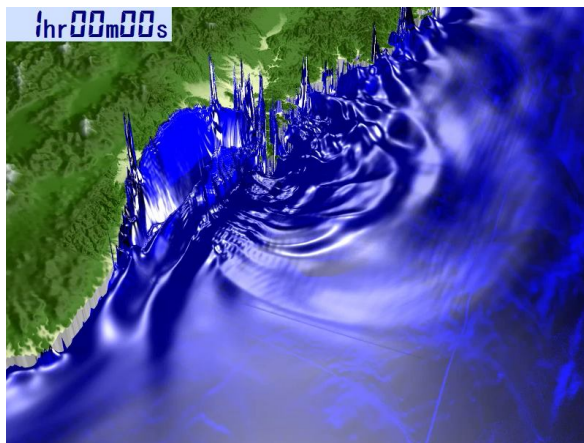


Field Guide of tsunami damage and reconstruction site visit in Miyagi prefecture

Onagawa – Ishinomaki – Sendai – Natori – Iwanuma

11 May 2013



Tsunami struck Sendai Plain after one hour



Tsunami inundation in Natori city



Recovery of Sendai Airport and tsunami mark



New tsunami evacuation map in Sendai

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1. Itinerary

Time	Activity
0745	Meet participants at the hotel lobby
0800 -1000	Depart for Onagawa town. Short break at service area.
1000 - 1100	Visit Onagawa town (Overturned buildings, Onagawa hospital)
1100 - 1200	Move to Ishinomaki city and have lunch
1200 - 1230	Visit Ishinomaki city (Damaged school, factory area)
1230 - 1400	Move to Sendai City. Short break at service area.
1400 - 1415	Visit Arahama town (Damaged school, seawall, tsunami memorial)
1415 - 1430	Move to Natori City
1430 - 1445	Visit Yuriage town (Past tsunami memorial, reconstruction model)
1445 - 1500	Move to Sendai Airport
1500 - 1515	Visit Sendai Airport (Short break , tsunami inundation mark, Sendai access line)
1515 - 1530	Visit Thousand years hope hill (10-15 m hill made of tsunami debris)
1530 - 1600	Back to Sendai JR Station (Optional: Namiwake shrine on the way back)

2. Route Map

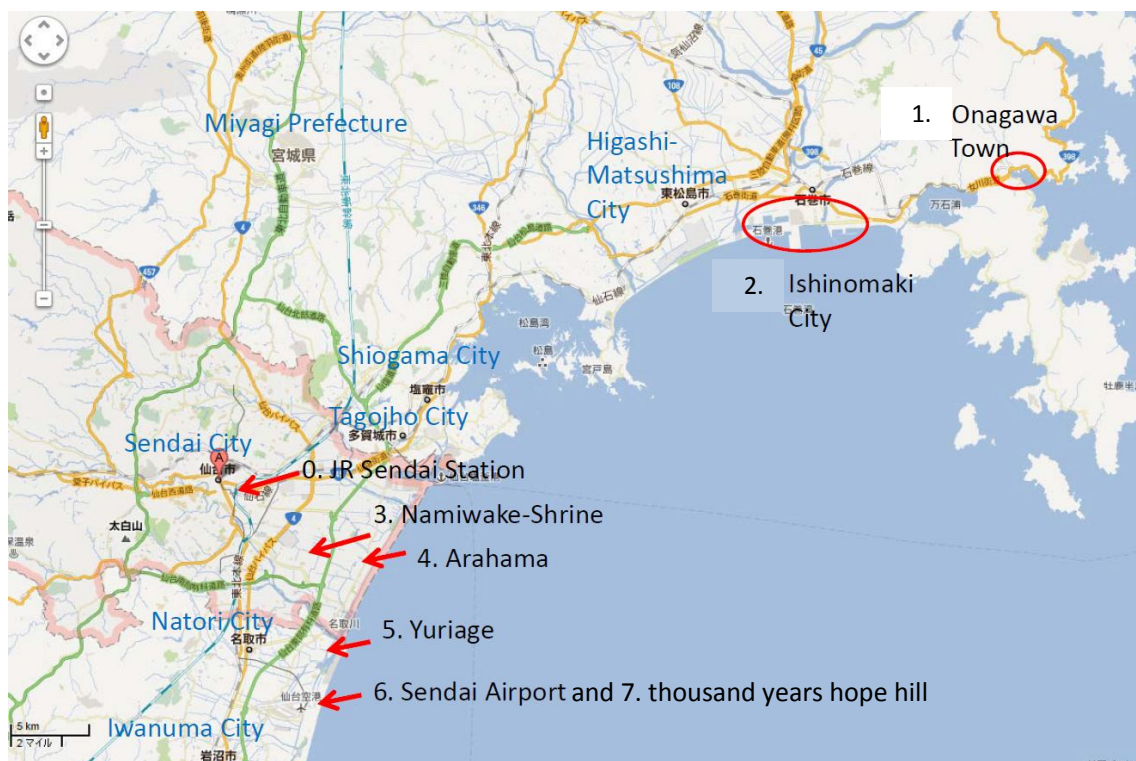


Figure 1: Onagawa – Ishinomaki – Sendai – Natori – Iwanuma

3. Background of tsunamis in the Sanriku coast and Sendai plain

Japan is well known for having the world's best tsunami countermeasures and evacuation mechanism because of its long history of tsunamis, especially along the Sanriku coast. The Sanriku area extends northward from Sendai, passing through Iwate to Aomori as a saw-toothed coastline more than 600 km in length. Because of its ria coast, the tsunami height can easily reach 20 m. Therefore, a number of large-scale structural and non-structural mitigation facilities were constructed in the past, especially after the 1960 Chile tsunami (Abe and Imamura, 2010). The Sanriku coast was often hit by giant tsunamis. Considering only tsunamis that were generated by earthquakes over M8.0, the first historical tsunami around this area is the Jogan tsunami. It was generated by the M8.3 EQ in 869, followed by M8.1 EQ in 1611, M8.5 EQ in 1896, M8.1 EQ in 1933 and finally the M9.0 EQ in 2011. In 1896 the tsunami caused nearly 22,000 deaths, which is the highest number of deaths that have been caused by a tsunami in Japanese history. The three events in 869, 1611 and 2011 caused large tsunami inundation in the Sendai plain area of the Miyagi prefecture. In summary, great tsunamis have stricken the Sanriku area every 600 years on average (two events in 1,100 years). However, before the 2011 event, there was a 99% probability of a magnitude M7.5-8.0 earthquake to strike off the Miyagi Prefecture within 30 years (Sendai city, 2011). A series of M7.4-M8.0 earthquakes have occurred in the Miyagi Sea since 1793, and the average time between them is 37 years. Many countermeasures have been constructed in preparation for this tsunami. Based on previous events, the Sendai plain area was considered as a low risk area and the primary concern was for the ria coast, with its remarkable tsunami amplification. For instance, in Ofunato, maximum runup heights of 38.2 m and 28.7 m were recorded from the 1896 Meiji and 1933 Showa tsunamis, respectively. However, for these same two tsunamis, maximum runup heights of less than 5 m and 3.9 m, respectively, were recorded in the Sendai plain (Sawai et al., 2008 and Yamashita, F., 2008).

4. The 2011 Great East Japan earthquake and tsunami

At 14:46 on March 11th, 2011, a massive earthquake was recorded in Japan, occurring at N38.1, E142.9 with a magnitude of 9.0 and a depth of 24 km (JMA, 2011). It was followed by aftershocks and a devastating tsunami with a maximum height of 40 m (The 2011 Tohoku Earthquake Tsunami Joint Survey Group, 2011). The earthquake was ranked as the fourth largest in the world following the 1960 Chile (M9.5), 2004 Sumatra (M9.3) and 1964 Alaska (M9.2) earthquakes. The earthquake had a long period (about three minutes with the largest slip found to be approximately 30 m) (USGS, 2011). The maximum recorded earthquake intensity was 7, the maximum level on the Japanese scale (JMA, 2011). The earthquake early warning system was issued 8 seconds after the detection of a first P-wave (JMA, 2011). A tsunami warning was issued 3 minutes after the earthquake.

Table No. 1. Historical tsunamis in the Sanriku area and their resulting damage

Date	Name	Magnitude	Damage
9 Jul 869	Jogan tsunami	8.3-8.6	More than 1,000 deaths
2 Dec 1611	Keicho Sanriku	8.1	More than 5,000 deaths
15 Jun 1896	Meiji Sanriku	8.5	21,959 deaths and > 10,000 houses destroyed
3 Mar 1933	Showa Sanriku	8.1	3,064 deaths and 1,810 houses destroyed
11 Mar 2011	Great East Japan	9.0	19,295 deaths and 359,073 houses destroyed

Table No. 2. Records of earthquakes in the Miyagi Sea

Date	Lag time		Magnitude
17 Feb 1793			8.2
20 Jul 1835	42.4 years	37.1 years in average	7.3
21 Oct 1861	26.3 years		7.4
20 Feb 1897	35.3 years		7.4
3 Nov 1936	39.7 years		7.4
12 Jun 1978	41.6 years		7.4
Before 11 Mar 2011	33 years passed with 99% possibility of occurrence		7.5 - 8.0

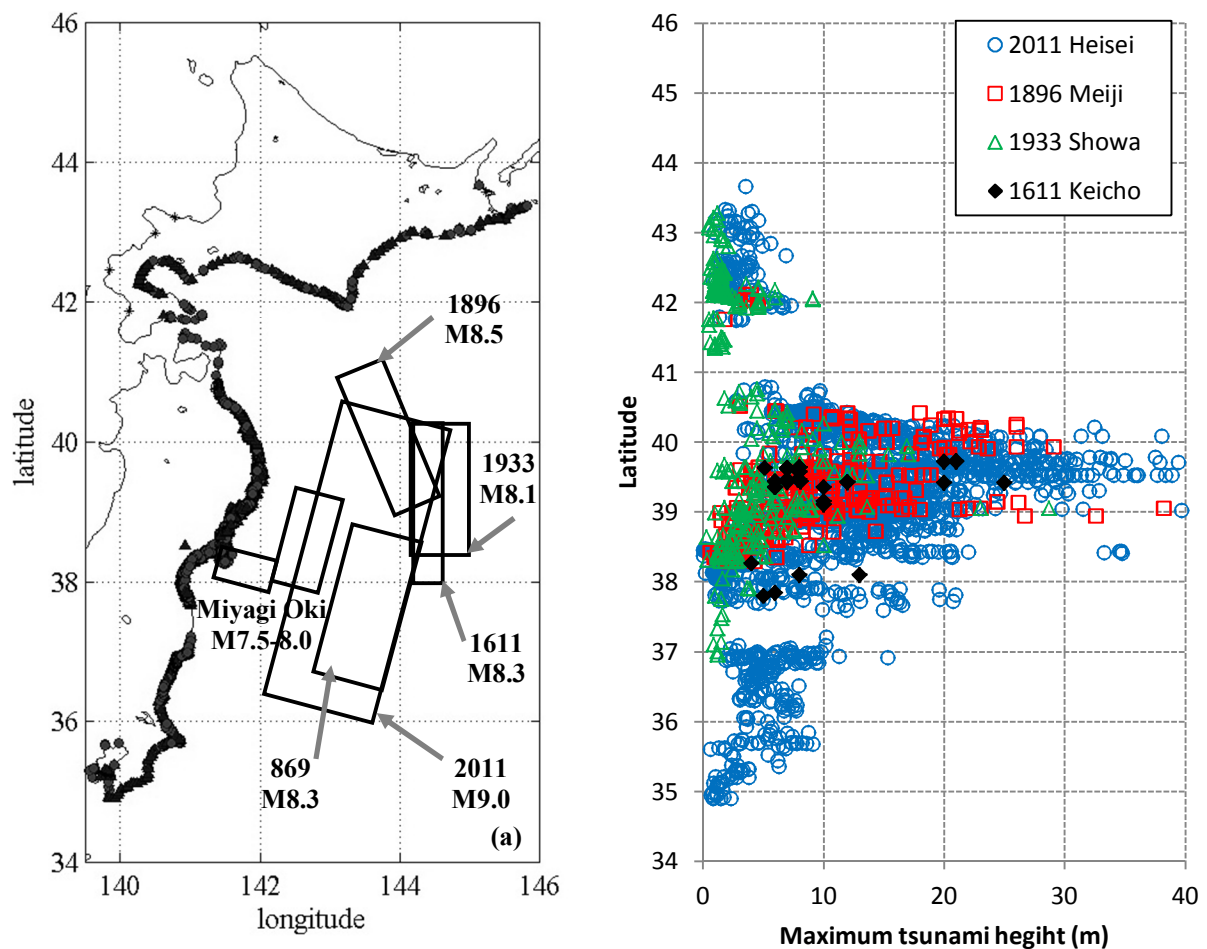


Figure 2 **Left**: Major historical tsunamis and the expected Miyagi-Oki earthquake and location of the main shock; **Right**: tsunami height distribution of the 2011 Great East Japan tsunami (Coastal Engineering Committee, 2011 and The 2011 Tohoku Earthquake Tsunami Joint Survey Group, 2011) and of the historical 1611 Keicho-Sanriku, 1933 Showa-Sanriku and 1896 Meiji-Sanriku tsunamis (Tsunami Engineering Laboratory, 2011b)

5. Onagawa hospital, Onagawa town

Category	Outline of Damage
Casualties & Missing	941 (Dead: 816)
Damaged houses	3,888 (85% of housing)

Onagawa town is approximately 50 km northeast of Sendai city and is part of the Oshika Peninsula. Although the town is located along the ria coast, it had comparatively less tsunami impact from the 1896 and 1933 Sanriku tsunamis. On March, 11, according to survivors, the tsunami warning sounded just after the earthquake, but the system stopped a few minutes later. Like other locations along the Sanriku coast, i.e., Kesenuma, many residences had experienced the 1960 tsunami and tsunami awareness campaign. However, the inundation area of the 2011 tsunami was wider than that of the 1960 Chile tsunami. The town hospital (Fig. 3(a)), which is located on a hill, was inundated on the first floor with a maximum observed tsunami height larger than 18 m. A clock stopped at 15:36 was found in the hospital, which is in agreement with the last record from the tide gauge station at Ayukawa, Ishinomaki city where the observed tsunami was 7.6 m high at 15:25 before the station was destroyed. Most of the damage was to houses, cars, trains, boats and fishing tools. Fig. 3-Right shows the result of land subsidence, where some parts of the land were submerged under sea water during the high tide period of the day. The most remarkable feature in this area is that six reinforced concrete (RC) buildings were overturned by the tsunami, as shown in Figs. 3(a) and 4. All of them were 2-4 stories high and possessed shallow or pile foundations. Before this event, no reports of overturned RC buildings had been made for any recent tsunami events. In the final reconstruction plan only three buildings will be kept as the memorials namely building #C, #D and #F. Present condition of Onagawa town after two years is shown in Fig. 5(a) and 5(b). Tsunami inundation mark (Fig. 5(a)) is put in the hospital entrance showing the tsunami depth of 1.95 m from the first floor of the hospital. Fig. 5(b) shows an example of the reconstruction plan in increasing road elevation to +5.4 m above mean sea level which to be used as another belt to reduce tsunami impact.

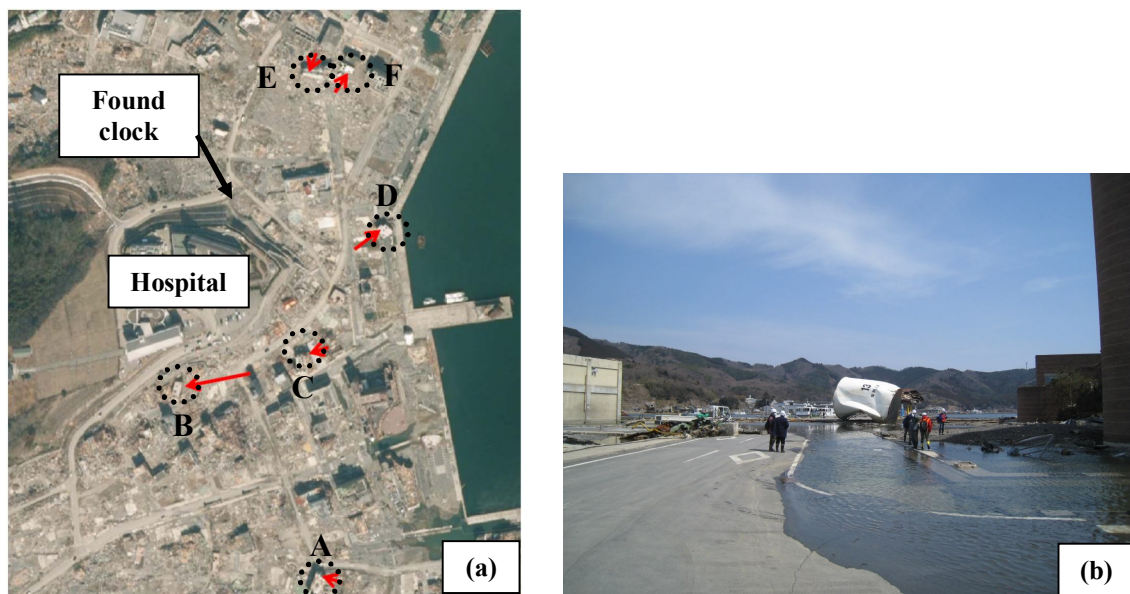


Figure 3 (a) Area map of Onagawa town and location of six overturned buildings A to F (6/4/2011) and (b) Land subsidence causing submerged land by sea water (29/3/2011)

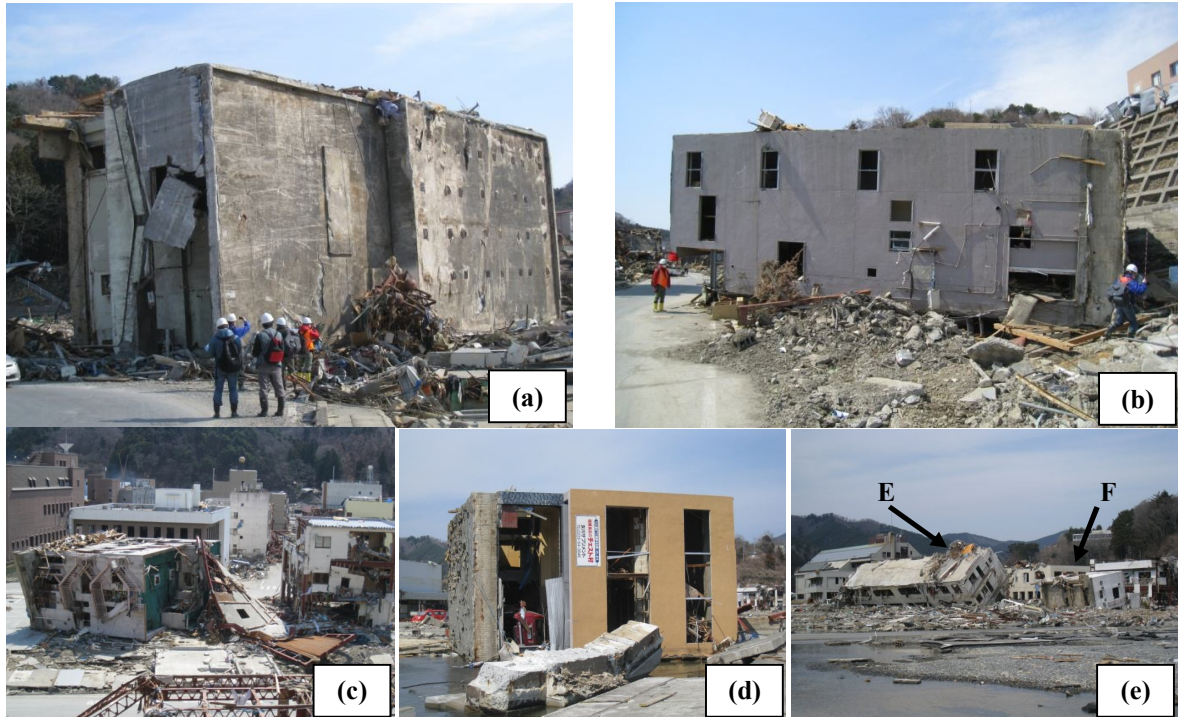


Figure 4 Overturned buildings in Onagawa namely A, B, C, D, E and F which some were moved up to 70 m (29/3/2011)

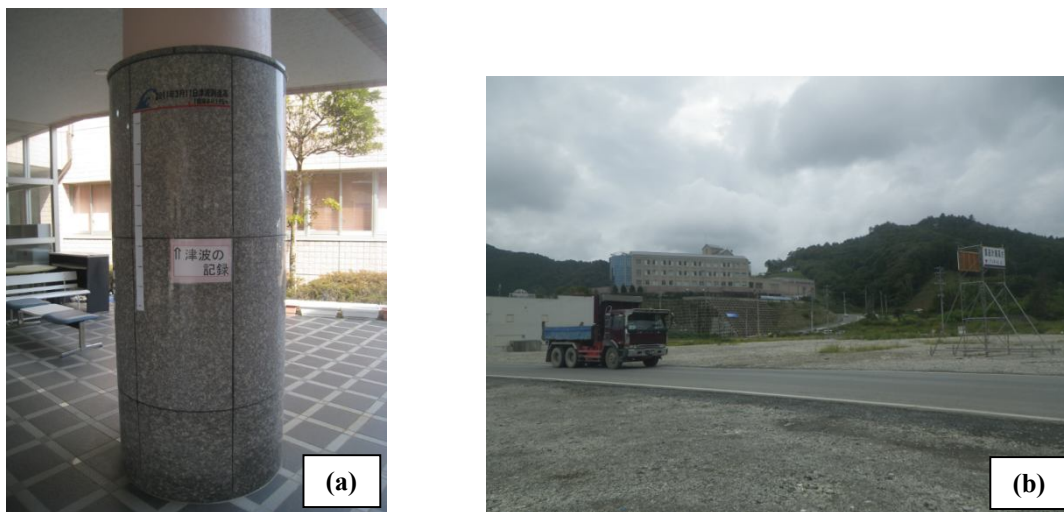


Figure 5 (a) Tsunami inundation mark (16/3/2012) and (b) Increase of road elevation (3/10/2012)

6. Kadonowaki elementary school, Ishinomaki city

Category	Outline of Damage
Casualties & Missing	3,647 (Dead: 2,978)
Tsunami inundated area	73km ² (13% of the city)
Damaged houses	53,742 (70% of housing)
Damaged Agricultural field	1,800 ha
Debris	6,163,000 t (100 yr.eq)

Ishinomaki city was protected by breakwaters, seawalls and control forests. Based on a visual inspection from satellite images, washed-away building probability in the zone outside breakwaters was as high as 88.4% whereas it was of only 42.8% inside breakwaters zone. Although the damage to breakwaters was not large, the seawalls were seriously damaged by erosion on their back side. However, these structures were able to protect the control forests behind them (Fig. 6). The tsunami height measured around the control forests was 7-8 m. The populated residential area behind the control forest was generally less damaged on the outside. This shows a reduction effect of the control forest. Figure 7(a)-(d) presents a very good example during the survey of the fragility of each structural type under the same tsunami inundation depth of 4 m. Only broken windows were found for the RC building in Fig. 7(b) and some walls and columns were destroyed in the 2-story wooden house in Fig. 7(c); however, the 1-story wooden house was completely collapsed in Fig. 7(d). Tsunami also caused fire in wide areas on Ishinomaki. One of them is the fire at Kadonowaki elementary school (Fig.8(a)). The fire was first occurred by electrical short in a car battery. Then the car was flown as debris to the school enlarging the fire area. However, all teachers and children had already evacuated to the hill behind the school via their evacuation route before the tsunami arrived. Fig. 8(b) shows example of tsunami inundation mark in Ishinomaki city.

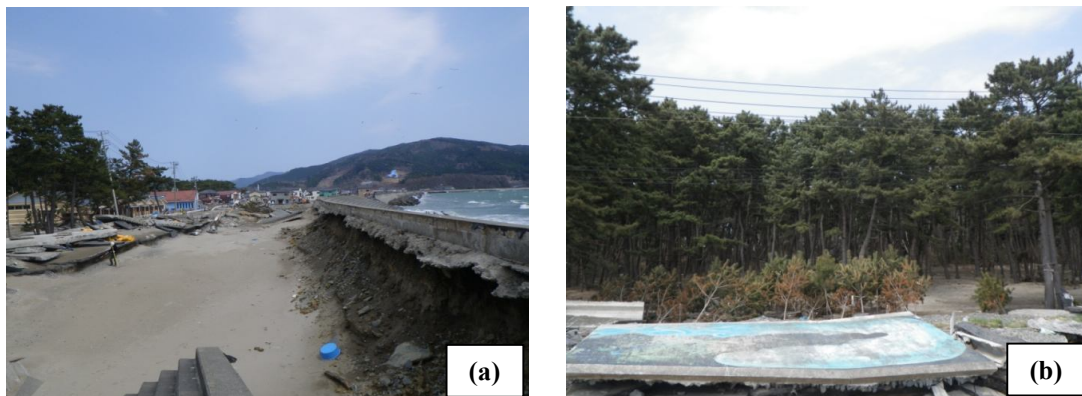


Figure 6 (a) Damaged seawall foundation (26/4/2011) and (b) Survival of most pine trees after the tsunami in Ishinomaki city (26/4/2011)

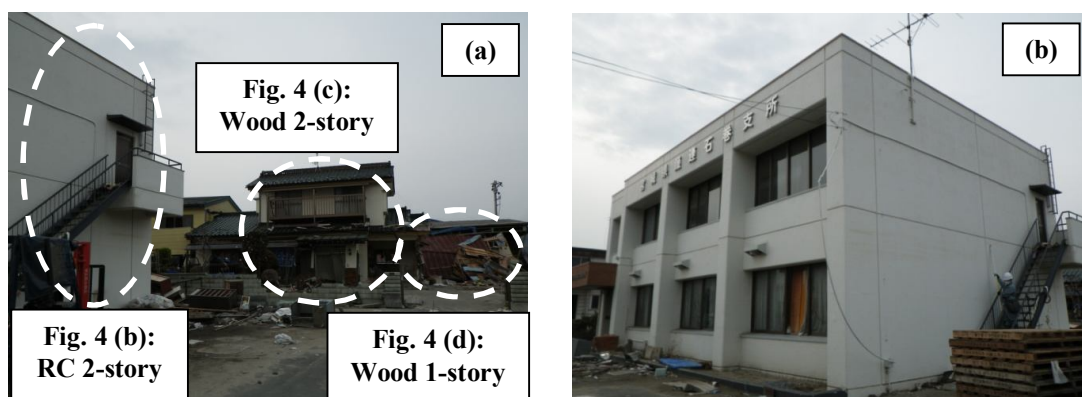


Figure 7 (a) Damage condition of a RC building, 2-story wooden house and 1-story wooden house under the same inundation depth of 4 m in Ishinomaki city and (b) RC building

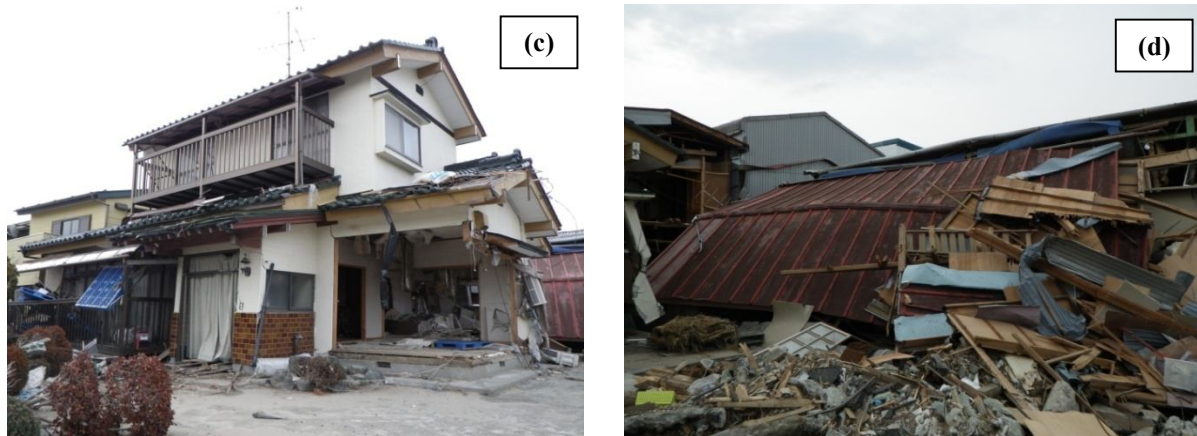


Figure 7 (c) Damage conditions of a 2-story wooden house and (d) 1-story wooden house

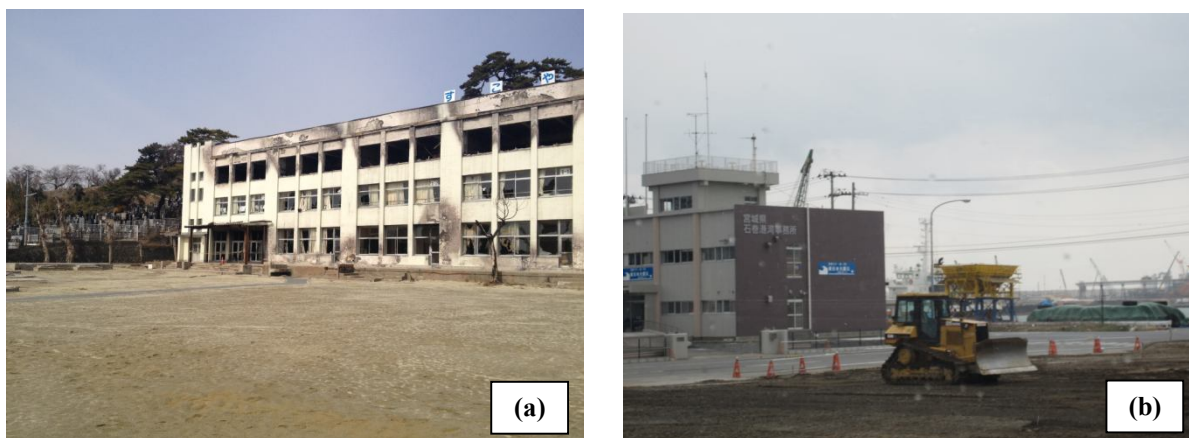


Figure 8 (a) Kadonowaki elementary school (16/3/2012) and (b) Tsunami inundation mark (26/3/2012)

7. Namiwake shrine, Sendai city

The Namiwake shrine is a monument in the Sendai area. It is located approximately 5.5 km from the sea in a low-lying area in the Wakabayashi ward of Sendai city. Namiwake was originally built in 1703 (Fig. 9).

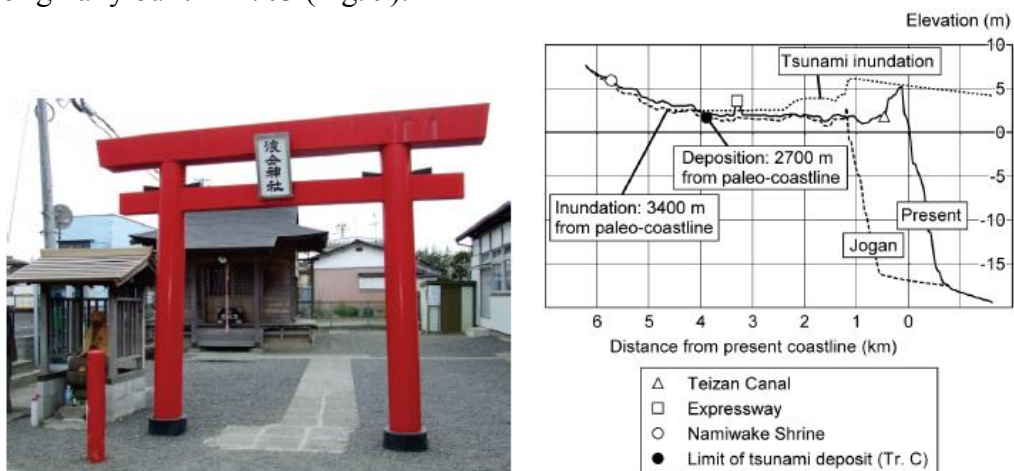


Figure 9 (a) Namiwake shrine and (b) Topographic profile of the Sendai plain and inundation by the Jogan tsunami (Sugawara et al., 2010)

Many flood and tsunami disasters have occurred in this area in the past. In the 1611 Keicho event, the tsunami inundated the shrine's original site, and approximately 1,700 people were killed. At one site, the tsunami wave, which approached from the East, was split in the North-South direction; at that time, people believed that the tsunami was created by the God of the sea. In 1835, the shrine was moved to the actual site to protect it from the next tsunami; it was given the name "Namiwake" ("Nami" means wave and "Wake" means separate) and is viewed as a symbol of tsunami prevention. In fact, also deposits from the 869 Jogan tsunami were found 200-300 m from the front of the shrine (Fig. 10).

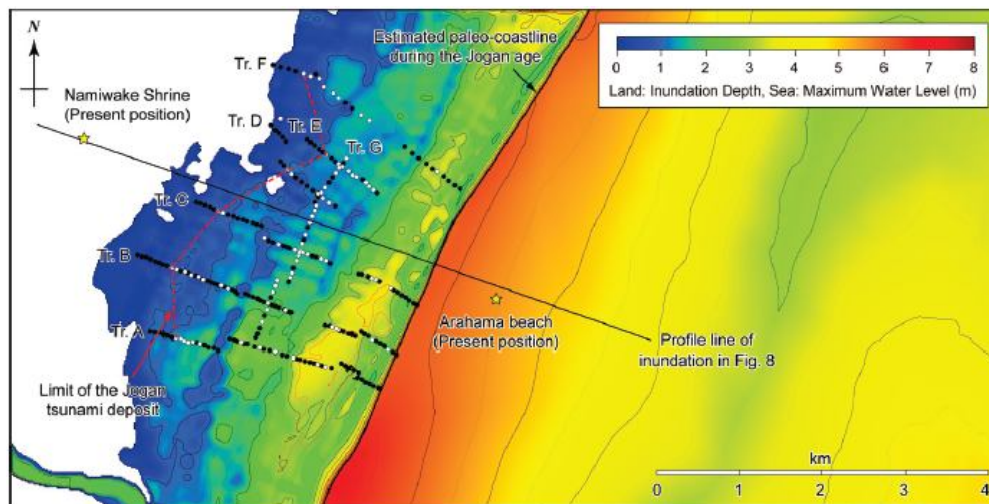


Figure 10 Locations of excavation sites and distribution of the Jogan tsunami deposit

8. Arahama village, Wakabayashi ward, Sendai city

Arahama is a populated village of the Wakabayashi area of Sendai city in the Miyagi Prefecture. It is located between the Natori and the Nanakita rivers, six kilometers south of Sendai Port. A total of 2,704 residents (Census, 2010) lived in this area; after the 2011 tsunami, Sendai city bureau reported a total of 2,421 residents (Census, 2011). The discounted 283 might be casualties. After the earthquake local media reported between 200 to 300 victims found in the area. Tsunami arrived around one hour after the earthquake with maximum wave height of 10 m and inundated 5 km inland, around ten times of the expected Miyagi-oki tsunami. Arahama is provided with not so many high reinforced concrete buildings; however the only official tsunami evacuation building in the area is the Arahama Elementary School of four stories and accessible roof. It remained after the earthquake and tsunami sheltering around 520 evacuees.



Figure 11 **Left:** Arahama before (*Google Earth*); **Right:** Arahama after (*Google Earth*)



Figure 12 Videos show inundation heights and RC buildings standing tsunami force



Figure 13 Adventure Park in Arahama. 400m from shoreline. Tsunami did not overtop this area and continue until 4km inland. 5 persons evacuated here (2 staff members and 3 locals). Tsunami height was around 10m.

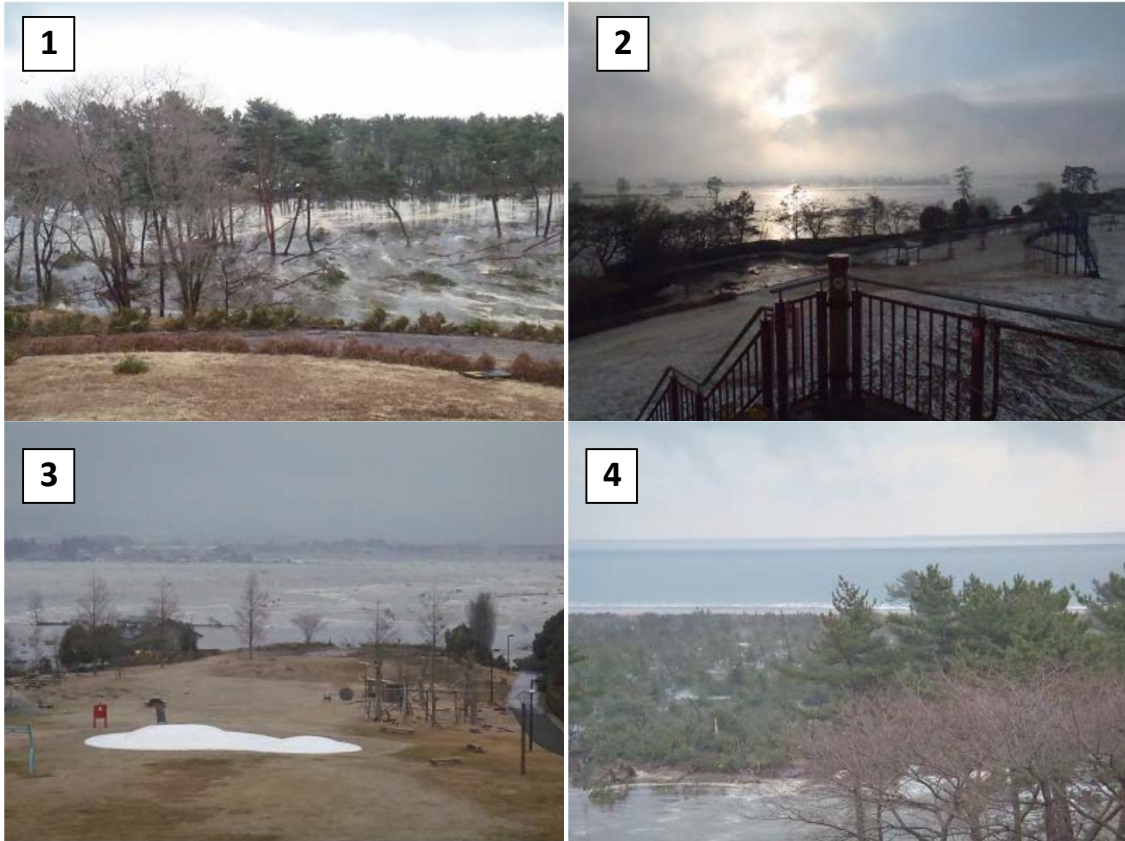


Figure 13 (Continued)

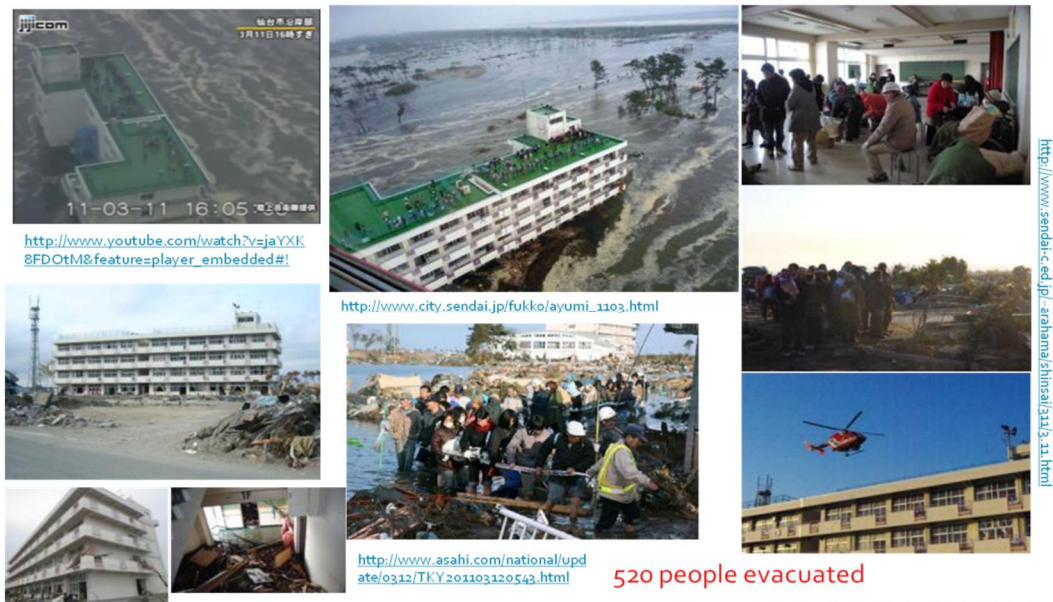


Figure 14 Arahama Elementary School.



Figure 15 Interview to Chief of Nursing Home in Arahama



Figure 16 **Left:** Hazard Map; **Right:** Seawall



Figure 17 (a) Staircase built for access to the surface of the Sendai-East expressway and (b) New tsunami memorial (13/3/2013)

9. Yuriage town, Natori city

Yuriage area is located in Natori city, Miyagi. It is a former high-activity fishery port with only 7,000 residents. Yuriage is near the Natori River; therefore tsunami inundation ran up faster. There were many deaths reported here including firefighters on duty. 890 dead, 231 missing and 310 damaged roads were reported. Around 1,588 ha of agricultural area were damaged. Tsunami height was of 8 meters and 45min arrival.



Figure 18 **Left:** Yuriage 2008; **Right:** Yuriage 2011



Figure 19 **Left:** Hiyoriyama; **Right:** Yuriage town view



Figure 20 **Left:** Fish market; **Right:** Fishery port

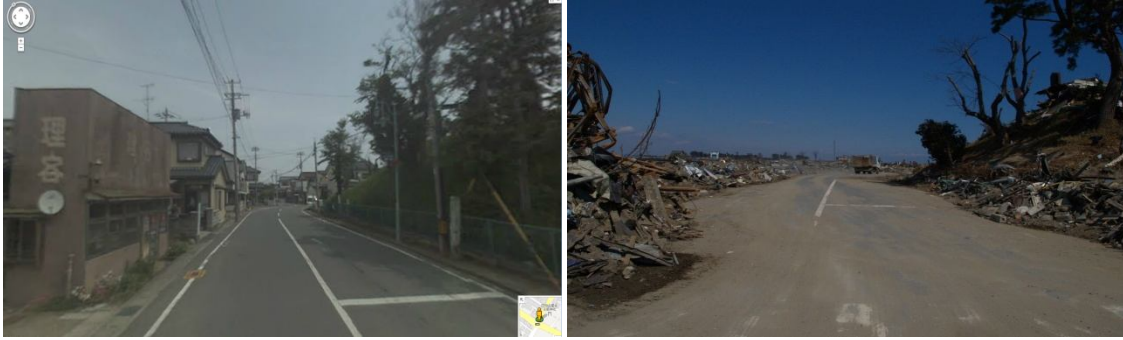


Figure 21 **Left:** Hiyoriyama before (*Google street view*); **Right:** Hiyoriyama after (*Panoramio*)



Figure 22 **Left:** An aerial view of Yuriage, the most devastated area in Natori city, in the direction from south to north. The Teizan Canal, cut over 400 years ago, is seen in the middle. The right side of the canal is Yuriage 6-chome, and the left side is Yuriage 7-chome; **Right:** Yuriage is a densely populated area. The nursing home Urayasu is seen in the front. After the tsunami attack, the area was flooded and the nursing home was isolated for 4 days. Most of the houses in the area in this photo were washed away. (*Self Defense Force*)



Figure 23 **Left:** An aerial view of Yuriage in the direction from north to south. The floodgate at the bottom in the photo is the entry point from Natori river to the Teizan Canal. Many bodies and vehicles lie at the bottom of water in this area. Rescue divers have been in search and rescue work since March 19. **Right:** Yuriage Junior High School served as a temporary evacuation center. Many cars and fishing boats were swept into the school yard. (*Self Defense Force*)



Figure 24 **Left:** Tsunami inundation mark on the pedestrian bridge that saved many lives in Yuriage (30/5/2012); **Right:** About 3 m land elevation in Yuriage will be increased as shown in the model

10. Sendai Airport, Natori city

Sendai Airport is located 13.6 km southeast of Sendai city in Natori, Miyagi. It was built in 1940 by the Imperial Japanese Army, turned into national airport in 1957 and then upgraded to international airport in 1990. In 2011, the airport was first damaged by the earthquake and tsunami. Inundation reached up to some areas of the 2nd level of passenger terminal (3.5m). All services were stopped at the moment and 1,300 people stranded in the terminal until March 13th. It was reopened only for tsunami response flights on March 17th. The US Air Force and Japan Self-Defense forces removed debris until the airport reopened to limited commercial traffic on April 13th. Regular domestic flights resumed on July 25th and most international flights on October 2011.



Figure 25 Damages to Sendai Airport (**Left:** before [www.japan-i.jp]; **Right:** after)



Figure 26 **Left:** South to North; **Right:** North to South [www.photos.oregonlive.com]



Figure 27 **Left:** Us Army; **Right:** Airport June, 2011 [AP/Kyodo News]



Figure 28 **Left:** Tsunami inundation mark in the Sendai airport (25/1/2012); **Right:** display of tsunami damage in the Sendai airport train station (25/1/2012)

11. Thousand years hope hill, Iwanuma city

Iwanuma city was one of the cities that had a coastal pine tree forest along their coast linked from the northern part of Miyagi prefecture. However, the greenbelt was heavily damaged and the city has a plan to replant it again. Besides, they have an idea to construct an artificial hill which height varies from 10-15 m using tsunami debris. The purpose of the hill is to use as a memorial park and evacuation place as an escape hill for a future tsunami called “Hill of thousand years hope” (Iwanuma city, 2011). This hill will also help with new seawall to reduce tsunami energy for the new populated area behind it. The town has a plan to use solar energy in a large scale to build an eco-compact city project.

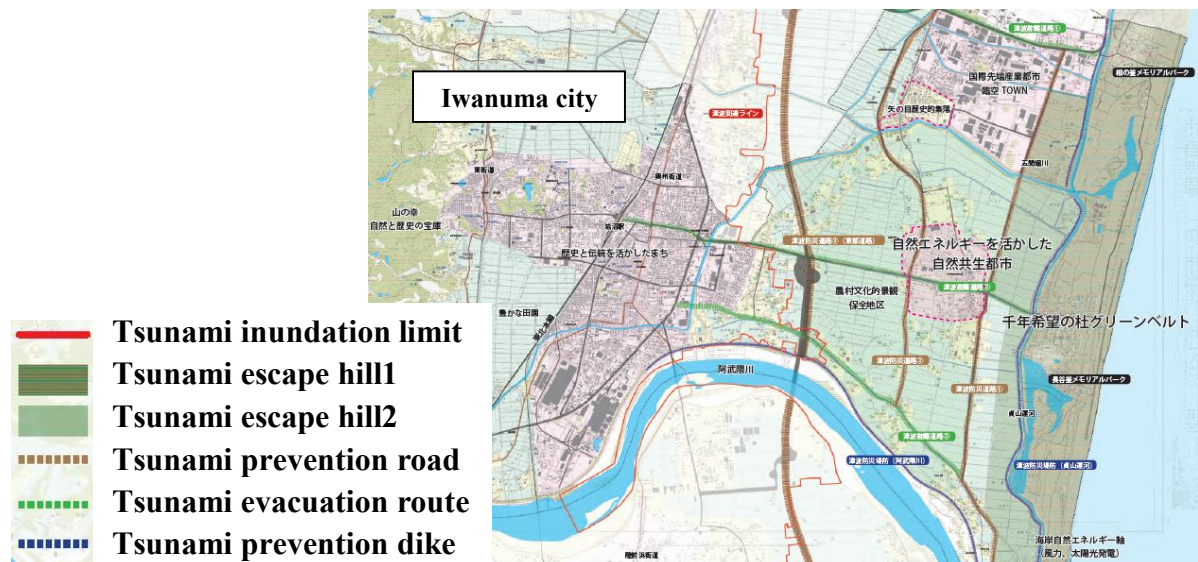


Figure 29 Reconstruction plan of Iwanuma city

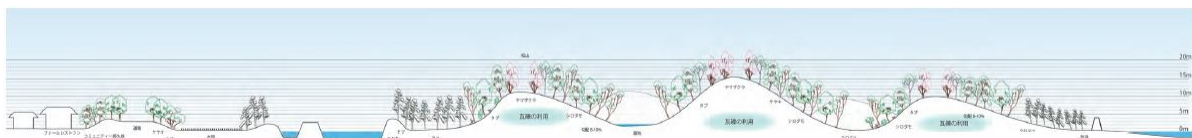


Figure 30 Cross section of the hill of thousand years hope



Figure 31 **Left:** Experiment model of the thousand years hope hill (3/8/2012); **Right:** Tsunami inundation mark in Iwanuma city area (3/8/2012)

12. Sengan shrine, Iwanuma city

There is a historical record showing that the word “tsunami” was first used after the 1611 Keicho Sanriku tsunami that caused a wide range of damage in Sendai plain areas. The area was controlled by the great lord “Date Masamune”. At that time, Masamune asked his samurais for fish who were then swept by the tsunami and could survived by getting struck on a pine tree under the Sengan mountain. Old Abukuma River was overflowed and disappeared after the town reconstruction.



Aides then tell of the 1611 disaster. A so-called tsunami (*yo ni tsunami to yu'u*) has drowned 5,000 people in the territory of Masamune and 3,000 persons and horses (*jimba*) in the Nambu clan's domain (Morioka-han) and in adjoining Tsugaru. Along with this news comes a story about a samurai who survived the tsunami by faithfully serving his daimyo:

Masamune wants fish. Two samurai receive the order. They round up fishermen. The fishermen balk because the sea has a strange color and the skies look ominous. One of the samurai insists on obeying the daimyo's order. All set out in a boat. Soon it meets the tsunami, which drives it inland into the crown of a pine tree. The waves also sweep away entire villages along the shore. Later, after the water recedes, the men clamber down from the tree. Scanning the shore, they realize that they too would have been swept away had they not gone fishing for Masamune. The two samurai return to Masamune, who bestows a gift upon the one who had insisted on following orders.

Figure 32 **Left**: Samurai left Sendai castle to catch fish for Masamune. They were swept by the tsunami which dragged them to Sengan Mountain; **Right**: Story at that time (Tsuji, 2011)

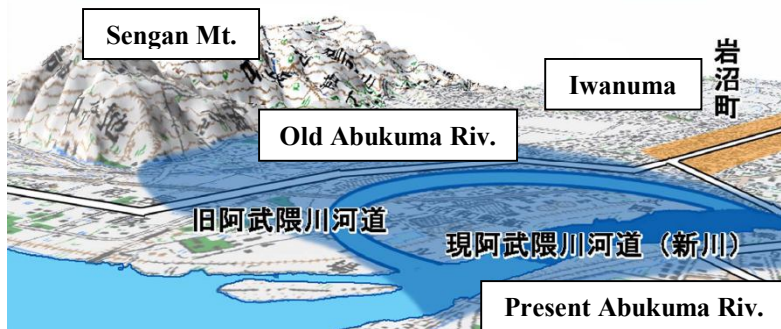


Figure 33: Historical map in Sengan Mountain area showing location of the old Abukuma River and estimated inundation area by the 1611 tsunami is shown in blue (Ebina, 2011)

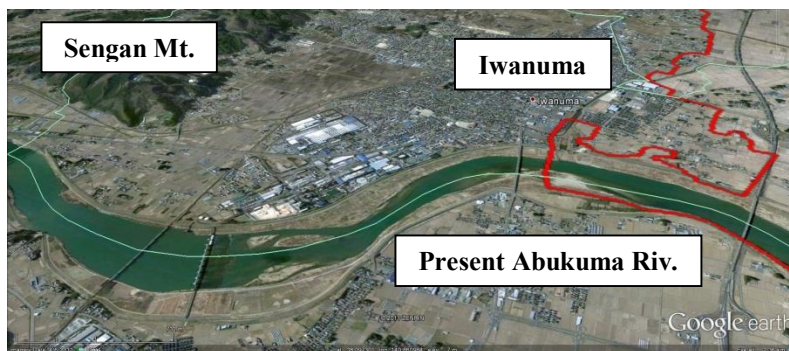


Figure 34: Present map in Sengan Mountain area where the old Abukuma River was disappeared (Red line shows tsunami inundation limit of the 2011 tsunami). It can be noted that coast line at the time of 1611 tsunami was about 400 m more inland

More information on our publications

Suppasri, A., Shuto, N., Imamura, F., Koshimura, S., Mas, E. and Yalciner, A.C., Lessons learned from the 2011 Great East Japan tsunami: Performance of tsunami countermeasures, coastal buildings and tsunami evacuation in Japan, Pure and Applied Geophysics (published online)

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