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A Study on Hydrodynamic Characteristics and Resulting Morphological Formation of Sand Spit around the Tenryu River Mouth based on Image Analysis

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Abstract

This study aimed to investigate hydrodynamics and morphology around river mouth. The propagation of long period waves along the river side of sand spit around the Tenryu River mouth was analyzed by means of image analysis. A series of field surveys were conducted using video cameras to observe shoreline morphology on the river side of the sand spit. Characteristics of the swash motion were extracted and used to describe the fluid motion on the river side. On the basis of image analysis, it was concluded that the shoreline undulation was developed by sediment transport affected by edge wave. This was suggested by shoreline undulation properties found in the images and was confirmed by the edge wave wavelength calculated based on frequency of the corresponding swash motion. In addition, longshore transport instability due to oblique wave with large angle appeared to change the shape of the shoreline undulation.

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Keywords: Sand spit, Image analysis, Edge wave;

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1. Introduction

Nearshore hydrodynamics, especially around river mouth area, comprises complex physical interactions among various acting forces. In this area, the acting forces are mainly wave action from the ocean and discharge from the river as well as sediment movement from both sides. This complexity keeps challenging researchers to develop models for describing the underlying mechanism. One of the methods to study phenomena around nearshore area is by using image analysis, which covers wider area in less cost. This study applied the image analysis to describe the morphology of shoreline on the river side of sand spit around the Tenryu River mouth and the hydrodynamic characteristics during normal wave condition.

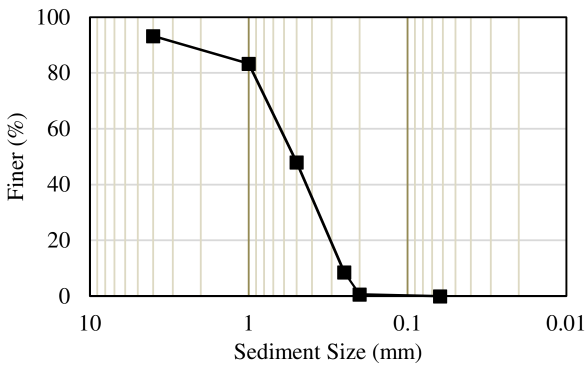
Tenryu River, which flows to Enshunada coast in Iwata and Hamamatsu cities, Shizuoka Prefecture, Japan, is the main sediment source for the coast (Uda, 2007 in Hoan, 2013). Studies in sand spit morphology has been carried out in both short term and long term scales. In the short term scale, studies revealed that the sand spit was quite sensitive towards short term event, such as typhoon and flood or overtopping waves (Liu et al., 2008, Tajima et al., 2009, Liu et al., 2011, and Takagawa et al., 2011). On the other hand, in the long term scale, morphodynamics at Tenryu River sand spit was insignificant (Liu et al., 2011). Liu et al. (2008) suggested that daily wave climate helped to transport the sediment back to the river mouth after the sand spit breached due to massive river flood during a typhoon T0704.

Hoan et al. (2013) calculated wave rose around the area and suggested that the dominant wave direction were from south direction, which is normal to the river mouth, and from southeast, which is against the sand spit direction. This supports the assumption that the sand spit in the Tenryu River mouth was formed by the wave action which brought back the sediment from the ocean.

2. Field Monitoring and Image Analysis

Field observations of sand spit in Tenryu River mouth were conducted by using field cameras and observation of sediment sample along the sand spit. Based on grain size analysis, sediment size of the sand spit was dominated by size 0.2 mm – 1 mm (Figure 1 left). However, larger sand and gravel were observed at few locations.

The estuary has a diurnal type of tide with two high water level and two low water level in 24 hours as shown in Figure 1 (right).



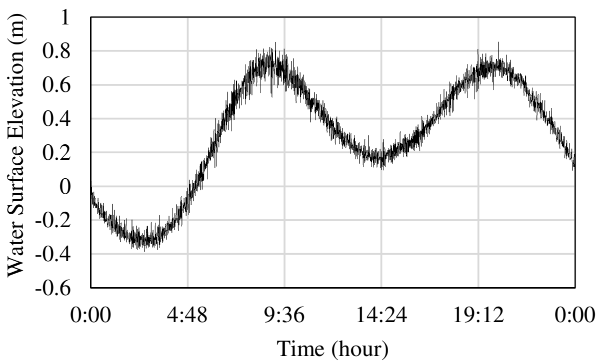


Figure 1. Sediment size distribution (left) and tidal features at the river mouth on October 24th, 2013 (right)

2.1. Monitoring using field camera

A series of monitoring were conducted using outdoor field camera system, MOBOTIX M22M. The camera was installed at the Kaketsuka Lighthouse (C1) as seen in Figure 2(left) in October 24th – 26th, 2013. The camera recorded one still image (1280 x 960 pixels) in every 0.6 seconds. During the observation, no storm event was detected. Images from the field camera were taken from an oblique angle due to the height of camera position. To transform them to top view images, rectification was applied. Therefore, world coordinate points were also recorded simultaneously using RTK-GPS and used as Ground Control Points (GCP's). Red circles in Figure 2 (right) represents the GCP's used in the rectification, while both vertical and horizontal axes in the image show the pixel coordinates.

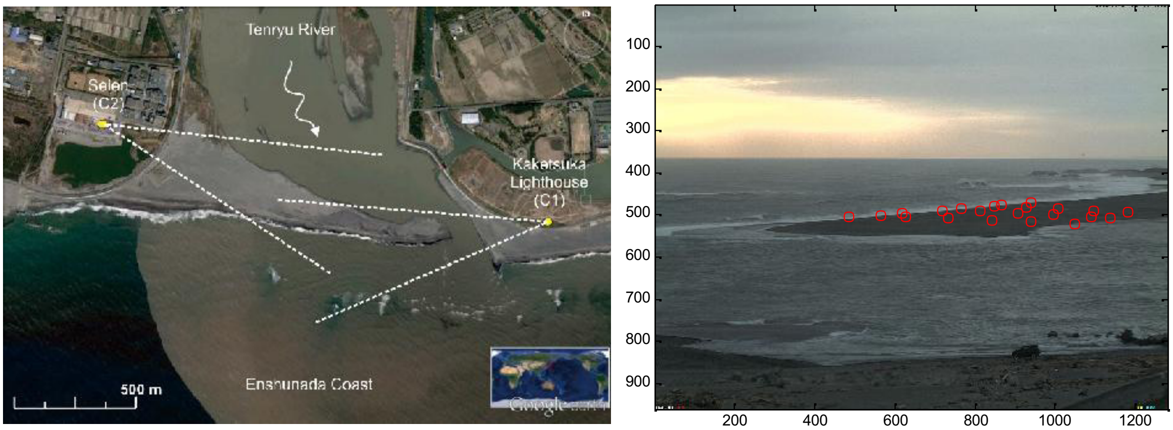


Figure 2. Location of field cameras installation (left) and an image from the field monitoring and its GCP's for image rectification (right)

2.2. Image Rectification

Two main procedures of image analysis were performed to extract information from the images quantitatively: image rectification and edge detection. In the first procedure, the original images were transformed into top view. Then, the rectified images were rotated to obtain shoreline position normal to the vertical axis. Then, the edge detection, was carried out to detect the swash motion on the river side shore.

Calculation of image rectification followed the procedure suggested by Holland (1997) based on the collinearity equations for transformation as follows:

$$u - u_0 = -\frac{f}{\lambda_u}\left[\frac{m_{11}(x-x_0)+m_{12}(y-y_0)+m_{13}(z-z_0)}{m_{31}(x-x_0)+m_{32}(y-y_0)+m_{33}(z-z_0)}\right]$$
$$v - v_0 = -\frac{f}{\lambda_v}\left[\frac{m_{21}(x-x_0)+m_{22}(y-y_0)+m_{23}(z-z_0)}{m_{31}(x-x_0)+m_{32}(y-y_0)+m_{33}(z-z_0)}\right] \qquad (1)$$

where f is effective focal length of the camera, λ_u and λ_v are horizontal and vertical scale factors respectively. The individual element m_{ij} is element of the orthogonal rotation matrix. Liu et al. (2008) derived the Eq (1) and applied nonlinear least square method to optimize parameters.

Figure 3 shows comparisons between GCP's coordinates (triangles) and the estimation (squares) from rectification. The RMS error of the image coordinate was found to be 0.96 which is less than one pixel. Therefore, the coordinate estimation was accepted and the rectified images were used for further analysis.

2.3. Edge Detection

Edge detection process extracted information of shoreline location, especially on the river side. Many studies have developed methods in shoreline detection using image analysis. One of the fundamental concept was presented in Canny (1986) which used the Gaussian operator and introduced three criteria in evaluating an edge detector: good detection, good localization, and low spurious response. This study adopted one of Canny's edge detection concepts to distinguish the shoreline by employing the first derivative of Gaussian operator expressed by Eq (2) as a filter.

$$G^{\sigma}(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \qquad (2)$$

where σ represents scale multiplication of Gaussian filter, while (x, y) represents the pixel coordinate. Although small scale multiplication approximated an accurate edge, some false local maxima would also be detected. Nevertheless, larger scale multiplication would result a single local maxima, but the detected edge might be shifted from the actual location. Therefore, the value of σ should be small enough to detect the actual edge, yet large enough to avoid the false local maxima.

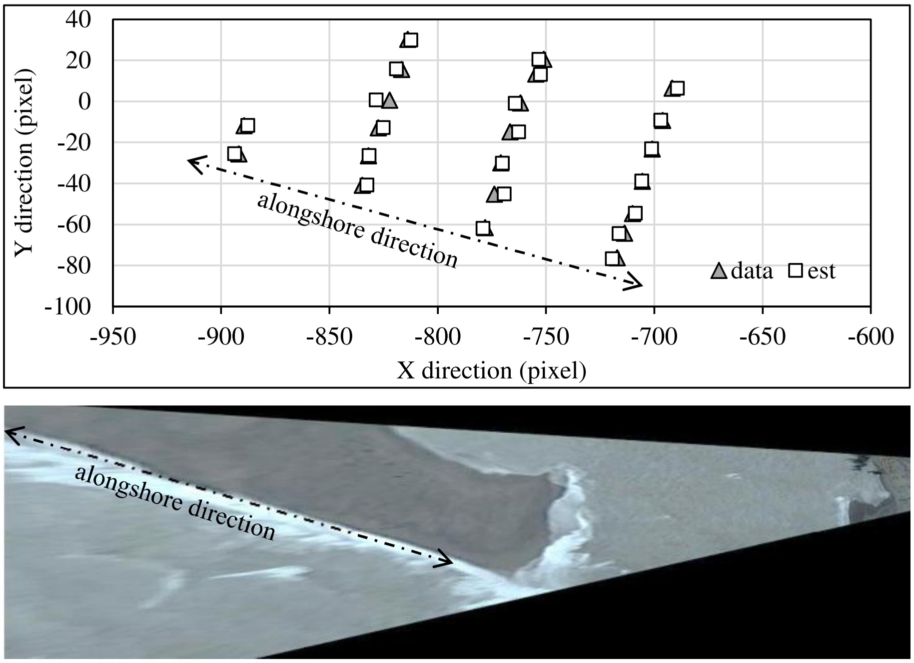


Figure 3. Coordinate data and estimation after rectification (upper) and one of the rectified image (bellow)

Figure 4 illustrates the image detection method used in this study. Figure 4 (a) represents the image intensity of red component of RGB. Image intensity of water area is higher than that of sand area, because it is brighter. Here, it clearly shows the segmentation between sand and water. This pattern was also found in most images for river mouth monitoring in this work. Therefore, the edge detection could be defined as maximum absolute differences between the image intensity. Nevertheless, the absolute differences often resulted false edges. Therefore, the Gaussian filter was applied. Figure 4 (b) shows the image intensity multiplied by the first derivative of Gaussian filter. It shows that on the river side, the shoreline should be detected in local minima of graph (b). However, on the sea side, shoreline should be detected in local maxima of the same graph. Edge detection was proceeded by employing this criteria. Figure 5 depicts the result of shoreline detection, which shows good agreement with the actual shoreline position. Therefore, the edge detection concept which was used in this work could be applied.

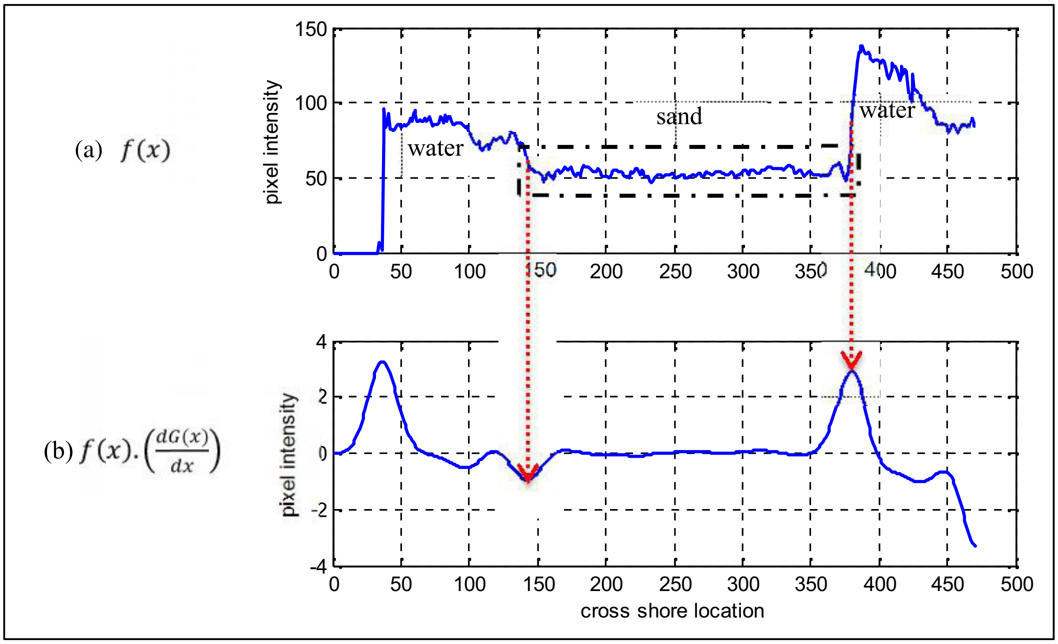


Figure 4. Image intensity before (a) and after (b) multiplied with first derivative of Gaussian Filter

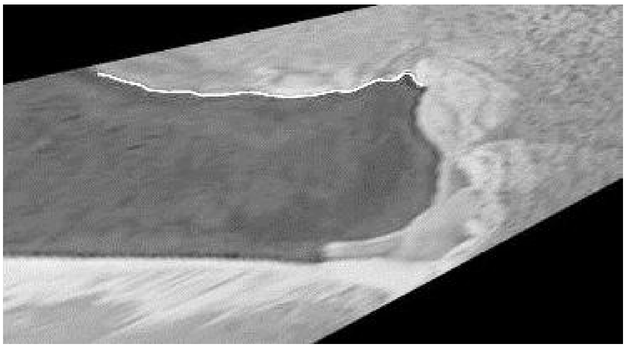


Figure 5. Rectified and rotated image and its shoreline in the river side resulting from the edge detection technique

3. Result and Discussion

3.1. Dominant wave period

Fast Fourier Transform (FFT) method was employed to the instantaneous motion extracted from the edge detection to obtain the dominant wave height in each location along the shore on the river side of the sand spit. Figure 6 shows the FFT result, which demonstrates that short period wave (frequency > 0.03 Hz) are still observed around the river mouth. This short period wave decays as it propagates farther from the river mouth and longer period wave becomes dominant in this area. Frequency of this longer period is between 30 s – 5 min, which includes the range of infragravity wave. Furthermore, in the area around 150 – 300 meters from the river mouth, the frequency spectrum suggests the existence of standing wave. The spectrum indicates node and anti-node around frequency 0.015 – 0.02 Hz. Therefore, edge wave must have been developed in this area and contributed to the morphology change.

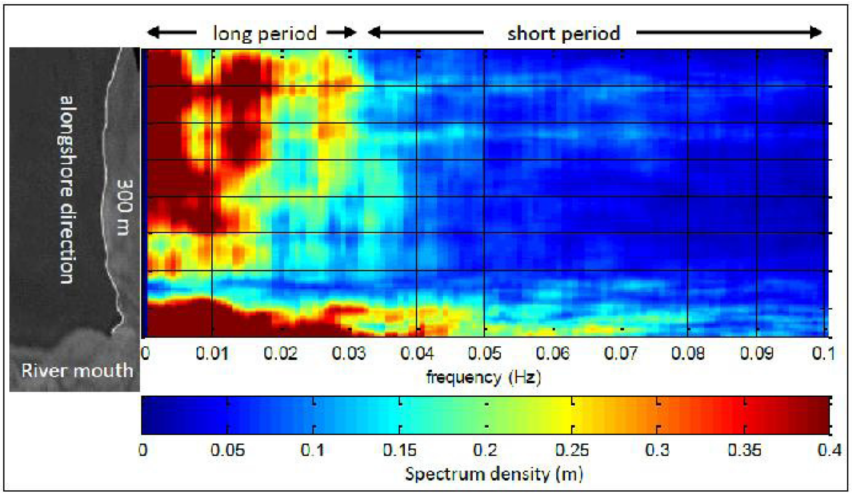


Figure 6. Frequency spectrum in space domain of instantaneous swash motion on October 24th, 2013

3.2. Formation and development of the undulation

In addition to field camera images from camera C1 in the previous section, images from camera C2 (Figure 2), which was a continuous monitoring system of the river mouth, were also utilized to observed whole area of sand spit from other angle. Camera C2 was taking one image in every 2 minutes. However, to minimize the shoreline change effect due to tide, images were selected by considering the exact same time in each day to show undulation formation

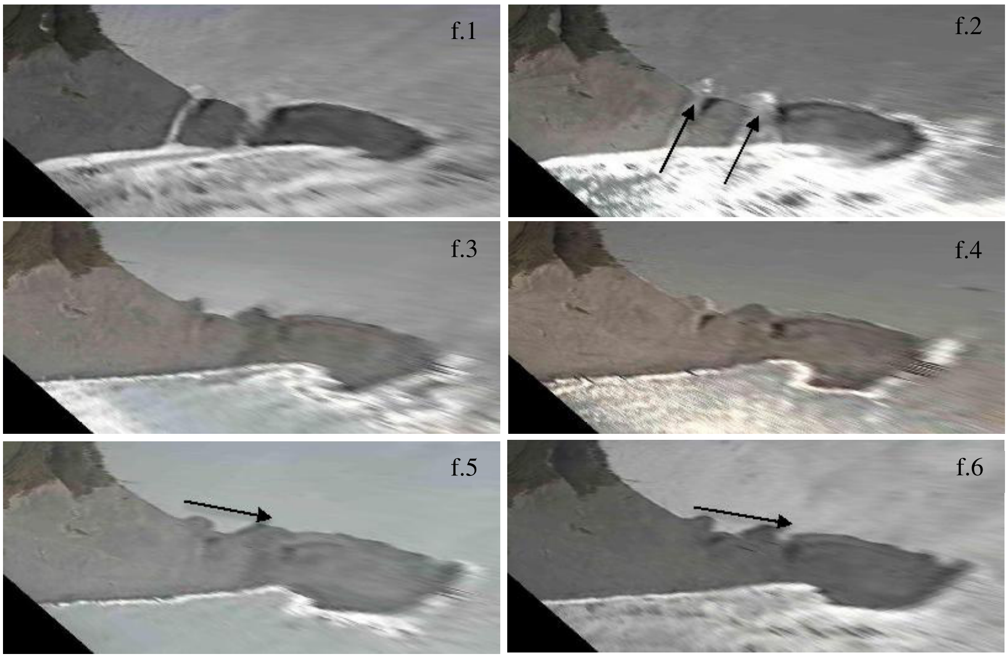


Figure 7. Sequential photos of shoreline undulation formation and development (f1: 25/09/2013, f2:26/09/2013, f3:27/09/2013, f4:28/09/2013, f5:30/09/2-13, f6: 04/10/2013)

and development (Figure 7Figure 7). The figures indicate that the undulation shape changes and the peak moves toward the river mouth. This movement was observed until it reached equilibrium where the undulation shape stable.

Ashton et al. (2001) and Falqués & Calvete (2005) described the longshore sediment transport caused by wave in oblique angle which induce the growth of shoreline perturbation with a steep shoreline in the downdrift and milder shoreline in the updrift. This phenomena was found in aerial images as shown in Figure 8. In the figure, red lines represents the steep shoreline, while blue lines indicates mild shoreline. Nevertheless, direction of the undulation in Figure 8 is contrary to that of Figure 7. This indicates that in the area far from the river mouth, effect of longshore transport due to oblique wave decays. Hence, effect of edge wave was considered.

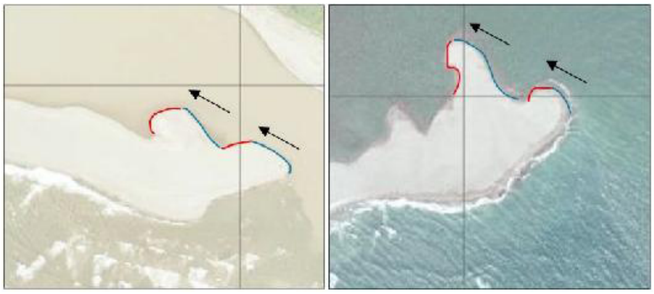


Figure 8. Aerial photos of tip of the sand spit in the Tenryu River mouth in Year 1991 (left) and Year 1976 (right)

Shoreline undulation observed from the aerial photograph indicated a beach-cusps like feature, which is usually found in a shoreface with rhythmic features in the alongshore direction. Although beach cusps are said to be rhythmic, it is interesting that Dalrymple & Dean (2004) suggested that beach cusp spacing is sometimes not very regular. This is because the spacing might be adjusted by other acting forces, which, in this case, river flow could be one of the other acting factor affecting the beach cusps formation. Guza & Inman (1975) and Bowen & Inman (1971) correlated this formation to the existence of edge wave.

The wavelength of edge wave was expressed by Eq, (3) originally developed by Ursell (1952). Table 1 summarized the edge wave wavelength which might be excited around the river mouth based on the observed condition.

$$L = \frac{g}{2\pi} T^2 \sin(2n+1)\beta \tag{3}$$

In Figure 9, the shoreline undulation spacing is estimated at about 350 meters (Figure 9) which corresponds to wavelength of edge waves with lower frequency (about 0.015 to 0.02 Hz). This appears to support that the presence of edge waves affects the rhythmic morphology in a region distant from the river mouth.

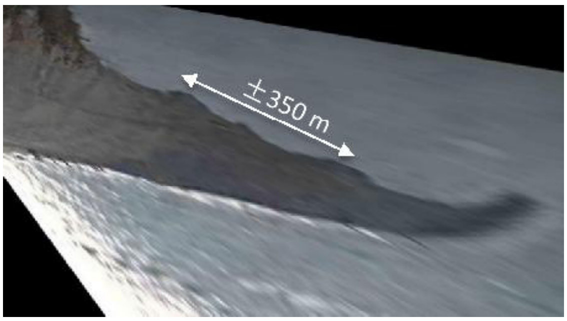


Figure 9. Stable shoreline undulation from Seien field camera (C2) on October 24th, 2013

Table 1. Edge wave wavelength agitated around the river mouth

Frequency (Hz)	0.002	0.015	0.02	0.03	0.05
Period (s)	500.00	66.67	50.00	33.33	20.00
beach slope	0.05	0.05	0.05	0.05	0.05
L (m), Eq. (3)	$19x10^3$	350	190	87	31

4. Conclusions

Shoreline undulation on the river side of sand spit in Tenryu River was found to be developed by interaction of edge wave which was reflected around the river mouth with the other acting forces, such as river flow, or tide. Such shoreline undulation on the river side were found frequently and the possible mechanisms were investigated. This phenomena could be approximated at least by two mechanisms; the excitation of edge waves and the oblique incidence of waves from the opening gap of the river mouth. The presence of long period motion extracted by image analysis suggested that the periodic shape of shoreline geometry was formed by edge waves. Instability of longshore transport due to oblique incident wave appears to be a minor mechanism in the shoreline undulation while it contributes to asymmetric shape of the shoreline, especially when the river mouth opening was narrow.

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