influence on each other. The effects of channel resistance, flood discharge distributions and so on appear in the time series of observed water surface profiles (Fukuoka et al. 2004, Okamura et al. 2012). So, we determined channel resistances so as to agree with time series of observed water surface profiles. This calculation method using the time series of observed water surface profiles was able to evaluate flood flows, bed variations and flood discharge distributions in actual river conditions of the Ota River delta. In order to understand temporal changes in the bed profiles of the tidal flats along the riverside, the calculation method which can accurately evaluate flood flows and bed variations around the tidal flats along the riverside is needed. Therefore, the calculation method in this study has two kinds of grids which consist of coarse grids and fine grids. The fine grids are used in order to evaluate the flood flows and bed variations around the tidal flats along the riverside. The coarse grids are used in order to evaluate the flood flows and bed variations in the channel network on the Ota River delta, providing boundary conditions for fine grid region.

To evaluate bed surface velocities is important for more accurate calculations of bed variations around the tidal flats. So, we applied the unsteady quasi three-dimensional flow analysis (Uchida & Fukuoka. 2011, Okamura et al. 2012) and 2D bed variation analysis. The vertical velocity distributions in this method assumed by a cubic curve are determined by using depth averaged velocity and difference between water surface and bottom velocities. The shear stresses on the river bed and vegetations resistance are calculated by equation (1)

$$(\tau_{sw\xi}, \tau_{sw\eta}) = \left(\frac{gn^2}{h^{1/3}} + \frac{gh}{K^2} \right) \sqrt{u^2 + v^2} (\tilde{U}, \tilde{V}) \quad (1)$$

where $\tau_{sw\xi}, \tau_{sw\eta}$: Channel flow resistances by river bed roughness and vegetation in direction of ξ and η , n : Manning's roughness coefficients, K : Vegetation permeability coefficients, \tilde{U}, \tilde{V} : Velocities in direction of ξ and η , u, v : Velocities in direction of x and y .

The bed variation analysis is used conventional method which consists of bed load formula (Ashida & Michiue, 1972) and continuity equations for sediment and grain sizes (Hirano, 1971). The critical tractive force for sediment mixtures

is calculated by the modified Egiazaroff formula (Egiazaroff, 1965; Ashida & Michiue, 1972). The suspended load concentration was calculated by depth averaged 2D convective diffusion equation.

Figure 8 shows the Water level hydrographs in 2010's flood. In this flood, the high tide occurred about an hour earlier than the flood peak. Figure 9 shows the grain size distributions in the section studied. The bed materials around 13.0 km consist of many cobbles and gravel. On the other hand, the bed materials in the Ota river floodway and the branched rivers (Kyu Ota River, Temma River, Motoyasu River) mainly consist of sands while silt and clay deposits along the river bank in the branched rivers. Table 1 shows Manning's roughness coefficients and vegetation permeability coefficients which were determined so as to satisfy temporal observed water surface profiles (Author et al. 2011). It is found that Manning's roughness coefficients contain the effects of topography such as sand waves because the coefficients are larger compared with those caused by bed materials. (e.g. Manning's roughness coefficients in the Temma River is about 0.012 ($m^{-1/3} \cdot s$) by using Strickler's empirical formula).

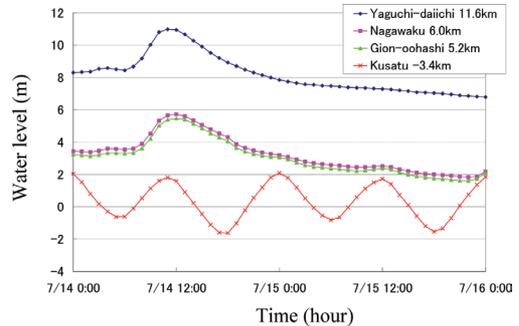


Figure 8. Water level hydrographs in 2010's flood.

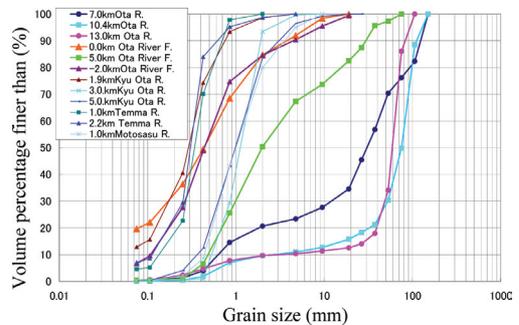


Figure 9. Grain size distributions in the channels of the Ota river delta.

Table 1. Manning's roughness coefficients and vegetation permeability coefficients.

Ota River, Ota river floodway			Kyu Ota river		Temma River	
<i>Manning's roughness coefficients ($m^{-1/3} \cdot s$)</i>						
12.4–5.8 km	Main channel	0.03	6.2–2.2 km	0.025	3.6–(-2.4 km)	0.03
	Flood channel	0.035	2.2–(-1.6 km)	0.022	Motoyasu River	
5.8–2.0 km	Main channel	0.028	Kyobashi River		2.6–(-2.4 km)	0.022
	Flood channel	0.035	5.2–2.4 km	0.033	Enko River	
2.0–(-3.4 km)	Main channel	0.022	2.4–(-0.8 km)	0.02	2.6 km–(-3.1 km)	0.035
	Flood channel	0.035				
Ota River			Kyu Ota River			
<i>Vegetation permeability coefficients (m/s)</i>						
8.0–9.6 km	Right bank	40	6.2–5.0 km	40		
10.4–10.8 km	Right bank	50				
10.8–11.4 km	Right bank	40				
8.0–8.8 km	Left bank	50				
9.6–10.6 km	Left bank	50				

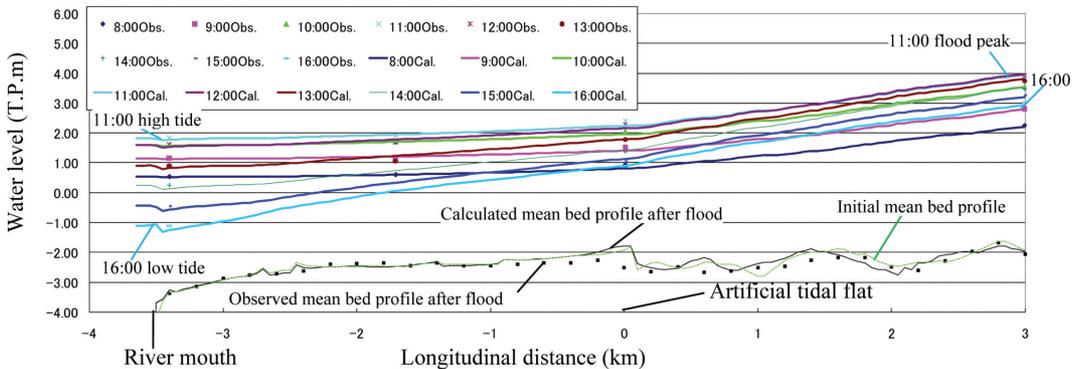


Figure 10. Comparison between observed and calculated water surface profiles in July 2010's flood.

3.2 Bed variations in the Ota River floodway with the tidal flats during July 2010's flood

July 2010's flood was middle scale flood for the Ota River floodway. The flood peak discharge was about 4500 (m^3/s) at Ygauchi-daiichi observation station (the Ota River: 11.6 km). Author et al. (2011) indicated that the discharge to the floodway was about 60% of the total discharge in this flood.

Figure 10 shows the comparison between observed and calculated water surface profiles. The calculated water surface profiles are good agreements with observed water surface profiles. In this flood, the water surface profiles around the river mouth in flood receding period are steeper than them in flood rising period due to ebb tide.

Figure 11(a) shows the contour map of the initial bed profiles in the downstream of 0.0 km in the

Ota River floodway. The initial bed profiles were surveyed in 2005. Figure 11(b) and Figure 11(c) show the observed and calculated contour maps of the bed profiles after the flood. And, the black lines in these figures show the edges of the tidal flats after July 2010's flood. The red lines show the edges of the tidal flats before this flood. The calculation results explain the observed movements of alternate bars. From these figures, it is found that the bed scouring on the tidal flats along the riversides are induced by movements of the alternate bars. When the pools of alternate bars approach to the tidal flats on the riverside, the bed scouring on the tidal flats is induced by bed variations around the pools. The above calculation results demonstrate the characteristics of the observed bed variation in the floodway with the tidal flats as shown in Figure 11(c).

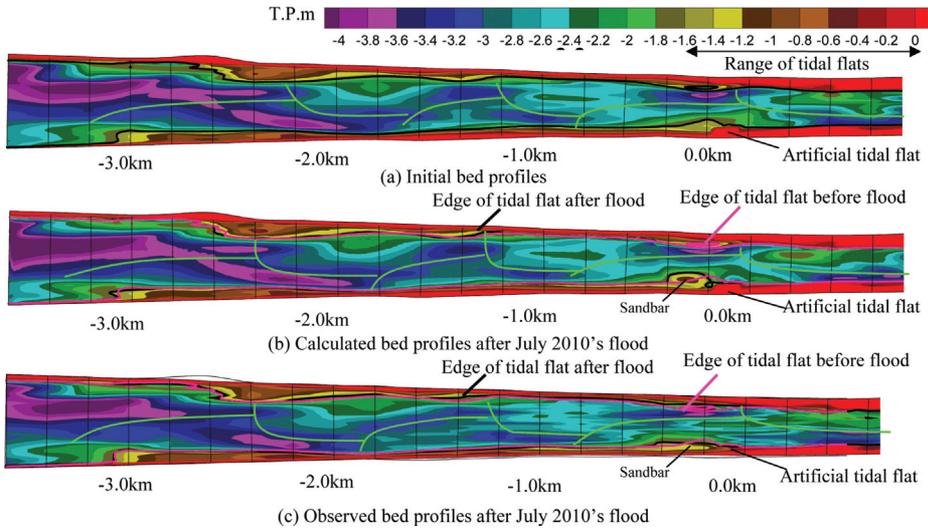


Figure 11. Comparison between observed and calculated contour of bed profiles in the Ota River floodway after July 2010's flood.

3.3 Estimation of effects of the emergency transportation road constructions on changes in bed profiles of the tidal flats

In this section, we estimate effects of the road constructions on the temporal and spatial changes in bed profiles of the tidal flats when the major flood events for past 30 years (Fig. 12) are repeated. The estimations are conducted by using the previous calculation method under various riverside conditions (Fig. 13). Each condition is as follows.

Case 0 is the present river conditions. Condition of Case 1 is that the emergency transportation road is constructed along the riverside of left bank from 0.0 km to -1.5 km. In Case 2, ripraps are installed in front of the tidal flats for protecting the tidal flats against erosion and bed scouring as shown Figure 13.

Figure 14 and Figure 15 show the calculated contour map of the bed profiles in Case 0 and Case 2, respectively. The travel distance, wave length and wave height of alternate bar are similar in each case. At the downstream of the artificial tidal flat (0.1 km), the sandbar which is above the water surface at low tide is formed and moves to downstream. The leading edge of the sandbar in each case reaches to about -0.7 km by the flood flows (Fig. 14 & Fig. 15). Figure 15 shows the calculated contour maps around the tidal flats after 8th flood event of Case 2. The orange line shows the edge of tidal flats of Case 1. The black line shows that of Case 2 which installs ripraps in front of the tidal flats. It is found that the tidal flats area decreases due to the bed scouring at around -0.8 km in

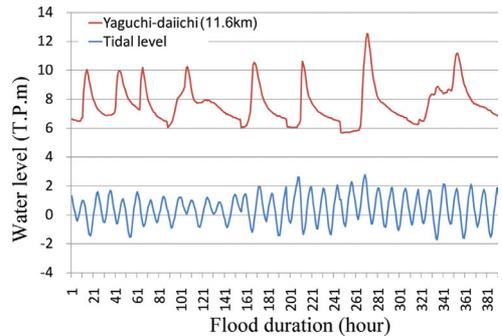


Figure 12. Boundary conditions of upstream end and downstream end when major flood events for past 30 years are repeated.

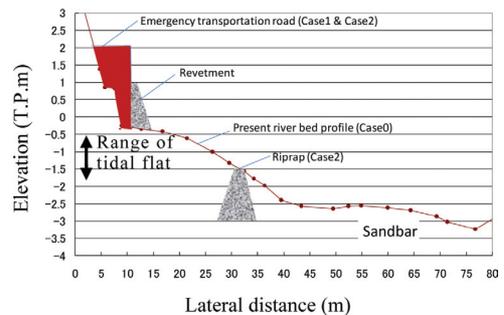


Figure 13. Calculation conditions of riverside at the left bank where the emergency transportation road is planned to be constructed.

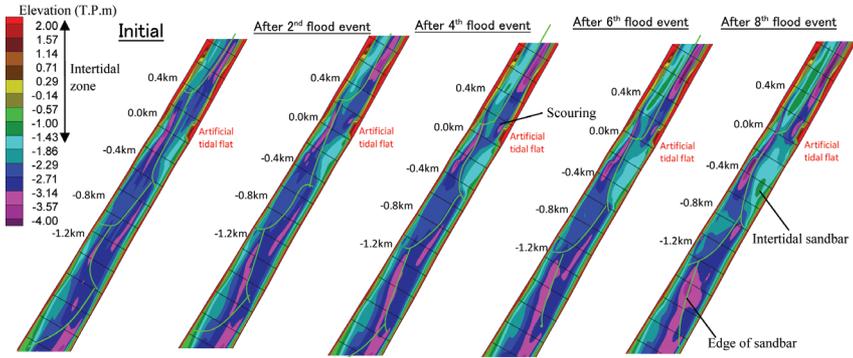


Figure 14. Calculated contours of bed profiles of Case 0.

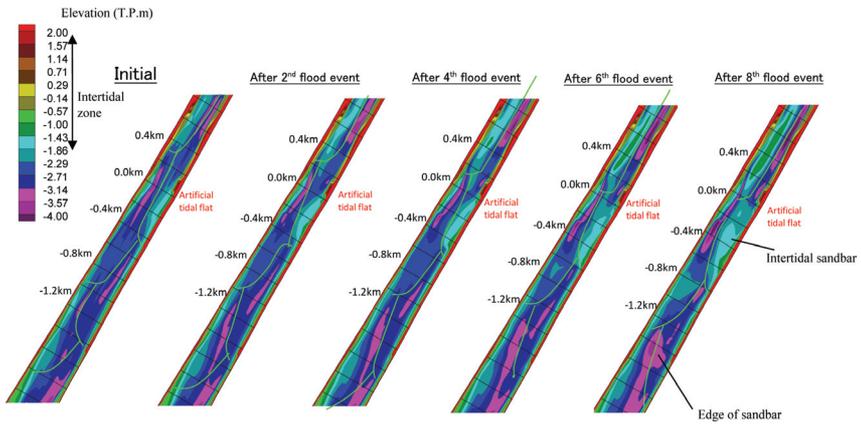


Figure 15. Calculated contours of bed profiles of Case 2.

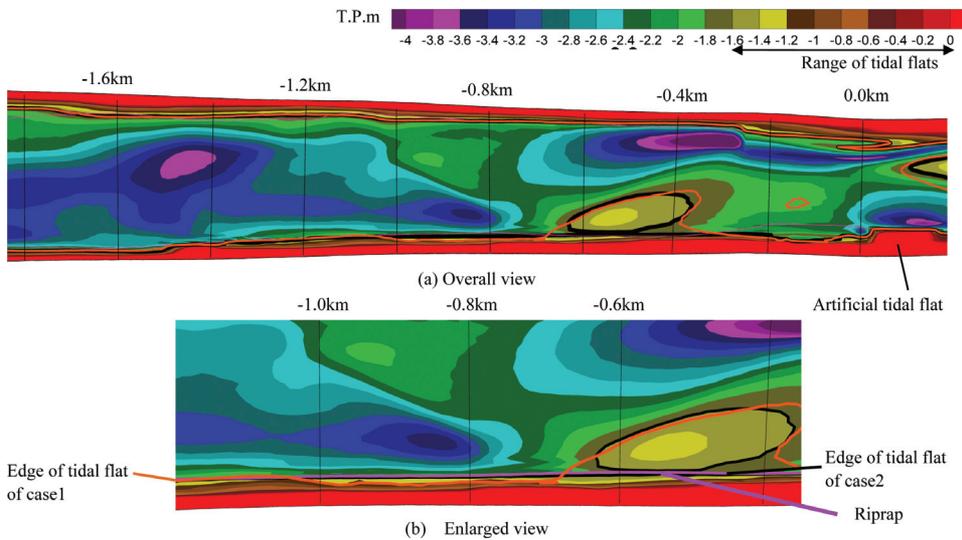


Figure 16. Calculated contours of bed profiles around the tidal flats after 8th flood events of Case 2.

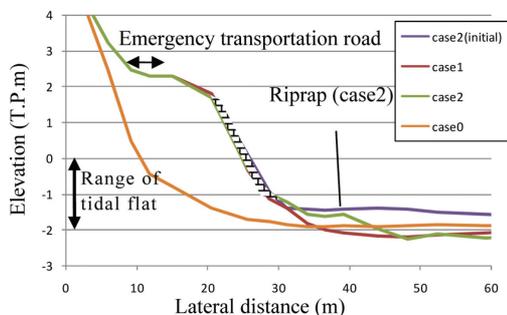


Figure 17. Calculated cross-sectional bed profiles around the tidal flats at -0.8 km.

case that ripraps were not installed in front of the tidal flats (Case 1). Figure 17 shows the calculated cross-sectional bed profiles near the riverside of left bank at -0.8 km. Height of the tidal flats decreases over time in case that ripraps were not installed in front of the tidal flats along the riverside (Case 0 & Case 1). The emergency transportation road induces the bed scouring on the tidal flats in front of the road (Case 1). On the other hand, the tidal flats are remained by installing the ripraps in front of the tidal flats along the riverside as Case 2. Therefore, to install ripraps in front of the tidal flats is effective for preservation of tidal flats in the Ota River floodway.

4 CONCLUSIONS

The following conclusions were derived from in this study.

1. The alternate bars with about 1 km wave length are formed in main channel of the Ota River floodway. Although the alternate bars are under water even at low tide, the tidal flats are remained along the riverside in the floodway. The surveying data indicates that height of the tidal flats along the riverside decreases due to alternate bars movements by a series of flood events.
2. The numerical model for flood flows and bed variations was developed to evaluate temporal and spatial changes in bed profiles of the tidal

flats in the actual river conditions of the Ota River floodway. Moreover, we estimated effects of the road constructions on changes in bed profiles of the tidal flats by using the numerical model. As a result, it is found that the emergency transportation road induces the bed scouring of the tidal flats in front of the road. Finally, it is indicated that ripraps installed in front of the tidal flats along the river side is effective for preserving tidal flats against the erosion and bed scouring by flood flows.

REFERENCES

- Ashida, K. & Michiue, M. 1972. Study on hydraulic resistance and bed-load transport rate in alluvial streams, *Proc. JSCE*, 206: 59–69.
- Egiazaroff, I.V. 1965. Calculation of nonuniform sediment concentration, *J. Hydraul. Div.*, 91(HY4): 225–247.
- Fukuoka, S., Watanabe, A., Hara, T. & Akiyama, M. 2004. Highly accurate estimation of hydrograph of flood discharge and water storage in river by using an unsteady two-dimensional flow analysis based on temporal change in observed water surface profiles, *J. Hydraul. Coastal & Environ. Engng*, 761(II): 45–56.
- Gotoh, T., Fukuoka, S., & Tanaka, R. 2011. Evaluation of flood discharge hydrographs and bed variations in a channel network on the Ota River delta, *5th International Conference on Flood Management (ICFM5)*, CD-ROM.
- Hirano, M. 1971. River-bed degradation with armouring, *Proc. JSCE*, 195: 55–65.
- Ministry of Construction, Chugoku Regional Construction Bureau. 1963. *30 year's history of the Ota River*.
- Ministry of Construction, Chugoku Regional Construction Bureau. 1993. *60 year's history of the Ota River*.
- Okamura, S. & Fukuoka, S., 2012. Numerical analysis of unsteady flow and bed variation using temporal changes in water surface profiles during 1981 flood of the Ishikari river mouth, *3rd International Symposium on Shallow Flows (ISSF)*: CD-ROM.
- Onuma, K., Fujita, K., Mochizuki, T., Amano, K., Satou, Y., & Abe, T. 2010. Characteristics of geographical features and consideration on the mechanism of stabilization of tidal flats in otogawa discharge channel, *Annual Journal of Hydraulic Engineering JSCE*, Vol. 54: 782–787.
- Uchida, T. & Fukuoka, S. 2011. Numerical Simulation of Bed Variation in a Channel with a Series of Submerged Groins, *In 34rd IAHR Congress, Water Engineering for a Sustainable Environment*: 4292–4299.