Liquefaction characteristics of sand due to various waves by cyclic torsional shear test

Keisuke Ishikawa & Susumu Yasuda

Div. of Architectural, Civil and Environmental Engineering

Tokyo Denki University, Japan

Kousuke Oikawa

Architectural, Civil and Environmental Engineering

Graduate School of Tokyo Denki University, Japan

0. The outline of presentation

1. Introduction

2. Test procedure

3. Test results

3.1 Liquefaction behavior under irregular wave loading

3.2 Comparison of liquefaction strength ratios based on stress method

3.3 Comparison of liquefaction characteristics based on cumulative dissipation energy

4. Conclusions

1. Introduction

The major earthquakes that have caused liquefaction damage for Japan in recent years have the following characteristics.

2011 Great East Japan Earthquake Huge trench-type

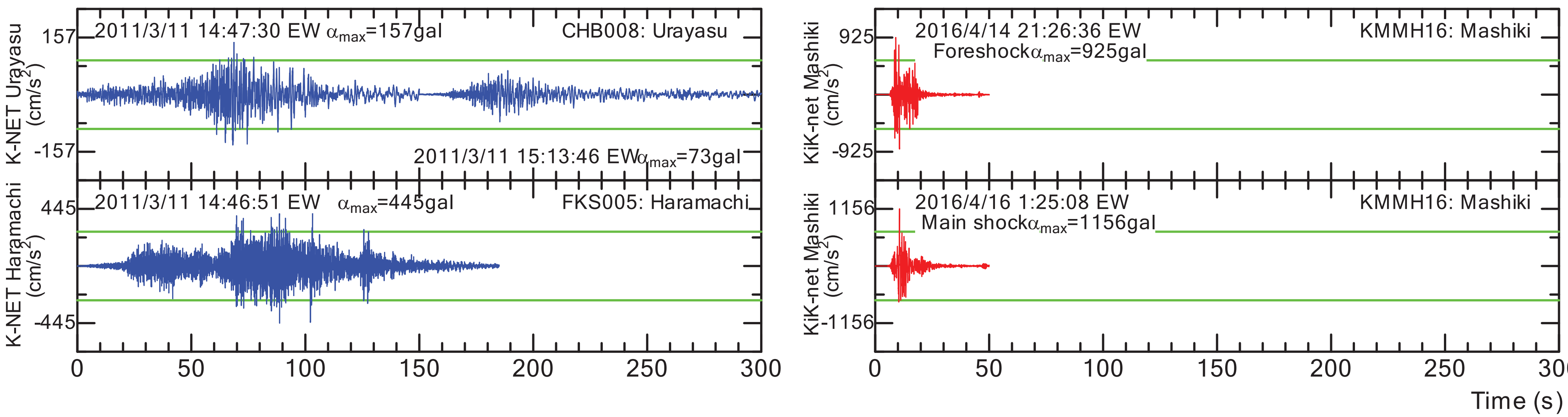
>>Maximum acceleration was not very high.

>>The duration was very long.

2016 Kumamoto Earthquake Inland type

>>**Maximum acceleration exceeding 1G occurred.**

>>The duration was short.



1. Introduction

There are concerns that earthquakes similar to the 1923 Great Kanto earthquake and Tokyo Bay Northern earthquakes will occur in Tokyo.

Trench-type: Taisho Kanto wave

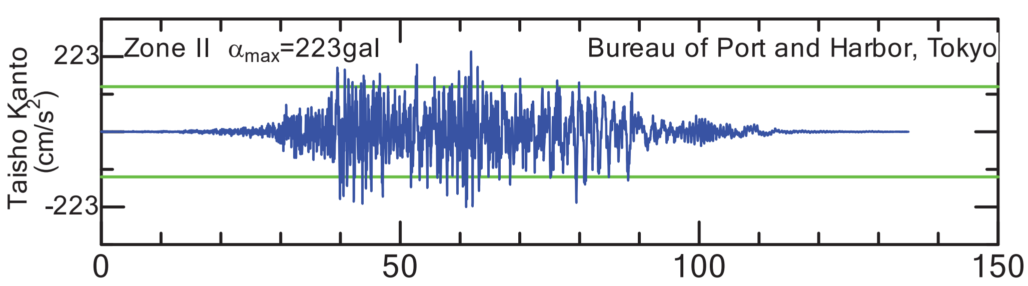
>>**The duration was very long.**

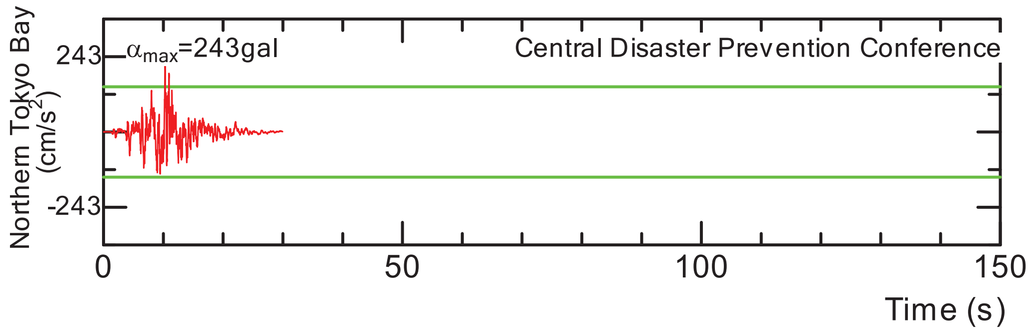
>>Estimated by Tokyo Metropolitan Government

Inland type: Northern Tokyo Bay wave

>>**The duration was short.**

>>Estimated by the Central Disaster Prevention Council of the Cabinet Office





Purpose of the study

The cyclic torsional shear tests were performed using various irregular waves to evaluate the following liquefaction properties.

i. Liquefaction behavior by seismic wave
ii. Effect of waveform on liquefaction strength
iii. Evaluation of waveform by accumulated dissipation energy

2. Test procedure

Device: Cyclic torsional shear test

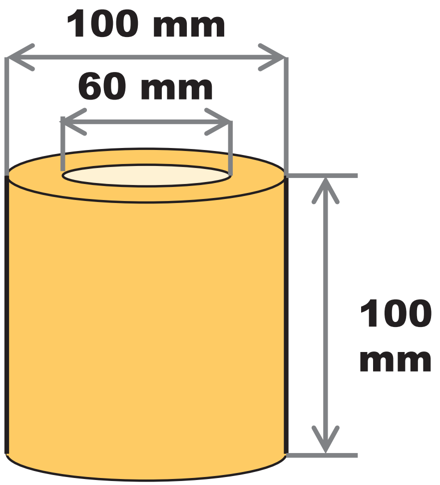
Sample: Toyoura sand

Preparation of specimen: Air-pluviation method

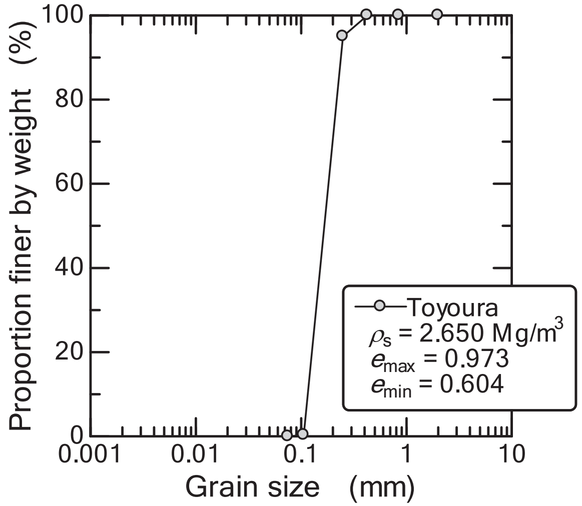
Relative density: 70%

Effective confining pressure: 50 or 100 kPa

Loading method: Sine and Irregular waves by stress control

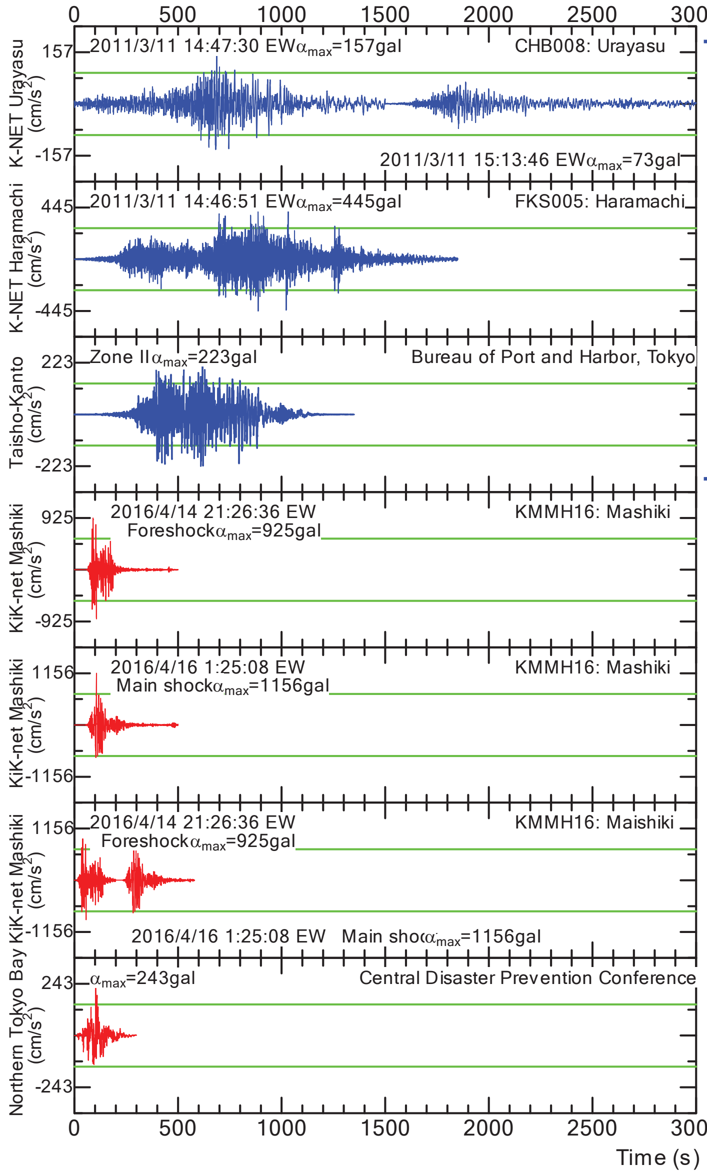


Hollow cylindrical specimens



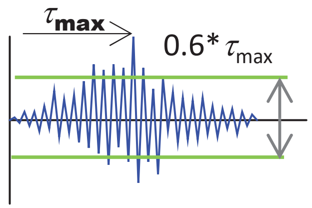
Grain size distribution curve

Irregular waveforms:



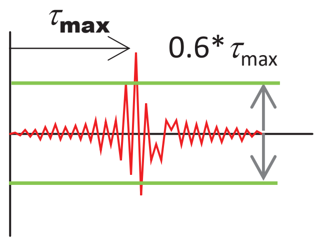
Trench-type

60% t_{max} acts more than 10 times.



Inland-type

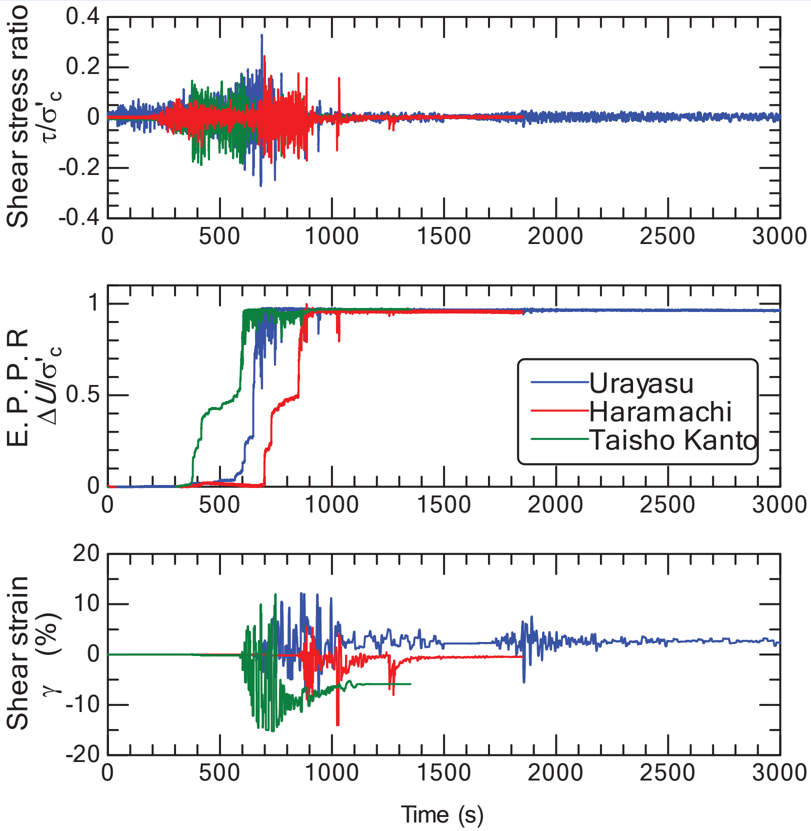
60% τ_{max} acts less than 10 times.



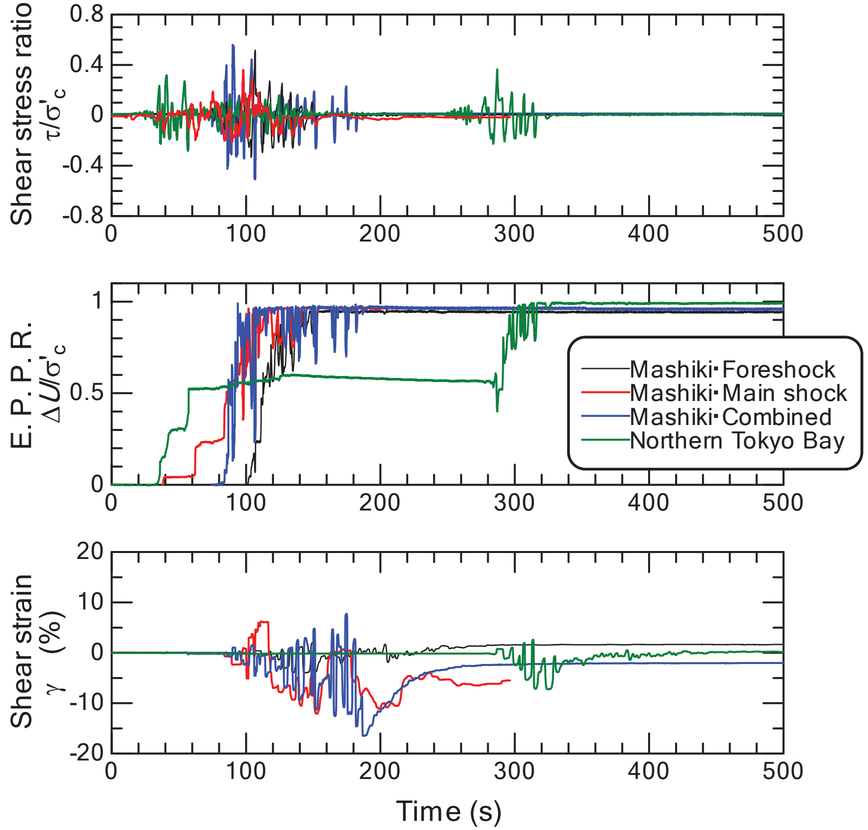
3. Test results

3.1 liquefaction behavior under irregular wave loading

*Results of liquefaction test for **trench-type waves***



*Results of liquefaction test for **inland-type waves***

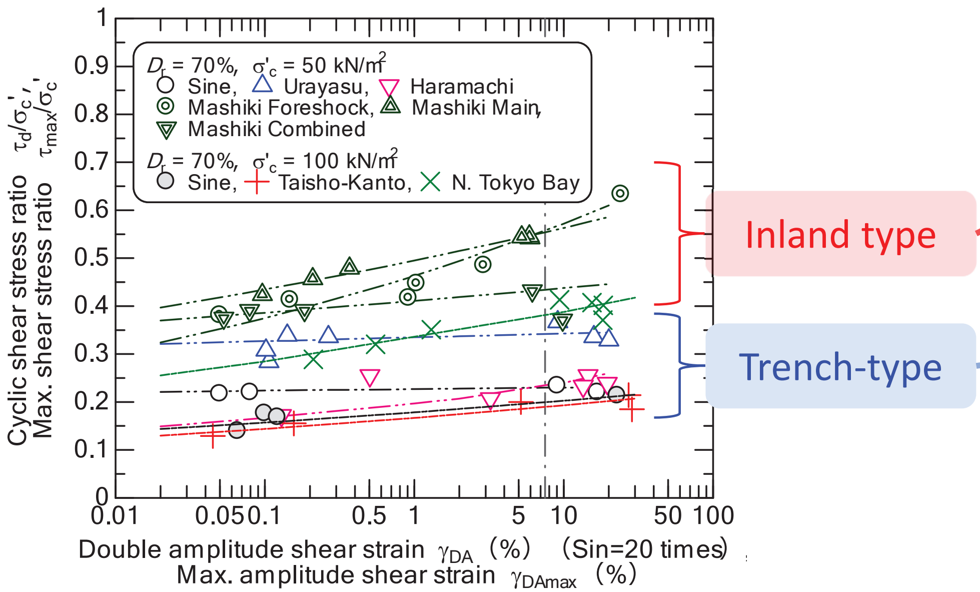


- The maximum shear stress differs between trench and inland types, and is lower in the trench-type with more waves.
- Shear strain increment is affected on the shear stress level and wave number after the maximum shear stress was applied.

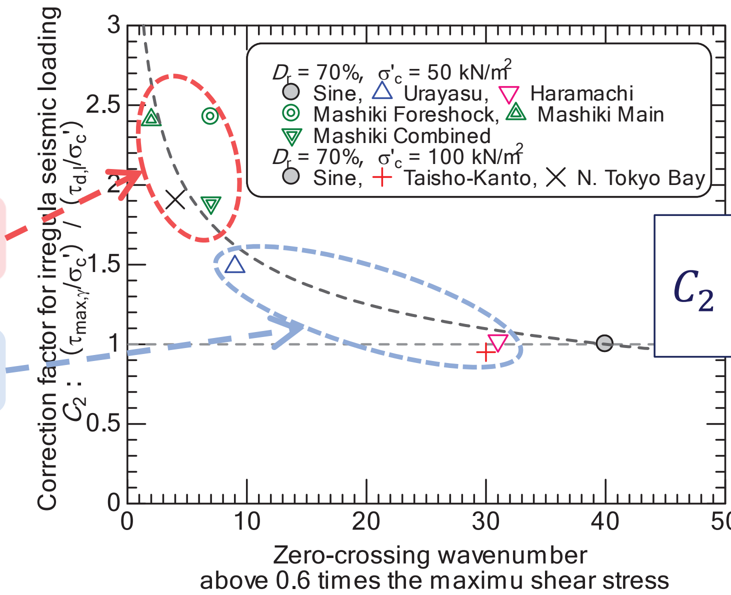
3. Test results

3.2 Comparison of liquefaction strength ratios based on stress method

Liquefaction strength curve based on shear strain



Relationship between zero-cross wavenumber and C_2



$$C_2 = \frac{(\tau_{max,l}/\sigma'_c)}{(\tau_{d,l}/\sigma'_c)}$$

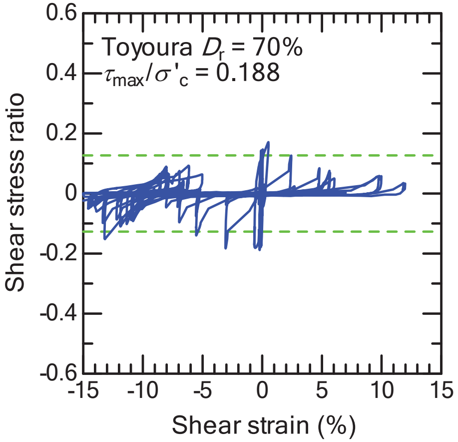
- The liquefaction strength ratio is the max. shear stress ratio at a max. amplitude shear strain of 7.5%.
- The liquefaction strength ratios were larger for the inland-type earthquakes, which have a shorter duration, compared to the trench-type earthquakes.

- C_2 is 2.0–2.4 for the inland-type waves, which have the lowest number of repetitions at more than 60% of the max. shear stress. In contrast, C_2 is approximately 1.0 for the trench-type waves, which have the highest number of repetitions.

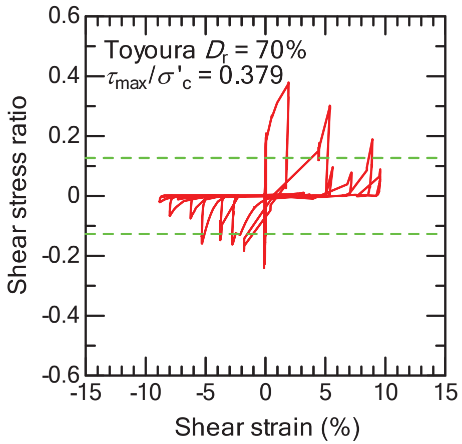
3. Test results

3.3 Comparison of liquefaction characteristics based on cumulative dissipation energy

Taisho Kanto wave



N. Tokyo Bay wave

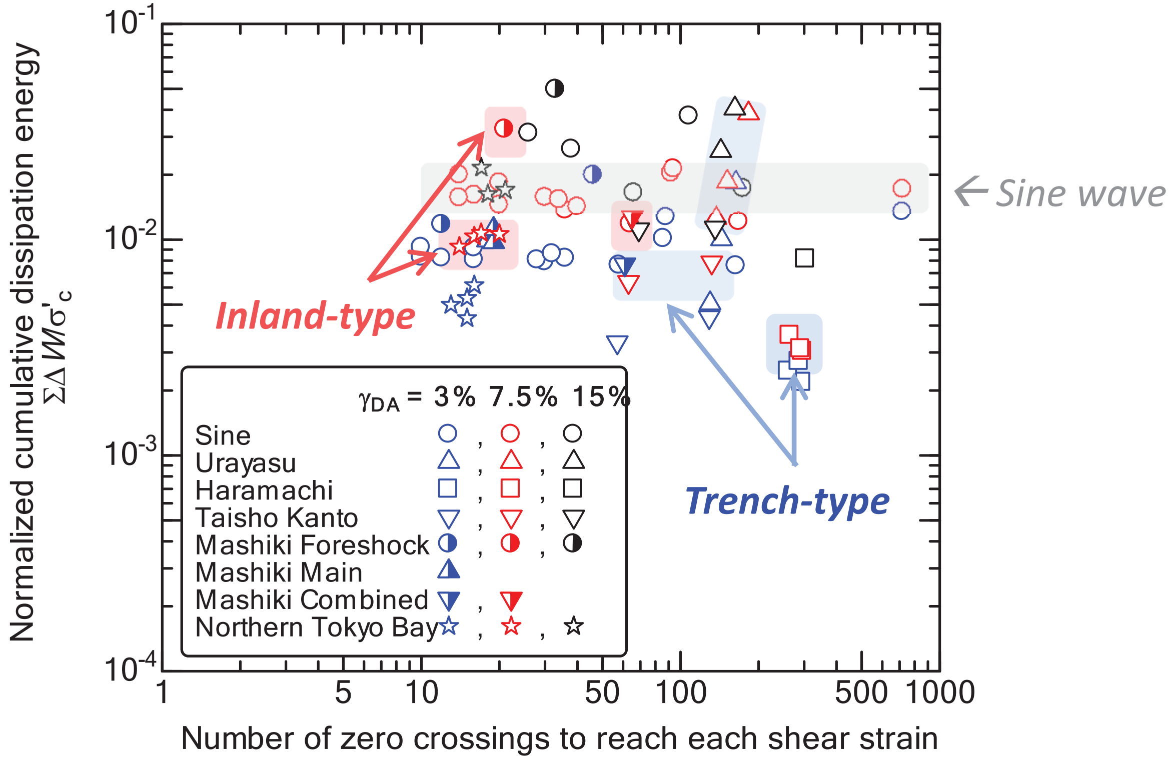


Cumulative Dissipation Energy

$$\sum \Delta W = \int \tau \, d\gamma$$

Normalized Cumulative Dissipation Energy

$$\sum \Delta W / \sigma'_c$$



- ➢ The sine wave was at the same level regardless of the number of cycles.
- ➢ The irregular waves were changed by the number of cycles.
- ➢ Additionally, the cumulative dissipation energy required for complete liquefaction for long-duration seismic waves is different by approximately one order of magnitude.

4. Conclusions

The effects of waveform shape and duration on liquefaction strength and behavior were experimentally evaluated by performing cyclic torsional shear tests using irregular waves with various shapes.

- In the liquefaction test carried out using irregular waves, the shear strain occurs only when shear stresses that are 0.3–0.4 times the maximum shear stress ratio are applied after the effective stress is lost.
- The increase in shear strain is more significant for the irregular waves that are loaded for long-duration repeatedly.
- The correction factor for irregular seismic loading is correlated with the number of cycles when approximately 0.6 times the maximum shear stress ratio is applied.
- The cumulative dissipation energy is a quantitative indicator of the ease of liquefaction due to the shapes of irregular waves. **The ease of liquefaction is more likely to be caused by the waveforms that are subjected to the interaction of duration and strong shear stress compared to the sine wave**.

Thank you for kind attention!!

For questions or comments,

↓↓↓

Email: ishikawa@g.dendai.ac.jp