FLOW STRUCTURE AND SEDIMENT TRANSPORT IN ESTUARY: A CASE STUDY OF THE TOJINGAWA RIVER, JAPAN

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ABSTRACT

Observations of suspended sediment concentration, salinity and current were made in the Tojingawa River estuary, Northern Kumamoto prefecture, Japan. The estuarine reaches are approximately 11 km in length, and are formed a compound channel by clay and silt. Flow measurements were undertaken in a straight part to investigate the effect of stratification on secondary flow in well-mixed estuary. Flow velocity was measured using an ADCP. Salinity was also carried out using a water quality monitoring sensor. The sediment concentration goes up on the flood plain in the vicinity of the low waterway shoulder at the ebb though the change in the direction of the crossing is small. The perpendicular direction change in the sediment concentration has become small oppositely high by the vicinity of the surface of the water in the vicinity of the bottom. That is, it is thought that sedimentation on not low-water channel's sedimentation but the flood plain is rolled up, and it is floating in the surface of the water. It is understood that the sedimentation transportation in the direction of the crossing is predominant in the cross-section. The measured data shows that the position of maximum flow velocity in the low-water channel convected downward on flood tides. Suspended sediment concentration profiles were very well-mixed both vertically and laterally. Salinity profiles showed a cross-channel salinity gradient have a sharp inclination than flood tides. The salinity profiles produce an effective transverse flow velocity distribution for natural compound channels.

Keywords: Tidal river, sediment transport, flow structure, compound channel flow

1. INTRODUCTION

Observations of suspended sediment concentration, salinity and current were made in the Tojingawa river estuary, Northern Kumamoto prefecture, Japan. The estuarine reaches are approximately 11 km in length, and are formed a compound channel by clay and silt. Flow measurements were undertaken in a straight part (Nezu and Rodi, 1986; Tominaga and Nezu, 1991; Shiono and Muto, 1998; Ishigaki et al., 2001) to investigate the effect of stratification on secondary flow in well-mixed estuary. In previous studies, few studies have examined the flow structure and lateral sediment transport in the tidal zone.

Ridd et al. (1998) concludes that the difference in density of saltwater in the horizontal direction is the dominant factor in the generation of density-circulating currents paired with river channels from the convergence and divergence of mangrove leaves at the mouth of the Normanby River in northern Australia (Figure 1 and Figure 2). The grasp of the stream regime in the river channel is not enough because of the fixed-point observation in several points that is the flow velocity distribution of the cross-section.

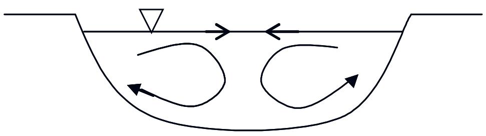

Figure 1. Secondary currents at the flood tide.

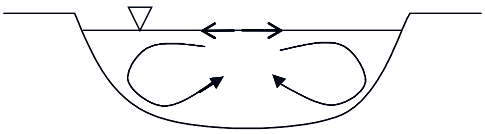

Figure 2. Secondary currents at the ebb tide.

Several studies have been conducted on the transverse flow mechanism in open channel flow. For example, DNS has been applied to a rectangular open channel flow with an aspect ratio of 2, which is said to be the most basic flow that generates a secondary currents, and the secondary currents structure has been elucidated by changing the inclination angle of the side wall (Figure 3). Furthermore, the three-dimensional turbulent structure at the corner of the open channel was studied by directly observing the swirling vortex using the vortex structure extraction method (Hayashi et al., 2006). It has been shown that the basic structure in which a pair of secondary currents occurs at such corners is not limited to solid corners and water corners, but is also universal in trapezoidal cross sections with inclined side walls.

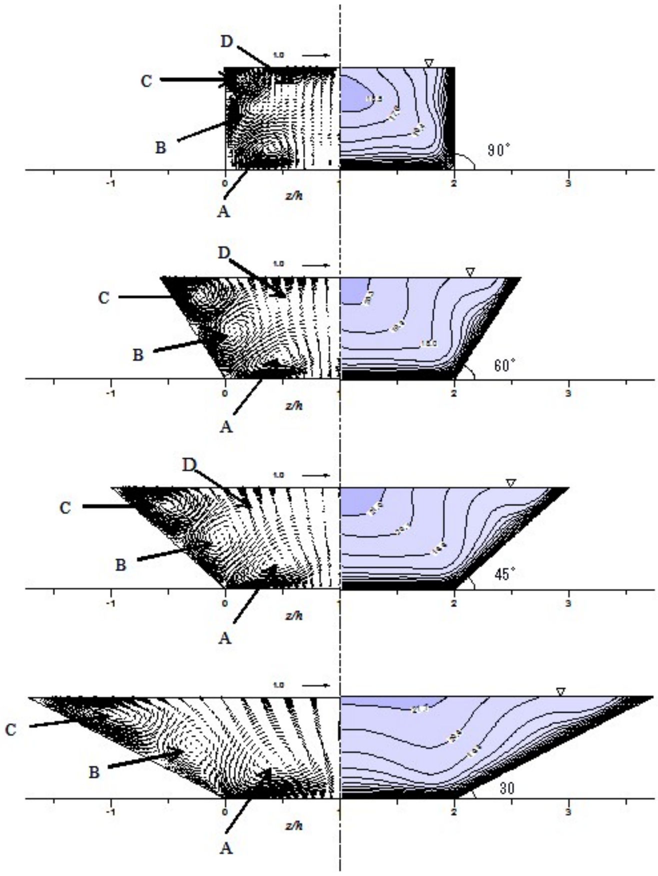

Figure 3. Distribution of secondary flow vector and main flow velocity due to the difference of the inclination angle of the side wall.

In the present study, it aimed to clarify the carrier mechanism of the clay and silt to the direction of the crossing.

2. STUDY AREA AND METHODS

2.1 Tojingawa River

The Tojingawa River in Kumamoto prefecture drains the western of the Mt. Kinpo and flows through the Tamana Plain before entering Ariake Sea (Figure 4). The basin area is about 16 km^2 and the length of the channel is about 11 km. The survey point is about 3.9 km from the estuary, the river width is 46 m, and the width of the low water channel is about 20 m. The cross-sectional shape is a compound channel consisting of a straight double-sided embankment and a trapezoidal cross section with a gentle slope on the lower channel.

Figure 4. Study site: flood channel has reappeared at low tide.

2.2 Measuring techniques

The observation dates are November 20, 2010 and December 3, 2010. As shown in figure 5, the tide level difference between the ebb tide and the flood tide was almost the same day.

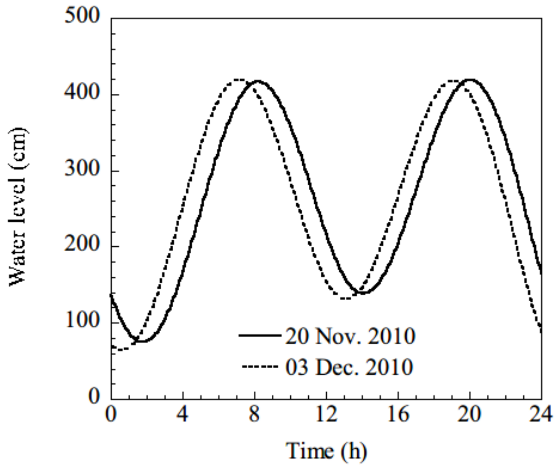

Figure 5. The tide levels on the observation day.

ADCP measurements were carried out with a RDI Stream Pro ADCP. This device measure discharge in shallow streams. ADCP was used to measure transects across the river. Celle size under optimized conditions is 5 cm for velocity measurements. Measuring parameters are: (i) flow velocities; (ii) Signal-to-Noise ratios (SNRs) along the water column; and (iii) depth. Furthermore, ADCP measurements allow to track turbidity currents (Kawanishi and Yokoshi, 1997; Yokoyama and Fujita, 2001).

Multiparameter water quality sondes was used to measure water quality. It allowing simultaneous measurement of water temperature, salinity, DO and pH. In this study, a YSI 600QS was applied. The device was slowly lowered manually to the bottom of the channel, and slowly transversed with a boat. Operating mode was set at fixed sample rates of 1 s.

The tide gate at the estuary was always open during observation.

3. RESULTS AND DISCUSSION

3.1 Riverbed materials

The riverbed material on the flood channel surface and the low flow channel surface was gathered, and the grain diameter was examined. A shown in figure 6, the median grain size of both the sediment of the flood channel and the low flow channel was about 0.05 mm, and the dominance of silt was high. In the study area, the sediment concentration is considered to be high due to the tidal transport of suspended sediment in the ordinary river flow, as in the Kikuchigawa River (Ohmoto and Hirakawa, 2012).

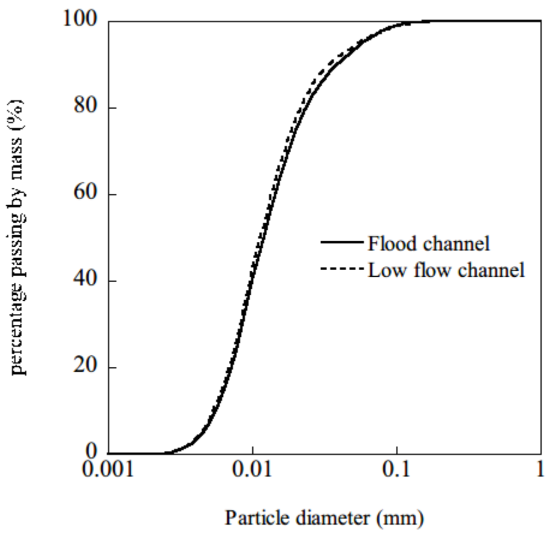

Figure 6. Grain size accumulation curve.

3.2 Discharge and sedimentation flux

In the amount of the maximum passing sedimentation, at the ebb tide was 33 g s-1 against 400 g s-1 at the flood tide (Figure 7 and Figure 8). The observation day of this study was the day when the tidal fluctuation was almost symmetrical between the ebb tide and the flood tide. However, the amount of sedimentation was asymmetry at the flood tide and the ebb tide.

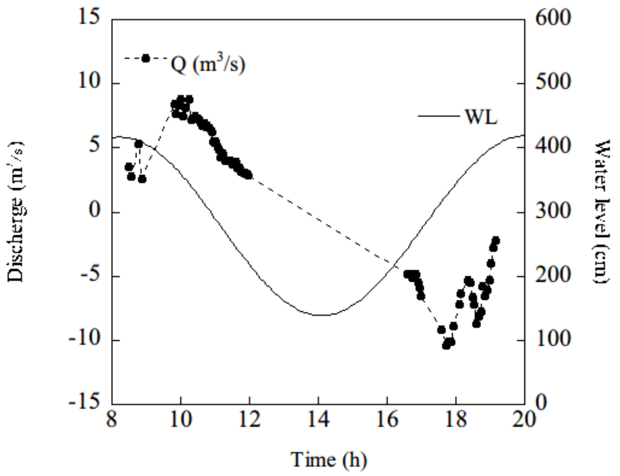

Figure 7. Distributions of discharge and water level. Discharge is measured values. Water level is astronomical tide.

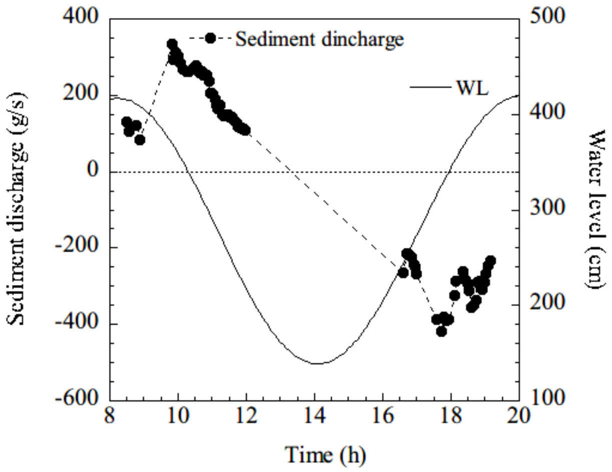

Figure 8. Distributions of sedimentation flux and water level.

3.3 Sediment transport and velocity distribution at the strong tide

The sedimentation concentration goes up on the flood channel in the vicinity of the low flow channel shoulder at the ebb tide though the change in the direction of the crossing is small (Figure 9). The perpendicular direction change in the sediment concentration has become small oppositely high by the vicinity of the surface of the water in the vicinity of the bottom. That is, it is thought that sedimentation on not low flow channel's sedimentation but the flood channel is rolled up, and it is floating in the surface of the water. The main current velocity U is fast in the vicinity of the surface of the water as shown in figure 10 and the maximum flow velocity position moves to the left bank side. The vertical flow velocity W is upward in the vicinity of the right bank of the low flow channel. It is thought that the secondary current cell is formed in this point (Figure 11).

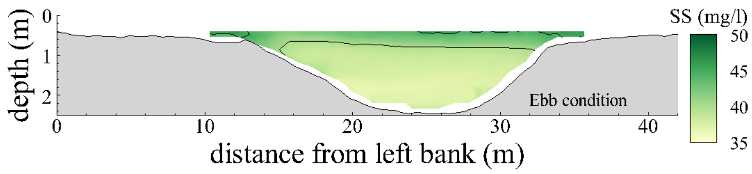

Figure 9. Sediment concentration at the ebb tide along the cross-section of a stream.

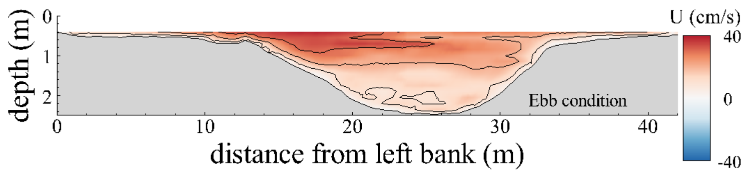

Figure 10. Main current velocity at the ebb tide along the cross-section of a stream.

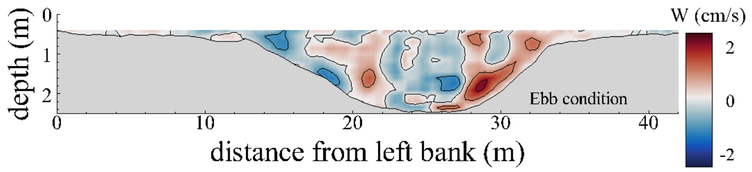

Figure 11. Vertical flow velocity at the ebb tide along the cross-section of a stream.

The sedimentation concentration at the flood tide becomes the maximum on the flood channel and it has been minimized in the central part of a low flow channel (Figure 12). A perpendicular change in the sedimentation concentration rises in the vicinity of the surface of the water, and has become small oppositely in the vicinity of the bottom. It is thought that the sedimentation transportation in the direction of the crossing is predominant as well as at the ebb tide. The downward current is suggested from the main current velocity U distribution at the flood tide of shown in figure 13 in the vicinity of the central of the channel. In the vertical flow W, the downward current is caused in the central of the low flow channel (Fiugre14). This proved that the maximum flow velocity position at the main current velocity U dropped.

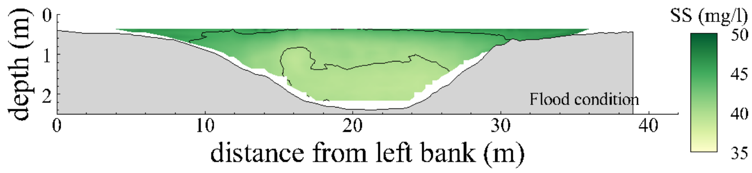

Figure 12. Sediment concentration at the flood tide along the cross-section of a stream.

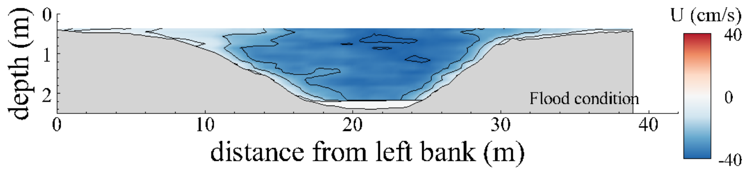

Figure 13. Main current velocity at the flood tide along the cross-section of a stream.

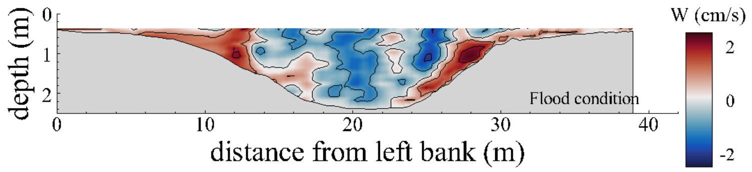

Figure 14. Vertical flow velocity at the flood tide along the cross-section of a stream.

3.4 Salinity concentration

Figure 15 shows a salinity in the central part of a low flow channel, and had risen from there to the flood plain at an ebb strongest tide. This is thought that it is because there are a lot of ratios of the fresh water in half depth from the surface. Moreover, it is thought that it is because there are a lot of ratios of seawater in the vicinity of the bottom layer. It is thought that a stable density stratification is formed at an ebb strongest tide.

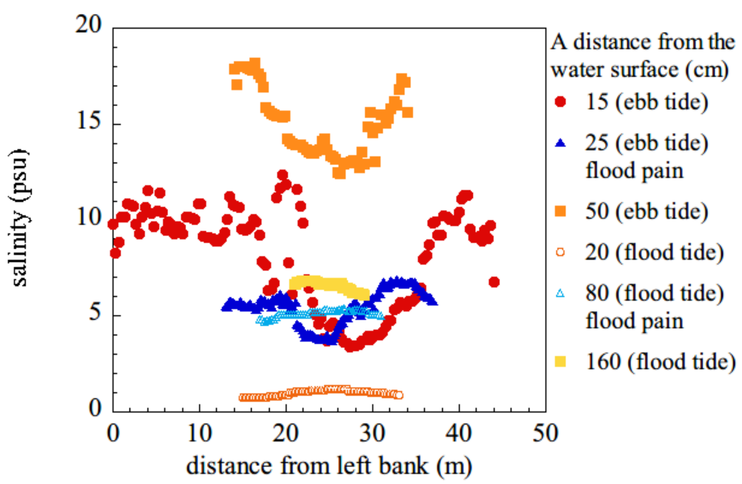

Figure 15. Salinity distributions on the cross section.

4. CONCLUSIONS

Based on the case study, the following can be concluded.

The measured data showed that at the ebb tide, the vertical velocity was slow, and the phenomenon that the maximum velocity point of the main velocity decreased did not appear. It was also shown that the secondary current cell affected the main flow velocity and sediment concentration in the central part of the low flow channel and at the shore.

The position of maximum flow velocity in the low flow channel convected downward on flood tide. It was suggested that the fine sediment transported from the upstream flowed down as suspended soil.

Salinity profiles showed a cross-channel salinity gradient at ebb tide have a sharp inclination than at flood tide. The salinity profiles produce an effective transverse flow velocity distribution for natural compound channels.

ACKNOWLEDGMENTS

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