FIELD SURVEY ON THE COASTAL IMPACTS OF MARCH 11, 2011 GREAT EAST JAPAN TSUNAMI

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ABSTRACT

A field survey has been performed in the tsunami hit areas of Great East Japan Tsunami. We report our findings from Sendai Airport, Yuriage, Natori, Sendai port, Taro, Miyako, Yamada, Kamaishi, Rikuzentakata, Ofunato and Kesennuma. We also present simulations of tsunami inundation and compute nearshore tsunami parameters and different characteristics of the incoming tsunami. We present an assessment of the performance of coastal structures (tsunami walls, breakwaters, port structures, quays and defense structures), countermeasures, building damage, possible reasons of building damage. Furthermore, the tsunami impact, building response and tsunami mitigation strategies are discussed.

INTRODUCTION

The 11 March, 2011 Great East Japan Earthquake with Mw: 9.0 struck at 05:46:23 UTC with its epicenter estimated at 38.322°N, 142.369°E, and focal depth of 32 km
Field Survey on the Coastal Impacts of March 11, 2011 Great East Japan Tsunami

The tremor triggered a tsunami and caused massive damage in NE coast of Japan. In Taro, Miyako, Yamada, Kamaishi, Rikuzentakata, Kesennuma and Ofunato the tsunami energy focused inside narrow bays and huge volumes of water overtopped tsunami walls, penetrated from the estuaries and propagated along the rivers inland and on the low lands with the extensive damage on the coastal settlements. 22626 people are presumed dead.

The tsunami amplitude, flow depth, current velocity and resulting Froude number are the major parameters controlling the level of damage in the inundation zone. Better understanding and categorization of the related impact levels can only be achieved through better description of spatial and temporal changes of these parameters in relation with the tsunami source parameters. Correlating observed inundation and impact with model predictions after an event is essential in benchmarking models and understanding their limitations (Synolakis et al, 2008).

In this paper, we summarize our observations from the tsunami impact of 11 March 2011 tsunami. We also report our findings concerning structural damage to different structures.

THE REGION AND TSUNAMIS IN THE PAST

The Sanriku coast extends northward from Sendai to Aomori. It is an indented coast with a shoreline longer than 600 km. Sanriku is derived from the words of three (“San”) and land (“Riku”), as three provinces existed here in ancient times. Along the Sanriku coast, there are many picturesque gulfs and capes, which sadly contributed to the local amplification of the tsunami, with heights exceeding 10 m. The Sanriku coast has been attacked by a series of tsunamis since the first historical record in 869 (M~8.6), 1611 (M~8.1), 1896 (M~8.5) and 1933 (M~8.1). In the 1896 Meiji-Sanriku Tsunami, it is known that the tsunami ran up to the height of 38.2 m, killing more than 22,000 people. Before the recent event, a possible Miyagi-oki earthquake with magnitude ranging from 7.5 to 8.0 had been estimated as 99% within 30 years, the highest earthquake risk in Japan. Along this coast, tsunami countermeasures have been extensively explored and built (Abe and Imamura, 2010).

The Sendai plain had been considered low tsunami risk compared to the Sanriku coast. For instance, the 1933 Showa-Sanriku tsunami caused maximum runup of 28 m, but only 3.9 m in Yamamoto. The 38.2m maximum runup height from the 1896 tsunami was recorded in Ofunato, but less than 5 m was recorded in Sendai (Sawai et al., 2008). As a result of focusing on a 7.5-8 Miyagi-oki earthquake, tsunami countermeasures in the Miyagi prefecture were not sufficient for the 2011 Mw=9.0 Great East Japan tsunami.

EVACUATION BEFORE THE TSUNAMI ARRIVAL

A questionnaire prepared by CeMI, (2011) was distributed in the (http://www.npocemi.com/works/image/2011touhoku/110609tsunamisurvey.pdf) Kamaishi-Iwate
Prefecture with 113 responders and in the Natori - Miyagi Prefecture with 105 responders. 65% of responders reported that the main reason for the evacuation was “I thought a tsunami will come”, while 13% reported that “People around me recommended me to evacuate” (13%). High awareness and altruistic behavior was observed. Dominant intervals for triggering the evacuation time was “less than 10min” (60%) for Kamaishi and “21 to 30min” (30%) for Natori. The tsunami arrived these area around 20min after the earthquake.

People who decided not to evacuate remembered the Chilean earthquake 2010 with the tsunami amplitude less than 50cm, and did not expect a tsunami with the height of 10m. They also compared what happened with the earthquake (Mw=7.9) occurring two days earlier on 9 March 2011, which did not trigger a significant tsunami and they thought that a tsunami was unlikely in the newer event. Kamaishi residents evacuated mostly on foot (65%), while Natori citizens escaped by car (63%). 37% of the latter indicated the difficulty in evacuation due to the traffic jam (37%), as had been observed by Okal et al (2010) during the Samoan tsunami.

According to the Weathernews (2011) questionnaire with a sample of 88,604 for the entire Japan versus 9,316 for the tsunami hit areas 52% were informed of the tsunami warning first through TV news for the sample around Japan. In the affected areas, 32% were informed from TV and 27% from radio (27%). Surprisingly, even though a tsunami warning was issued 3 min after the earthquake, according to the questionnaire results, people in the affected areas waited to evacuate for information from the authorities for an average of 16.4 minutes. Given that the tsunami arrived within 15-20 min, this wait for information may have caused loss of life.

Casualties, fatality rates and local maximum runup in the Iwate and Miyagi prefectures as of 7 June 2011 are listed in Table 1.

FIELD SURVEY IN TSUNAMI HIT AREAS

The field survey was held between 29th of May and 4th of June. The leader of survey team was Prof. Dr. Ahmet Cevdet Yalciner and other team members were Anawat Suppasri, Erick Mas, Nikos Kalligeris and Ocal Necmioglu. Costas Synolakis visited the sites earlier.

The field survey consisted of two parts, one the Sendai area, Miyagi Prefecture and two, the Sanriku coast along Iwate and Miyagi Prefecture from Taro to Kesennuma, as shown in figure 1. In the Sendai area, we surveyed the Sendai Airport, Arahama, Natori, Yuriage and Sendai port. In Iwate-Miyagi Sanriku region, we visited Taro, Miyako,Yamada, Otsuchi, Kamaishi, Ofunato, Rikuzentakata and Kesennuma. We describe below our main observations.

Miyagi Prefecture

Sendai Region

Sendai is a castle town controlled by the powerful feudal lord Date Masamune.
<table>
<thead>
<tr>
<th>Prefecture</th>
<th>Location name</th>
<th>Population in inundated area</th>
<th>Number of casualty and missing</th>
<th>Casualty rate (%)</th>
<th>Maximum Runup height (m)</th>
</tr>
</thead>
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<tr>
<td><strong>Iwate</strong></td>
<td>Hirono</td>
<td>2,733</td>
<td>0</td>
<td>0.00</td>
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<td></td>
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<td>4</td>
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<td>38</td>
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<td>38.0</td>
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<td>1</td>
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<td>2.28</td>
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<td>7</td>
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<td>20.4</td>
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<td>Miyako</td>
<td>18,378</td>
<td>772</td>
<td>4.20</td>
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<td>Yamada</td>
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<td>848</td>
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<td>Otsuchi</td>
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<td><strong>Miyagi</strong></td>
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<td>1,199</td>
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<tr>
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<td>8.0</td>
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<tr>
<td></td>
<td>Yamamoto</td>
<td>8,990</td>
<td>729</td>
<td>8.11</td>
<td>15.3</td>
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</table>
Masamune built Sendai Castle (Aoba Castle) in 1601. After the Meiji era, there were many earthquakes with great magnitude (the 1896 Meiji Sanriku earthquake, 1933 Showa Sanriku earthquake, 1938 Fukushima sea earthquake, 1952 Tokachi sea earthquake, 1962 North Miyagi earthquake and 1968 Tokachi sea earthquake). However, there was no damage recorded in Miyagi prefecture except the 1978 Miyagi sea earthquake in Sendai. Just only some damage report on a paddy field from the tsunami in 1901. On the other hands, tsunami also resulted in extensive damage, including the Sanriku region. However, there was no record of heavy tsunami damage in Sendai due to the great tsunami event such as the 1896 Meiji Sanriku tsunami, 1933 Showa Sanriku tsunami and 1960 Chile tsunami.

Sendai airport is located in Natori city, Miyagi prefecture near the Pacific Ocean coast on center of south part of Miyagi prefecture. The airport is about 20 km south from the Sendai port with protected by sandy coast and control forest (Pine tree) all along the coast. Yuriage area is located in Natori city, Miyagi prefecture. It is a former high-activity fishery port with only 7,000 populations. Though Yuriage port which locates in a river mouth of Natori River is one of the best for fishing, there is a road for cycling along the coast and weekend market which is popular for the people. Arahama is located in place of rough sand beach, including the nuances of its name (“Ara” means rough). The name of the beach has become a “Fukanuma” (“Fuka” means deep and “Numa” means pond) which is derived from the swamp area between the beach ridges. Sendai port is one of the a few ports in the northeast region of Japan can handle a 40ft container including crude oil, automobiles, fuel oil as cargo handling various types of products and liquefied petroleum gas. In 2006, the port handling capacity of about 37 million tons and 7,024 vessels were entered. The port is also served for passengers by ferry between the Port of Nagoya and Tomakomai Port in Hokkaido.

The Sendai region is one of the most affected as the area is plain and lowland.
Figure 2 Arahama, Sendai

Figure 3 Elementary School in Arahama, Sendai
Figure 2 shows the damage to roads and safety rails along the Arahama coastline. The figure also reveals the high level of scouring at the foundations of buildings.

Figure 3 shows up the tsunami damage of an elementary school in Arahama. As seen from the photos, tsunami waves penetrated through the entire base floor, which had a small stage for the students’ performances. The entire stage was covered with mud and debris, while two cars had been carried into the building by strong wave currents.

Iwate Prefecture

Taro Town

Taro is a typical example of hardest hit areas by tsunamis in 1611, 1896 (15 m high) and 1933 (10 m high). In 1934, the town started the construction of two lines of
10m high seawalls with total length of 2.4 km. In the 1970’s, the town constructed another two lines of 10m seawalls to accommodate the increasing population (See Figure 4-5). The 2011 tsunami overflowed these two-line seawalls and broke the eastern part of the new seawalls that had deteriorated due to poor maintenance.

Miyako City

Miyako lies along the coast where the Hei river flows into the Pacific Ocean. The city has a port but much of the shipping traffic is taken by larger cities along the coast. The city has currently population of 59,442, the largest number of population among coastal cities in Iwate prefecture.

Miyako city has been etched in our collective memory by the video footage taken from the upper floors of a building just behind the tsunami wall of the city, broadcast by the station ANN - it is easily searchable in youtube. In this video, there were agonizing scenes as the tsunami overtops the seawall at high speed and a large boat is seen to be drift then get trapped under the bridge and bent like a toy. Our team visited that city hall building where this video footage has been shot, from a balcony on the second floor. Figure 6 shows captures from this footage and our pictures, taken from the identical location. There were adequate tsunami evacuation signs in the city, but, the tsunami amplitude reached 9.4m just under the bridge. Measurements were made using standard tsunami survey protocols (Synolakis and Okal, 2005).

Yamada Town

Yamada is a natural harbor and its naturally protected bay is used for mussel farms. All aquaculture farms were destroyed by the tsunami. Like elsewhere in Iwate prefecture, Yamada was protected from the tsunami flooding by a 5m-high tsunami wall. As seen from the photos in Figure 7, the locks of the wall of 50 m length were drifted by strong tsunami currents far inland.

The hill shown in Figure 7 is over 8 m high above sea level and had been designated
as an evacuation site during tsunami attack. Sadly, the tsunami height exceeded that elevation by more than 2 m according to our flow depth measurement of garbage hanging on a tree, the hill was flooded and the evacuees lost their lives.

Otsuchi Town

Figure 8 shows the layout of Otsuchi bay. It has a narrow and long entrance that permits the tsunami to amplify before flooding inland. Otsuchi was one of the most damaged cities after 2011 tsunami. The panoramic views in Figure 8 reveal the level of damage. The tsunami wall surrounding the harbor can also be seen in the figure. The tsunami waves damaged some parts of tsunami wall, overtopped and flooded all the residential area behind the wall. The mayor of Otsuchi lost his life at the town.

Figure 8 Otsuchi - layout of the bay and panoramic view of the town after tsunami
hall and recovery in this area was slower than elsewhere. Stopped clock found in the city office shows the tsunami arrival time at 15:25.

In Figure 9, there is a surprising picture of a dragged ferry boat, carried inland and placed on the roof of a two-storeyed building. During the survey, it was observed that this building was the only one surviving. The filled area behind its berthing place and the road in the coastal strip subsided. As also seen in Figure 8 some parts of tsunami wall were destroyed from the interlocking points.

**Kamaishi City**

Kamaishi produces iron ore and it is a good natural harbor (see Figure 10). Consequently, Kamaishi City is the birthplace of the modern iron manufacture in Japan and known as the city of “iron and the fish”. The 1896 Meiji Sanriku tsunami devastated Kamaishi. At that time, the population of the Kamaishi area was 6,524 people and 4,985 of them were lost. Its current population reached about 40,000 due to the steel industry.

For the mitigation of tsunami disasters, a tsunami breakwater was constructed at the Kamaishi Bay entrance in 1978-2008. There are two breakwaters at the entrance of the bay with 4m crest elevation, 300 m opening and lengths of 670m and 990m. These breakwaters were built at a water depth of 63 m, the deepest in the world where a breakwater has been constructed. The tsunami wave reached 6.7m at 20 km - 300m water depth- offshore Kamaichi. At least four of the town’s 69 designated evacuation sites were inundated by the tsunami (Kamaishi Port Office, 2011). As seen from the photos in Figure 10, most of the timber-framed buildings collapsed, a huge tanker was carried onto the pier and the foundations of buildings on the waterfront were highly scoured.
Ofunato City
Ofunato is located on the southern coast of Iwate prefecture with a population of 45,000. Ofunato Bay has a long north-south elongation (Figure 11) and this layout enables resonance for a long period of time. In the aftermath of the 1960 Chilean Tsunami, 53 people were killed or left missing, which was the highest death toll then in Japan. After the 1960 Chilean Tsunami, a breakwater was constructed (1963-1966) in the entrance of the Ofunato Bay at 22 m water depth with a 6m crest elevation and 200 m opening for navigation. The length of the breakwater is 290 and 250 m on each side. Just after its completion, the 1968 Tokachi-oki earthquake tsunami struck and the breakwaters successfully offered protection. Harbor maintenance has been delayed due to the natural protection provided by the bay and many containers and timber were kept in Ofunato. The 2011 tsunami overtopped and damaged the breakwater and propagated in the narrow bay, flooding the city about 3 km inland. The town’s theatre is one of the very few buildings left standing and remains remarkably undamaged. It provided shelter to about 250 survivors. At least six of the town’s 58 designated evacuation sites were inundated by the tsunami (see Figure 11).
Rikuzentakata City

The city is famous in Japan as a summer vacation locale featuring a beautiful sandy beach. Takata-Matsubara is a 2-km stretch of shoreline lined with approximately seventy thousand pine trees (Figure 12- before tsunami). In 1927 it was selected as one of the 100 landscapes of Japan (Shōwa era) and in 1940 designated as a place of Scenic Beauty. The population of the city was about 23,000. After the 2011 tsunami, only a single 10m-high and 200 year-old tree survived out of 70,000 (Figure 12- after tsunami and the single pine tree) in Rikuzentakata. In fact, a forest for tsunami protection could withstand a tsunami up to 3-5 m (Shuto, 1985), while the measured runup height of the 2011 tsunami was almost 20 m. Similar results from large tsunamis completely overaking coastal forests have been observed during the 2006 Java tsunami (Fritz et al, 2007) and in Tonga during the 2009 Samoan tsunami (Okal et al, 2010). Due to coastal erosion, the only surviving tree is now only 5 m away from the sea and at risk. The Association for the Protection of Takata-Matsubara is taking measures, including the erection of barriers, to protect it.

Figure 12 Rikuzentakata city- Pine trees before and after the tsunami, and the surviving tree

Kesennuma City

Kesennuma is a city of 75,000 and well-known nationwide in Japan as a harbor city where tons of fresh fish are unloaded daily. Kesennuma has an outstanding catch of Pacific fishes like Saury, Bonito, Tuna, and Shark, shipped all over Japan. Above the fish market, an observation deck had been installed, from which people could watch fish being unloaded below (the roof could also be used as an evacuation site), and tsunami hazard maps are in place throughout the local community and a tsunami height sensor had been installed at the entrance of the Kesennuma Bay to confirm the tsunami size in advance of its arrival. Tide gauge station inside the Kesennuma Bay is totally destroyed. However, during our survey, we found one designated evacuation shelter was inundated. On 11 March 2011, a large part of the city was destroyed by the tsunami (Figure 13). The island of Oshima and its 3,000 residents, included in the city limits, were isolated by the tsunami which damaged the ferry connections. After the tsunami, spilled fuel from the town’s fishing fleet caught fire and burned for four days.
SUMMARY EVALUATION OF THE TSUNAMI IMPACT AND COUNTERMEASURES

As opposed to the 2004 Indian Ocean tsunami (Geist et al, 2006), the 11 March 2011 event provided an unfortunate opportunity to observe a world class warning system in action, and observe tsunami effects in possibly the most sophisticated nation in the world in terms of tsunami preparedness.

In some instances, the Japan Meteorological Agency (JMA) recorded seismic waves up to 22 seconds before the earthquake was felt in other locales, i.e., before the arrival of the P waves. In the first TV broadcast, the magnitude was initially stated as 7.9. Two minutes later, the areal distribution of seismic waves was calculated and JMA determined that all of Japan from Okinawa to Hokkaido Islands had been shaken and a tsunami warning was broadcasted. Three minutes after rupture initiation of the main earthquake, tsunami warning announcing a 6m was broadcasted, whereas 28 minutes post-earthquake, the wave amplitude was recalculated and announced as 10m (Figure 14) (JMA, 2011, PARI, 2011, Takahashi et al., 2011). This last message, however, could not possibly have been disseminated successfully due to damage to communications infrastructure.

Tsunami waves penetrated through narrow and long bays and focused energy amplified the flooding in the shallower regions in front of settlements. The waves overtopped tsunami walls, caused massive damage by very strong currents in inundation zone and spreaded the devastation area by moving along the rivers. The tsunami inundated up to 5 km distance in Sendai plain.
Coastal forestation was one of Japan’s tsunami mitigation strategies. 4000 pine trees were planted in Rikuzentakata city between the settlements and the sea. Only one single pine tree survived and 20% of residents of this city lost their lives.

The period of waves in Great East Japan Tsunami is estimated at about 50 minutes. As the tsunami waves shoaled in shallow and narrow reasons, they caused massive flooding that lasted for up to 25min. The in-situ tsunami surveys revealed that the tsunami flow was reached to supercritical conditions in most of the areas and therefore caused significant damage.

**Tsunami breakwaters, seawalls and structures.**

Large tsunami breakwaters had been constructed at the entrance of Kamaishi and Ofunato Bays at 62m and 22m depth respectively. Both breakwaters did not withstand the strong tsunami forces and collapsed. The protected settlements were thus exposed to the tsunami attack and suffered significant damage. Figure 15 shows the locations and dimensions of the tsunami breakwaters at the entrance of Kamaishi and Ofunato Bays.

After the 1896 Great Meiji and 1933 Great Sanriku events, tsunami seawalls were constructed along the coastlines of Fudai, Taro, Miyako, Yamada and Otsuchi to prevent tsunami flooding. Those walls were concrete structures ranging in height from 5m to 15m. Only the 15m high gate in Fudai protected the settlements behind it and prevented loss of life. The 2011 tsunami was 17 m high at the gate, it overtopped it but only further inundated a few hundred meters inland from the gate. In Taro, Otsuchi and Yamada walls collapsed while in Miyako the tsunami overtopped the seawall and caused tsunami inundation in the settlements behind the wall.

Unlike Otsuchi and Rikuzentakata, Miyako and Kamaishi have many concrete house and structures. Concrete structures with more than three storeys adequately resisted...
the tsunami induced forces. However, in many areas where flow depth was high the first two floors of these buildings were flooded. Concrete buildings were used for vertical evacuation and saved lives, however in some cases buildings designated as suitable for vertical evacuation were not high enough and people were drowned. In a couple of instances, air trapped between the ceiling and door and window frames increased the bouyancy of structures, they were uplifted and moved laterally or overturned. Damage to bridges were severe in Rikuzentakata and Ofuchi with the damage increasing with diminishing distance to the shoreline. Large scale erosion was observed around the concrete structures due to strong and long lasting currents and in some cases causing overturning. Scouring occured as expected during tsunami attacks (Sumer, 2007).

Almost all wooden structures were either destroyed by debris impact or carried away due to strong currents - few out of thousands of buildings survived. Examples of areas where wooden houses were seriously damaged or destroyed are Otsuchi and Rikuzentakata. The difference in survival between engineered wooden structures and reinforced concrete buildings was striking.

Summary

In our survey, we observed tsunami inland heights almost twice as large as those of the 1896 Great Meiji tsunami which resulted in about 22 000 casualties. Although the 11 March 2011 tsunami death toll was similar, it was much lower in relative terms compared to the population size. Hence tsunami protection and mitigation measures and public education were effective in reducing loss of life.

Condolences

The authors extend their sincere deep condolences to the families of those who died during to the Great East Japan earthquake and tsunami, and their wishes for the quick recovery of those injured.
Acknowledgments

The authors thank Professor Nobuo Shuto for his long leadership in tsunami studies worldwide, and also for invaluable contributions to this study. The field survey was supported by Turkish Chamber of Civil Engineers, Yuksel Project Int. Co., Kiska Commandite Co., Dolsar Ltd. Co, Cesas Ltd. Co. Turkey. This study was partly supported by TUBITAK (Turkey)-RFBR (Russia) Joint Research Grant (MORAT, Project No: TUBITAK 108Y227), DPT2010K140200 and DPT2011K140210 Projets, METU and Bogazici University KOERI Turkey, HCMR Greece, Tohoku University Japan. and a RAPID grant from the National Science Foundation of the US. Dr. Masahiro Yamamoto, the anonymous contributors to the series of IOC/UNESCO, Dr. Laura Kong and Prof. Shunichi Koshimura, Aykut Ayça, PARI are also acknowledged

References

http://www.coastal.jp/tjtj/index.php?%E7%8F%BE%E5%9C%B0%E8%AA%BF%E6%9F%BB%E7%B5%90%E6%9E%9C


Fujii Y., Satake K., Sakai S., Shinohara M. and Kanazawa T: (2011), Tsunami source of the 2011 off the Pacific coast of Tohoku, Japan earthquake, Submitted to EPS (Letter to the Editor)

Geist EL, Titov VV, Synolakis CE (2006), Tsunami: Wave of change, Scientific American, 294 (1) 56-63


Imamura F. (2011), Tohoku University Source Model version 1.0 of Great East Japan Tsunami. (Due on June 06, 2011)


A. C. Yalciner, C. Ozer, A. Zaytsev, A. Suppasri, E. Mas, N. Kalligeris, O. Necmioglu, 
F. Imamura, N. M. Ozel, C. Synolakis

Early Warning Systems and the Tsunami Analysis” - Takeshi Koizumi (JMA); 
UNESCO/IOC Tsunami and Civil Protection Workshop: “Tsunami hazard in the 
North-eastern Atlantic, the Mediterranean and connected seas (NEAM region) - 
A challenge for Science and Civil protection”; 15-16 June, JRC-Ispra, Italy


Nagoya University, Japan (2011), Tsunami inundation map, http://danso.env.nagoya-u.ac.jp/20110311/map/index_e.html


NPO CeMI, Japan, (2011), Crisis and Environmental Management Policy Institute, 

Okada, Y. (1985), Surface Deformation Due to Shear and Tensile Faults in a Half-

Okal, E.A., H.M. Fritz, C.E. Synolakis, J.C. Borroto, R. Weiss, P.J. Lynett, V.V. Titov, 

PARI, (2011), Executive Summary of Urgent Field Survey of Earthquake and Tsunami 
Disasters by the 2011 off the Pacific coast of Tohoku Earthquake, March 25, 2011-07-10


of tsunamis at Suijin-numa, a coastal lake facing the Japan Trench,” The Holocene 
18, 4, 517-528.


and Tsunami Damage, in: Proceedings of the 4th National Convention on Water 

Suppasri, A., Muhari, A. and Imamura, F. (2011b) “JST-JICA and RISTEK Indonesia: 

Sumer, B.M., Ansai, A. Cetin, K.O., Damgaard. J., Gunbar, A.R., Ottesen, N.E., Sawicki, 
Liquefaction around Marine Structures, Journal of Waterway, Port Coastal and 
Ocean Eng., 133, 55-82.


