February 22, 2012

Tsunami Impacting Eastern Japan and Preparedness for Extraordinary Natural Disaster

Takehiko Fujita

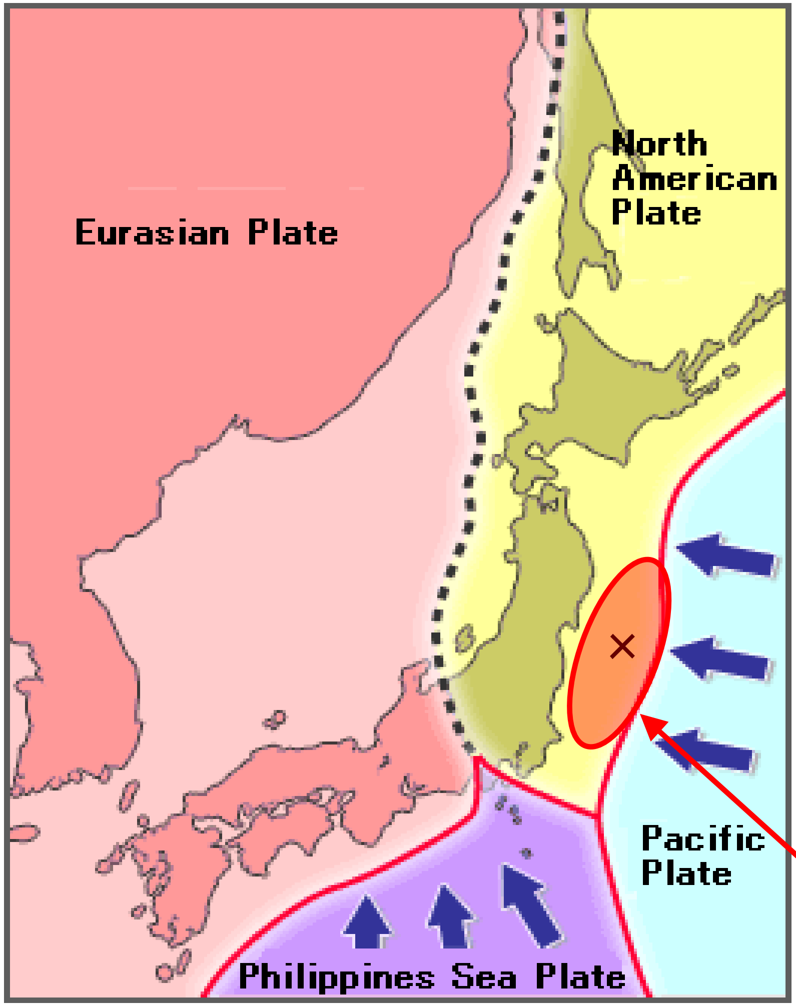
Executive Director
Port and Airport Research Institute, Japan

Contents

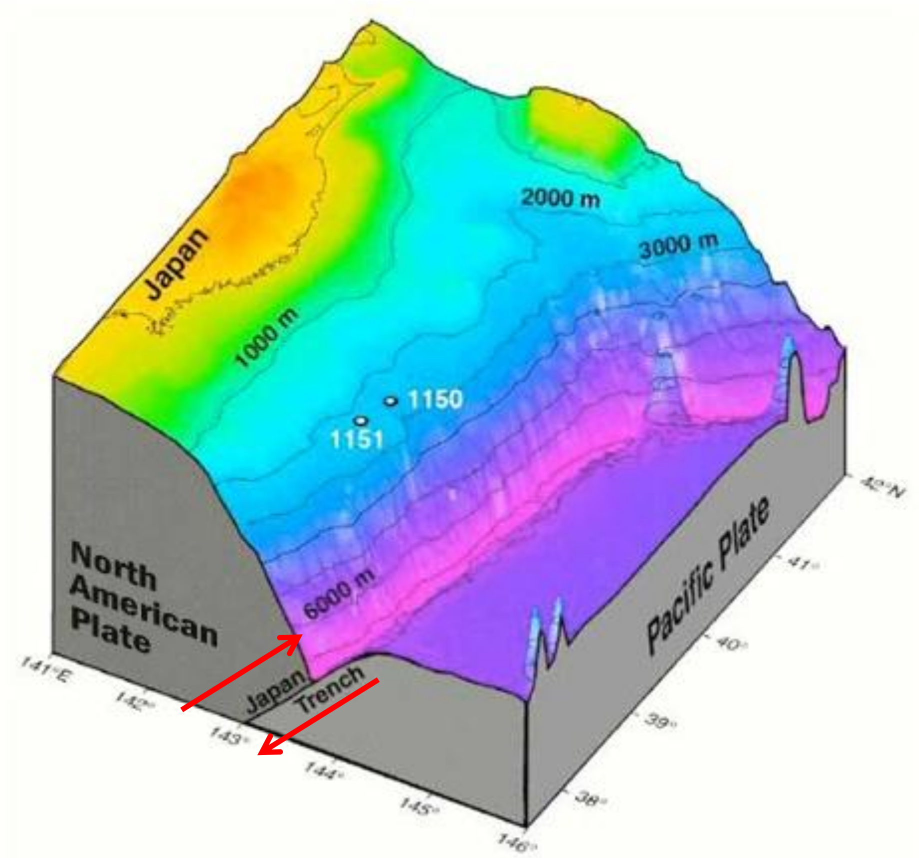
1. Outline of The 2011 off the Pacific coast of Tohoku Earthquake
2. Measured tsunami height
3. Validation of the implemented counter-measures against tsunami
4. Principles for future countermeasures against tsunami
5. Efforts to biodiversity and climate change in port areas

Outline of The 2011 off the Pacific coast of Tohoku Earthquake

Source region of the earthquake



http://www.sonpo.or.jp



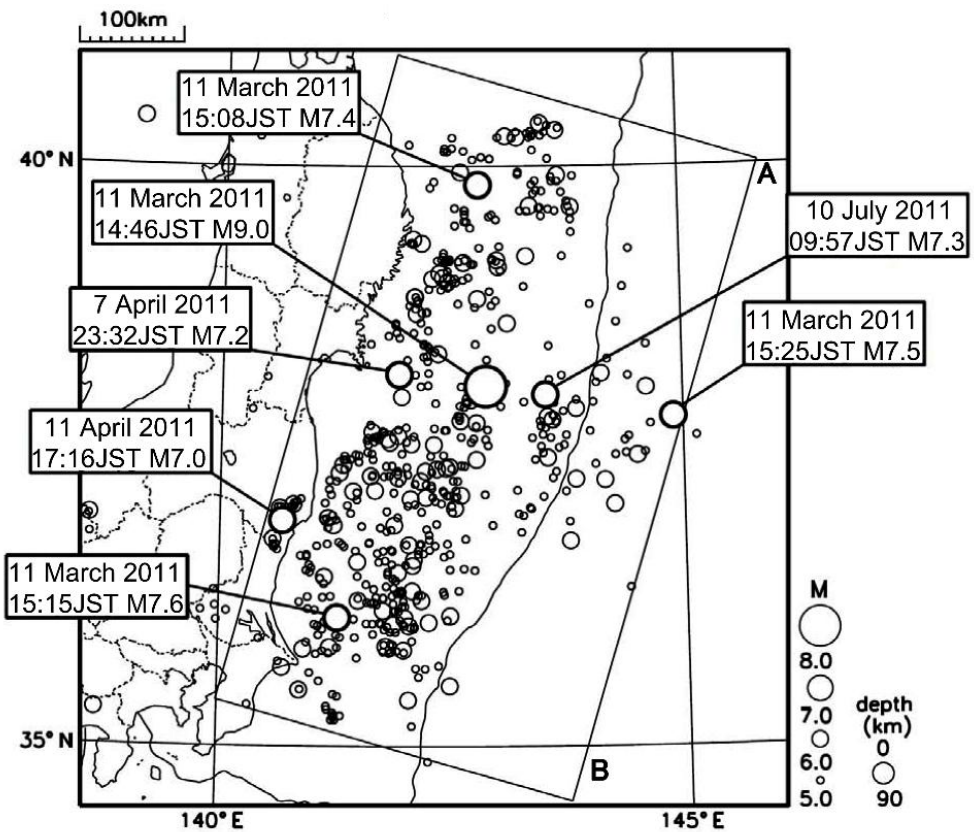
http://alterman47.wordpress.com

Approximate source region of the earthquake. 'X' denotes the epicenter.

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

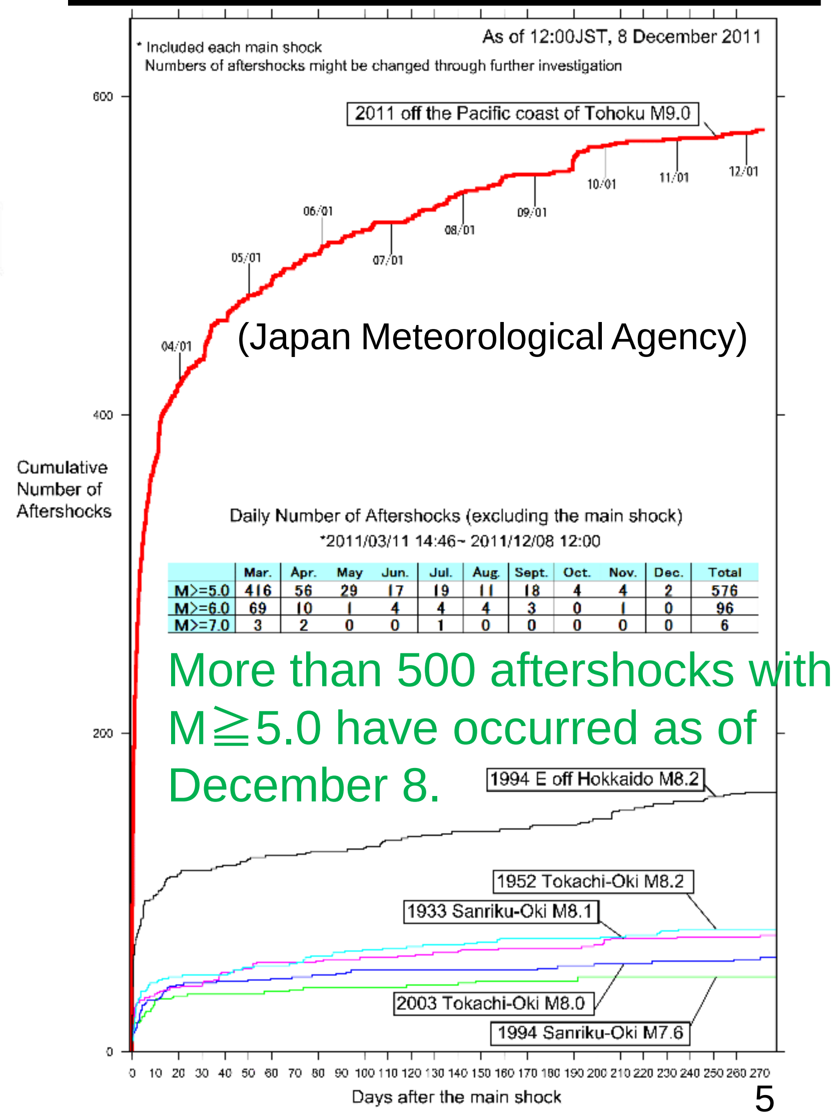
Distribution of aftershocks with M≧5.0



(Japan Meteorological Agency)

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

Cumulative number of aftershocks
(Magnitude>=5.0)



(Japan Meteorological Agency)

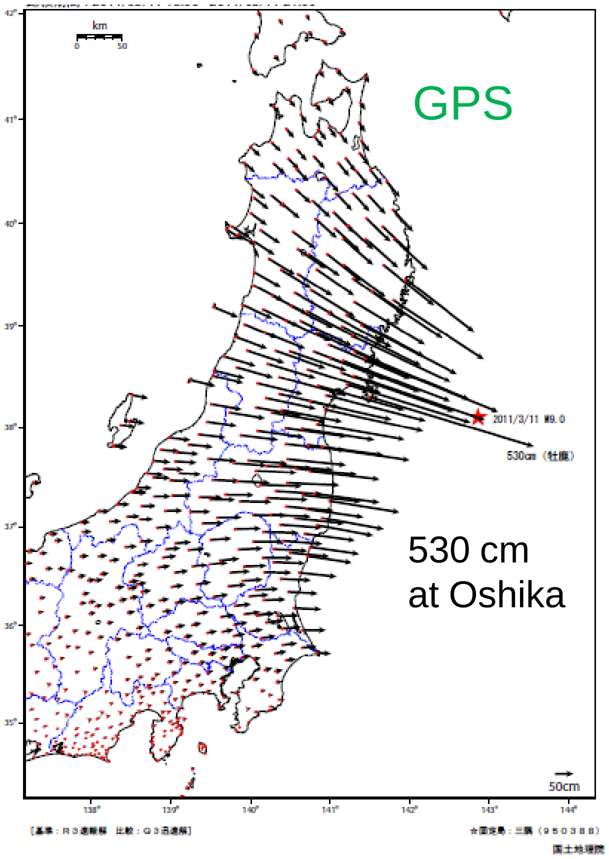
Daily Number of Aftershocks (excluding the main shock)
*2011/03/11 14:46~ 2011/12/08 12:00

	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
M>=5.0	416	56	29	17	19	11	18	4	4	2	576
M>=6.0	69	10	1	4	4	4	3	0	1	0	96
M>=7.0	3	2	0	0	1	0	0	0	0	0	6

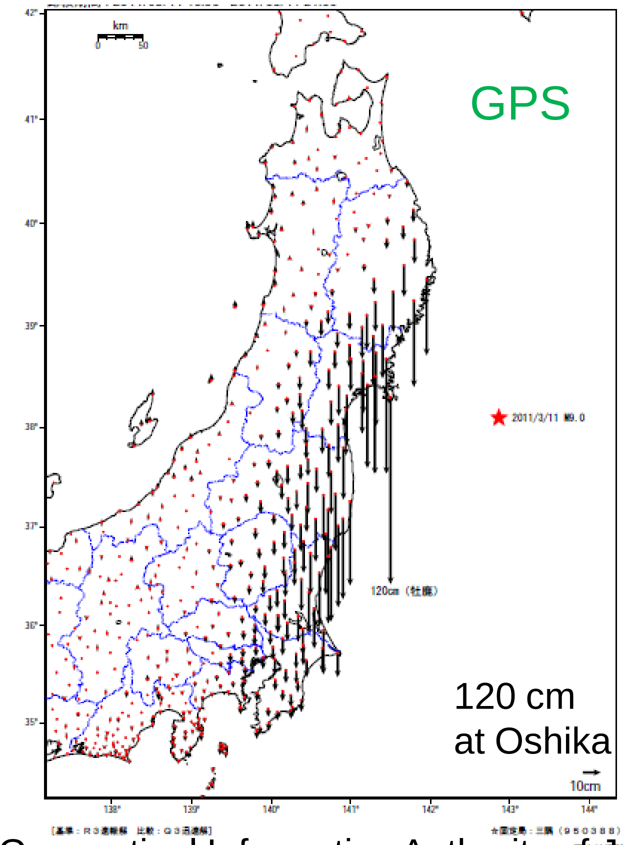
More than 500 aftershocks with M≧5.0 have occurred as of December 8.

Great amount of subsidence due to coseismic slip

Horizontal displacement



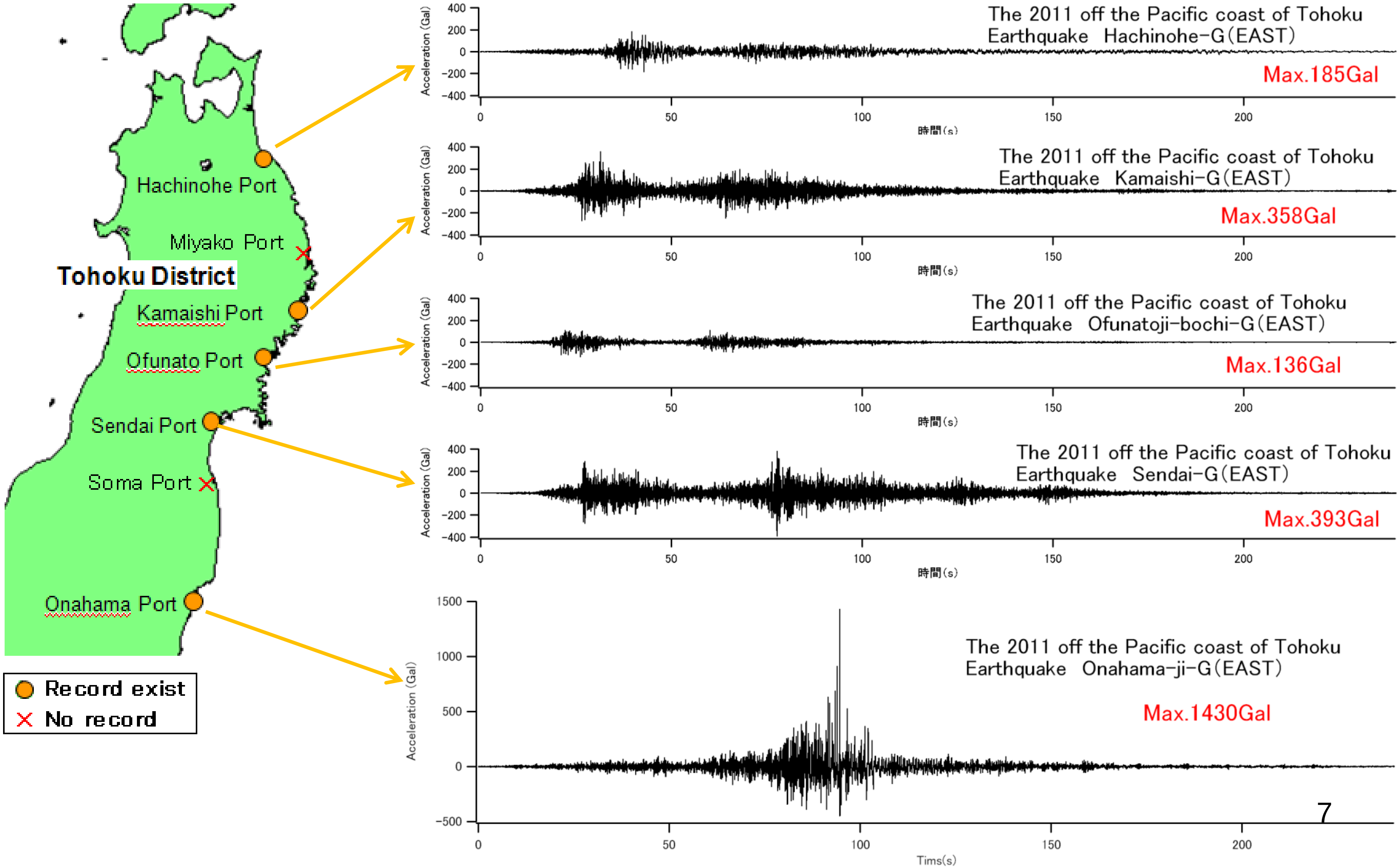
Vertical displacement



(Geospatioal Information Authority of Japan)

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.

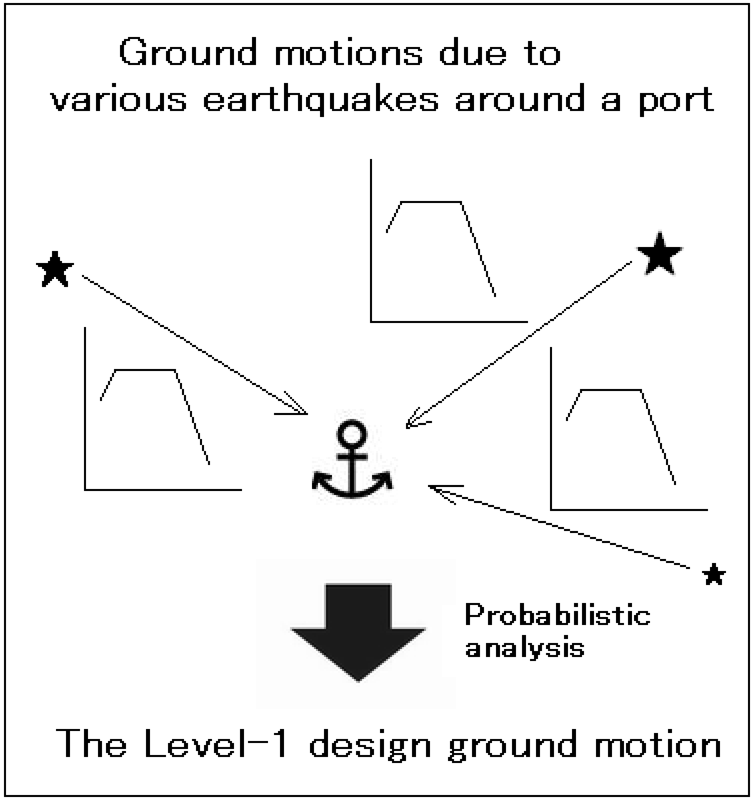
A large number of strong motion data was successfully recorded by the "Strong Motion Earthquake Observation in Japanese Ports"

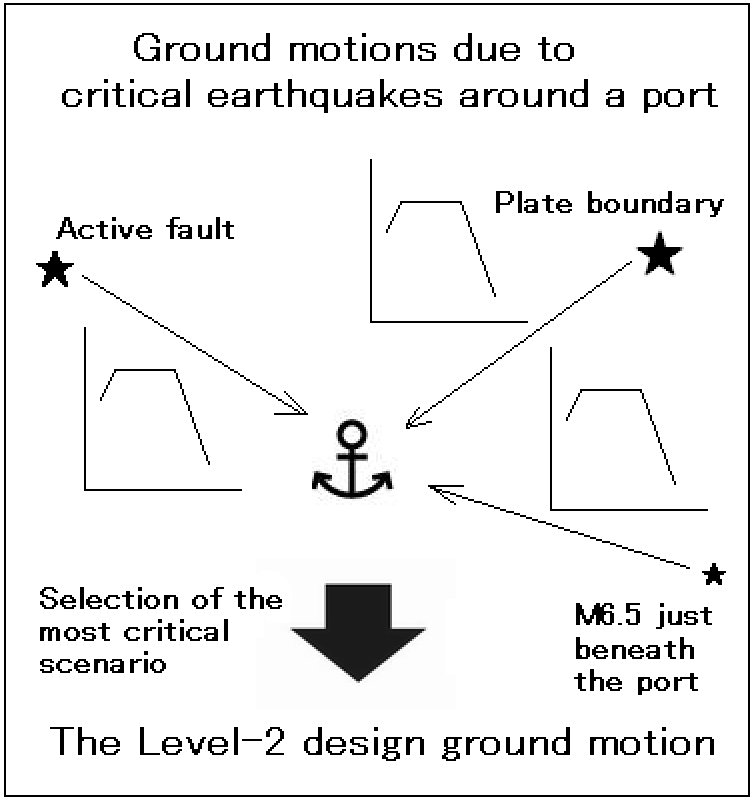


Design ground motions for Japanese Ports

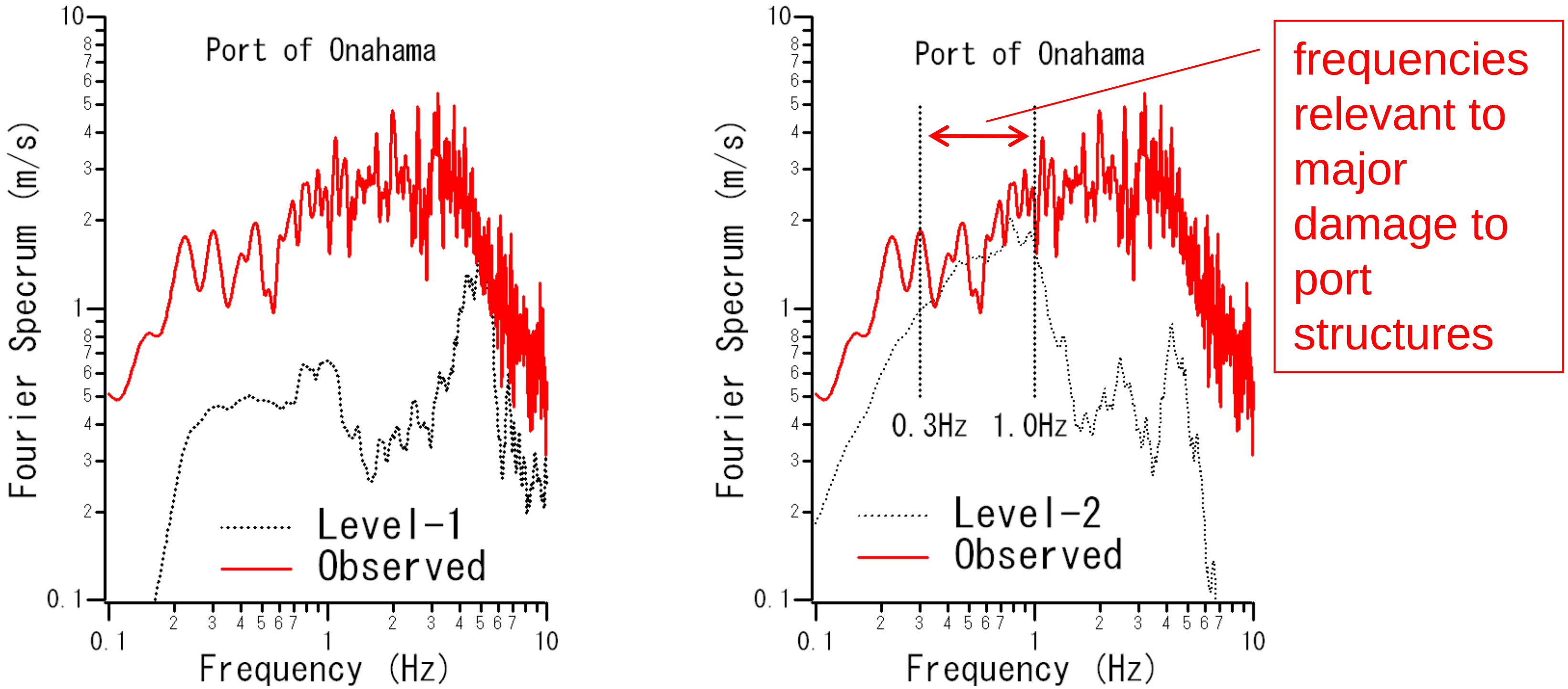
Two kinds of design ground motions are considered in the seismic design of Japanese port structures.

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.





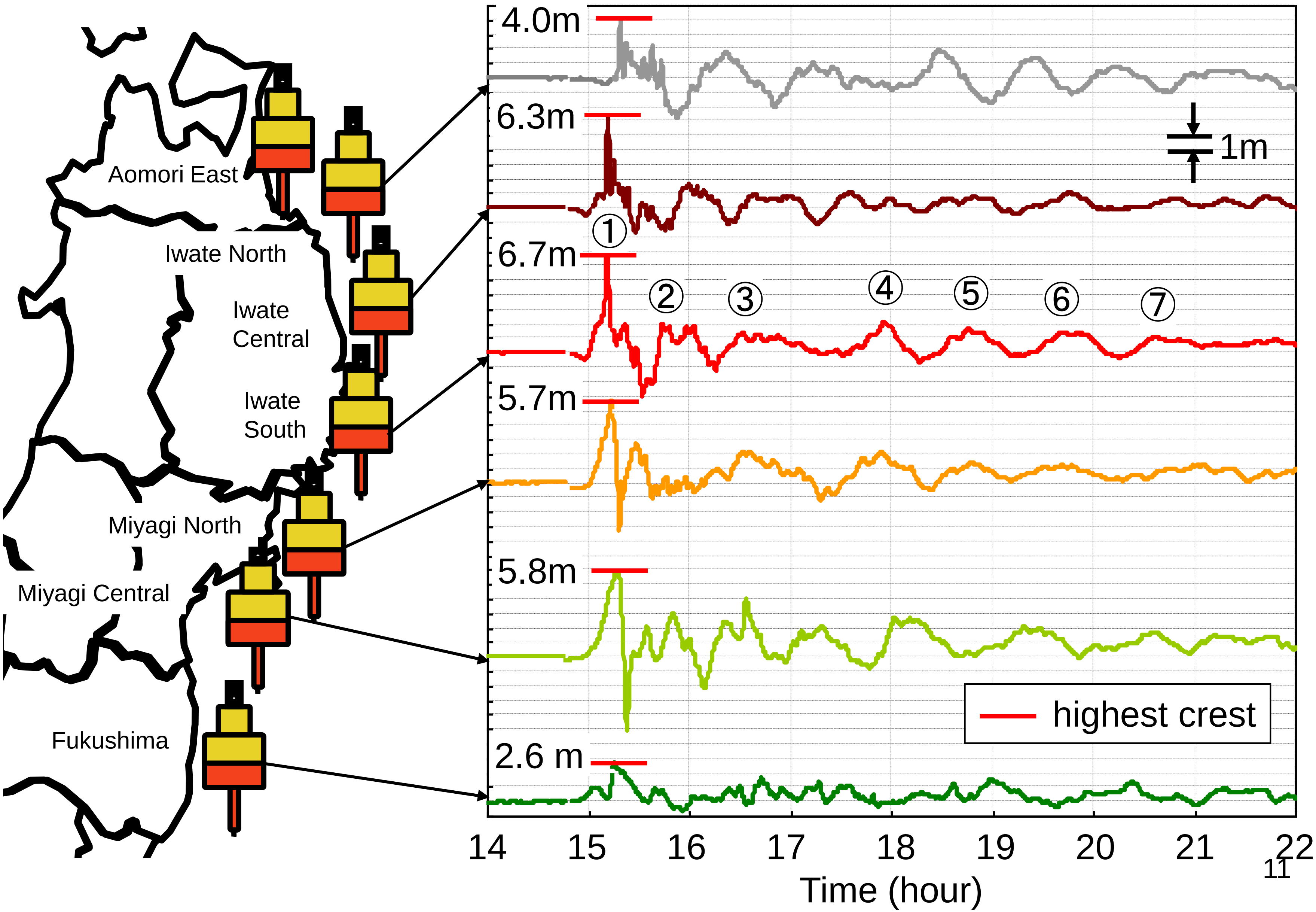
Comparison with design ground motions
- The case of Onahama Port -



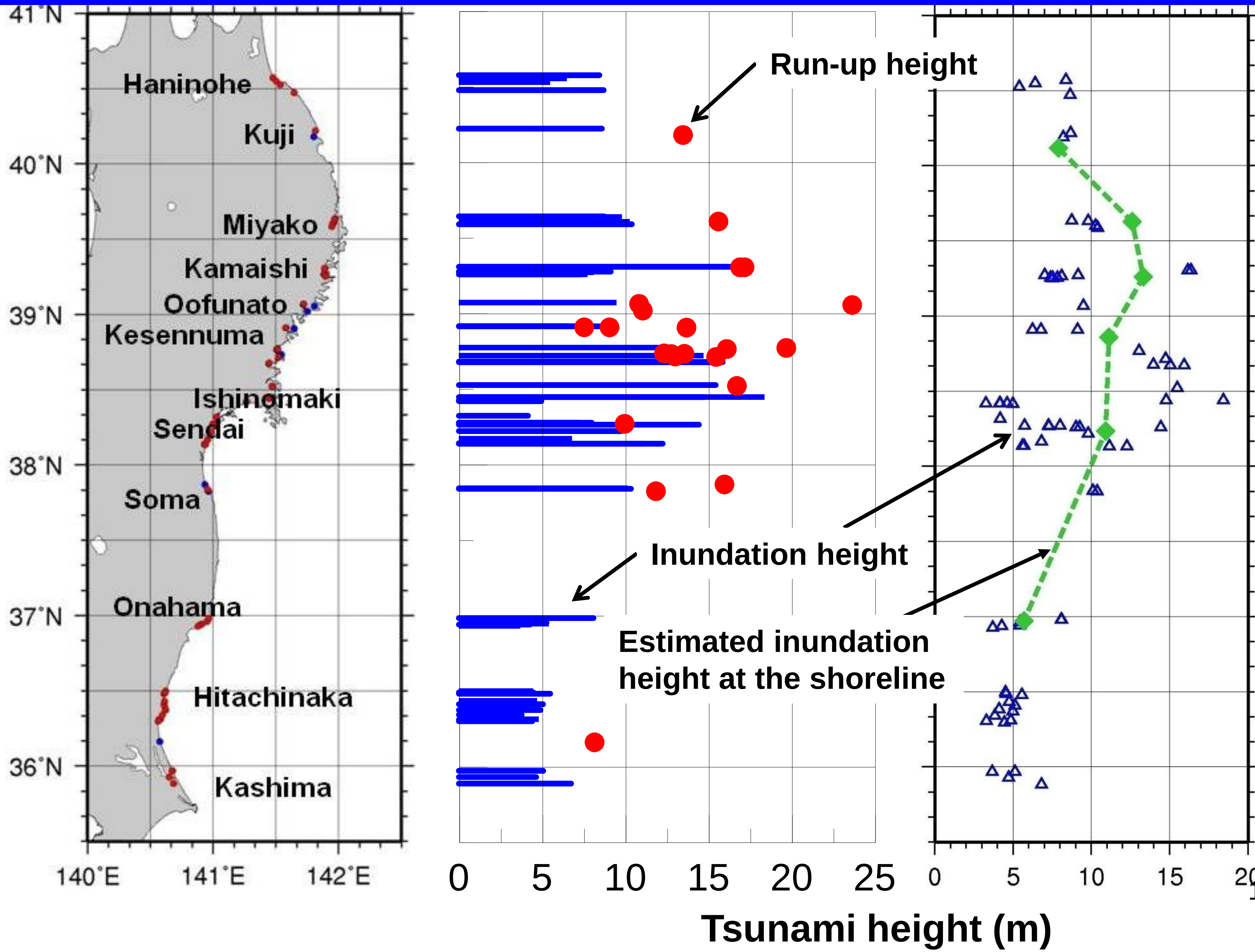
It is quite natural that the observed ground motion exceeded the Level-1 design ground motion. The observed ground motion was close to the Level-2 design ground motion at frequencies relevant to major damage to port structures (0.3-1Hz). But at higher frequencies, the observed ground motion exceeded 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

GPS-mounted wave buoy



Tsunami height measured and estimated



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


Drifted tank trucks (Sendai)


Ship drifted in a town (Kesennuma)


Destroyed seawall (Taro)

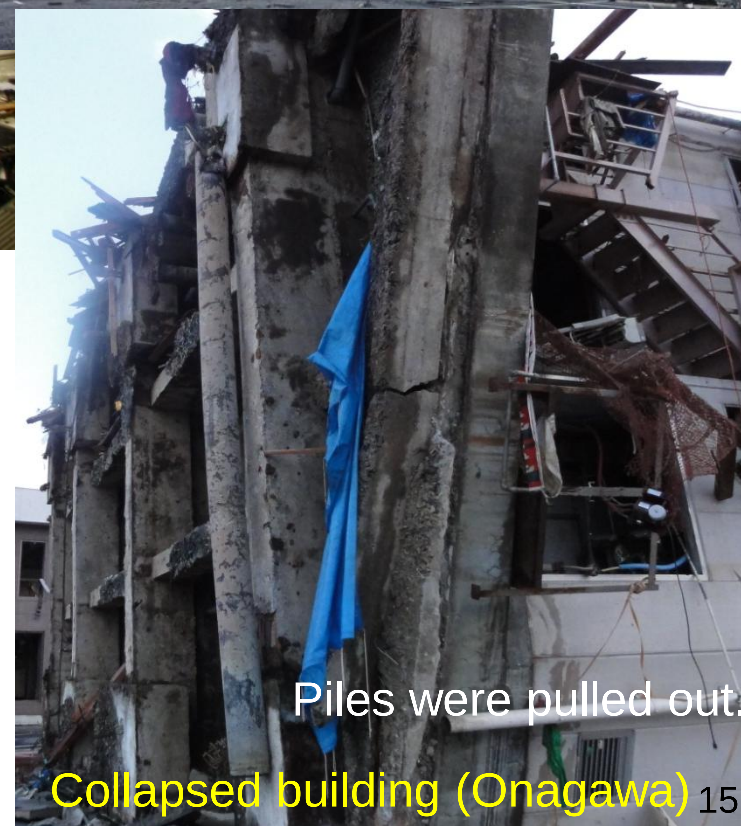
Smashed oil tank and oil spill (Kesennuma)

Tsunami and earthquake damages

Washed vehicles and debris (Kamishi)


Broken and tilted buildings (Onagawa)

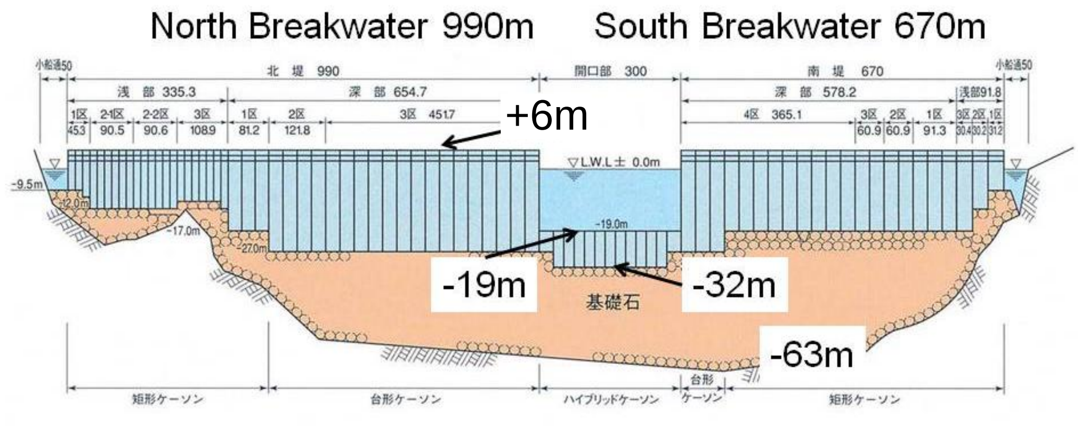

Burned wooden houses and vehicles (Ishinomaki)


Piles were pulled out.

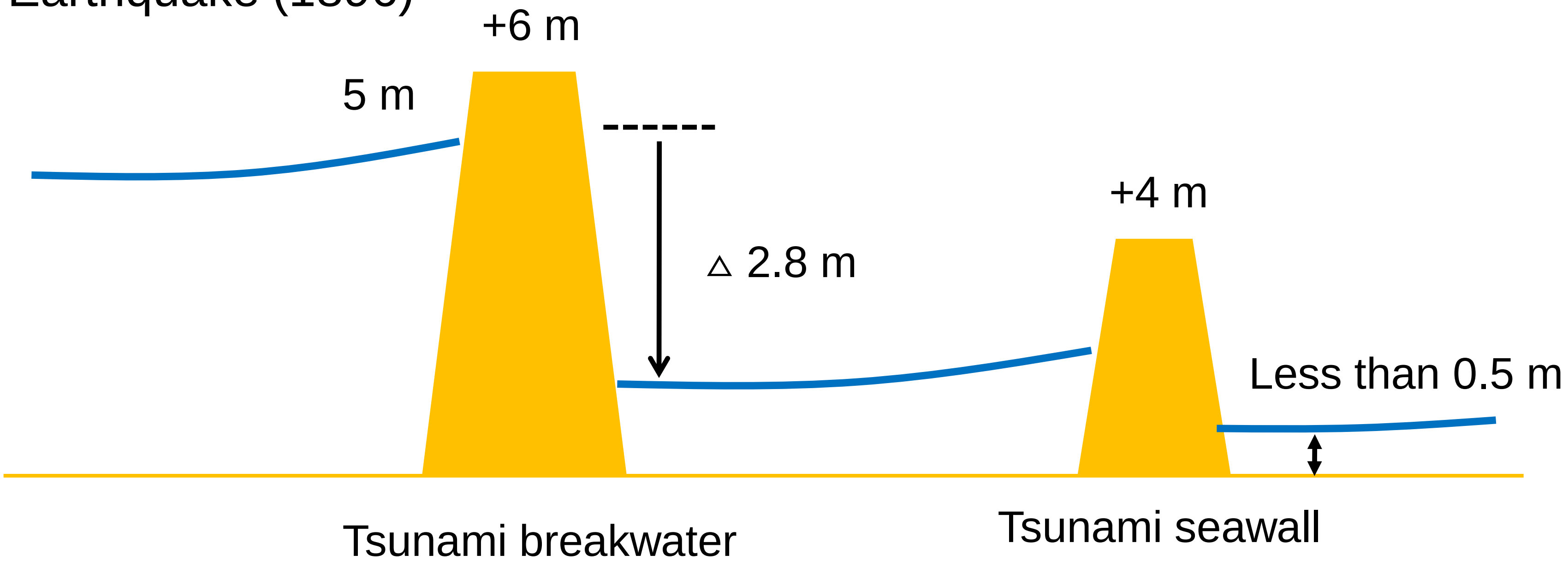
Collapsed building (Onagawa)

Validation of the implemented countermeasures against tsunami

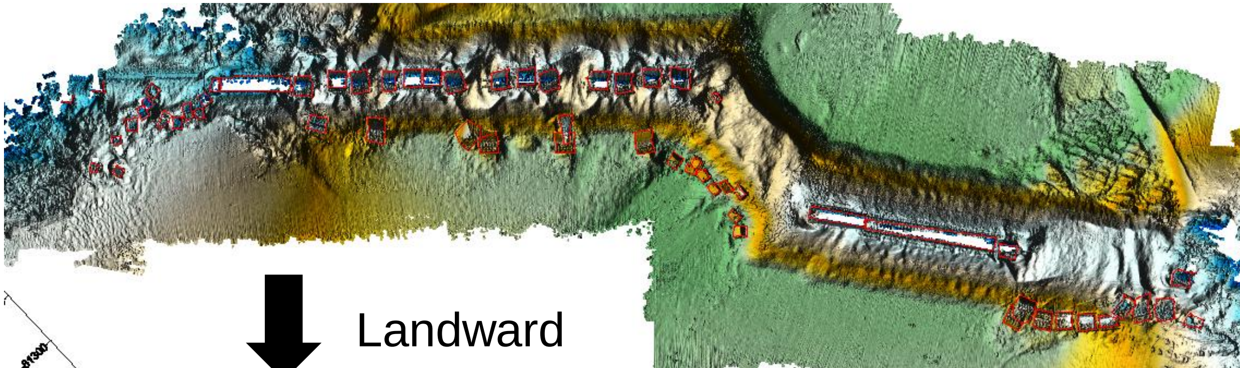
Kamaishi Tsunami Breakwater



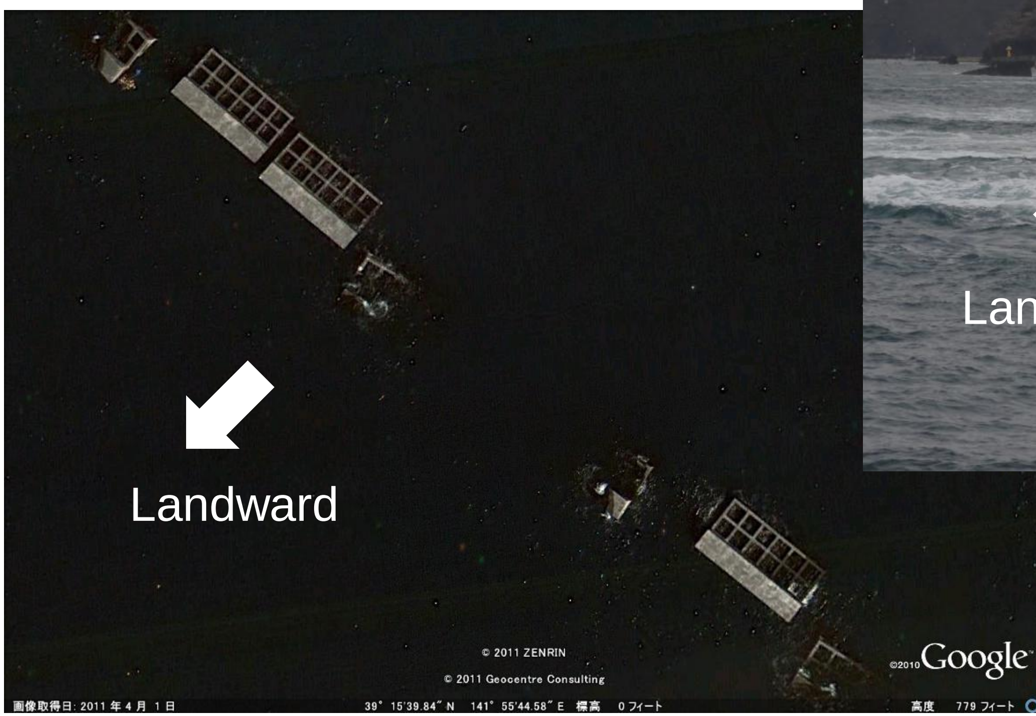
Meiji Sanriku
Earthquake (1896)



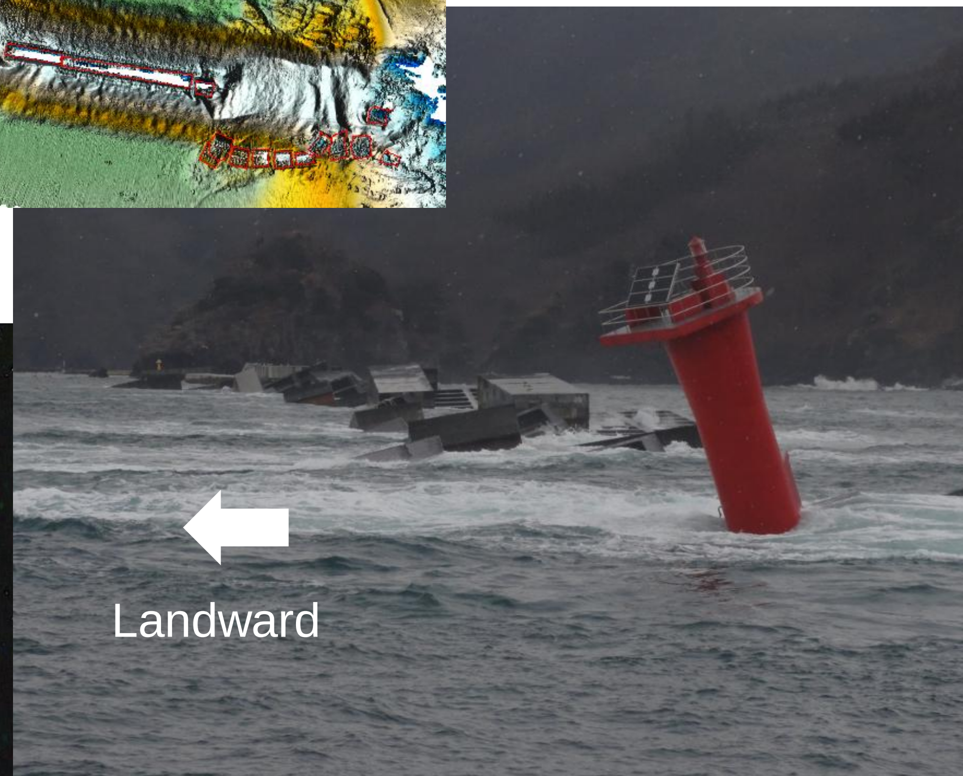
Damages of breakwater



Landward

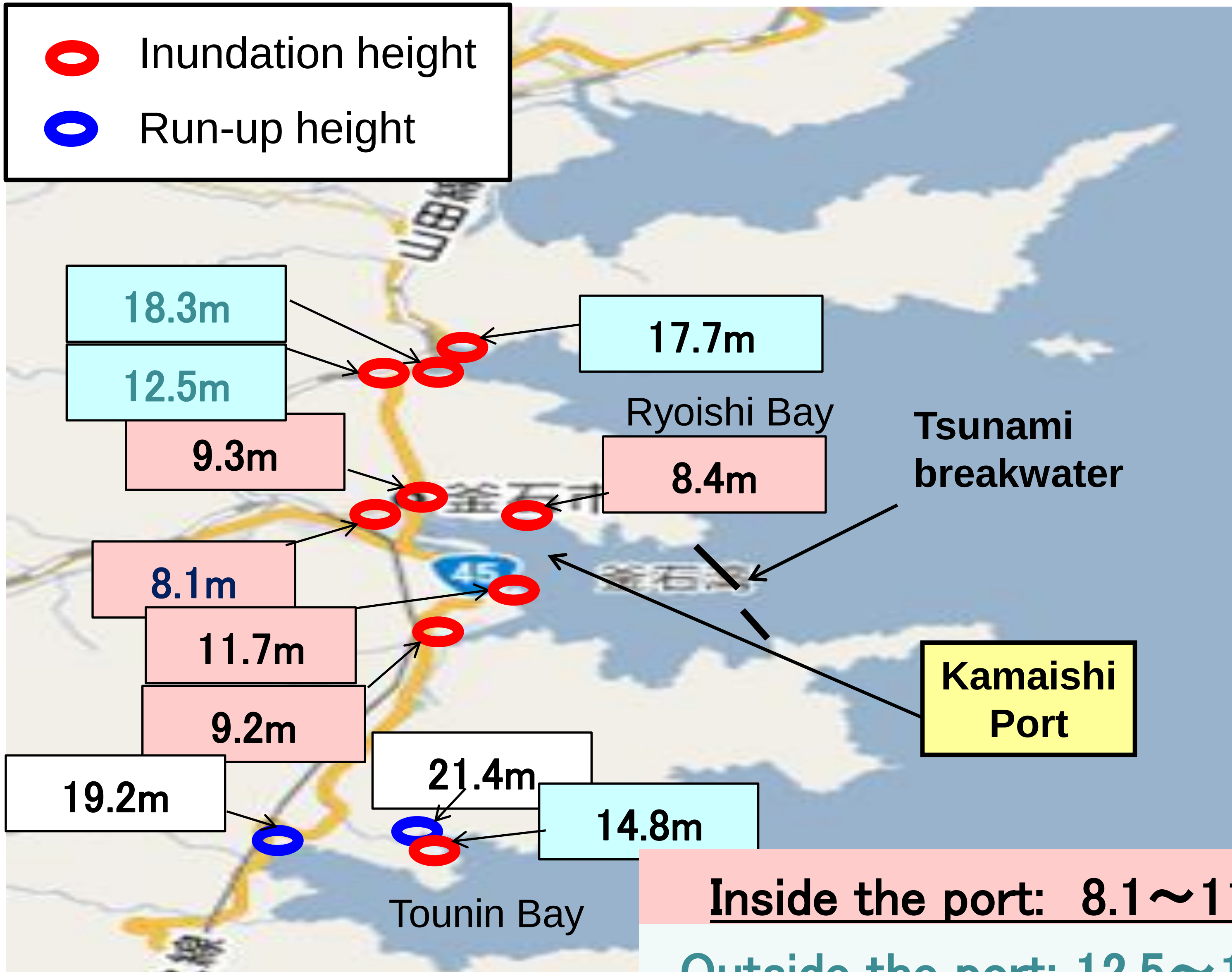


Landward



Landward

Tsunami heights at Kamaishi Port and neighboring bays

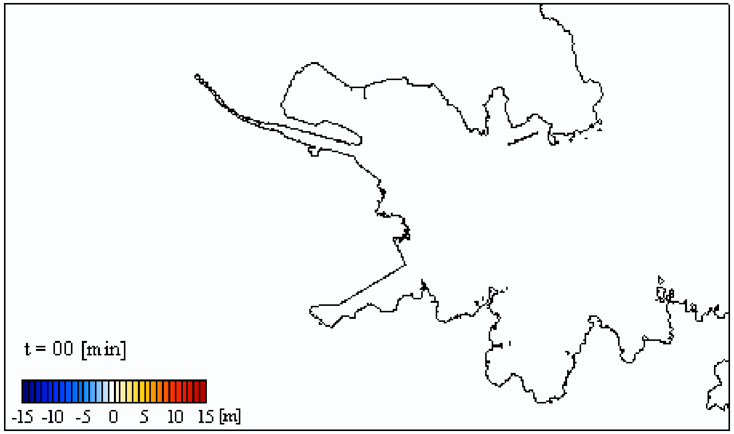


Inside the port: 8.1～11.7 m

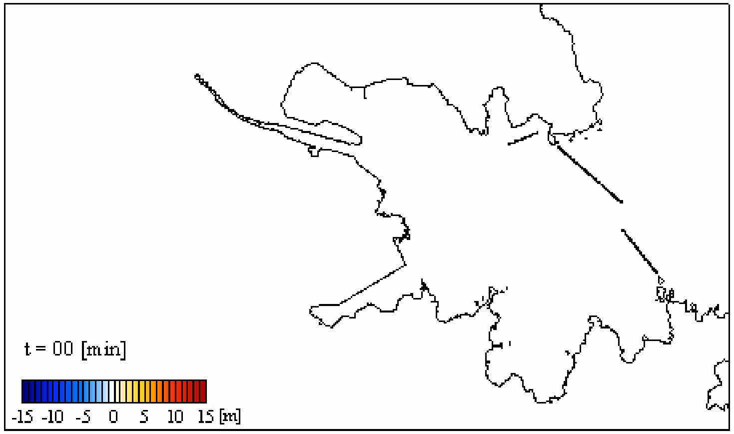
Outside the port: 12.5～18.3 m

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



Without Breakwater

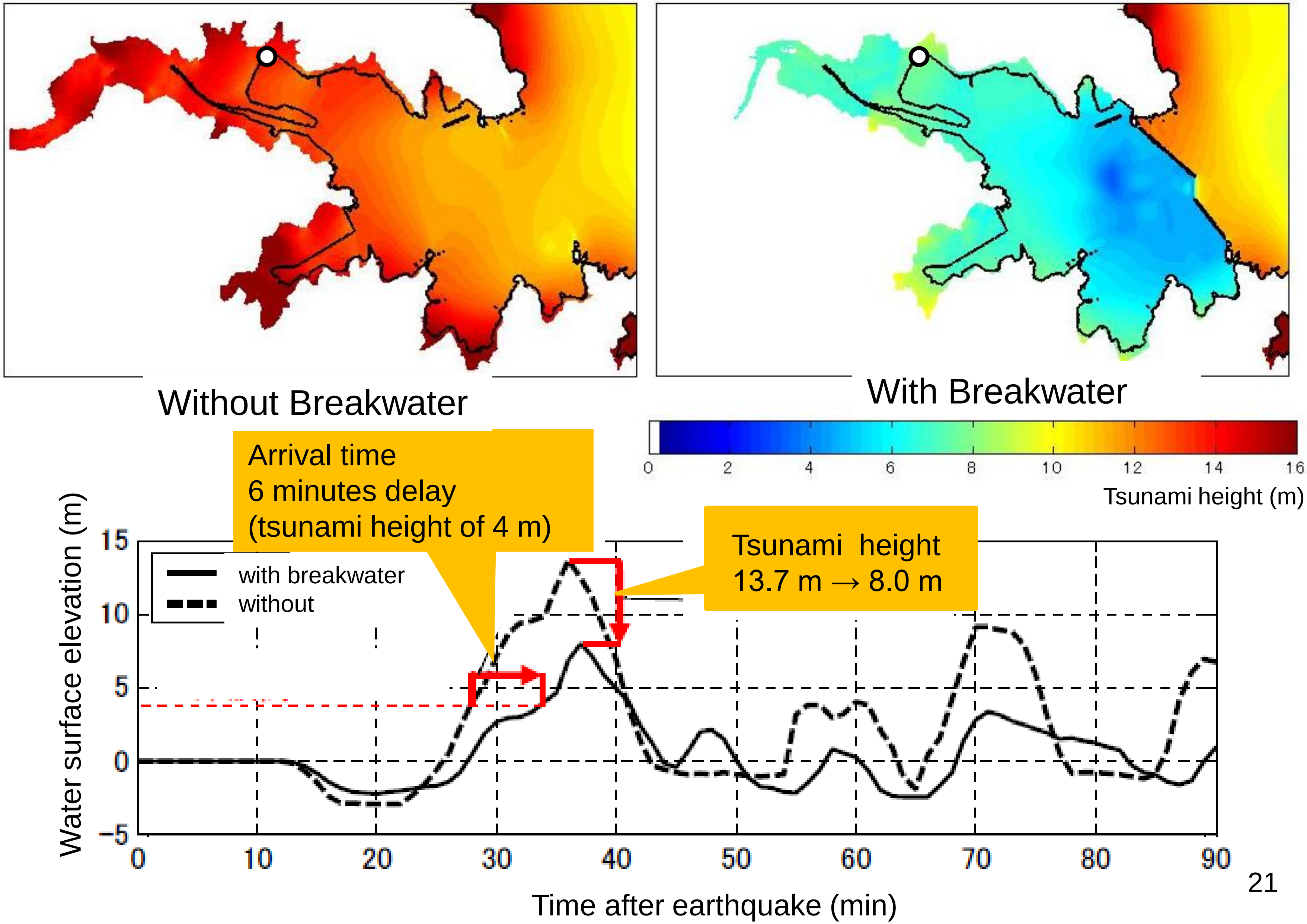


With Breakwater

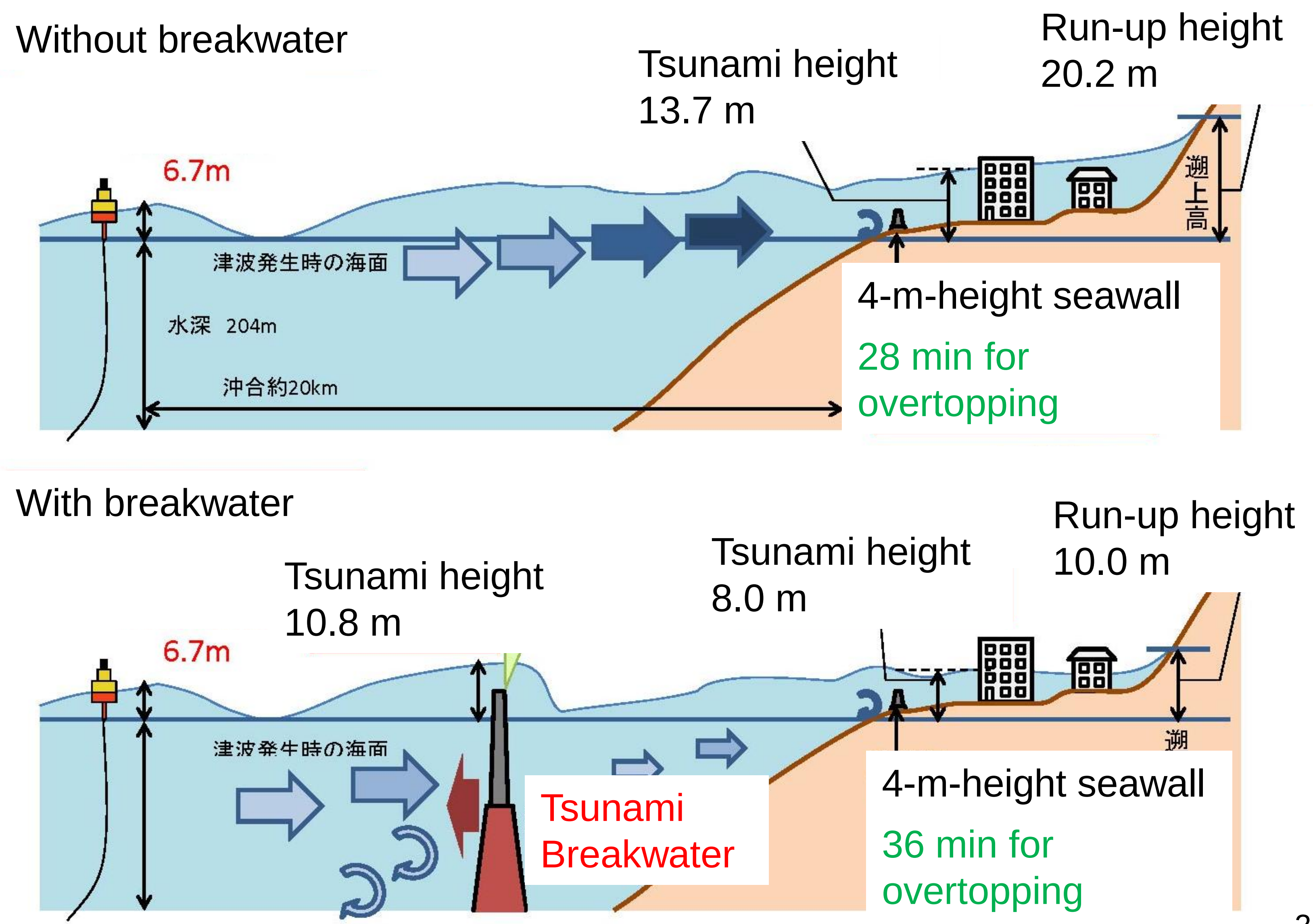
The 2011 off the Pacific Coast of Tohoku Earthquake (2011)

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

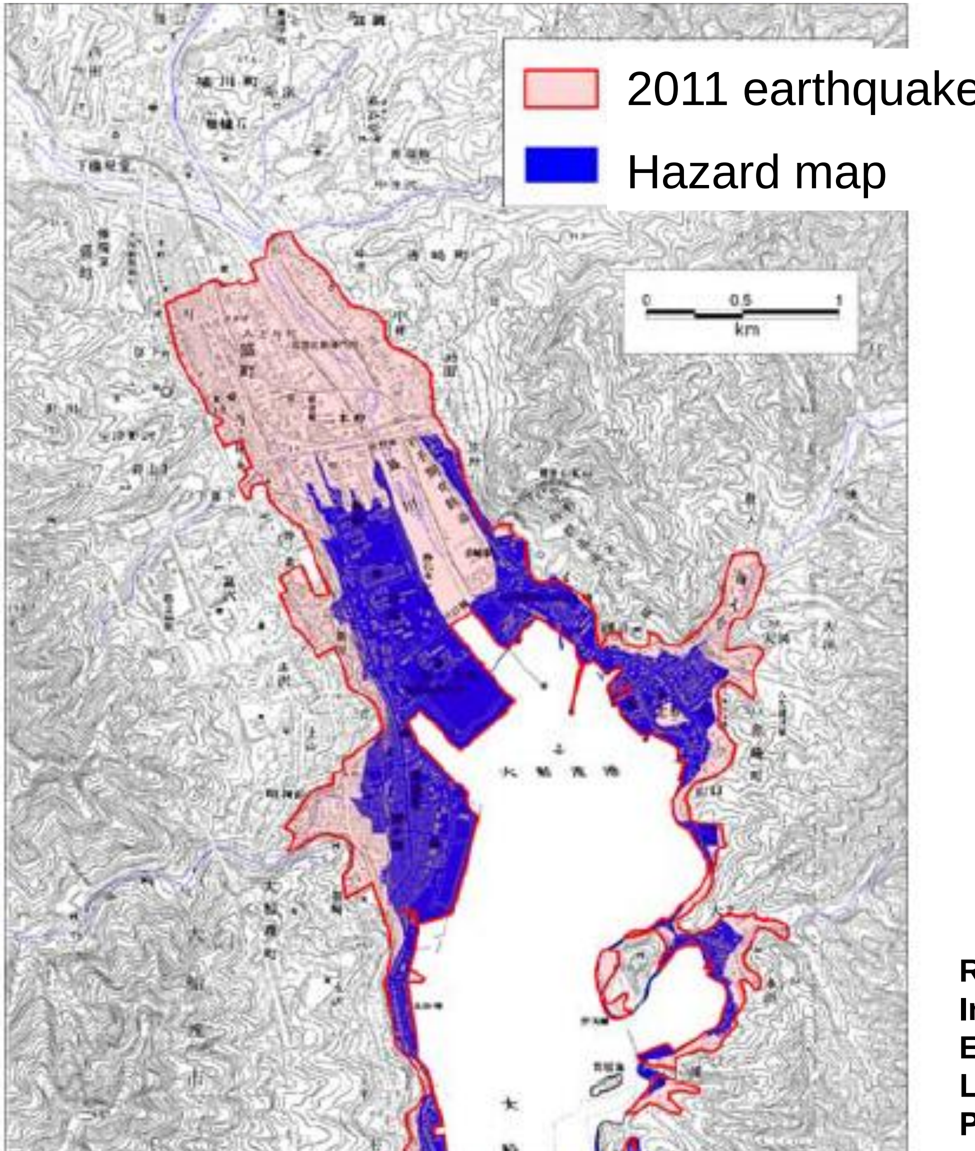


Effect of breakwater



Hazard map at Oofunato

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

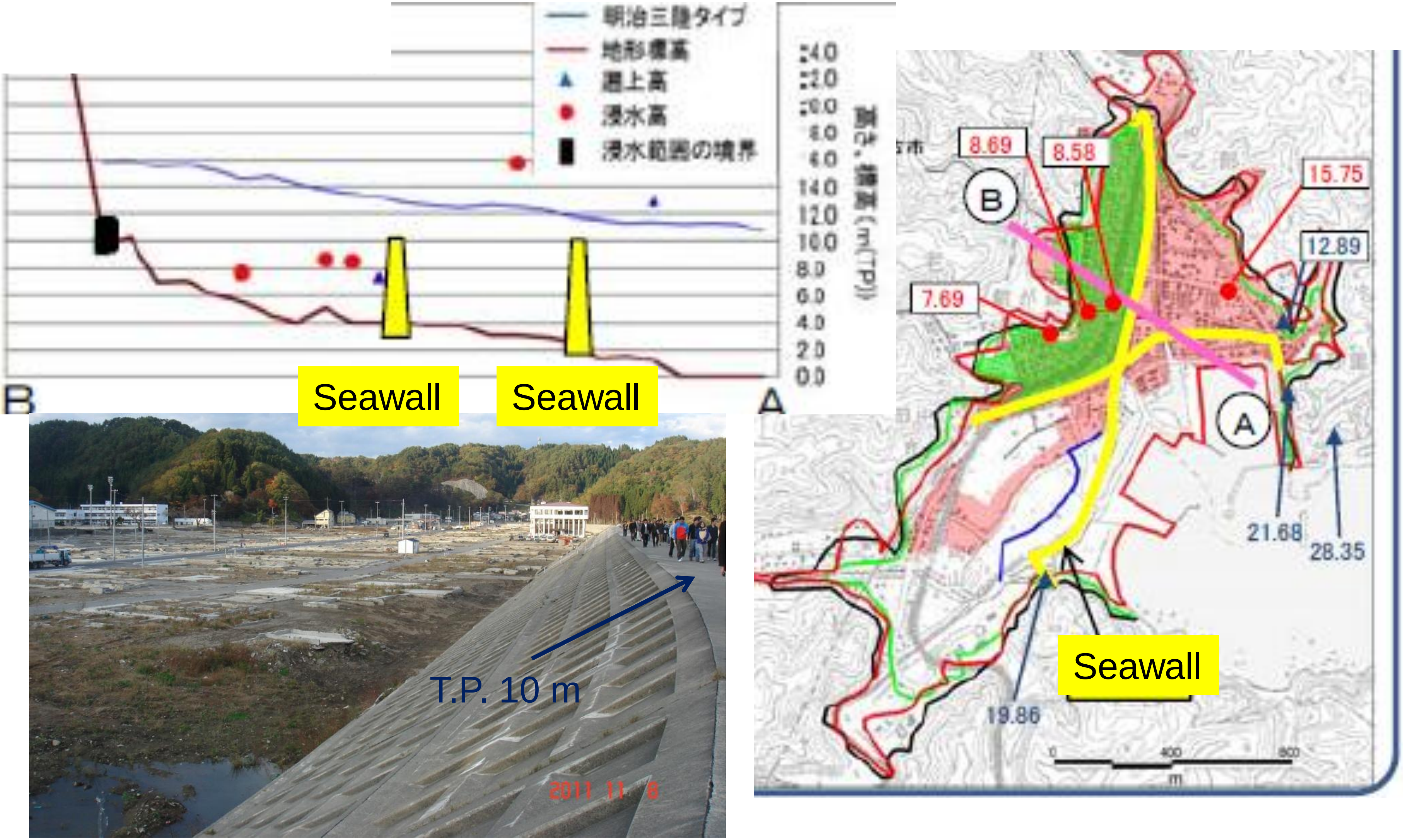


Hazard map

- Meiji Sanriku Earthquake (1896)
- with tsunami breakwater & river dyke
- without coastal and tsunami seawalls & floodgate

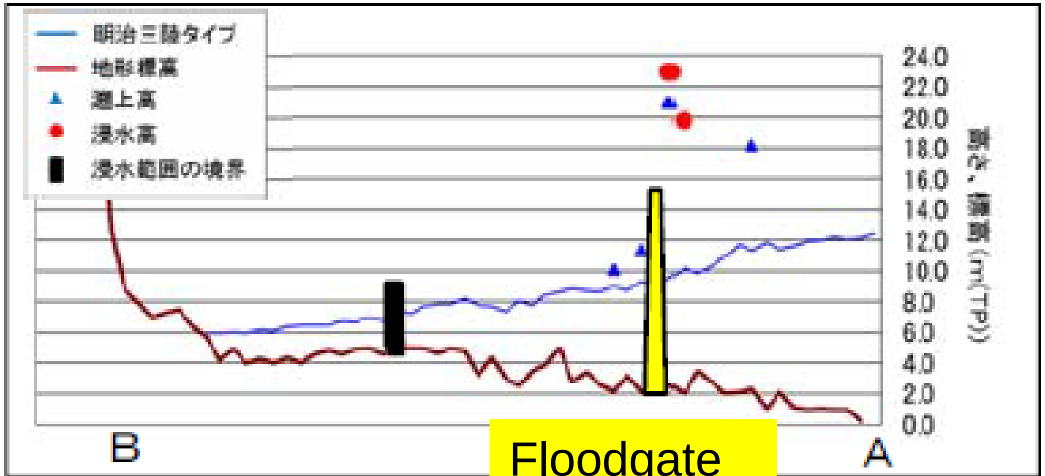
Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the "2011 off the Pacific coast of Tohoku Earthquake"

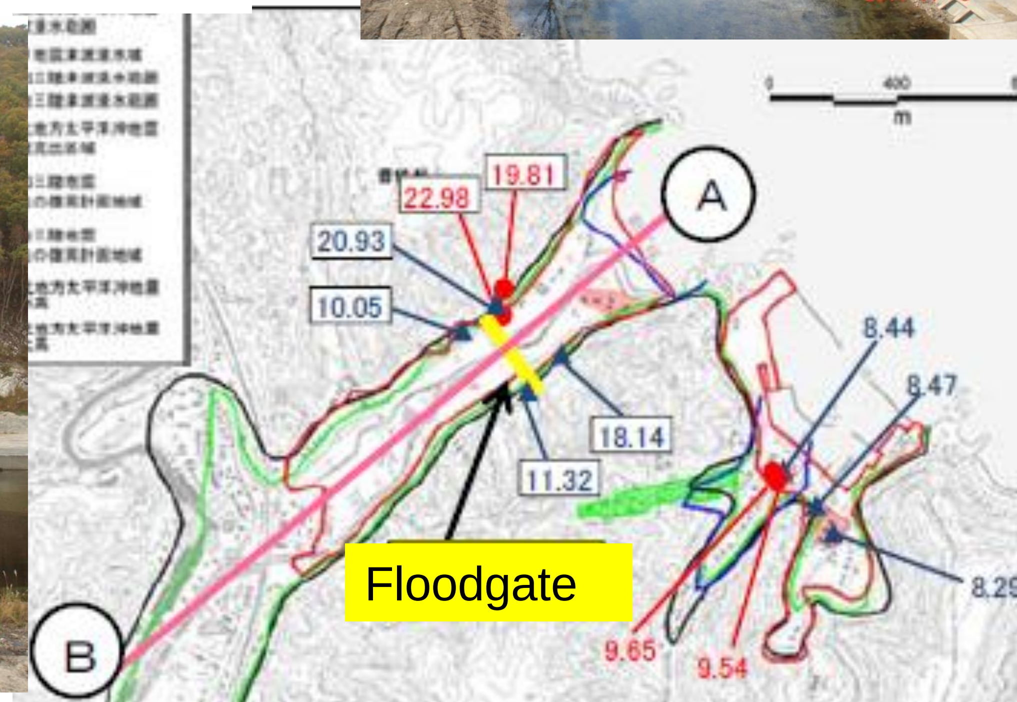
Severe damage at Taro, Iwate



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

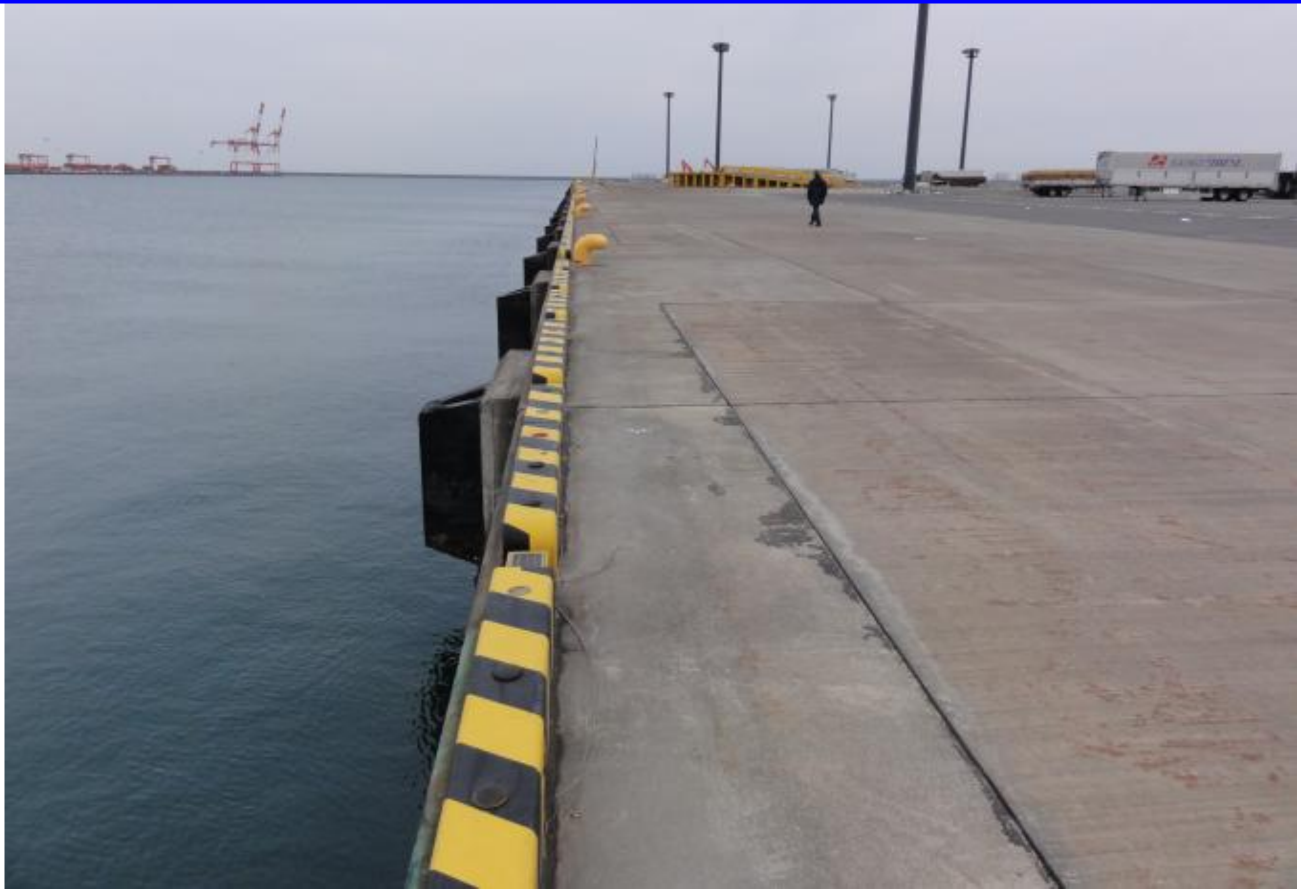




Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the “2011 off the Pacific coast of Tohoku Earthquake”

High earthquake-resistance quay wall

Central Wharf, Hitachi-naka District, Ibaraki Port

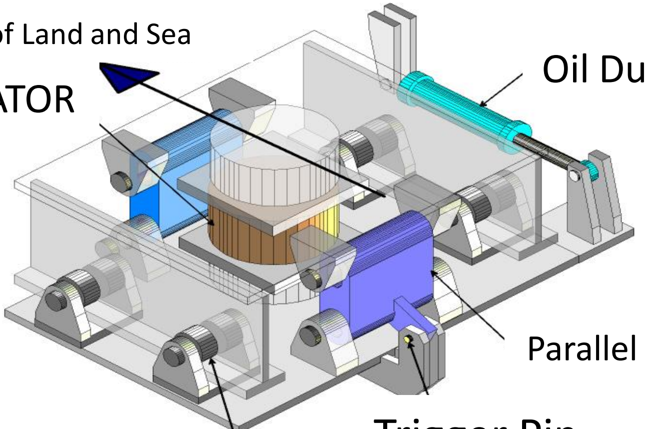


- Little lateral displacement of the quay wall.
- Liquefaction evidence was not recognized since un-sieved crushed stone is filled as liquefaction countermeasure.
- The high earthquake resistance quay wall showed good seismic performance. The quay went into service on March 15 after checking the burying of navigation channel by tsunami.

Sendai Port: Base Isolated Gantry Crane

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

Damage occurred in one non-base-isolated crane



Base Isolation system

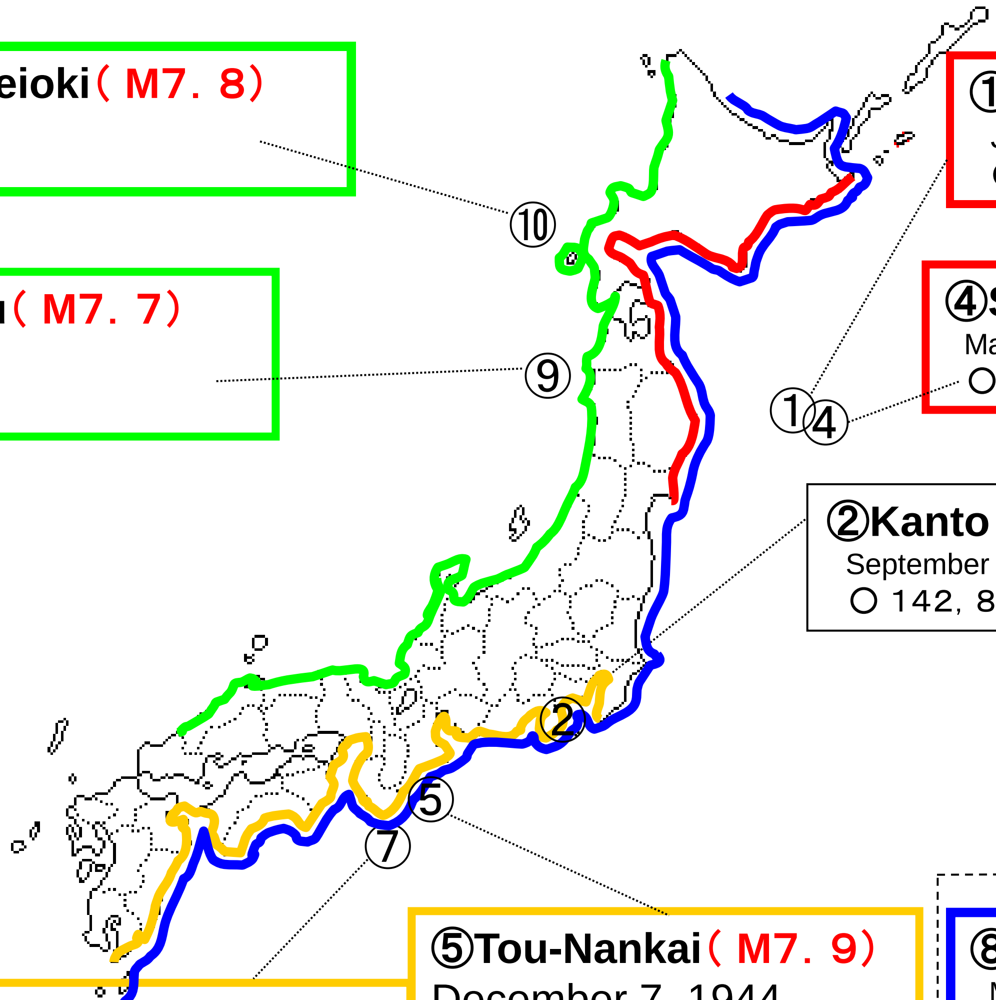
Patent holder : PARI and Mitsui Engineering & Shipbuilding Co, Ltd.

Base-isolated cranes: **No structural damage**

Principles for future countermeasures against tsunami

Major earthquakes and tsunamis in Japan(1896-2005)

○ Number of casualties, ● Maximum run-up height



⑩Hokkaido Nanseioki（M7．8）
July 12, 1993
○ 230, ● 30m

⑨Nihonkai-chubu（M7．7）
May 26, 1983
○ 104, ● 14m

①Meiji-Sanriku（M8．5）
June 15, 1896
○ 22，000, ● 38．2m

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

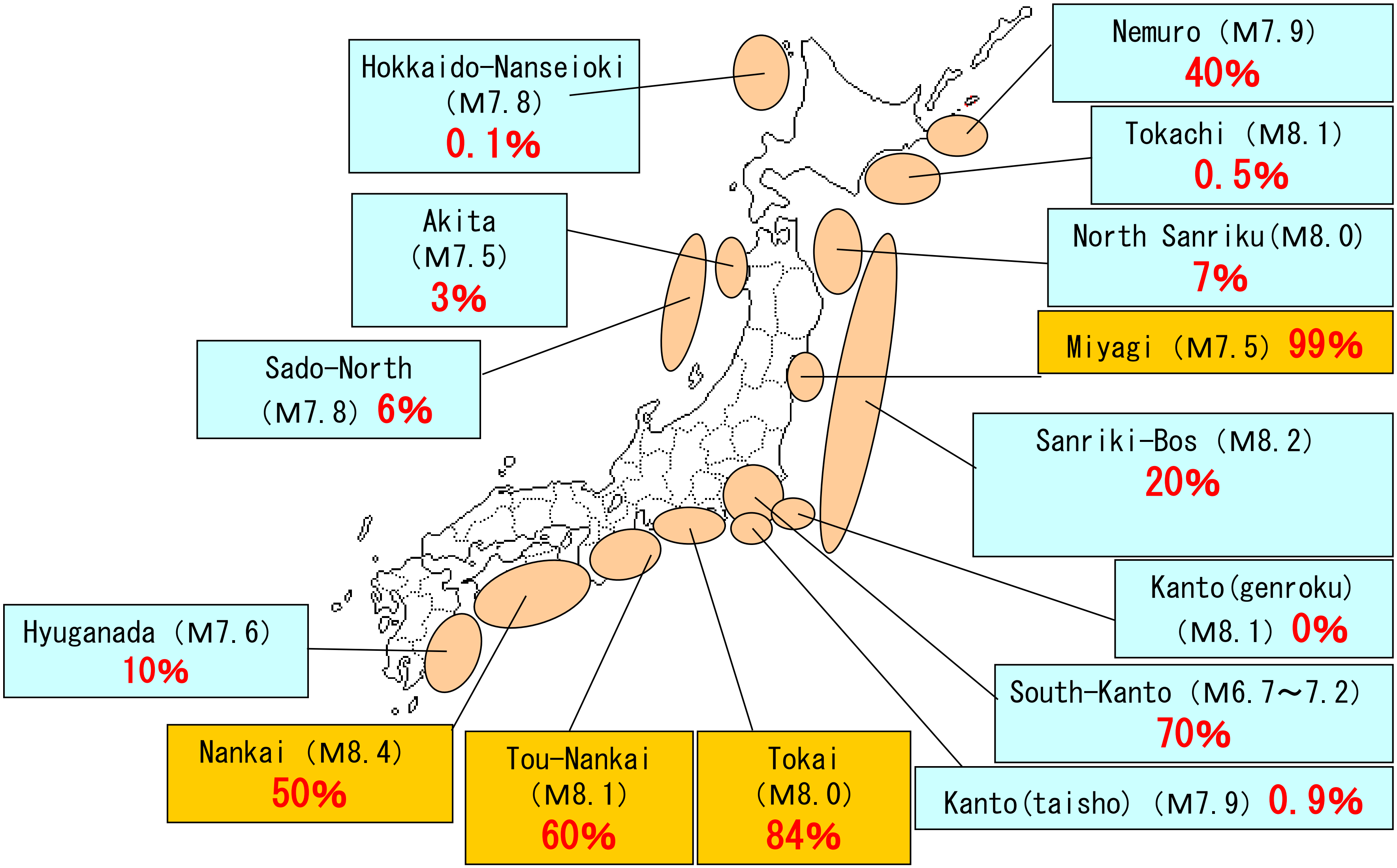
②Kanto（M7．9）
September 1, 1923
○ 142，807

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

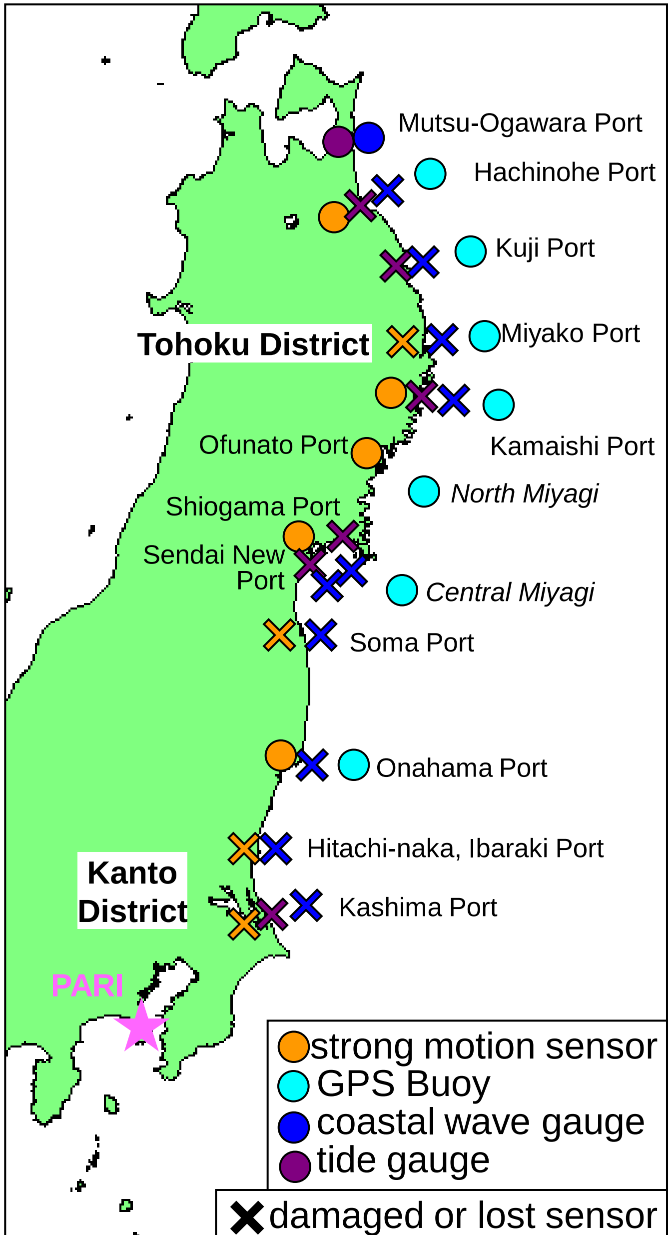
⑧Chile（M9．5）
May 23, 1960
○ Dead 142, ● 6m

⑦Showa-Nankai（M8．0）
December 21, 1946
○ 1，443, ● 6m

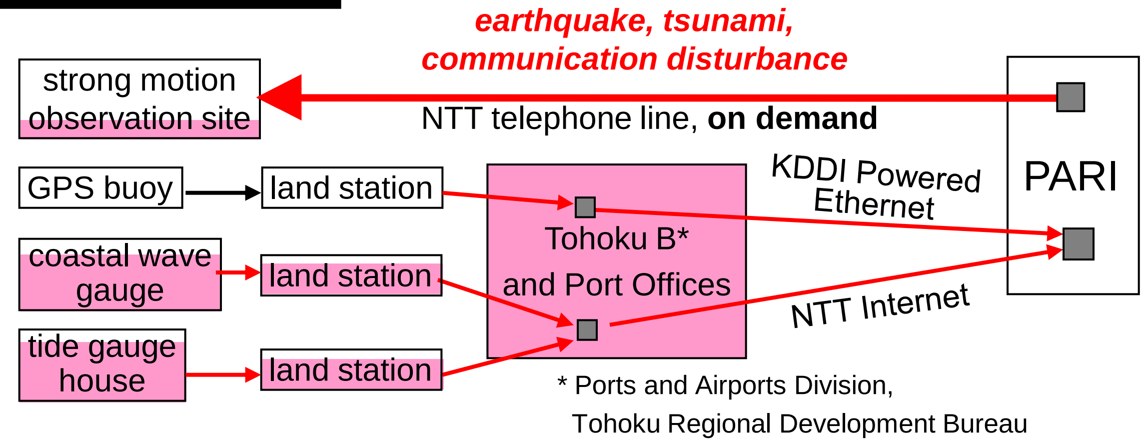
Occurrence probability of subduction zone earthquake within 30 yrs



Future Improvement in Information Network

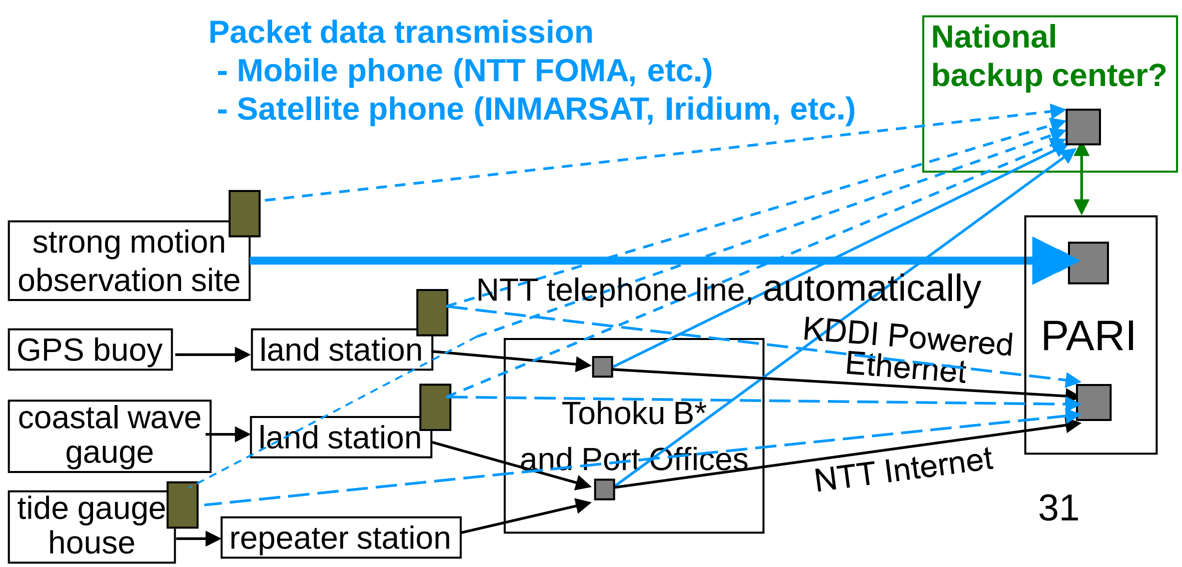


Present System



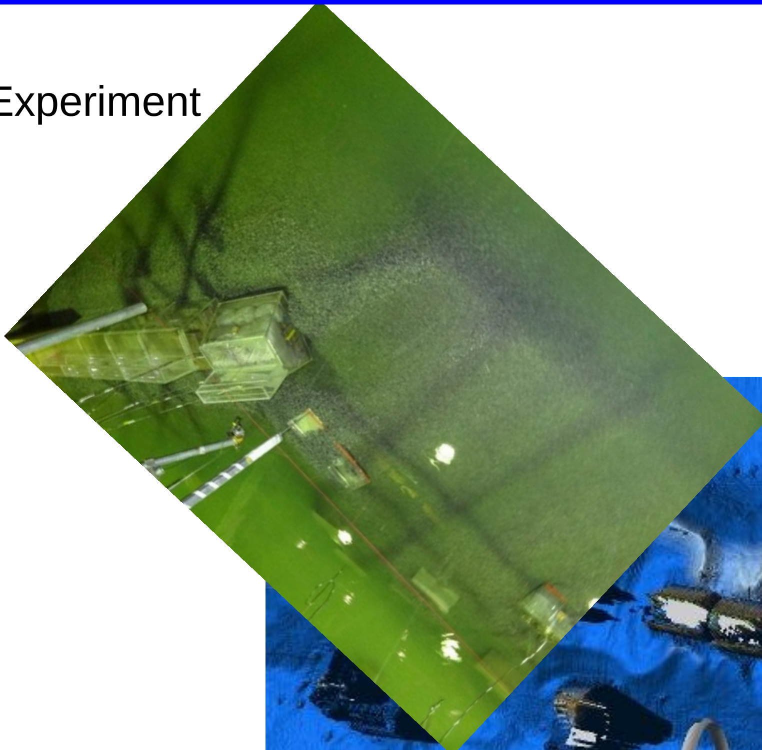
Idea for Future System

Toward redundant system !!

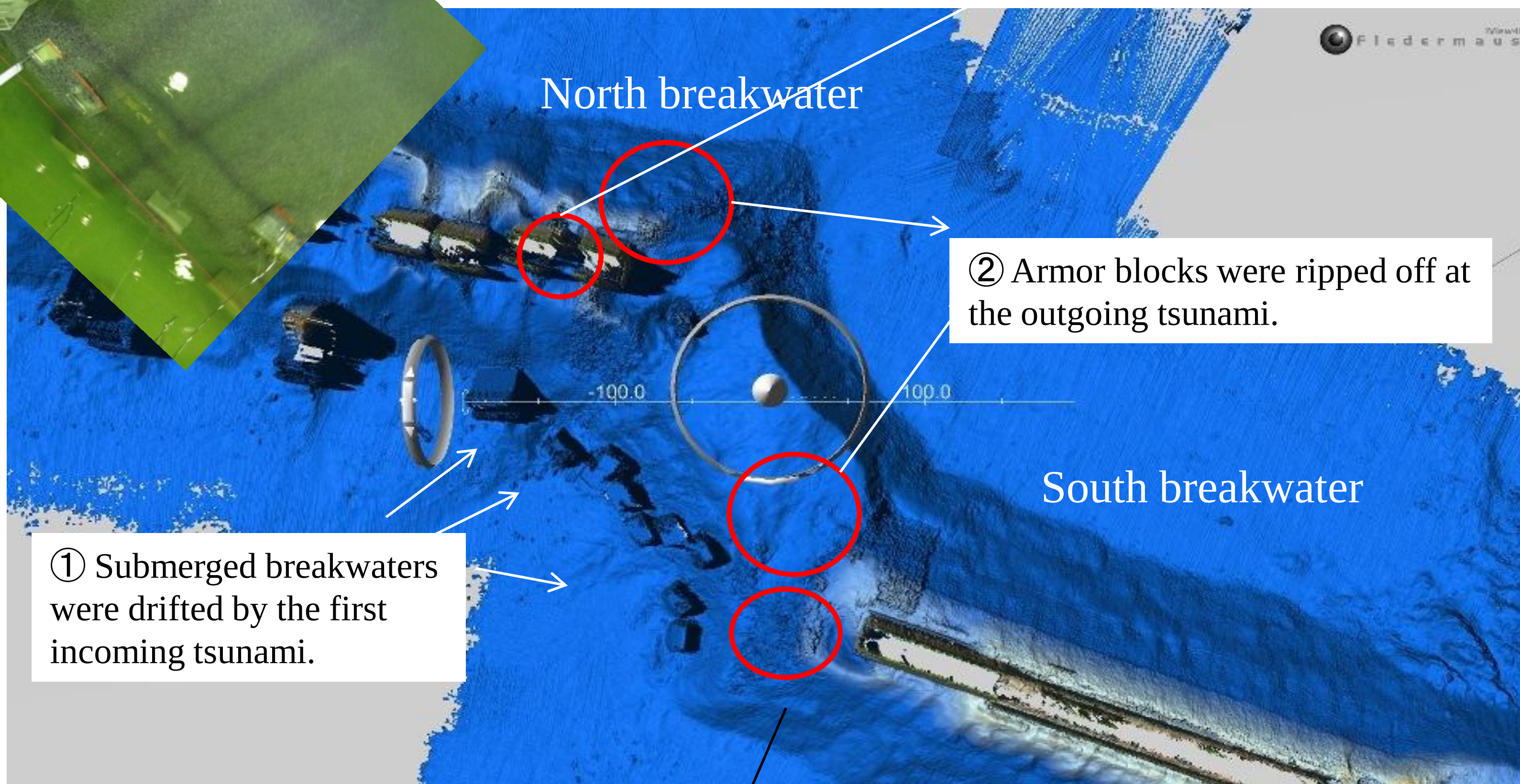


Failure mechanism of head breakwater at Kamaishi

Experiment



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

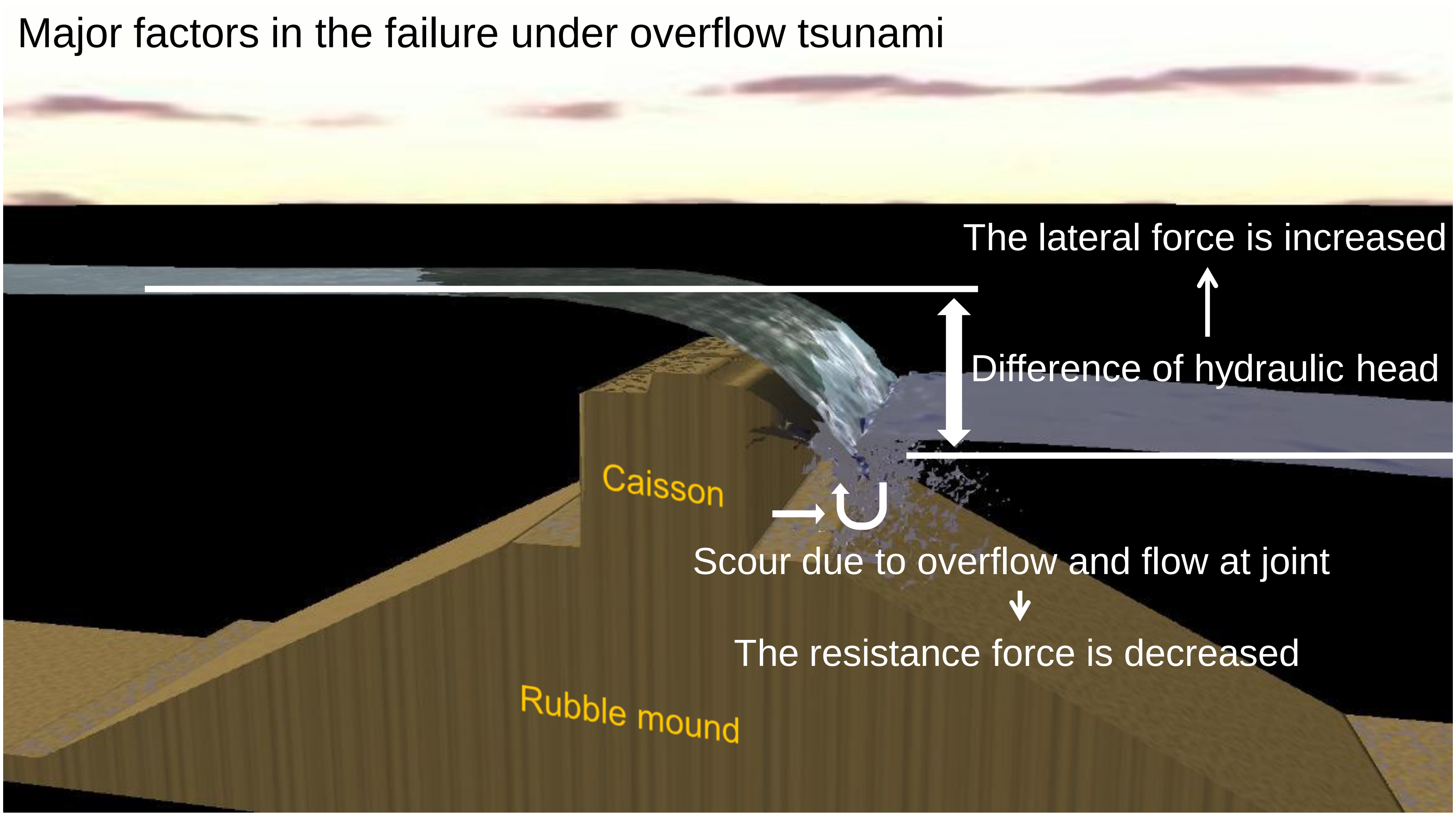


② Armor blocks were ripped off at the outgoing tsunami.

① Submerged breakwaters were drifted by the first incoming tsunami.

Although the mound was scoured, the head breakwater was not tilted.

Failure mechanism of breakwater at Kamaishi



$$\text{Safety factor against sliding of caisson} = \frac{\text{Lateral Force}}{\text{Resistance force}}$$

Failure mechanism of breakwater at Kamaishi

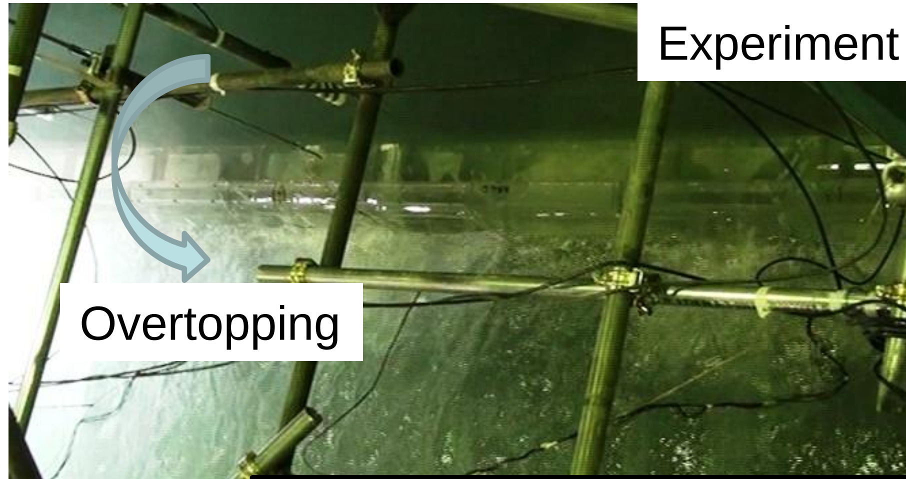
Experimental Video under overflow tsunami

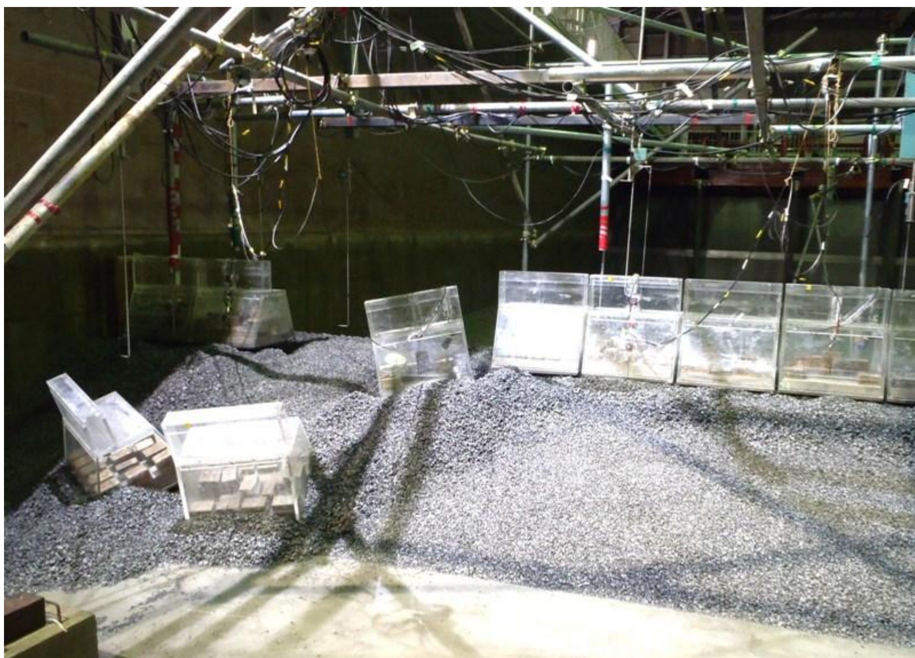
Failure mechanism of breakwater at Kamaishi

Experimental Video under overflow tsunami

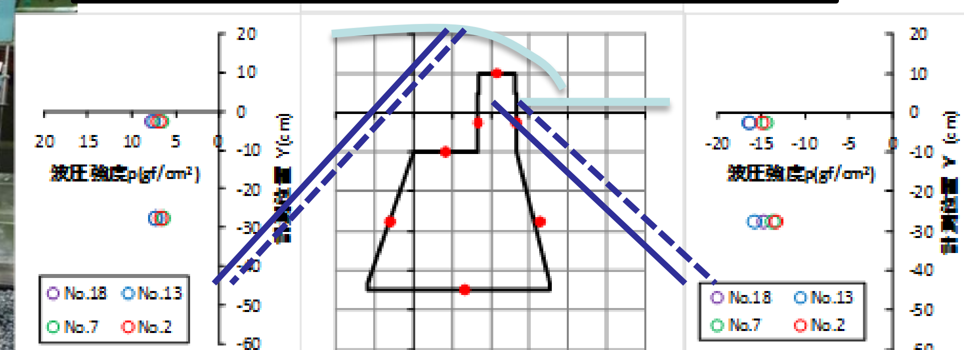
Failure mechanism of breakwaters at Kamaishi

Damaged north breakwater





About the amount of increasing of the lateral force

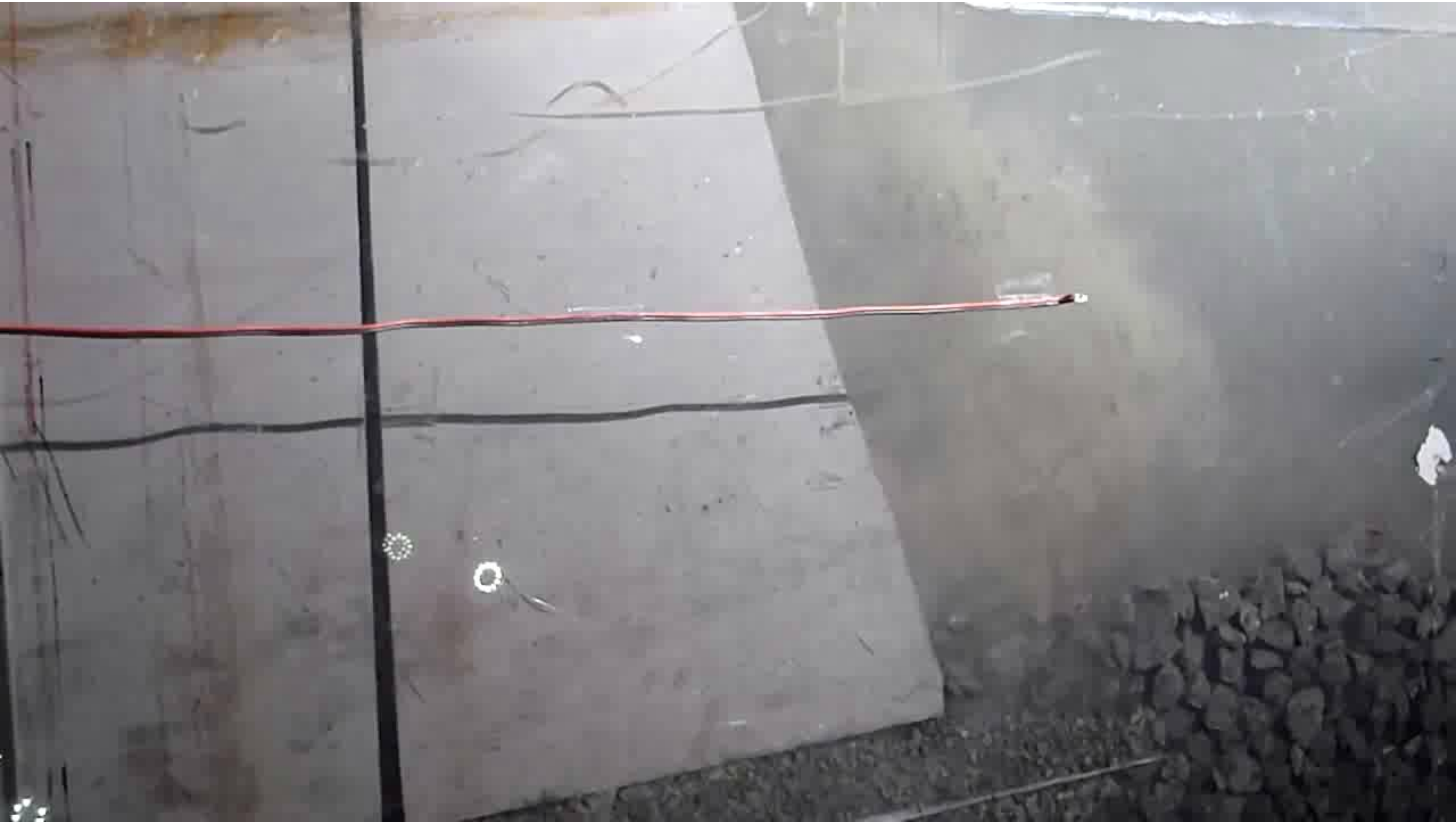


The wave pressure is slightly higher at the front wall and about 10% lower at the rear wall than the hydrostatic pressure.

Two out of 17 caissons were slid and one was tilted.

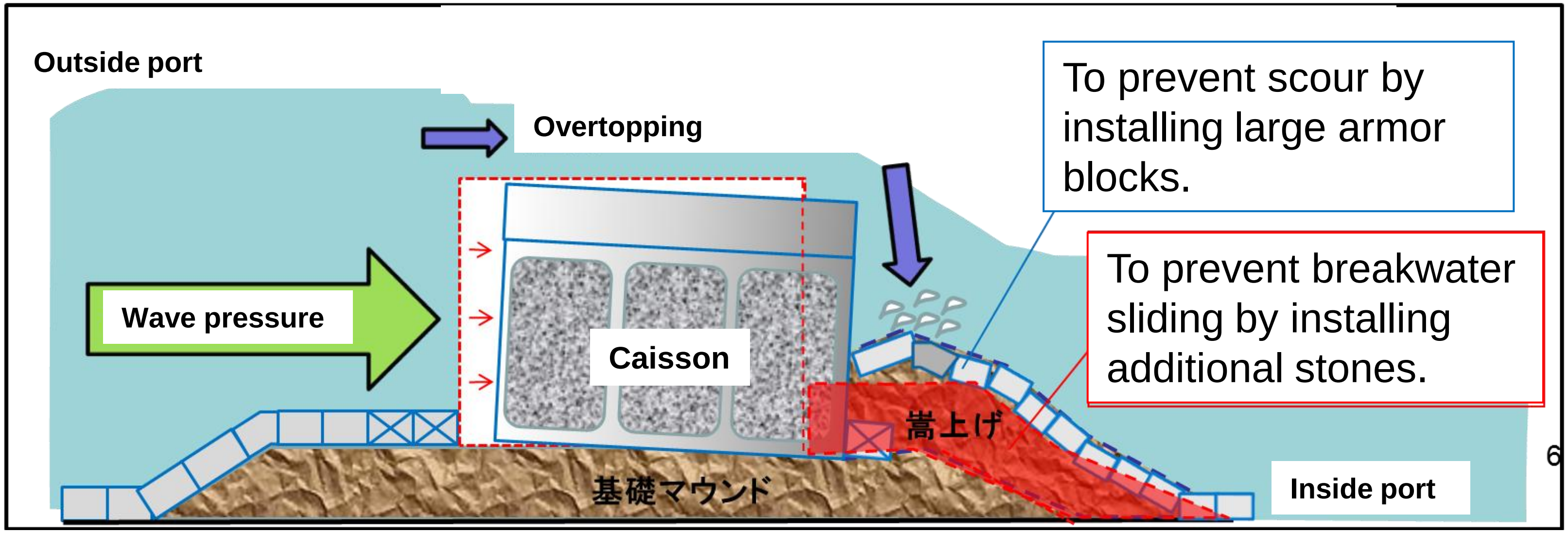
Failure mechanism of breakwaters at Kamaishi

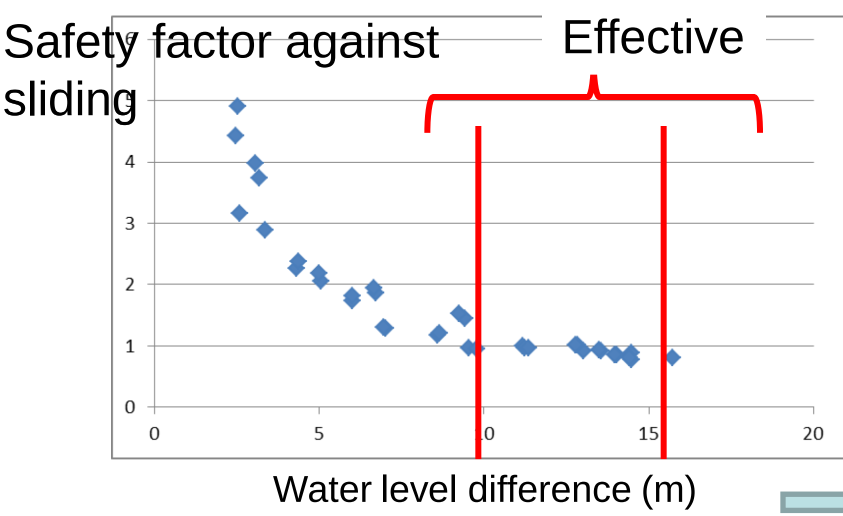
Influence of scour due to overflow tsunami



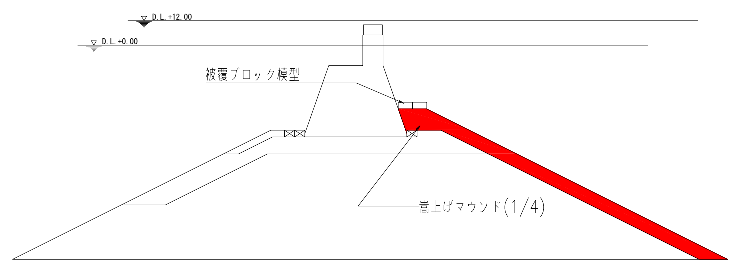
The quantification of the amount of a decrease of the sliding resistance force is a future task

Tenacious breakwater





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



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

Recommended countermeasures against tsunami

Based on the Reports of Central Disaster Management Council and Council of Transport Policy

	Design tsunami	Required performance
Level 1	Tsunami with relatively high frequency (return period: 50 to 150 years)	• To protect human lives • To protect properties • To protect economic activities
Level 2	One of the largest tsunamis in history (return period: 600 to 1000 years)	• To protect human lives • To reduce economic loss, especially by preventing the occurrence of severe secondary disasters and by enabling prompt recovery

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.

Recommended countermeasures against tsunami

Based on the Reports of Central Disaster Management Council

(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

Recommended countermeasures against tsunami

Based on the Reports of Central Disaster Management Council

(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

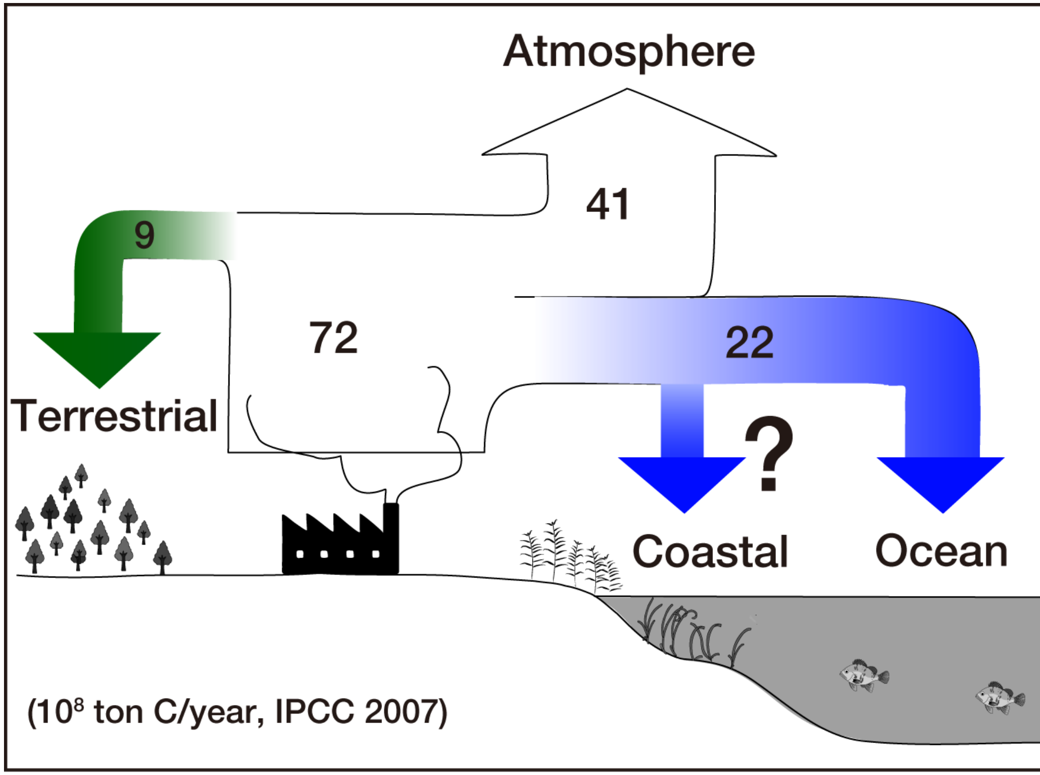
Efforts to biodiversity and climate change in port areas

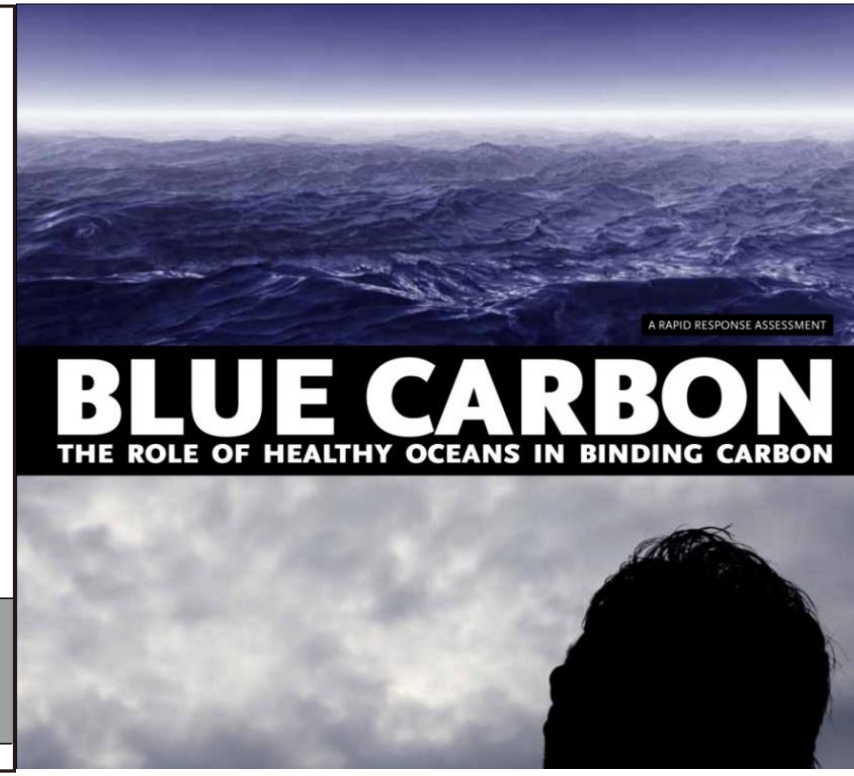
Restoration of coastal ecosystems located in port areas

Sandflat for clam fishery

Tidal flat- and seagrass bed-hybrid breakwater

Global carbon cycle and “Blue Carbon” reported in Oct, 2009





- 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