

## Pre- and post- tsunami morphology changes on Kodanohama Beach

Hoang Dong Hai<sup>1</sup>, Yuta Mitobe<sup>2</sup>, Vo Cong Hoang<sup>3</sup>, Nguyen Trung Viet<sup>4</sup> and Hitoshi Tanaka<sup>5</sup>

### Abstract

Kodanohama Beach is a famous sightseeing and tourism spot on Oshima Island, Kessenuma City, Miyagi prefecture, Japan. The Tsunami in 2011 caused severe erosion on it. This beach located in a closed area with very little or no sediment supplies hence its recovery processes are expected to be different from that of other sandy beaches. The purposes of this study are: investigating the behaviors of the shoreline of Kodanohama Beach before and after the 2011 tsunami, discussing about these behaviors by analyzing the aerial photographs taken in this area. The results obtained show that morphology of this pocket beach was mainly influenced by the constructions of the port and the breakwater before the catastrophic tsunami in 2011. After being hit by the tsunami, severe erosions on the beach could be clearly observed. At some points, the erosion was so severe that the shoreline retreated close to the position of the dyke. The period from the tsunami event to present day, the beach has showed recoveries but doesn't reach the shoreline position before the tsunami.

### 1. Introduction

Kodanohama Beach is a sandy pocket beach (According to MacLennan et al. (2011) pocket beach is defined as a beach that is contained between two bedrock headlands that essentially function as a closed system in term of littoral sediment transport) located on Oshima Island, off shores from Kessenuma City, Miyagi Prefecture, Japan (Fig. 1). This beach is about 500 m in length, facing the Pacific Ocean. In the North part of the beach, from left to right are the port and the breakwater. The South part of the beach is adjacent to the bedrock headland. There is a sea-dyke built along the sandy coast.

Before the tsunami, the harbor and the breakwater were constructed in the area. The roles of these structures on the morphological changes of Kodanohama Beach in this period will be discussed in the following chapters in this study.

On 11th March 2011, a huge earthquake of magnitude 9.0 occurred off the coast of Japan, resulted in an enormous tsunami which the maximum wave height reached 39.7 m (Mori et al., 2012). This extreme event caused a significant number of beaches in the coastal areas in Japan to harshly erode. Kodanohama Beach was not an exception. The Great East Japan Earthquake and Tsunami totally changed the morphology of Kodanohama Beach. The erosion could be easily witnessed.

Many researches have been conducted on morphological changes and recoveries of coastal and estuarine areas after disasters. Liew et al. (2010) and Choowong et al. (2009) studied about the damages and recovery processes in the coastal areas of Thailand using aerial images after the 2004 Indian Ocean Tsunami. Tanaka et al. (2014), Mitobe et al. (2013), Udo et al. (2012), Tanaka et al. (2012) and Tappin et al. (2012), Hoang et al. (2013), etc., conducted researches about the recoveries of coasts and estuaries in Japan after the 2011 Tsunami utilizing aerial photographs. In these studies, researchers investigated the recovery processes in long sandy beach with river mouths as sediments supplies. There are few

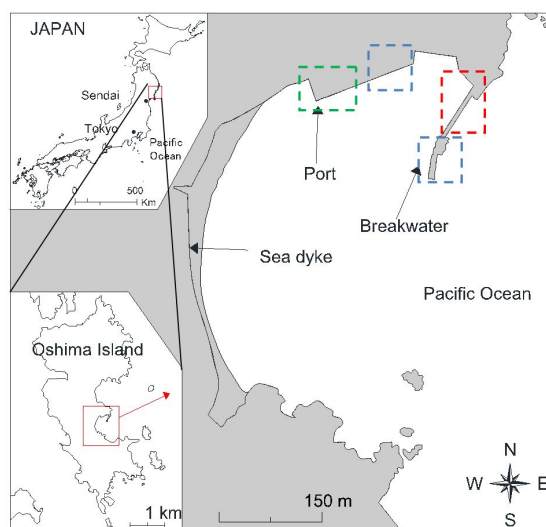


Fig. 1 Study area

<sup>1</sup> Undergraduate Student, Water Resources University, Ha Noi, Viet Nam

<sup>2</sup> Assistant Professor, Department of Civil Engineering, Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan

<sup>3</sup> Graduate Student, Department of Civil Engineering, Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan

<sup>4</sup> Associate Professor, Water Resources University, Ha Noi, Viet Nam

<sup>5</sup> Professor, Department of Civil Engineering, Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan

researches about the recovery processes in small pocket beach with no or little sediment supplies. Therefore this study aims to investigate the recoveries of this pocket beach after the tsunami event (2011-2014) along with its long-term morphological changes before the tsunami (1966-2001) and how these changes were influenced by the harbor and the breakwater by analyzing aerial photographs taken in this area by airplanes and satellites.

## 2. Data collection and analysis

This study utilizes aerial photographs taken by airplanes and satellites from 2 main sources: GSI (Geospatial Information Authority of Japan) and Google Earth. Google Earth provides images taken in 13 March 2011, 2 day after the tsunami, and a variety of photos taken in different time of the year 2011, 2012 and 2014. In order to investigate the behaviors of shoreline of Kodanohama Beach before the tsunami event and to have more data in the period after this catastrophe, this study also uses images from GSI which provides photographs taken in 1966, 1967, 1977, 1978, 1981, 2000, 2001, 2011 and 2013.

Collected images were rectified to the same coordinate system using a set of 55 Ground Control Points (GCPs). GCPs were selected in approximately the same elevation and close to the sea level. Due to the images qualities, the visibilities of the features of the beach in different times etc., some aerial photographs may use more or less than 55 GCPs. All the photographs collected from Google Earth and GSI haven't been justified for the tidal level due to the lack information of exact time of taking.

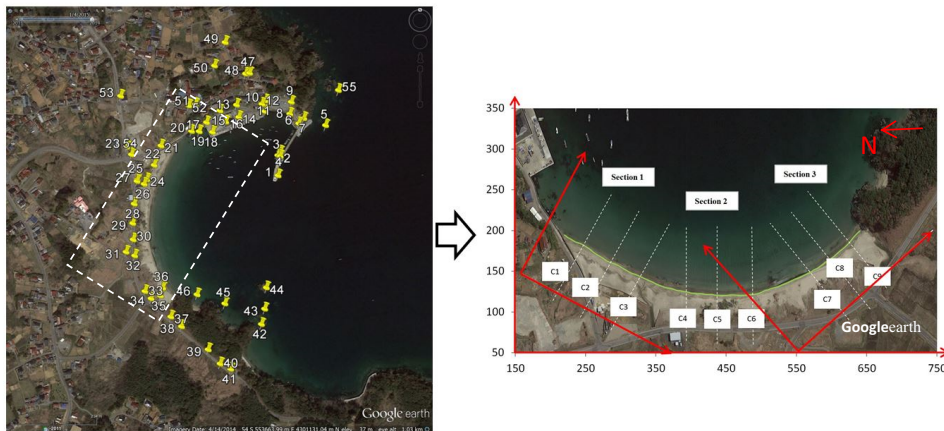


Fig. 2 Rectification and shoreline detection processes

The beach is divided into 3 sections. In each section, one baseline is chosen such that it is nearly parallel to the shorelines to minimize the errors when plotting temporal variation of shoreline positions. The baseline of each section is oriented an angle  $\alpha$  clockwise from the North. In section 1  $\alpha$  equals  $151^\circ$ . In section 2  $\alpha$  is  $182^\circ$  and in section 3  $\alpha$  equals  $24^\circ$  (Fig. 2). Shoreline can be defined as the physical interface between land and sea (Boak and Turner, 2005). Shoreline positions  $y_s(x, t)$  were extracted every 5m with respect to the baselines in each section (Fig. 2).

## 3. Results and discussions

### 3.1 Morphology changes before the tsunami (1966-2001)

As a pocket beach, located in a geographically closed area (Fig. 1), the morphology of Kodanohama Beach is predicted to be stable with time. Nonetheless the temporal variations of shoreline positions in this period show that the shoreline positions weren't stable. (Fig. 3) shows the evolution of shoreline position in this period. As we can see, from 30<sup>th</sup> August 1966 to 9<sup>th</sup> October 1967, it retreated in all sections. From 9<sup>th</sup> October 1967 to 18<sup>th</sup> October 1977, it generally advanced. From 3<sup>rd</sup> October 1978 to 24<sup>th</sup> June 1981, the shoreline accreted in section 2 and section 3 and forwarded in section 1. From 1981

to 2000, the shoreline advanced. From 31<sup>st</sup> October 2000 to 15<sup>th</sup> October 2001, the shoreline advanced in section 1 and retreated in section 2 and 3.

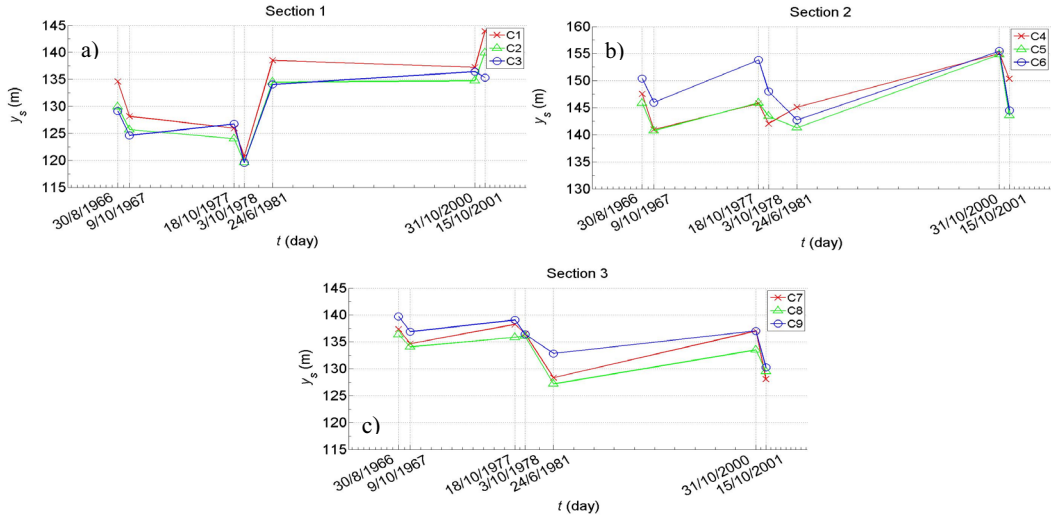


Fig. 3 temporal variations of shoreline positions before tsunami

As can be seen from Fig. 3, the shoreline position in section 1 changed more dramatically than shoreline position in section 3. In section 1 the maximum amplitude of  $y_s(x,t)$  is approximately 25 m while in section 3 the maximum amplitude is only 10 m. There are many factors that may cause the phenomenon. One of the possible causes can be the constructions and extensions of the harbor and the breakwater. Wave direction is also needed to take into account.

### 3.2 Morphological changes under the influence of the harbor and the break water.

From 9<sup>th</sup> October 1967 to 18<sup>th</sup> October 1977, the breakwater was constructed (Fig. 1, Red square). In the same period, the shoreline was almost the same in section 1, retreated in and 3 and advanced in

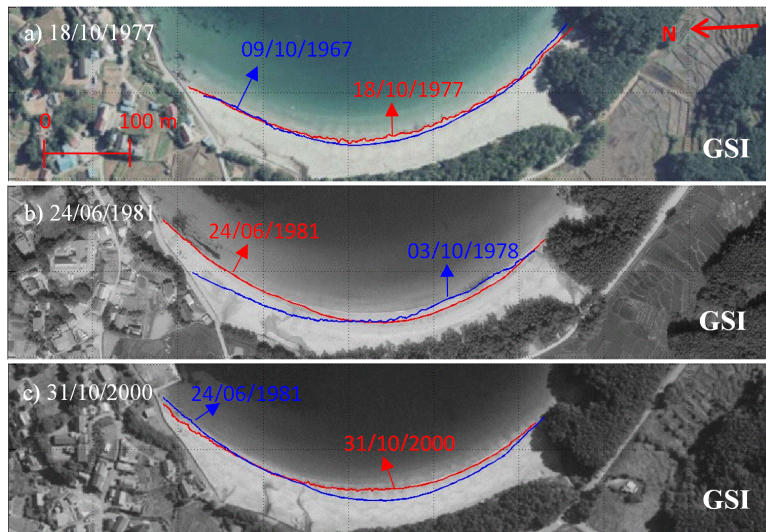


Fig. 4 Rectified images with shoreline positions before tsunami

section 2 (Fig. 4a). From 3<sup>rd</sup> October 1978 to 24<sup>th</sup> June 1981, the breakwater was extended and the part of the harbor was built (Fig. 1, Blue squares). In the same period, it can be observed that the shoreline advanced in section 1 and retreated in section 3 (Fig. 4b). The similar phenomenon was pointed out in Tanaka and Srivihok (2004); Tanaka (1983) and Uda (2010). From 24<sup>th</sup> June 1981 to 31<sup>st</sup> October 2000, the harbor was extended to its current size (Fig. 1, Green square). At the same time, it can be seen that the shoreline advanced in section 1 and retreated in section 2 and section 3 (Fig. 4c).

The results obtained show that the constructions of the harbor and the breakwater influenced the morphological changes of the beach. The long-term morphology changes of the beach are related to the sediment transportation in along-shore direction which is caused by the constructions of the harbor and breakwater whereas the short-term morphological changes are the changes related to the sediments transportations in cross-shore direction which are seasonal changes caused by tidal levels, wind and wave directions, storm events, etc., (Horikawa, 1988). Due to the lack of photos taken in high frequency, tidal and wave data from the study area, this research cannot explain these variations.

### 3.3 The recovery of the Shoreline after the 2011 tsunami (2011-2014)

The attack of the tsunami reformed the shape of kodanohama Beach. Overall, more severe erosion can be observed in section 3. As can be seen from Fig. 5, the shoreline positions are separated into 2 groups. The upper group consists of shoreline positions before the tsunami (dash line) and the lower group contains shoreline positions after that (continuous line). The separation is not clear in section 1 but becomes visible in section 2 and can be clearly seen in section 3. It also can be observed from Fig. 5 that the lower group of shoreline positions is shorter than the upper group.

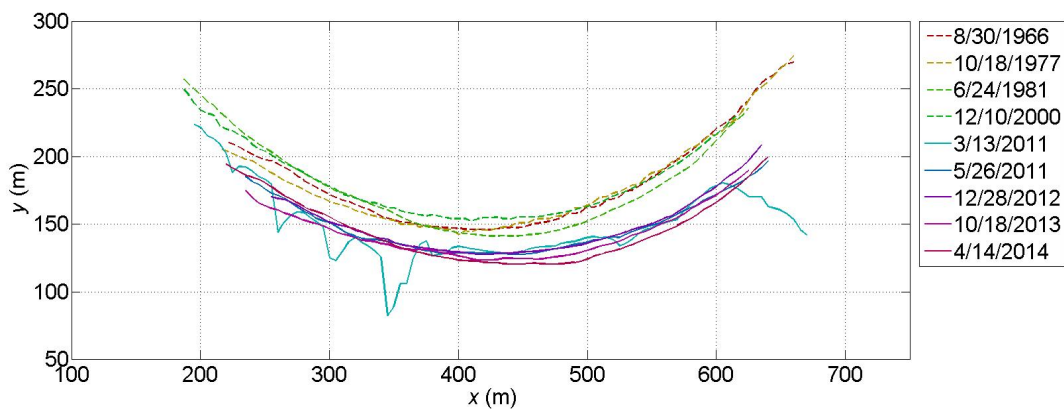


Fig. 5 Shoreline positions

After being smashed by the tsunami (13<sup>th</sup> March 2011), Kodanohama Beach was heavily damaged (Fig. 6 and Fig. 7a). The shoreline retreated from 10 m (C6, Fig. 6b) to more than 40 m (C9, Fig. 6c). At some points, the beach eroded so severely and shoreline reached to the position of the sea dike. In section 1, a part of the harbor and the sea-dyke were exposed (Fig. 7a). In section 3, shoreline retreated nearly 100m to the center of the main road and it can be seen that the road was ruined. 76 days after the tsunami (26<sup>th</sup> May 2011), the beach recovered in section 1 and section 3, and the shoreline already became smooth (Fig. 7b). From 26<sup>th</sup> May 2011 to 18<sup>th</sup> October 2013, the shoreline fluctuated but in general it retreated (Fig. 6). In the period between 18<sup>th</sup> October 2013 to 14<sup>th</sup> April 2014, Shorelines advanced in section 1 and retreated in section 2 and 3 (Fig. 6). Especially in section 2, shoreline erosion was more severe than in 13<sup>th</sup> March 2011. Three year after the tsunami, it can be observed that, the shoreline reaches the dynamic equilibrium state in section 1 and gradually retreats section 3 and section 2. Especially, in section 2 the shoreline reaches to the position of the sea-dyke (Fig. 7e). It can be said that the shoreline of the Kodanohama Beach will not recover to its prior state any time soon.



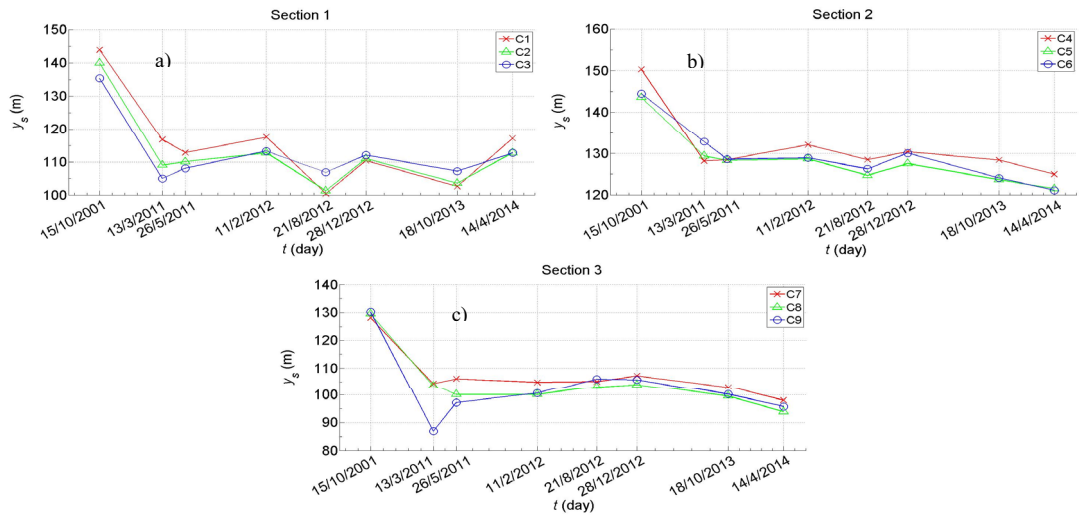


Fig. 6 Temporal variations of shoreline position after the tsunami

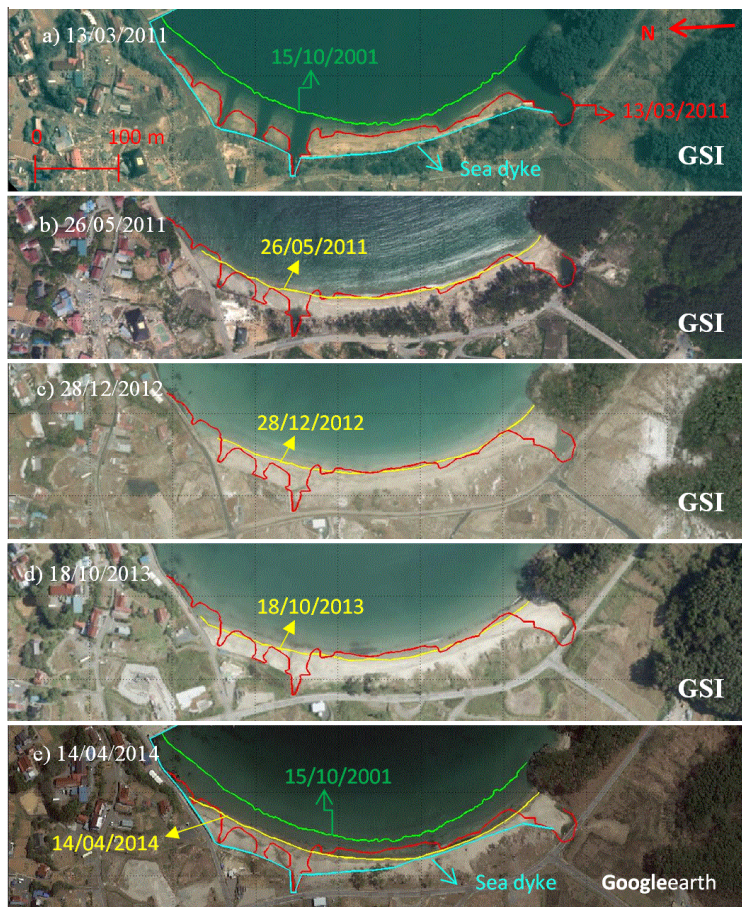


Fig. 7 Rectified images with shoreline positions after tsunami

#### 4. Conclusions

After analyzing data, the conclusions can be made as follows: Before tsunami, the constructions and extensions of the harbor and the breakwater influenced the morphological changes of Kodanohama Beach. By the earthquake and tsunami event, the beach was severely damaged. Morphological characters of the area were changed dramatically. Three years after this catastrophe, the shoreline recovered but far from reaching its position before the tsunami. Results from the most recent aerial images show that sediments were transported from section 2 and section 3 to section 1. Further studies need to be conducted in order to give more suitable explanations about the past behaviors of the beach and make more precise predictions of the future morphological changes.

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