

**Tsunami Resilient Ports
on the Basis of Lessons
from
the 2011 Great East Japan Earthquake and
Tsunami**



Takashi Tomita, Taro Arikawa
and Shigeo Takahashi

Port and Airport Research Institute

Contents



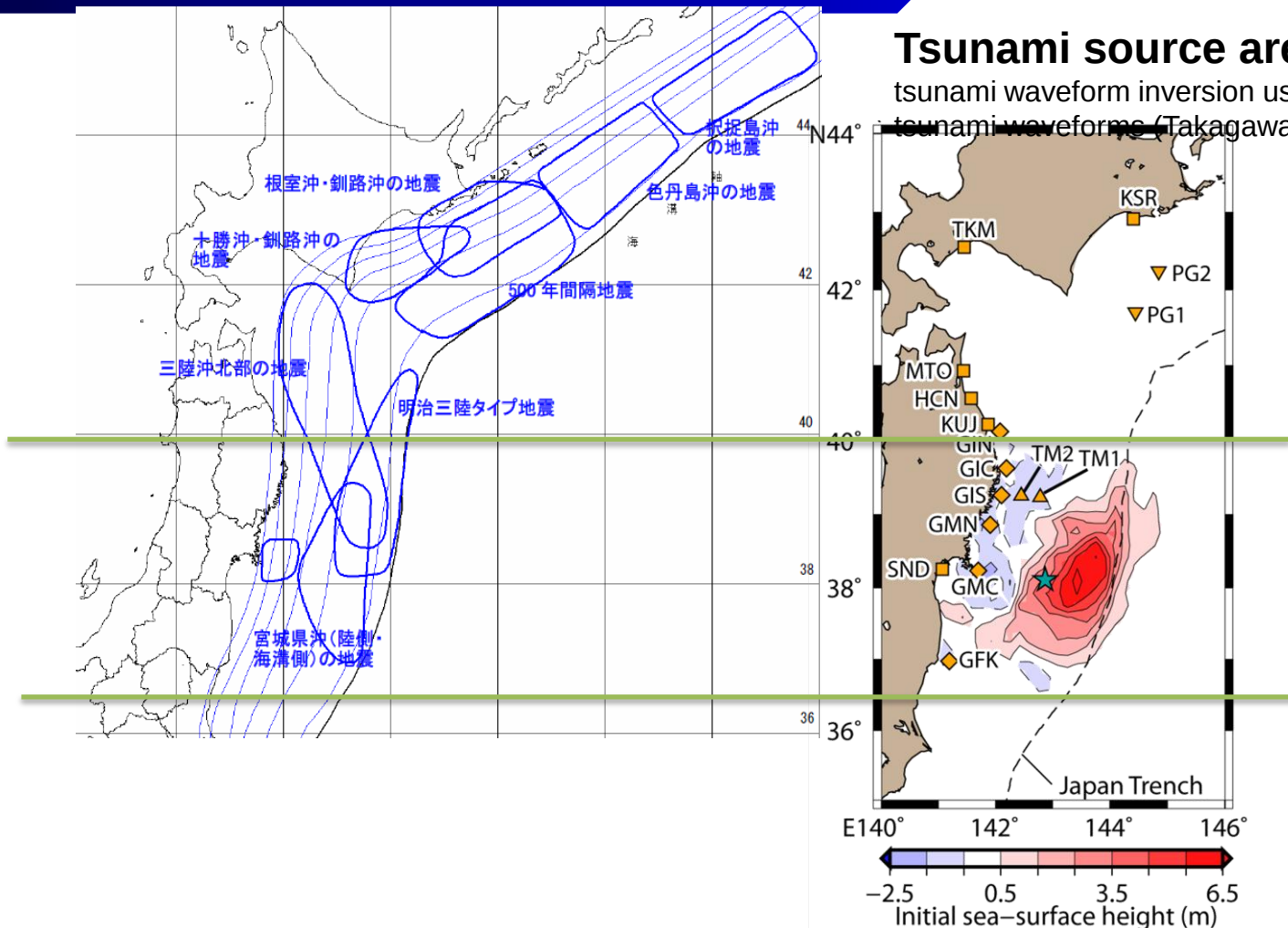
1. GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI
2. EFFECTIVE COUNTERMEASURES FROM THE M11 TSUNAMI
3. REDUCTION OF TSUNAMI IMPACTS BY BREAKWATER AND SEAWALL
4. TOWARD TSUNAMI-RESILIENT PORTS
5. SUMMARY

The prepared paper introduces the concepts to make a port resilient to tsunamis, based on the lessons learned from the 2011 disaster. The more examples and discussions will be detailed in an Appendix to Report 112 of PIANC (*the World Association for Waterborne Transport Infrastructure*) MarCom (*Maritime and Navigation Commission*).

The 2011 off the Pacific Coast of Tohoku Earthquake

- Mw 9.0
 - The triggered tsunami source area was wider than those which were estimated so far.
- Gigantic tsunami
 - Highest runup height above the tide level at the time of tsunami arrival is 40 m in Ryori of Ofunato city and Taro of Miyako city.
- Casualties: 19,000 people among population of 600,000 in the affected areas by the tsunami
- Inundated area = 561 km²
- Fully and partially-destroyed houses = 400,000

Estimated Earthquakes and 2011 Earthquake

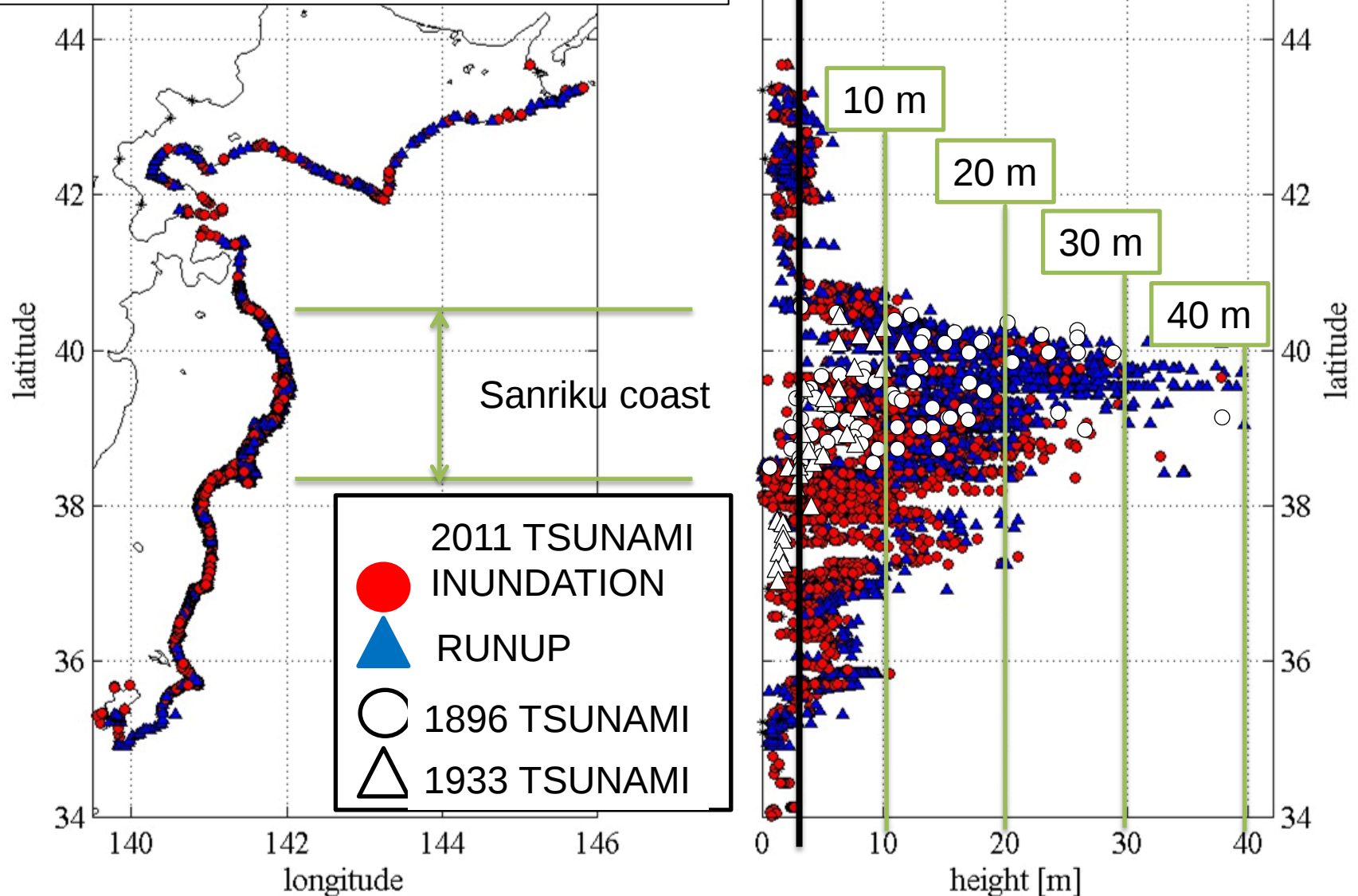


The estimated scale of the possible earthquakes before the 2011 event were smaller than the 2011 earthquake.

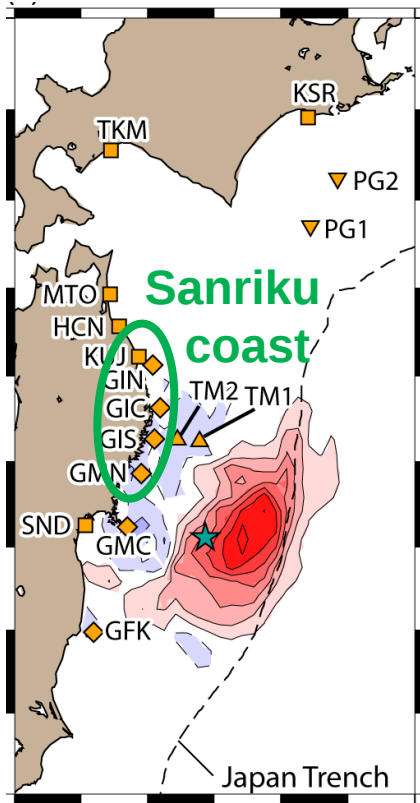
➔ We need to estimate the largest possible earthquake and tsunami like the 2011 event.

Height of Tsunami Run-up and Inundation

The 2011 Tohoku Earthquake Tsunami Joint Survey Group, <http://www.coastal.jp/tsunami2011/>



Well-Prepared Areas were Attacked Tsunami Disaster ⁶



- The Sanriku coast, which suffered the devastating tsunami disaster, is the area that tsunami disaster mitigation has been planned and prepared well.



- School children had learned tsunamis and their threats, and had conducted evacuation drills.
- They had prepared well against tsunamis.



- At the 2011 event, all school children controlled by elementary and junior-high schools in Iwate prefecture did prompt action for evacuation, resulting in saving their lives.

Well-prepared people through conducting disaster education and evacuation drill is IMPORTANT to save human lives



Photo courtesy of Katada Lab, Gunma Univ.

Tsunami-Induced Debris



- Tsunami destruction caused a lot of and a kind of debris.
- Some of them covered the sea surfaces in all of 13 damaged major ports, and others sank to the seabed, resulting in obstacles to navigation
- Activities to remove the debris started immediately in the aftermath of the disaster in order to carry emergency supplies into the damaged areas.



➔ Part of all damaged port was reopened for 2 weeks after the disaster



- Dredging and construction companies signed support agreements at the occurrence of disasters with the Tohoku Regional Bureau of MLIT in advance.

Reduction of Tsunami Impacts by Coastal Green Belt

Hachinohe

Inundation
height 5.88m

Inundation
height 8.38m

Width of green belt, 150~300 m



Tsunami debris trapped by coastal green belt



Inundation depth 3.2m

Countermeasures against Tsunami-Debris

Hokkaido Regional Development Bureau of MLIT



Erimo Port



Tokachi Port



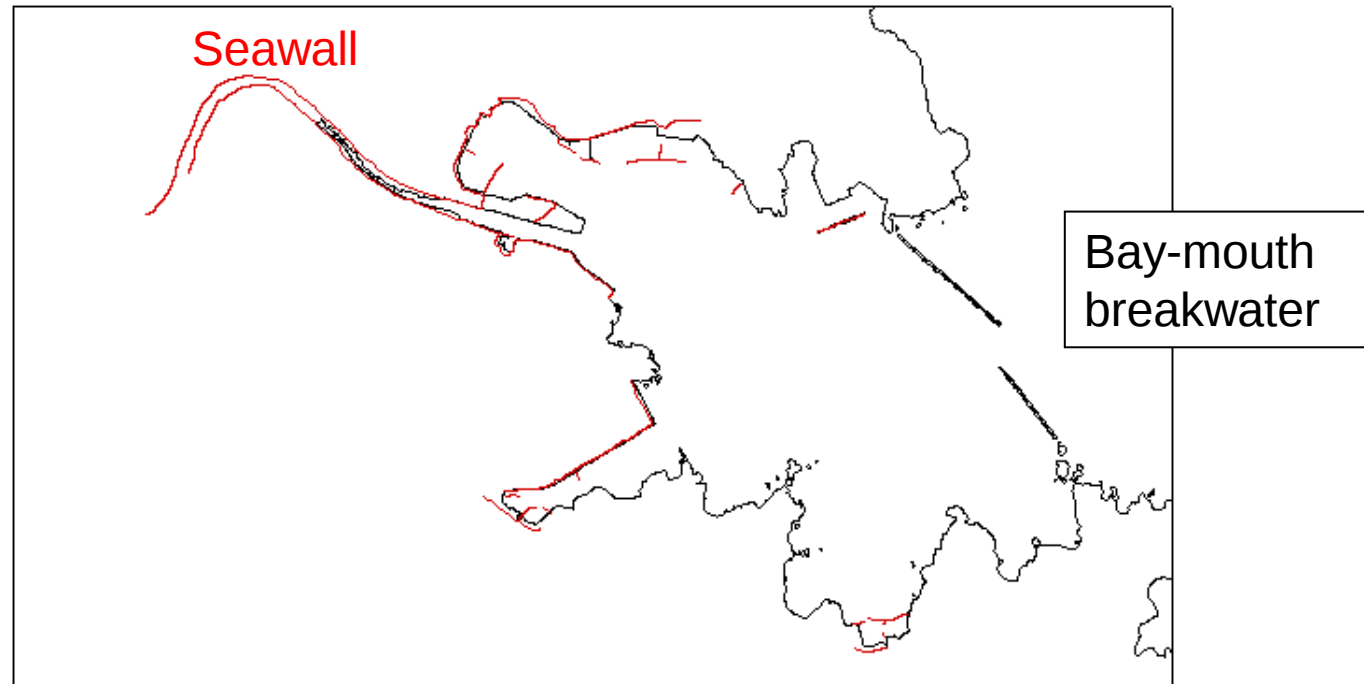
Kushiro Port

A photo removed due to the copyright.

Failure of Breakwaters by the Tsunami

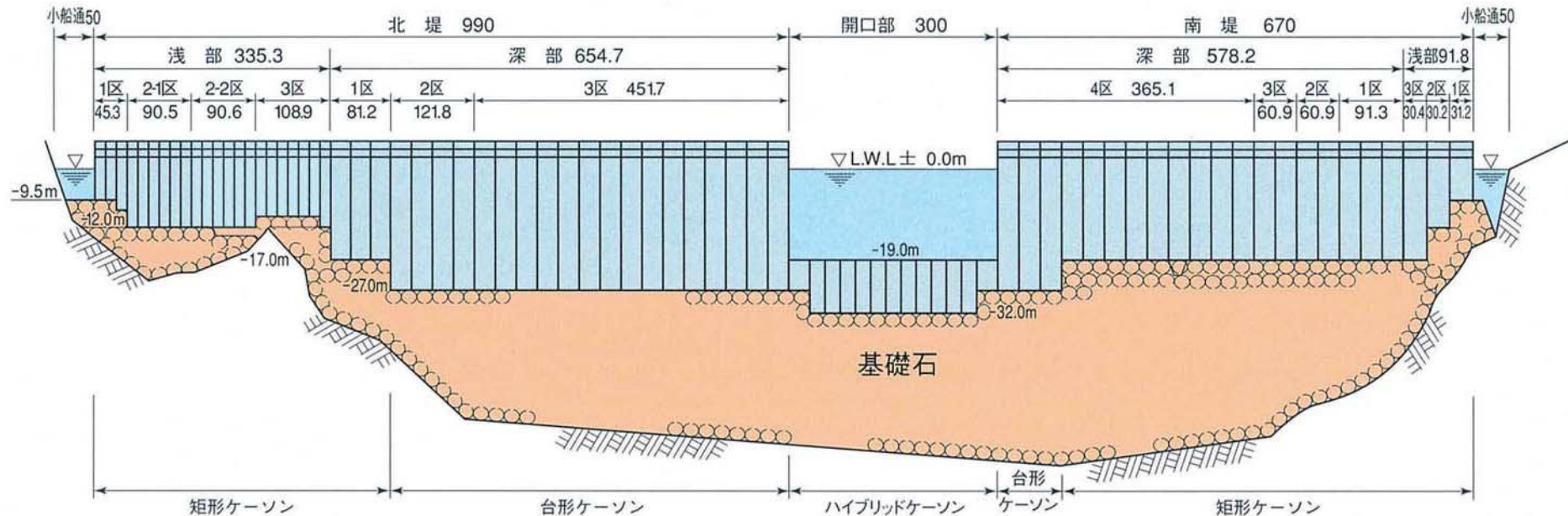
Bay of Kamaishi:

Bay-mouth breakwater and seawalls along the coastlines to prevent inundation by the 1896 Tsunami which is highest at the site in history.



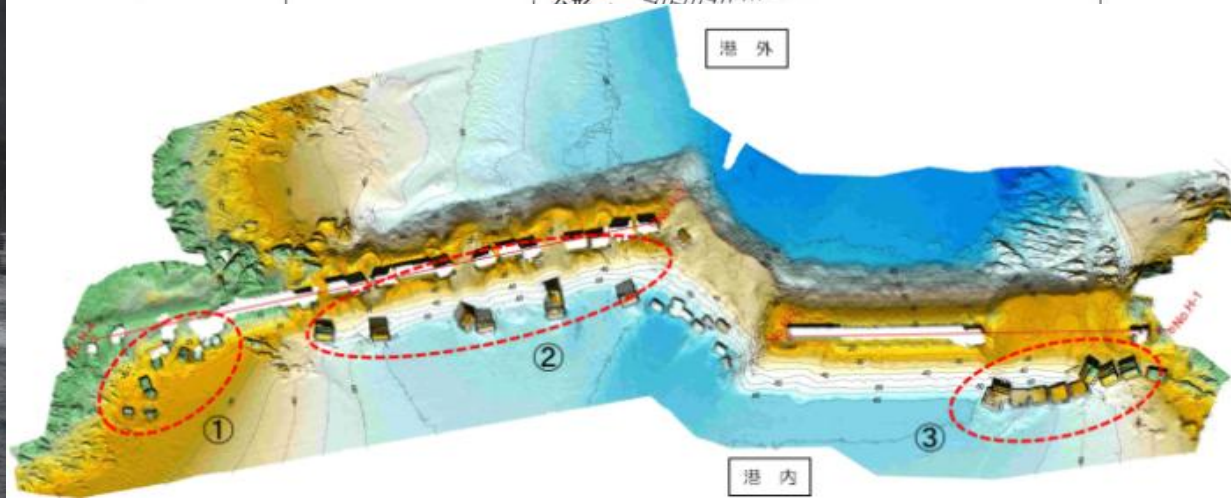
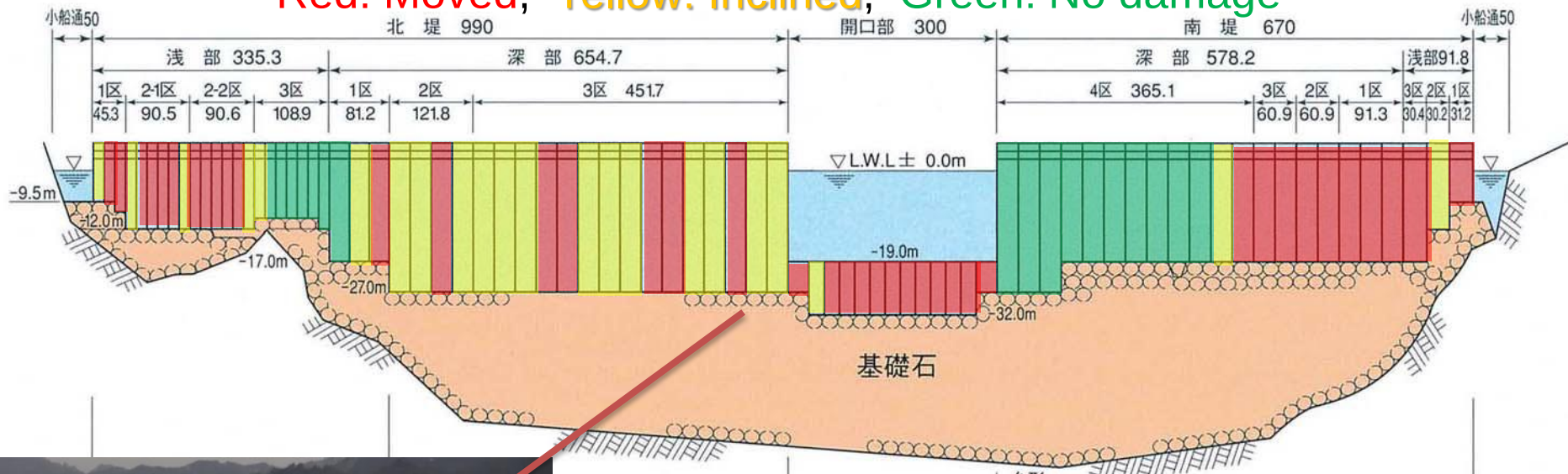
- Some breakwaters were destroyed by the tsunami.
- Even damaged breakwaters seem to have the effect to reduce the tsunami impacts behind them.

Cross section of the bay-mouth breakwater



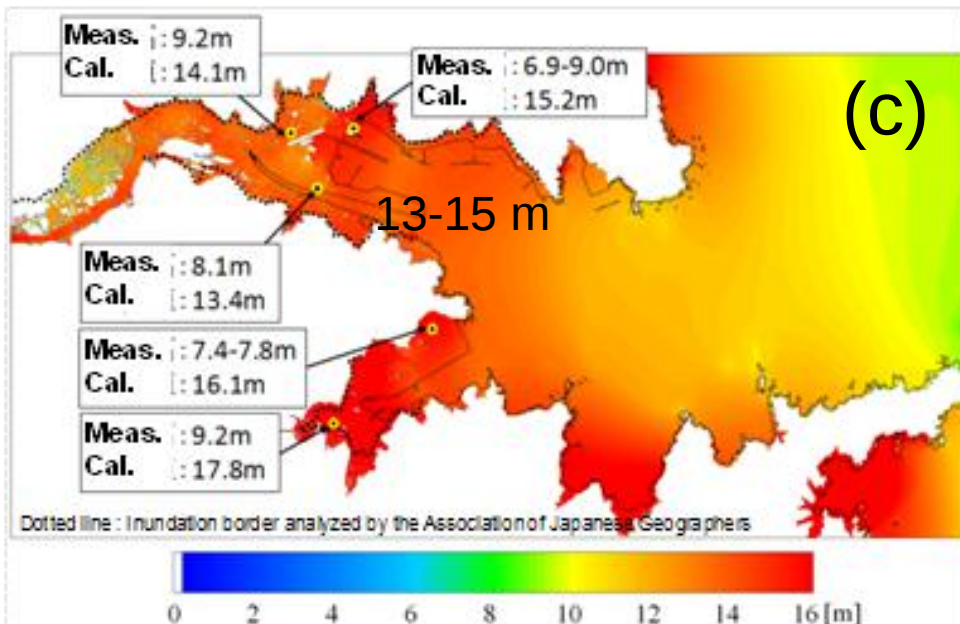
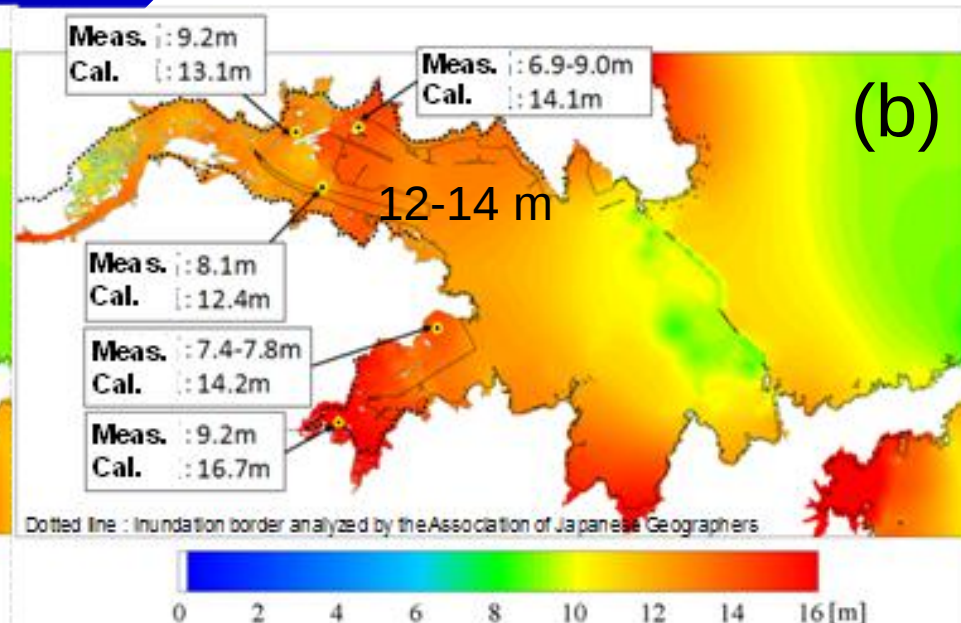
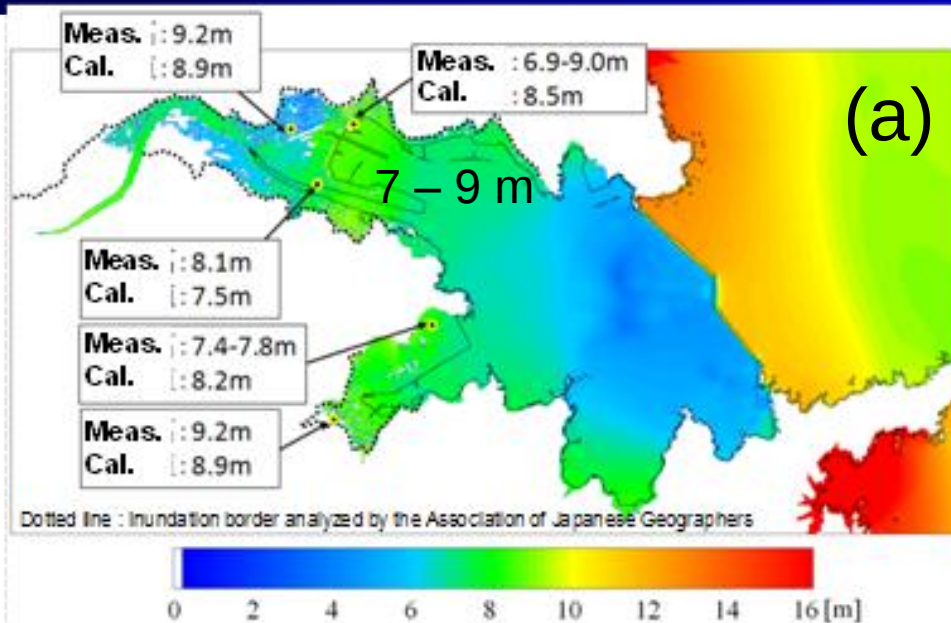
Half of the depth in the bay mouth was made up with stones constructing the breakwater mound, and caissons 30 m high were installed on the mound in order to reduce intrusion of the estimated tsunamis.

Red: Moved, Yellow: Inclined, Green: No damage



Tsunami-Reduction Effects of Breakwater

13



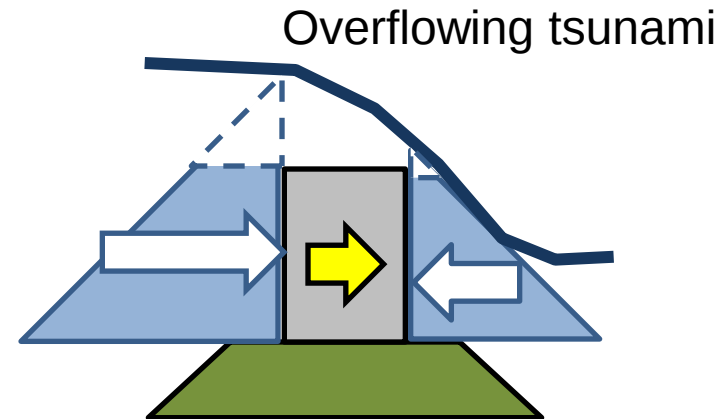
- (a) Breakwater with no failure
- (b) Breakwater with failure before arrival of the tsunami
- (c) No breakwater

Even damaged breakwater reduced by 40 % of tsunami inundation height around the coastal line in the port

Failure modes of breakwaters were investigated from physical model experiments.

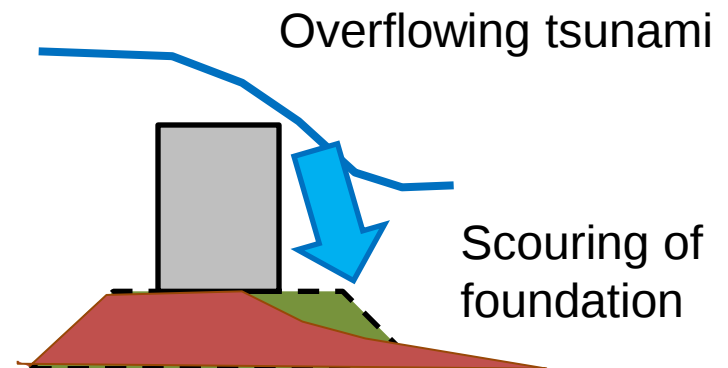
Horizontal force

due to much difference of the front sea level from the back sea level, which exceeds the friction resistance of the caisson



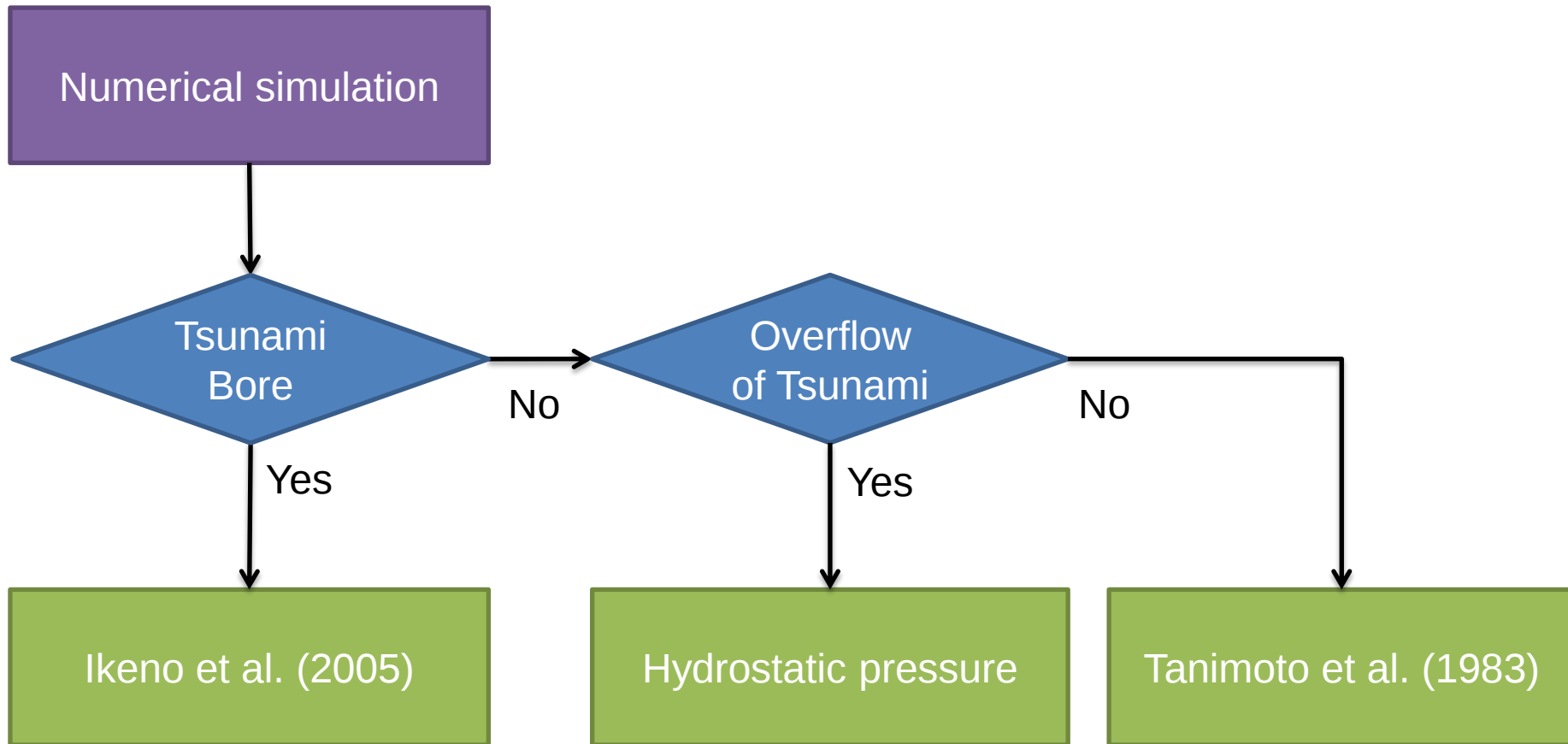
Foundation failure

due scouring of the foundation caused by the impacts of the tsunami overflowing the caisson



Guideline for breakwaters against Tsunamis

Tsunami wave force

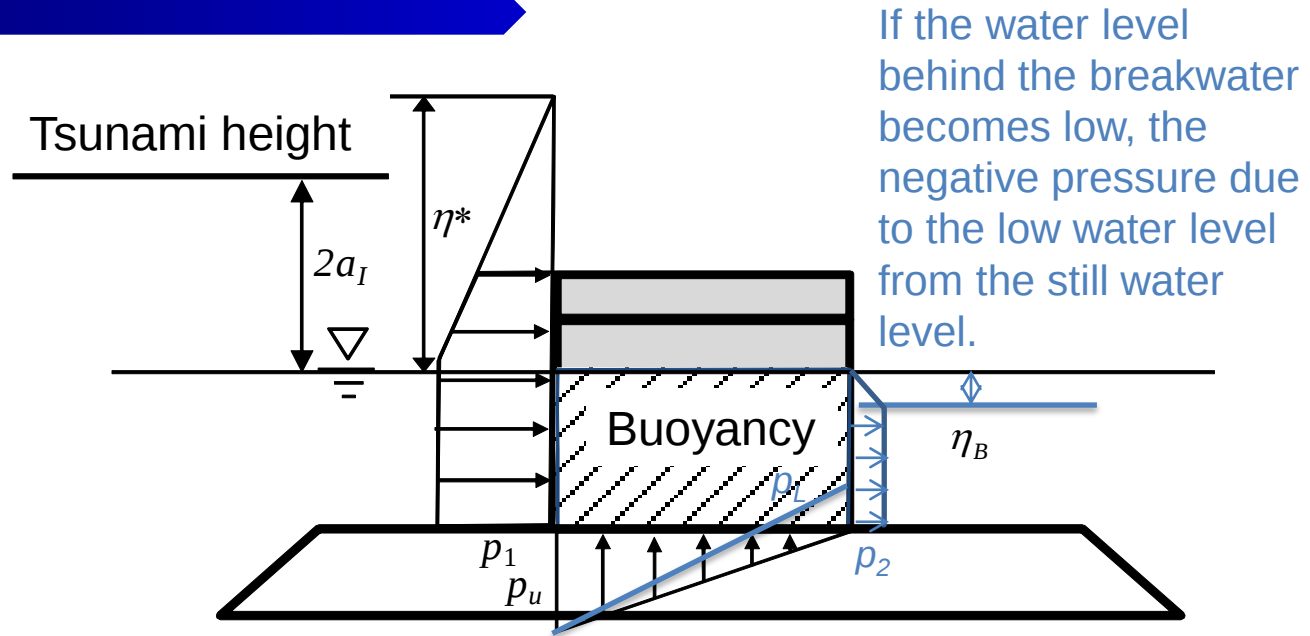


Ikeno et al. (2005)

$$\eta^* = 3.0a_I$$

$$p_1 = 3.0\rho_0ga_I$$

$$p_u = p_1$$

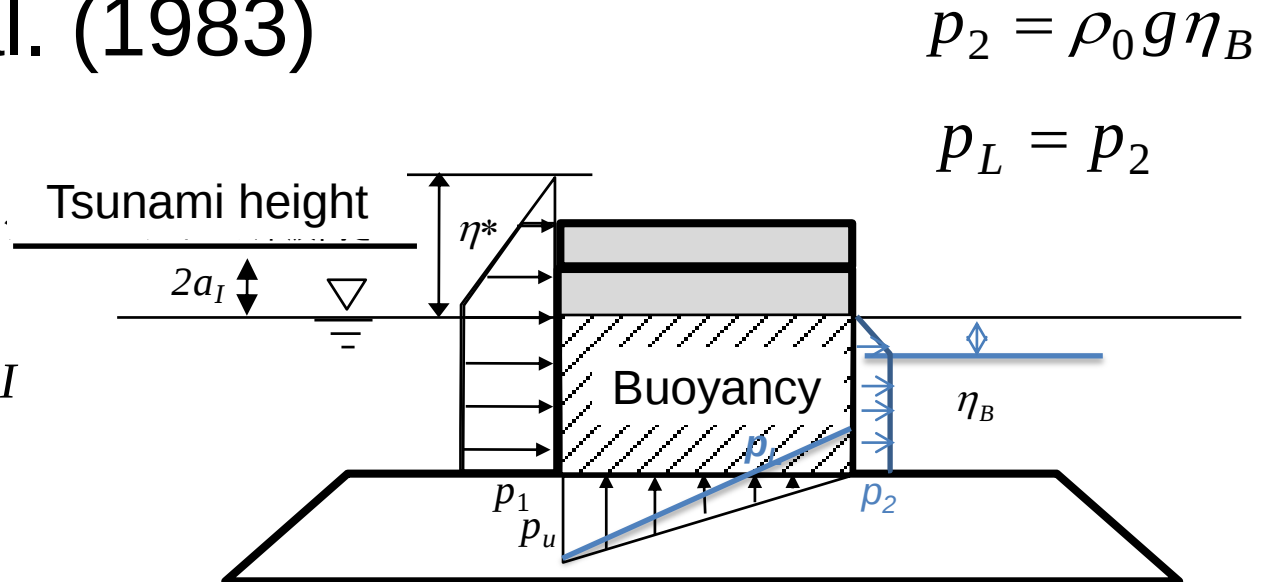


Tanimoto et al. (1983)

$$\eta^* = 3.0a_I$$

$$p_1 = 2.2_0ga_I$$

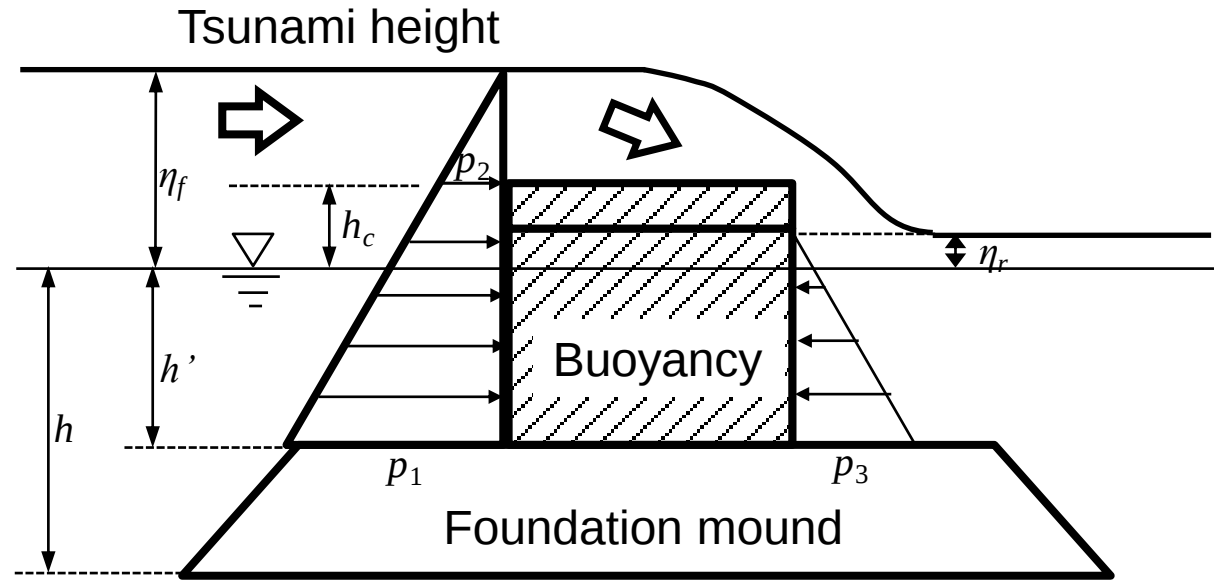
$$p_u = p_1$$



In the Case of the Overflowing Tsunami

$$p_1 = \alpha_f \rho_0 g (\eta_f + h') \quad \alpha_f = 1.05 \quad \text{from hydraulic experiments}$$

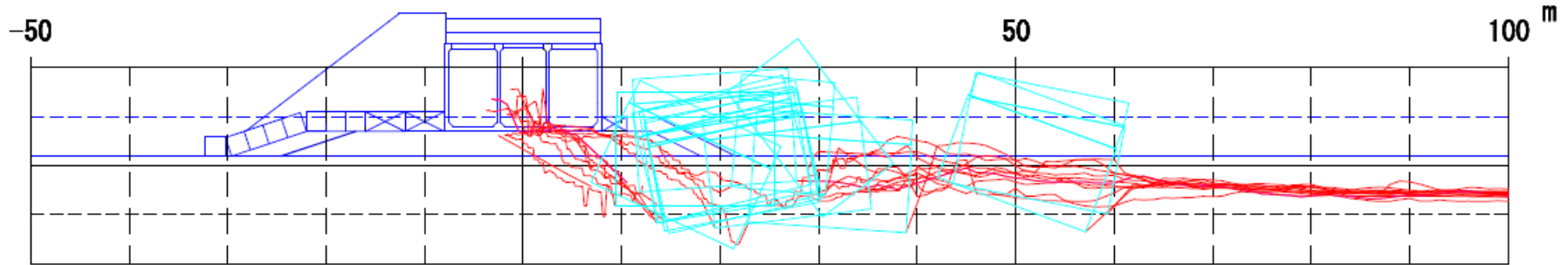
$$p_2 = \frac{\eta_f - h_c}{\eta_f + h'} p_1$$



$$p_3 = \alpha_r \rho_0 g (\eta_r + h') \quad \alpha_r = 0.9 \quad \text{from hydraulic experiments}$$

In case of the tsunami overflowing slightly, comparing the wave force calculated with the method of Tanimoto et al. (1983), the stronger wave force is used as the design force.

A Breakwater Resilient to Tsunamis



Tsunami flow and overtopping

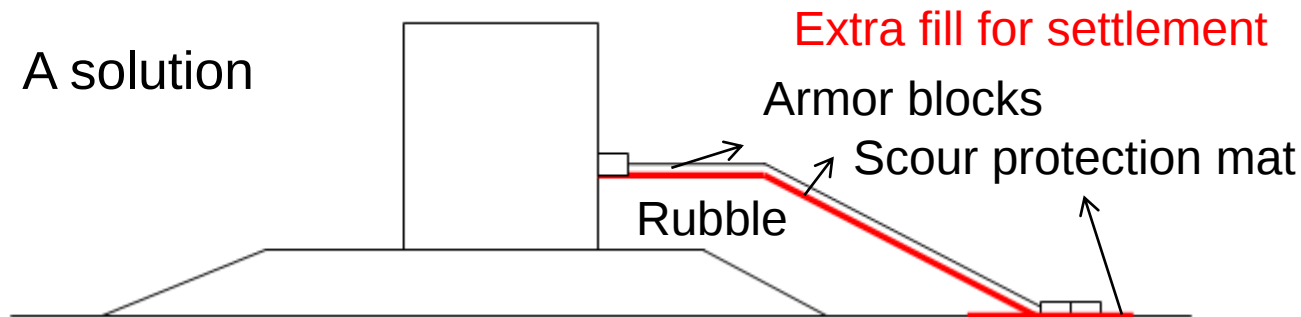
→ Deformation of seabed and foundation

→ Failure of caisson



Resilience of Mound and Foundation to them

A solution



MERITs

- Resistance to movement of caisson
- Delay of caisson failure due to foundation failure

Toward Tsunami-Resilient Port



- The Great East Japan Earthquake and Tsunami caused the devastating disaster in all the Pacific coasts of Tohoku and Kanto regions in ports.
- Responsible organizations have been discussing the causes of the disaster and lessons learned from the disaster
- Five major items are discussed in the appendix:
 1. Worst case scenario and disaster mitigation
 2. Tsunami defenses with toughness
 3. Tsunami resilient coastal towns
 4. Vertical evacuation
 5. Tsunami observation and warning

Worst-Case Scenario and Disaster Mitigation

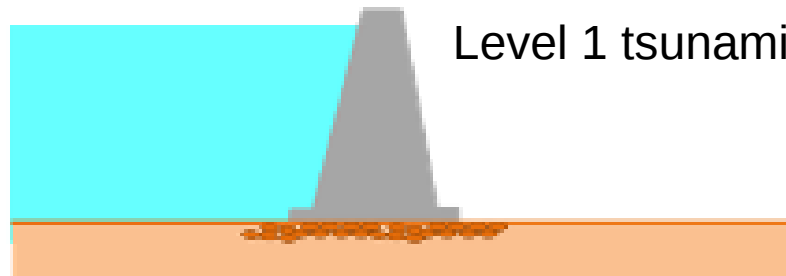
Importance of preparation for the worst case scenario, that is, a case exceeding ordinary design levels

Performance design for tsunami defense

Tsunami level	Design tsunami	Required performance
Level 1 Tsunami	Largest possible tsunami in the return period of around 100 years	Disaster Prevention • To protect human lives • To protect properties • To protect economic activities
Level 2 Tsunami	One of the largest possible tsunami (Return period: around 1000 years)	Disaster Mitigation • To protect human lives • To reduce economic loss, especially by preventing the occurrence of severe secondary disasters and by enabling prompt recovery

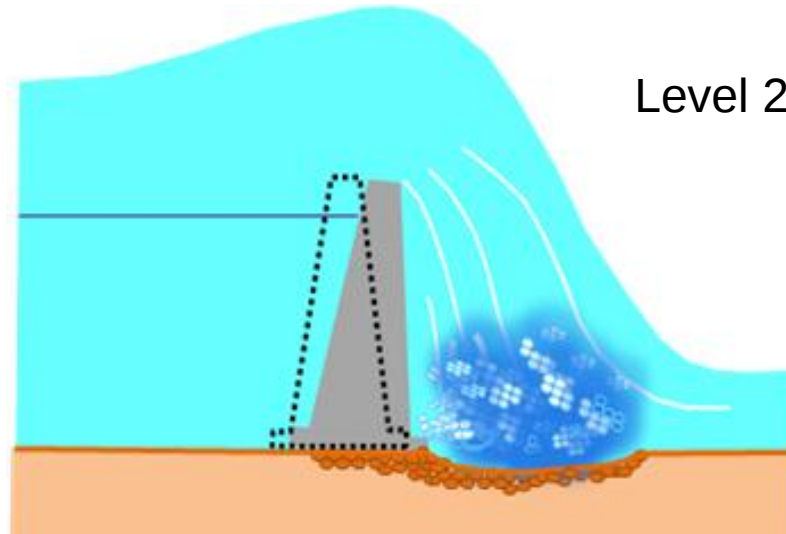
Disaster mitigation is not so simple. ◀ It is difficult to estimate the extent of failure of coastal defenses. It is more difficult to estimate the secondary damage and economic consequences of the disaster.

Strengthen Tsunami Defenses



Level 1 tsunami

The Level 1 tsunami would not exceed the height of the tsunami defense.



Level 2 tsunami

The Level 2 tsunami might exceed the height of the tsunami defense. Therefore, we need to mitigate the disaster by maintaining strong tsunami defenses to reduce the tsunami height.

If the tsunami defenses may be damaged by the exceed tsunami design force but they are not destroyed completely, the tsunami impacts behind them are reduced. Breakwaters and seawalls are generally large structures built to resist huge storm waves; therefore, many of them can withstand the Level 2 tsunamis if scouring and trough-wash are prevented.

Tsunami Resilient Coastal Town

- Relocation to higher ground: One of the best solution for coastal towns to survive from tsunami
- Better solutions should be investigated not only to save lives but also to save livelihood using advanced technologies.
- Especially, since port towns should be located near the sea, we should develop well-planned tsunami survivable town.

Relocated residential area to high ground

Coastal town with high buildings



Not only tsunami defense structures but also ground reclamation and high buildings to make survival coastal town for the Level 2 tsunami

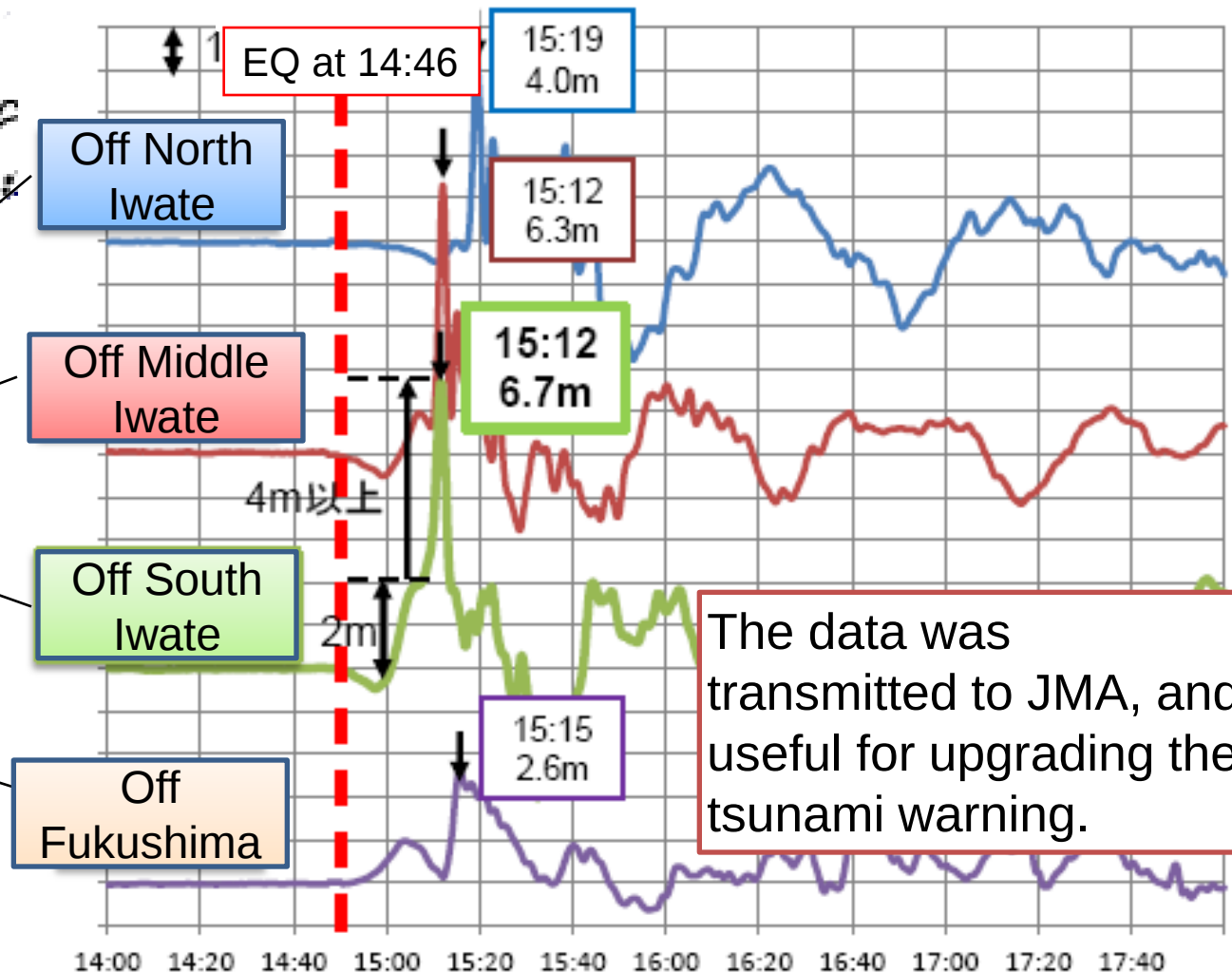
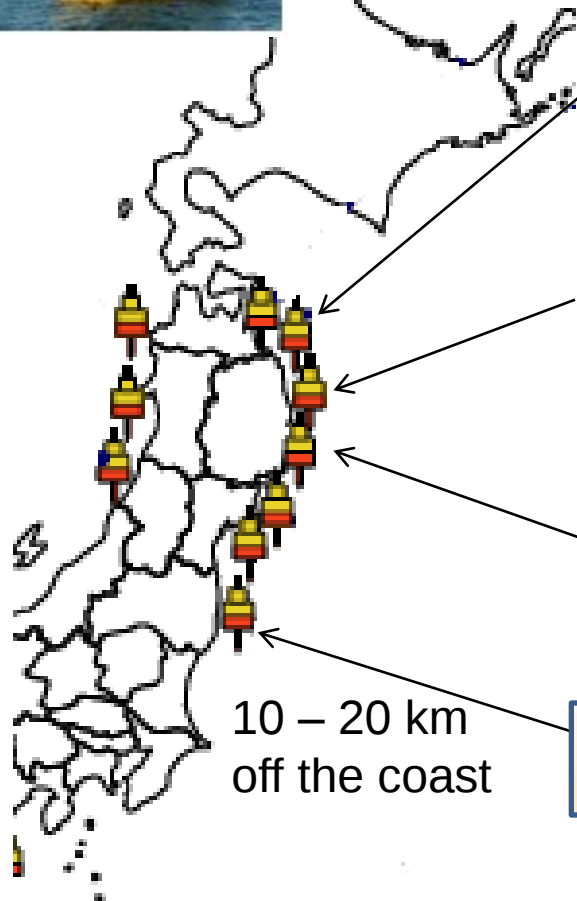
Offshore Tsunami Observation

23



GPS buoys detected the tsunami in offshore areas 10 min. before the tsunami reached coasts.

Utilize the offshore measurement of tsunami



The data was transmitted to JMA, and useful for upgrading the tsunami warning.

Summary



- Well-prepared people through conducting disaster education and evacuation drill
- Suitable arrangement of tsunami shelters especially in a port area
- Countermeasures against tsunami debris to reopen the ports in order to carry the emergency supplies into the damage areas
- Tsunami-resilient defense infrastructures to reduce tsunami impacts
 - Even though the facilities are damaged but still alive, they reduce the tsunami impacts behind them.