Analysis of erosion and accretion waves on Cua Dai Beach in Central Vietnam

Dinh Van Duy[1], Hitoshi Tanaka[2], Yuta Mitobe[3], Nguyen Trung Viet[4] and Le Thanh Binh[5]

Abstract: Propagation of erosion wave was observed along Cua Dai Beach in Central Vietnam with the propagation speed is 54m/y from 1990 to present. The significant coastal erosion on Cua Dai Beach in recent years is presumed as a result of insufficient sediment supply to this beach as well as constructions of seawalls along the beach. In addition, new method has been introduced to determine the diffusion coefficient expressing time scale shoreline change based on the propagation of the erosion waves.

1. Introduction

In recent years, beach erosion has occurred at almost all delta coastlines in Vietnam. Cua Dai Beach located on the left coastline of Thu Bon River delta in Central Vietnam is also one of such cases (Figure 1). Because of significant beach deformation at Cua Dai Beach, there have been many studies related to this problem such as simulating the morphological change on Cua Dai Beach based on analytical solution (Hoang et al., 2015) or discussing the shoreline change in a wide area on both sides of Cua Dai River mouth (Tanaka et al., 2016). In addition, Duy et al. (2016) applied the analytical solution of one-line model for delta formation proposed by Larson et al. (1987) to find the diffusion coefficient expressing time scale shoreline change at Cua Dai Beach, which is denoted by ε. However, the study of Duy et al. (2016) is just one approach for finding the value of ε. Therefore, it is necessary to find further approach for the estimation of the constant ε. For that reason, an analysis of erosion and accretion waves on Cua Dai Beach will be performed in this study to clarify the value of ε.

2. Study area and data collection

Cua Dai Beach is a 5km long coastline on the left of Thu Bon River mouth (also known as Cua Dai River mouth) (Figure 1). Cua Dai Beach used to be one of the most beautiful beaches in Vietnam. However, severe erosion has resulted in the disappearance of this white sandy beach. Moreover, the erosion zone is proceeding northward to the neighbor beaches (from A to B in Figure 1) and this phenomenon can be observed clearly from the recent field

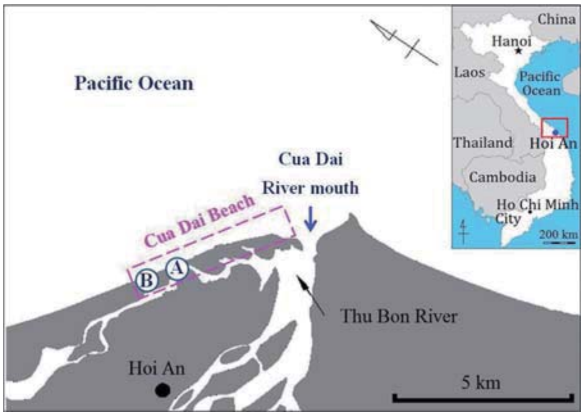


Figure 1. Study area

[1] Graduate student, Department of Civil Engineering, Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan
[2] Professor, Department of Civil Engineering, Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan
[3] Assistant Professor, Department of Civil Engineering, Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan
[4] Associate Professor, Thuyloi University, 175 Tay Son, Dong Da, Hanoi, Vietnam
[5] Vietnam Hydraulic Engineering Consultants Corporation, 95/2 Chua Boc, Dong Da, Hanoi, Vietnam.

trips.

Concerning the data set used in this study, beside the photos taken during the field trips, Landsat images from 1995 to 2016 were utilized (Figure 2). Those images are rectified to the same coordinate system in the World Geodetic System 84 (WGS-84) with the coordinates of the origin are 217,298.08 E and 1,754,078.07 N. The baseline is set at 144.94 degrees counter clockwise from the north. In this study, tidal correction was not performed since the maximum difference between shoreline positions before and after tidal correction is still smaller than the resolution of Landsat images. Spatial moving average was applied to reduce the effect of big scatter in shoreline positions due to low resolution of the Landsat images.

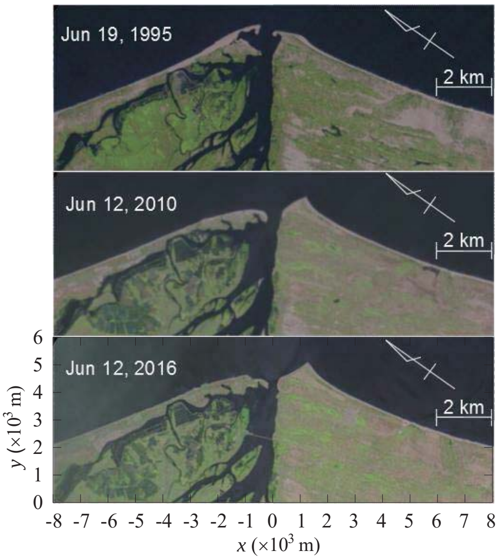


Figure 2. Typical Landsat images

3. **Results and discussion**

3.1. Propagation of the erosion zone on Cua Dai Beach through the field observations

Photos in Figure 3 represent the erosions at point A and B in Figure 1. These photos were taken during the field trips on Dec 24, 2014 and Dec 20, 2016. From Figure 1 and Figure 3, it is easy to recognize that the erosion zone extended 700m to the north from Dec 24, 2014 to Dec 20, 2016. This value well agrees with the analysis of Tanaka et al. (2016). According to Tanaka et al. (2016), the alongshore movement of the erosion end from Dec 24, 2014 to Oct 10, 2016 is around 500m. The difference can be resulted from the short term effect such as Typhoon Sarika (Oct 16, 2016) because the period from October to December is the storm season in Vietnam.

a) Dec 24, 2014 (Tanaka et al., 2015) b) Dec 20, 2016

Figure 3. Erosion ends correspond to point A and B in Figure 1

Nagasawa et al. (2016) indicated that the constructions of countermeasures against coastal erosion at Cua Dai Beach such as groins, shore protections, bamboo fences have caused the further erosion downstream of these structures and the erosion is propagating to the northern area.

3.2. Beach erosion measured from Landsat images

Shoreline positions extracted from Landsat images between 1990 and 2016 can be seen in Figure 4 with the significant retreat of shorelines at the river mouth (1,200m). As mentioned previously, one of the main purposes in this study is to determine the diffusion coefficient expressing the time scale shoreline change. In order to determine the value of diffusion coefficient, comparison will be made between measured data and analytical results. Therefore, it is necessary to simulate the shoreline evolution using analytical solution as in the following section.

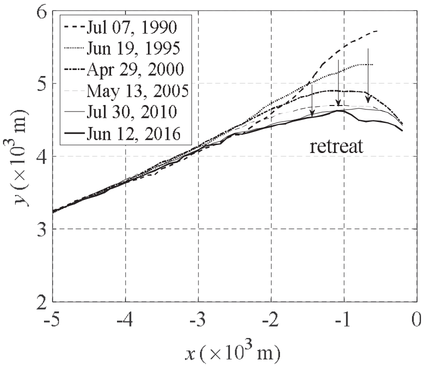


Figure 4. Shoreline evolution obtained from Landsat images

3.3. Beach erosion measured from analytical solution

In order to observe the propagation of erosion zone on Cua Dai Beach using analytical solution, shoreline retreat in this area must be simulated. Beach erosion can be explained by the unbalance of sand income and outgo (Matsuki, 2016). Cua Dai Beach is a part of the Thu Bon River delta coastline formed by alluvial sand supply from Thu Bon River. Therefore, beach erosion is the reaction to insufficient sediment supply from the river. With regard to simulating beach erosion due to decrease of sediment supply, a model, which was simplified from one-line model by Hoang et al. (2015) can be used with the governing equation as follows:

$$\frac{\partial y}{\partial t} = \varepsilon \frac{\partial^2 y}{\partial x^2} \tag{1}$$

In which, *y*: shoreline positions; *x*: longshore coordinate with the origin at the river mouth; *t*: time. In order to derive Eq. (1) from one-line model, assumptions such as small angle of wave breaking crest to local shoreline and constant breaking wave height along the coastline have been made (Hoang et al., 2015).

In the study of Hoang et al. (2015), they divided the evolution of Thu Bon River delta coastlines into two phases. The first phase represents the formation process of the delta with the advance of shoreline position. After that, beach erosion happens because of insufficient sediment supply from the river.

The formation process of Thu Bon River delta was mathematically expressed in the following equation with the river mouth is located at x=0m:

$$y = \frac{q_0}{D}\sqrt{\frac{t}{\pi\varepsilon}}e^{-x^2/(4\varepsilon t)} - \frac{q_0}{D}\frac{|x|}{2\varepsilon}erfc\left(\frac{|x|}{2\sqrt{\varepsilon t}}\right) \tag{2}$$

In which, q_0: sediment supply rate from the river, $D=D_B+D_C$ (D_B: berm height, D_C: depth of closure), erfc: complementary error function;

After the formation of delta coastlines, beach erosion due to reduction of sediment supply can be simulated using the following equation:

$$y=\frac{q_0}{D}\sqrt{\frac{t}{\pi\varepsilon}}e^{-x^2/(4\varepsilon t)}-\frac{q_0}{D}\frac{|x|}{2\varepsilon}erfc\left(\frac{|x|}{2\sqrt{\varepsilon t}}\right)-\left\{\frac{R\cdot q_0}{D}\sqrt{\frac{(t-t_0)}{\pi\varepsilon}}e^{-x^2/[4\varepsilon(t-t_0)]}-\frac{R\cdot q_0}{D}\frac{|x|}{2\varepsilon}erfc\left[\frac{|x|}{2\sqrt{\varepsilon(t-t_0)}}\right]\right\} \quad (3)$$

In which, t_0: starting time of sediment reduction, R: reduction rate of sediment supply from Thu Bon River. This should be noticed that the right side of Eq. (3) consists of two parts; the first part is the formation term as in Eq. (1) and the remaining part represents the shoreline evolution after t_0 with the reduction of sediment supply by neglecting the existence of shoreline positions formed before t_0. Since Eq. (1) is linear, these terms can be combined (linear superposition) to express a more complex situation such as beach erosion at Cua Dai Beach. Values for variables in Eq. (3) are taken from Duy et al. (2016) as in the following table:

Table 1. Calculation conditions (Duy et al., 2016)

Diffusion coefficient	ε=125 m^2/day
Sediment suppy from the river	600,000 m^3/y
Formation time	t_0=500 years
Erosion duration (erosion at Cua Dai Beach started from 1990)	27 years
Depth of closure	D_C=6 m
Berm height	D_B=2 m
Reduction rate of sediment supply from Thu Bon River	R=0.8

Figure 5 shows the shoreline evolution on Cua Dai Beach from 1990 to 2016 using Eq. (3). As can be seen from the diagram, shoreline retreat at the river mouth shows similar configuration with the shoreline position obtained from Landsat images. However, the retreat is just 600m compared to 1,200m of shoreline retreat in Figure 4. The difference of shoreline retreat can be caused by the assumptions to simplify the model.

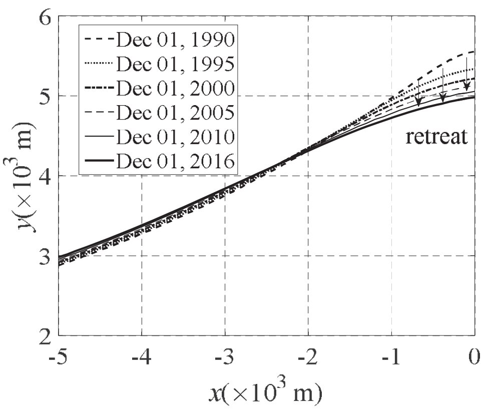
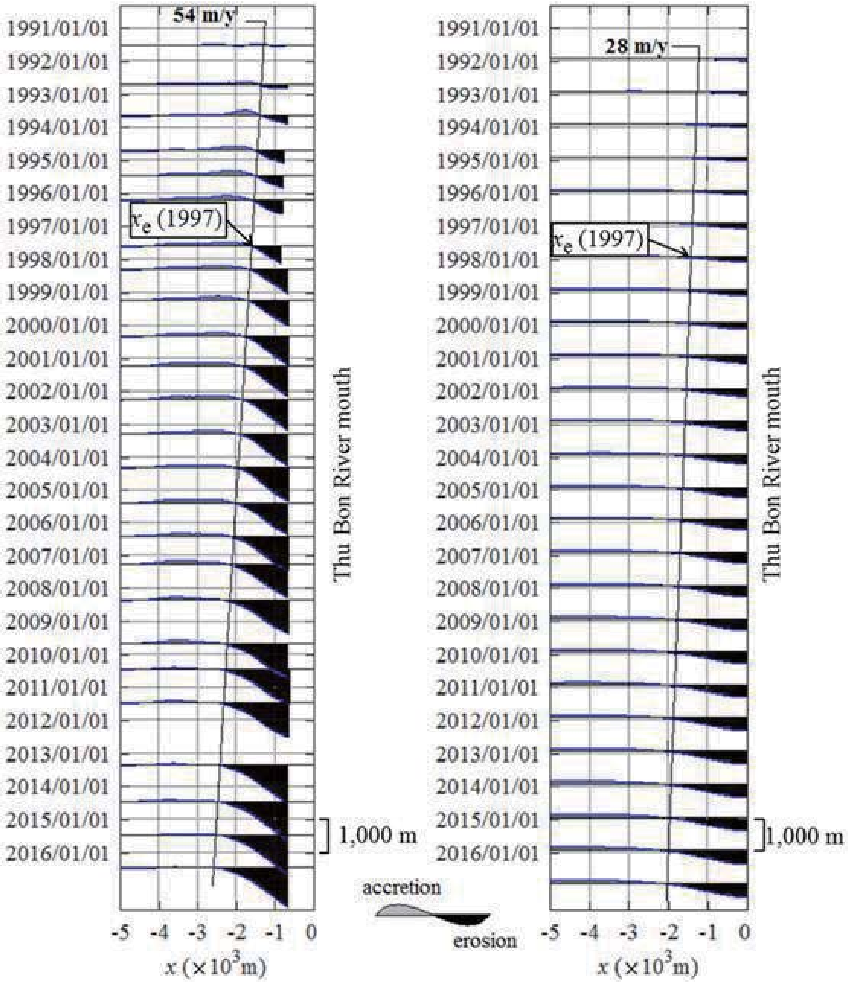


Figure 5. Shoreline evolution obtained from theory

3.4. Propagation of erosion waves and new method to determine the diffusion coefficient



a) Measured data b) Analytical solution

Figure 6. Comparison between measured data and analytical solution

Figure 6a and 6b show the shoreline changes with reference to the shoreline position in 1990 obtained from the Landsat images and the analytical results, respectively. Intersections between shoreline changes and the horizontal axes are the ends of erosion zones denoted by x_e (m). Thu Bon River mouth is located at the right end of each figure. As can be seen from Figure 6, the propagation speed of the erosion waves measured from Landsat images is about two times higher than the value obtained from the theory. Higher value of propagation speed from measured data indicates that erosion is more severe in reality.

In addition, ending positions of erosion zones are plotted to clarify this severe erosion as can be seen in Figure 7. This diagram shows good agreement between theory and measured data from 1990 to 1999.

From 1990 to 1999, there was no construction activity on Cua Dai Beach, which means the model of Hoang et al. (2015) is sufficient to study natural beach morphological change. Furthermore, this good agreement indicates the reliability of ε=125m^2/day. However, from 2000, the erosion at Cua Dai Beach has become more serious compared to the predicting trend from analytical solution. The seawalls along the coastlines, which block the longshore sediment transport and cause further erosion in the down drift side, have resulted in this difference. Therefore, it is highly required to improve the model by including the effect of seawall in the next study.

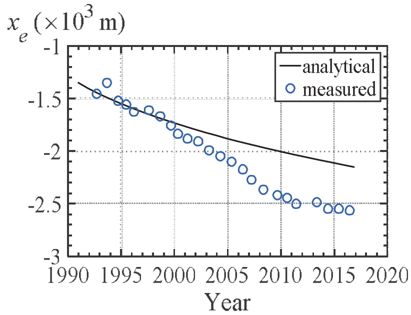


Figure 7. Comparison between measured data and analytical solution

4. Conclusions

Propagation of erosion waves on Cua Dai Beach has been analyzed using Landsat images from 1990 to 2016. The propagation velocity is 54m/y, which is higher than the result obtained from analytical solution (28m/y). Seawalls on Cua Dai Beach have caused excess erosion along the beach. Furthermore, a new approach has been introduced to determine the diffusion coefficient by making comparison between analytical results and measured data in terms of the propagation of the erosion waves. The result shows that diffusion coefficient expressing time scale shoreline change on Cua Dai Beach is ε=125m^2/day.

5. References

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