Field measurements on morphological change and tidal Exchange in a mangrove estuary

Y. Nihei and T. Nakamura
Dept. of Civil Eng., Tokyo University of Science, Chiba, Japan

Abstract: To investigate the morphological features and seawater exchange in a mangrove area, we have performed a long-term monitoring for the sill morphology and tidal exchanges at the mouth of the Fukido River located in the Ishigaki Island, Okinawa, Japan. The observed results for the sill topography indicate that the sill height increased rapidly in the two episodic events in which the propagation of higher ocean wave and flood flow of inflow rivers occurred. The comparison of the discharges before and after the episodic events shows that the river discharge after the event with relatively higher sill height was smaller than that before the event with lower sill height. This fact demonstrates that the tidal exchanges at the river mouth are appreciably influenced by the variations of the bottom topography of the sill.

1 INTRODUCTION

Mangrove forests with complicated-shaped roots in tropical and sub-tropical coasts are generally located next to nearshore zone. The tide circulations cause the exchange of seawater and substances between a mangrove area and nearshore zone, and play an important role on a rich ecosystem of mangrove area (Wolanski *et al.*, 1992; 2001). The tidal exchange in a mangrove estuary is known to be appreciably influenced by the morphological features of river mouth that a vast inter-tidal flat, referred to be here as sill, often exists between the nearshore zone and mangrove area. However, we have poor information on the morphological change of sills and tidal exchange because studies on these processes in mangrove estuaries are few compared to those of temperate estuaries.

To clarify the morphological features and seawater exchange in a mangrove area, in the present study, we have performed field measurements at the mouth of the Fukido River of the Ishigaki Island, Okinawa, Japan. Here we have done a long-term monitoring for the temporal and spatial variations of the sill morphology. We also measured the discharges at the river mouth and then examined the relationship between the sill topography and the river discharge.

2 OUTLINE OF FIELD MEASUREMENTS

The field site chosen for this study was the mouth of the Fukido River located in the north-west part of the Ishigaki Island, Okinawa, Japan. The Fukido River has a mangrove-fringed estuarine section with the area of 0.2km^2. In this region, the area in the swamp with densely vegetated mangrove trees is about ten times as large as that in the main channel, named creek. In the mouth of the Fukido River, as shown in typical riverine-forest type mangroves (Lugo & Snedaker, 1974), there exists a vast sill which is exposed at low tides. The mangrove area is usually separated with the nearshore zone at low tides due to the exposed sill, and therefore the temporal variations of the water elevation in the creek was appreciably distorted in this field site (Nihei *et al*., 2002). In the present study, we have conducted a long-term monitoring of the sill

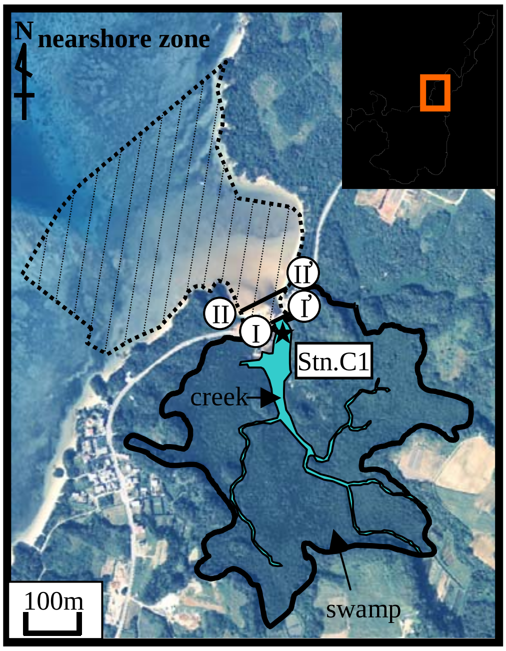


Figure 1. Field site and locations of measuring stations.

(a) high tide（10:54am）

(b) low tide（1:38pm）

Figure 2. Situations of the sill at high and low tides (Dec. 4, 2002).

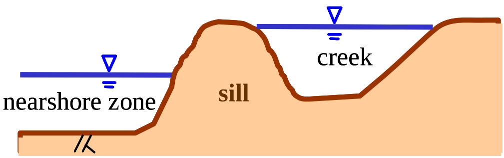


Figure 3. Schematic view of a spatial distribution of water elevation between creek and nearshore zone at a low tide.

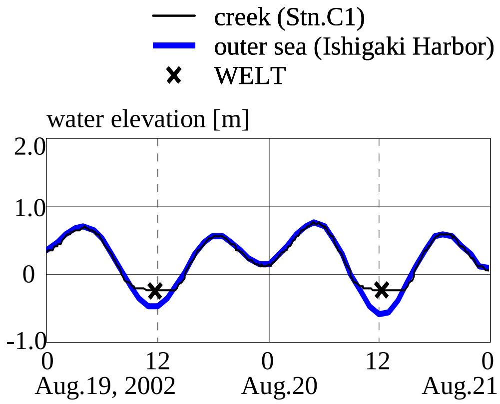
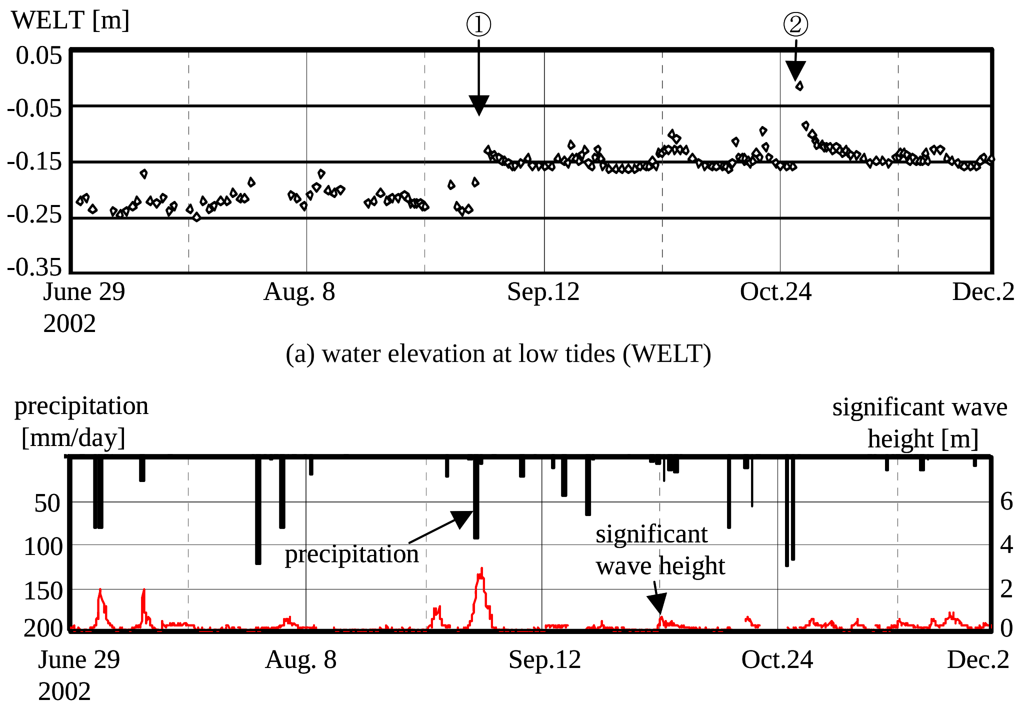


Figure 4. An example of water elevation in the creek (Stn.C1) and the outer sea (Ishigaki Harbor).

morphology and the measurement for river discharge.

To monitor the spatial variations of the sill morphology, we made 7 surveys of the leveling over the sill from June in 2002 to December in 2003. We selected the domain of the surveys, enclosed with the dashed line in Fig. 1, in which Stn.C1 is situated at the boundary between the nearshore zone and mangrove area. To display the situations of the sill, Fig. 2 represents the photographs taken at high and low tides, indicating that the sill inundated at the high tide was partially exposed at the low tides. To continuously measure temporal variations of the sill height, we use time sequences of water elevation observed in the creek. The water elevation in the creek at a low tide becomes almost constant due to the exposed sill as shown in Fig.3. We may think of the water elevation at a low tide, referred to be here as WELT, as the sill height. We therefore have deployed the memory-type pressure gauge for the measurement of the water elevation at Stn.C1 from June 29, 2002 to the present.

For the measurement of the river discharge at the mouth of the Fukido River, we deployed the moored buoy with a current meter at Stn.C1 from September 24 to December 5, 2002. The observed current data in the surface layer can be translated into the river discharge with the numerical simulation using the shallow-water flow model, recently presented by the authors (Nihei *et al*., 2004).



(a) water elevation at low tides (WELT)

(b) precipitation and significant wave height

Figure 5. Time series of WELTs and driving forces.

3 RESULTS AND DISCUSSION

3.1 *Temporal variations of water elevation at low tides*

To indicate the fundamental variations of the water elevation in the creek, an example of the time series of the water elevations in the creek (Stn.C1) and outer sea is shown in Fig.4. The measuring station of the outer sea is located at the Ishigaki Harbor. We choose the mean sea level at the Ishigaki Harbor as the reference plane of the water elevation. At high tides, the water elevations in the creek and outer sea were almost in agreement. On the other hand, at low tides, the water elevation in the creek was higher than that in the outer sea, and became almost constant. As illustrated in the above, the difference of the water elevations between the creek and outer sea occurs due to the vast sill exposed at low tides.

Since the water elevation at low tides (WELT) is approximately constant as depicted with crosses in Fig. 4, we can obtain a WELT in each tide. Figure 5(a) displays the time history of the WELTs from June to December in 2002. The WELTs at the beginning and end of the period shown in Fig. 5(a) were about –0.25m and –0.15m, respectively. The WELT therefore increased about 10cm during this period. It is noteworthy that the rapid increases in the WELTs of about 10cm appeared in the two episodic events: the events 1 and 2 as depicted with arrows in Fig. 5(a), occurred on 7 September and 30 October, respectively. The WELTs after the event 2 decreased slowly and approached to those before the event 2.

To examine the fundamental mechanism of the rapid increases of the WELTs, Fig. 5(b) illustrates the time sequences of the significant wave height and the daily precipitation which are generally related with topographic deformation of river mouth. We use here the wave height observed at the Ishigaki Harbor and the precipitation measured at Ibaruma, located near the Fukido River, by the Meteorological Agency. The comparison of Figs. 5(a) and 5(b) represents that in the event 1, the significant wave height propagating from offshore exceeded 3m due to the approach of the typhoon no.0216 to the Yaeyama Islands. From the results, we can find that, in the event 1, the sediment deposition on the sill may be caused by the propagation of the

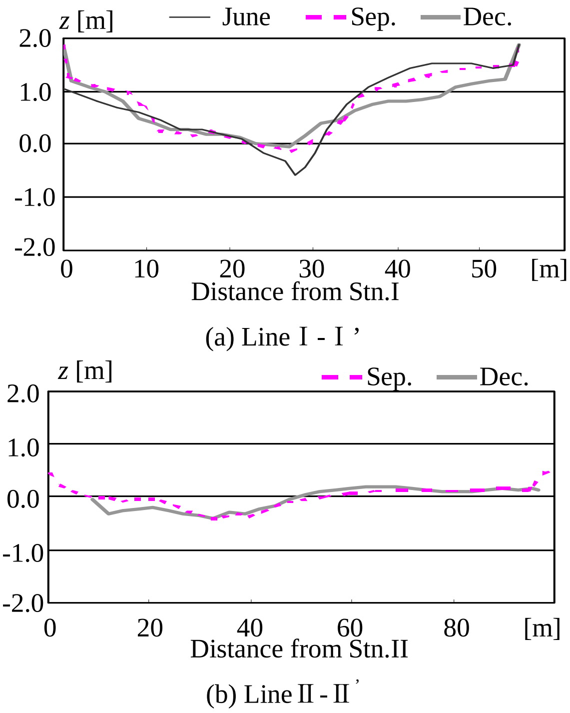


Figure 6. Bottom topography *z* surveyed in 2002.

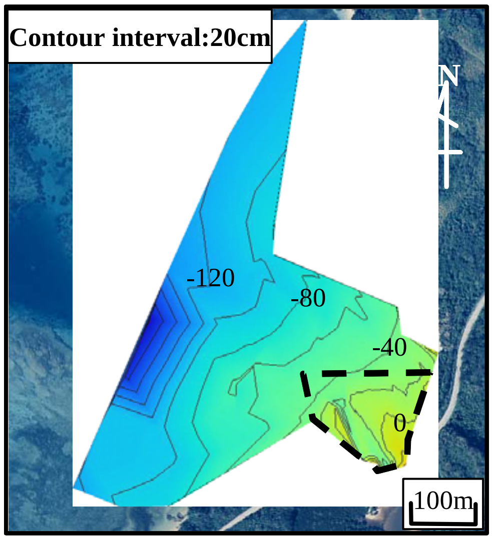


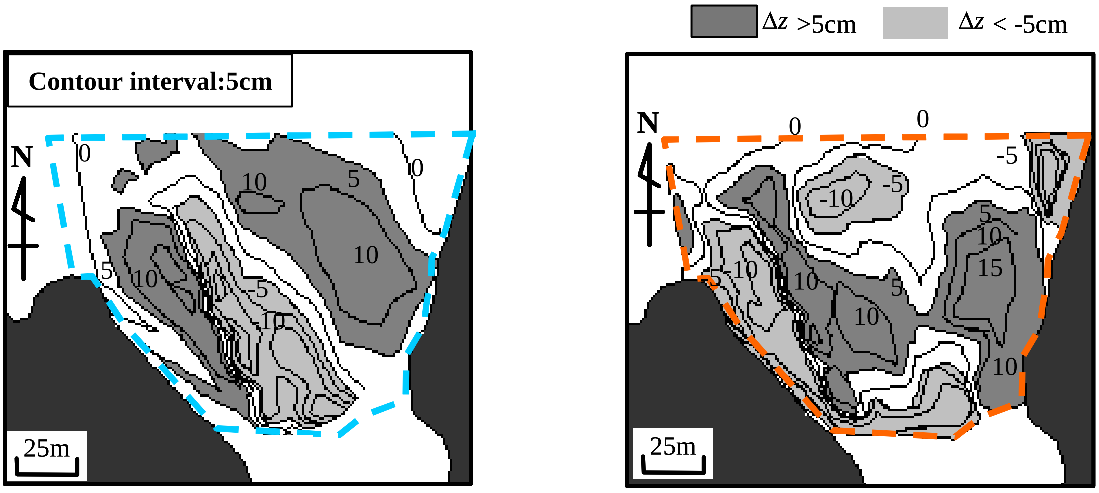
Figure 7. Bathymetry map in September, 2002.

higher ocean wave. On the other hand, in the event 2, the total precipitation reached to about 200mm. In the event 2, therefore, the flood flow of inflow rivers may supply a large amount of sediments into the river mouth. These facts indicate that the WELTs may increase intermittently through the propagation of high ocean wave and the hydrologic event of inflow rivers.

3.2 *Spatial distribution of sill topography*

To investigate the spatial variations of the sill topography, Fig. 6 reveals the bottom topography surveyed in June, September and December in 2002 along the lines I - I' and II - II' as depicted in Fig.1. The transverse axis in the figure means the horizontal distance from the reference points which correspond to Stns. I and II in the lines I - I' and II - II', respectively. Such as the water elevation, the mean sea level at the Ishigaki Harbor is adopted as the reference plane of the bed level *z*. Since the survey along the line II - II' was not conducted in June, the only results surveyed in September and December are shown here. In the line I - I', the overall bed levels in September and December were rather higher and more smoothly than that in June. In the line II - II', the increase and decrease of the bed level were exhibited in the central and western parts, respectively. Figure 7 indicates the contour of the bottom topography surveyed in September, 2002. The contour lines were almost normal to the main flow direction in the creek.

To compare the bottom topography among June, September and December in 2002, Fig. 8 displays the differences of the bed level Δz over the region enclosed with the dashed line in Fig.7. The values of Δz in Figs. 8(a) and (b) are defined as $z|_{Sep.} - z|_{June}$ and $z|_{Dec.} - z|_{Sep.}$, respectively, where $z|_{June}$, $z|_{Sep.}$ and $z|_{Dec.}$ represent the bed levels in June, September and December, respectively. The positive and negative values of Δz mean the deposition and erosion, respectively. It is found from Fig. 8(a) that the positive Δz was observed in the whole region except the central region. This indicates that the deposition process on the sill was dominant from June to September, in 2002, giving qualitatively agreements with the results of the WELTs as illustrated in Fig.5. In Fig. 8(b), although the negative and positive values of Δz appeared in the region, the spatially-averaged Δz was almost zero, corresponding to the result that there was no appreciable differences of the WELTs between September and December. From these results, therefore, we can confirm that the temporal variations of the WELTs give



(a) $z|_{Sep.} - z|_{June}$ (b) $z|_{Dec.} - z|_{Sep.}$

Figure 8. Contour of the differences of bed level Δz .

qualitatively agreements with the tendency of the erosion and deposition processes on the sill.

3.3 *Influence of the variations of the sill height on river discharge*

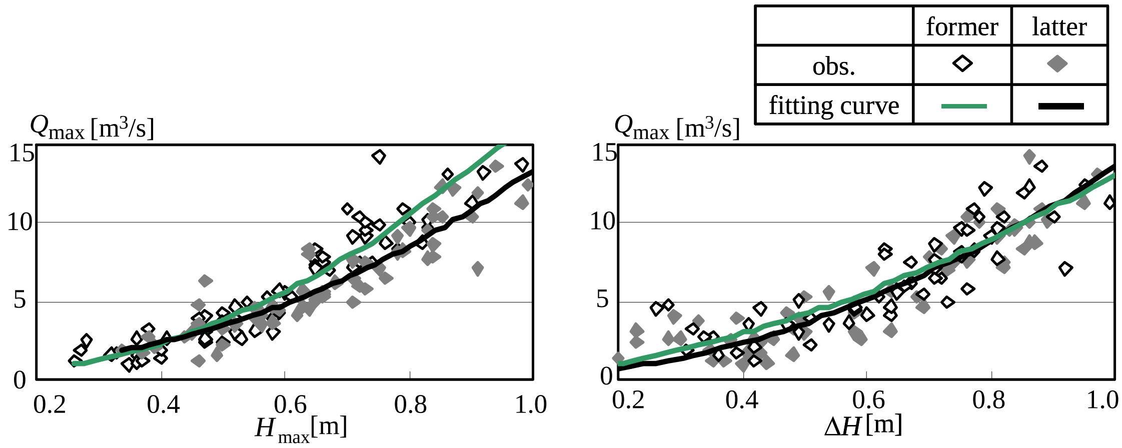
The river discharge is evaluated with the numerical simulation in which the observed results for surface velocity are assimilated. The river discharge obtained here is used to examine the relationship between the river discharge and the sill topography. Figure 9 indicates the variations of the maximum discharge in each tide, $Q_{\max}$, with the tidal range in the creek, ΔH , and the high water level $H_{\max}$. $Q_{\max}$, ΔH and $H_{\max}$ are calculated in each flood and ebb tide. The observational period of the river discharge included the event 2 in which the rapid increase of the sill height occurred as shown in Fig.5. In the figures, therefore, the observed results are separately displayed in the former and latter of the observational periods, which correspond to before and after the event 2, respectively. The correlation between $Q_{\max}$ and ΔH in the former period was almost same as that in the latter period, while there appeared the appreciable difference of the correlations between $Q_{\max}$ and $H_{\max}$ in two periods. Since ΔH is the difference of the water elevation in high and low tides, the effects of the sill height are included in ΔH through the WELTs. On the other hand, $H_{\max}$ is not directly related with the sill height. These facts demonstrate that the variations of the sill height have a significant influence on the discharge at the river mouth.

4 CONCLUSIONS

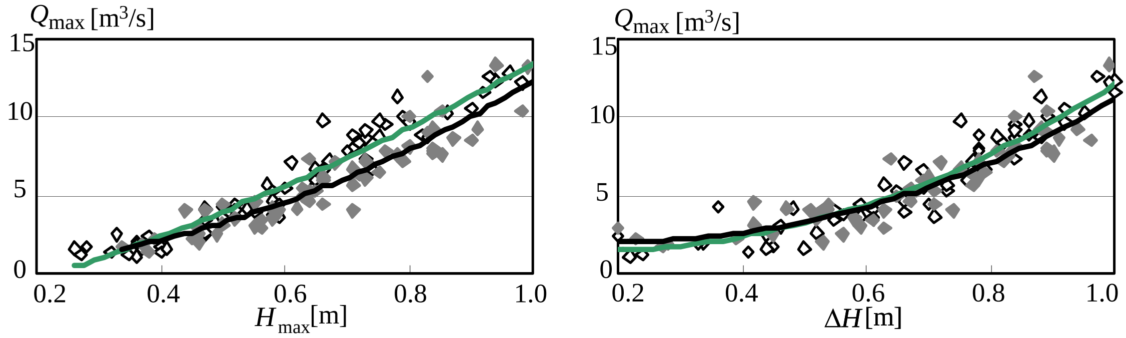
We have done the field measurements of the sill morphology and the river discharge in the Fukido River mouth, Ishigaki Island, Okinawa, Japan. The main conclusions in the present study are as follows:

(1) We succeeded to measure the rapid increases of the sill morphology using the WELTs observed with the memory-type pressure gauge. The spatially-averaged height of the sill rapidly increased due to the propagation of higher ocean wave from offshore and flooding event of inflow rivers.

(2) The relationship between the maximum discharge in each flood and ebb tide, $Q_{\max}$ and the tidal range in the creek, ΔH had a better correlation than that between $Q_{\max}$ and the high water level $H_{\max}$ This fact indicates that the tidal exchanges at the river mouth are closely related with the bathymetry of the sill.



(a) flood tide



(b) ebb tide

Figure 9. Influences of the sill height on the maximum discharge in each flood and ebb tide Q_{max} .

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REFERENCES

[1]Wolanski, E., Mazada, Y. and Ridd, P. (1992): Mangrove hydrodynamics in Tropical mangrove ecosystems (eds. Robertson, A.I. and Alongi, D.M.), *American Geophsical Union*, pp.43-62.
[2] Wolanski, E., Mazada, Y., Furukawa, K., Ridd, P., Kitheka, J., Spagnol, S. and Stieglitz, T. (2001): Water circulation in mangroves, and its implications for biodiversity (ed. Wolanski, E.), CRC Press, pp.53-76.
[3]Lugo, A. E. and S. C. Snedaker (1974): The ecology of mangroves, *Annual Review of Ecology and Systematics*, Vol.5, pp.39-64.
[4]Nihei, Y. Nadaoka, K. Aoki, Y. Wakaki, K. Yai, H. and Furukawa, K. (2002): An intensive field survey of physical environments in a mangrove forest, *ISOPE2002*, Vol.2, pp.357-361.
[5]Nihei, Y. Kimuzu, A. and Sato, K.: Evaluation of River Velocity and Discharge with A New Assimilated Method, *IAHR-APD 2004* (submitted).