BED FORM AND BED VARIATION DURING FLOODS OF THE TONE RIVER MOUTH

Seiji Okamura[1], Shoji Fukuoka[2] and Takayuki Takemoto[3]

Abstract*: In this paper, the characteristics of the flood flow and bed variation of the Tone River mouth during the 2007 flood is elucidated by the surveyed bed form, the observed data of the flood, and numerical analysis. It is examined that the water surface gradient became steep at the reach downstream of 5km from the river mouth and became mild at the reach upstream from 5km at the 2007 flood peak occurred at low tide. This paper clarifies the reasons for the steep water surface gradient as follows. At first, the existence of the sand waves considered as dunes are verified by the longitudinal survey of the bed form in the Tone River mouth. Next, the gravel bed material around the narrow river mouth maintains the bed elevation during the flood. At last, the unsteady analysis of flood flow and bed variation using observed temporal changes in water surface profiles demonstrates that the gravel bed material and the bed resistance due to sand waves causes the steep water surface profile just upstream of the river mouth.*

Keywords*: water surface profile; flood; bed variation; sand wave; 2D unsteady flow analysis*

INTRODUCTION

We are faced with the problem that the discharge capacity of the Tone River mouth is decreased by the steep water level rising in the mouth. To solve this problem, it is important to clarify the characteristics of flood flows and bed variations of the Tone River mouth during floods.

The longitudinal water surface profile and its temporal variation upstream of the river mouth are interrelated with bed variation and tidal level change during floods. So, it is necessary to develop the unsteady analysis based on the observed temporal changes in water surface profiles to clarify the characteristics of flood flows and bed variations in the river mouth (Fukuoka, 2005, Kawaguchi, Fukuoka et al., 2009, Suzuki, Fukuoka et al., 2009).

The sand waves sometimes appear during floods at the river mouth where the bed slope is mild. In that case, the water surface profile varies with the bed resistance due to the sand waves. At the Ishikari River mouth, the observation of the temporal changes in water surface

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profiles and the survey of the bed form were conducted during the 1981 flood. Kuroki & Kishi (1983) and Shimizu et al. (1986) investigated the change in the bed resistance due to the bed form during the flood and conducted numerical analysis of the flood flow and bed variation, containing the bed resistance due to the sand waves.

In this paper, the characteristics of the flood flow and bed variation during the 2007 flood in the Tone River mouth is elucidated by the numerical analysis based on the observation of the bed form and temporal changes in longitudinal water surface profiles.

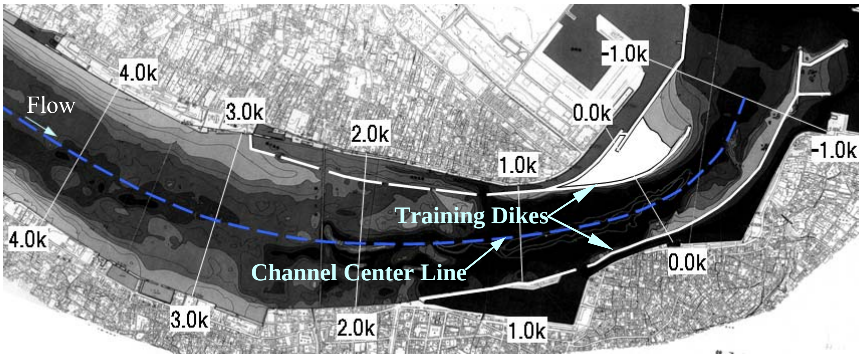
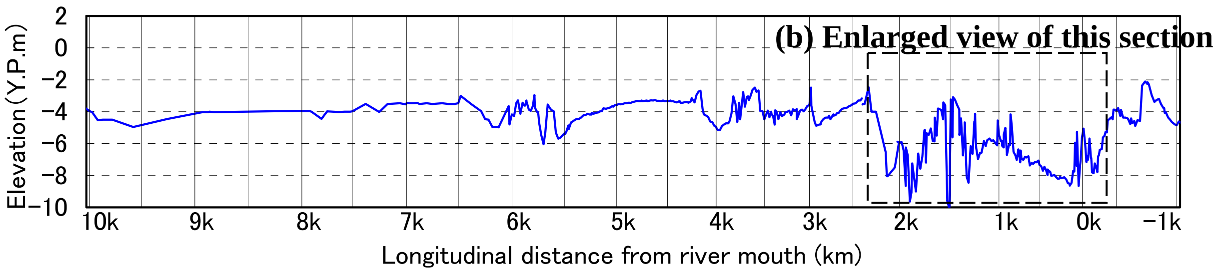
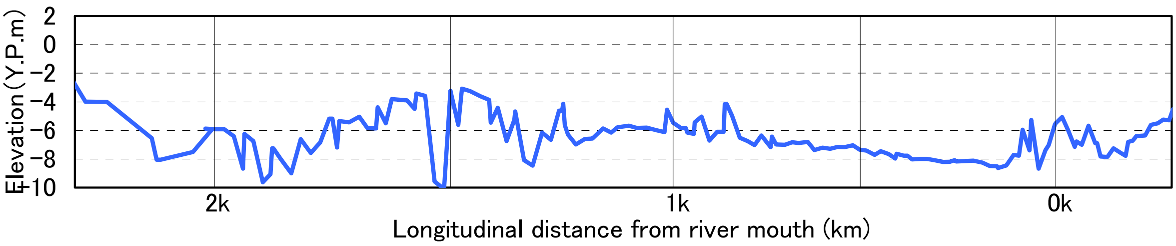


Figure1. Planform of the Tone River mouth



(a) From -1km to 10km section



(b) Enlarged view of section from 0km to 2km

Figure2. Longitudinal bed form of the Tone River mouth

THE LONGITUDINAL BED FORM IN THE TONE RIVER MOUTH

Figure 1 shows the plan form of the Tone River mouth. The discharge capacity of the river mouth is not enough because of the training dikes which decreases the channel width.

Figure 2 shows the longitudinal bed forms along the channel center line shown in Figure 1. Bed elevations are surveyed at 50m intervals in 2003 and 20m intervals in 2009 longitudinally. While the undulation of bed form is mild from 5km to 10km section, the bed form downstream of 5km section is rugged. In the reach, the large scale waves (wave length is about 500m, wave height is about 4m) and the small scale waves (wave length is about 50m, wave height is about 1m) are generated, as shown in Figure 2(b). The small scale waves are considered as dunes for the following reason. The water depth of the section is from 5m to 10m during floods. Generally, the wave length and wave height of the dune estimated about ten times longer than the water depth and from one-fifth to one-tenth of the water depth, respectively.

As above, existence of the sand waves considered as dunes are verified by the longitudinal survey of the bed form in the Tone River mouth.

TEMPORAL CHANGES IN LONGITUDINAL WATER SURFACE PROFILES AND BED VARIATION DURING 2007 FLOOD

A large flood occurred in the Tone River in September 2007. During the flood, temporal data of water levels were measured at many observation points in the reach 30km upstream from the river mouth.

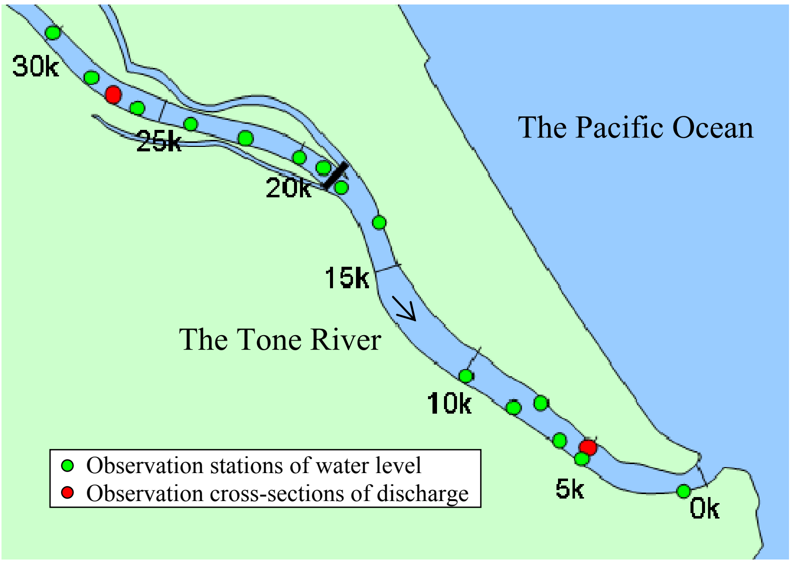


Figure3. Planform of the Tone River and observation stations of 2007 flood

Figure 3 shows observation stations of water levels and discharge in the reach 30km upstream from the river mouth. The discharge was measured at 27km and 5km. Cross-sectional bed forms were measured at 5km by the Acoustic Doppler Current Profiler (ADCP) during the flood.

Figure 4 shows observed water level hydrographs and discharge hydrographs of the 2007 flood. Figure 5 shows temporal changes in observed longitudinal water surface profiles. The peak discharge was about 6,000m^3/s and the water level near the river mouth was close to high water level. The flood peak occurred in the stage of low tide as shown in Figure 4. The water surface gradient became steep just upstream of the river mouth and became mild at the reach upstream from 5km as shown in Figure 5.

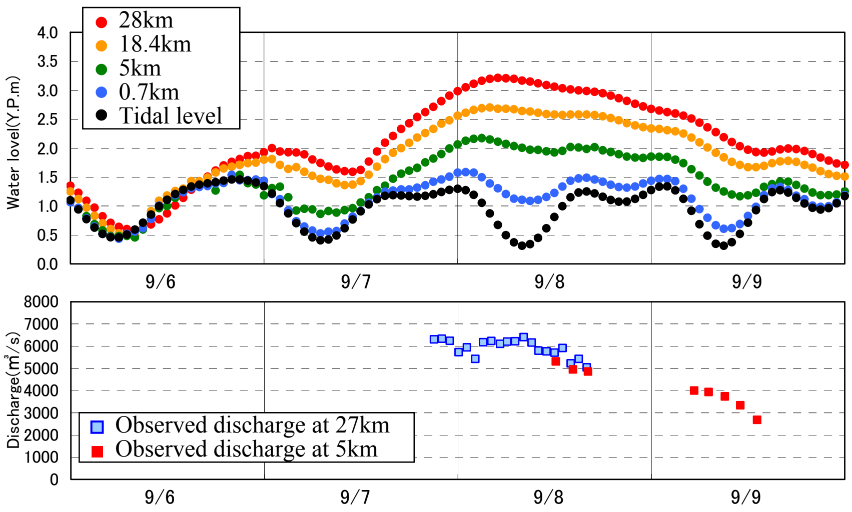


Figure4. Observed water level hydrographs and Observed discharge hydrographs

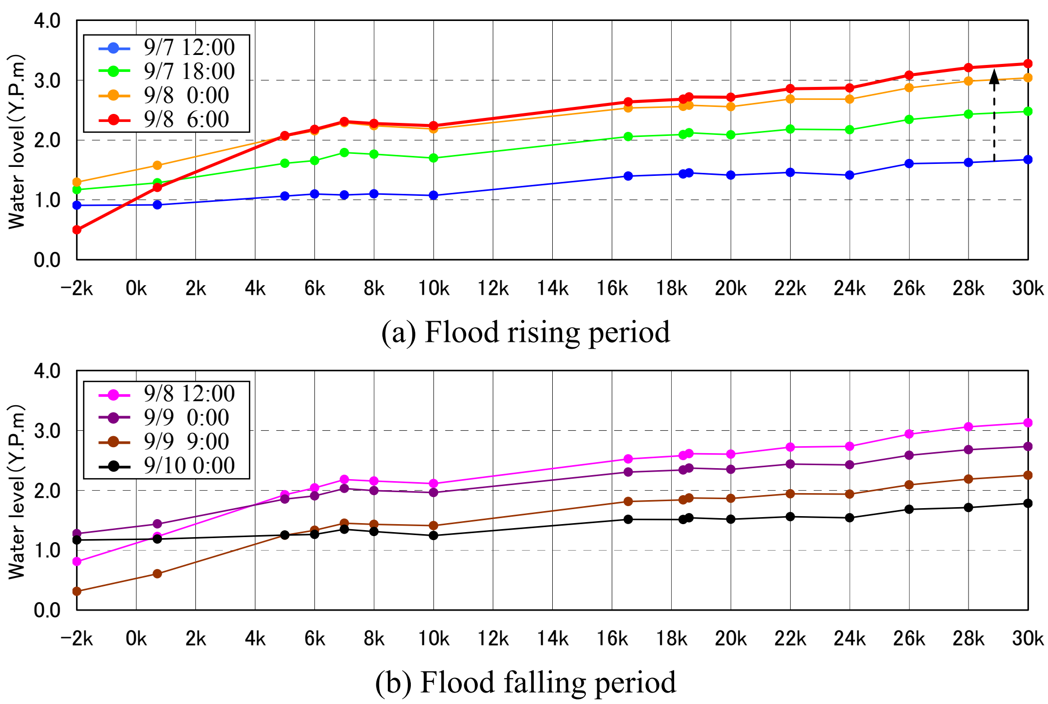


Figure5. Observed temporal changes in water surface profiles

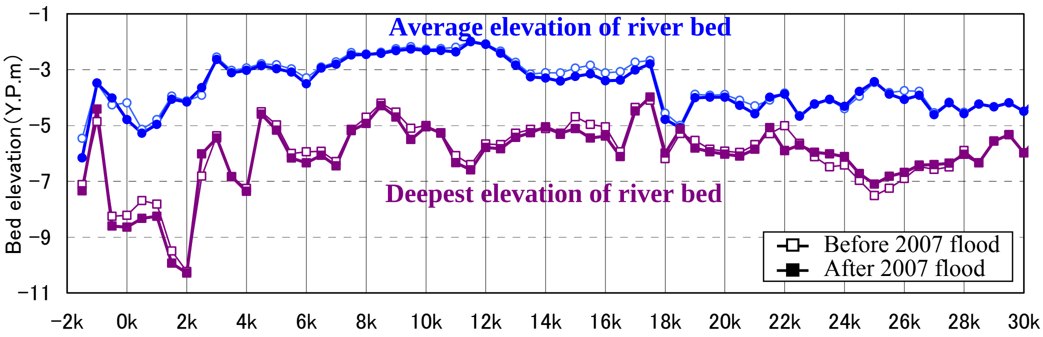


Figure6. Bed elevation change before and after 2007 flood

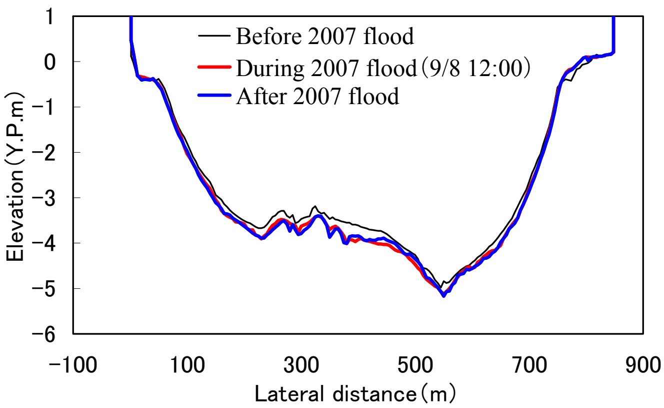


Figure7. Cross-section of 5.0km

Figure 6 shows the comparison of average elevation and lowest elevation of river bed before and after the flood. Although the river bed elevation decreases about 0.5m around 0.0km point, the bed elevation was maintained for the most part of the 0.0-30.0km section. Figure 7 shows the cross-section at 12 o'clock on September 8th just after the flood peak which was surveyed by ADCP at the 5.0km point. The bed elevation just after the flood peak coincides with the bed elevation after the flood.

As above, although the flood peak occurred at low tide and water surface gradient became steep just upstream of the river mouth, the bed elevation was maintained during the 2007 flood.

BED MATERIAL GRAIN SIZE AND BED VARIATION AT THE RIVER MOUTH

Figure 8, 9 shows the planer distribution of grain size of bed material in the surface layer and these grain size distributions, respectively. Whereas the bed material is composed of silt or sand in most areas around the river mouth, the gravel component dominates the bed material from -1.0km to 0.5km section, where the channel width is decreased by the training dikes. Figure 10 shows the vertical profiles of average grain size surveyed at left and right side of -0.5km and 0.0km cross-section. The comparison of cross-sectional bed form before and after 2007 flood is also shown in Figure 10. At the left side, although the sand exists in surface layer, the gravel exists in lower layer. At the right side, the gravel exists from river bed to the depth of about 5m from river bed. The river bed elevation at the right side of -0.5km and 0.0km cross-section is maintained due to the gravel bed materials even though there are located at the outer side of the narrow curved channel. Non-dimensional shear stresses (τ_*) for material grain size from 3mm to 10mm is estimated by using the observed water surface gradient at flood peak. These values are from 0.04 to 0.12, slightly over the Non-dimensional critical shear stress (τ_{*c}=0.05). Therefore, the bed elevation at the narrow river mouth was maintained. This is one of the reasons for the water surface gradient became steep just upstream of the river mouth.

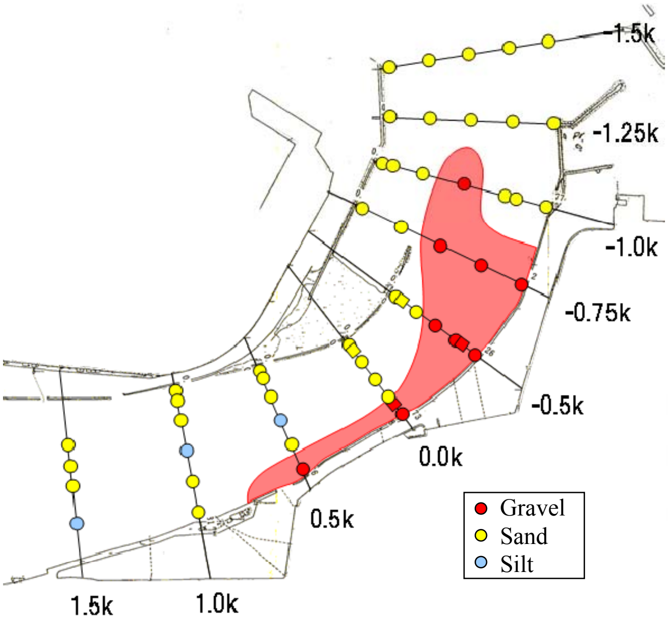


Figure8. Planer distribution of bed material

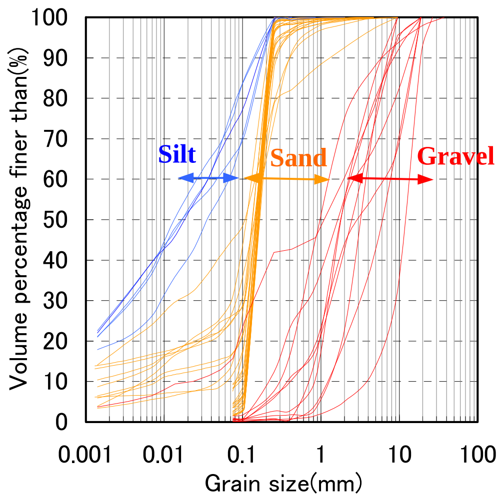
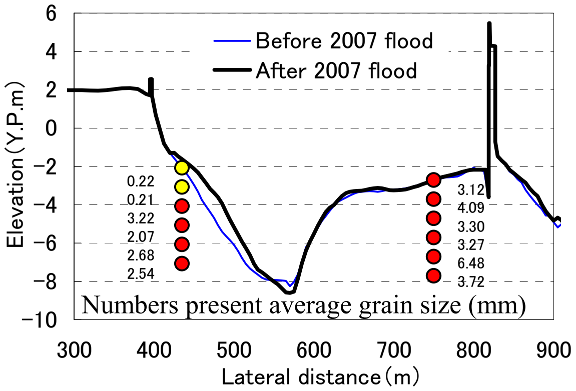
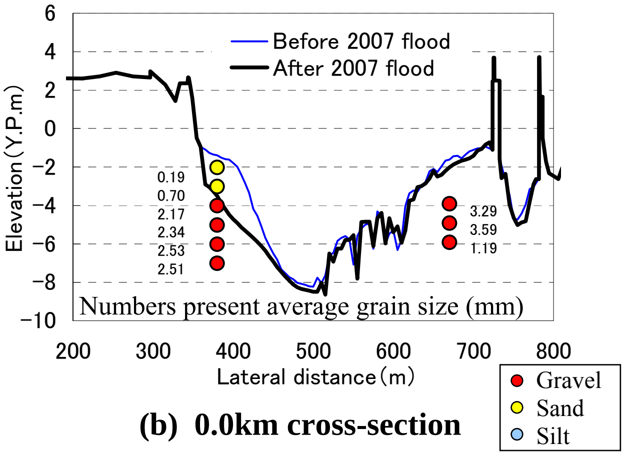


Figure9. Grain size distributions



(a) -0.5km cross-section



(b) 0.0km cross-section

Figure10. Vertical profiles of average grain size of -0.5k and 0.0k cross-section

UNSTEADY NUMERICAL ANALYSIS OF FLOOD FLOW AND BED VARIATION USING OBSERVED WATER SURFACE PROFILES

To clarify the characteristics of the flood flows and bed variations during floods of the Tone River mouth, we develop the unsteady numerical analysis of flood flow and bed variation using observed temporal changes in water surface profiles to 2007 flood. The analysis is conducted based on the method of Kawaguchi, Fukuoka et al. (2009), Suzuki, Fukuoka et al. (2009). This analysis consists of quasi-three-dimensional unsteady flow analysis (Uchida and Fukuoka, 2009) and two-dimensional bed variation analysis (Fukuoka, Watanabe et al., 1998), employing the general coordinate system. The boundary conditions of upstream and downstream ends are defined as observed water levels at 28km point and astronomical tide levels of the Choshi tidal observatory at sea 4km from the river mouth, respectively. The planer shape of training dikes and the drag force acting on piers of the Choshi Ohashi Bridge are considered in the analysis as shown in Figure 11.

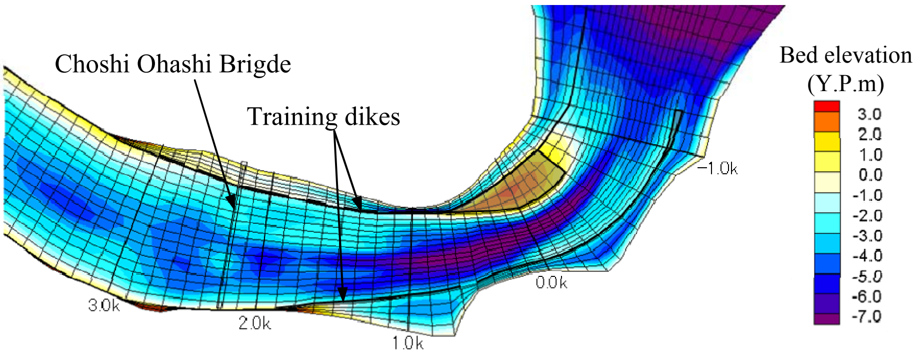


Figure11. Planform of calculation grid and counter diagram of bed elevation

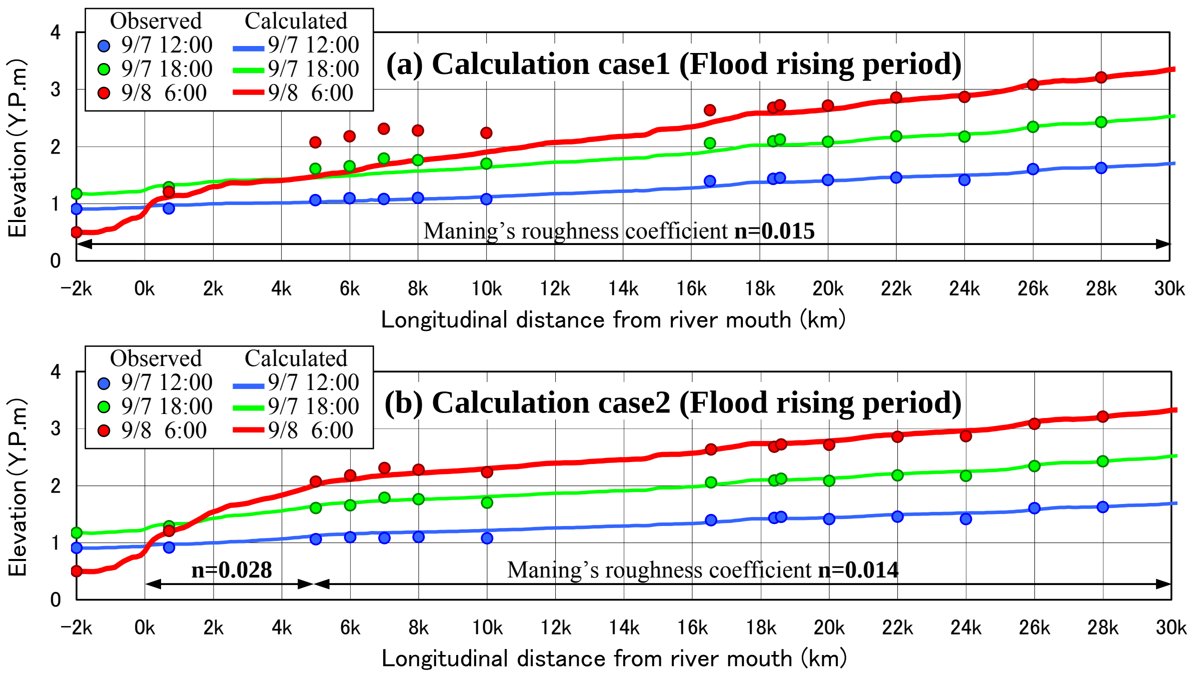


Figure12. Temporal changes in observed and calculated water surface profiles

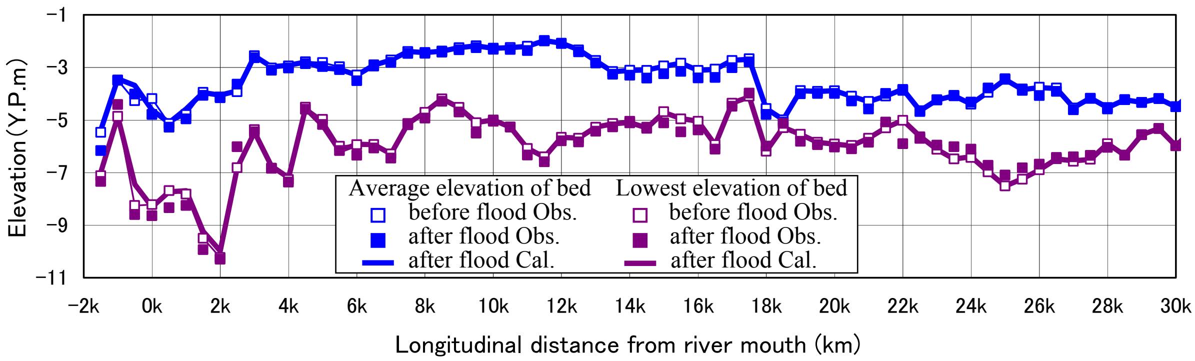


Figure13. Comparison between observed and calculated bed elevation before and after the 2007 flood (calculation case2)

At first (as calculation case1), we use the uniform value of the Manning's roughness coefficient n=0.015, assuming that the bed form is flat in all areas of the section in question. Figure 12 (a) shows temporal changes in the observed and the calculated water surface profiles for calculation case1. The calculated water surface profile at 12 o'clock on September 7th (low stage of 2007 flood) coincides with the observed water surface profile. At 6 o'clock on September 8th (the flood peak), the calculated water level increases from -1.0km to 1.0km section due to decrease of the channel width and the calculated water surface profile downstream of 1.0km coincides with observed water level. However, the gradients of the calculated water surfaces are milder than that of observed water surfaces from 1.0km to 5.0km section.

This steep water surface gradient downstream of 5.0km section is considered as the bed resistance due to sand waves, as shown in Figure 2. So next (as calculation case2), the Manning's roughness coefficient is determined so as to minimize the difference between the observed and the calculated water surface profiles. As a result, the observed temporal changes in water surface profiles is accurately re-created by deciding the Manning's roughness coefficient n=0.028 from 0.0km to 5.0km section where the sand waves exist and n=0.014 upstream from 5.0km section, respectively.

Figure 13 shows the comparison between observed and calculated bed elevation before and after the 2007 flood for calculation case2. The calculated bed variation is similar to observed bed variation in that the bed elevation is maintained in most parts of the section in question and the bed elevation decreases about 0.5m at 0.0km point. The calculated discharge hydrograph corresponds with the observed discharge hydrograph as shown in Figure 14.

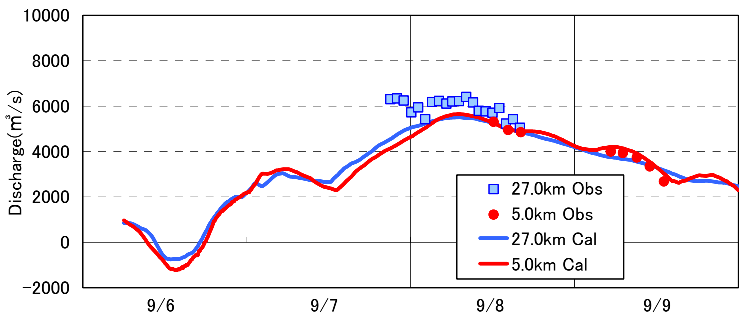


Figure14. Comparison between observed and calculated discharge

We also apply the model using same resistance distribution to the 2008 flood whose peak discharge was 3,000m^3/s about half that of 2007 flood as shown in Figure 15. As a result, the observed temporal changes in water surface profiles are accurately re-created as shown in Figure 16.

As above, the large bed resistance due to sand waves in 0.0-5.0km section is estimated at the Manning's roughness coefficient n=0.028. According to the relation between the bed forms and the bed resistances researched by Kishi and Kuroki (1972), for the hydraulic conditions of the 2007 flood, the value of the Manning's roughness coefficient of dunes is estimated as about n=0.040. Non-uniformity of bed form of the Tone River mouth and the difference of scale between the Tone River and the experiment channels are regarded as the reasons for the discrepancy.

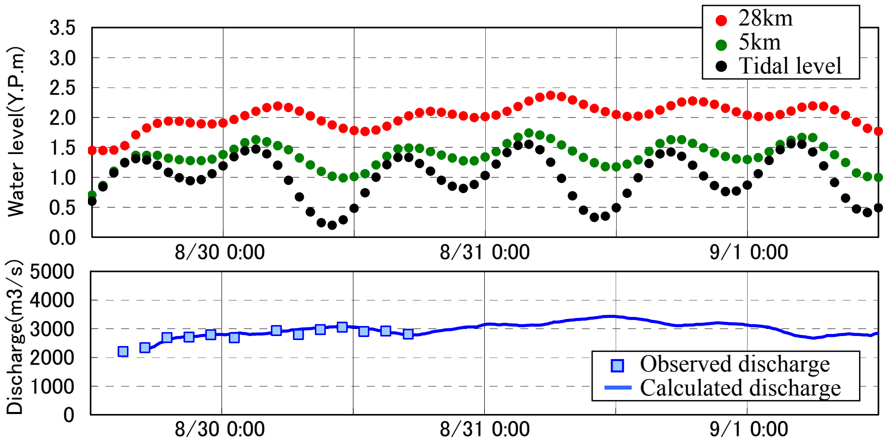


Figure15. Observed water level and discharge hydrographs of the 2008 flood

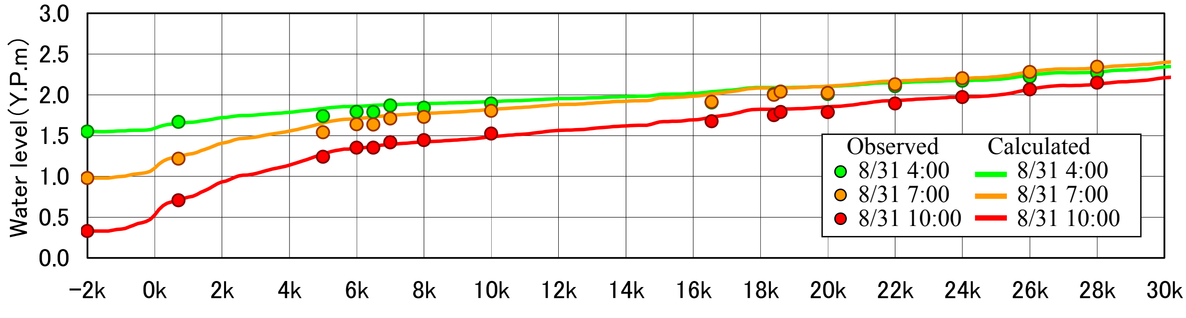


Figure16. Temporal changes in observed and calculated water surface profiles of the 2008 flood

CONCLUSIONS

In this paper, the characteristics of the flood flow and bed variation during the 2007 flood in the Tone River mouth is elucidated by the numerical analysis based on the observation of the bed form and temporal changes in longitudinal water surface profiles.

Main conclusions are drawn as follows.

1. Existence of the sand waves considered as dunes are verified by the longitudinal survey of the bed form in the Tone River mouth.
2. The water surface gradient became steep just upstream of the river mouth and became mild at the reach upstream from 5km at the 2007 flood peak occurred at low tide.
3. The gravel bed material around the narrow river mouth maintains the bed elevation during the flood. This is one of the reasons for the steep water surface gradient just upstream of the river mouth.
4. The unsteady analysis of flood flow and bed variation using observed temporal changes in water surface profiles estimates the bed resistance due to sand waves in 0.0-5.0km section.

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