# RECOVERY OF TSUNAMI-INDUCED CONCAVE SHORLEINE ON THE COAST BOUNDED BY COAST STRUCTURES


Tohoku University Student Member ○ Vo Cong HOANG
Tohoku University Fellow Member Hitoshi TANAKA
Tohoku University Regular Member Yuta MITOBE


## 1. INTRODUCTION

Concave shoreline was commonly observed at the areas of river mouth and the breaching of sandy beach after the 2011 tsunami (Tanaka et al., 2012). During the recovery process, longshore sediment, which is transported from adjacent sandy coasts, deposits in the concave portion. That makes the advance of shoreline in this area. Coastal structures, which exist on the sandy coast on both sides of the concave portion, are considered as rigid boundaries and have influence on the evolution of shoreline. This study would like to discuss on the analytical solutions of one-line model, which describe the evolution of concave shoreline in cases without and with rigid boundaries. Moreover, the proportion of backfill of sediment deposition in the concave portion is also presented.

## 2. STUDY AREA AND DATA COLLECTION

This study focuses on area around the Nanakita River mouth which is located on the northern part of Sendai Coast, Miyagi Prefecture, Japan (Fig. 1). There are a long breakwater of Sendai Port at north and drainage of waste water treatment plant at south. These structures are considered as rigid boundaries.

In addition, the Akaiko Breaching, which is located approximately 16.5km south of the Nanakita River mouth, is also taken as the study area. This breaching was formed by the tsunami at the location of an old river mouth.

Aerial photographs of study area have been taken frequently in every one or two month since 1990. All raw aerial photographs are georeferenced to the World Geodetic System (WGS-84). In addition, aerial photographs of the Akaiko Breaching were collected from Geospatial Information Authority of Japan (GSI) and Google Earth.

## 3. RESULTS AND DISCUSSION

### (1) Analysis on analytical solution describing the evolution of concave shoreline

The evolution of shoreline position around the concave portion can be described by analytical solution of one-line model. Larson et al. (1987) and Hoang et al. (2015) introduce solutions, Eqs.(1) and (2), respectively, for cases without and with rigid boundaries at both ends.

$$y = \frac{1}{2}Y_0\left[\mathrm{erfc}\left(\frac{B\text{-}2x}{4\sqrt{\varepsilon t}}\right)+\mathrm{erfc}\left(\frac{B\text{+}2x}{4\sqrt{\varepsilon t}}\right)\right] \quad (1)$$

$$y=Y_0\left[1\text{-}\frac{B}{L}\text{-}\frac{2}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\sin\frac{n\pi B}{L}\exp\left(\text{-}\frac{4\varepsilon n^2\pi^2 t}{L^2}\right)\cos\frac{2n\pi x}{L}\right] \quad (2)$$

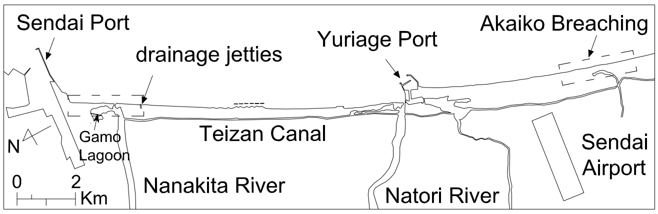


**Fig.1**. Location map of study area

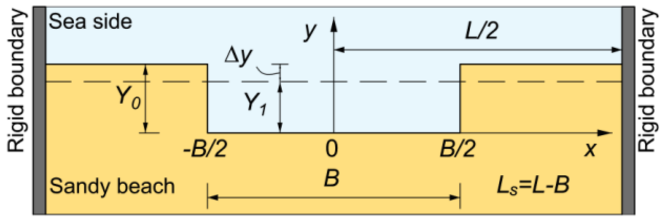


**Fig.2**. Schematic diagram of tsunami-induced concave shoreline

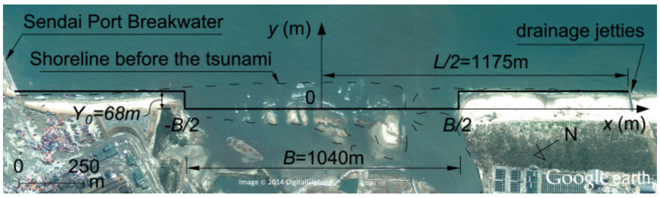


**Fig.3** Area around the Nanakita River mouth (Case 1), (background image: March 14th, 2011)

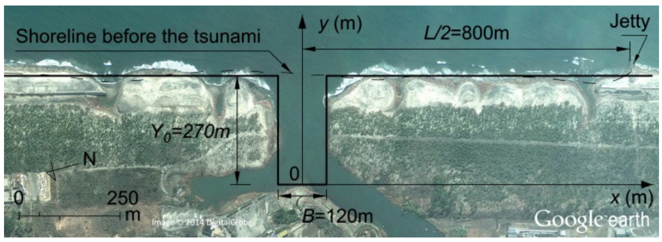


**Fig.4** Area around the Akaiko Breaching (Case 2), (background image: March 14th, 2011)

where $x$ and $y$ are the coordinates which are defined as in **Fig.2**; $t$ is the time; $\varepsilon$ is the diffusion coefficient, $Y_0$ is the cross-shore distance of the beach cut region from the initial shoreline. This distance is estimated based on the actual condition of shoreline right after the tsunami; *erfc* is the complementary error function; $B$ is the width of concave portion; $L$ is the total length of sandy coast bounded by two rigid boundaries.

**Fig.3** and **4** show concave shoreline after the tsunami at the areas around the Nanakita River mouth and the Akaiko Breaching.

The recovery time, $T_E$, is defined to be time when shoreline position at the central line ($x$=0m) becomes 99% of the equilibrium shoreline position. $Y_0$ and $Y_1$ ($Y_1=Y_0(L\text{-}B)/L$), respectively, are equilibrium shoreline positions of cases without and with rigid boundaries. The relationship between dimensionless total length of the sandy coasts, $L_S$*, and the dimensionless recovery time, $T_E$*, for cases without and with rigid boundaries can be obtained from Eqs.(3) and (4).

$$0.99=\mathrm{erfc}\left(\frac{1}{4(L_S^*+1)\sqrt{T_E^*}}\right) \tag{3}$$

$$0.99\left(\frac{L_S^*}{L_S^*+1}\right)=1-\frac{1}{L_S^*+1}$$
$$-\left[\frac{2}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\sin\frac{n\pi}{L_S^*+1}\exp\left(-4n^2\pi^2T_E^*\right)\right] \tag{4}$$

where the dimensionless total length of sandy beach and recovery time are defined as follows.

$$L_S^*=\frac{L-B}{B} \tag{5}$$

$$T_E^*=\frac{\varepsilon T_E}{L^2} \tag{6}$$

**Fig.5** shows the relationship between dimensionless total length of sandy coasts, $L_S^*$, and dimensionless recovery time, $T_E^*$. According to that result, when $L_S^*$ increasing, $T_E^*$ values obtained from two solutions are asymptotic. Whereas, when $L_S^*$ decreasing, value of $T_E^*$ obtained from solution for case without rigid boundaries tends to be larger than one from case with rigid boundaries. $T_E$* obtained from the solution for case with rigid boundaries approaches 50% of one without rigid boundaries at $L_S$* of 250 (demarcated by dash line).

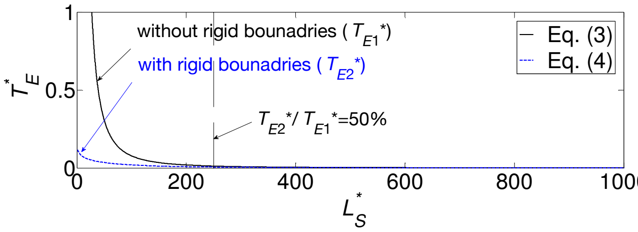


**Fig.5**. Relationship between $L_S$* and $T_E$*

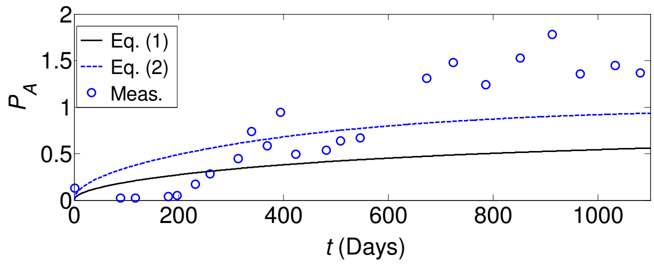


**Fig.6**. Relationship between $P_A$ and $t$ (Case 1)

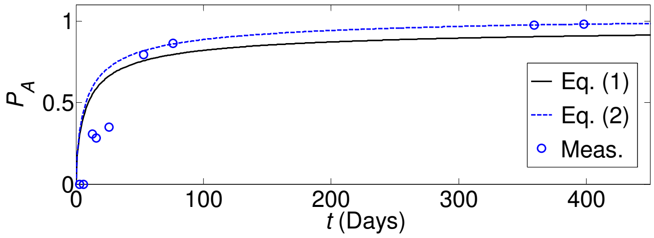


**Fig.7**. Relationship between $P_A$ and $t$ (Case 2)

**(2) Analytical shoreline evolution at Akaiko area**

The proportion of backfill, $P_A$, is the parameter representing the percentage of concave portion which has been filled by the sediment from adjacent sandy coasts. Dean (2003) introduces the solution to obtain $P_A$, Eq.(7), for case without rigid boundaries. Whereas, this study introduces solution for case with rigid boundaries, Eq.(8).

$$P_A = 1-\frac{2\sqrt{\varepsilon t}}{B\sqrt{\pi}}\left[exp\left(-\frac{B}{2\sqrt{\varepsilon t}}\right)^2-1\right]-erf\left(\frac{B}{2\sqrt{\varepsilon t}}\right) \tag{7}$$

$$P_A=\frac{2L^2}{B(L-B)\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\sin^2\frac{n\pi B}{L}\left[1-\exp\left(-\frac{4\varepsilon n^2\pi^2 t}{L^2}\right)\right] \tag{8}$$

**Fig.6** shows the comparison between temporal proportion of backfill obtained from Eqs.(7) and (8) with measured data for Case 1, concave shoreline around the Nanakita River mouth. Good agreement can be obtained for the period from 300 to 600days after the tsunami. Prior to that period, results are not consistent. This can be related to reasons such as the complicated geometry and the inconstant depth of the concave portion after the tsunami. Similar comparison is also made for Case 2, concave shoreline around the Akaiko Breaching (**Fig.7**). Simulated and measured results are not consistent in the early stage. The reason can be similar to Case 1. However, results obtained for period from 60days after the tsunami are in very good agreement.

As the concave portion in this area of Case 2 is much smaller than the Case 1, thus, the required time for the proportion of backfill approaching the equilibrium state is shorter.

## 4. CONSLUSIONS

This study has discussed on the analytical solutions of one-line model which describe the evolution of shoreline around the concave portion in cases without and with rigid boundaries. The dimensionless recovery times obtained from analytical solutions of one-line model for above cases are asymptotic when the dimensionless total length of adjacent sandy coasts is large. Equations for estimating the proportion of backfill of sand deposition in the concave portion is introduced. The comparison between simulated results and measured data of cases of the Nanakita River mouth and the Akaiko Breaching areas are presented.

## REFERENCES


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