BREACHING AND TSUNAMI WATER DRAINAGE AT OLD RIVER MOUTH LOCATIONS DURING THE 2011 TSUNAMI

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This study investigated the effect of the past drainage system and river mouth to the return flow of the 2011 Great East Japan Tsunami at the Arahama Coast and the Akaiko Coast, Sendai, Japan. At both locations, there were old river mouths, which have been closed for many years. They used to be the down stream end of the past drainage system that was confirmed from historical map. Breaching occurred at the location of these old river mouths due to the strong return flow induced by the 2011 tsunami. A detail GIS analysis was carried out based on topographic data (DEM) to obtain the flow direction and accumulation. The results revealed that the topography appears as a river basin with mild slope towards the old river mouth locations. Analysis of the flow accumulation confirms that the topographical features caused the flow to accumulate through the past drainage system towards the location of the old river mouths, which caused the breaching due to the tsunami return flow. This allowed the return flow to be effectively drained.

Keywords: the 2011 tsunami; breaching; topographical features; drainage.

INTRODUCTION

The Great East Japan Earthquake and Tsunami on 11 March 2011 had greatly damaged the affected coastal area in the north east coast of Japan. Mori et al. (2012) reported the tsunami wave height reached a maximum of approximately 40 meters. The massive tsunami wave reached the shoreline and caused destruction to the affected shoreline. Supasri et al. (2012) reported a large number of casualties and damages to coastal structures. Tappin et al. (2012) reported based on their study in the Sendai Coast that coastal protection may not be highly effective in the case of massive tsunami as in the event of 2011. These studies have shown the great impact of the 2011 tsunami to the affected shoreline along the north east coast of Japan.

The coastal structures, built for protection against tsunami, were damaged in most places. They are re-evaluated and redesign for better protection in relation to the future tsunami event. Various other means of protection, i.e., elevated roads, embankment, and coastal forest, are also being evaluated and redesigned to give better resistance in the future. The tsunami effect to these structures can be quantified easily using conventional approaches (Adityawan et al. 2012, Adityawan et al. 2014, Tanaka et al. 2014, Dao et al. 2013), which will lead to a new design process.

In the event of the 2011 tsunami on the Sendai Plain, the effects of the local drainage system and its catchment were observed. The drainage system, collected the return flow of the tsunami, and caused the sandy coast breaching in some places, in which the return flow was effectively drained (Tanaka et al. 2012). Therefore, this phenomenon should be a part of the disaster mitigation plan. However, it is quite difficult to quantify and requires a more detail study.

This study focuses on the effect of the drainage system to the tsunami return flow, based on the tsunami of 2011 in the Arahama Coast and the Akaiko Coast. The return flow mechanism in the study areas was analyzed using historical map and GIS analysis of the topographic data.

STUDY AREA

The study areas are the Arahama Coast and the Akaiko Coast. Both located at the Sendai Plain, Japan as shown in Fig. 1. These areas were severely hit by the 2011 tsunami. However, shoreline at both locations remained relatively unharmed with the exceptions of local breaching. Figures 2 and 3 show the sandy coast breaching, following the tsunami of 2011 on the Arahama Coast and the Akaiko Coast, respectively. The breaching width at the Arahama Coast was approximately 50 m, while the breaching width at the Akaiko Coast is approximately 130 m.

Figure 4 shows the video image, captured from a helicopter during the tsunami event at the Akaiko Coast. The video image showed that a very strong return flow occurred through the drainage system and caused the sandy coast breaching. This phenomenon is analyzed in detail in the following sections based on historical maps and GIS analysis.

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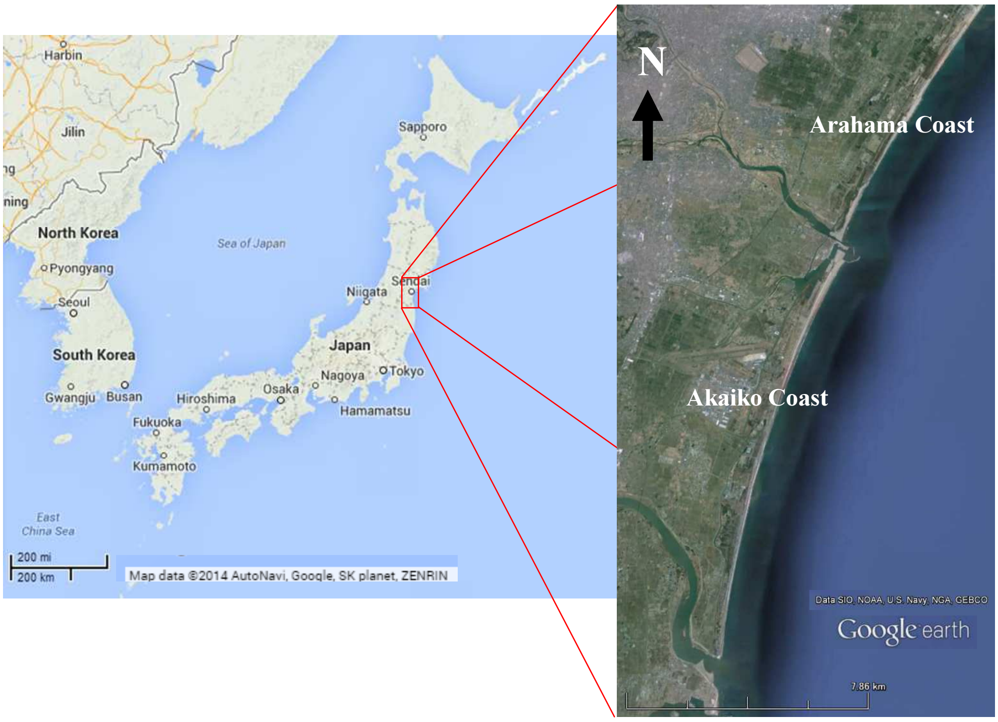


Figure 1. Study area

Figure 2. Sandy coast breaching on Arahama Coast (13 March 2013).

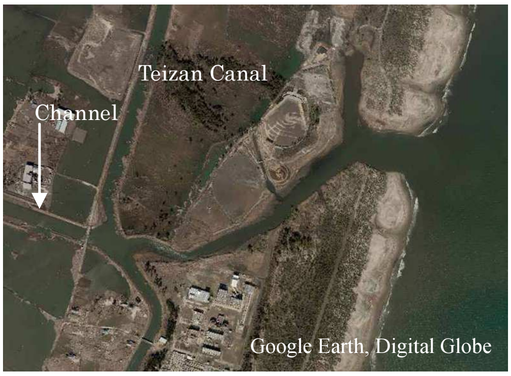


Figure 3. Sandy coast breaching on Akaiko Coast (13 March 2013).

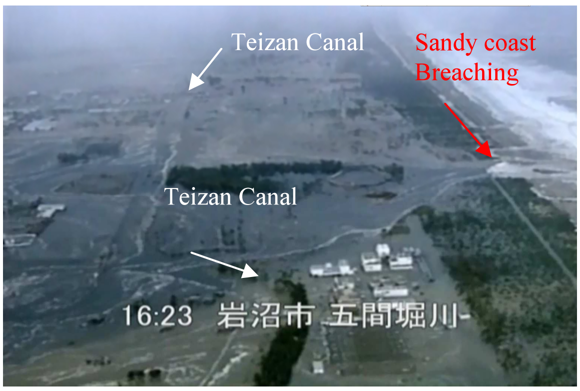


Figure 4. Video image at the Akaiko Coast during the 2011 tsunami.

HISTORICAL MAP ANALYSIS

Figure 5 shows the comparison of the study area based on Google Earth image (2012) to the historical map (1853). It is noted that the old map was slightly less accurate. The Natori River Mouth in the old map was located further on the seaside. Nevertheless, the existence of the Teizan Canal on the right side of the Natori River was also confirmed in both maps. The location of the Ido Lagoon at the left side of the river mouth was also confirmed in both maps. However, the Teizan Canal on the left side of the Natori River was not yet constructed in 1853. Hence, it was not drawn in the old map. The river mouth at the Arahama Coast was also confirmed from an older map, drawn in 1701 (Fig. 6). Both river mouths were closed around the Meiji Era until present, as shown in Fig. 7 and Fig. 8.

Based on the comparison, the sandy coast breaching in both locations (Fig. 2 and Fig. 3) occurred at the former location of river mouths (Fig. 5). These river mouths were part of the old drainage system, which have been closed for many years. Back then, the water from the Sendai Plain flowed to the sea from these river mouths. After the closure, the Teizan Canal serves to collect and to flow the water from the plain to the sea through the Natori River. However, in the tsunami of 2011, it was suggested that the return flow was very strong and caused the sandy coast breaching at these locations, e.g., as captured and shown in Fig. 4.

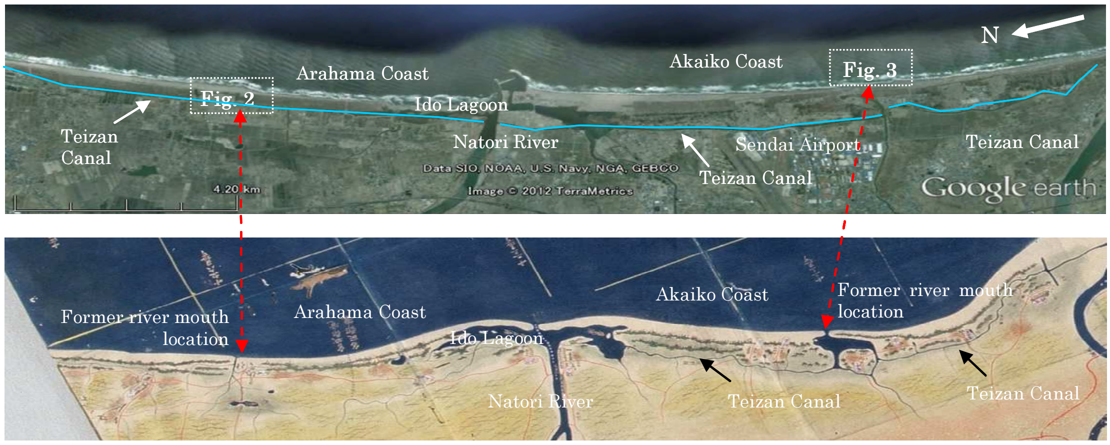


Figure 5. Map comparison (Top: in 2012, Bottom: in 1853)

Figure 6. River Mouth at the Arahama Coast (1701)

Figure 7. Arahama Coast (Present Map)

Figure 8. Akaiko Coast (Present Map)

TOPOGRAPHICAL ANALYSIS

Topographical analysis was conducted based on a 5 meters resolution DEM data (Udo et al. 2012) as given in Fig. 9. The bird eye view for the Arahama Coast and the Akaiko Coast is shown in Fig. 10 and Fig. 11, respectively. In general, the topographical condition around the breaching point at both locations resembles a river basin with the breaching location as the exit points. Figure 10 shows that the topographical condition in the Arahama Coast around the breaching point (near the shore) was higher than the inland area due to the existing sand dunes. However, traces of past sand dunes were found parallel to the present sand dunes, showing higher elevation than the surroundings.

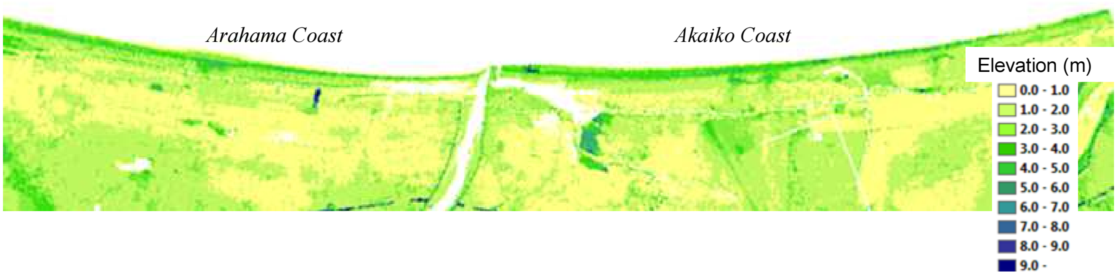


Figure 9. DEM Data (5 Meters Resolution)

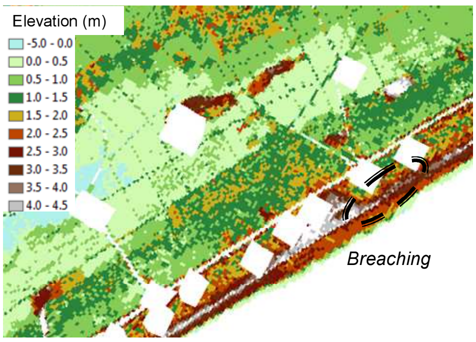


Figure 10. Bird Eye View of the Arahama Coast

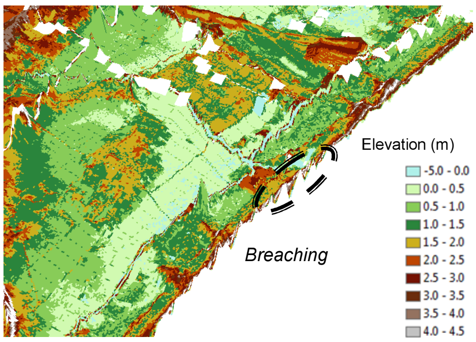
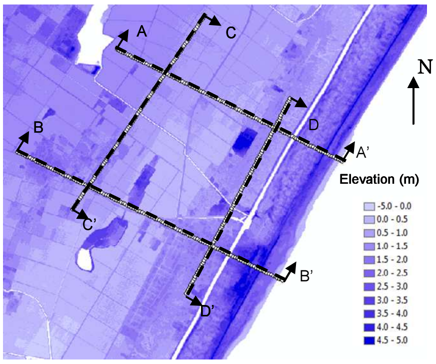
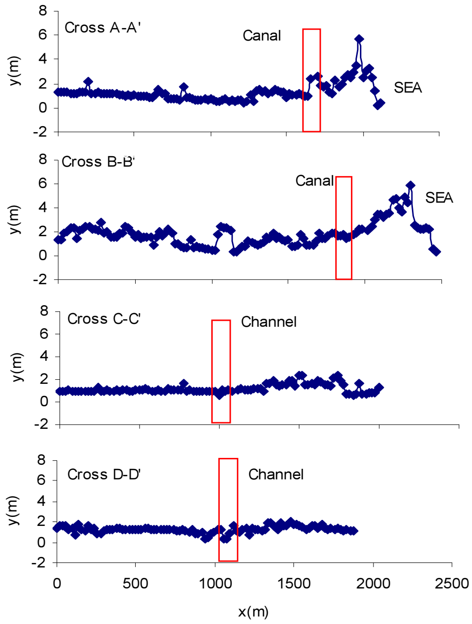


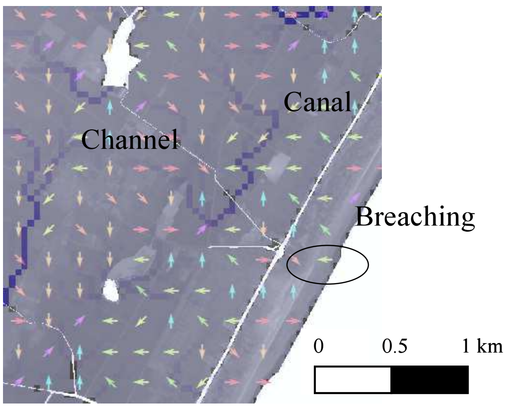
Figure 11. Bird Eye View of the Akaiko Coast



(a) Contour

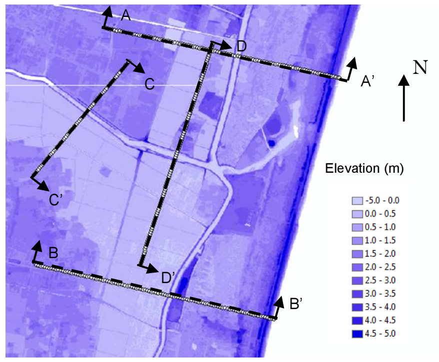


(b) Cross sections

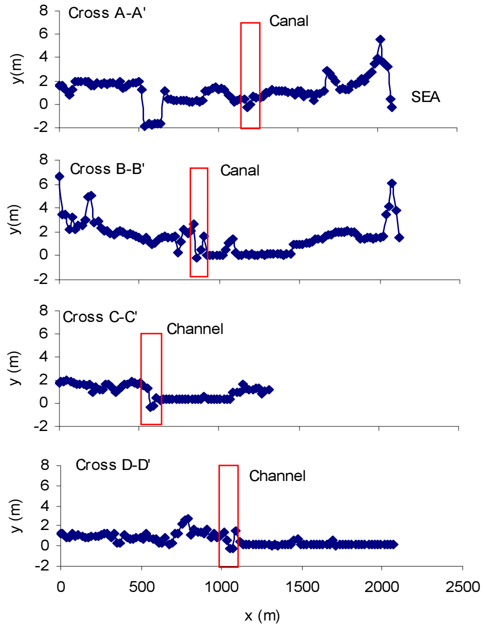


(c) Flow direction and accumulation

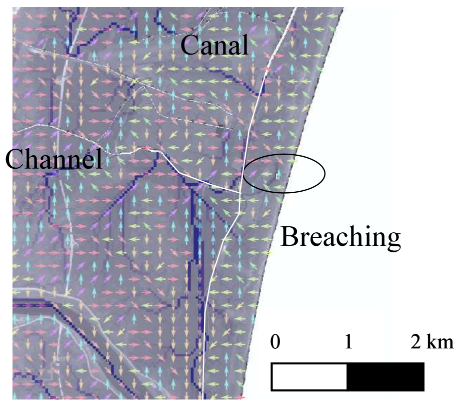
Figure 12. DEM Analysis at the Arahama Coast



(a) Contour



(b) Cross sections



(c) Flow direction and accumulation

Figure 13. DEM Analysis at the Akaiko Coast

In general, the topographical features in both study areas cause the flow to accumulate towards the old river mouths. Thus, breaching occurred at the former river mouths due to the very strong return flow, induced by the tsunami. A more detail analysis of the topographical condition around the breaching area is given in Fig. 12 and Fig. 13, for the Arahama Coast and the Akaiko Coast, respectively. Contour map at both locations (Fig. 12(a) and Fig. 13(a)) was analyzed by drawing cross section profiles (Fig. 12(b) and Fig. 13(b)). Moreover, GIS analysis was conducted to obtain the flow direction and accumulation based on the topographical features (Fig. 12(c) and Fig. 13(c)).

The cross sectional profile at the Arahama Coast is given in Fig. 12(b). The past sand dunes at the Arahama coast still exists at the south side of the channel (perpendicular to the shoreline) as seen in Cross B-B' and Cross C-C'. It was also found that the existing canal (parallel to the shoreline) was located higher than its surroundings as shown in cross A-A' and cross B-B'. Hence, the return flow of the tsunami may not enter the canal freely. On the contrary, Cross C-C' and D-D' show that the topographical profile parallel to the shoreline was relatively flat to mild slope towards the channel. This suggest that the return flow was gathered through the channel (perpendicular to the shoreline), which may lead to the breaching incidents at the end of the channel. This agrees well to the flow accumulation analysis as shown in Fig. 12(c). It clearly shows that the flow accumulated towards the former river mouth mainly through the channel instead of the canal.

The cross sectional profile at the Akaiko Coast is given in Fig. 13(b). Cross A-A' and B-B', perpendicular to the shoreline, show that the topography has mild slope towards the canal. Cross C-C' and D-D', parallel to the shoreline, show that the topography also has mild slope towards the channel. Thus, the return flow was gathered from all directions in the canal as well as in the channel. This agrees well to the flow accumulation analysis. Figure 13(c) clearly shows that the flow was gathered in both channel and canal. Therefore, the meeting point of the canal and the channel received flow from all directions, which may lead to a more severe breaching than in the Arahama Coast. The estimated breaching width at the Akaiko Coast (130 m) was more than twice of that at the Arahama Coast (50 m). This confirms that the return flow towards the old river mouth was stronger in Akaiko Coast.

CONCLUSIONS

The effect of past drainage system at the Arahama Coast and the Akaiko Coast during the 2011 tsunami has been investigated in details. Breaching occurred in both areas at the location of the former river mouths. This was confirmed by analyzing and comparing present maps with historical maps. The breaching occurred due to the strong return flow induced by the tsunami, which was confirmed from video recordings.

GIS analysis was conducted based on a 5 m resolution DEM. It was found that the tsunami return flow was closely related to the topographical features and the drainage system at each location. The topographical features collected the return flow through the old drainage system, which lead to the breaching at the former river mouth locations. The drainage system at the Akaiko Coast collected the return flow through the Teizan Canal as well as channel. However, the return flow at the Arahama Coast was collected mainly through the channel. Therefore, the return flow flowing to the old river mouth was stronger in the Akaiko Coast, causing a more severe breaching.

This study has shown that the topographical features and drainage system are very important to the return flow of a tsunami. These factors allow the tsunami return flow to be effectively drained. Thus, they should be assessed in detail concerning disaster mitigation plan.

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