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Recent Studies on Coastal Disaster Mitigation with Implications for Ports

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Frequent attacks by tsunamis, storm surges and high wind waves

Field Surveys → New Findings → New Analysis → Mitigation

Analysis of Mechanism: Hydraulic Laboratory Experiment,
Numerical Simulation: Turbulence Numerical Model, Tsunami Flooding Model, Weather-Storm Surge Model
Mitigation Methods: Evacuation Model, Cost-Benefit Analysis

Table 1. List of Major Coastal Disasters after 2004.

Year	Event	Locations	Dead (D) and Missing(M)
2004	Indian Ocean Tsunami	Sri Lanka, Indonesia,Thailand	220,000
2005	Storm Surge by Hurricane Katrina	USA (New Orleans)	1,200
2006	Java Tsunami	Indonesia	668
2007	Storm Surge by Cyclone Sidr	Bangladesh	5,100
2008	Storm Surge by Cyclone Nargis	Myanmar	138,000
2009	Tsunami in Samoa Islands	Samoa	183
2010	Chile Tsunami	Chile	500
2010	Tsunami in Mentawai islands	Indonesia	500
2011	Tohoku Tsunami	Japan	D15,782 M4,086
2012	Storm Surge by Hurricane Sandy	USA(New York City)	170 (USA: 80)
2013	Storm Surge by Typhoon Yolanda (Haien)	Phillipines	D4.011 M1,602
2014	Storm Surge in Nemuro	Japan (Hokkaido Island)	0
2018	Storm Surge by Typhoon Jebi	Japan (Kaisai Airport, OsakaBay)	D14
2018	Tsunami in Sulawesi Islands	Indonesia (Palu)	D2,081 M1,309
2018	Tsunami in Sunda Strait	Indonesia (Krakatoa Volcano)	D426 M29
2019	Storm Surge and High Waves by Typhoon Faxai	Japan(Tokyo Bay)	D9

2024 Tsunami in Noto Peninsula Japan (Noto Peninsula) D245

Recent Modifications of Concepts of Coastal Resilience in Japan

1. Two Different Defense Levels: Once for 100 years, 1000 years
2. Robustness of Structures: Not broken by overflow
3. Future Projection—Change of Local Climate: 1)increase of Ocean Surface Temperature, 2)Absence of Westerlies
4. Effective Evacuation Planning and Support to Disaster Area (Lessons from Tohoku and Application to Noto)
5. Inclusion of Strong Wind Effect in Water Inundation

Tohoku Tsunami: Japanese Debates on the Reconstruction Process

The idea that hard measures can protect against the loss of life has been discarded.

Level I Tsunami Protection Height

1. The function of coastal structures would be to attempt to protect property or to help evacuation process against the more frequent but low-level events (typically with a return period of several decades to 150 years). "Once for 100 years" Coastal protection structures are designed for this tsunami height.

Level II Tsunami Evacuation Height

2. Soft measures (Evacuation), on the other hand, would be used to protect lives, and be designed with more infrequent higher level events (with much longer return periods, for example 1,000 years). "once for 1000 years"

For Level II tsunami, structures are overflowed but are required not to be destructed. They are expected to reflect tsunami partially and will assist evacuation process by reducing tsunami height and delaying tsunami flood time.

We are applying the same concept to Storm Surges.

Field Survey of the 2024 Noto Peninsula Earthquake Tsunami

Fishery Ports and Fishery Villages

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4. Civil Engineering Department, K.N. Toosi University of Technology, Tehran, Iran
5. Leichtweiß-Institute for Hydraulic Engineering and Water Resources, Technische Universität Braunschweig, Braunschweig, Germany

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TADANO
Marine

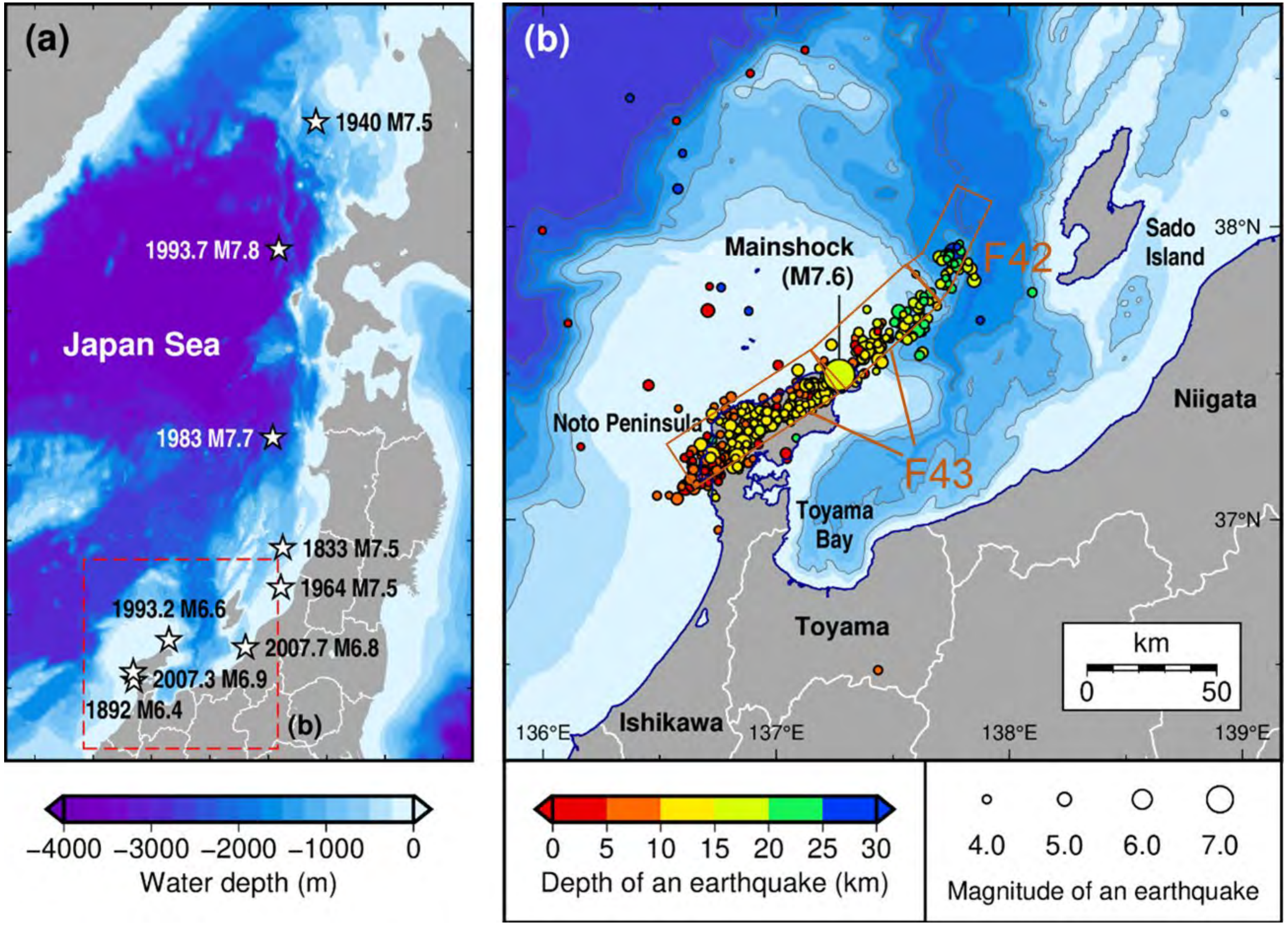


Figure 1. (a) Map of the northeastern part of the Japan Sea, showing past earthquakes which caused tsunamis that affected Noto Peninsula. The locations and magnitudes of the earthquakes are based on data by Usami et al. (2013). The bathymetry is displayed as a color contour (using Global tsunami Terrain Model (GtTM); Chikasada, 2020).

(b) Map of Noto Peninsula with the epicenters of the mainshock and aftershocks (whose magnitude was more than M3.5) on January 1 (the data was retrieved from Japan Meteorological Agency (2024c)). The rectangles show the active faults around Noto Peninsula F42 and F43 proposed by MLIT (2014).

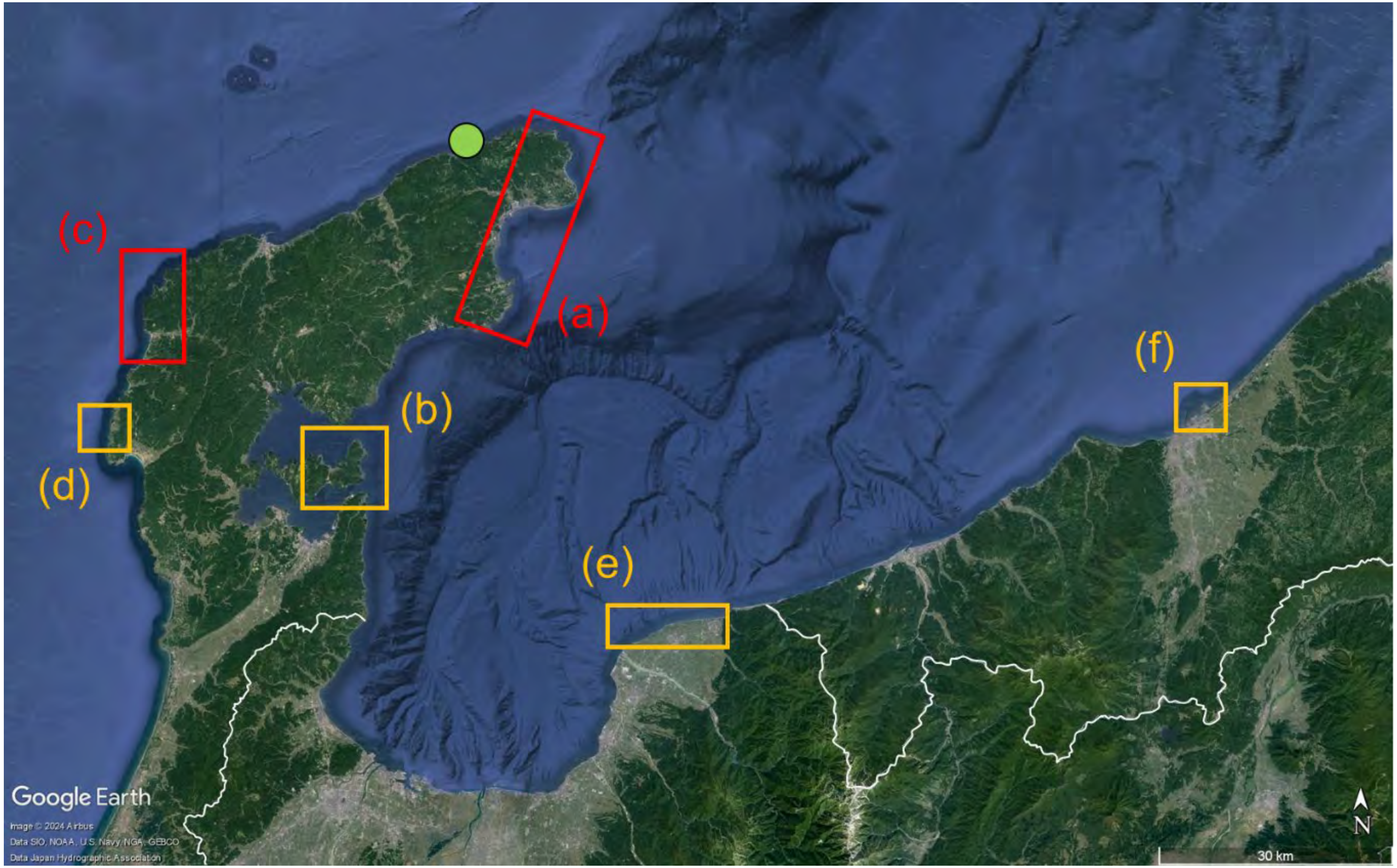


Figure 2. Locations which the authors visited. (a) Suzu City and Noto Town (Section 2.1), (b) Notojima Island (Section 2.2), (c) Wajima City (Section 2.3), (d) Shika Town (Section 2.4), (e) Nyuzen Town (Section 2.5), and (f) Naoetsu (Section 2.6). The yellow and red rectangles show that the authors visited the place in January 2024 and in March 2024, respectively. The green circle represents the epicenter of the mainshock.

Table 1. Tsunami inundation and run-up heights measurements. The format of the data follows Mori et al., 2012. The elevation of the tsunami trace from the sea surface at the time of the field survey was firstly measured. Then, the level was corrected according to the tide level at the time of the maximum tsunami wave arrival, according to tidal records at the closest tidal observatory for each location, which are displayed in the right two columns as tidal-corrected tsunami height from the sea surface and T.P. . (Geospatial Information Authority of Japan, 2024a; JMA, 2024d; NOWPHAS, 2024d,e). Time of the maximum tsunami wave arrival was estimated according to several local news and tidal observatories nearby, and thus there could be the difference of ± 0-3 minutes. The distance from the shoreline at 6A and 6B is left blank, as the inundation appeared to be caused by run-up of along a river.

ID	Coordinates		Time of measurement (JST)	Trace type	Distance from shoreline [m]	Time of the maximum tsunami wave arrival (JST)	Tidal-corrected tsunami height from the sea surface [m]	Tidal-corrected tsunami height from T.P.[1] [m]
	Latitude [deg]	Longitude [deg]						
1A	37.49734° N	137.34944° E	2024.03.13 14:15	Inundation	50	2024.01.01 16:15	3.76	3.86
1B	37.49508° N	137.34653° E	2024.03.13 14:45	Inundation	50	2024.01.01 16:15	4.10	4.20
1C	37.40634° N	137.24195° E	2024.03.14 12:30	Inundation	180	2024.01.01 16:15	2.56	2.66
1D	37.32974° N	137.26077° E	2024.03.14 15:00	Inundation	80	2024.01.01 16:15	3.89	3.99
2A	37.13569° N	137.00014° E	2024.01.06 11:12	Inundation	80	2024.01.01 16:25	2.08	2.05
2B	37.13469° N	137.00014° E	2024.01.06 10:57	Run-up	70	2024.01.01 16:25	1.05	1.02
2C	37.1595° N	137.04411° E	2024.01.06 9:48	Run-up	60	2024.01.01 16:25	1.85	1.84
2D	37.15456° N	137.04914° E	2024.01.06 10:08	Run-up	20	2024.01.01 16:25	0.90	0.88
4A	37.16944° N	136.67406° E	2024.01.06 13:08	Inundation	60	2024.01.01 17:45	3.73	3.88
6A	37.17961° N	138.24944° E	2024.01.05 12:10	Inundation	-	2024.01.01 16:35	3.29	3.26
6B	37.18025° N	138.24967° E	2024.01.05 12:32	Inundation	-	2024.01.01 16:35	2.44	2.35
6C	37.17881° N	138.24092° E	2024.10.05 13:15	Run-up	120	2024.01.01 16:35	6.65	6.64

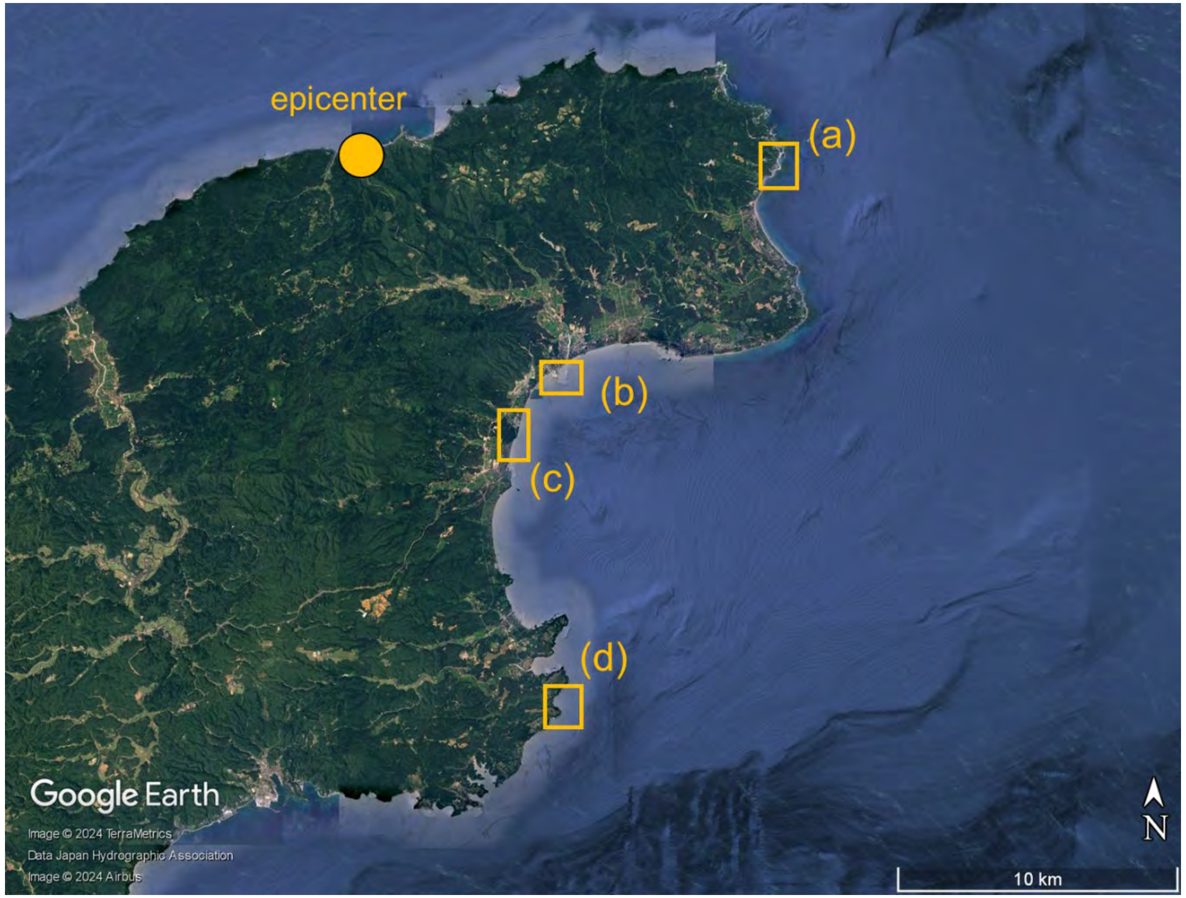


Figure 3. Survey locations in the east tip of the peninsula, Suzu City and Noto Town. **(a)** Jike (Suzu City). **(b)** Iida (Suzu City). **(c)** Ukai (Suzu City). **(d)** Shiromaru (Noto Town). The detailed survey results of **(a)** and **(b)-(d)** are presented in **Figure 4** and **Figure 5**, respectively.

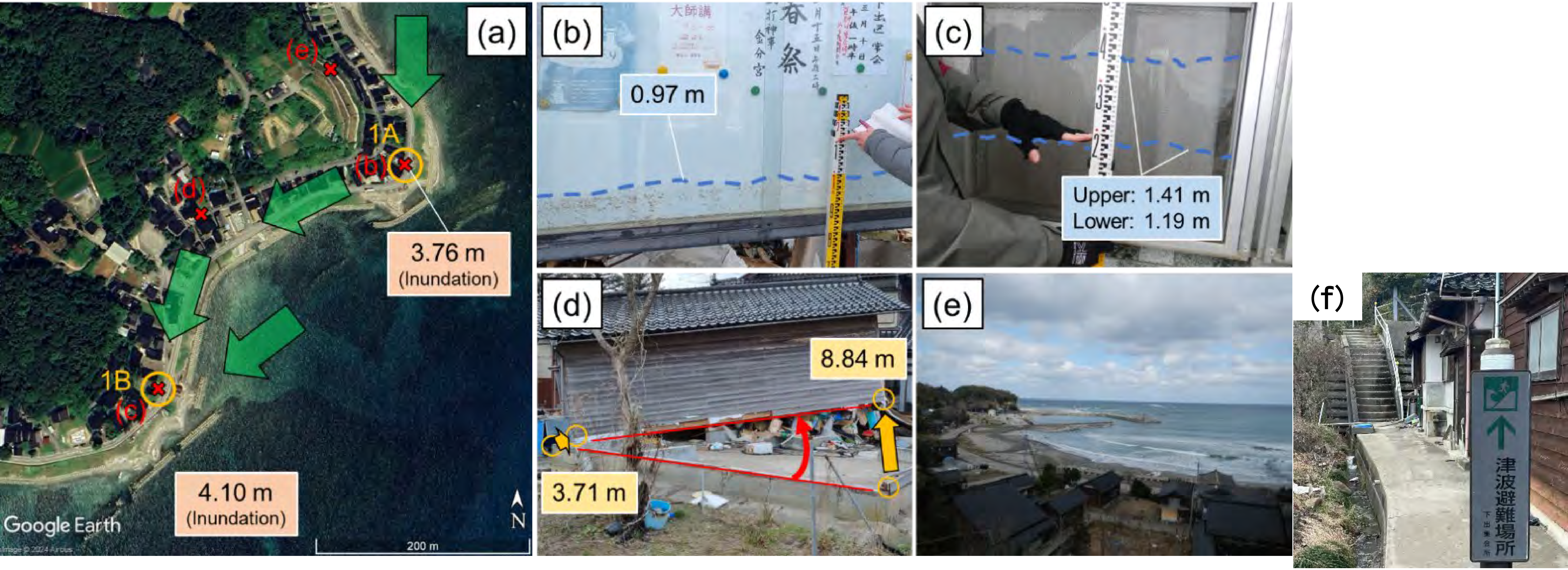


Figure 4. (a) Aerial map of Jike. The yellow circles indicate measured inundation heights. The red-crosses indicate the locations of the photos in **(b)-(e)**. The green arrows represent the incoming direction of the tsunami waves, as inferred from the traces. **(b)** Watermark at 1A. **(c)** Watermark at 1B. **(d)** Housing that could be drifted by tsunami. **(e)** View from tsunami evacuation hill. **(f)** The stairs of evacuation route to the top of the hill behind the residential district.

Solar Power System for Lighting at night

Land Subsidence due to liquefaction in reclaimed area

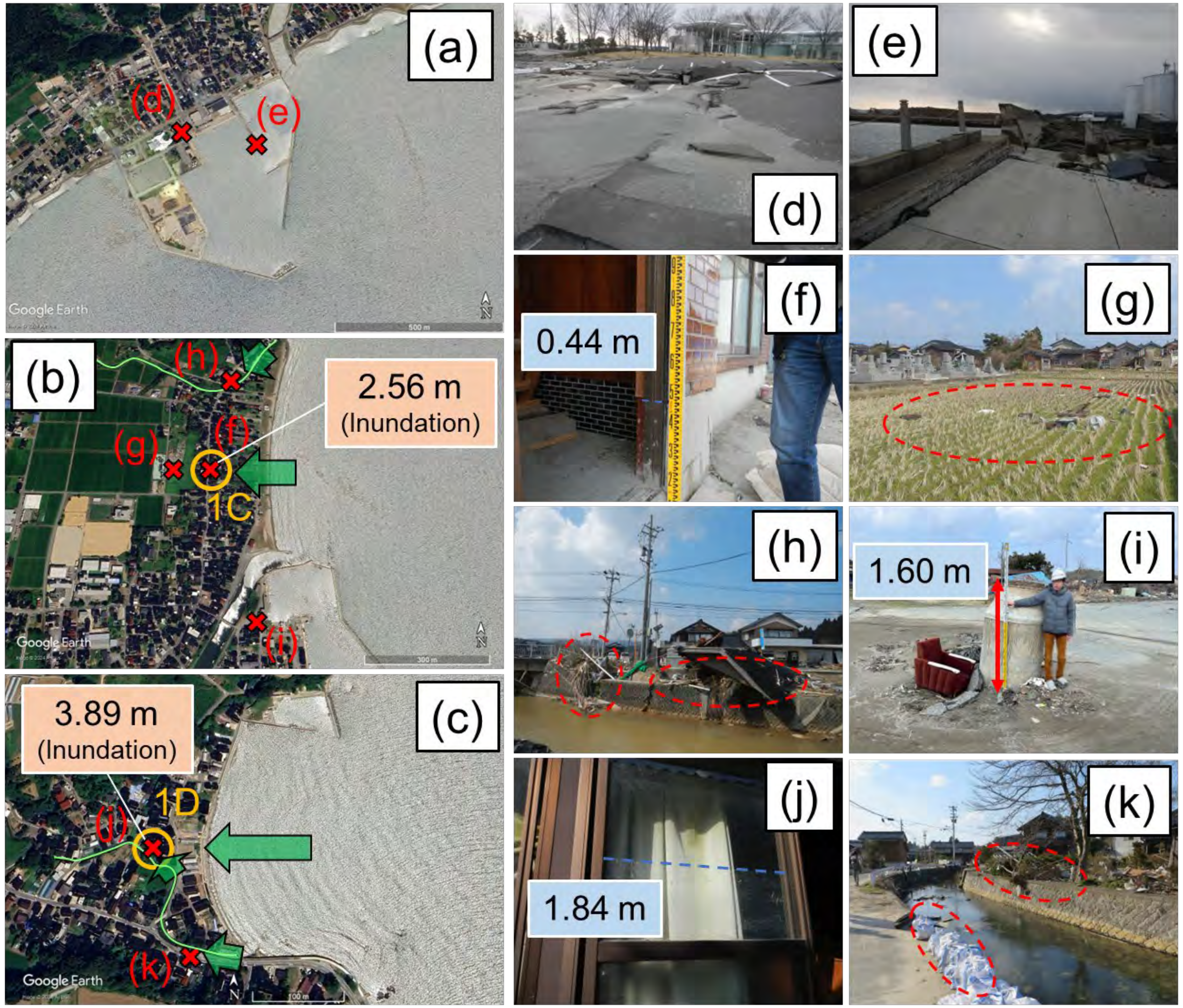


Figure 5. Aerial maps of **(a)** Iida, **(b)** Ukai, and **(c)** Shiromaru. The yellow circles indicate measured inundation heights. The red-crosses indicate the locations of the photos in **(d)-(k)**. The green arrows represent the incoming direction of the tsunami waves, as inferred from the traces. The light green line represents the rivers that would have affected the inundation. **(d)** Liquefaction around Iida Port. **(e)** Significant damage to the pier of Iida Port. **(f)** Watermark at 1C. **(g)** Tsunami debris in a farm field (the red circle shows tires and timbers). **(h)** Debris piled on a riverside. **(i)** A manhole protruded from the ground. **(j)** Watermark at 1D. **(k)** Remained debris and sandbags for rehabilitation along a river.

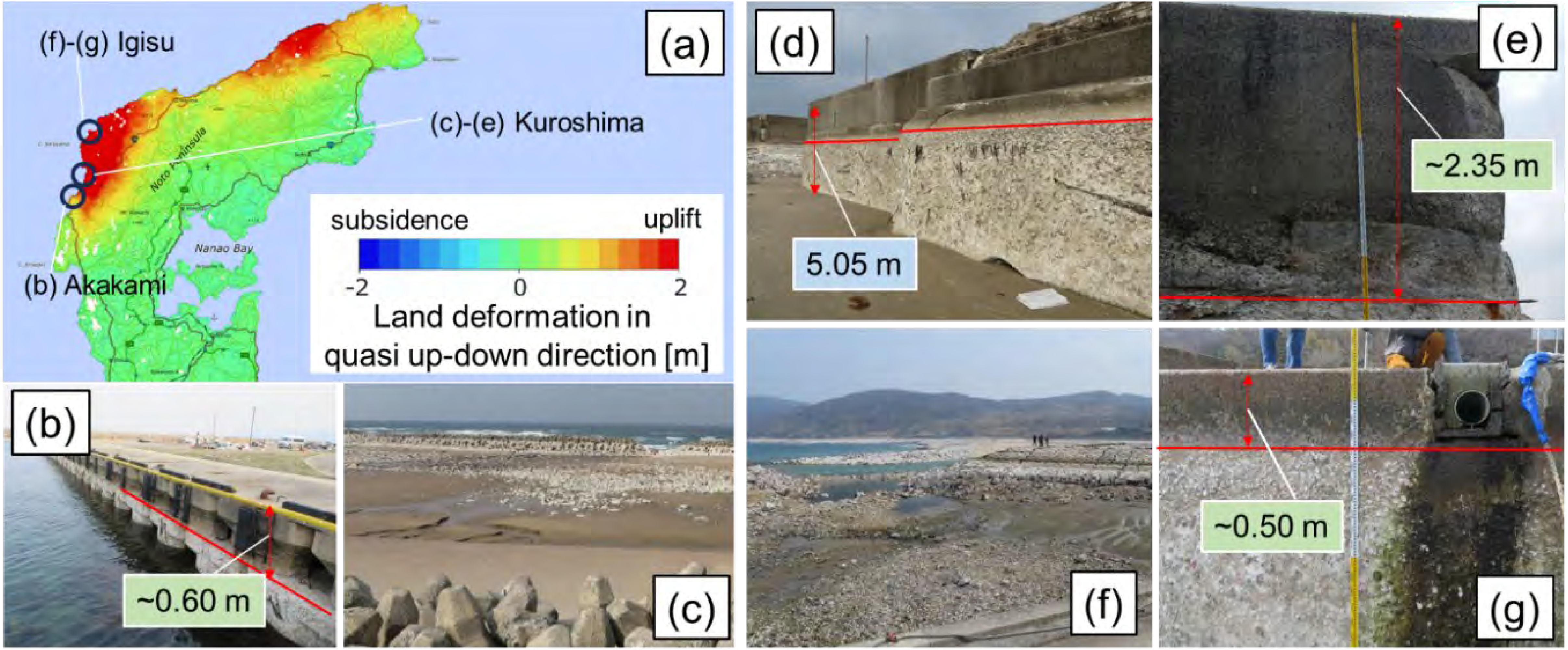


Figure 9. **(a)** Estimated land deformation in quasi up-down direction (representing subsidence or uplift). Open data was published by GSI (2024). Red lines in **(b)**, **(d)**, **(e)**, and **(g)** represent the visually judged water surface before the land uplift and thus, the distance in light green means the previous freeboard. **(b)** Pier in Akakami Fishing Port, where the uplift was estimated. **(c)** Overview of Kuroshima Fishing Port. **(d)-(e)** Pier in Kuroshima Fishing Port, where the uplift was estimated. **(f)** Overview of Igisu Fishing Port. **(g)** Pier of Igisu Fishing Port, where the uplift was estimated.

Port Without Water

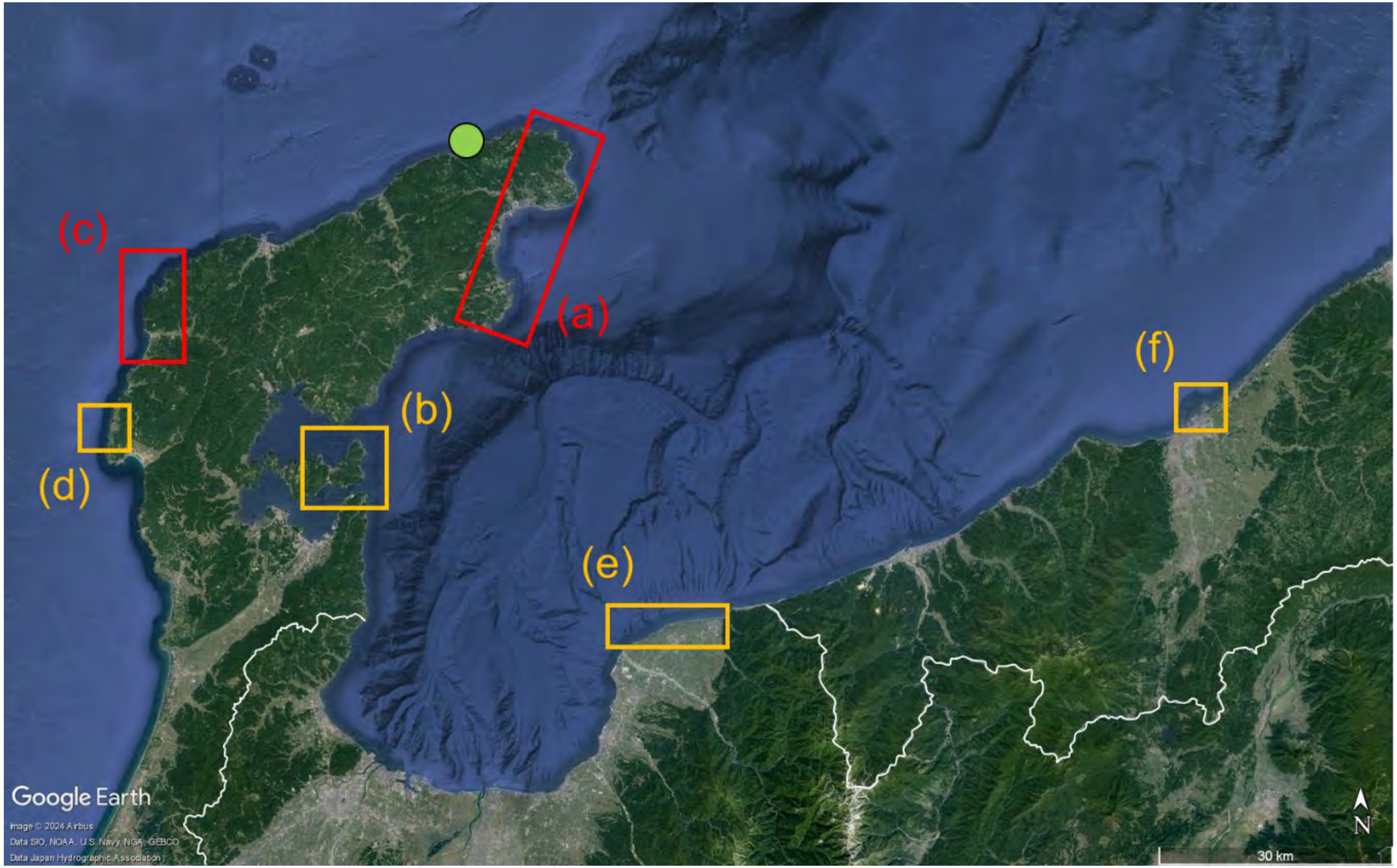


Figure 2. Locations which the authors visited. (a) Suzu City and Noto Town (Section 2.1), (b) Notojima Island (Section 2.2), (c) Wajima City (Section 2.3), (d) Shika Town (Section 2.4), (e) Nyuzen Town (Section 2.5), and (f) Naoetsu (Section 2.6). The yellow and red rectangles show that the authors visited the place in January 2024 and in March 2024, respectively. The green circle represents the epicenter of the mainshock.

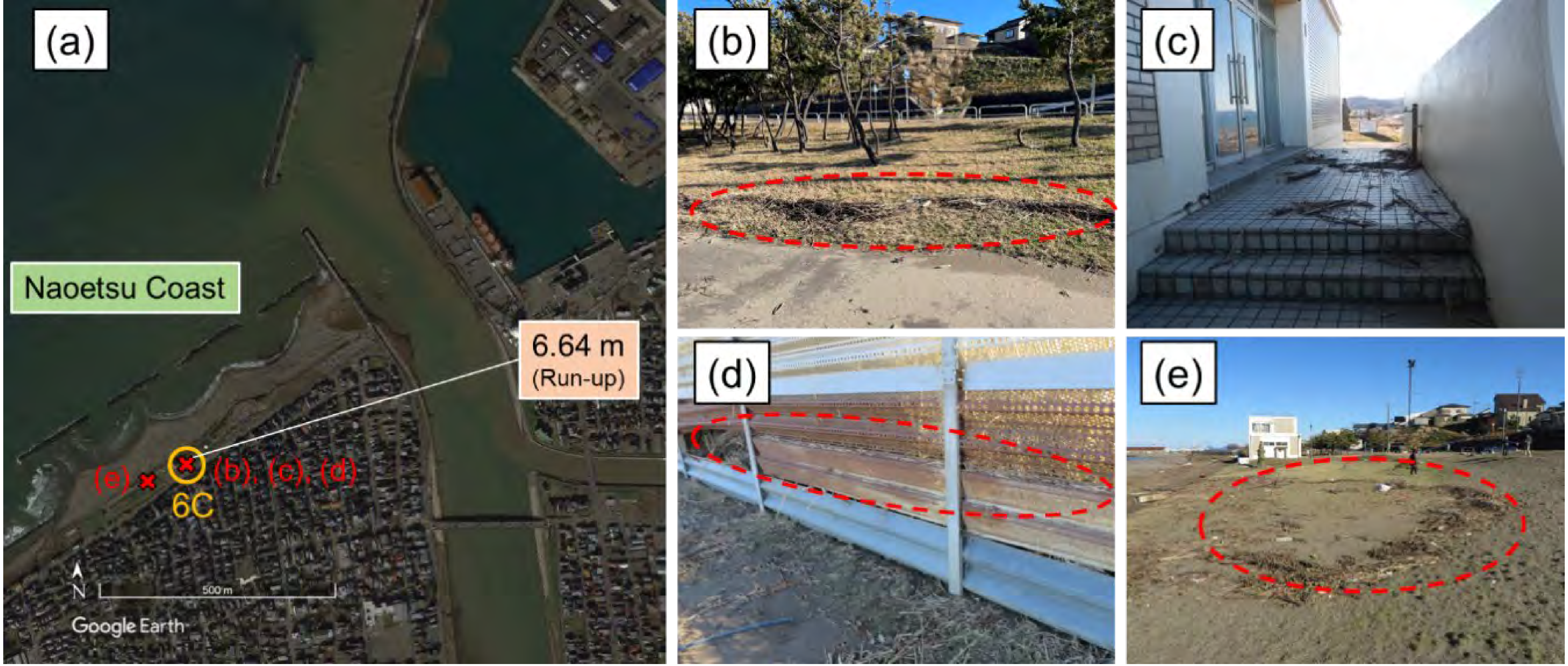


Figure 12. **(a)** Aerial map of Naoetsu area. The locations of tsunami traces along Naoetsu Coast are presented. Yellow circles indicate the location where the run-up heights were measured. The red-crosses indicate the locations of the photos in **(b)-(e)**. **(b)** Tsunami trace at 6C. The vegetation debris exhibited a clear tsunami run-up wave pattern. **(c)** Tsunami debris remained at the rest house in the vicinity of the coast. **(d)** A watermark and debris on a sand barrier. **(e)** Tsunami debris at the beach.

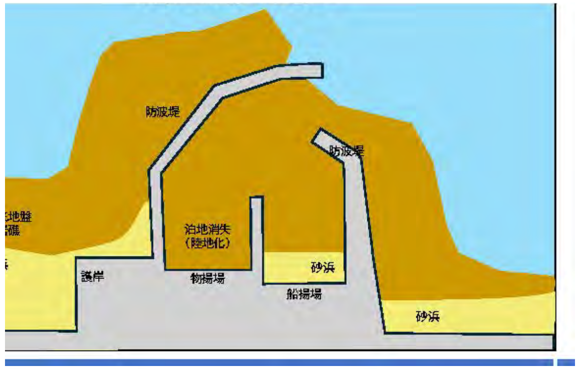
Summary

1) The coastal areas at the north tip of the peninsula experienced wide flooding damage by tsunamis.

2)However, on the other hand, damage patterns varied across location, and were generally higher in areas where coastal defenses and/or land uplift was at its lowest. Particularly, it could be seen that the tsunami could penetrate inland through weak points in the coastal defenses, especially in areas which were devoid of offshore protection structures (such as detached or port breakwaters).

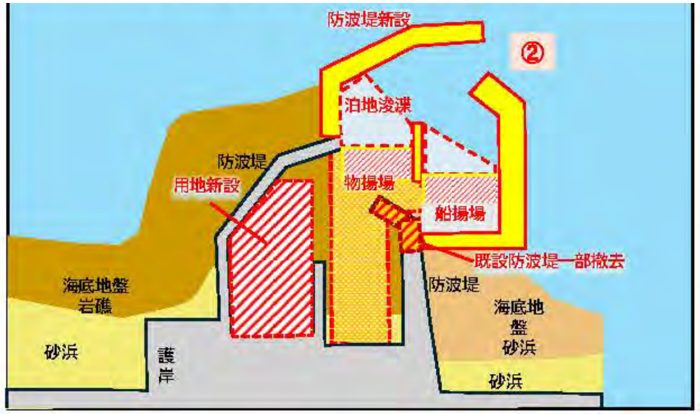
3) Coastal regions in Wajima City experienced significant land deformation, particularly affected by a large land uplift.

Uplift of Port and Reconstruction Plan (Fishery Agency, Japanese Government）Now under Consensus Formation Process



Lifted Port

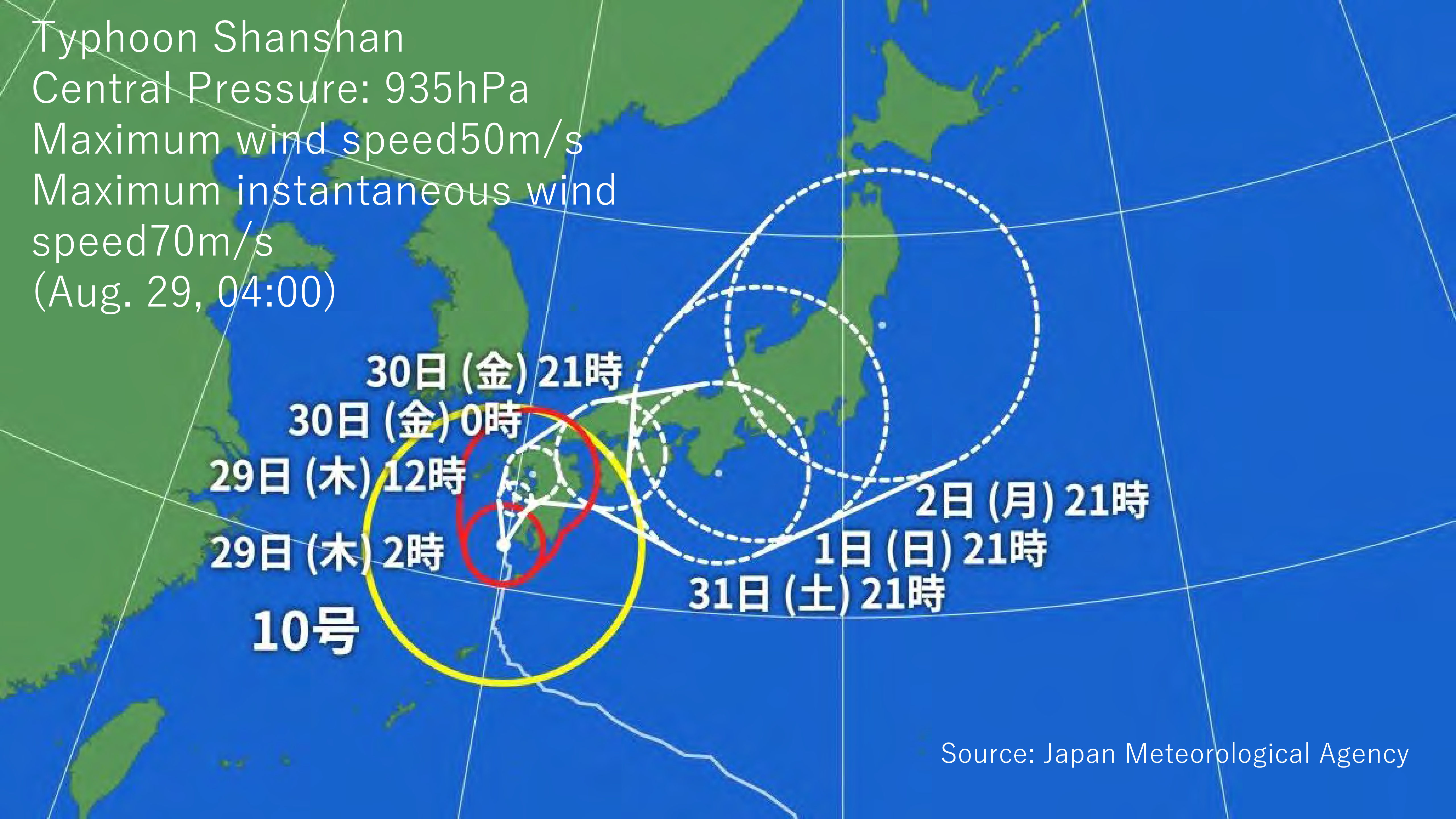
Plan A: Dredging Waterway



Plan B: Move Offshore

Plan C: Move Alongshore

Typhoon Shanshan
Central Pressure: 935hPa
Maximum wind speed50m/s
Maximum instantaneous wind speed70m/s
(Aug. 29, 04:00)



Source: Japan Meteorological Agency

The second topic: Yokohama Port

2019, Storm Surge and High Waves by Typhoon Faxai Tokyo Bay, Japan

Inagaki, N., Shibayama, T., Nakamura, R., Ishibashi, K., Esteban, M. (2024): Experimental investigation into the effects of strong winds on the transport of overtopping water mass over a vertical seawall, Coastal Engineering Journal

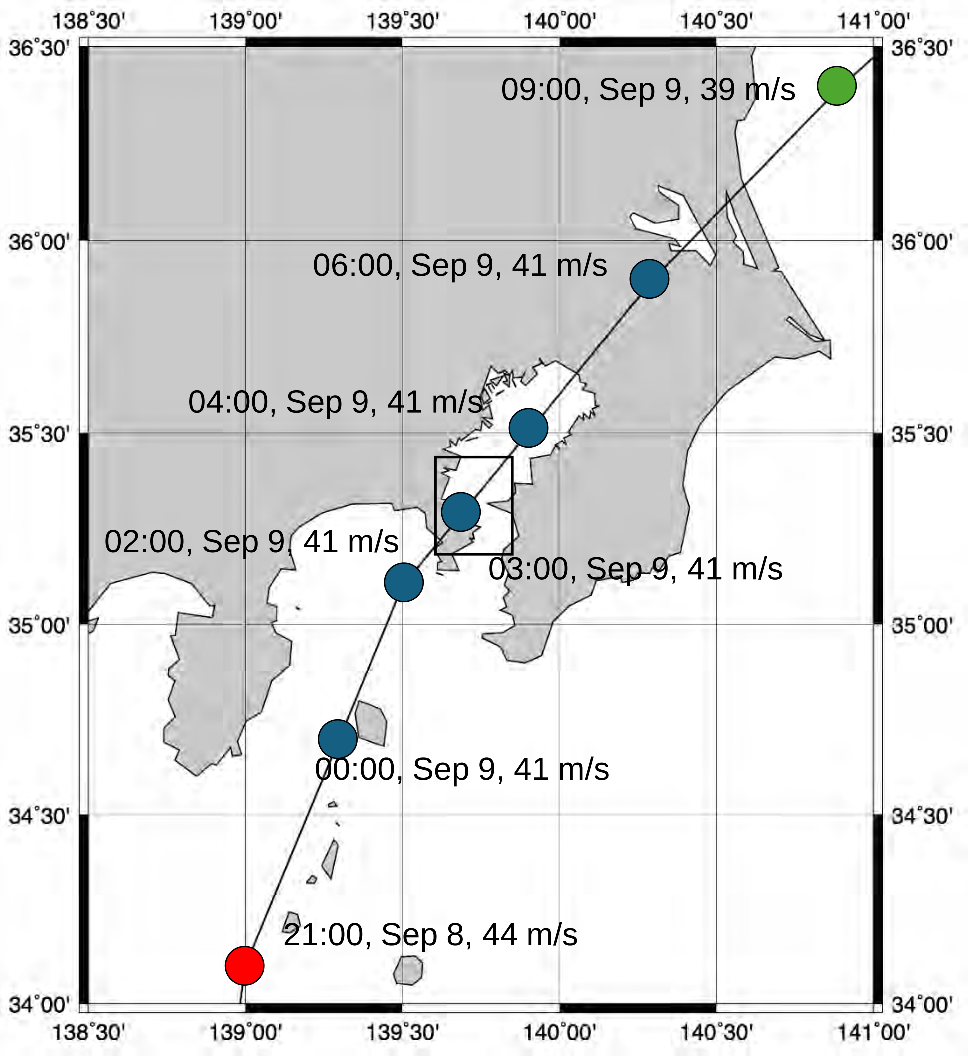
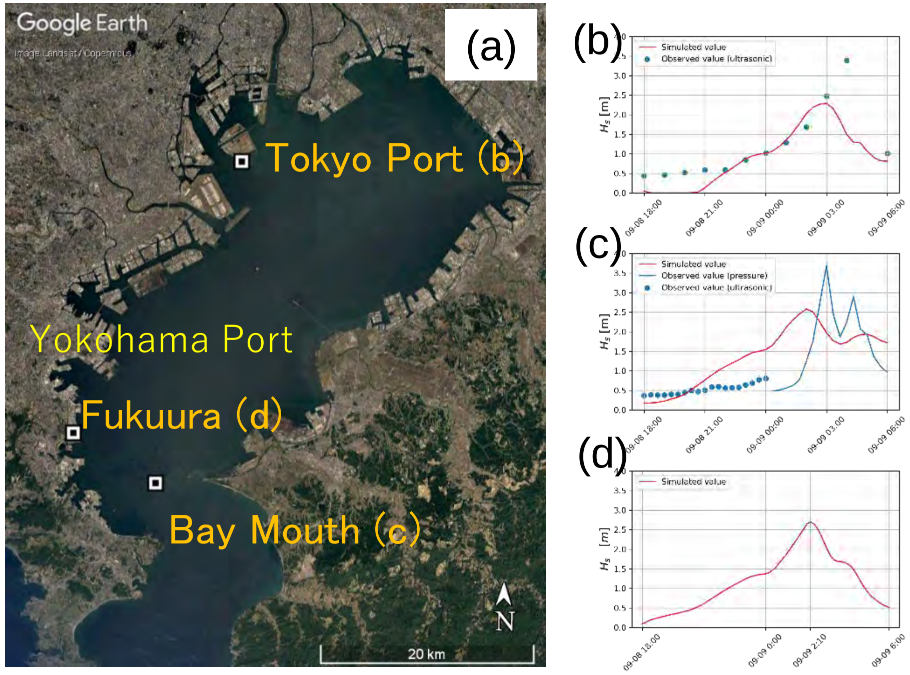


Fig. Typhoon Route over Tokyo Bay



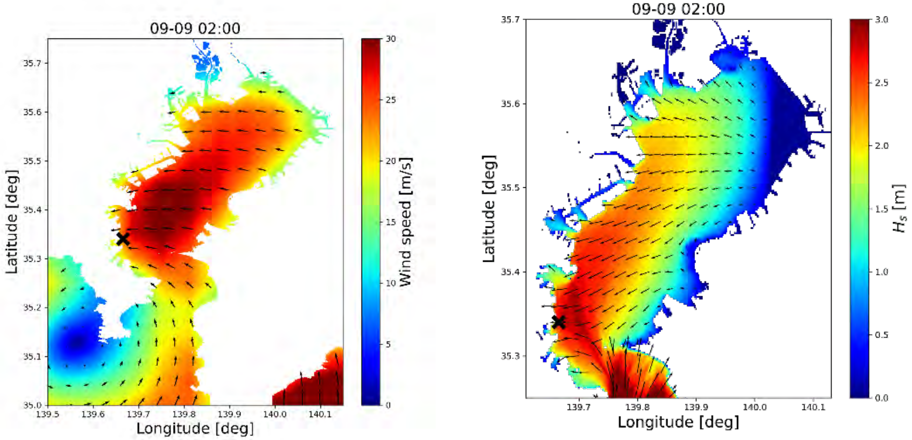


Fig. Wind Field and Wave Field

Inagaki and Shibayama (2022)

2019 Storm Surge and High Waves by Typhoon Faxai Japan(Tokyo Bay)

How do we prepare for coastal hazards caused by intense storms?

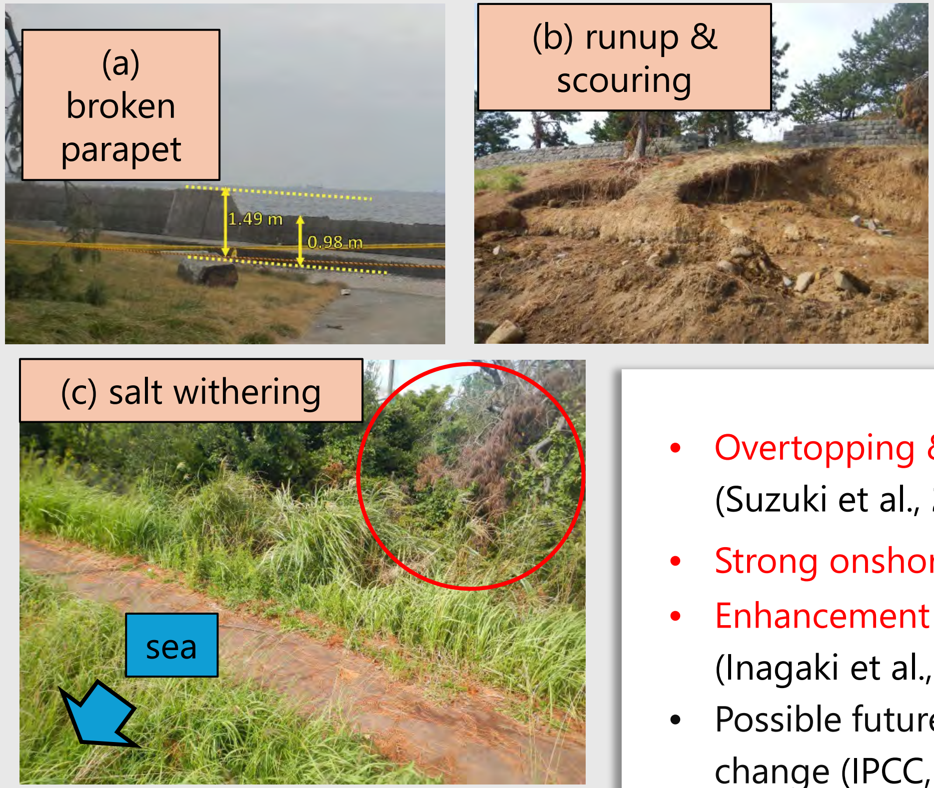


Fig.1 Field survey in Fukuura Coast

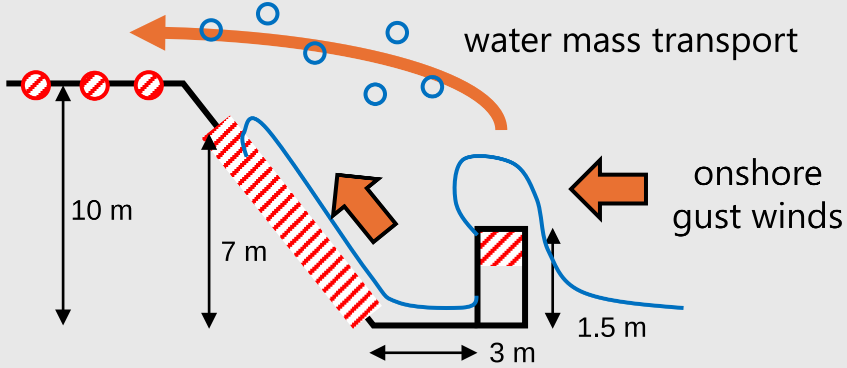


Fig.2 Possible mechanisms of wave overtopping event in Fukuura Coast

- Overtopping & flooding damage to Fukuura Coast, Japan in 2019 (Suzuki et al., 2020; Inagaki et al., 2022)
- Strong onshore gust winds due to an intense typhoon ($U_{max} = 41$ m/s)
- Enhancement of wave overtopping and transport of water mass (Inagaki et al., 2022)
- Possible future intensification of tropical cyclones due to climate change (IPCC, 2022)

Industrial Area with Machinery Factories Attached to Yokohama Port

Methodology (Overtopping Laboratory Experiments)

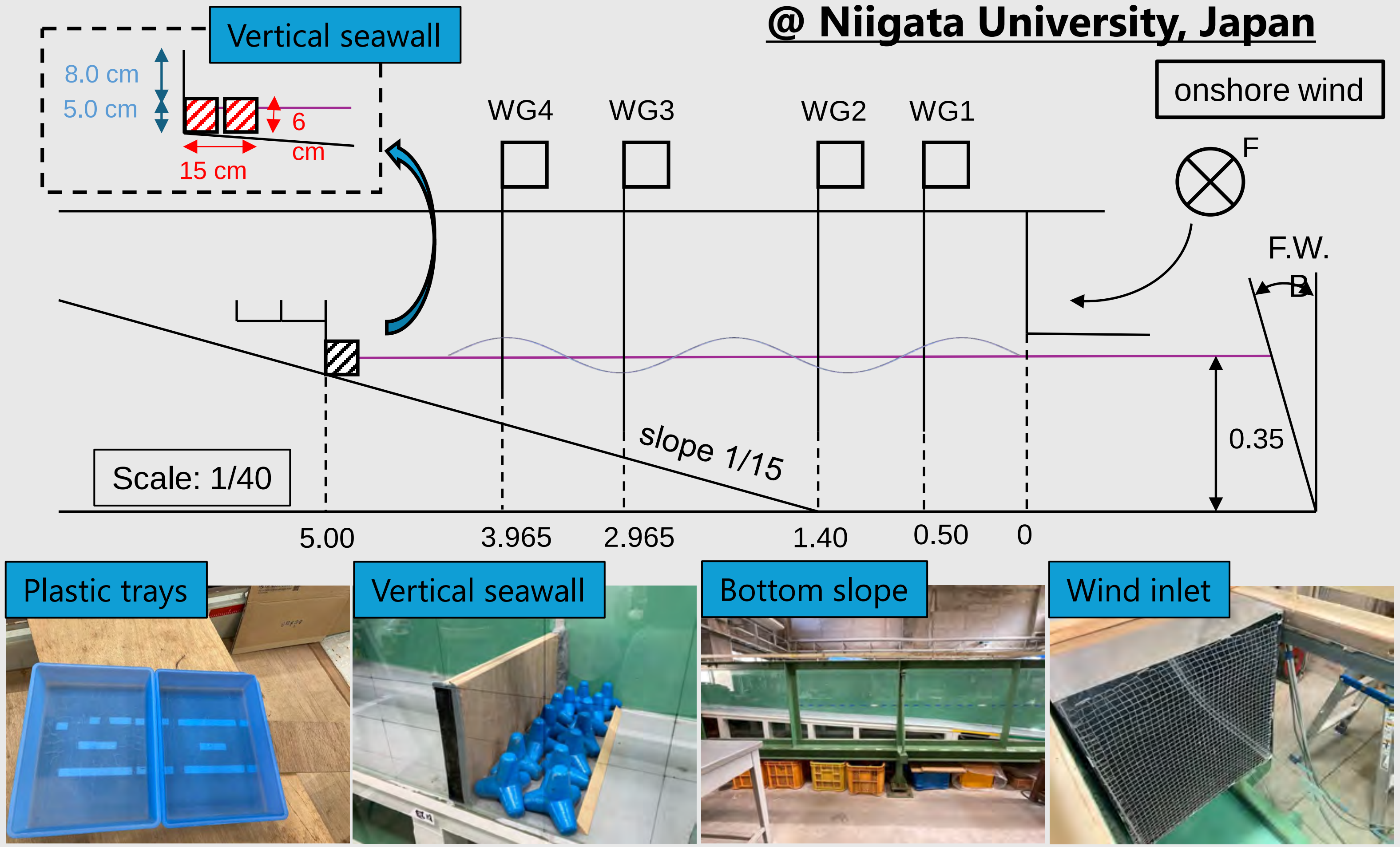


Fig.3 Laboratory set-up of overtopping experiments

Methodology (PIV Analysis)

- The representative *xz*-plain was placed in the middle of the wave tank.
- The mass transport was quantified as the mass flow rate.

Fig.4 Laboratory set-up of PIV analysis and video recordings

Mass flow rate

$$\boldsymbol{m} = \iint \boldsymbol{J_m} \cdot \boldsymbol{n}\, dA = \sum_{A} (\rho \boldsymbol{u})(\Delta x_1 \times \Delta x_2)$$

J_m: mass flux
$\boldsymbol{n}$: normal vector
Δx: PIV grid size

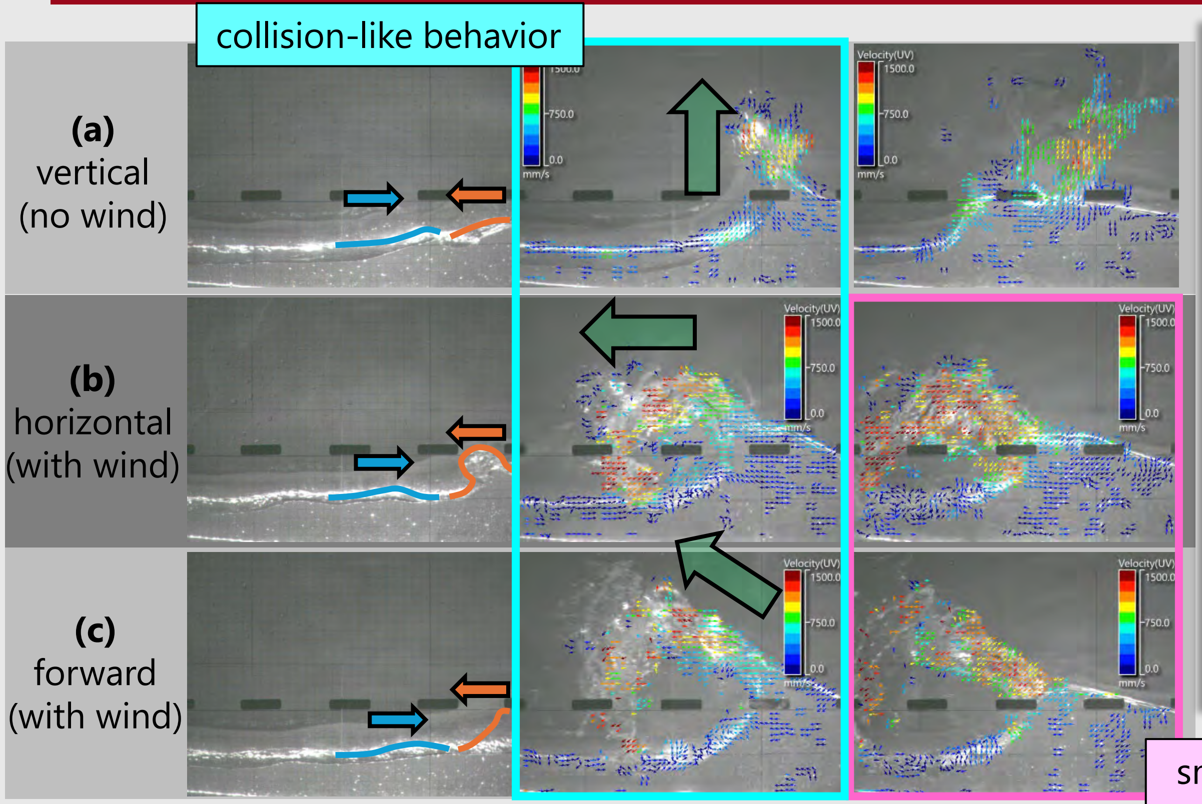
PIV settings

- Nd: YVO4 laser (KATO KOKEN, G2000), continuous sheet laser with a wavelength of 532 nm
- Ion exchange resin particle (Mitsubishi Chemical Corp., HP20), size of 250 µm
- CMOS high speed camera (KATO KOKEN, k4), 400 fps, open
- Direct cross-correlation method

Discussion 1: Partially standing wave (H_0/L_0= 0.0220)

Flow Velocity Measurement using PIV

- Mechanism of the maximum overtopping rate due to a specific wave steepness
- With wind, the size of wave breaking looked relatively smaller, but resulted in larger overtopping.

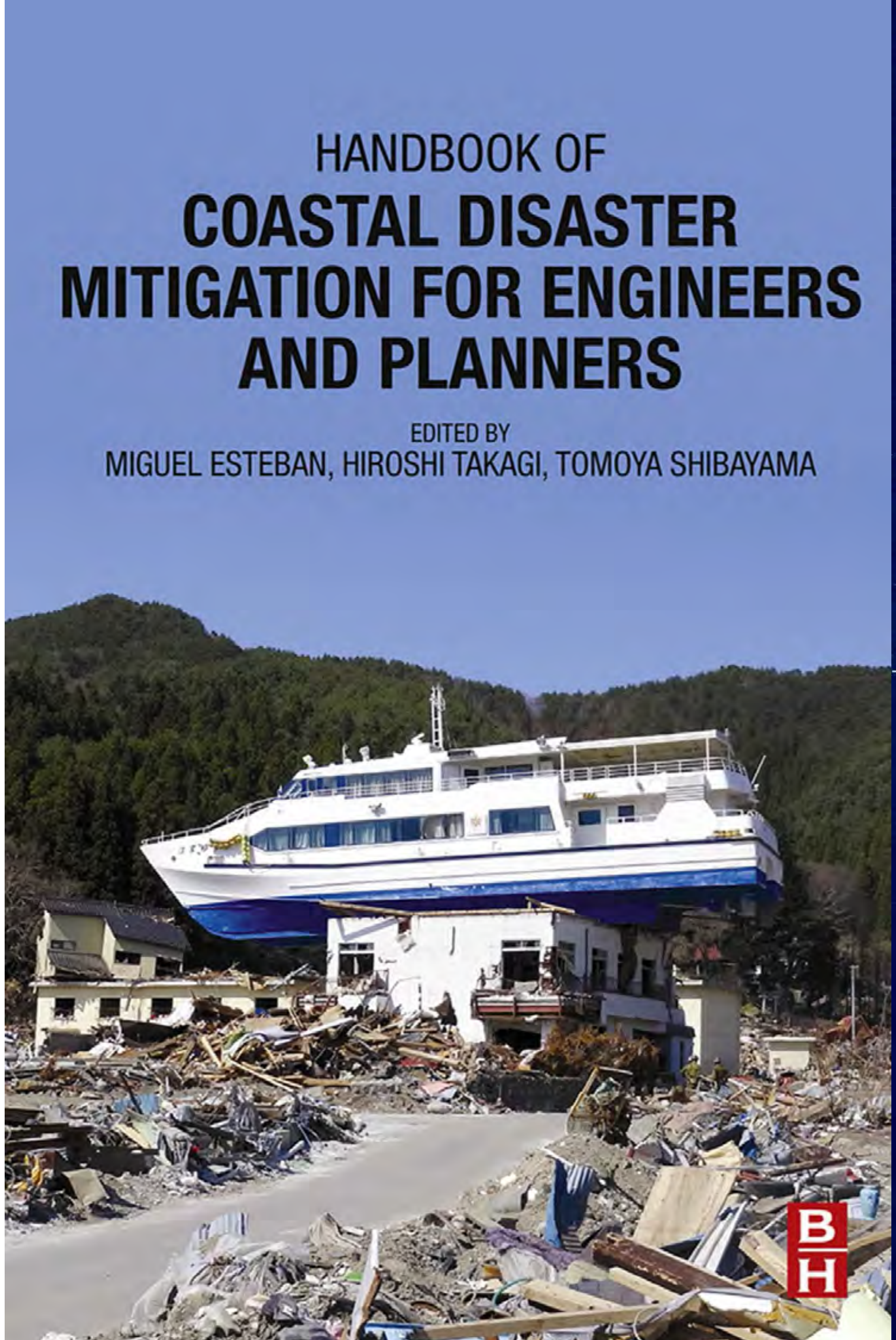


collision-like behavior

smaller size of wave breaker with wind

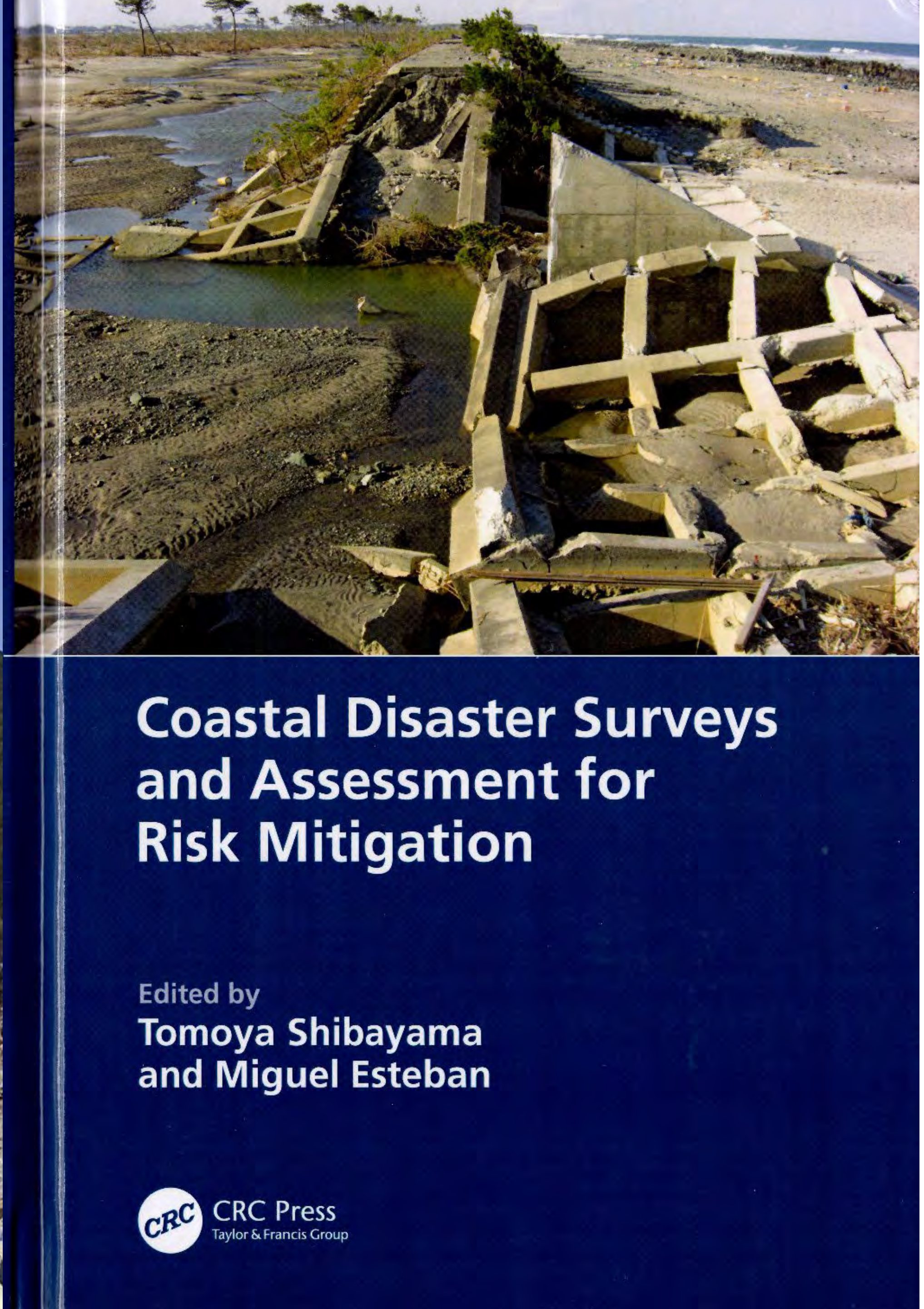
Fig.7 Snapshots of each overshooting type

- The velocity fields suggested collision-like behavior when a partially standing wave was created.
- The maximum overtopping rate could occur as the combination of:
  - Mode 1: Transported water mass due to wind
  - Mode 2: Usual overtopping
- Mode 1 could account for the salt withering observed along the Fukuura Coast.



HANDBOOK OF
COASTAL DISASTER MITIGATION FOR ENGINEERS AND PLANNERS

EDITED BY
MIGUEL ESTEBAN, HIROSHI TAKAGI, TOMOYA SHIBAYAMA



Coastal Disaster Surveys and Assessment for Risk Mitigation

Edited by
Tomoya Shibayama
and Miguel Esteban

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The classification of evacuation points in Japan into three separate categories.

Category A: This category would include hills (higher terrain) that are adjacent to the coast but continue to increase in elevation for a long distance. These would not be isolated low hills, but those that form part of larger geographical features and have a higher hinterland region. Kamaishi, Tarou

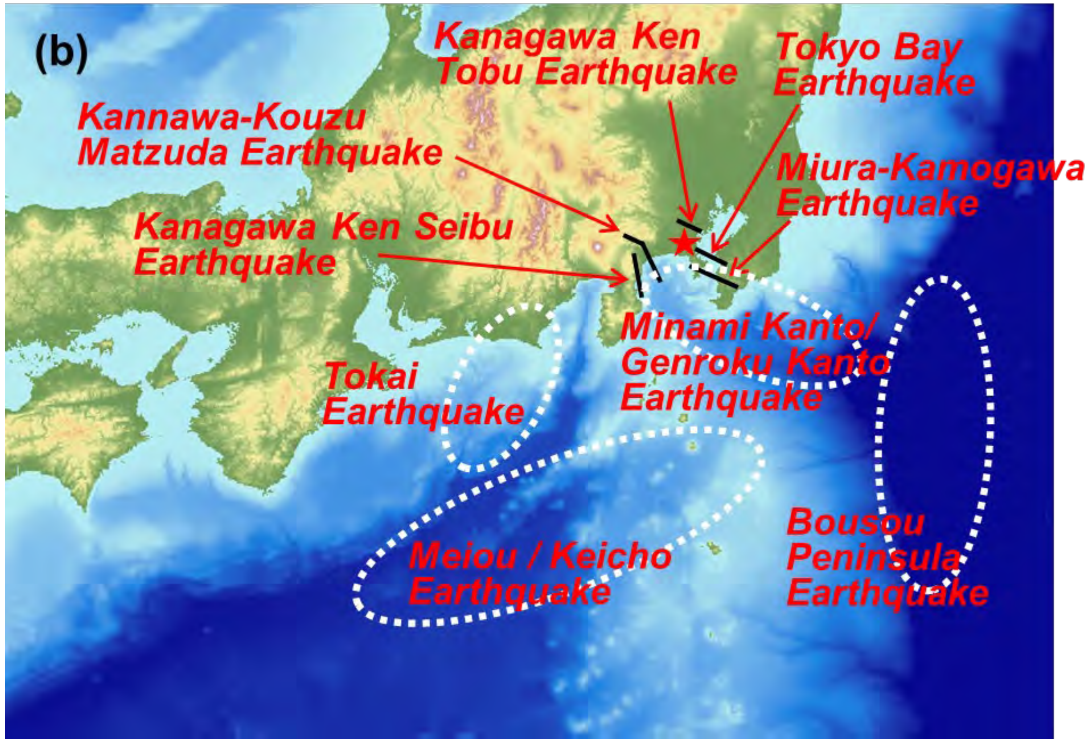
Category B: This would include robust buildings that have 6 or more floors , or hills that are more than 20m in height. This category would have the inherent risk of being isolated during the worst tsunami, but would likely be safe for most events

Category C: This would include robust buildings that are over 4 floors high. This category, however, would have the risk of being overtopped during the worst tsunami events. Minami-Sanriku

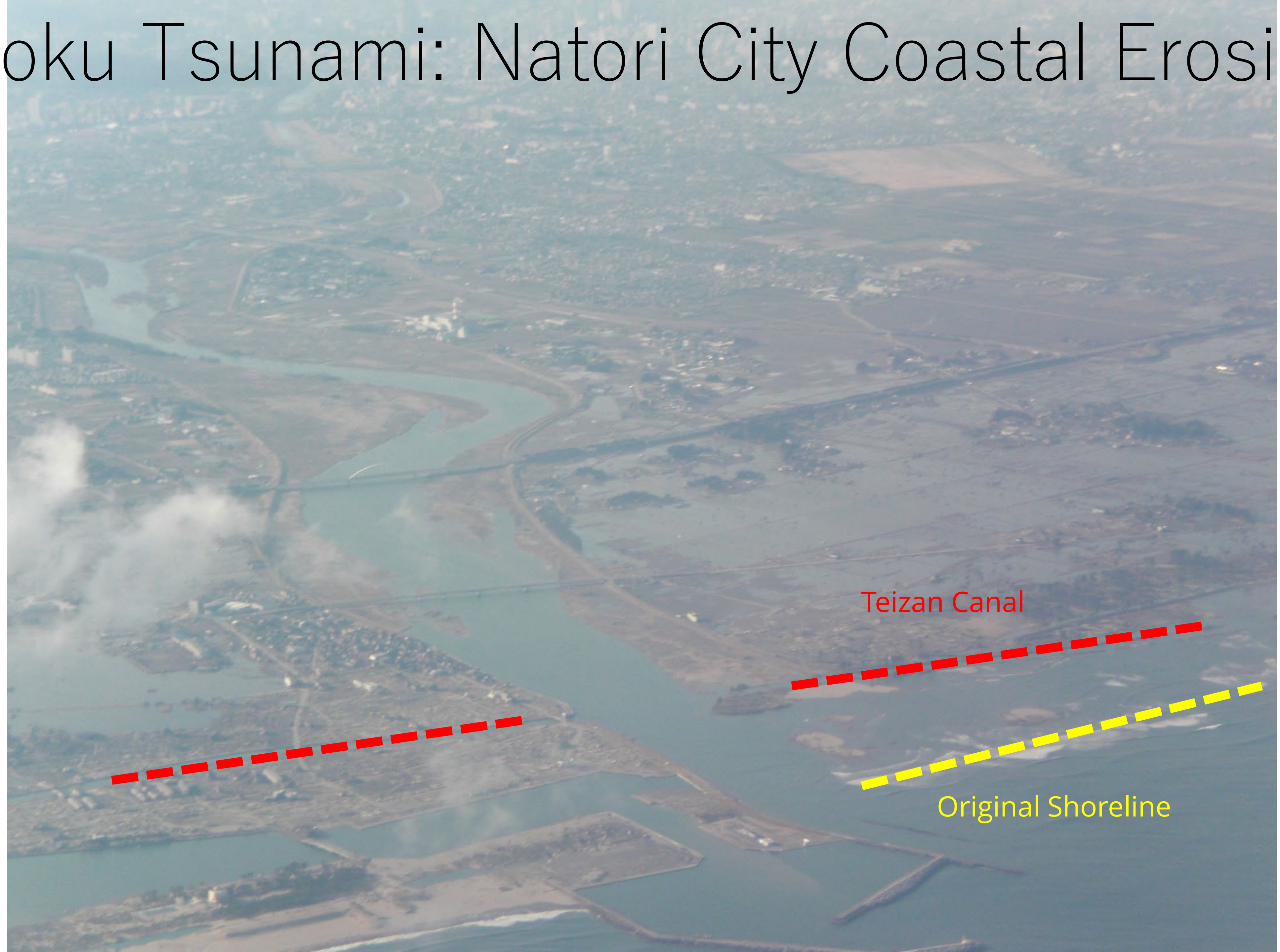
2. Study area & Earthquake scenarios

Kamakura City in Japan was selected as a study area

- The study area has suffered a number of earthquakes and tsunamis in the past.
- The Keicho earthquake was selected as the target earthquake, which is regarded as one of the most hazardous event to the study area (Kanagawa Prefecture, 2012)



Tohoku Tsunami: Natori City Coastal Erosion



Three different approaches

1. Construction of high coastal dike again and protection of low land area against the next tsunami attack. (Tarou)
2. Making artificial elevated area over old downtown in low land area by land fill. Use the elevated ground surface for residential area. (Rikuzentakata)
3. Movement to higher hill side and developing new residential area. (Onagawa)

Those methods are commonly used in part in these cities in Tohoku.

Tarou

Height of Tsunami Barrier wall is changed

from 10m to 14.7m.

Rikuzentakata

Raise the Ground Level Elevation for 10-12m

There are selections for residents.

1) Natural Hill (45 ha)
2) New Artificial Hill (91 ha)

Onagawa

Change of Land-use:

Downtown in Low Land
→
No Residence, Open space

Construction of New Residence Area in Natural Hill

Arahama

Movement

All residents moved to a new area in inland.