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Excerpted version

Submarine Geohazards and Mitigation Concept for Offshore Wind

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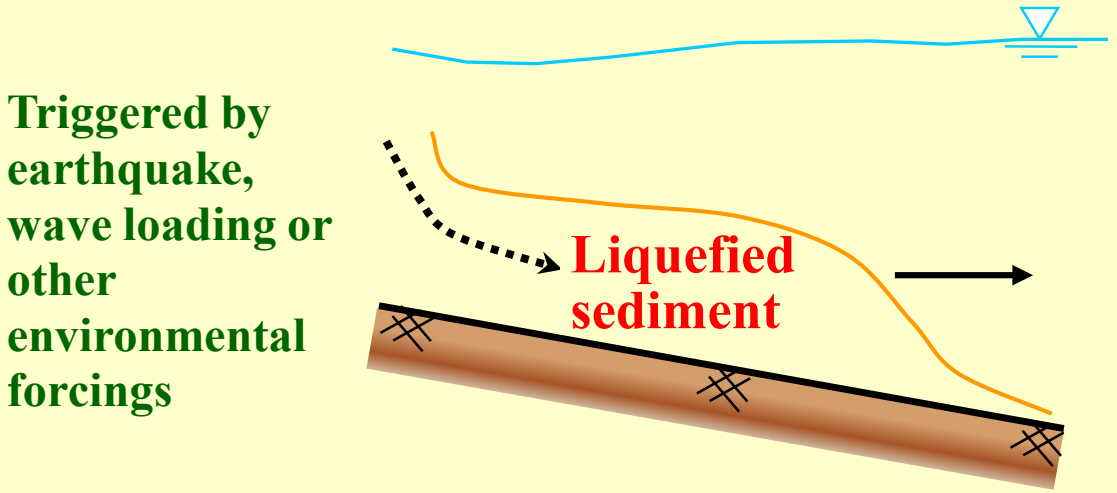
Content

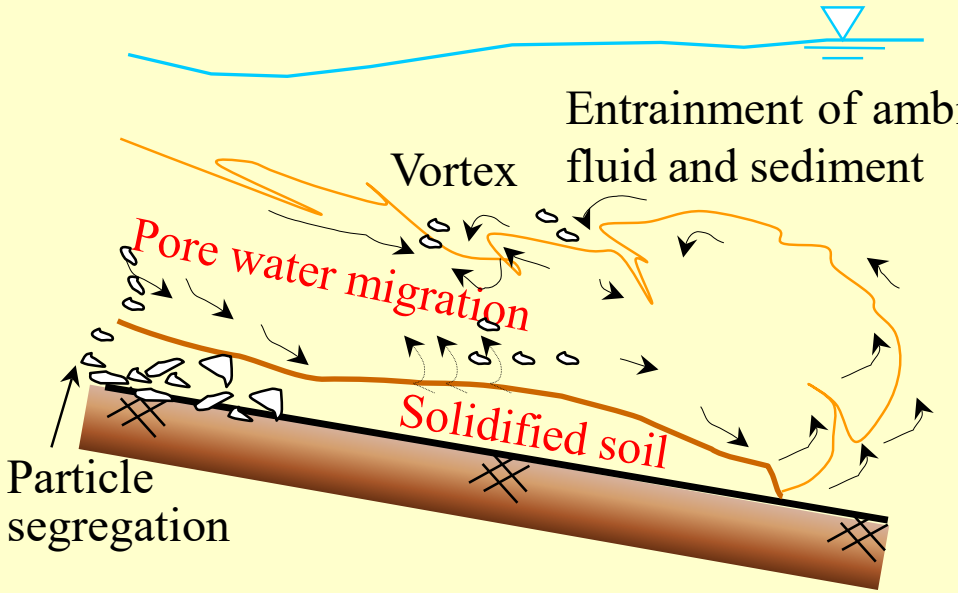
- Introduction
- Submarine Geohazards with a Special Emphasis on Liquefaction, Coastal and Submarine Landslides, and Tsunamis
- Mitigation Concept for Offshore Wind
  a. Wave-induced Liquefaction-Scour Countermeasure Concept for Bottom-Fixed Offshore Wind
  b. Submarine Landslide Flow Impact Assessment and Preventive Maintenance
  c. Submarine Geohazards Resistant Design Concept for Anchors and Cables of Floating Offshore Wind
- Summary

Concurrent processes governed by multi-phased physics

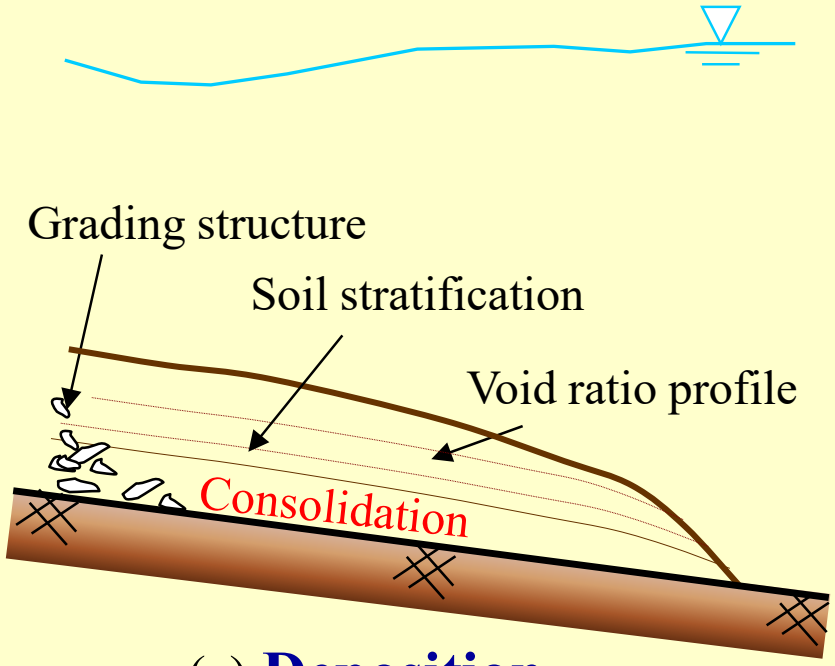
Substantial impact of liquefied gravity flows on infrastructures and tsunami generation



(a) **Coastal and submarine landslide**



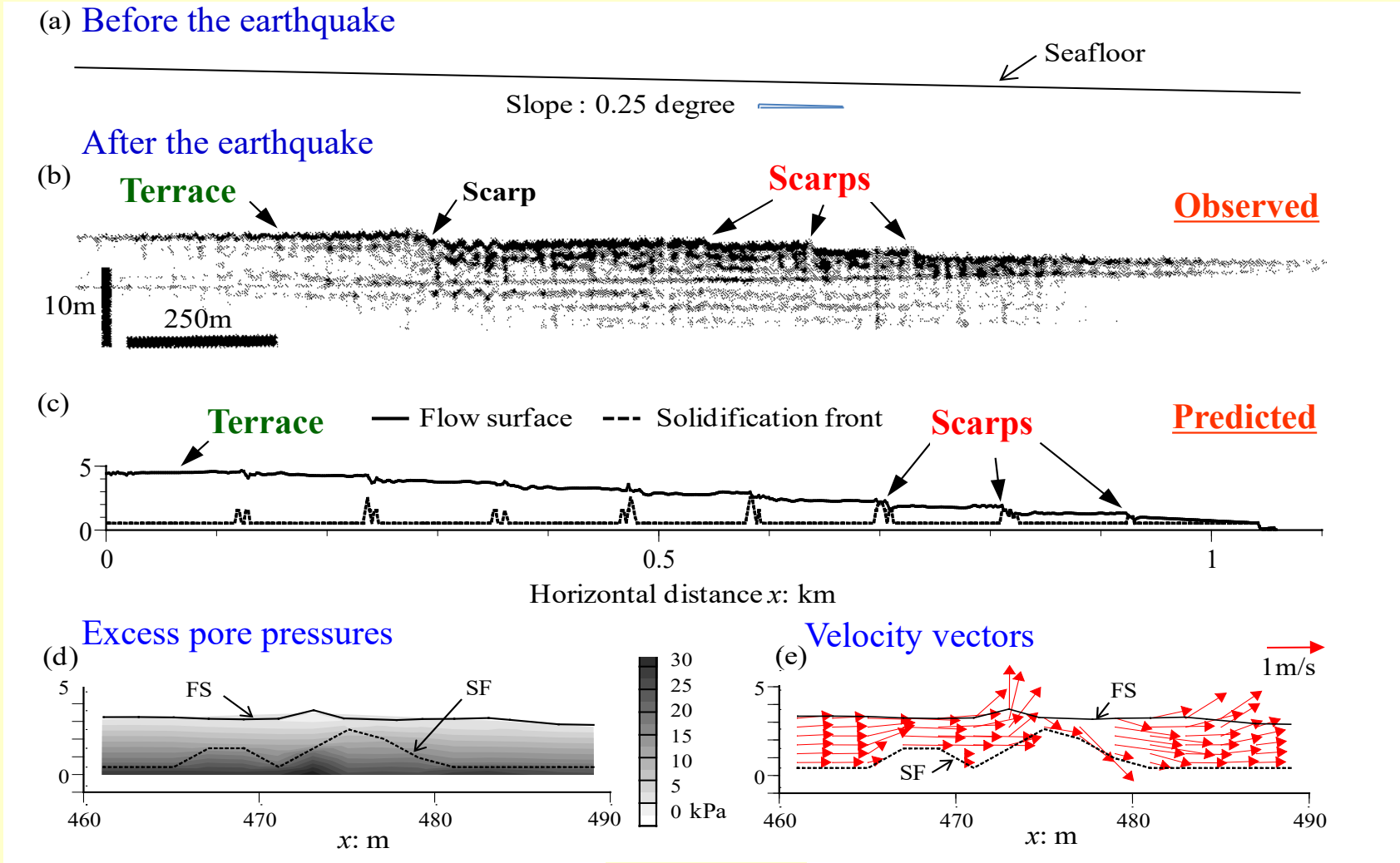
(b) **High-density gravity flow**



(c) **Deposition**

Relevant Features of Liquefied Gravity Flows

Analysis of the 1980 submarine slide on the Klamath River delta, California

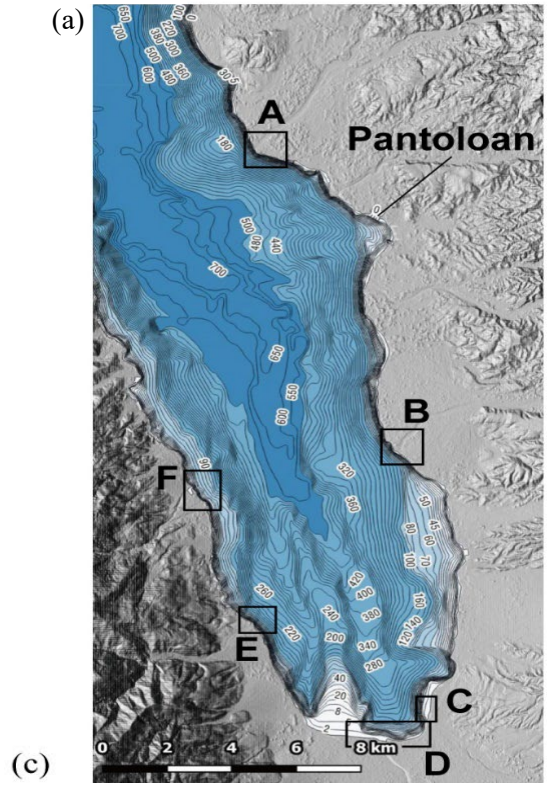


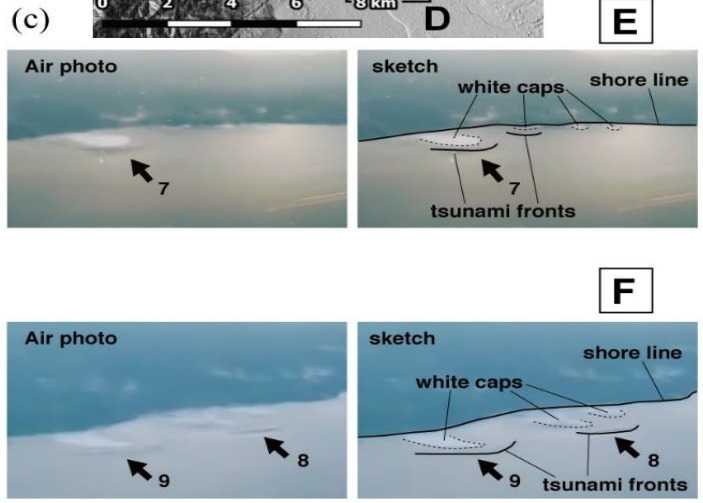
The multiple scarps as well as the terrace were predicted to occur !

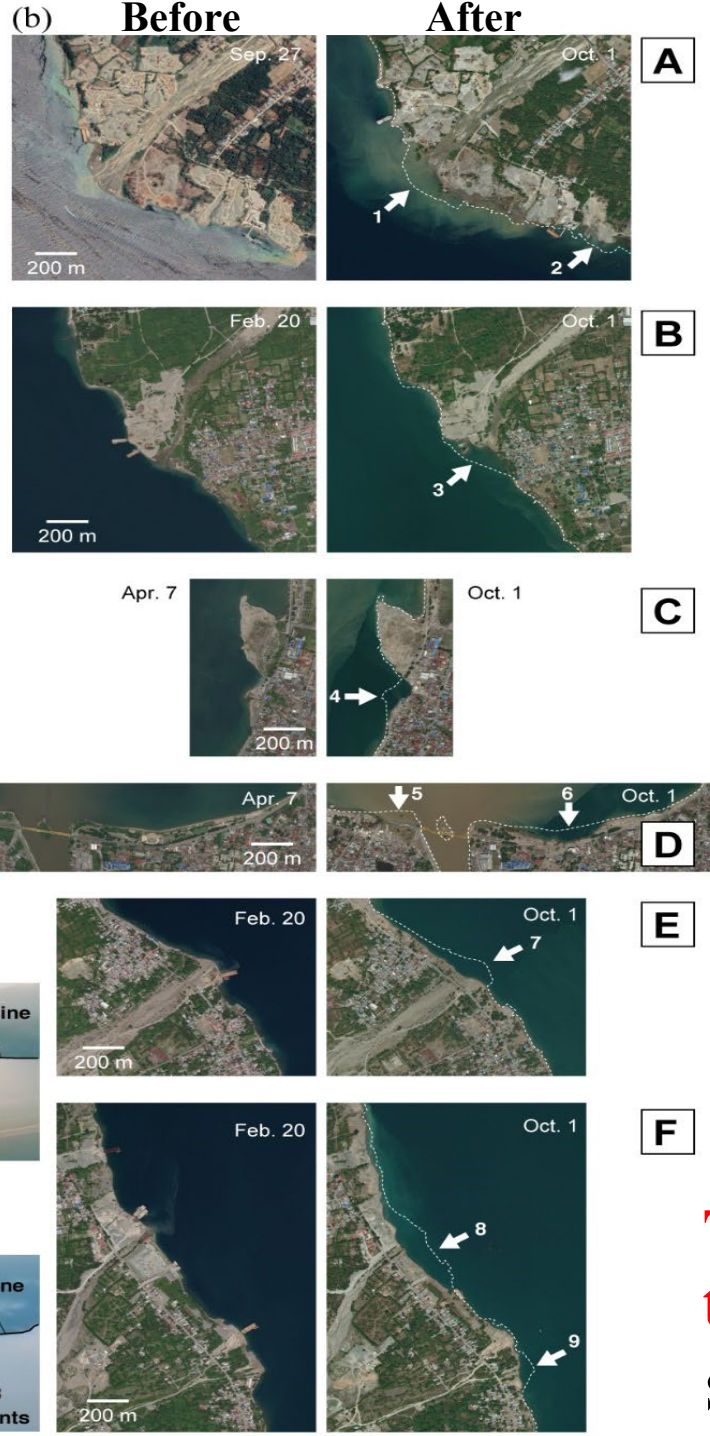
The area of the scarp formation corresponded to locations where the solidification front reached earlier the flow surface than other locations, giving rise to the intermittent flat area between each scarp formed.

Cascading Earthquake-Liquefaction-Landslide-Tsunamis

More than 4000 fatalities







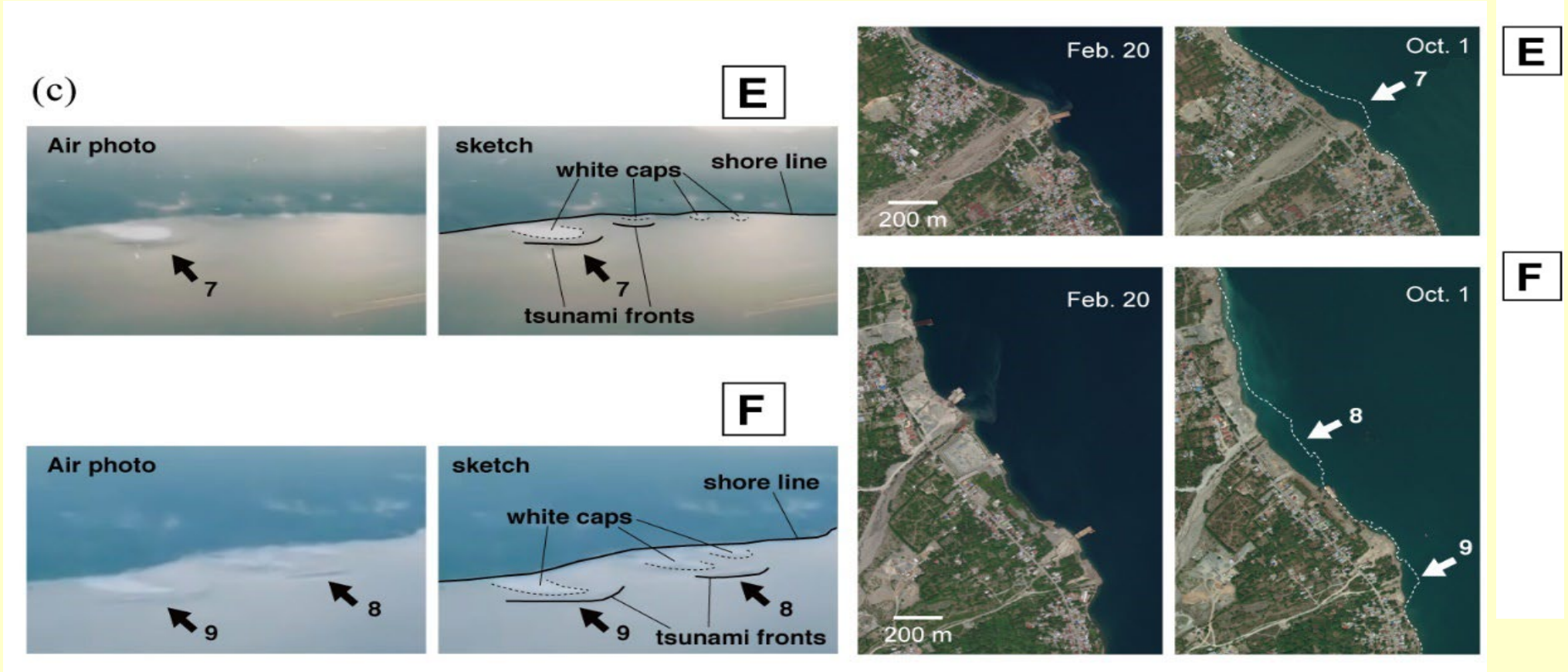
Extensive liquefaction-induced total collapse and flow of coastal land caused multiple tsunamis throughout the bay and coastal areas.

No.	Area (m^2)
1	59593
2	13508
3	28447
4	14866
5	11661
6	22961
7	35183
8	55211
9	9452
More than 250,000	

Ten times greater collapse than Haiti earthquake

Sassa and Takagawa, Landslides, 2019

Liquefaction-induced Coastal and Submarine Landslide Tsunamis

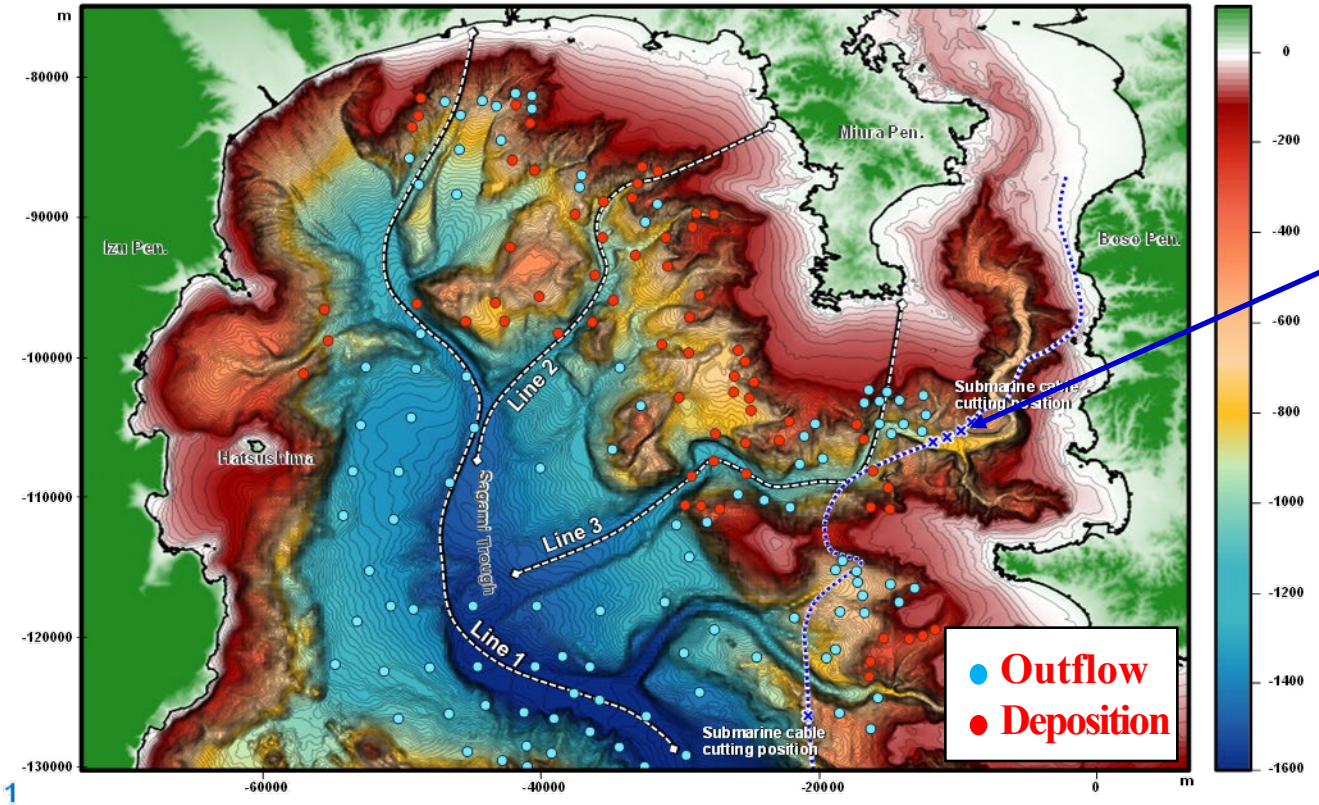


All of the locations of the multiple tsunami generations, alongshore distributions and directions

Conforming to the locations, distributions and directions where the coastal lands collapsed and flowed due to the occurrence of liquefaction !

Sassa and Takagawa, Landslides, 2019

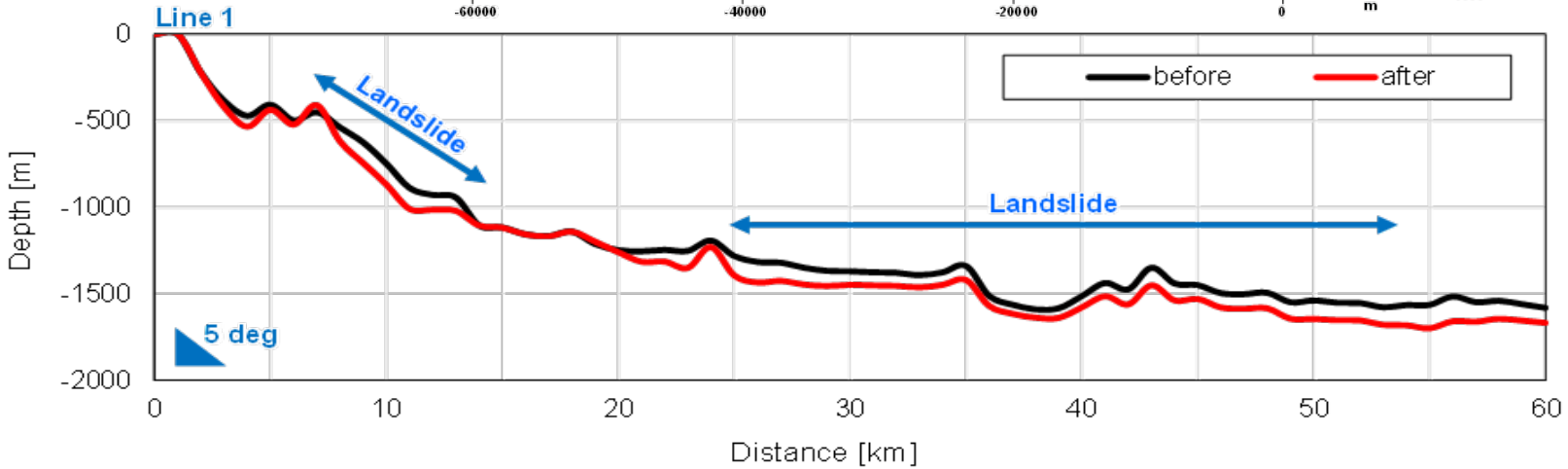
Large-Scale Submarine Liquefied Sediment Flows during the 1923 Great Kanto Earthquake



Murata, Ebisuzaki, Sassa et al. (2024)

Submarine Cable Cutting Positions

Over 40km Long-Runout Submarine Liquefied Flows



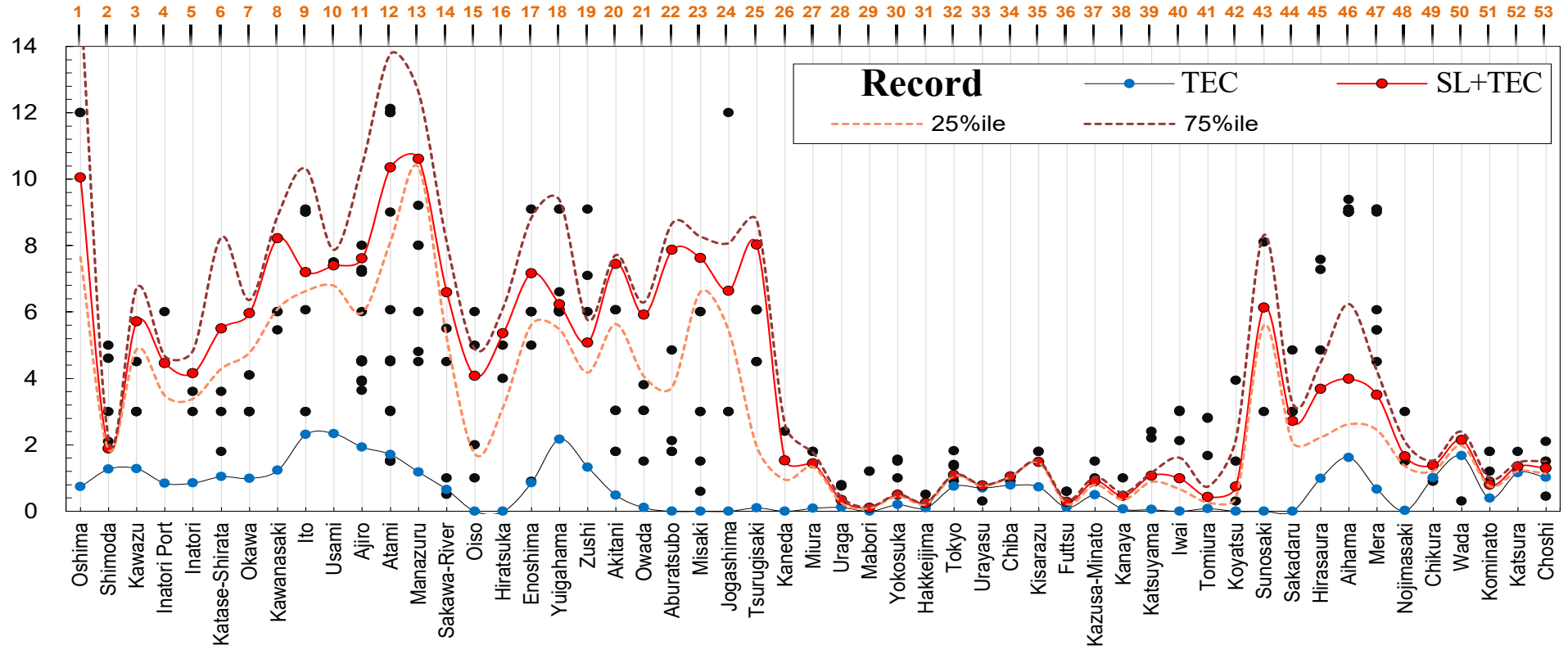
Based on the Theory, Experiments, and Analysis of Field Behaviour of SLSF

(Sassa et al., 2001, Sassa and Sekiguchi, 2010, 2012, Sassa and Takagawa, 2019)

Landslides and Tsunamis

Liquefied Gravity Flows-induced Tsunamis: Predictions and Observations

Maximum tsunami elevation: m



Coastal Points over Three Peninsulas

Submarine landslides as represented by a high-density liquefied gravity flow played a pivotal role in consistently accounting for the observed maximum tsunami elevation distributions along the whole coastal areas along three peninsulas involving Izu, Miura, and Boso Peninsulas facing Sagami Bay, Tokyo Bay, and the Pacific Ocean.

Murata, Ebisuzaki, Sassa et al. (2024)

Essentials for understanding and reducing the disaster risk of Landslide-induced Tsunamis

S. Sassa

S. Grilli

1. Triggering => when, where, how
2. Tsunami generation propagation => magnitude, where, how
3. Landslide tsunami detection/warning => magnitude/where

D. Tappin

- Submarine landslide tsunami locations
- Broad global understanding of the hazard and mapping required
- Dual and multiple mechanisms form basis for improved mitigation and warning

K. Sassa

- Coastal and submarine landslide-induced tsunami
- Role of landslide motion in tsunami generation
- Toward improved landslide tsunami hazard assessment technology

D. Karnawati

- Controlling factors and characteristic of typical prone areas
- Multiple triggering sources
- Mitigation strategy with hazard map and evacuation

V. Gusiakov

- Oceanic sedimentation zones and tsunamigenic potential
- Overlooked tsunami generation mechanism
- Toward improved warnings and long-term risk assessment

F. Løvholt

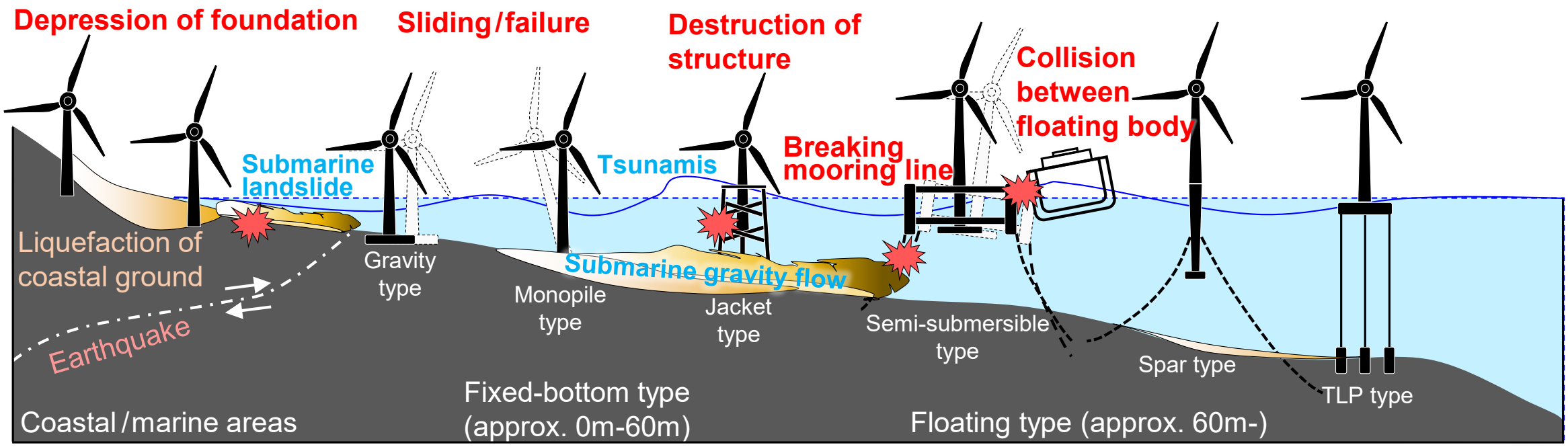
- Lack of data for landslide volume probability with limited mapping
- Uncertainty in landslide dynamics leading to tsunami genesis
- Toward well-developed early warning systems

Better understanding of multiple mechanisms and multi-phased physics of Landslide Tsunami Hazard

Hazard Mapping / Improved Early Warning

The framework, essential content and a short summary of the panel discussion in the World Tsunami Awareness Day Special Event of the Fifth World Landslide Forum

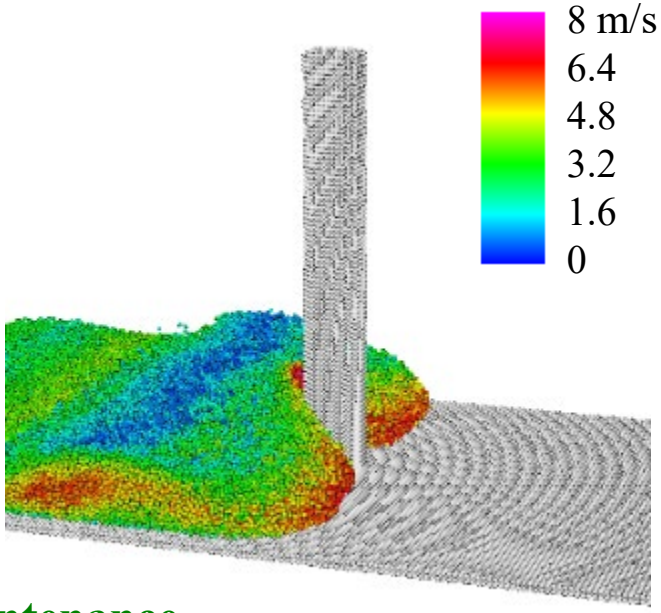
(Sassa et al. Landslides 2022, Progress in Landslide Research and Technology 2023)



Murata, Sassa et al. 2022

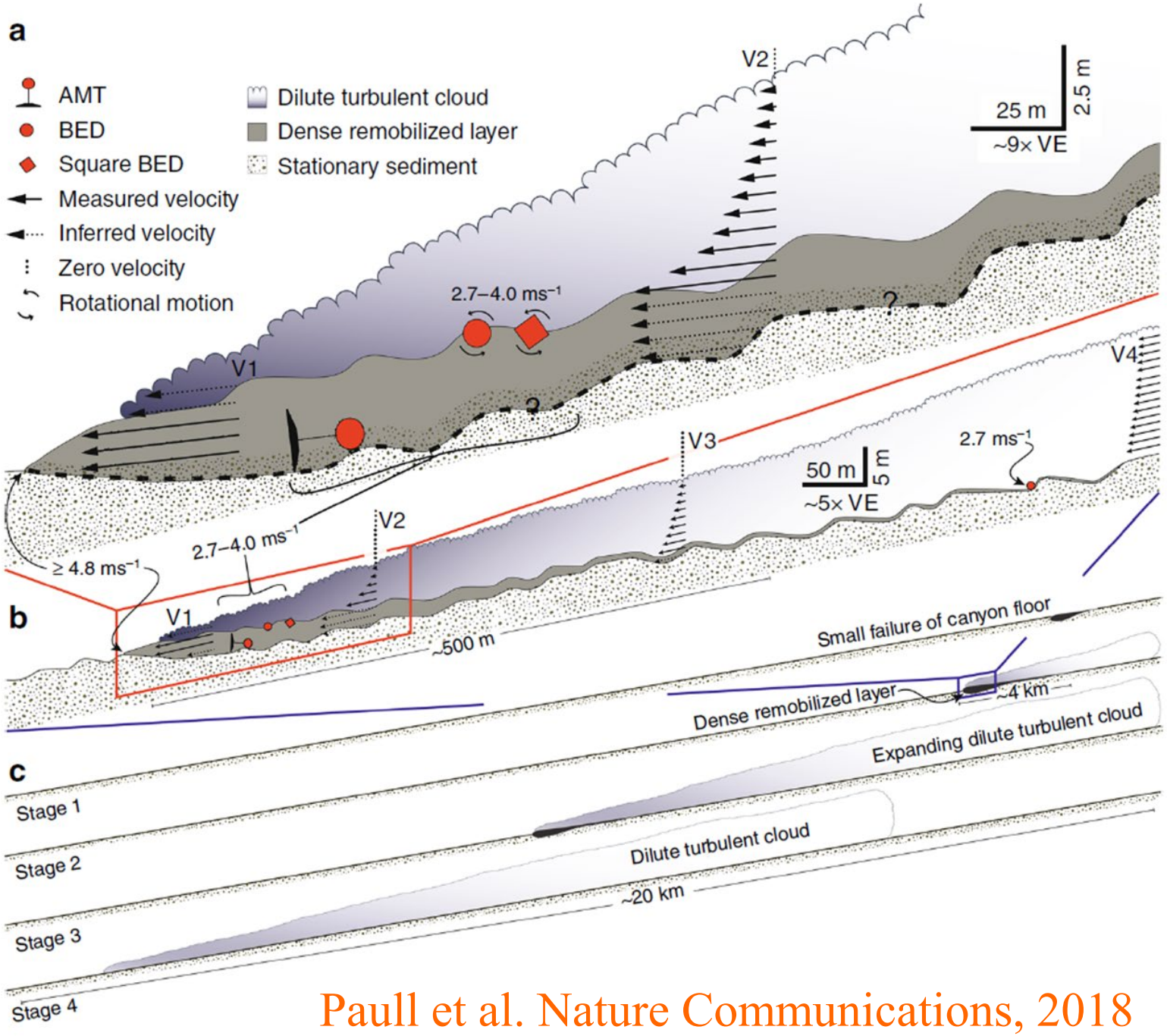
Diverse types of Offshore Wind Foundations (Seabed mounted and Floating type) subject to Submarine Liquefied Flows

Submarine liquefied sediment flows can have a substantial impact on both seabed-mounted and floating type offshore wind structures causing significant consequences.



Murata, Sassa et al. 2024

Design and Preventive Maintenance

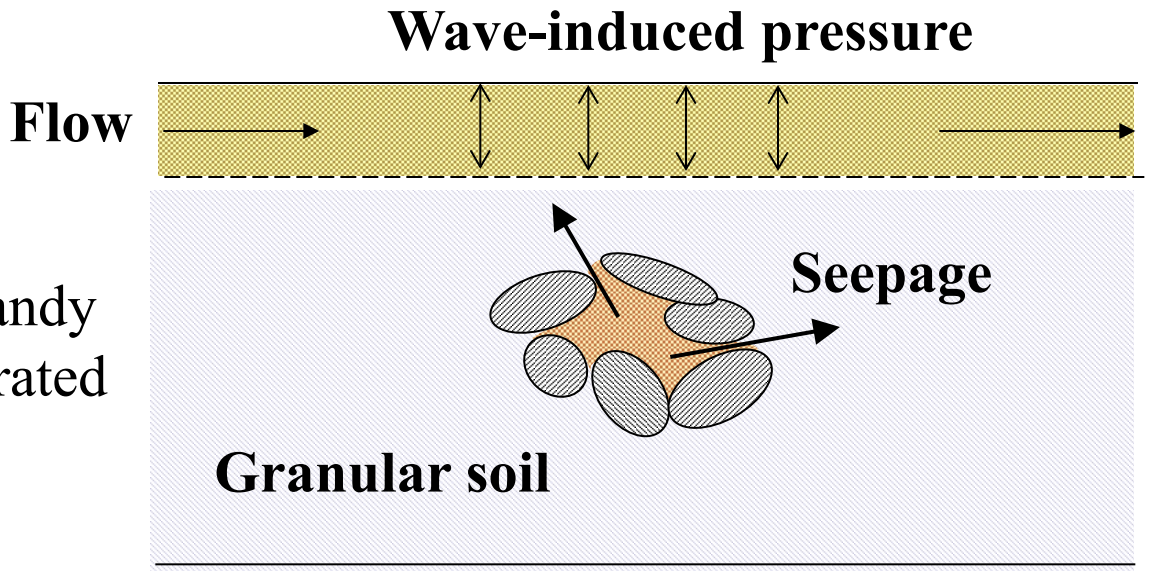


Paull et al. Nature Communications, 2018

Powerful high-density and long-travelling turbidity currents share some essential features with those of liquefied gravity flows

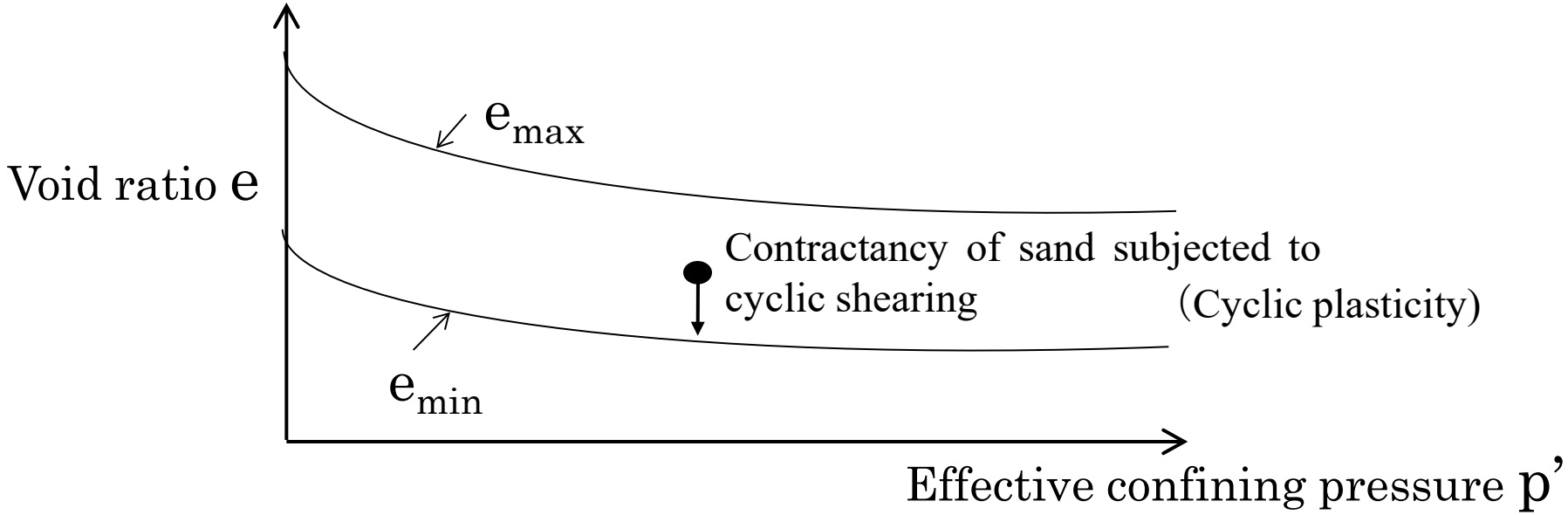
(Sassa and Sekiguchi 2010, 2012)

Disasters caused by such turbidity currents include cable breaks, rupture and pipeline damage

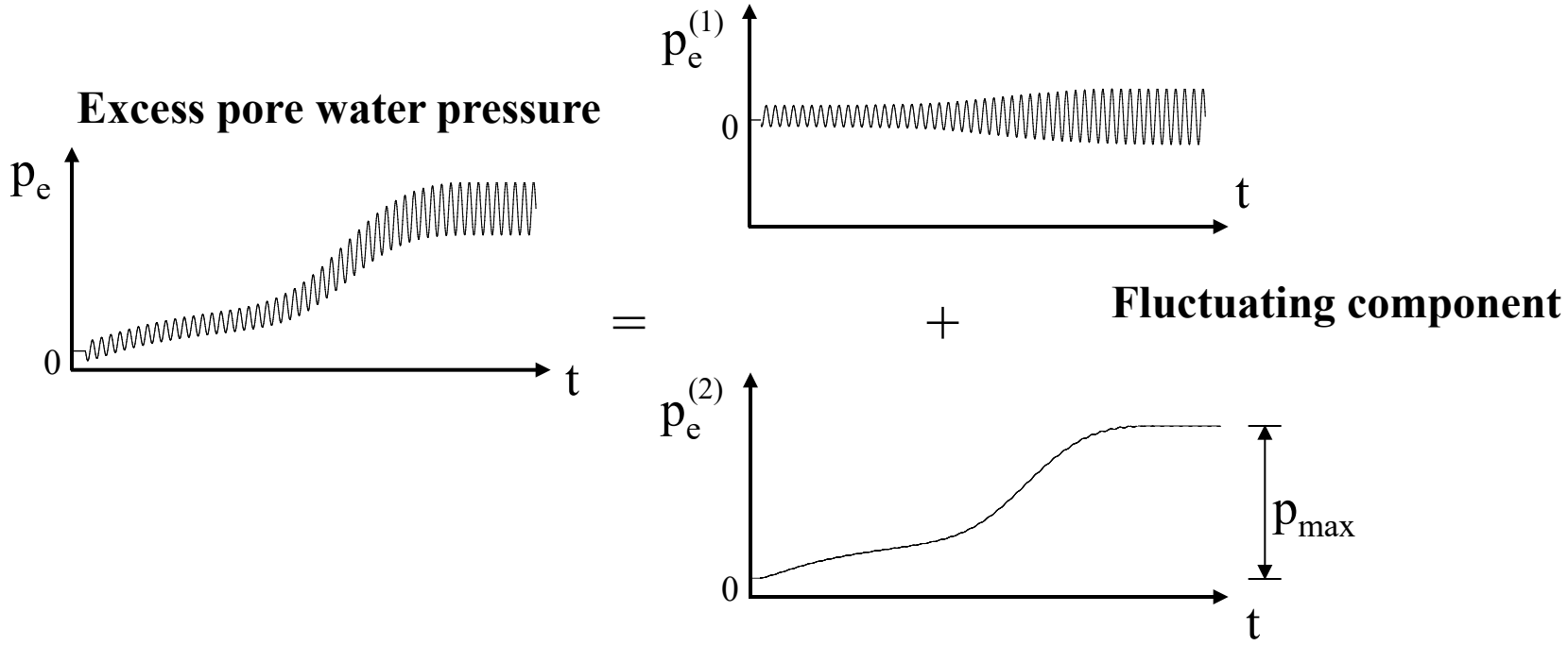


Sketch of sandy seabed saturated with water

Unstable granular structures easily fail under dynamic environmental loadings such as ocean waves



Sketch of excess pore water pressures in sand beds under severe wave conditions

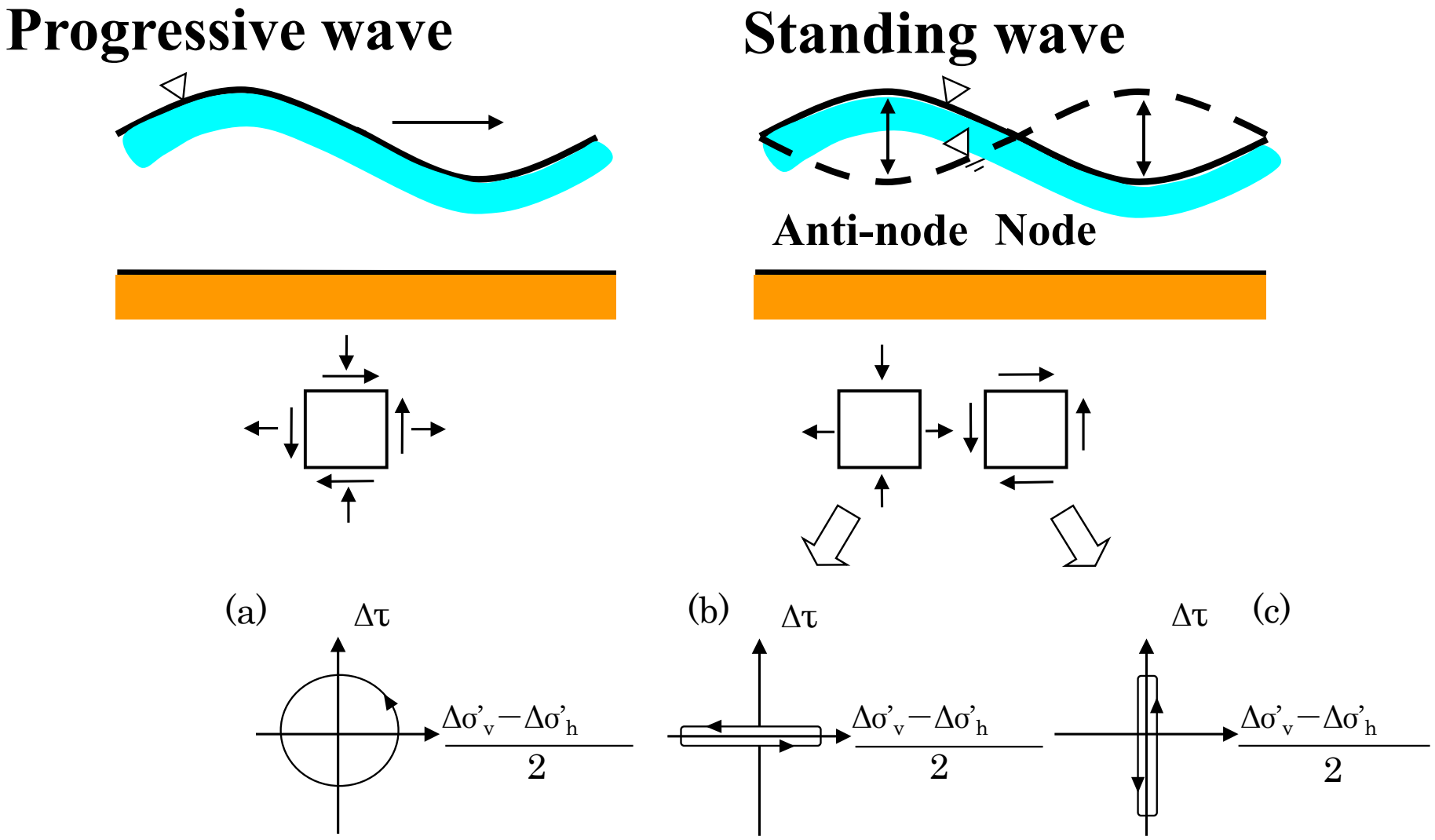


Contractive nature of sand ⇨ **Residual component**

(Contractancy)

$p_{max} = \sigma'_{v0}$ (Vertical effective confining pressure of soil) ⇒ Liquefaction

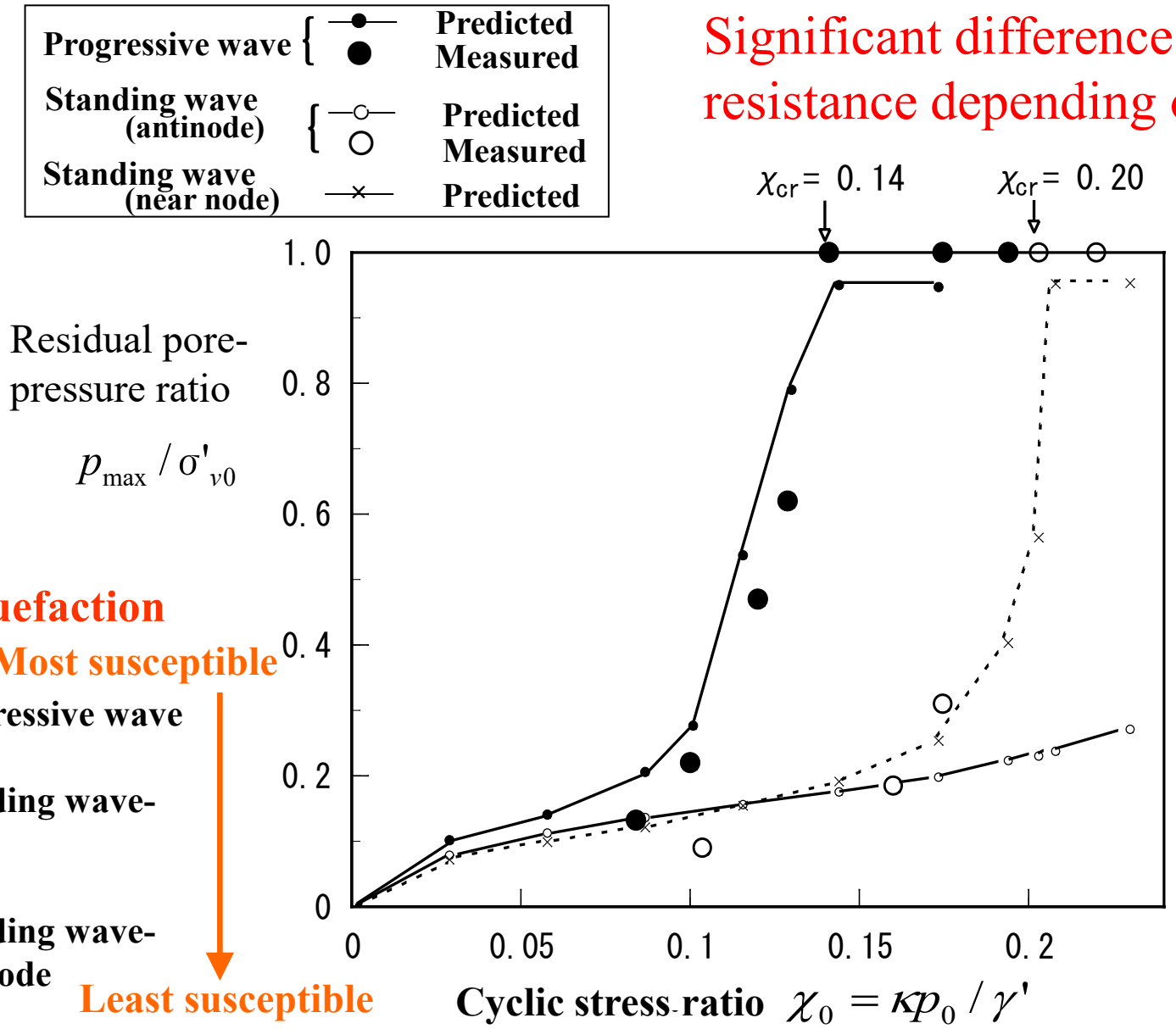
Stress paths induced in seabed under the action of ocean waves



$\Delta\sigma'_v$: Vertical effective stress increment

$\Delta\sigma'_h$: Horizontal effective stress increment

$\Delta\tau$: Shear stress increment



Significant difference in liquefaction resistance depending on wave forms!

χ_{cr}: Critical cyclic stress ratio below which liquefaction does not occur

Recent case histories of wave-induced liquefaction

- Settlement of submerged dykes
- Submarine slope failure/flow
- Pipeline floatation and breakage

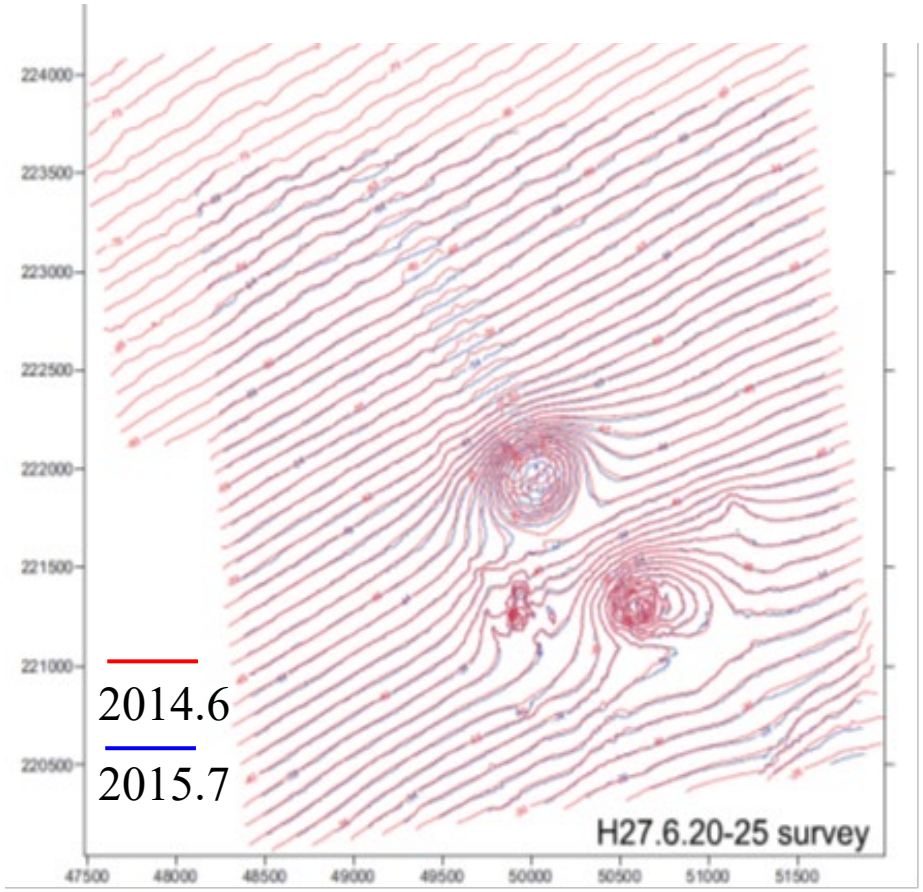
κ: wave number $2\pi/L$

p_0: pressure amplitude

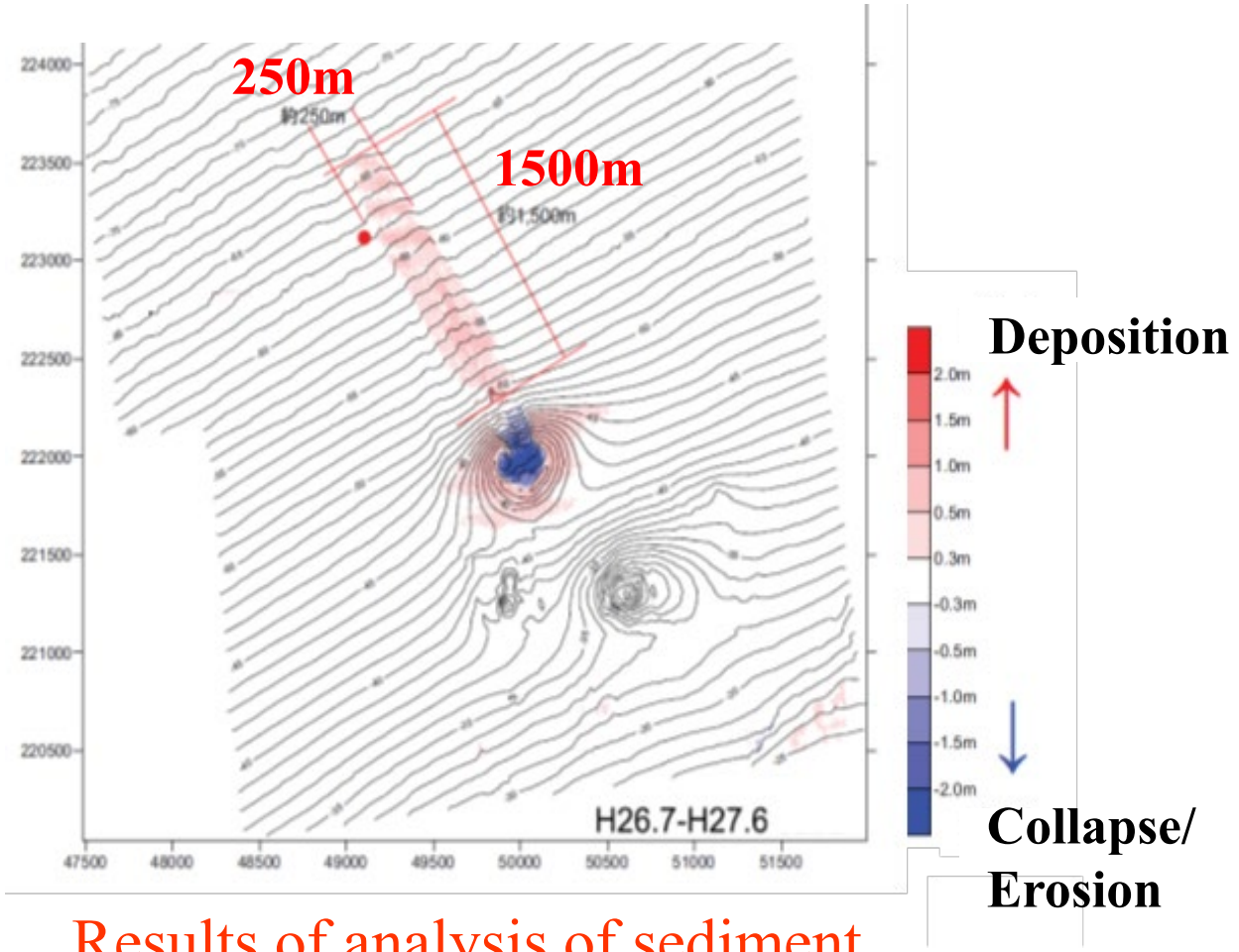
γ': submerged unit weight of soil

Comparison of liquefaction resistance to progressive- and standing- waves

Wave-induced liquefaction and sediment flows: Water depth 47m, Significant wave height 6.5m

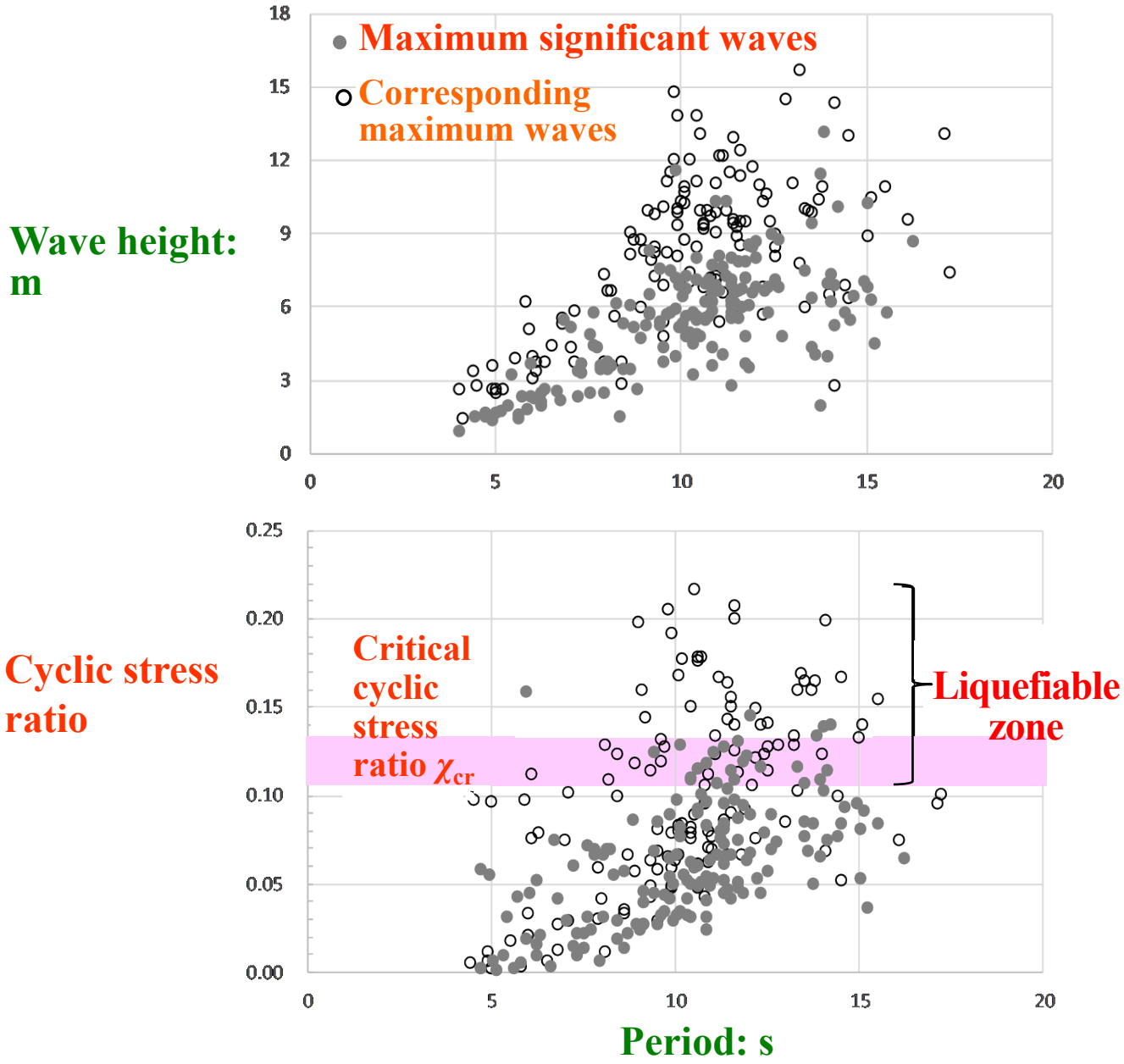


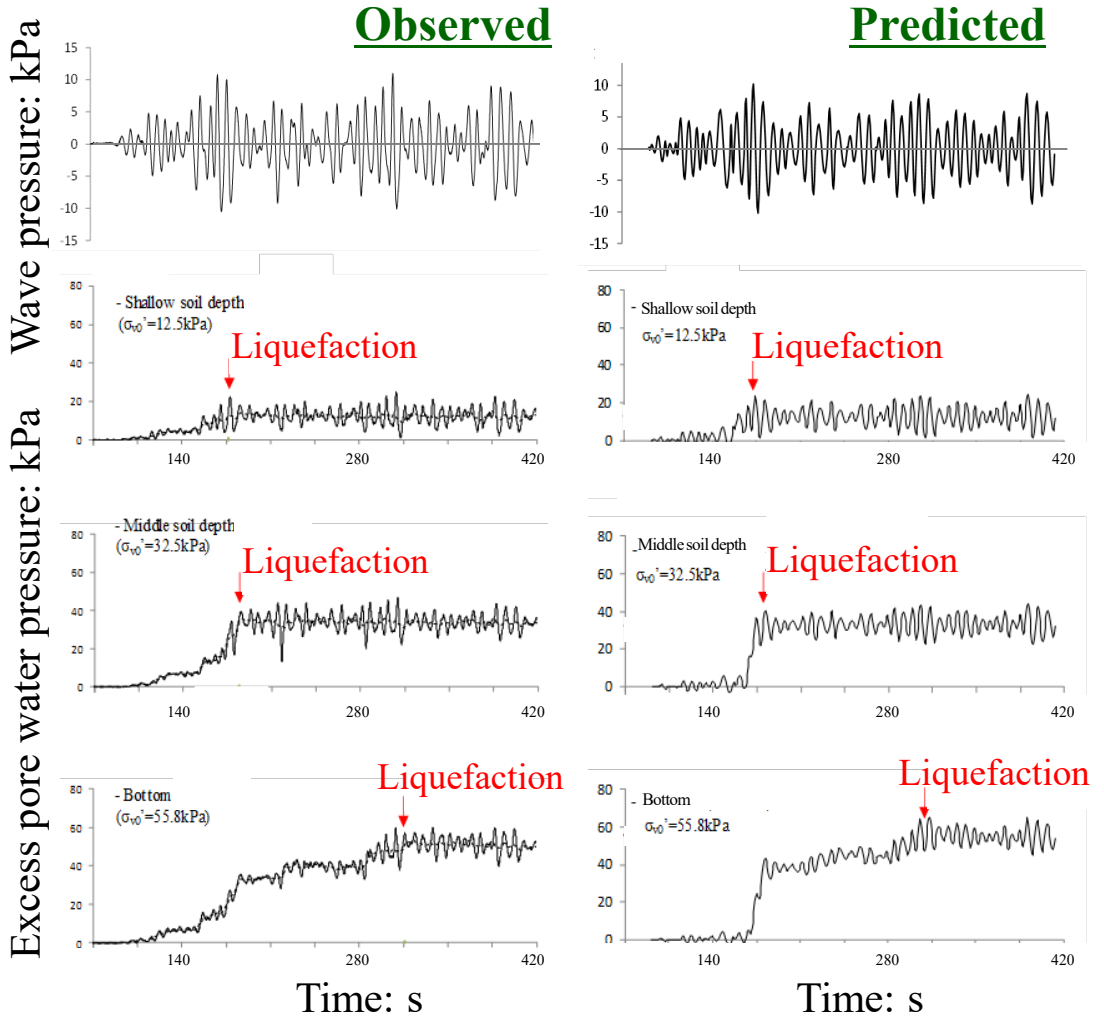
Comparison of seabed topography before and after the event (2014-2015)



Results of analysis of sediment flows (2014-2015)

Wave-induced seabed liquefaction caused a subtantial flow of a total of one-hundred and twenty thousands cubic meters of sediment 250m wide over 1.5km.

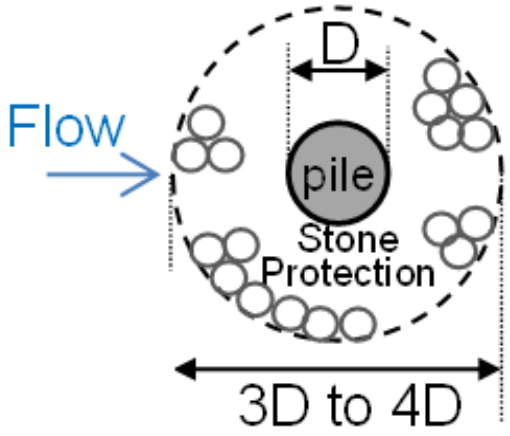


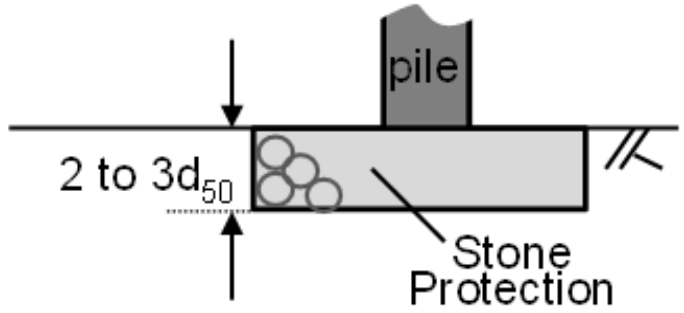


Irregular wave-induced liquefaction predictions and observations

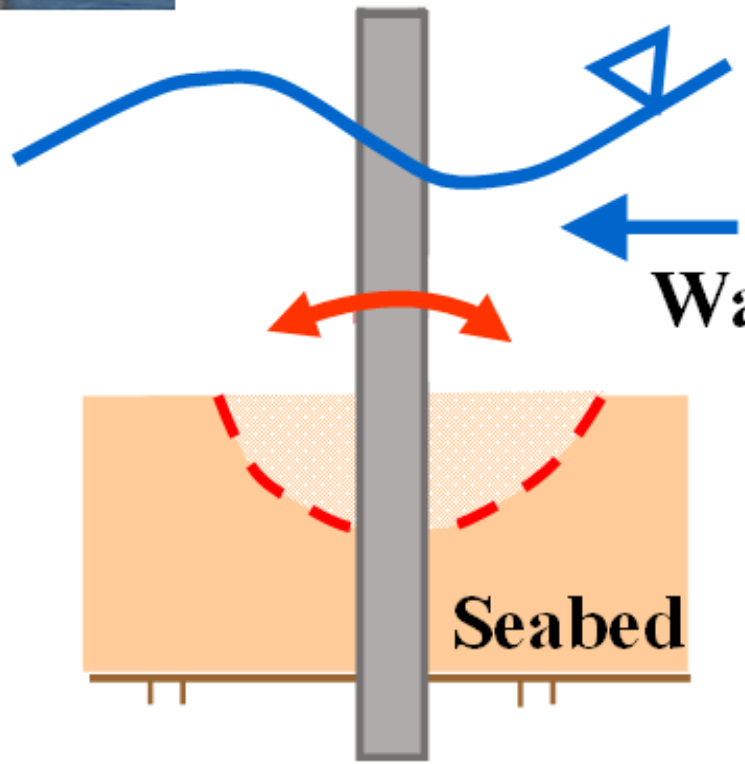
Miyamoto and Sassa (2021)

Wave-induced Liquefaction Potential and Prediction

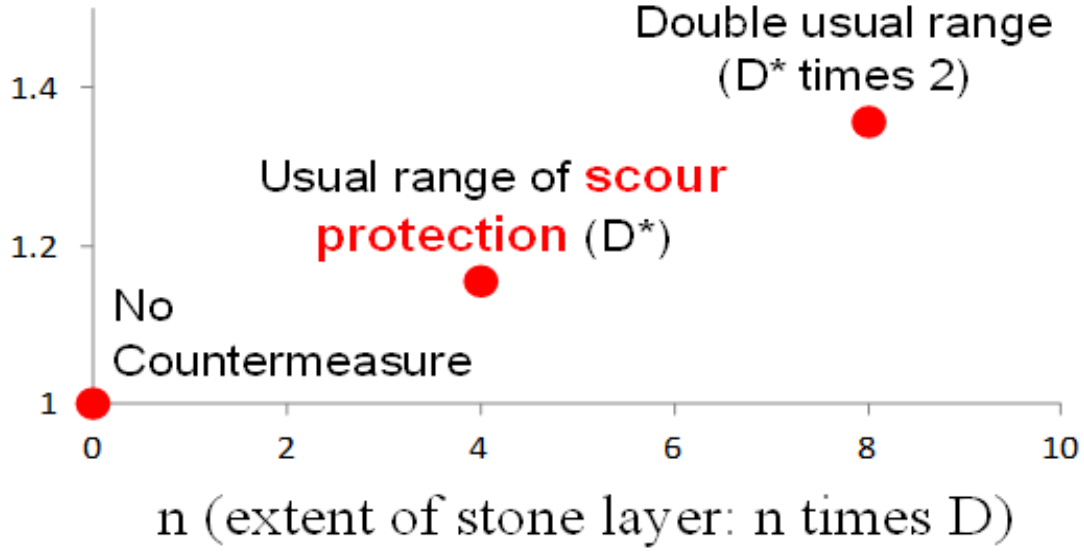




d_{50}: median grain size of stone



Ratio of increase in wave-induced liquefaction resistance

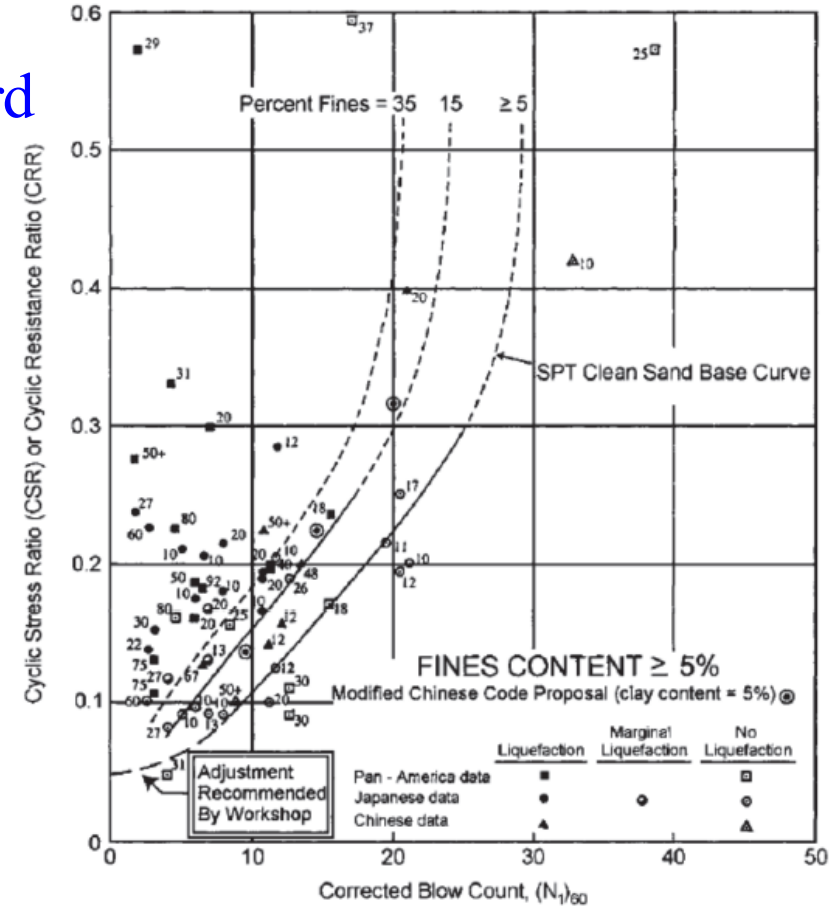


Wave-Seabed-Structure Interaction: Wave-induced Liquefaction-Scour Countermeasure Concept for Offshore Monopile Foundations (Sassa 2023b, 2024)

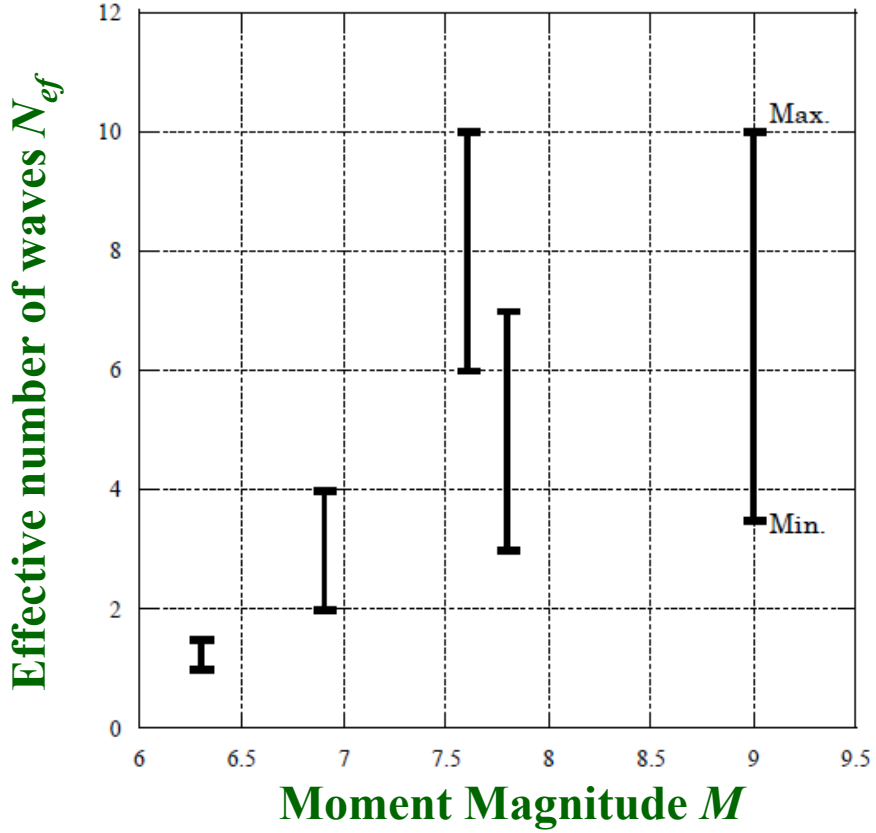
Rational Liquefaction Prediction and Assessment

Top-Read Paper in ASCE Most Read Articles 2017-2021

US standard



Sassa and Yamazaki (2017), American Society of Civil Engineers Journal of Geotechnical and Geoenvironmental Engineering



This simplified practical liquefaction prediction and assessment method is capable of considering the influence of the waveforms and durations of earthquakes.

Applicable to all types of liquefaction charts based on SPT, CPT and shear wave velocities

Submarine Geohazards and Mitigation Concept for Offshore Wind

- I have concisely summarized the characteristics, mechanism, prediction and assessment of submarine geohazards with a special emphasis on liquefaction, coastal and submarine landslides, and tsunamis.

- The cascading mechanisms involving the earthquake-liquefaction-coastal and submarine landslides-tsunamis highlight the multi-phased physics of the multi-geohazards. Notably, the critical importance of the liquefied gravity flows in coastal and submarine landslides, landslide-induced tsunamis, as well as in the high-density turbidity currents has been demonstrated, in the light of their devastating consequences on human lives and critical infrastructures.

- Based on the state-of-the-art understanding of the seabed liquefaction-induced impact on coastal and offshore infrastructures, I have presented the novel submarine geohazards resistant design concepts for the bottom-fixed and floating offshore wind facilities for a safe sustainable development worldwide.