**IHO MSDI Industry Demonstration Workshop and Open Forum**
海洋空間データ基盤に関する国際会議
Miraikan Hall, National Museum of Emerging Science and Innovation, Tokyo. Japan,
25-26 January 2016

# Tsunami damage estimation and spatial data infrastructures
# 津波被害想定と空間データ

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# Outline

- Preparation for tsunami disaster management needs estimating what may happen if tsunamis of various heights hit a target area.
- A tsunami in the target area depends on not only a scale of the tsunami generated, but also an area where the tsunami is generated, because tsunamis are transformed and deformed during their traveling in the sea, affected by change of bathymetry and topography.
- We need bathymetric and topographic data detailed for accurate estimation of tsunami hazards, especially in regions of shallow water depth, where the wavelength of a tsunami is not so long.

# Tsunami Disasters

# Tsunami Deformation

The 2011 Tohoku Tsunami was deformed in Kuji Bay, Japan, affected by bathymetric change.

Captured from a video footage taken by the National Defense Force of Japan

Captured from a video footage taken by the Kamaishi Port Construction Office of MLIT, Japan

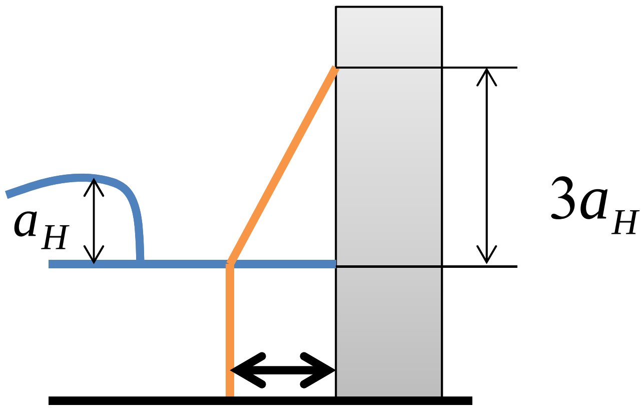
# Tsunami Deformation

**Captured from a video footage taken by the Kamaishi Port Construction Office of MLIT, Japan**

# Impact of Deformed Tsunami

## Increase of tsunami force acting on a structure

**Not-deformed tsunami**

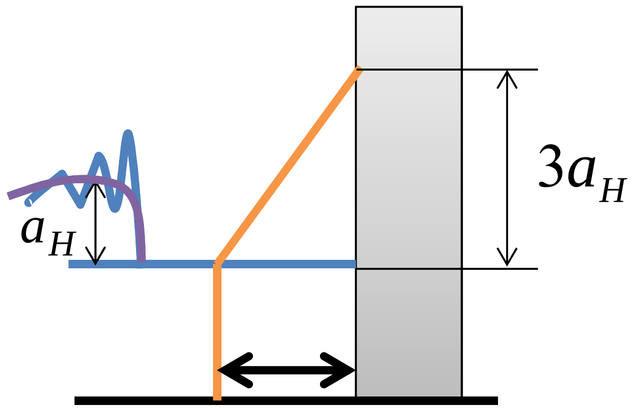



$$2.2\rho g a_H$$

Tanimoto et al. (1983)

**1.4 times**

**Deformed tsunami**
(Undular bore)

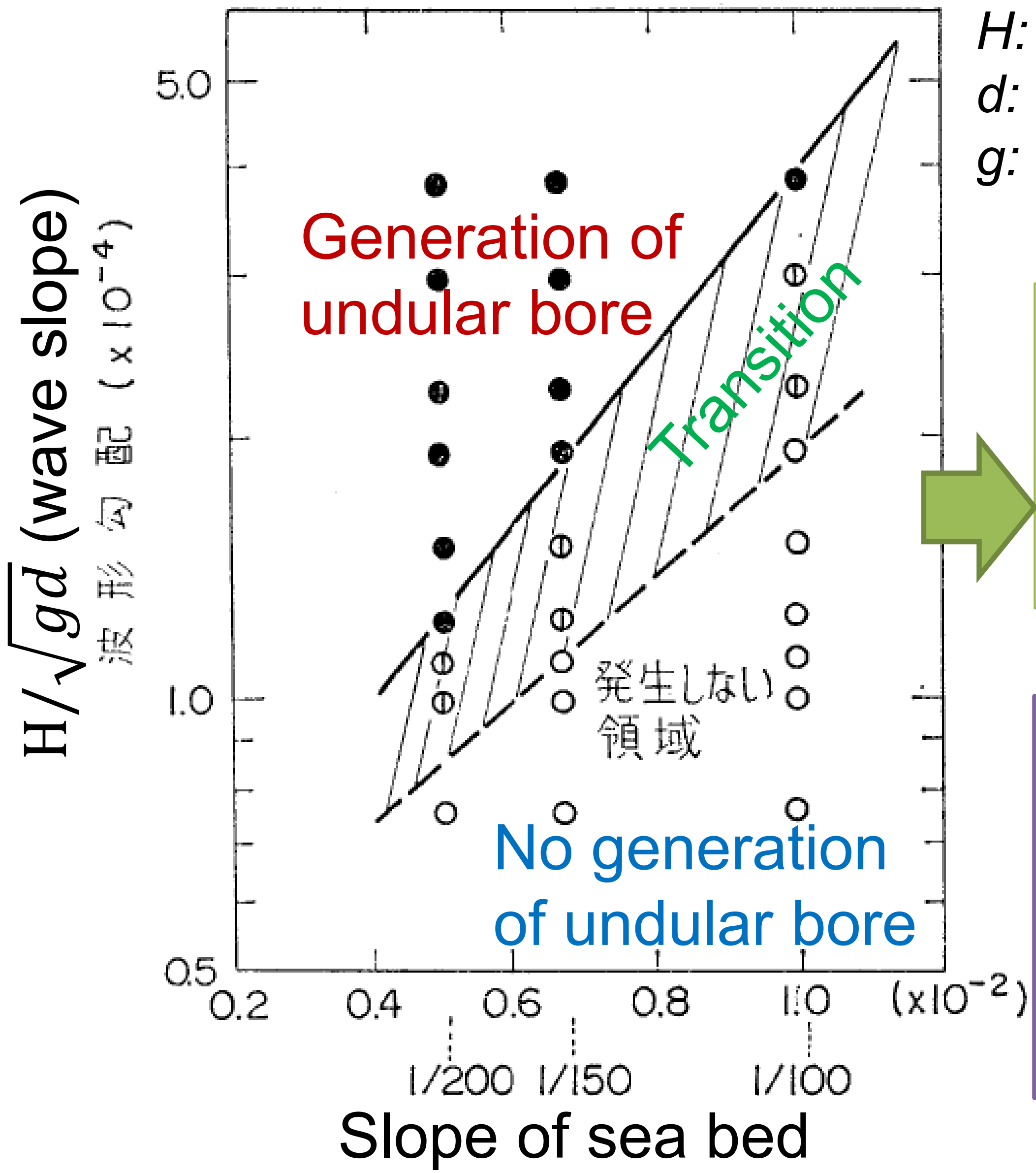



$$3.0\rho g a_H$$

Ikeno et al. (2006)

<u>Profile of tsunami wave pressure acting a vertical wall</u>

# Generation Condition of Undular Bore




Kubota et al. (1986) doi:10.2208/proce1970.33.66

*H: Wave height*
*d: Water depth*
*g: Gravitational acceleration*

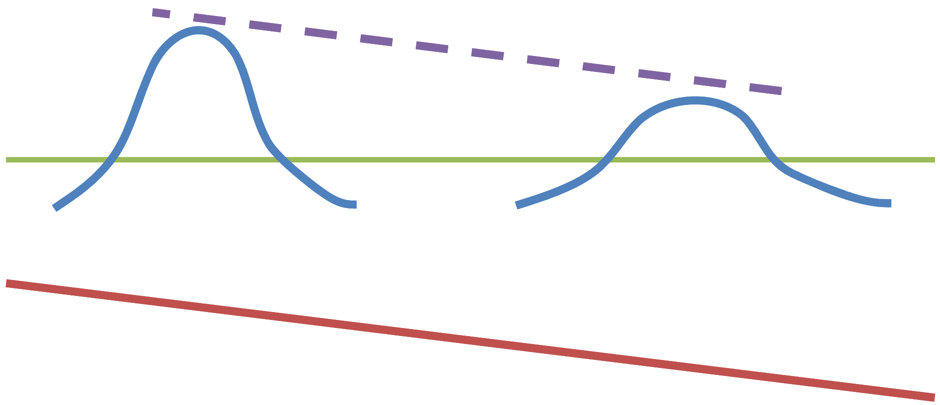
Possibility of generation of undular bores is higher in a shallow sea whose bottom slope is milder.

Generation of undular bores depends on the **water depth and sea bottom slope** as well as height of the tsunami.

# Physics of Tsunamis

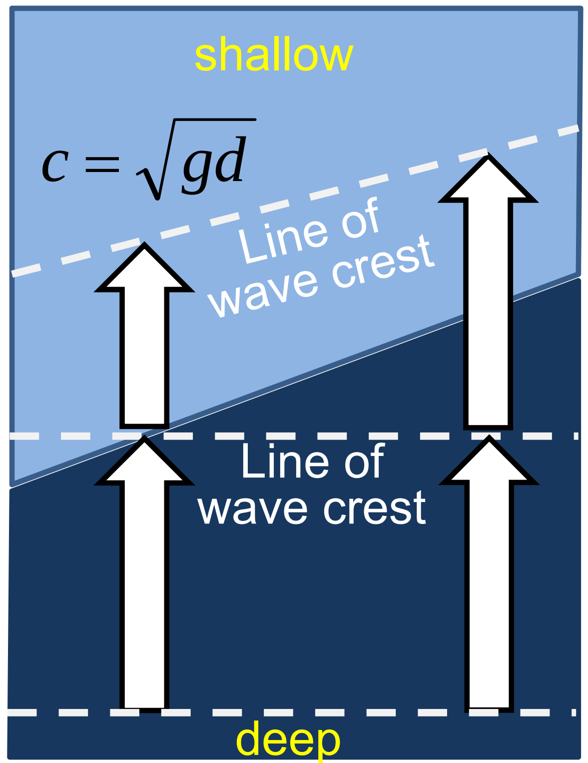
## Effect of water depth

### Increase of tsunami height



$$\frac{H_{shallow}}{H_{deep}} = \left(\frac{d_{deep}}{d_{shallow}}\right)^{1/4}$$

### Change of propagation direction

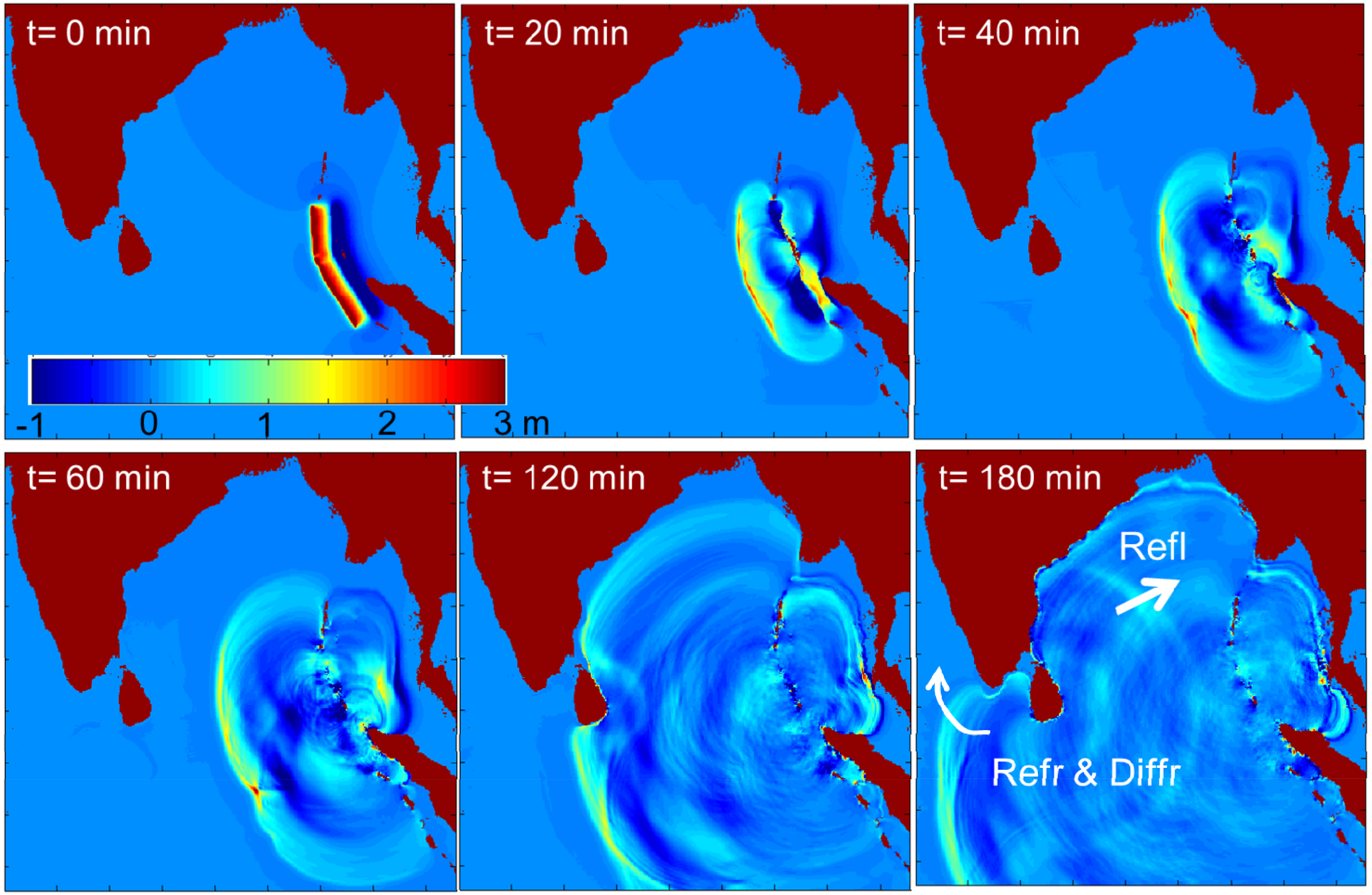



Snell's law

$$\frac{\sin\theta_{shallow}}{\sin\theta_{deep}} = \frac{c_{shallow}}{c_{deep}} = \sqrt{\frac{d_{shallow}}{d_{deep}}}$$

# Refraction, Diffraction and Reflection

- Not-uniform seafloor
- Existence of an island and coast




Calculated propagation of the 2004 Indicant Ocean tsunami (Tomita & Honda 2006)

# Spatial Resolution

If the wavelength of a tsunami ($L$) is 100 km in the sea 1000 m deep, the wave period ($T$) is 1,010 sec. (17 min.).

$$L = Tc = T\sqrt{gd}$$

When this tsunami comes to the sea 20 m deep,
the wavelength decreases to $\boxed{\text{14 km}}$,
while wave height of the tsunami is 3 times higher than that of the offshore tsunami.

$$L_{d=20m} = 1010 \times \sqrt{9.8 \times 20} = 14{,}140\,(\mathrm{m})$$

$$\frac{H_{shallow}}{H_{deep}} = \left(\frac{d_{deep}}{d_{shallow}}\right)^{1/4} = \left(\frac{1000}{20}\right)^{1/4} = 2.7$$

**About 500 m grid spacing at least**, because the calculation grids should be ensured at least 20 to 30 points per tsunami wavelength.

# Spatial Resolution

- Finer grid size of **1/100th or less** of tsunami wavelength is recommended for calculation of a refracted tsunami
- In an opening section of breakwaters, the gird size should be **1/5th or less** of width of the opening.
- On an area a tsunami runs up , the grid size should be **less than $7 \times 10^{-4} \alpha g T^2$** ($\alpha$, bottom slope, $g$, gravitational acceleration, and $T$, wave period) , in the case of consideration of bottom roughness with Manning's coefficient, $n$=0.03 m$^{-1/3}$s.

If $T$=600 s and $\alpha$=0.002, the grid size is 5 m or less.

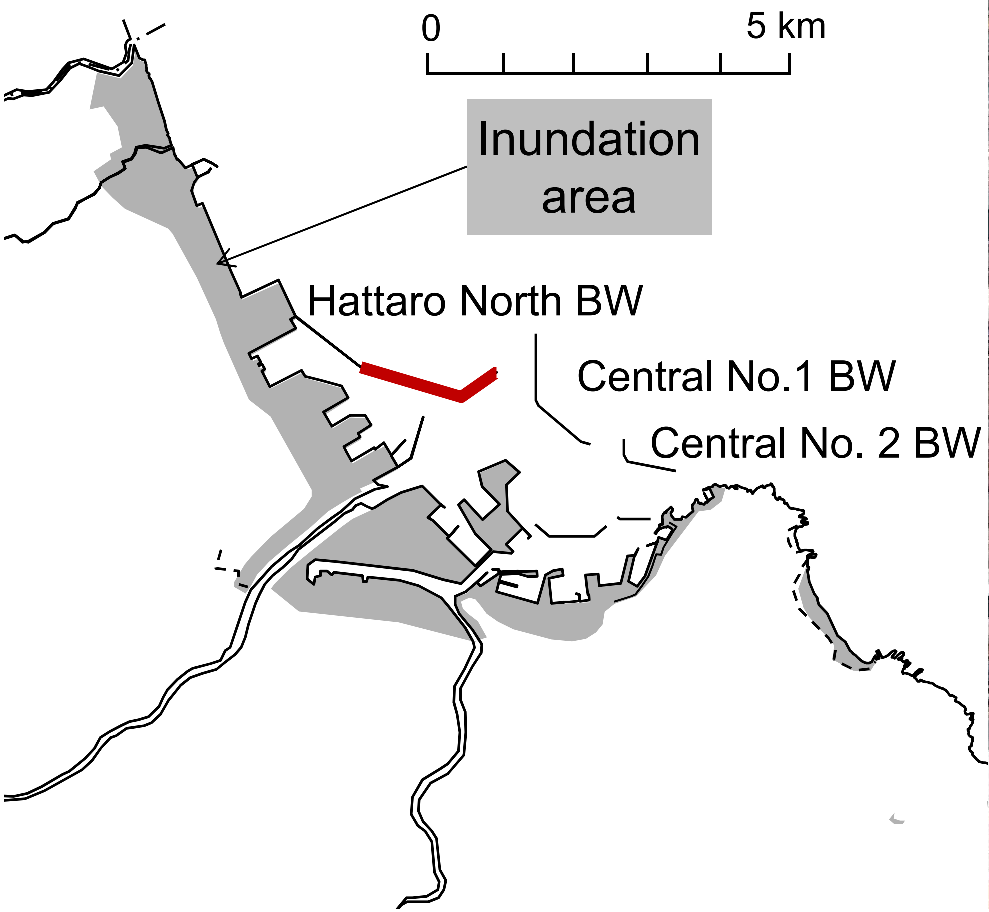
Bathymetric data with finer spatial resolution is required in areas of shallower water depth, and near structures.

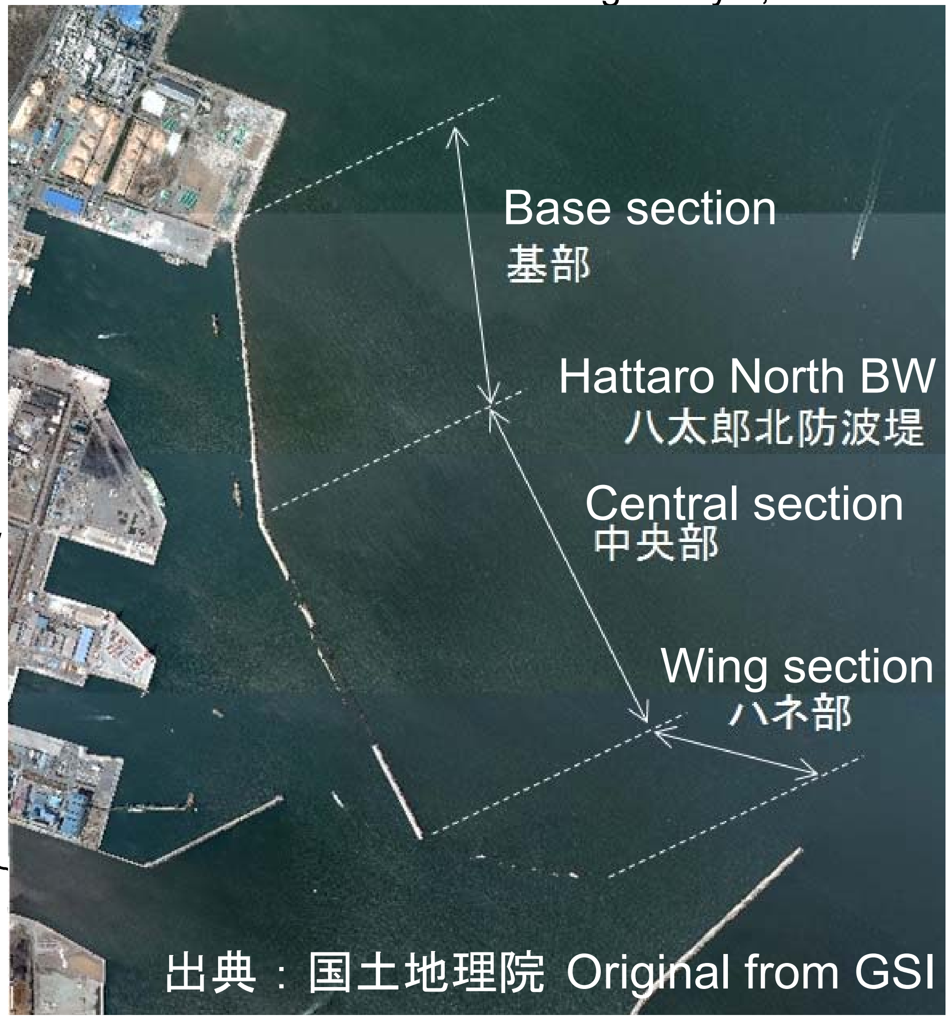
Tsunami Assessment Method for Nuclear Power Plants in Japan (JSCE 2002)

# Calculation Example 1

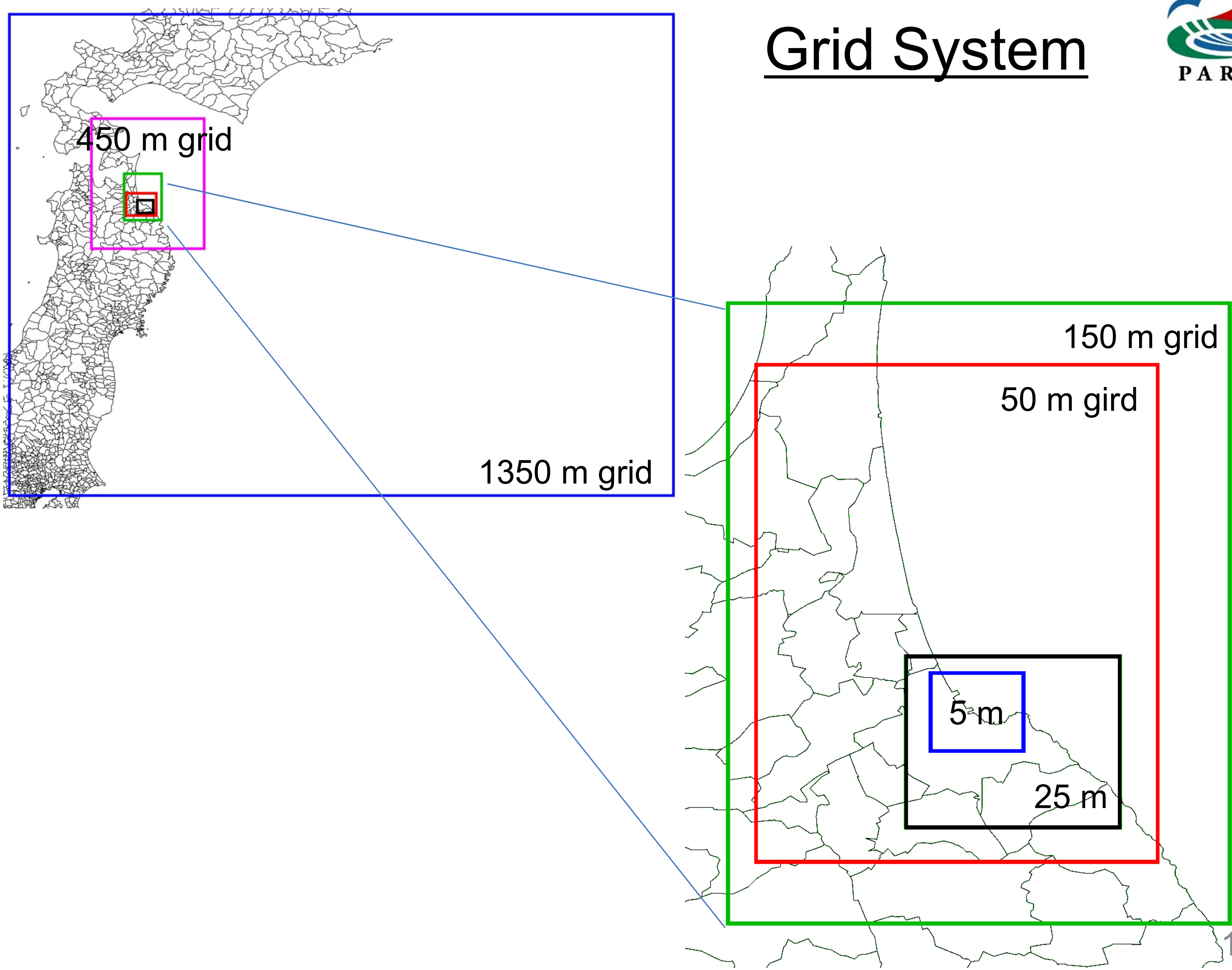
- The 2011 Tohoku tsunami in Hachinohe port
- Wing and central sections of Hattaro North breakwater were damaged by the tsunami.

Caissons in 1,437 m were moved and tilted among totally 3,504 m.



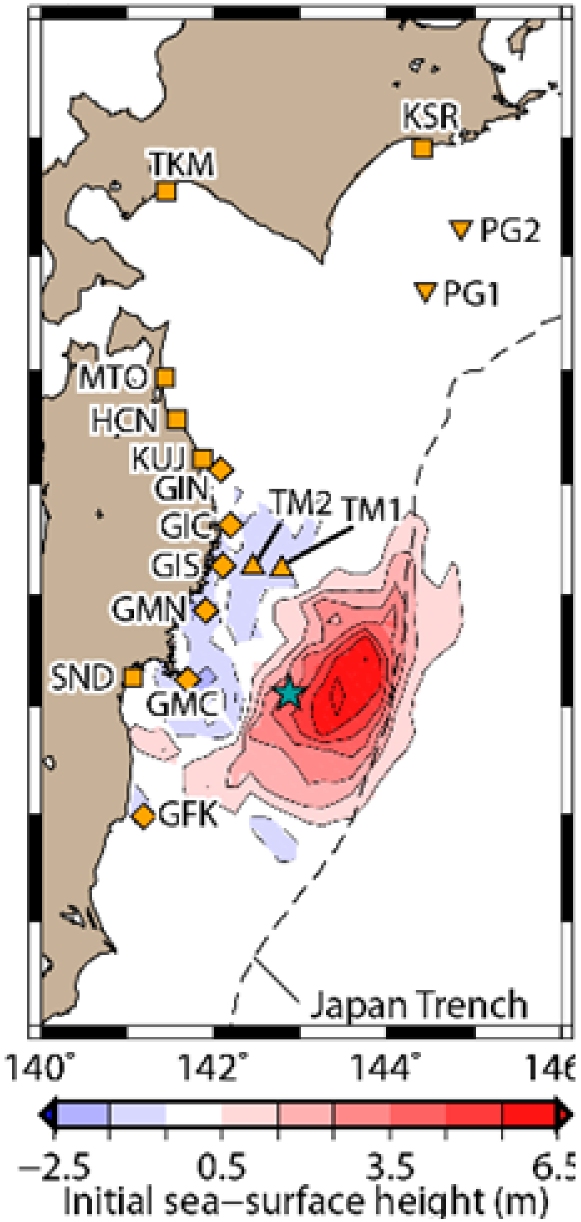
# Grid System



# Calculation conditions

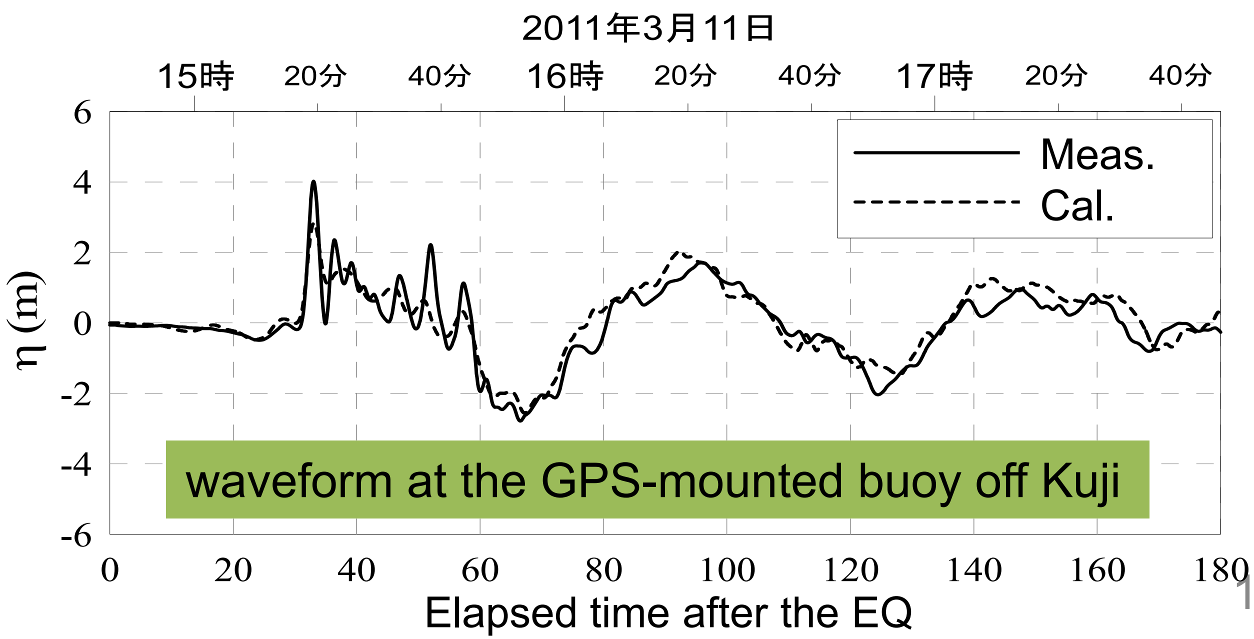
- Applied model: **STOC-ML (single layer)**
- Grid system: Nested grid system
  - 5 m grid spacing was applied in Hachinohe port.
- Integral time:
  - 180 minutes in which the second tsunami arrives Hachinohe port
- Time interval: 0.1 s
- Topography:
  - Buildings are arranged in the computation field, based on laser profiler data obtained before the disaster.
- Tide condition
  - Tide level at the arrival time of second wave, which is highest tsunami in Hachinohe, is applied. (T.P.-0.1 m)

# Model of Tsunami Source

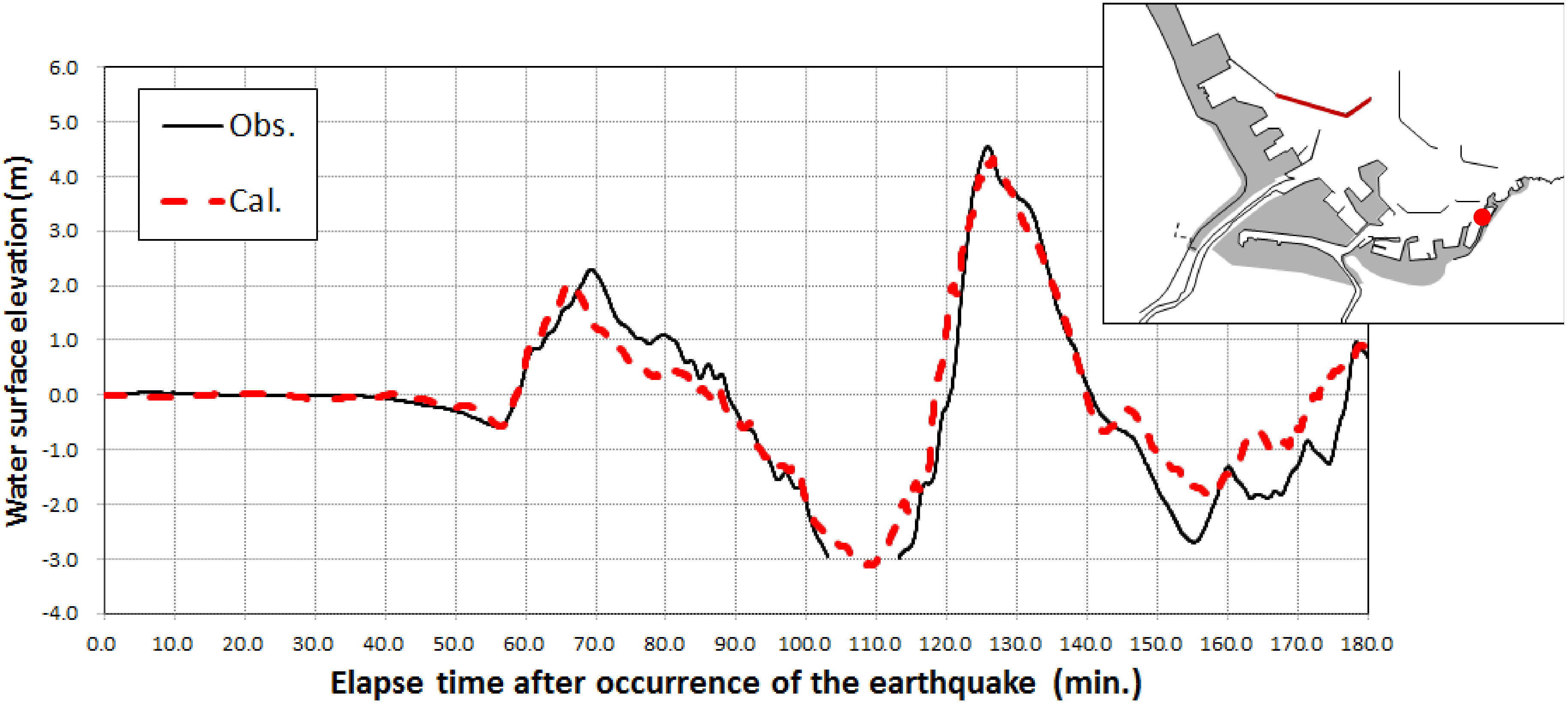



**Model by Takagawa & Tomita (2012)**

- obtained from inversion analysis with tsunami waveforms measured offshore by GPS-mounted buoys and seabed-mounted pressure gages
- provided tsunami inundation height near coast line in Hachinohe well comparing with measured height in post field surveys.



# Validation




Considering destruction of the wing section of the breakwater at the time that the tsunami broke the section in stability analysis of the breakwater, the calculated tsunami waveform agreed well with an observed one at a tide station in the port.

# Calculation Example 2

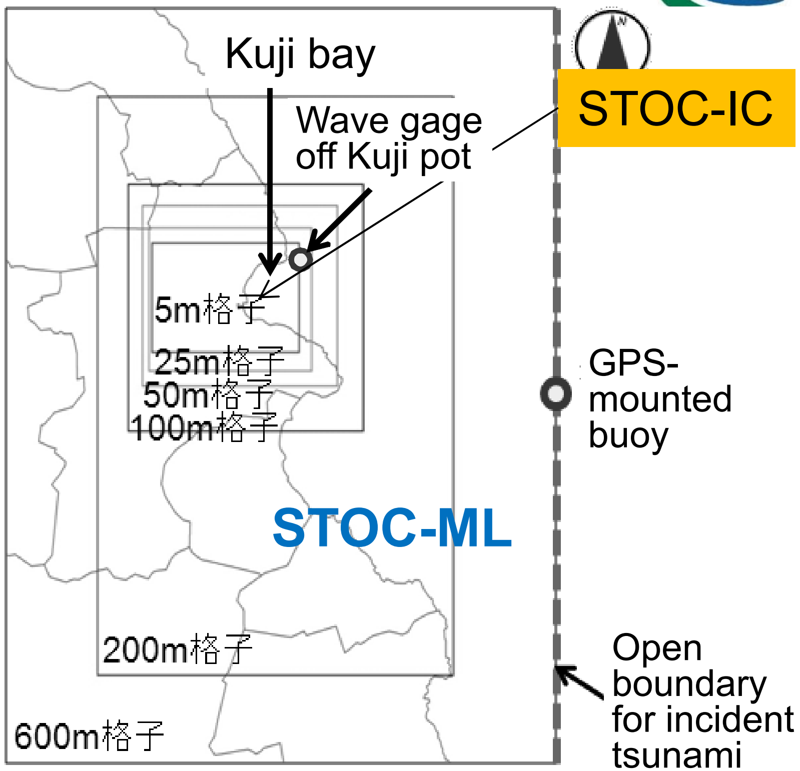
- The 2011 Tohoku tsunami in Kuji port
- STOC-IC that is a non-hydrostatic and 3d model to calculate tsunamis was applied for this tsunami.

Captured from a video footage by Japan Ground Self-Defense Force

Captured from a video footage by Tohoku Regional Bureau of MLIT

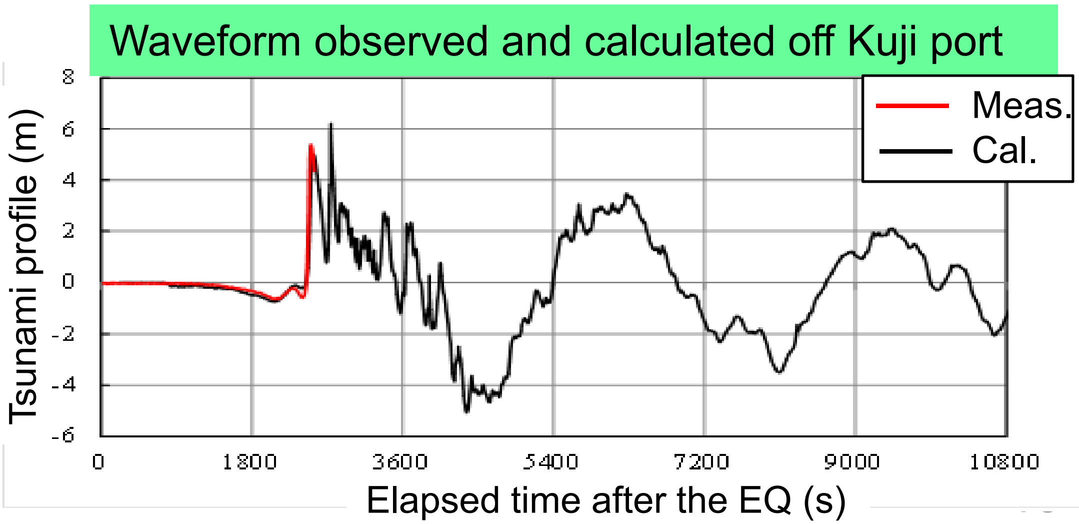
# Tsunami Condition

- An open boundary was set at the east end of computational domain
  - a GPS-mounted buoy installed offshore Kuji bay measured the tsunami in the 2011 event.
- The measured tsunami profile was numerically generated as the incident tsunami.




- Referring Inukai and Nagasawa (2012), the normal incident (right angle to the open boundary) is not so bad assumption for this case.

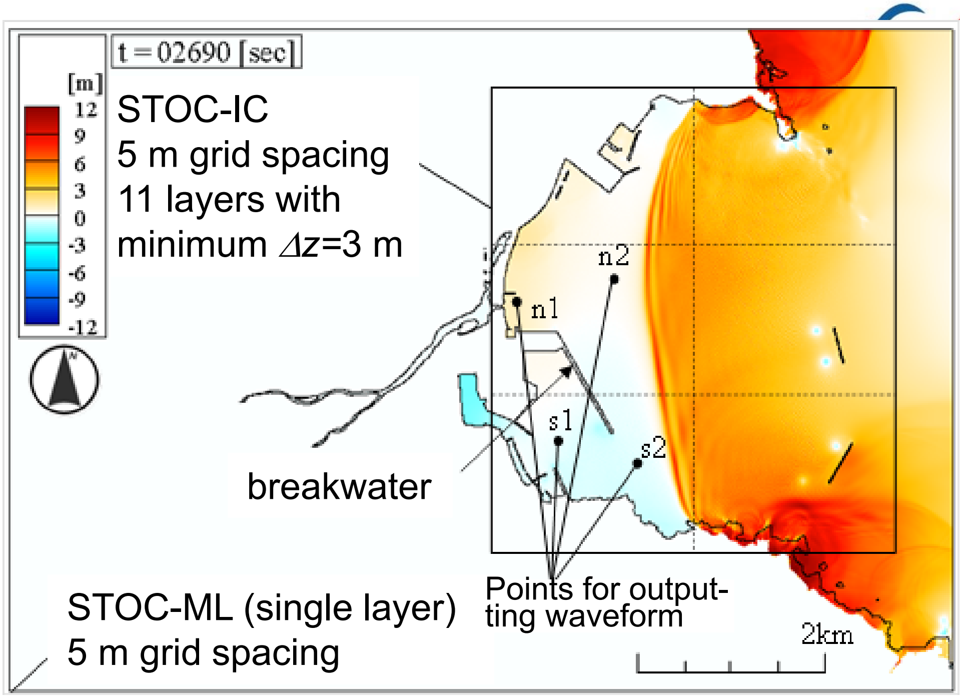
- The nested grid system was applied, and the grid size in the Kuji port area was 5 m.

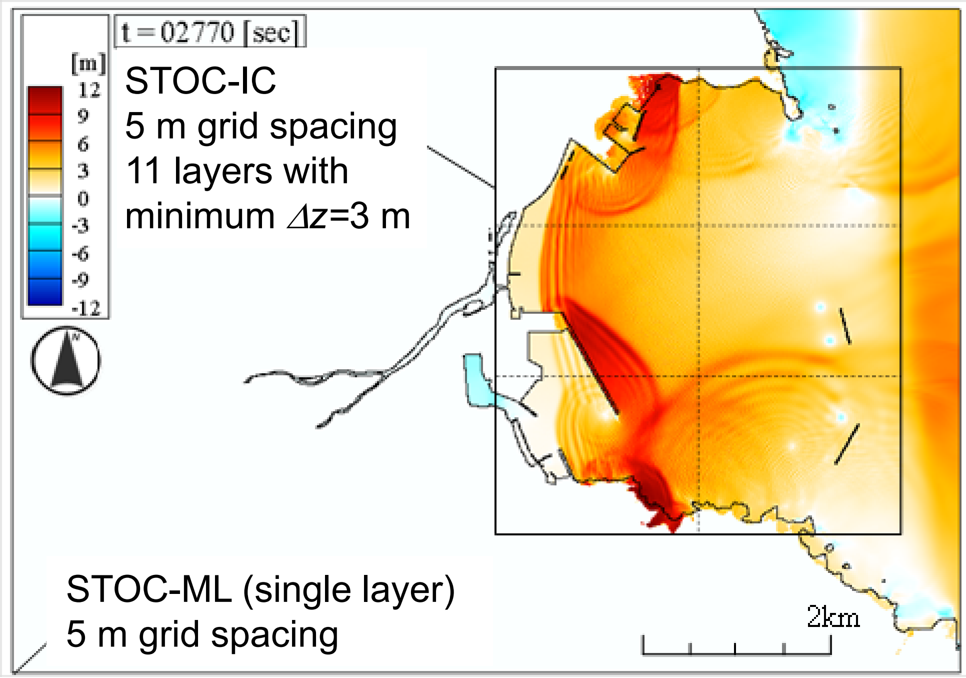


# Calculation Results & Phots

Captured from a video footage by Japan Ground Self-Defense Force

Captured from a video footage by Tohoku Regional Bureau of MLIT

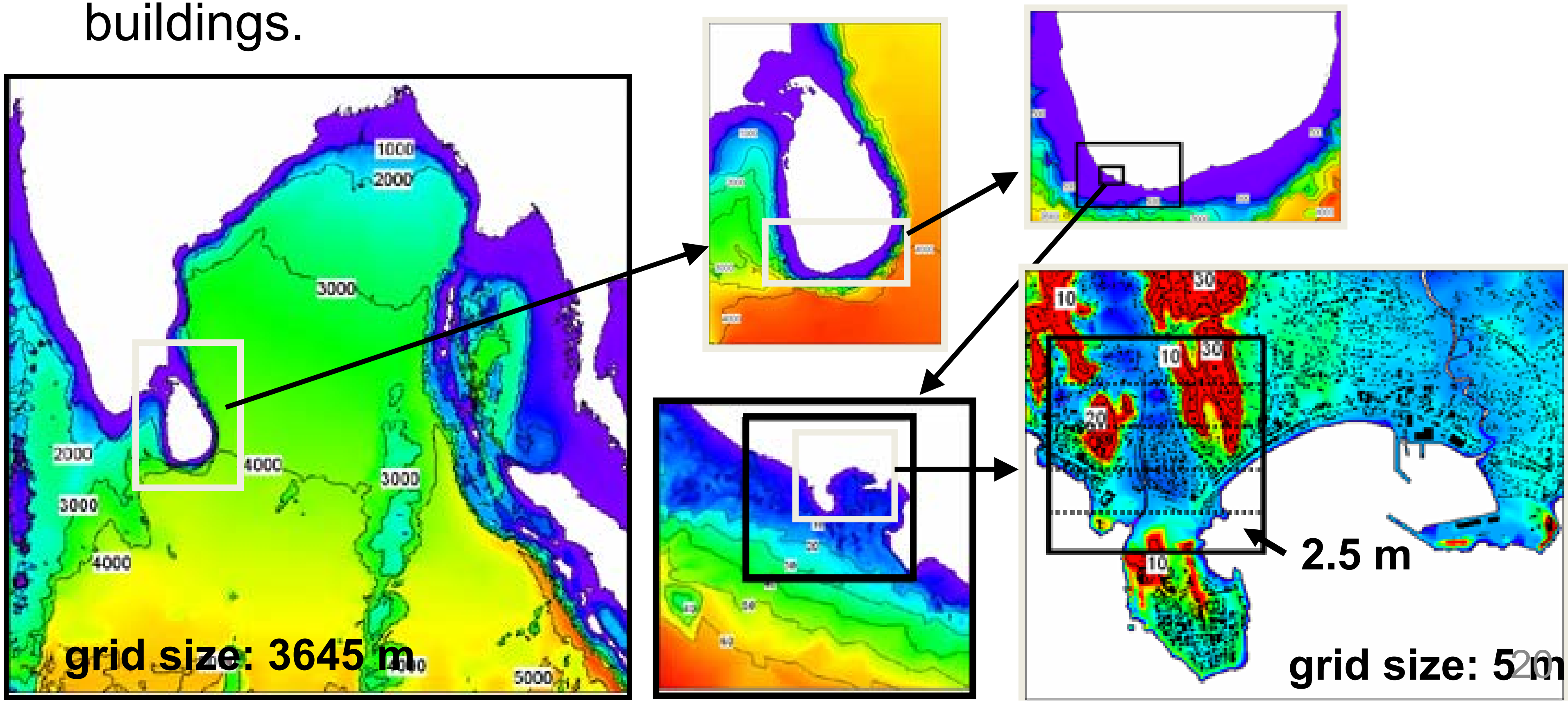


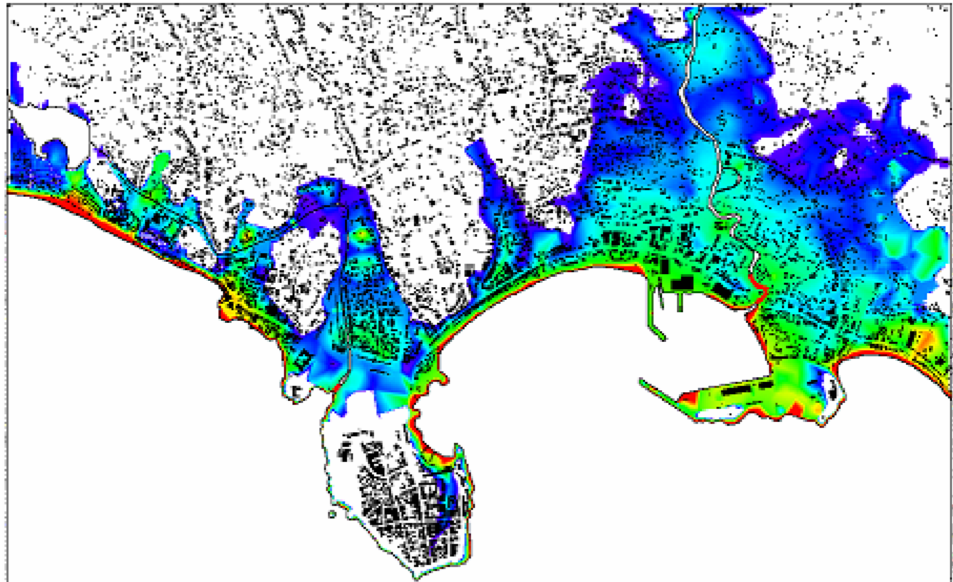




Red strips: Short-period waves on the tsunami front in orange color

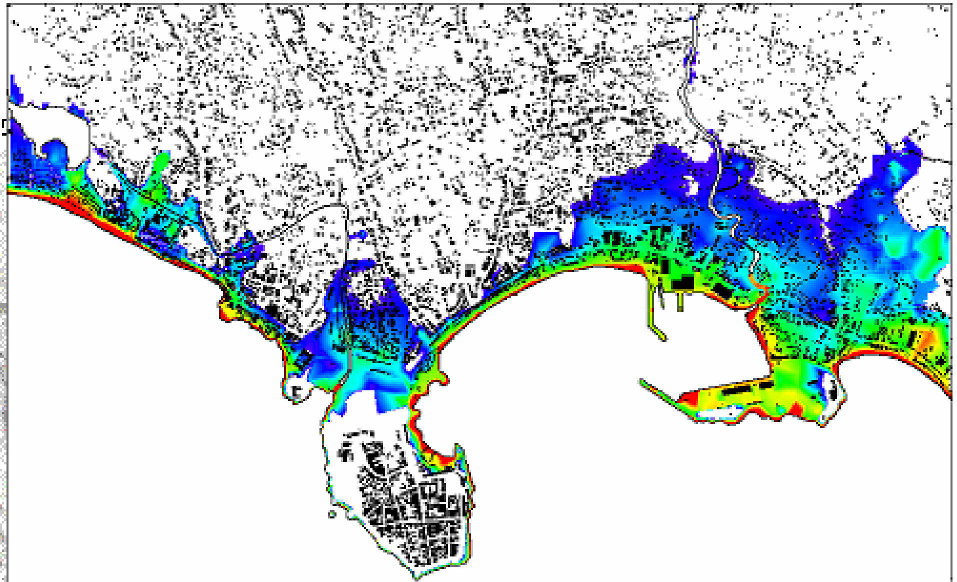
# Calculation Example 3

- The 2004 Indian Ocean tsunami in Galle, Sri Lanka
- Bathymetric data: GEBCO 1.0-minute grid data & Nautical Chart (data: 1/10,000 topographical digital map with structure shape data 1/312,000 ~ 1/10,000; USA)
- Topographic by Survey Department, Sri Lanka, which includes buildings.



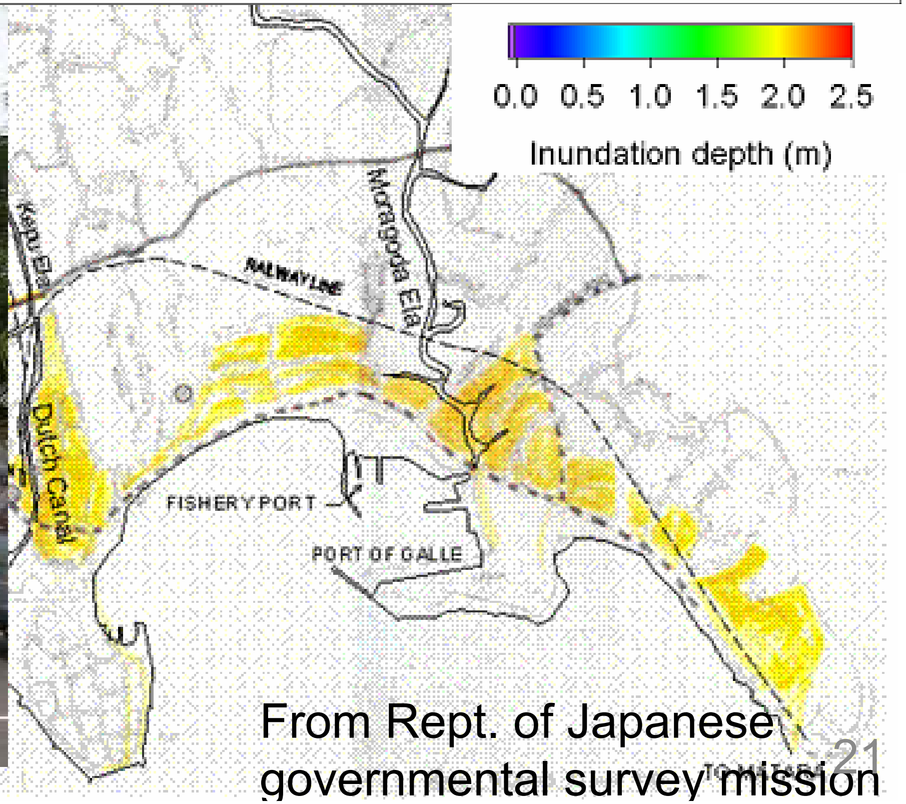


STOC-ML **with no buildings**



Combination of IC-ML **with buildings**

Reduction of tsunami inundation by buildings




From Rept. of Japanese governmental survey mission

# Simulation for Tsunami Damage Estimation


CG of a result of tsunami inundation and debris calculated by a tsunami numerical simulation model of STOC

# Expectation for Spatial Data Infrastructures

- Detailed data around shorelines and reefs
  - Some treatments are needed to connect bathymetric data to topographic one for calculation of tsunami propagation and inundation.
  - Aircraft-based hydrographic survey with green laser is expected to obtain bathymetric data near shores.
- Integrated spatial data including both bathymetric and topographic data
  - It is better that buildings and infrastructures data are included.
    - We don't have any special preparation for tsunami calculation if such a data infrastructure is established.

Thank you for your attention!