Tsunami Impacting Eastern Japan and Preparedness for Extraordinary Natural Disaster

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1. Outline of The 2011 off the Pacific coast of Tohoku Earthquake
2. Measured tsunami height
3. Validation of the implemented countermeasures against tsunami
4. Principles for future countermeasures against tsunami
5. Efforts to biodiversity and climate change in port areas
Outline of The 2011 off the Pacific coast of Tohoku Earthquake
The Pacific plate is subducting beneath the continental plate at the Japan trench. The earthquake occurred between the two plates.
A large number of aftershocks

The size of the circle indicates earthquake magnitude. 6 aftershocks with M≥7.0 have occurred as of December 6.

More than 500 aftershocks with M≥5.0 have occurred as of December 8.
Great amount of subsidence due to coseismic slip

A great amount of horizontal and vertical displacement occurred due to coseismic slip. The Oshika Peninsula subsided about 120cm according to GPS observation by the Geospatial Information Authority of Japan. The sea floor around the epicenter moved 24m according to Japan Coast Guard. The movement was as large as 50m according to JAMSTEC.
A large number of strong motion data was successfully recorded by the “Strong Motion Earthquake Observation in Japanese Ports”
Two kinds of design ground motions are considered in the seismic design of Japanese port structures.

The Level-1 design ground motion is defined as a ground motion with the annual probability of exceedance of 1/75. The Level-2 design ground motion is so called “the worst case scenario” ground motion.
Comparison with design ground motions
- The case of Onahama Port -

It is quite natural that the observed ground motion exceeded the Level-1 design ground motion. The observed ground motion was close to the Level-2 design ground motion at frequencies relevant to major damage to port structures (0.3-1 Hz). But at higher frequencies, the observed ground motion exceeded the Level-2 design ground motion. In the case of Onahama, the Level-2 design ground motion was based on a scenario earthquake with magnitude 6.5 (but just beneath the port). The appropriateness of the scenario should be investigated once more.
Measured tsunami height
Tsunami height measured and estimated

- **Run-up height**
- **Inundation height**
- **Estimated inundation height at the shoreline**

**Locations:****
- Haninohe
- Kuji
- Miyako
- Kamaishi
- Oofunato
- Kesennuma
- Ishinomaki
- Sendai
- Soma
- Onahama
- Hitachinaka
- Kashima
Tsunami in deep water

NHK Special “The Great Eastern Japan Earthquake” by NHK (Japan Broadcasting Corporation) on May 7, 2011.
Tsunami at Kuji
Tsunami at Kuji

NHK Special “The Great Eastern Japan Earthquake” by NHK (Japan Broadcasting Corporation) on May 7, 2011.
NHK Special “The Great Eastern Japan Earthquake” by NHK (Japan Broadcasting Corporation) on May 7, 2011.
Tsunami at Kamaishi

NHK Special “The Great Eastern Japan Earthquake” by NHK (Japan Broadcasting Corporation) on May 7, 2011.
Tsunami at Sendai Plain

NHK Special “The Great Eastern Japan Earthquake” by NHK (Japan Broadcasting Corporation) on May 7, 2011.
Tsunami and earthquake damages

Quay damaged by the combination of earthquake and tsunami (Soma)

Scattered containers (Sendai)

Tilted floating dock (Kuji)

Collapsed crane (Kashima)
Tsunami and earthquake damages

- Smashed oil tank and oil spill (Kesennuma)
- Drifted tank trucks (Sendai)
- Destroyed seawall (Taro)
- Ship drifted in a town (Kesennuma)
- Smashed oil tank and oil spill (Kesennuma)
Tsunami and earthquake damages

- Washed vehicles and debris (Kamishl)
- Broken and tilted buildings (Onagawa)
- Burned wooden houses and vehicles (Ishinomaki)
- Piles were pulled out.
- Collapsed building (Onagawa)
Validation of the implemented countermeasures against tsunami
Meiji Sanriku Earthquake (1896)

Kamaishi Tsunami Breakwater

Tsunami breakwater

Tsunami seawall

North Breakwater 990m
South Breakwater 670m

+6m

-19m

-32m

-63m

Less than 0.5 m

5 m

+6 m

Δ 2.8 m

+4 m
Damages of breakwater
**Tsunami heights at Kamaishi Port and neighboring bays**

- **Inundation height**
- **Run-up height**

**Inside the port:** 8.1~11.7 m

**Outside the port:** 12.5~18.3 m

- **Ryoishi Bay**
  - 17.7 m
  - 17.7 m

- **Kamaishi Port**
  - 18.3 m
  - 12.5 m
  - 9.3 m
  - 8.1 m

- **Tounin Bay**
  - 21.4 m
  - 14.8 m
  - 9.2 m

Made by Port Bureau of Ministry of Land, Infrastructure, Transport and Tourism on the basis of Coastal Engineering Committee of Japan Society of Civil Engineers.
Simulation results for the ToHoku Earthquake in 2011

The 2011 off the Pacific Coast of Tohoku Earthquake (2011)

This tsunami simulation is conducted by ‘Storm Surge and Tsunami Simulator in Oceans and Coastal Areas (STOC)’, which is developed by PARI.
Effect of breakwater

Without Breakwater

With Breakwater

Arrival time
6 minutes delay
(tsunami height of 4 m)

Tsunami height
13.7 m → 8.0 m

Water surface elevation (m)

Time after earthquake (min)
Effect of breakwater

Without breakwater

- Tsunami height: 13.7 m
- Run-up height: 20.2 m
- 4-m-height seawall: 28 min for overtopping

With breakwater

- Tsunami height: 10.8 m
- Tsunami height (with seawall): 8.0 m
- Run-up height: 10.0 m
- 4-m-height seawall: 36 min for overtopping
Hazard map at Oofunato

Comparison between the inundation areas at the 2011 earthquake and shown in the hazard map

Hazard map

- Meiji Sanriku Earthquake (1896)
- with tsunami breakwater & river dyke
- without coastal and tsunami seawalls & floodgate
Severe damage at Taro, Iwate

Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the “2011 off the Pacific coast of Tohoku Earthquake”
Minor damage at Fudai, Iwate

Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the “2011 off the Pacific coast of Tohoku Earthquake”
• Little lateral displacement of the quay wall.
• Liquefaction evidence was not recognized since un-sieved crushed stone is filled as liquefaction countermeasure.
• The high earthquake resistance quay wall showed good seismic performance. The quay went into service on March 15 after checking the burying of navigation channel by tsunami.
Sendai Port: Base Isolated Gantry Crane

Damage occurred in one non-base-isolated crane

4 Gantry Cranes: 2 base-isolated cranes, 2 non-base-isolated cranes

Base-isolated cranes: No structural damage

Direction of Land and Sea

ISOLATOR

Oil Dumper

Parallel Motion Link

Trigger Pin

Moment Transmission Bearing

Patent holder: PARI and Mitsui Engineering & Shipbuilding Co, Ltd.
Principles for future countermeasures against tsunami
Major earthquakes and tsunamis in Japan (1896-2005)

○ Number of casualties, ● Maximum run-up height

① Meiji-Sanriku (M8.5)
June 15, 1896
○ 22,000, ● 38.2m

② Kanto (M7.9)
September 1, 1923
○ 142,807

③ Chile (M9.5)
May 23, 1960
○ Dead 142, ● 6m

④ Showa-Sanriku (M8.1)
March 3, 1933
○ 3,064, ● 29m

⑤ Tou-Nankai (M7.9)
December 7, 1944
○ 998

⑥ Showa-Nankai (M8.0)
December 21, 1946
○ 1,443, ● 6m

⑦ Hokkaido Nanseioki (M7.8)
July 12, 1993
○ 230, ● 30m

⑧ Nihonkai-chubu (M7.7)
May 26, 1983
○ 104, ● 14m

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Occurrence probability of subduction zone earthquake within 30 yrs

- **Nemuro** (M7.9) 40%
- **Tokachi** (M8.1) 0.5%
- **North Sanriku** (M8.0) 7%
- **Miyagi** (M7.5) 99%
- **Kanto (taisho)** (M7.9) 0.9%
- **Sanriki-Bos** (M8.2) 20%
- **Kanto (genroku)** (M8.1) 0%
- **South-Kanto** (M6.7~7.2) 70%
- **Tou-Nankai** (M8.1) 60%
- **Tokai** (M8.0) 84%
- **Sado-North** (M7.8) 6%
- **Akita** (M7.5) 3%
- **Hokkaido-Nanseioki** (M7.8) 0.1%
- **Hyuganada** (M7.6) 10%
- **Nankai** (M8.4) 50%
Future Improvement in Information Network

**Present System**

- strong motion observation site
- NTT telephone line, on demand
- GPS buoy
- coastal wave gauge
- tide gauge house
- land station

**Idea for Future System**

- Toward redundant system !!
- Packet data transmission
  - Mobile phone (NTT FOMA, etc.)
  - Satellite phone (INMARSAT, Iridium, etc.)
- National backup center?

**Tohoku District**
- Mutsu-Ogawara Port
- Hachinohe Port
- Kuji Port
- Miyako Port
- Kamaishi Port
- North Miyagi
- Ofunato Port
- Sendai New Port
- Soma Port
- Shiogama Port
- Kamaishi Port
- Hitachi-naka, Ibaraki Port
- Kashima Port
- Central Miyagi
- Onahama Port
- Soma Port
- Sendai New Port

**Kanto District**
- PARI
- Hitachi-naka, Ibaraki Port
- Kashima Port
- Central Miyagi
- Ofunato Port
- Sendai New Port

*Ports and Airports Division, Tohoku Regional Development Bureau*
① Submerged breakwaters were drifted by the first incoming tsunami.

② Armor blocks were ripped off at the outgoing tsunami.

③ The mound was scoured at the outgoing tsunami and the head breakwater was tilted.

Although the mound was scoured, the head breakwater was not tilted.
Major factors in the failure under overflow tsunami

Failure mechanism of breakwater at Kamaishi

Safety factor against sliding of caisson

\[ \text{Safety factor} = \frac{\text{Lateral Force}}{\text{Resistance force}} \]
Failure mechanism of breakwater at Kamaishi

Experimental Video under overflow tsunami
Experimental Video under overflow tsunami
Failure mechanism of breakwaters at Kamaishi

Damaged north breakwater

Experiment

Overtopping

About the amount of increasing of the lateral force

The wave pressure is slightly higher at the front wall and about 10% lower at the rear wall than the hydrostatic pressure.

Two out of 17 caissons were slid and one was tilted.
Failure mechanism of breakwaters at Kamaishi

Influence of scour due to overflow tsunami

The quantification of the amount of a decrease of the sliding resistance force is a future task.
Safety factor against sliding  

The thickness of additional stones is 1/4 the caisson height.

The problem is the scour caused by overtopping behind the breakwater.

- To prevent scour by installing large armor blocks.
- To prevent breakwater sliding by installing additional stones.

Wave pressure

Outside port

Overtopping

Caisson

Inside port
Recommended countermeasures against tsunami
Based on the Reports of Central Disaster Management Council and Council of Transport Policy

<table>
<thead>
<tr>
<th>Design tsunami</th>
<th>Required performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
<td>• To protect human lives&lt;br&gt;• To protect properties&lt;br&gt;• To protect economic activities</td>
</tr>
<tr>
<td>Tsunami with relatively high frequency (return period: 50 to 150 years)</td>
<td></td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>• To protect human lives&lt;br&gt;• To reduce economic loss, especially by preventing the occurrence of severe secondary disasters and by enabling prompt recovery</td>
</tr>
<tr>
<td>One of the largest tsunamis in history (return period: 600 to 1000 years)</td>
<td></td>
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</tbody>
</table>

In the event of ‘Level 2 tsunami,’ the deformation of the facilities have to be not so large to maintain the performance to reduce tsunami.
(1) Basic principles

- For the largest-possible tsunamis, implement structural measures, such as coastal protection facilities, and non-structural measures centering on evacuation, such as preparation of hazard maps, in accordance with a ‘disaster reduction’ philosophy that focuses on minimizing damage.

- The fundamental step in protecting human life from tsunamis is evacuating to higher ground without hesitation, swiftly and autonomously, as soon as a strong or extended shaking is felt.

- In communities where tsunamis arrive quickly, community development should aim to enable evacuation within around five minutes. However, in communities where topographical conditions or the state of land use make such responses difficult, it is essential that measures for tsunami evacuation are thoroughly examined with consideration to factors such as the tsunami arrival time.
Recommended countermeasures against tsunami
Based on the Reports of Central Disaster Management Council

(2) Preparation of a system and creation of rules for efficient evacuation

- Tsunami warnings and disaster management responses
- Improvement and strengthening of tsunami warnings and information delivery systems
- Improvement and strengthening of earthquake and tsunami observation system
- Designation of tsunami evacuation buildings and development of evacuation sites and evacuation routes
- Development of rules of conducts for guiding residents for evacuation and disaster management measures

(3) Development of communities resilient to earthquakes and tsunamis

- Multi-layer protection and construction of facilities
- Governmental and welfare facilities will be constructed in places with low flooding risks
- Organic coordination between local disaster management plans for municipalities and city planning
(4) Raising disaster awareness about tsunamis

- Improving hazard maps
- Thoroughness in the principle of evacuation on foot, and education about the importance of evacuation
- Implementation of disaster education and improvement of community disaster management capabilities
Efforts to biodiversity and climate change in port areas
Restoration of coastal ecosystems located in port areas

Sandflat for clam fishery

Tidal flat- and seagrass bed-hybrid breakwater
- Role of coastal ecosystems are unknown; a slight sink for carbon or source?
- More than half of carbon are absorbed in coastal ecosystems?
Blue Carbon flow to be tested

- Terrestrial
  - CO₂
- Intertidal
  - Seagrasses
  - Microphytobenthos
- Subtidal
  - Phytoplankton
  - DIC
  - DOC prod.
- Coastal ocean
  - DOC exchange
  - DOC outflow

Particulate Organic C (POC)
Dissolved Organic C (DOC)
Dissolved Inorganic C (DIC)
Thank you for your kind attention.