# Guidebook of World Bank and JICA Field Trip

## Nobiru, Matsushima, Shiogama, Shichigahama,

## Tagajo and Sendai port

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Prepared by

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# Contents

Table 1 Schedule

| Time | | Course | | Location | Details |
|---|---|---|---|---|---|
| | | World Bank | JICA | | |
| 6:28 | 8:16 | Tokyo --> Sendai | | | Hayate 153 |
| 8:30 | 10:00 | Depart JR Sendai Station | | | |
| 10:00 | 10:30 | Survey 1: Nobiru | | | Seawall / Control forest / Train |
| 11:00 | 11:45 | Survey 1: Matsushima | | | Seawall / Evacuation sign |
| 11:45 | 12:30 | Lunch | | Beef tongue restaurant "Rikyu" | |
| 12:50 | 13:20 | Survey 2: Shiogama | | | Evacuation building |
| 13:40 | 14:30 | Survey 2: Shichigahama | | | Breakwater / meeting staff |
| 14:30 | 15:00 | Survey 2: Tagajo | | on car | Housing damage |
| 15:00 | 15:20 | Survey 2: Sendai port | | | Elevated park/ containner |
| 15:20 | 16:25 | Move to Tohoku University | | | |
| 16:30 | 17:00 | Visit Prof. Imamura | | Tohoku University | |
| 17:00 | 18:00 | Arrive JR Sendai Station | | | |
| 18:33 | 20:24 | Sendai --> Tokyo | | | Hayate 222 |


Fig. 1 Field trip area map and route (Sendai → Nobiru → Matsushima → Shiogama →Shichigahama → Tagajo → Sendai port)

**Abstract:** Japan had just been hit by a tsunami generated by the largest earthquake in the history of the country. The tsunami warning systems performed well but most of the structural countermeasures were not able to withstand the tsunami since they were designed for smaller tsunami.. This paper explains about damage information collected from field surveys during four months after the March $11^{th}$ tsunami hit the North East part of Japan. The field survey covers 13 areas in Miyagi prefecture from Kesennuma city in the Northernmost to Yamamoto town in the Southernmost. The damage types are summarized for casualty, building, coastal structure and transportation facilities. Impression gained from the field survey results should be taken into consideration in the reconstruction efforts for better tsunami countermeasures in the future.

## 1. Introduction

Japan is well known country for the world's best tsunami counter measures and evacuation recognition because of the long historical tsunami experience, especially along the Sanriku coast. The Sanriku area extends northward from Sendai passing through Iwate to Aomori as a saw-toothed coastline with more than 600 km length. Because of its ria coast, the tsunami height can easily amplify more than 10 m. Therefore, numbers of large-scale structural and non-structural mitigation facilities were constructed (Abe and Imamura, 2010) in the past, especially after the 1960 Chili tsunami. In fact, Sanriku coast has experienced series of tsunamis along its history (Fig. 2 (a)) on 869 (M8.6), 1611 (M8.1), 1896 (M8.5), 1933 (M8.4) and 2011 (M9.0) (Suppasri et al., 2011b). It can probably says that there is a larger than M8.0 earthquake every 100 years, also and M8.5 every 1,000 years. Before the 2011 event, the expected occurrence of the Miyagi-oki earthquake was of more concern in this area with the estimated probability of a M7.5-8.0 will occur is 99% within 30 years. That is the highest earthquake probability in Japan. Sendai plain was considered as low tsunami risk compared to Sanriku coast. For instance, the maximum runup height from the 1896 tsunami of 38.2 m was recorded in Ofunato Bay, but only less than 5 m was recorded in Sendai (Sawai et al., 2008).

At 14:46 of 2011 March, $11^{th}$, the massive earthquake recorded in Japan occurred at N38.1, E142.9 with the magnitude of 9.0 and 24 km depth (JMA, 2011). It was followed by the aftershocks and devastating tsunami (Fig. 2 (b)). The earthquake was ranked as the fourth in the world following the 1960 Chile (M9.5), 2004 Sumatra (M9.3) and 1964 Alaska (M9.2). The earthquake had a long period (about three minutes and the largest slip is found to be around 30 m (USGS, 2011). The maximum recorded earthquake intensity was 7 (JMA, 2011). Earthquake early warning system was issued 8 seconds after a detection of the first P-wave (JMA, 2011). Tsunami warning was issued 3 minutes after the earthquake. The tsunami caused 20,000 (half of them belongs to Miyagi Prefecture) dead and missing, and more than 676,000 damaged houses and buildings. Total number of completely and moderate damaged building in Miyagi prefecture are about 70,000 and 30,000 buildings from the estimated total of 150,000 buildings in the tsunami inundated area and about 146,000 cars and 1,758 boats were damaged. Summary of estimated population in inundated area, number of death and missing, calculated death rate and reported maximum runup height is shown in Table 2. The summary of estimated household in inundated area and housing damage in different level is shown in Table 3. Relationship between maximum runup height and death rate and relationship between housing damage (completely destroyed) and death rate is shown in Fig. 3.

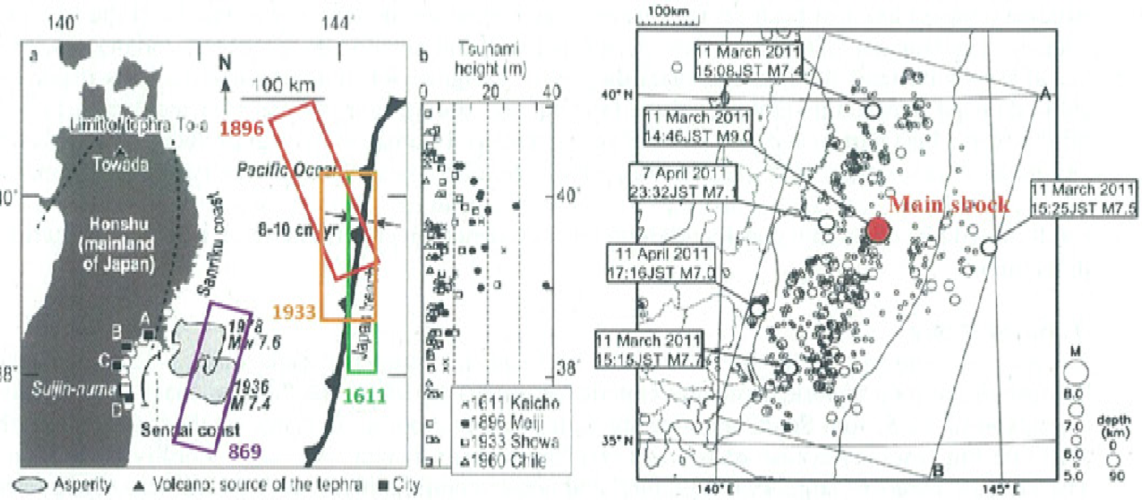


Fig. 2 (a) and (b) Tsunami height distribution of the major historical tsunamis and the expected Miyagi-Oki earthquake and location of the main shock (Sawai et al., 2008) and aftershocks of the 2011 tsunami (JMA, 2011)

Table 1 Summary of estimated population in inundated area, number of death and missing, calculated death rate and reported maximum run-up height

| Location | Estimated population in inundated area[1] | Number of death and missing[2] | Death rate (%) | Maximum runup height[3] (m) |
|---|---|---|---|---|
| Kesennuma | 40,331 | 1,487 | 3.69 | 22.2 |
| Minami-Sanriku | 14,389 | 1,199 | 8.33 | 15.5 |
| Ishinomaki | 112,276 | 5,795 | 5.16 | 16.0 |
| Onagawa | 8,048 | 902 | 11.21 | 18.4 |
| Higashi-Matsushima | 34,014 | 1,208 | 3.55 | 10.1 |
| Matsushima | 4,053 | 4 | 0.10 | 2.7 |
| Rifu | 542 | 2 | 0.37 | 2.5 |
| Shiogama | 18,718 | 22 | 0.12 | 4.6 |
| Shichigahama | 9,149 | 72 | 0.79 | 12.1 |
| Tagajo | 17,144 | 188 | 1.10 | 7.1 |
| Sendai | 29,962 | 884 | 2.95 | 9.4 |
| Natori | 12,155 | 1,027 | 8.45 | 12.0 |
| Iwanuma | 8,051 | 182 | 2.26 | 14.5 |
| Watari | 14,080 | 267 | 1.90 | 8.0 |
| Yamamoto | 8,990 | 729 | 8.11 | 13.6 |

1 Statistics Bureau, 2011
2Miyagi Prefecture, 2011
3Coastal Engineering Committee, 2011

Table 2 Summary of estimated household in inundated area and housing damage in different level (Damaged building data was obtained from Miyagi Prefecture, 2011)

| Location | Estimated household in inundated area | Completely destroyed | Half destroyed | Partially destroyed | Completely destroyed (%) |
|---|---|---|---|---|---|
| Kesennuma | 13,974 | 8,383 | 1,861 | 428 | 59.99 |
| Minami-Sanriku | 4,375 | 3,877 | N/A | N/A | 88.62 |
| Onagawa | 3,155 | 4,372 | 256 | 462 | 138.57 |
| Ishinomaki | 42,157 | 28,000 | N/A | N/A | 66.42 |
| Higashi-Matsushima | 11,251 | 4,791 | 4,410 | 1,032 | 42.58 |
| Matsushima | 1,477 | 163 | 752 | 657 | 11.04 |
| Rifu | 192 | 31 | 260 | 800 | 16.15 |
| Shiogama | 6,973 | 386 | 1,217 | 1,598 | 5.54 |
| Shichigahama | 2,751 | 667 | 381 | 595 | 24.25 |
| Tagajo | 6,648 | 1,500 | 3,000 | N/A | 22.56 |
| Sendai | 10,385 | 11,158 | 12,315 | 11,101 | 107.44 |
| Natori | 3,974 | 2,735 | 791 | 4,376 | 68.82 |
| Iwanuma | 2,337 | 699 | 1,057 | 1,010 | 29.91 |
| Watari | 4,196 | 2,369 | 823 | 633 | 56.46 |
| Yamamoto | 2,913 | 2,134 | 954 | 867 | 73.26 |

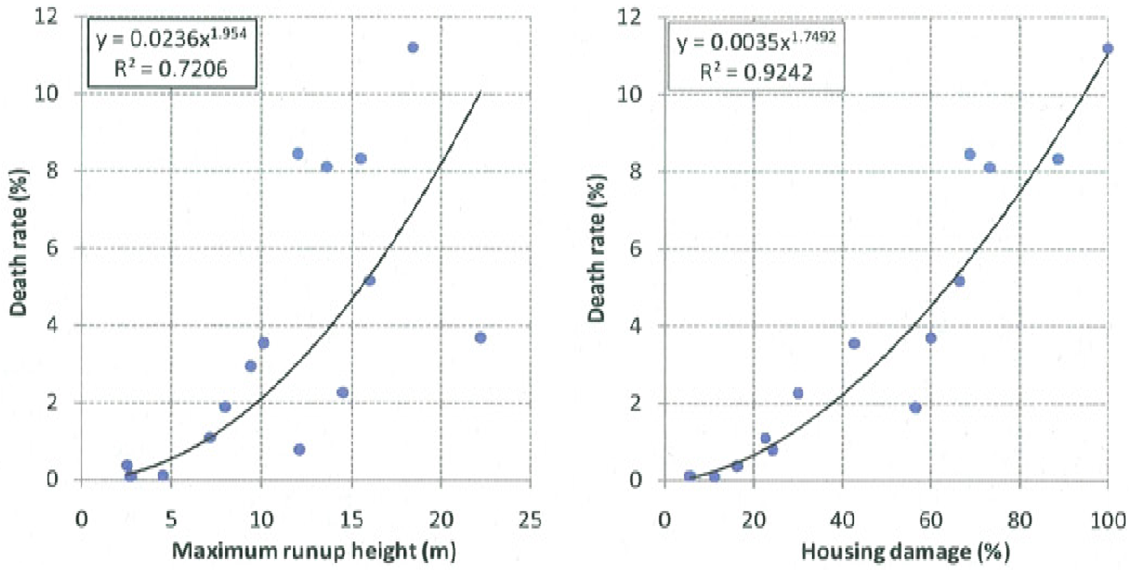


Fig. 3 (a) Relationship between maximum runup height and death rate and (b) Relationship between housing damage (completely destroyed) and death rate

## 2 Tsunami field survey

### 2.1 Field survey location and period

Tsunami field survey was conducted in 13 locations (Kesennuma city to Yamamoto town) in Miyagi prefecture (Fig. 4). The survey spent totally 17 one-day trips in four months during March to June 2011 (Table 3) for general damage survey, inundation depth measurement and structural damage inspection, can be found in the report of preliminary field survey results available in the Tsunami Engineering Laboratory (TEL) webpage (TEL, 2011).

### 2.2 General field survey results

Stopped clocks were found in many locations during the field survey. They may provide an estimation of arrival time of the peak tsunami. The peak tsunami was observed one hour after the earthquake at Soma tide gauge station (15:51) and has agreement with the stopped clocks found in Ishinomaki (15:58), Tagajo (15:55), Arahama (15:56), Natori (16:00) and Shinchi (15:51). In addition, stopped clock found in Onagawa which is after the earthquake about 40 min (15:22) has agreement with the observed tsunami at Ayukawa station in Ishinomaki that stopped at 15:25. Total measured inundation depth is 213 points including 189 buildings. The surveyed buildings comprise of 150 wooden houses, 31 reinforced concrete buildings and 8 steel buildings. Results of the measured inundation depth are summarized in Table 3.

Table 3 Surveyed area information of date, measured point, building type, inundation depth and summary of overall damage

| Location | Date | | | | Surveyed inundation depth (m) | Overall damage |
|---|---|---|---|---|---|---|
| | March | April | May | June | | |
| Kesennuma city | | | | 2 | 10.0 | Urban area, port, coastal structure and fishery |
| Minami-sanriku town | 25 | | | | | Urban area, port and coastal structure |
| Onagawa town | 29 | 25 | | | 18.20 | Urban area, port, fishery and train |
| Ishinomaki city | | 15, 25, 26 | 12 | | 6.20 | Urban area, port, coastal structure, fishery and agriculture |
| Higashi-Matsushima city | | | | | | Urban area, coastal structure, train and agriculture |
| Matsushima town | | | | 26 | 1.40 | Urban area, fishery and sightseeing |
| Shiogama city | | 29 | | | 1.90 | Urban area, port and fishery |
| Shichigahama town | | | | | | Urban area and coastal structure |
| Tagajo city | | 10, 14 | | | 5.75 | Urban area, port and agriculture |
| Miyagino ward | 14 | | 6 | | 3.90 | Urban area, port and agriculture |
| Arahama ward | | 14, 16 | | | 5.15 | Urban area and agriculture |
| Natori city | | 9 | 11 | | 12.10 | Urban area, port, airport, agriculture |
| Iwanuma city | | 9 | | | 4.00 | Urban area, fishery and agriculture |
| Watari town | | 6 | | | 8.60 | Urban area, fishery and agriculture |
| Yamamoto town | | 6 | | | 10.00 | Urban area, port, train and agriculture |

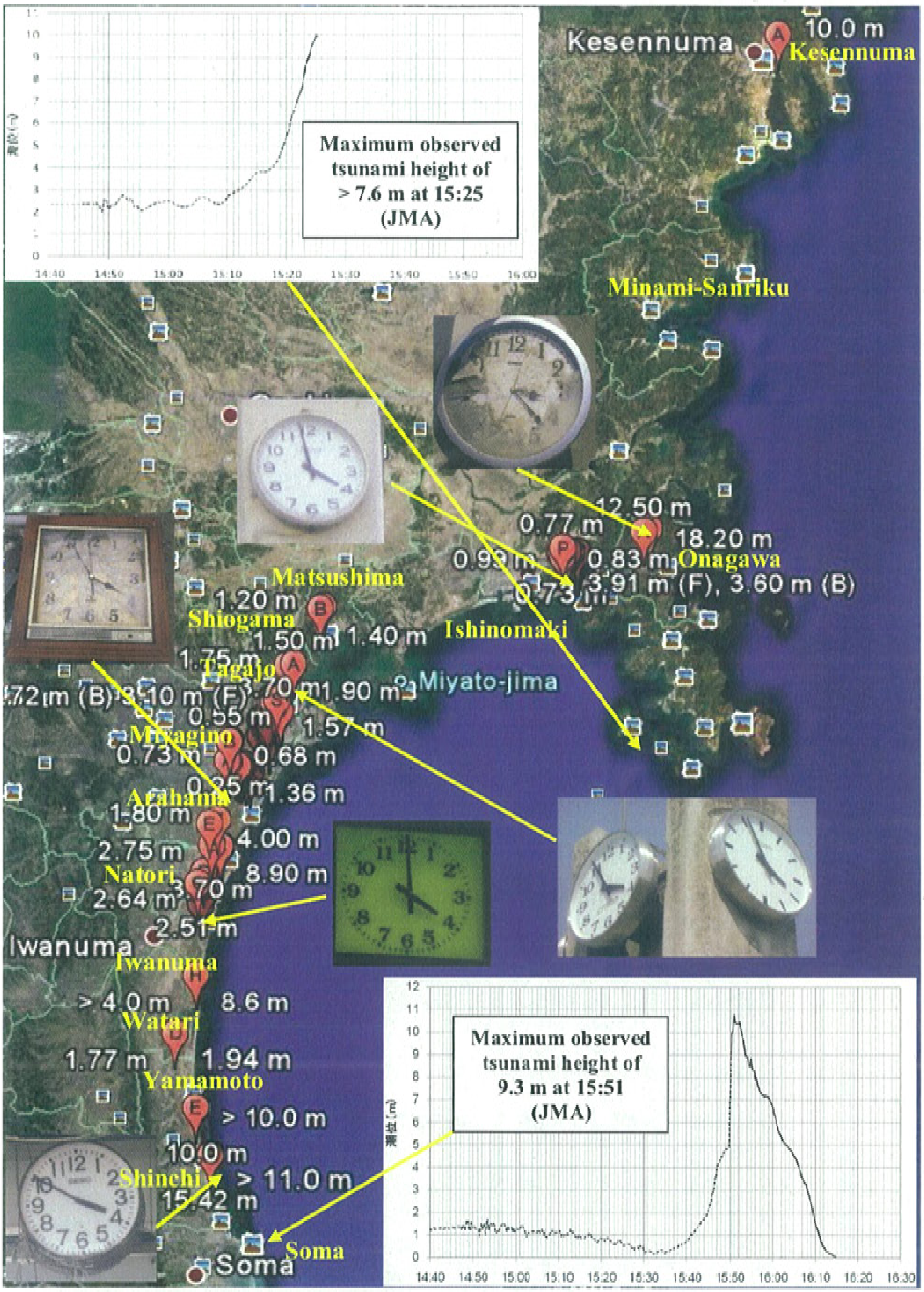


Fig. 4 Tsunami inundation depth and arrival time of peak tsunami from stopped clocks

## 3 Damage results for each area

### 3.1 Higashi-Matsushima city

Higashi-Matsushima is one of the locations that residence has high tsunami awareness since they suffered damage from the past tsunamis. Many researches regarding tsunami hazard map and evacuation behavior were performed. Figure 5 shows overall damaged houses in Higashi-Matsushima city. About 8 m height tsunami caused damage to seawall (Fig. 6) and control forest (Fig. 7 and 8). Also his city has many JR train stations locates close to shoreline of Ishinomaki Bay. Research on tsunami risk to the JR train was started since 2010 but still on the way and too late for the 2011 tsunami. Example of damaged JR train is shown in Fig. 9.

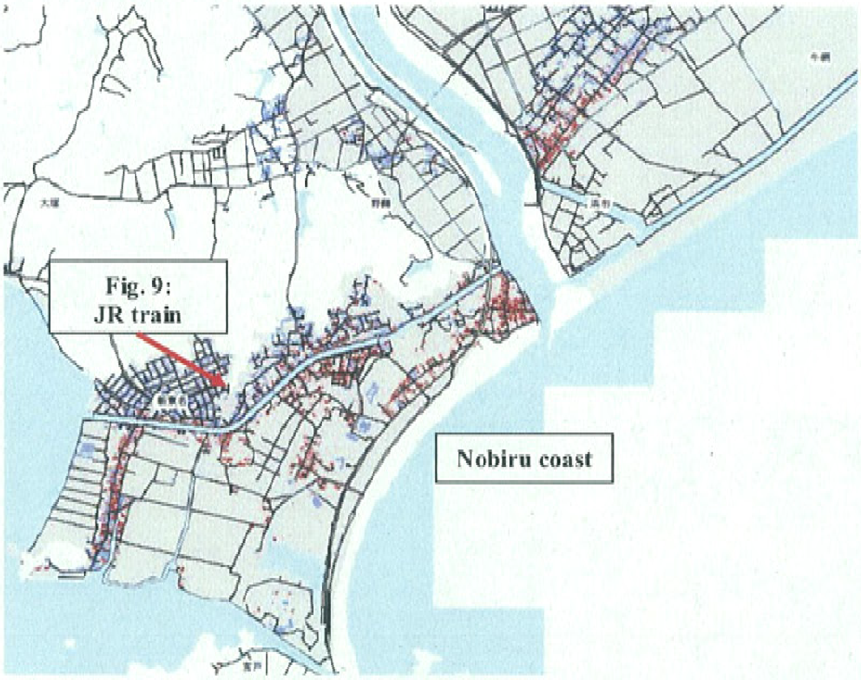


Fig. 5 Tsunami affected area in Higashi-Matsushima city (Blue: surviving house, Red: washed away house and Gray: inundated area)


Fig. 6 Seawall along Nobiru coast before and after tsunami


Fig. 7 Control forest along Nobiru coast before and after tsunami

Fig. 8 Satellite image showing a comparison of control forest before and after tsunami

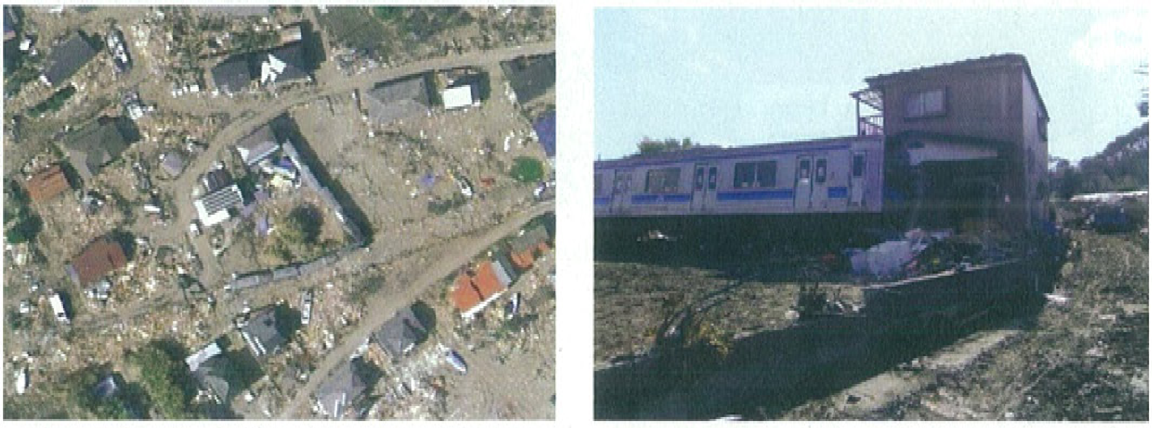

Fig. 9 Damaged JR train found between Tona and Nobiru station