This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 603839

ASTARTE

Assessment, STrategy And Risk Reduction for Tsunamis in Europe

Grant Agreement no: **603839**

Organisation name of lead contractor: IPMA
Coordinator: Maria Ana Baptista

Deliverable 5.3

Lessons From Recent Tsunamis Impacts on Coastal and Marine Structures and Coastal Utilities, and Performance of Mitigation Strategies

Due date of deliverable:	M12
Actual submission date to PC:	05/11/2014
Start date of the project:	01/11/2013
Duration:	36 months

Work Package:	5 "Tsunami-Coastal Impacts"
Lead beneficiary of this deliverable:	METU
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Version:	V2.6

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)	
Dissemination Level	
PU Public	
PP Restricted to other programme participants (including the Commission Services)	X
RE Restricted to a group specified by the consortium (including the Commission Services)	
CO Confidential, only for members of the consortium (including the Commission Services)	

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EXECUTIVE SUMMARY

ASTARTE (Assessment STrategy And Risk for Tsunami in Europe) project aims to develop a comprehensive strategy to mitigate tsunami impact in The NEAM (North East Atlantic, Mediterranean and Adjacent Seas) region of IOC/UNESCO. Within the project, Work Package 5 focuses on gaining a better understanding of tsunami impacts in coastal areas and on structures. The aim is to study the stability and performance of coastal defences, critical and strategic structures, to identify lessons and new innovative and cost-effective design concepts and solutions for coastal and marine structures, and to investigate the tsunami-induced boundary layer, sediment transport, and morphological changes on coastal areas. In this purpose, Deliverable 5.3 aims to gather available information on lessons from recent tsunamis, impacts on coastal and marine structures and coastal utilities, and performance of mitigation strategies. The research mainly focuses on the effects of the 2011 Great Eastern Japan Earthquake and Tsunami not only because 2011 event is the most recent catastrophic event, but also as Japan is a disaster prone country, it allows evaluation of several mitigation strategies that had already been implemented before 2011.

In this report, Chapter 1 provides information regarding to performances of coastal defences during the 2011 tsunami, and failure mechanisms. Damages due to tsunami in and around ports such as damages to ships, bathymetry change, debris from cargo containers and motor vehicles are summarized in Chapter 2. Finally Chapter 3 evaluates the contribution of non-structural mitigation strategies including disaster risk management plans, warning systems, evacuation planning, land-use regulation and use of greenbelts on saving human lives.

DOCUMENT INFORMATION

Project Number	FP7 - 603839	**Acronym**	ASTARTE
Full Title	Assessment, STrategy And Risk Reduction forTsunamis in Europe		
Project URL	http://www.astarte-project.eu/		
Document URL			
EU Project Officer	Denis Peter		

Deliverable	**Number**	D5.3	**Title**	Lessons From Recent Tsunamis Impacts on Coastal and Marine Structures and Coastal Utilities, and Performance of Mitigation Strategies
Work Package	**Number**	WP5	**Title**	Tsunami-Coastal Impacts

Date of Delivery	**Contractual**	M12	**Actual**	M12
Status	version 2.5		final □	
Nature	prototype □ report ■ dissemination □			
Dissemination level	public □ consortium ■			

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Abstract (for dissemination)	
Keywords	

Version Log			
Issue Date	**Rev. No.**	**Author**	**Change**
14 June 2014	1	Gözde Güney DOGAN, Gülizar OZYURT TARAKCIOGLU	First Draft
26 October 2014	2	Deniz Can AYDIN	Rewriting the document
30 October 2014	2.1	Ahmet Cevdet YALCINER	Review and modifications
05 November 2014	2.2	Ahmet Cevdet YALCINER	Figure Numbers are corrected
06 November 2014	2.3	Nilay DOGULU	List of Figures and Tables are revised.
11 November 2014	2.4	Nilay DOGULU	The chapter “Effect of human-made structures for reducing tsunami run-up in Lyngen, Norway” is inserted.

20 November 2014	2.5	Nilay DOGULU, Deniz Can AYDIN, Ahmet Cevdet YALCINER	General review and corrections of references
06 December 2014	2.6	Nilay DOGULU	General review. The chapter "Effect of human-made structures for reducing tsunami run-up in Lyngen, Norway" is moved to be included in D5.22, which is due on Month 24.

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ABBREVIATIONS AND ACRONYMS

CBO: Community Based Organizations

DRM: Disaster Risk Management

GEJE: Great Eastern Japan Earthquake

UNESCO: The United Nations Educational, Scientific and Cultural Organization is a specialized agency of the United Nations

NGI: Norwegian Geotechnical Institute

DEFINITIONS

The concepts and definitions related to tsunami run-up and inundation are summarized and shown on a diagram in Figure 1.

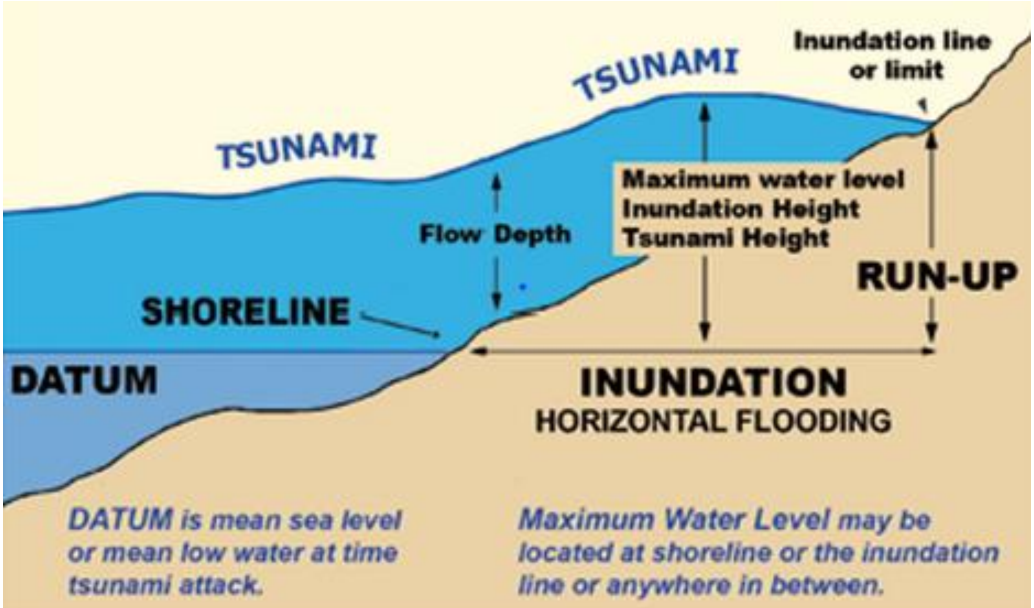

Figure 1: Tsunami run-up and inundation (IOC/UNESCO, 2008).

Sea Dikes

Sea dikes are onshore structures with the principal function of protecting low-lying areas against flooding. Sea dikes are usually built as a mound of fine materials like sand and clay with a gentle seaward slope in order to reduce the wave run-up and the erodible effect of the waves. The surface of the dike is armoured with grass, asphalt, stones, or concrete slabs. An example of asphalt-armoured sea dike is given in Figure 2. Various types of sloping front rubble-mound seawall/revetment structures can be seen in Figure 3.

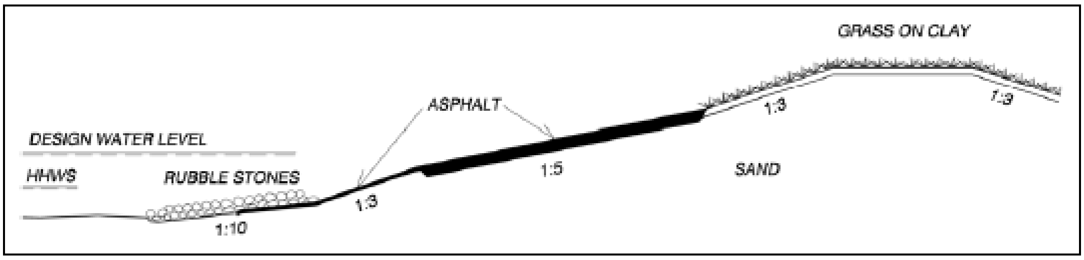

Figure 2: Example of asphalt-armored sea dike (Burchart and Hughes, 2011).

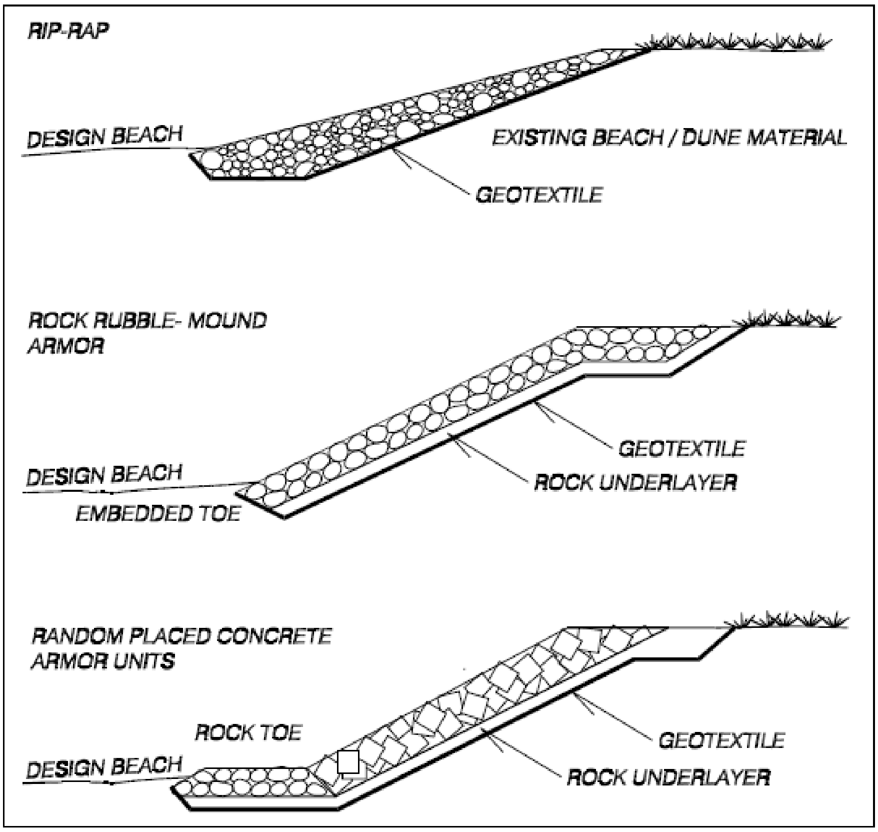

Figure 3: Examples of sloping front rubble-mound seawall/revetment structures (Burchart and Hughes, 2011).

Seawalls

Seawalls are onshore structures with the principal function of preventing or alleviating overtopping and flooding of the land and the structures behind due to storm surges and waves. Seawalls are built parallel to the shoreline as a reinforcement of a part of the coastal profile. Seawalls range from vertical face structures such as massive gravity concrete walls, tied walls using steel or concrete piling, and stone-filled cribwork to sloping structures with typical surfaces being reinforced concrete slabs, concrete armor units, or stone rubble. Figure 4 shows a typical example of a vertical front seawall.

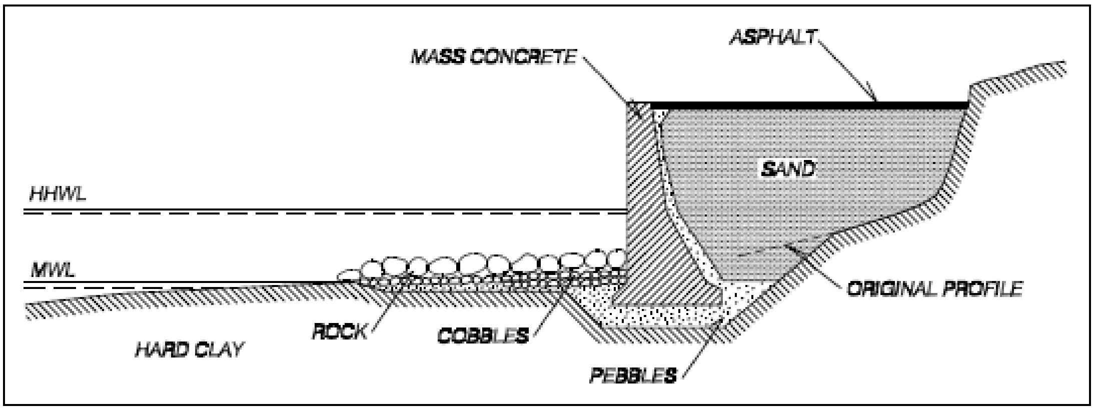

Figure 4: Example of a vertical front seawall (Burchart and Hughes, 2011).

Breakwaters

Breakwaters are built to reduce wave action in an area in the lee of the structure. Wave action is reduced through a combination of reflection and dissipation of incoming wave energy. When used for harbors, breakwaters are constructed to create sufficiently calm waters for safe mooring and loading operations, handling of ships, and protection of harbor facilities. Breakwaters are also built to improve maneuvering conditions at harbor entrances and to help regulate sedimentation by directing currents and by creating areas with differing levels of wave disturbance. Protection of water intakes for power stations and protection of coastlines against tsunami waves are other applications of breakwaters. When used for shore protection, breakwaters are built in near shore waters and usually oriented parallel to the shore.

Figure 5 provides a conventional outline of a multilayer rubble-mound breakwater.

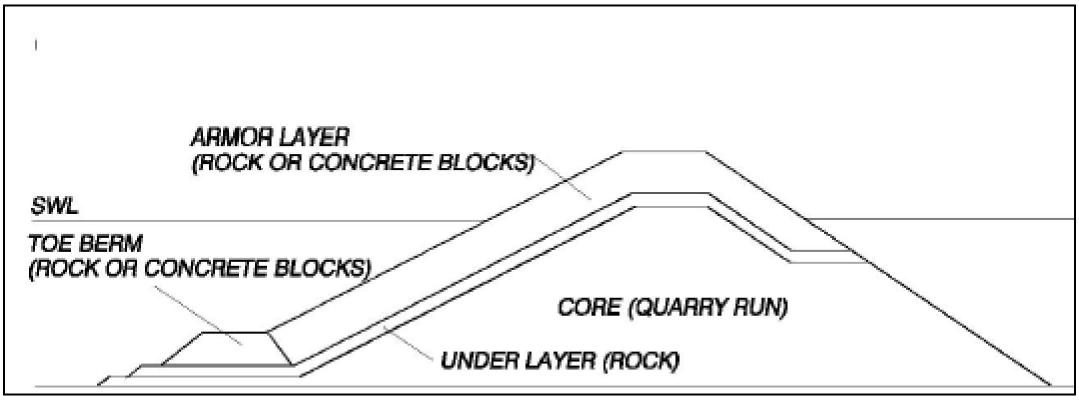

Figure 5: Conventional multilayer rubble-mound breakwater (Burchart and Hughes, 2011).

Greenbelt

"A Greenbelt is defined as a strip of natural or artificially created coastal vegetation designed to prevent coastal erosion, and mitigate the adverse impacts of natural coastal hazards on human lives and property" (Sri Lanka Country Office, 2007).

1. Coastal Protection Structures

1.1. Damage to Protection Structures

Many researchers have reported their field investigations of the 2011 Great East Japan Earthquake including tsunami damage to coastal protection structures and failure mechanisms of them (ASCE-COPRI-PARI Coastal Structures Field Survey Team, 2013; Chock et al., 2013; Hanzawa 2012; Hoshino, 2012, Kazama , 2011; Mori et al., 2011, and 2013). All those reports form a base for understanding the destructing effect of tsunamis on coastal structures and lessons that should be taken from such big events as identified during the surveys.

One group of the researchers, Jayaratne et al. (2013) have investigated coastal structure failures due to the 2011 Great Eastern Japan Earthquake Tsunami in Miyagi and Fukushima prefectures and found out that the major reason for failure of many sea dikes was due to scour created by overtopping waves in leeward and slope. Once the leeward is scoured, it exposes gravel and sand core to rapid flow and causes sea dikes to be washed away. Surveyed scour profiles of the studied sea dikes can be seen in Figure 6, 7, and 8.

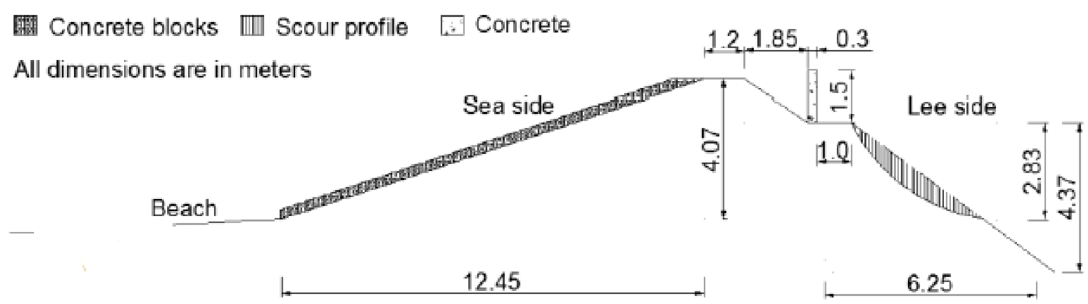

Figure 6: Sea dike at Soma City (north side) (Jayaratne et al., 2013).

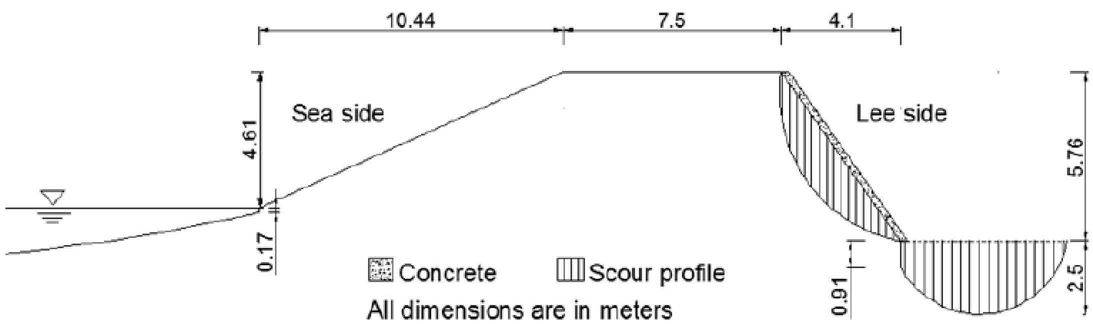

Figure 7: Sea dike at Iwanuma City (Jayaratne et al., 2013).

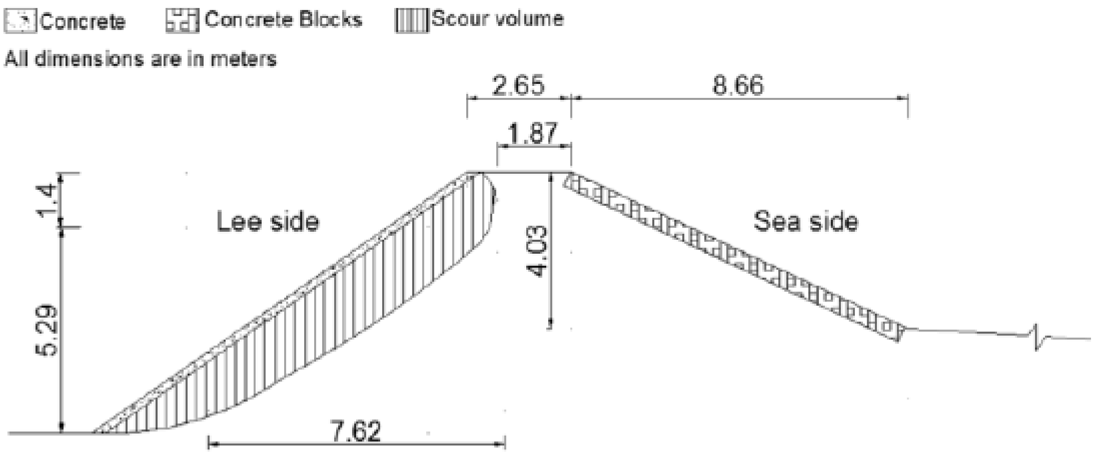

Figure 8: Sea dike at Yamamoto City (Jayaratne et al., 2013).

To strengthen sea dikes that encounter overtopping tsunami, the authors conclude that leeward side and toe should be reinforced against increased water velocity and vorticity. In order to do this, it is suggested to use impermeable concrete structures on the leeward side and heavy concrete for the toe that extends over a wide area.

Kato et al. (2012) have studied the mechanisms of coastal dike failure induced by the GEJE by means of field surveys and hydraulic model experiments and classified the results into eight failure patterns. Failure patterns for the coasts between Aomori and Chiba prefecture were judged for a total length of 99 km damaged coastal dike. Same as Jayaratne et al. (2013) they also found out that primary failure pattern was from scouring at landward toe with a ratio of 49.2%. Second most observed pattern was failure from the crown or the top landward armor which is caused by negative pressure acting on the landward armor during fast flow. The proportions of different failure patterns found in the study are provided in Figure 9.

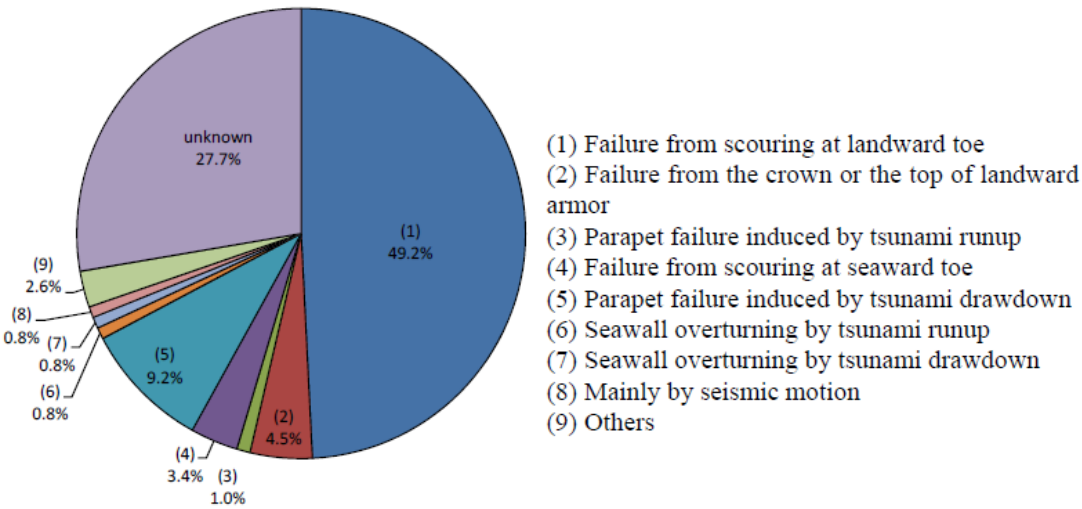

Figure 9: Proportion of each failure pattern along the length of damaged coastal dike (Kato et al., 2012).

In Taro region, majority of seawall units were almost toppled from their positions and the only parts of wall left standing were some buttress supports and blocks around the gates as stated by Fraser et al. (2013) field observations of the 2011 Tohoku Tsunami damage. In Kamaishi City, the tsunami on March 11th overturned the north section (990 m in length) of the newly completed offshore breakwater and although the south section (670 m in length) survived mostly intact, it was left inclined (Yagyu, 2011). In Ōfunato City, prior to the tsunami, there were two breakwaters at the mouth of the bay and they collapsed completely on March 11th (Yagyu 2011). The tsunami at Kesennuma flowed north up the bay, arrived at the harbor as a fast-flowing rising tide (Japan Coast Guard, 2011) and overtopped harbor walls and river defences. The impact of embankments was entirely related to their position and height relative to tsunami inundation depth; however, as stated in the study, these observations provide evidence that in low to moderate inundation depths, placement of infrastructure on embankments can limit damage to both infrastructure and structures in the lee of the embankment. The coastal defences in Minami-Sanriku Town consisted of a sea wall and two flood gates across the two river channels; the concrete pillars of these gates remain standing although the attached steel operating components were washed away. Long sections of the tsunami wall collapsed and evidence of inadequate interlocking of adjacent blocks in the concrete sea walls was observed, with the blocks relying on self-weight for stability. The coastline in Sendai City is east-facing with localized use of 6 offshore breakwaters; the main defence being concrete block revetments along Arahama Beach. The concrete defences at Arahama Beach had failed in several places and the sand infill had been washed out, while concrete blocks had been removed and washed up to landward into the coastal pine forest.

Yeh et al. (2013) presented another study of tsunami effects on coastal infrastructure and buildings of the 11 March 2011 East Japan Earthquake and Tsunami. Flow induced suction pressure near seawall crowns could have caused the failure of concrete panels that covered the infill according to them. Remarkable destruction of upright solid-concrete type seawalls was closely related with the tsunami induced scour and soil instability. The rapid decrease in inundation depth during the return-flow phase caused soil fluidization down to a substantial depth and this mechanism explains severely undermined roads and foundations observed in the area of low flow velocities. They found that soil instability played a major role in the failures. For the mound-type seawall in Kanahama, the centrifugal pressure force induced by the overtopping flow is capable of removing the concrete panels covered the rear face of the seawall. Furthermore, the fast flow velocities with intense turbulence resulted in severe undermining damage in the rear face of the seawall, as well as formation of a large scour hole behind. The solid upright type seawall in Kirikiri was destroyed during the tsunami's return-flow phase. Scouring and undermining actions are the primary cause of the failure.

Finally, Esteban et al. (2013) surveyed and then, analysed the damage in Japanese Ports due to the 2011 Great Eastern Japan Earthquake and Tsunami. During the field surveys, it appeared that composite breakwaters (those protected by armour units such as tetrapods) were far more resilient than simple caisson breakwaters. The armour behaved as designed at dissipating the impact of the tsunami wave forces on the seaward side of the caisson, although damage to armour units was also recorded for several composite breakwaters. Rubble mound structures might be more vulnerable to this scouring at the back than caissons, which are more massive and can resist this effect, provided that the toe of the structure does not fail.

1.2. Lessons and Mitigation

As far as the effects of the 2011 Great Eastern Japan Earthquake and Tsunami disaster have been understood, it prompts considerable re-thinking of constructing countermeasures and improving mitigation. The GEJE exposed the limitations of disaster risk management (DRM) strategies focused disproportionately on structural measures. Dikes, dams, and other structures are regarded as core measures in disaster risk management in Japan. However, those structures built before the GEJE were designed to protect against relatively frequent tsunamis, and were effective in preventing damage from those of limited height. In the GEJE, however, the height of the tsunami far exceeded predictions. Planning for the largest possible event is a significant policy shift in Japan’s thinking about disaster risk management. Building 20 or 30 meter tsunami dikes is neither realistic nor financially, socially, or environmentally practical. But lives can and must be protected by other means, notably multi-layered approaches that combine structural and non-structural measures to ensure the safe evacuation of residents.

Amongst the Japanese Coastal Engineering Community, following the GEJE, it has now started to classify tsunami events into two different levels (Shibayama et al., 2013): according to their level of severity and intensity. Level 1 Events would have a return period of several decades to 100+ years and be relatively low in height, typically with inundation heights of less than 7-10m. Level 2 Events on the other hand would be less frequent events, typically taking place between every few hundred to a few thousand years. A list of countermeasures against Level 1 and Level 2 tsunamis is provided in a report by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT, 2011) and can be seen in Figure 10.

	Tsunami to be considered	*Required performance*
Level 1 tsunami	Largest in recent history (return period of approx. 100 yrs.)	Disaster prevention • Protect human lives • Protect properties/economic activities
Level 2 tsunami	Maximum level (return period of approx. 1000 yrs)	Disaster reduction • Protect human lives • Mitigate economic loss • Prevent major secondary disasters • Enable early recovery

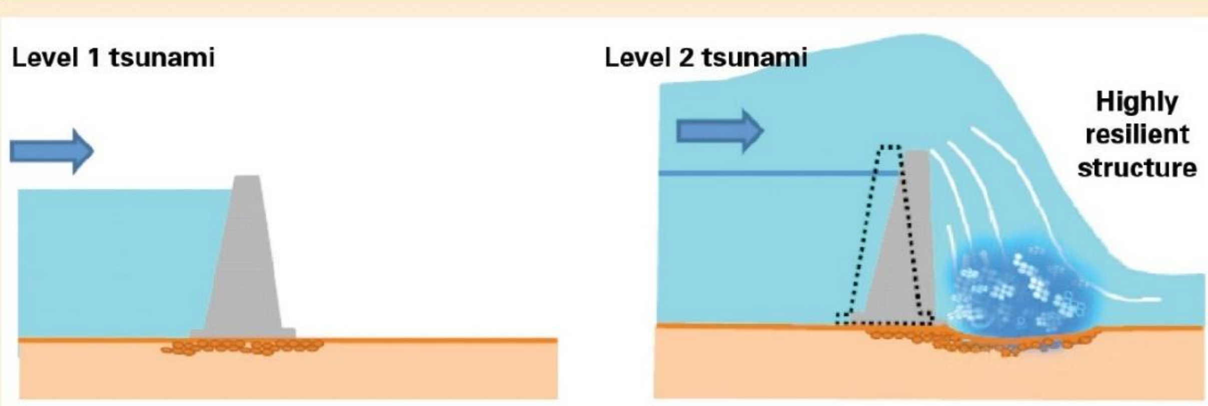

Figure 10: Countermeasures against level 1 and level 2 tsunamis. (World Bank KN 1-1, 2012).

Conventional structural measures such as dikes and breakwaters protect human lives and property, and stabilize local economic activities, in the face of level1 tsunamis. To withstand level 2 tsunamis, however, coastal structures must be improved to be more resistant to collapse and to reduce the likelihood of their complete destruction through scouring. An illustration of the structure of a highly resilient breakwater can be seen in Figure 11. Some 87 percent of dikes that had been reinforced against scouring were not damaged in the GEJE, although the tsunami spilled over them.

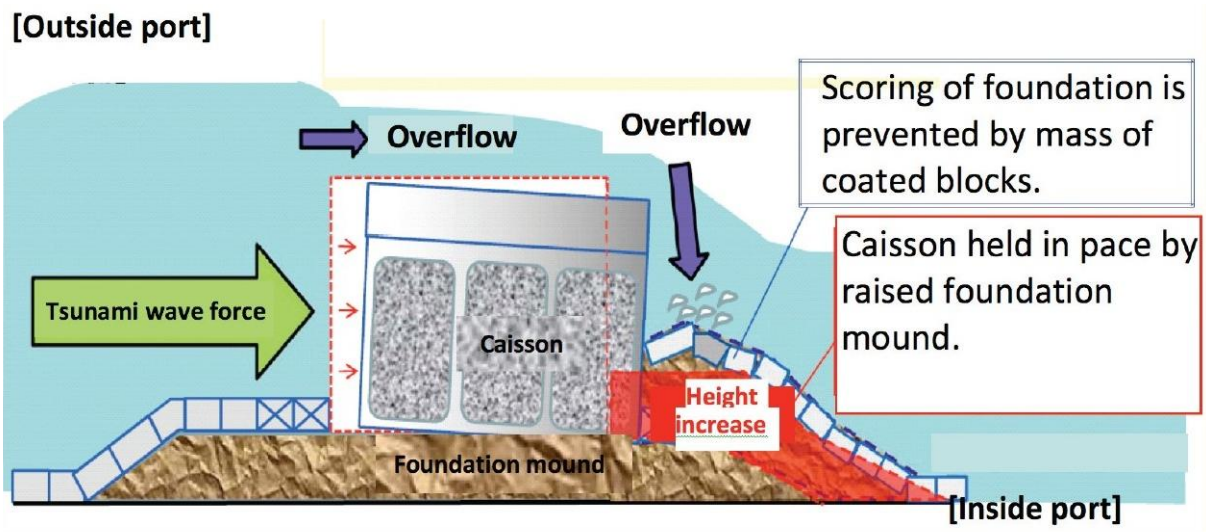

Figure 11: Structure of a highly resilient breakwater (World Bank KN 1-1, 2012).

If the issue is overflow from the points where crown heights are low, tsunami breakwaters are constructed to control the tsunami height whereas seawalls are constructed and reinforced to control the overflow. If the situation is overflow from river banks due to run up, water gates are constructed and reinforced to control the run up and river banks are constructed to control the overflow. Maintaining and controlling the facilities is also an essential point to prevent destruction of the measures.

1.3. Summary

A high-quality, high-density survey dataset was collected by many researchers since 11 March 2011, providing detailed information on various aspects of the tsunami behaviour for different geometries and conditions. The event, 2011 Great East Japan Earthquake and tsunami rigorously tested the sea defences, and where they failed to protect the coastal communities. It was primarily because the wave heights experienced in the 2011 event far exceeded the design values, which were based on the expected Miyagi-ken-oki event or inundation levels experienced in the 1896, 1933 and 1960 tsunami. Also, trees (from the coastal protection forest) and concrete blocks (from coastal revetments) proved to be damaging debris sources, contributing to structural damage and collapse of buildings in several locations. The 2004 Indian Ocean Tsunami also provided rich content information to the researchers. After the GEJE, amongst the Japanese Coastal Engineering tsunami events are classified as level 1 events which have a return period of approximately 100 years and level 2 tsunami events which have a return period of approximately 1000 years. Required performance for the structures that are designed against level 2 tsunami events include protection of human lives, mitigation of economic loss, prevention of major secondary disasters and enabling early recovery. In order for this, coastal structures must be improved and likelihood of their complete destruction due to scouring is must be prevented. Beside structural considerations, non-structural measures are also should be given enough attention alongside for safe evacuation of people as building 20-30 m tsunami dikes is neither realistic nor practical.

2. Damages Due to Tsunami

2.1. Damage to Ports

Due to the previous tsunamis several countermeasures had been taken in Japan to mitigate the disasters using past data. However the Great Japan Tsunami showed that tsunamis much devastating than expected are possible.

The Great East Japan Tsunami caused devastating damage to the ports of Iwate, Miyagi and Fukushima Prefectures, which were in its path. Because tsunami disasters have occurred in the past in these regions, various measures have been incorporated to mitigate the disasters using past tsunami data. However, the Great East Japan Tsunami was several times higher than estimated. The tsunami destroyed the tsunami breakwaters and seawalls that were built to mitigate tsunami impact, thereby causing region-wide inundation.

The Kamaishi Port which is situated in the center of the Sanriku coastline had suffered tsunami disasters in the past caused by the 1896 Meji Sanriku Earthquake, 1933 Showa Sanriku Earthquake and 1960 Chilean Earthquake. Highest-recorded tsunami in the area was the 1896 Meiji Sanriku Earthquake which had a magnitude of 8.5 and caused nearly 5 thousand deaths or missing. As a preparedness measure, a tsunami breakwater was built in the mouth of Kamaishi Bay to reduce the maximum tsunami inundation depth to less than 0.5 m. The plain and cross-section view of this tsunami breakwater is shown in Figure 12. The design tsunami height was 5.0 m and it was the breakwater constructed in the deepest water at the time with a water depth of 63 m. Despite the expectations the 2011 tsunami was over 10m high and damaged the breakwater. Still, post-tsunami surveys revealed that the breakwater reduced the tsunami height behind it.

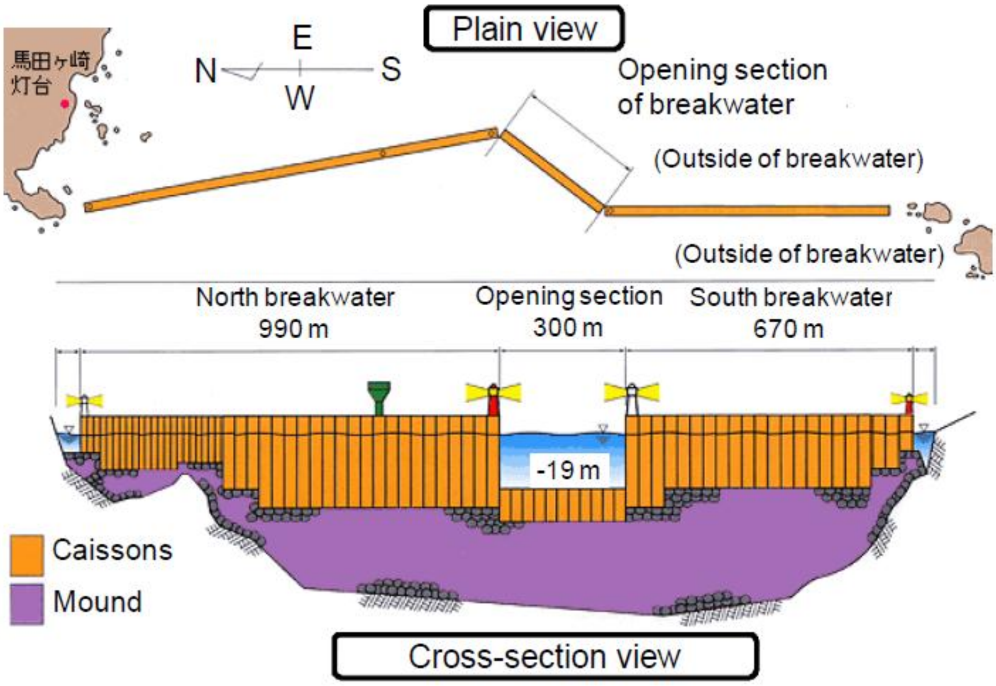

Figure 12: Outline of tsunami breakwater in Kamaishi Port (PIANC, 2009).

Breakwaters are designed to create calm area as ports or harbors for the vessels and their safe handling in the duration of service life under the storm and other unexpected conditions. They are not designed to resist under rare and extreme events such as tsunamis. However, some breakwaters especially rouble mound breakwaters resisted under the attack of Japan tsunami with minor damage. But the Japan tsunami destroyed block type breakwater, seawalls, warehouses, electric devices and other land facilities in the ports.

The movement of ships by tsunami current while handling of oil or liquefied material may cause breakage of the connection and leakage of material. Debris accumulated with marine vessels, boats, cars and the materials of destroyed houses increase the drag force of the moving water and cause extensive damage on the buildings. Breakage of electric and other transmission lines disrupts handling activities in the harbors.

Erosion, deposition, sea bed scour at the toe of the coastal structures and scour around concrete buildings in the inundation zone are other important effects of tsunamis. Scouring at the backside of the block type breakwaters by overtopped tsunami may also cause overturning of the blocks and hence damage.

2.2. Damage to Ships

When a tsunami hits a harbor area, it may set loose ships from their moorings or make manoeuvring ships to lose control and cause them to drift away with current. This may lead ships to collide with other ships or harbor work and being lifted out of water onto piers, quays or port fast land. In particular ships with relatively small sizes like fishing boats and pleasure boats are more easily damaged due to their small displacement volume.

Damage patterns observed during small and large tsunamis regarding to ship size is summarized in Table 1:

Table 1: Relationship between tsunami magnitude and ship damage (PIANC, 2009).

<table>
<tr><th>Tsunami Magnitude</th><th>Ship Size</th><th>Damage Pattern</th></tr>
<tr><td>Small (Tsunami height: more than 2 or 3 m)</td><td>Small Ship</td><td>Drifting
Collision with quay wall
Overturning / Sinking
Being cast ashore</td></tr>
<tr><td rowspan="2">Large (Tsunami height: more than 5 or 6 m)</td><td>Small Ship</td><td>Being cast ashore
Collision with buildings</td></tr>
<tr><td>Large Ship</td><td>Drift
Collision with quay wall
Being cast ashore
Collision with buildings</td></tr>
</table>

During the GEJE, among the boats and ships that were anchored at the ports and harbors, some quickly headed out to the sea to avoid the disaster, while others had no choice but to remain on the scene when the tsunami approached. Their evasive actions varied depending on the time lags before the tsunami reached the shorelines. Many boats and ships were afflicted because they were unable to evacuate before the tsunami hit.

2.3. Bathymetry Change in Channels and Basins

As tsunami waves pass through the opening of a breakwater, its flow velocity increases considerably causing erosion of breakwater mounds and creating eddies. Tsunami induced uprush and backwash flows with high velocities can cause change in seabed topography. As observed by the field investigations of different researchers, some of the breakwaters in Japan were damaged due to scour that occurred near the base of them after the 2011 tsunami. Along with scour, sediments deposits are also created by tsunami mainly at around the centers of inner port regions. Sediments introduced into harbors causes siltation inside the harbor. The extent of the damage to the Kesennuma Port and Kamaishi Port can be clearly seen in Figure 13.

Figure 133: Kesennuma (Left) and Kamaishi Port (Right) (Yalciner et al., 2011).

Goto et al. (2011) investigated the bathymetry change at Kirinda Harbor, Sri Lanka with data obtained one month before and 2 and 11 months after the 2004 Indian Ocean Tsunami and find out that offshore sediments brought by the waves were deposited along the shoreface slope creating a layer with a thickness up to 4m. However this change on the sea bottom was not permanent and harbor bathymetry were almost completely reversed to its pre-tsunami condition after a year.

After the GEJE, scour was occurred between the gaps of breakwaters of both Hitachi Port and Oarai Port along with accumulation at inner ports (PIANC, 2014) (Figure 14). The maximum depth of scour at Hitachi Port of which has a gap width of 280 m, was 7m whereas at Oarai Port the scour depth reached 6 m. Due to the wide gap width of Oarai Port which is 430 m, an accumulation also occurred around the center of the gap.

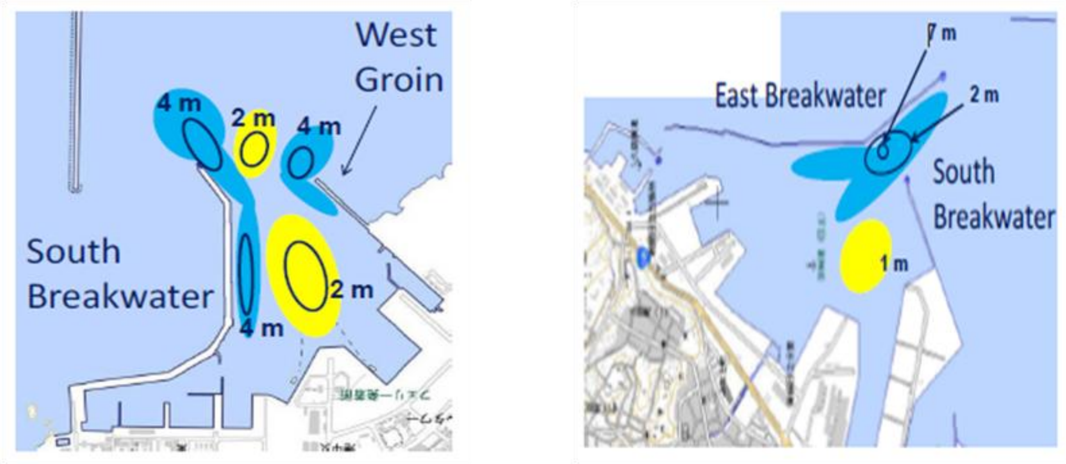

Figure 144: Hitachi Port (Left) and Oarai Port (Right) (dark blue: scour, yellow: accumulation) (PIANC, 2014).

2.4. Damage to Facilities of Wharf and Cargo Handling Machines

The tsunami eroded soil materials of many wharfs and washed out pavements of aprons. Sheet pile quay walls swelled and upper structures of the quay walls were shifted. Other facilities that were damaged or lost include mooring posts, lights, navigation aid signs and steel fences. Moreover cargo handling equipments such as loading cranes, gantry cranes, and winches were also damaged due to the tsunami. Some examples of damage that the GEJE created at the Ofunato Port and the Sendai Shiogama Port in Japan can be seen in Figure 15 and 16.

Figure 15: Tsunami damage and ground subsidence at Ofunato Port (Yalciner et al., 2011).

Figure 16: Damage to cargo handling machine at the container terminal of Sendai Shiogama Port (Photo courtesy: Y. Fukunaga).

2.5. Tsunami-Induced Debris from Cargo Containers and Motor Vehicles

Substantially high amount of debris was generated during the GEJE consisting of cargo containers, motor vehicles, ships, timber, rubble and another debris that were scattered, causing collision and damage.

A research conducted by Kumagai (2012) reveals that at least 3290 cargo containers (in total) were lost from container terminals in eight ports after the Tohoku tsunami. It was observed that the container loss rate (percentage of lost containers to total number of containers in the port) was zero for inundation depth less than 1.6 m and 0.4 or more for inundation depth of above 3.5 m. Number of drifted cargo containers from different ports are listed in Table 2, where the total amount of drifted containers is indicated with a box around.

In Figure 17, an aerial view of the sea surface of Sendai Bay following the Tohoku tsunami is provided. Here, it can be seen that many containers are floating on the sea surface.

Table 2: Number of cargo containers lost from ports (Kumagai, 2012; as cited in PIANC, 2014).

No.	Name of Port	Containers handled in the year 2010	Number of Drift Containers due to Tsunami	Data Source
1	Kushiro	31,731	0	Kanamoto et al.
2	Tomakomai	322,128	3	CERI
3	Muroran	5,482	0	NILIM
4	Mutsu-Ogawara	245	U	-
5	Hachinohe	45,430	700	Harada
6	Miyako	100	7	NILIM
7	Kamaishi	119	0	NILIM
8	Ofunato	2,839	72	NILIM
9	Ishinomaki	4,024	40	NILIM
10	Sendai-Shiogama	155,611	2,000	Asahi Shimbun Digital
11	Soma	622	U	-
12	Onahama	22,352	0	San-ei Shipping Co., Ltd.
13	Ibaraki Hitachinaka	21,261	12	NILIM
14	Kashima	6,189	456	NILIM
	Total	618,133	3,290	-

Figure 17: Aerial view of containers on the sea surface of Sendai Bay following the Tohoku tsunami (Kumagai, 2012)

Structures such as perforated fences can help prevent containers to drift during a smaller wave attack however during the GEJE installed fences were also damaged. Figure 18 shows the damaged and broken wire fences at the Hachinohe Port.

Figure 18: Damaged wire fence on March 16, 2011 at the Hachinohe Port (Kumagai, 2012).

Many cargo containers and motor vehicles were drifted to sea with tsunami current and sunk. Similar to cargo containers, many motor vehicles were also drifted to sea. Total mass of these drifted vehicles was announced to be 310,000 tonnes by the Ministry of Environment. It is known that 270,000 houses were inundated by the tsunami in Iwate, Miyagi and Fukushima which are close to the epicenter of the earthquake.

2.6. Oil Spills

Facilities dealing with oil and dangerous substances including oil industrial complex and oil terminals were also damaged during the GEJE. Among the 3,341 reported damage cases, 80% of them took place at facilities located along the shoreline. Earthquake caused

28% of the incidents whereas 68% were due to tsunami and cause for the 4% of the cases was undetermined (PIANC, 2014).

For outdoor tank storage facilities tsunami with a height of 3-5m caused damage to pipeline or accompanying equipment but not to tank itself. When tsunami height was over 7m, tanks and accompanying equipment faced extensive damage. In Kesennuma City where 9m tsunami was encountered, 21 of 23 oil tanks located near the shore were damaged or swept away resulting in a 12,810kL oil spill. In many of the swept tanks heavy oil was stored. The large scale fire on the sea surface (as shown in Figure 19) might have caused or enhanced by the oil spilled at sea. On the contrary, oil storage tanks in Kamaishi City survived the tsunami despite the 9m wave height.

Figure 19: Fire on the sea surface (PIANC, 2014).

Facilities in Kesennuma, Sendai, Ishinomaki and Kashima experienced damage due to tsunami. In an oil facility in Sendai, fire broke in tanks storing gasoline and asphalt. Some tanks exploded due to "Boiling Liquid Expansion Vapor Explosion".

For the case of oil spills from ships and vessels, there were almost no reported incidents among large vessels. However small ships and fishing vessels suffered excessive damage and number of oil spill cases that were associated or amount of the oil spilled from these vessels are undetermined.

2.7. Summary

Due to the fact that the GEJE was several times higher than estimated, it caused severe damage to the ports on its path. Tsunami breakwaters and seawalls that were built to mitigate tsunami impact were destroyed causing region-wide inundation. As post-tsunami field surveys show some of the damaged breakwaters still reduced the tsunami impact. Debris from destroyed houses and cars flowed inland and to the sea while several containers and oil tanks were displaced. Tsunami's force moved cargo containers and many of them were drifted to the sea and lost. As most of the large-scale vessels were in operation at the time tsunami struck, their operators were able to take immediate evacuation measures which resulted in reported almost no oil spill incidents among large oil vessels. On the other hand several boats and ships were damaged as they were unable to evacuate.

3. Non-structural Tsunami Mitigation Strategies in Japan

3.1. Community-based Disaster Risk Management

As timing plays a vital role in rescue operations during disasters, most people are saved by neighbours or relatives within the first 24 hours before professional rescue teams arrive. Although the authorities have the key responsibilities for community protection, local communities are always the first to take action in time of crisis.

Even before the formal state system, local communities have been participating in disaster risk management (DRM) as volunteers or community-based organizations for centuries in Japan. The GEJE experience has pointed out the important factors for successful community actions as first responders. First of all "strong and effective community based DRM requires grassroots support and linkages to the day-to-day life of the community" (World Bank KN 2-1, 2012). Activities that are ongoing in Japan such as annual disaster evacuation drills to mark the anniversary of tsunamis or festivals help to maintain the awareness of hazard and a culture of preparedness. In addition to these kind of events, to empower the local communities, they should be recognized by authorities and supported financially and technically.

The volunteer fire organizations are also critical elements of the disaster risk management system for several reasons. First of all, volunteers have knowledge of the local people since they are from the community and therefore they are familiar with those residents who may need help to evacuate, such as the disabled or bedridden. Second, the total number of volunteers is nearly six times that of the professional firefighting staff. That condition provides a cost-effective way of large-scale emergency response. Finally, the members receive regular training and their reaction is generally faster since they are locally based.

3.2. Disaster Management Plans

Relevant laws and regulations were established in Japan addressing disaster prevention and preparedness, recovery, reconstruction and financial measures and emergency response. After the severe damage caused by the Isewan Typhoon in 1959, Disaster Countermeasures Basic Act was published in 1961. The act formulates a comprehensive disaster management system with clear roles and responsibilities of governments and relevant stakeholders of both private and public sectors.

Under the act, the Central Disaster Management Council (Figure 20) was formed in order to act as the national level coordinating body for disaster management. The council consists of the Prime Minister, who is the chairperson, Minister of State for Disaster Management, all ministers, heads of major semi-public institutions such as Public Broadcasting, the Bank of Japan, Japanese Red Cross and a telecommunications company along with experts.

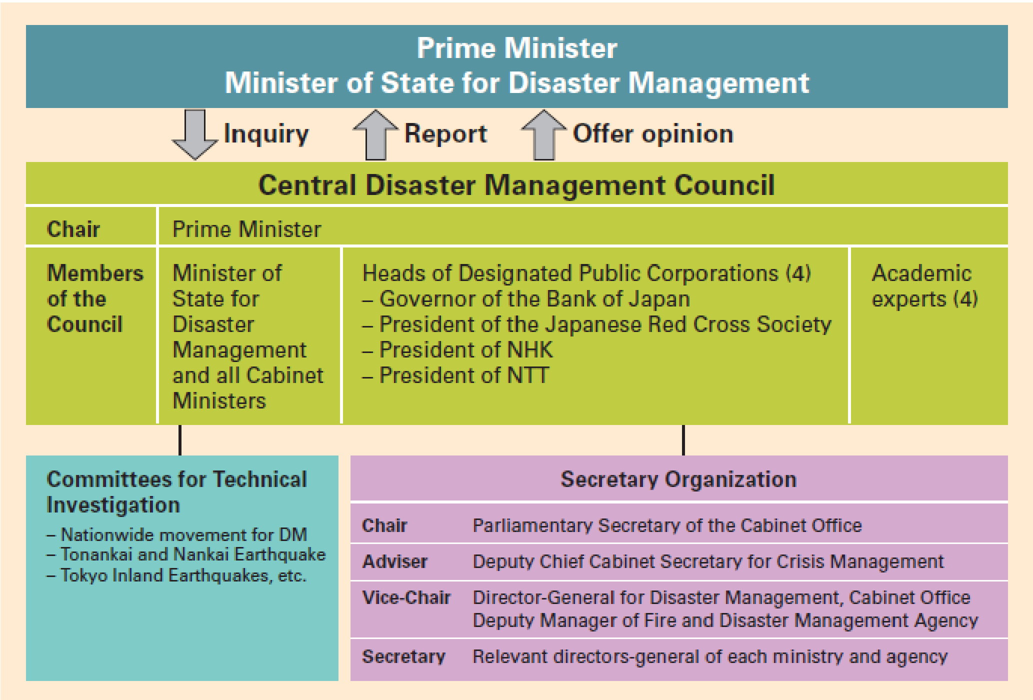

Figure 20: Central Disaster Management Council (World Bank KN 2-2, 2012).

The disaster management planning system consists of Basic Disaster Management Plan, Disaster Management Operation Plan and Local Disaster Management Plan. The Basic Disaster Management Plan is prepared by the Central Disaster Management Council in accordance with the Disaster Countermeasures Basic Act. It forms a basis for disaster reduction activities such as disaster management related systems, early and appropriate disaster recovery and rehabilitation, as well as scientific and technical research. After the GEJE, revisions were required to enhance countermeasures against multihazard, high-impact events. Disaster Management Operation Plan is prepared by each designated government organization and public corporation. Local Disaster Management Plan is made by each prefectural and municipal disaster management council that are aware of local circumstances. Japan’s disaster management system is summarized in Figure 21.

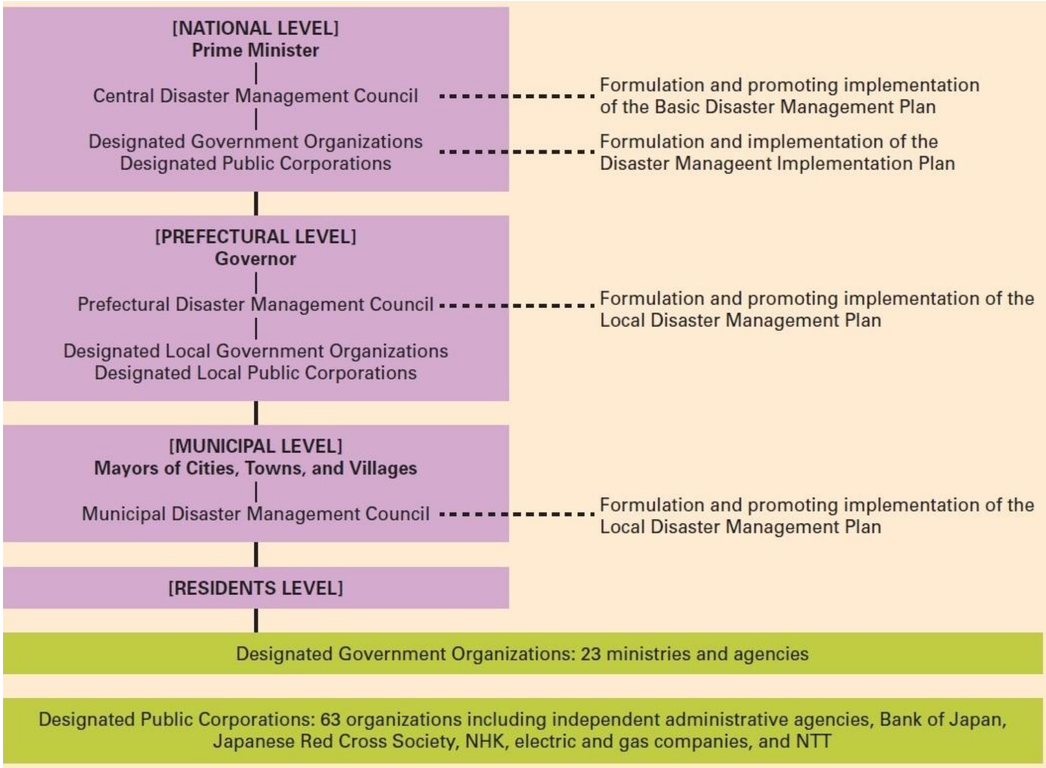

Figure 21: Outline of the disaster management system (World Bank KN 2-2, 2012).

3.3. Warning Systems and Evacuation planning in Japan

Before the GEJE Japan had already adopted highly sophisticated tsunami warning system to monitor and collect seismic data from 280 seismometers and sea level data from around 220 stations around the clock.

When an earthquake occurs, JMA is able to issue a tsunami warning within 3 minutes. Since real-time simulations take time, various earthquake scenarios had been considered and related tsunami simulation results are stored by JMA. Hypocenter and magnitude of the earthquake are quickly calculated and best match scenario's results are selected. Then JMA issues a tsunami forecast based on the expected wave height (Table 3). After the 1960 Chilean Tsunami, long distance tsunamis are also covered by the system. Earthquake magnitudes are calculated in Mj (Japan magnitude), the advantage of which is that it can be calculated quickly. Evacuation planning also had been integrated in DRM and after every disaster; plans were revised accordingly for fast and safe evacuation. Evacuation routes (Figure 22) and shelters on higher ground (Figure 23) are assigned based on past tsunami experiences by local authorities. Two examples of evacuation route signs can be seen in Figure 24. After tsunamis with high wave heights that allowed only a few minutes for evacuation, use of vertical shelter buildings are increased. Communities were informed of location of shelters through tsunami hazard maps that were displayed on sign boards in town or distributed to households. Past tsunami wave heights were also kept in sight by signs in town (Figure 25).

Table 3: Tsunami Warning.

Tsunami Forecast		Tsunami Height
Tsunami Warning	Major Tsunami	"3m", "4m", "6m", "8m", "over 10m"
	Tsunami	"1m", "2m"
Tsunami Advisory		"0.5m"

Figure 22: Tsunami Evacuation Map (World Bank KN 2-6, 2012).

Figure 23: Elevated platform used on Okushiri Island for tsunami evacuation (Scheer et al., 2011).

Figure 24: Tsunami Evacuation Signs in Miyako City (Yalciner et al., 2011).

Figure 25: Signs showing the inundated level of previous Tsunamis in Taro Town (Yalciner et al., 2011).

When the earthquake hit in 2011, tsunami warning was issued to municipalities by the Japan Meteorological Agency (JMA) within 3 minutes. Warning was then transmitted through loudspeakers in towns. However, post tsunami investigations had displayed the scantiness of warning systems and evacuation planning.

A safe evacuation in a timely manner requires high understanding of the risk. Although there had been activities conducted to raise public awareness, it was observed that after the warning issued, only 57% of the residents evacuated immediately. A survey conducted by the government that displays the evacuation behaviour of people is shown below.

The main reason for this might be the underestimation of the wave height during warning. The announced expected wave height was considerably smaller than the actual wave height. Although the warning was revised, all communities were not able to receive it due to power and communication failures. This led some residences to think that it would be safe to stay on second floor of their houses or the breakwaters along the coast that were higher than the announced wave height would protect them. Additionally many of the loudspeakers that the warnings were transmitted through did not function properly because of power cut or the earthquake had knocked down the poles, which reveals that the system was not reliable during a disaster with this magnitude. Also when the loudspeakers worked, the warning was delivered in such a calm tone that it caused residents that heard the message to underestimate the risk and delayed their evacuation.

Another problem that arose during the evacuation is that even though the average evacuation route on foot was 450m while by car it was 2 km by car, over half of the evacuees had chosen to leave by vehicle and one-third of them were stuck in the traffic jam. Moreover, some of the designated shelters failed providing safety as 30% of the evacuees at the shelters submerged by the tsunami.

3.4. Land-use Planning and Regulation

DRM systems can be supported through adoption of land use strategies. For example, the Japanese government implemented the Act on Building Communities Resilient to Tsunami (Figure 26). The act was based on lessons learned from GEJE and legislated in December 2011. Accordingly, the Ministry of Land, Infrastructure, Transport, and Tourism in Japan has developed some guidelines on tsunami mitigation strategies for prefectures and municipal governments. The guidelines point that the risk areas should be classified as the yellow zone, the orange zone and the red zone by prefectural authorities. Yellow zones are the areas where residents are likely to lose their lives. Therefore, evacuation measures, such as evacuation shelters, drills and hazard maps, are required in these zones. In the orange zone, where residents are highly likely to lose their lives, hospitals and other critical structures must be built as tsunami resilient structures. In the red zone where residents have no way to escape from the tsunami, all buildings must also be tsunami resilient, such as having multiple stories that rise high enough to avoid the tsunami water.

Land use planning and regulations can mitigate tsunami risk by minimizing the exposure of people and property and guiding the location, type and intensity of development and vulnerability in risk areas. Tsunami hazard areas should be designed for open-space use such as agriculture, parks and recreation areas. For instance in downtown Hilo, the area where several buildings facing the water once located before the tsunamis of 1946 and 1960, is being used now for open fields and parks. If restricting land to open-space use is not feasible, then the type of development and uses should be controlled and high-occupancy uses shall be avoided as much as possible. Regarding to tsunami run-up areas, most effective strategy is to avoid hazard areas, which might be achieved by raising structures above inundation level. Other than that slowing water current, steering or blocking water forces shall be considered during site planning. Industrial facilities and essential, critical facilities like fire stations, power stations etc. either should not be located on the risk areas, or should be designed to be tsunami resilient.

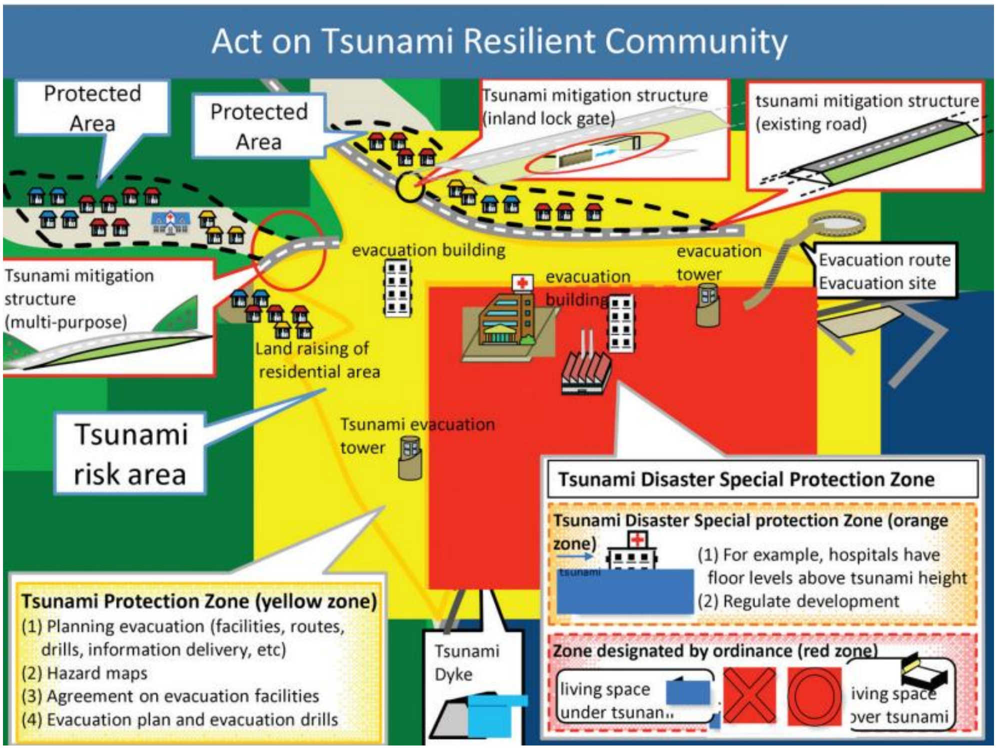

Figure 26: Concept of Act on Building Communities Resilient to Tsunami (World Bank KN 2-7, 2012).

3.5. Use of Greenbelts in Japan

Greenbelts are effective for protection the communities behind from coastal hazards such as salty winds, high tides or tsunamis. Hiraishi and Harada (2003) conducted a wave channel experiment to investigate the effects of greenbelts using chemical porous media representing greenbelt. They concluded that tsunami water level, flow velocity and pressure becomes smaller in case if greenbelt. The authors also carried out a two dimensional tsunami simulation representing the 1998 Papua New Guinea and found out that inundated water area in tsunami run-up decreases with increasing density of the greenbelt.

As an island country with a coastline of approximately 34000 km, Japan has been developing greenbelts for more than four centuries. After the GEJE 3,660 hectares (ha) of the greenbelt were damaged, 1,069 ha of this suffered damage more than 75 percent. However it has seen that greenbelts reduced the impact of tsunami by delaying the arrival time of tsunami and holding drifting debris (Figure 27).

Figure 27: The forest captures a floating ship (World Bank KN 2-8, 2012).

Although in order to be effective, large density and width are needed, greenbelts are economically feasible and they also have other environmental advantages such as conservation of biodiversity and providing scenic beauty. Their effects can be enhanced by combining them with dikes and embankments.

3.6. Summary

Non-structural mitigation strategies play a vital role in saving human lives during catastrophic events as protection by structural defences becomes limited. As tsunamis had occurred in the past, several countermeasures were already implemented and the 2011 event revealed the importance of them. Major limitations of the warning system and evacuation planning include underestimation of the wave height and failure in delivering the warning message to coastal communities.

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