Minami-Sanriku town field trip (17 March 2013)

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1. Background of tsunamis in Tohoku region

There were three major tsunami events that attacked Tohoku region including Minama-Sanriku town in the last century. They are 1896 Meiji-Sanriku, 1933 Showa-Sanriku and 1960 Chile tsunami respectively (Fig. 1 and Table 1). The 1896 event was a tsunami-earthquake event, a small shake causing large tsunami. This event was occurred at night and thus most of residence ignored evacuation. The second event happened 37 years later in 1933. Though the earthquake occurred at night again but total loss was significantly reduced owing to the experience from the previous event and smaller tsunami height. At the same time, there was still some misunderstanding based on the experience from the 1896 event that 'only' small shake generates large tsunami that led some people ignored the evacuation in the 1933 event. The third event is the 1960 Chili tsunami. It was generated by the great earthquake in Chile 1960 propagated across the Pacific Ocean and attacked the Tohoku coast in the early morning of the following day. At that time, there was no available knowledge for the far-field tsunami and their related protection system.

Before the 2011 event, there was a 99 % probability that another M 7.5-8.0 earthquake would strike off the Miyagi Prefecture within the next 30 years. 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, which may cause damage to the Sanriku coast and the Sendai plain. However, the 2011 tsunami was generated by M9.0 earthquake which caused much more damage than the previous estimation.

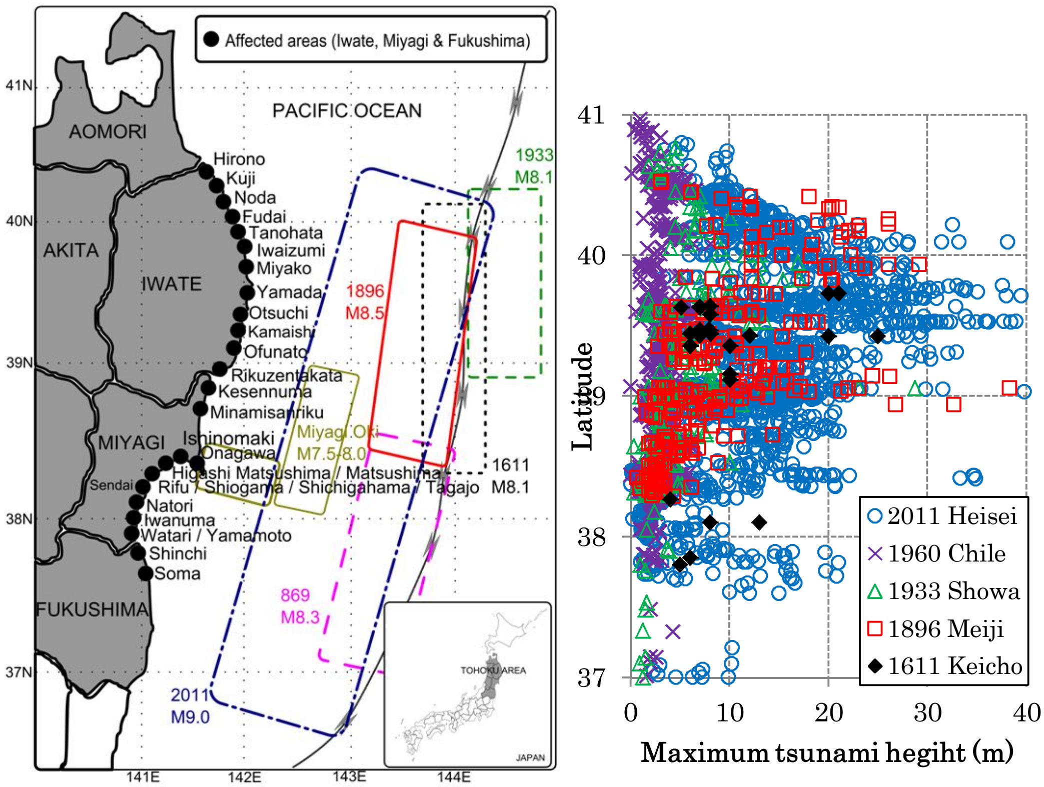


Fig. 1 Historical tsunamis in the Sanriku area and their maximum tsunami heights

2. Route and schedule

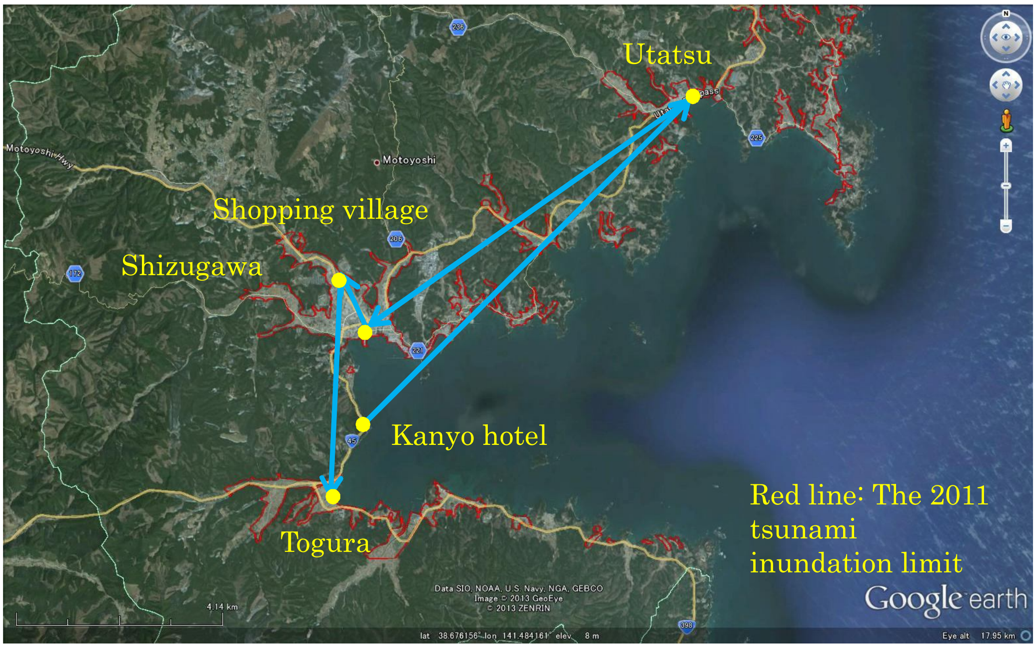


Fig. 2 Area map of Minami-Sanriku town and field trip route

Table 2 Field trip schedule

Time	Area	Activities
9:00 – 9:15	Leave for Utazu	
9:15 – 10:00	Utatsu area	Utatsu Ohashi bridge, temporary houses and surrounding areas
10:00 – 10:15	Leave for Shizugawa	
10:15 – 11:45	Shizugawa area	Tsunami gate, memorial stones, disaster prevention building and JR train station, Shizugawa Elementary School
11:45 – 12:00	Leave for shopping village	
12:00 – 13:30	Shopping village	Lunch and souvenir
13:30 – 13:45	Leave for Togura	
13:45 – 14:00	Togura area	Tsunami mark and damage areas
14:00	Leave for Sendai	

3. Minami-Sanriku before the 2011 tsunami

Minami-Sanriku is a town with prosperous fisheries and a population of about 18,000. In Minami-Sanriku, the culture of a silver salmon, scallops, and oysters are prosperous. Because of their economic importance, tsunami–induced damage to these aqua-cultural facilities is a grave concern. The 1960 Chilean Tsunami caused great damage to Minami-Sanriku. On the occasion of the 30th anniversary of the 1960 Chilean Tsunami, a Moai monument was received as a symbol of friendship with Chile, which also had a stricken area. The Moai monument was installed in Matsubara Park (Fig. 3-left) where inundation signs (Fig. 3-right) were also installed. Tidal gate was installed near to the park and a private apartment nearby the park is designated as evacuation shelter (Fig. 4-right). The 1896 Meiji-Sanriku Tsunami height was 7 m here; 441 people were killed. The 1960 Chilean Tsunami height was 5.5 m. It washed away or destroyed 965 houses.

Fig. 3 Moai monument of the 1960 Chile tsunami (27/5/2008) and tsunami inundation mark of the Chile tsunami (27/5/2008)

Fig. 4 Automatic tidal gate (27/5/2008) and evacuation building (27/5/2008)

4. Minami-Sanriku after the 2011 tsunami

In Minami-Sanriku, seawalls (+4.6 m) and tidal gates (+10 m) were constructed after the 1960 Chile tsunami. The town was fully protected from the tsunami generated in Tokachi Sea in the east coast of Hokkaido in 1968. However, these were not high enough for the 2011 tsunami which approximately greater than 10 m in every area. About 52% of the town area was inundated and destroyed 3,301 houses. The total reported death and missing is 695 from the approximated population inside inundation area of 14,389 (Total = 17,666). Total number of evacuee was 9,753 during the peak in 20th March 2011.

Table 1 Summary of major tsunamis in Tohoku region and impact to Minami-Sanriku

Event	Time	M_w	Tsunami (m)	Casualty	Damaged house
Meiji	15 Jun 1896 8:10 PM	8.0	12.6	Shizugawa = 441 Utatsu = 799 Total = 1,240	Shizugawa = 267 Utatsu = 306 Total = 573
Showa	3 Mar 1933 3:05 AM	8.4	10.5	Shizugawa = 1 Utatsu = 86 Total = 87	Shizugawa = 16 Utatsu = 72 Total = 88
Chile	24 May 1960 4:30 AM	9.5	5.6	Shizugawa = 41 Utatsu = 0 Total = 41	Shizugawa = 1,329 Utatsu = 13 Total = 1,342
Tohoku	11 March 2011 3:20 PM	9.0	23.9	Total = 695	Total = 3,301

4.1 Utatsu area

Utatsu Ohashi Bridge: VDO taken by survivors shows the moment of tsunami attacking Utatsu area and the Utatsu Ohashi Bridge (Fig. 5) and tsunami also came from the back side. The destroyed bridge is a typical example damage type of many bridges found in the 2011 event. Bridges were designed well enough against earthquake force but not for the hydrodynamic force including uplifting force by tsunami.

Mishima Shrine: A shrine called Mishima shrine (Fig. 6–right) that survived the 2011 tsunami located in a hill slope near to the bridge. There was large number of shrines that survived the tsunami. One of the main reasons is that experiences of historical tsunamis must be transferred as the shrines were built or re-built outside tsunami inundation zone of the historical events.

Fig. 5 Utatsu Ohashi Bridge (28/7/2012)

Fig. 6 Tsunami debris (28/7/2012) and Mishima Shrine (28/7/2012)

4.2 Shiuzugawa and Togura area

Tidal gate: Tidal gates were installed in some places in Minami-Sanriku town similar to other areas in the Sanriku coast as to protect and reduce tsunami damage. However, all of the tidal gates in Minami-Sanriku could not help to protect the town. Fig. 7-left shows an example of four gates with 4.5 m height and 11.0 m in total span length. On the other hand, there was one place that the gate could fully help to protect the village called Fudai as the number of casualty was zero.

Tsunami memorial stone: Such as stone monuments, can be found in many areas along the Sanriku coast. In Minami-Sanriku town, there are monuments for the 1896 Meiji, the 1933 Showa and the 1960 Chile tsunamis. The message on the stone monument for the 1960 Chile tsunami reads "to be cautious of an abnormal receding wave". However, these monuments, including a 2.6 m high monument for the 1960 Chile tsunami were destroyed by the 2011 Tohoku tsunami.

Fig. 7 Tsunami gate (3/9/2011) and tsunami memorial stone (3/9/2011)

Disaster prevention building: Similar to other areas officers and staff members that were stationed at the disaster prevention building (Fig. 8-left) in Minami-Sanriku Only 10 people of the 130 employee of the town hall (including the Mayor of Minami-Sanriku town were survived by reaching the top floor of this building). The remaining damaged building is considered as one of 37 structures in Miyagi prefecture proposed to be preserved as memorials of the 2011 event and to maintain tsunami awareness. During the 2011 tsunami, Miki Endo (遠藤未希), a 25 year old employed by the town's Crisis Management Department sacrificed her life to continue broadcast disaster advisories and warnings over the community loudspeaker system, located in the Crisis Management Department's building, as the tsunami overwhelmed it.

JR train station: Many train lines and train stations operated by the Japan Railway company (JR) were damaged or destroyed. There are seven main lines, Hachinohe, Yamada, Ofunato, Kesennuma, Ishinomaki, Senseki and Joban line. JR reported that there were 48 stations damaged or washed away and 99 stations were inspected and repaired. Total damage to the train line was 1,780 places covering the total length of 325 km. Shizugawa station (Fig. 8-right) belongs to the Kesennuma line. The station was washed away and the train line was totally destroyed. Most typical damage to the train is that the train was derailed or overturned.

Fig. 8 Disaster prevention building (3/9/2011) and JR train station (3/9/2011)

Shizugawa Elementary School: This school was used by tsunami evacuee for several weeks, and in the first week they wrote ‘SOS’ sign in the field to attract the rescue. The school was an example of a shelter that survived the tsunami. However, there were many example of an unfortunate result from the unexpected tsunami such as Okawa primary school which located near the mouth of the Kitakami River in Ishinomaki city where the tsunami claimed 74 out of a total of 108 children and 10 staff.

Minami-Sanriku Sun Sun shopping village: The shopping village was opened in Feb 2012 using the pre-fabricated structure similar to a typical temporary house for tsunami affected residents. The area comprises of 30 shops including fresh aqua-agricultural products and various kind of restaurant using ingredients from Minami-Sanriku town. There was also some event took place here to promote the town’s reconstruction.

Fig. 9 Shizugawa Elementary School and shopping village (28/7/2012)

Tsunami inundation sign: Tsunami inundation signs of the 1960 Chile tsunami were put in many places in the Sanriku coast including the Minami-Sanriku town. Most of the heights of the 1960 event were lower than 5 m in general, however, greater than 10 m for the 2011 event. At present, Miyagi prefecture has already prepared and put the inundation sign for the 2011 event in many places such as survived buildings and structures. These signs are very important to maintain tsunami awareness and recall about tsunami hazard in each tsunami affected area.

Fig. 10 Tsunami inundation sign (3/9/2011)

Appendix: Vulnerability of the 2011 tsunami for supporting the reconstruction

Human fatality

The great one in 1896 Meiji-Sanriku tsunami had an average tsunami height greater than 10 m with also high fatality ratio. After 37 years from the 1896 event, 1933 Showa-Sanriku had smaller fatality ratio even they also experienced large tsunami height. The fatality ratio for the 2011 Tohoku tsunami in Sanriku coast is similar to the 1933 event as they were attacked by great tsunami but experience may help decreasing the fatality ratio. For the 2011 Tohoku tsunami in Sendai Plain coast is comparatively smaller in tsunami height but caused somewhat high fatality ratio. This figure shows importance of experience in reducing human loss by tsunami.

Fishery boat

Damaged data of fishery boat due to three historical tsunamis in Japan namely, 1896 Meiji-Sanriku, 1933 Showa-Sanriku and 1983 Japan Sea tsunami were available. Ratios of damaged or washed away boats were then calculated against reported maximum tsunami height for each village. Based on the results obtained from the previous three events, it can concluded that damage is observed in small boat when tsunami height is greater than 2 m and totally damage when the height is greater than 5 m. However, half of ship is still has less damage even the height is greater than 5 m. These results are similar to what we obtained from the 2011 event. Fishery boats that is larger than 5 tons show higher performance.

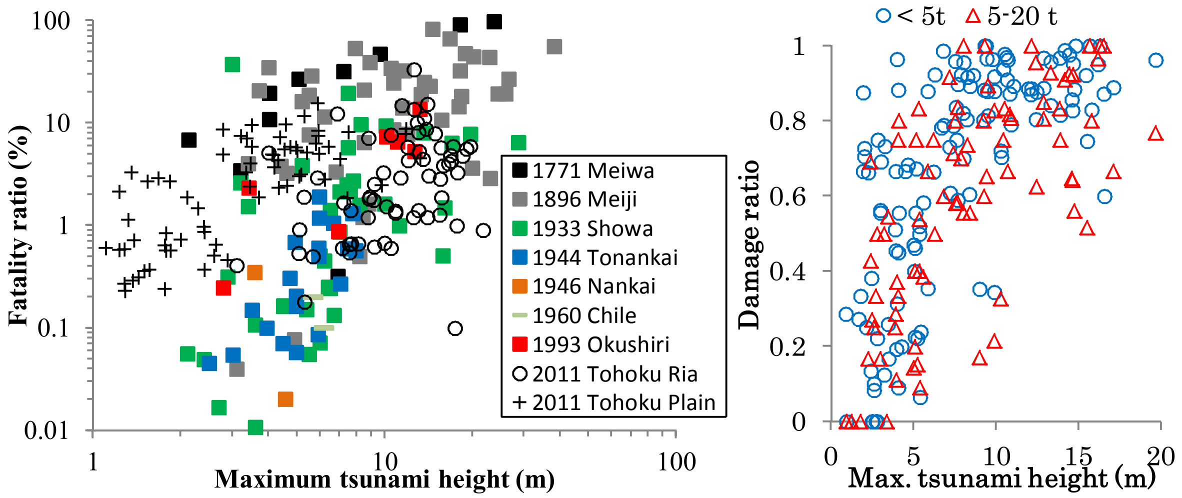


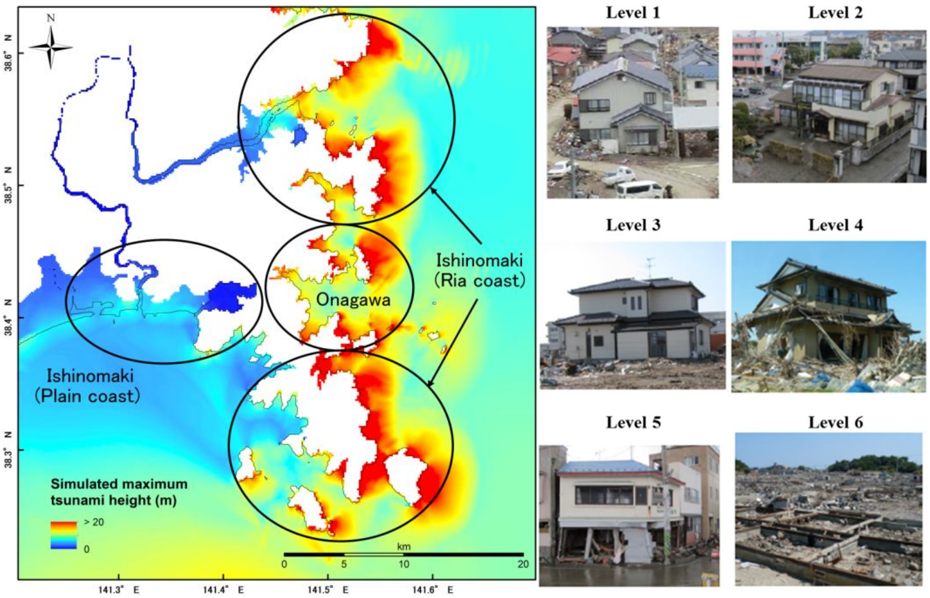
Fig. 11 Tsunami fatality ratio (2011 and historical events) and fishery boat damage ratio (2011 event) in Japan

Housing and building

Tsunami fragility curves were developed based on data for 63,605 buildings in Ishinomaki city and can be summarized as below.

- Coastal topography: For a given inundation depth, a higher damage probability exists on the ria coast due to higher flow velocity. The characteristic of building damage due to tsunami in the plain area are similar to those observed due to flooding in Japan.
- Building function: Performance by building function depends primarily on the building materials. The size and complexity of buildings might also be related to building performance, given that residential building was found to be the weakest.
- Structural material: It is clear that RC and steel buildings performed better than wood and masonry buildings.
- Number of stories: Better performance was observed for buildings with three or more

stories, followed by buildings with two stories and buildings with one story. The performance of buildings with three or more stories is particularly significant.
- Construction year: Buildings constructed after 1981 performed slightly better than buildings constructed between 1971 and 1981. The earthquake-resistant building code in force at the time of construction has almost no relation to tsunami damage.



LV1: Minor damage (To be used after minor clean up)
LV2: Moderate damage (To be used after moderate reparation)
LV3: Major damage (To be used after major reparation)
LV4: Complete damage (To be used after complete reparation and retrofitting)
LV5: Collapsed (Non-repairable)
LV6: Washed away (Non-repairable)

Fig. 12 Area map of Ishinomaki city and explanation of building damage level

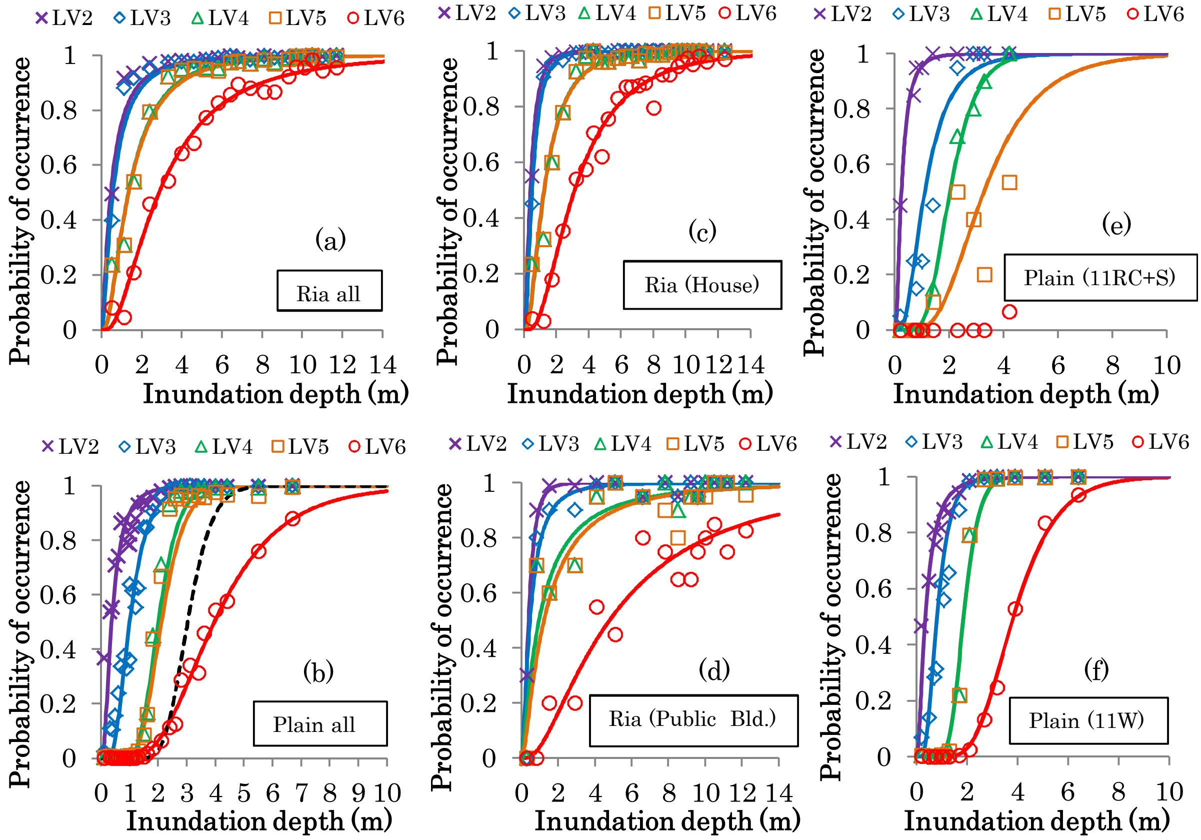


Fig. 13 Comparison of tsunami fragility curves for ria (a), plain coast (b), residential house (c), public building (d), RC or steel house with (e) and wooden house

Pedestrian bridge

Pedestrian bridges played important role as they saved many people's lives during the 2011 tsunami and can be used as an emergency tsunami evacuation place in the future. Total of 68 pedestrian bridges including the ones in train station from six prefectures along the East coast of Japan were analyzed. Damage is classified as a) heavily damage (washed away), b) slightly damage (only stair remained) and c) no damage (inundated only). We found from the results that the pedestrian bridge will start to be damaged by tsunami if 1) the tsunami flow depth is higher (1.5 times) than the bridge's height or 2) if the location of pedestrian bridge relative from the shoreline is 1/10 of the maximum inundation in land.

No	Prefecture	P. Bridge	T. Bridge	Total
1	Hokkaido	4	0	4
2	Aomori	0	1	1
3	Iwate	11	2	13
4	Miyagi	22	8	30
5	Fukushima	10	2	12
6	Ibaraki	0	8	8
	Total			68

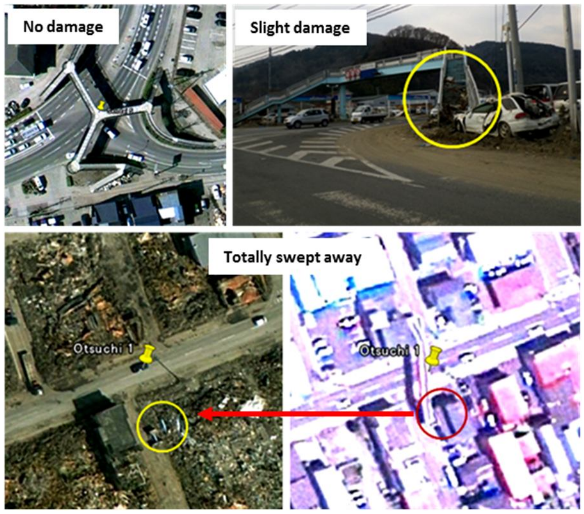


Fig. 14 Damage to pedestrian bridge and their damage classification

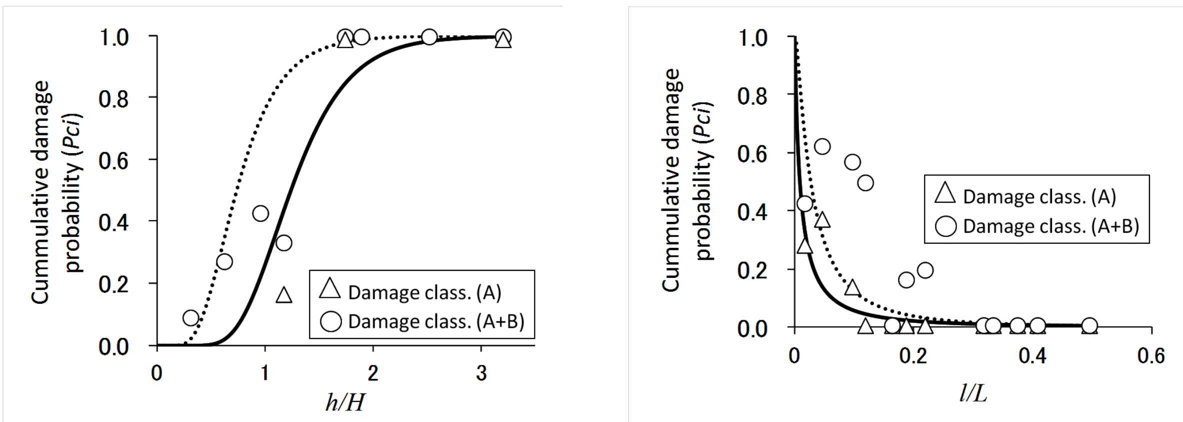


Fig. 15 Fragility curves of pedestrain bridge shown against the ratio of tsunami flow depth (h) over the bridge's height and distance from shoreline to the bridge (l) over the maximum inundation distance (L)

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