EXPERIMENTAL STUDY ON TRANSPORT CHARACTERISTICS OF COASTAL BOULDERS BY TSUNAMI AND HIGH WAVES

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関西大学

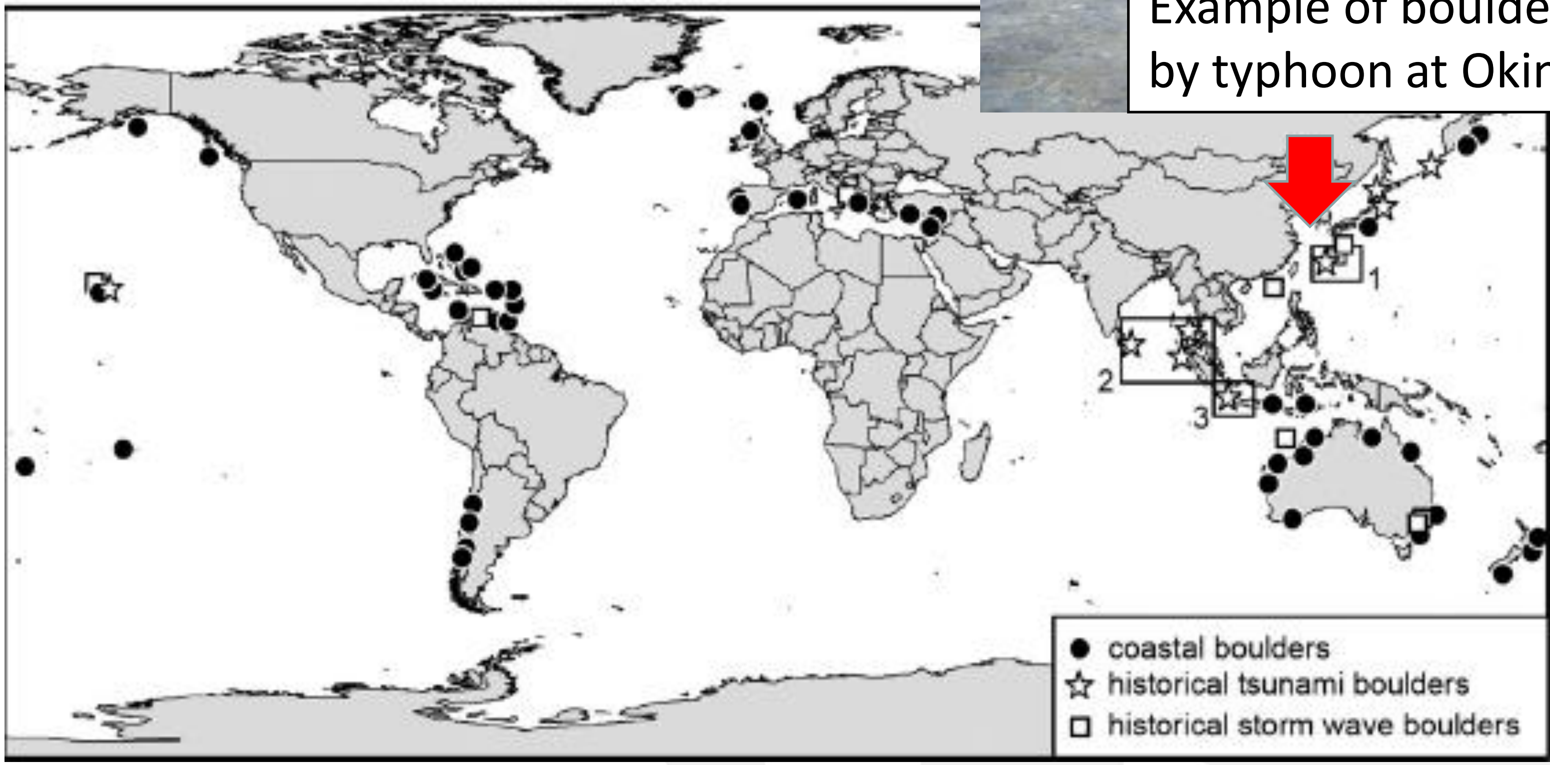
Outline

- Background and purpose
- Experimental setup and conditions
- Results and discussion
- Conclusions

Background and purpose

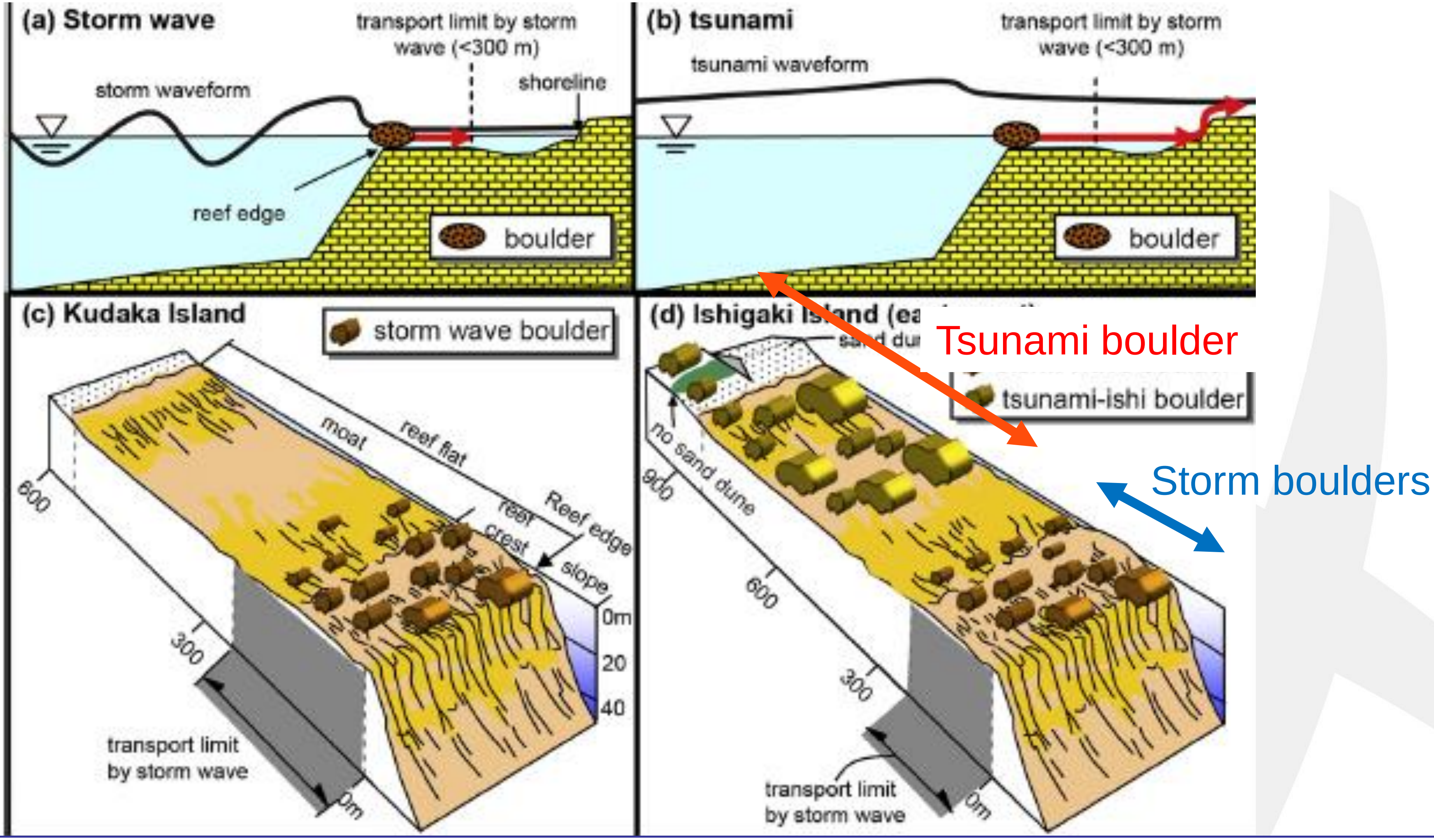
Boulders made of coral limestone transported shoreward have been observed many times, and are called storm boulders or tsunami boulders.

Example of boulder transported by typhoon at Okinawa in Japan.



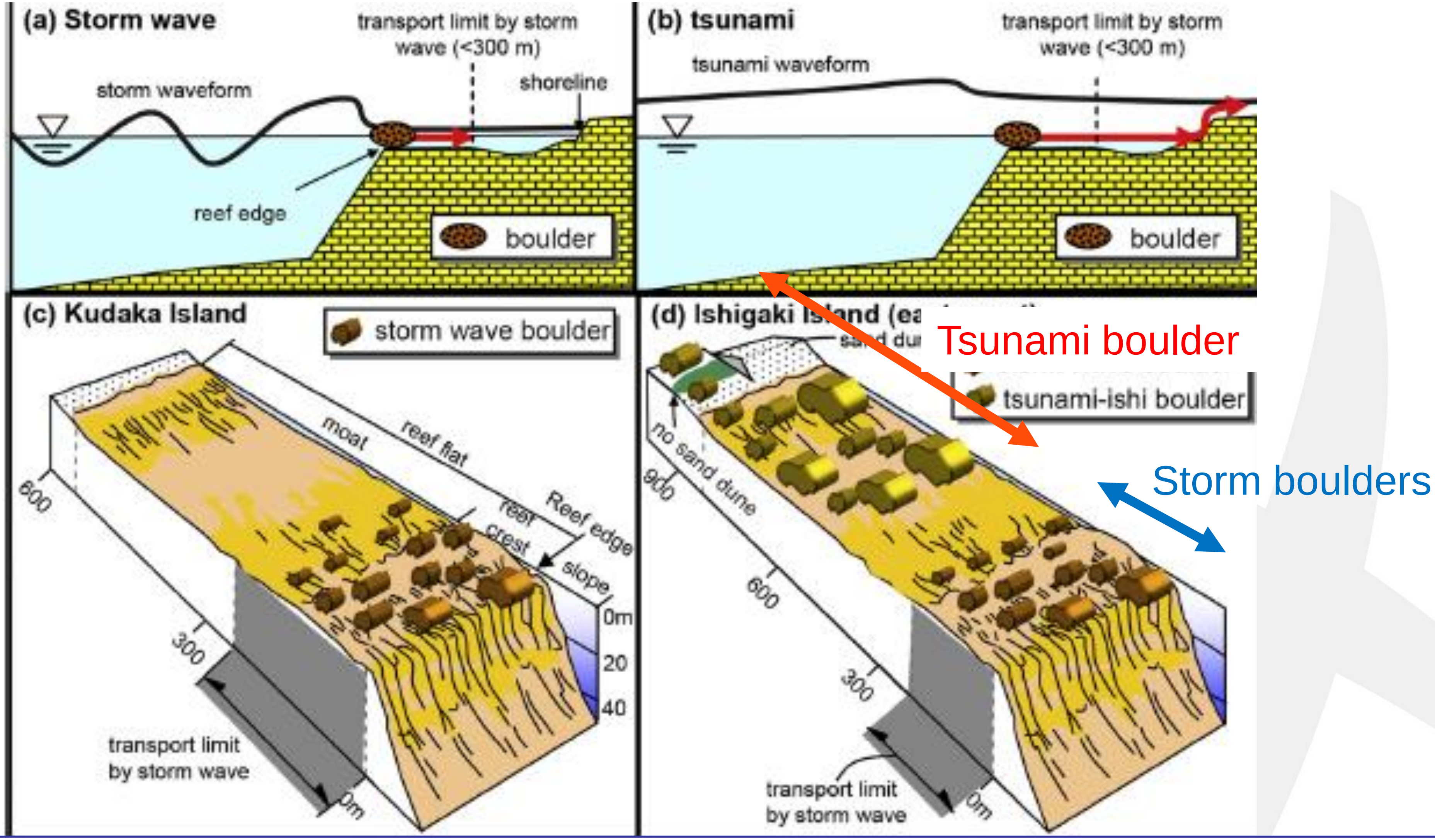
Map showing the distribution of coastal boulder at coastal zone world wide (Goto et al. 2010a).

Boulder distributions in the fields



Waveform and boulder displacement by (a) storm wave and (b) tsunami on the Ryukyu Islands, and distributions of the (c) storm wave boulders at Kudaka Island and (d) storm wave plus tsunami boulders at Ishigaki Island. （Goto et al. 2010a ）

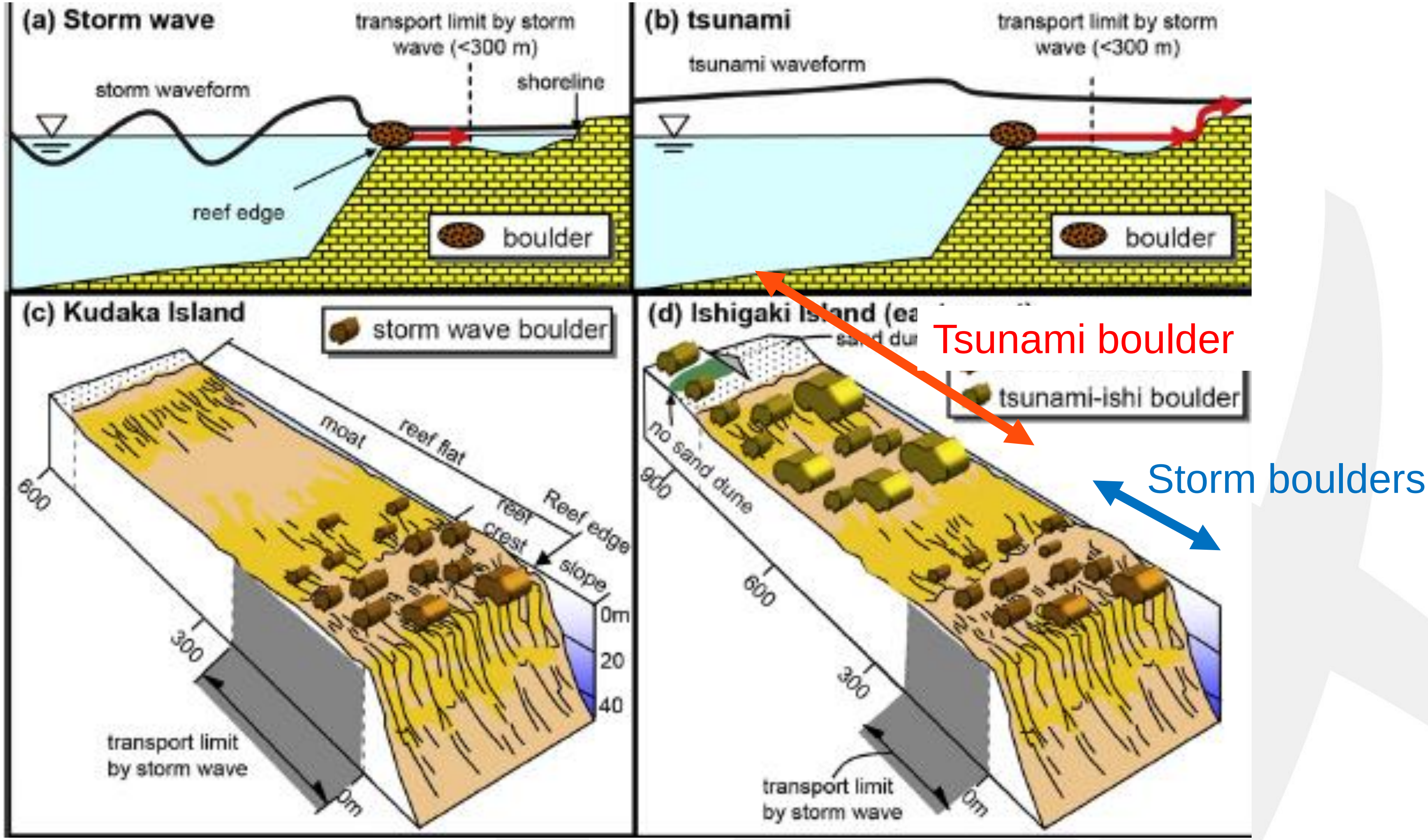
Boulder distributions in the fields



Imamura et al. (2008) and Goto et al. (2009a, 2010b) reported that;

- The storm wave period is expected to be less than 20s.
- A large tsunami is several tens of minutes to hours.

Boulder distributions in the fields



➢Therefore, the duration of a tsunami wave force acting on the boulder is considerably longer than that of a storm wave.

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Background and purpose

- Boulders can become lasting evidence of historical mega-tsunami or super typhoon occurrence during the past hundreds to thousands of years.
- There many geological survey but less research on hydrodynamics.

Even if no literature record remains, they can become lasting evidence

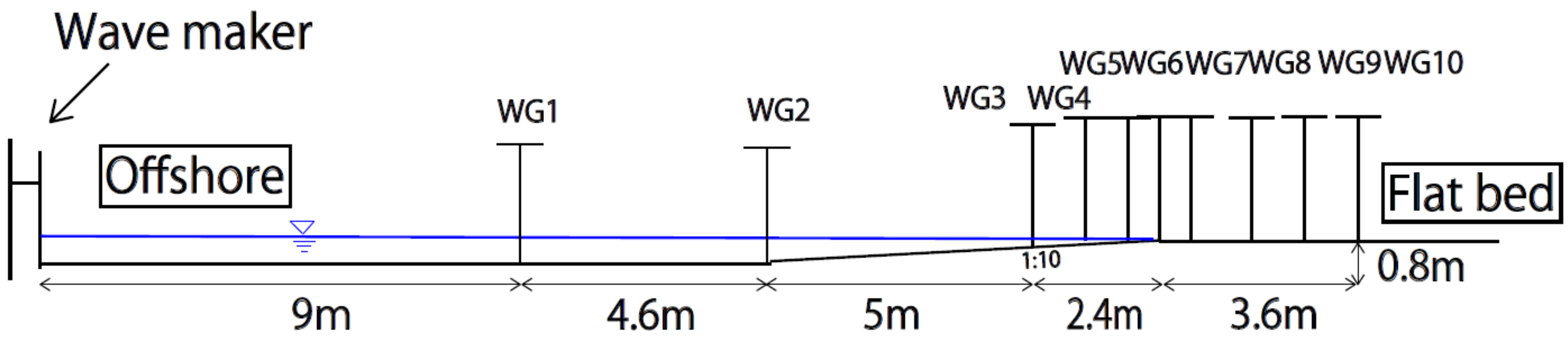
Since there is limited observational record, detailed movement mechanisms are still poorly known.

This study aims to measure transport characteristics of coastal boulders by storm waves and tsunamis through a series of experiments in a Hybrid Tsunami Flume .

Experimental setup and conditions

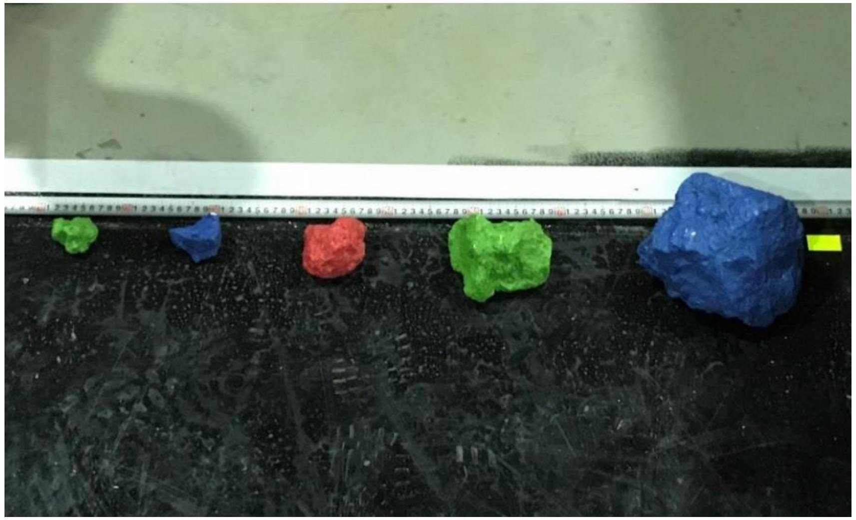
Experimental setup by two-way wave flume

- This study uses the Hybrid Tsunami Open Flume in Ujigawa lab, Kyoto University (HyTOFU) (45*4*2m).
- Set boulders on the flat reef edge (8*4*0.8m).
- Change the initial water level (h=0.74,0.79,0.84m).

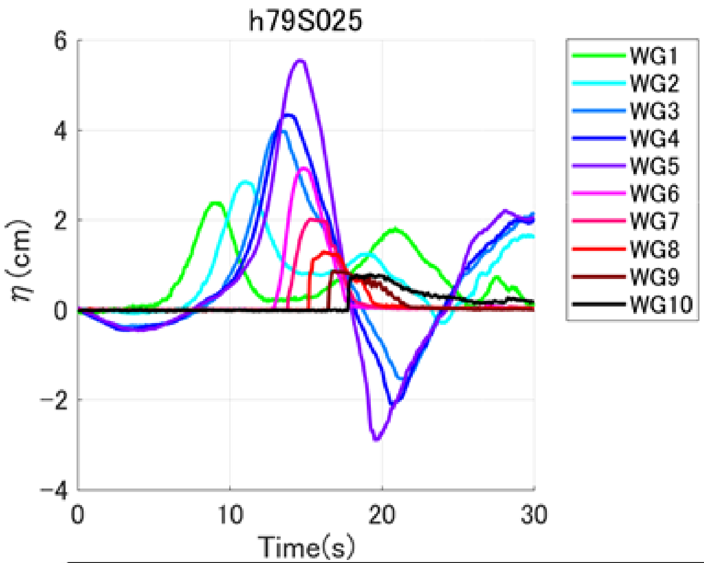


Cross-sectional view

Conditions: Input wave and boulders



	Model (S=1/50)	Prototype
Representative diameter	2~11cm	1~5.5m
Weight	17.7~2900g	2.27~366t



	Model (S=1/50)	Prototype
Solitary wave η	2.5, 5, 7.5, 10, 12.5, 15, 20 cm	1.25, 2.5, 3.75, 5, 6.25, 7.5, 10 m
Irregular wave Significant wave height $H_{1/3}$	7.5, 11, 15 cm	3.75, 5.5, 7.5 m
Wave period $T_{1/3}$	1.69, 2.12, 2.55 s	12, 15, 18 s

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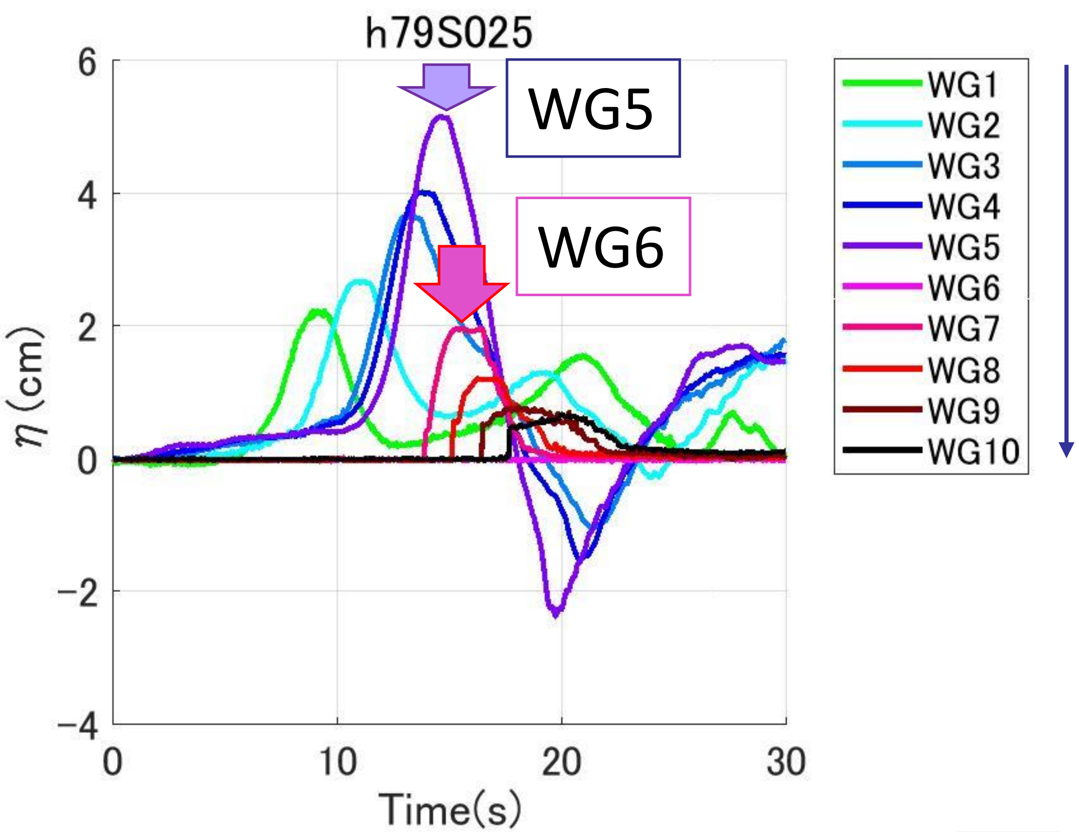
Wave characteristics: Solitary wave

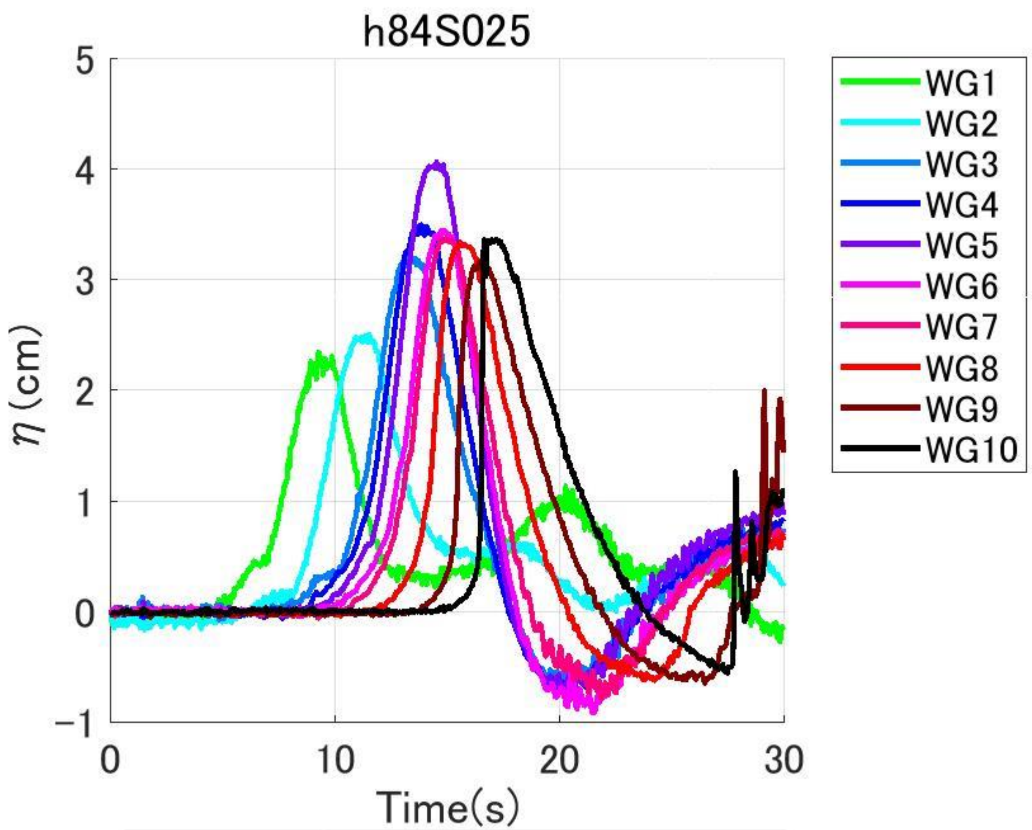
Solitary wave condition

h=0.79m η=2.5cm



Solitary wave condition

h=0.84m η=2.5cm



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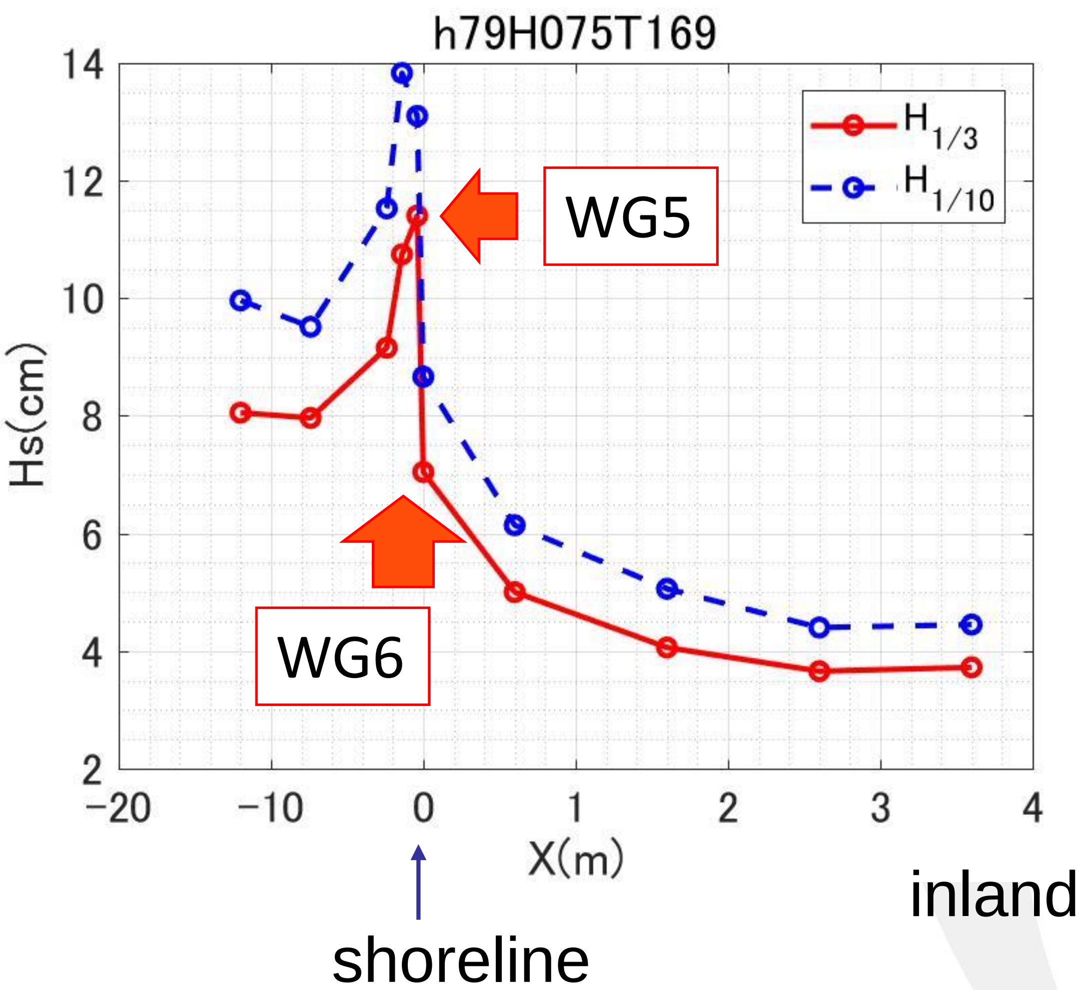
Wave characteristics: Irregular wave

Irregular wave condition
h=0.79m Hs=7.5cm



- Just like solitary wave condition, in case of irregular wave, wave height decrease remarkable at WG6 located in shoreline.

Experimental procedure

Set the different size of boulders on the flat reef edge inline

↓

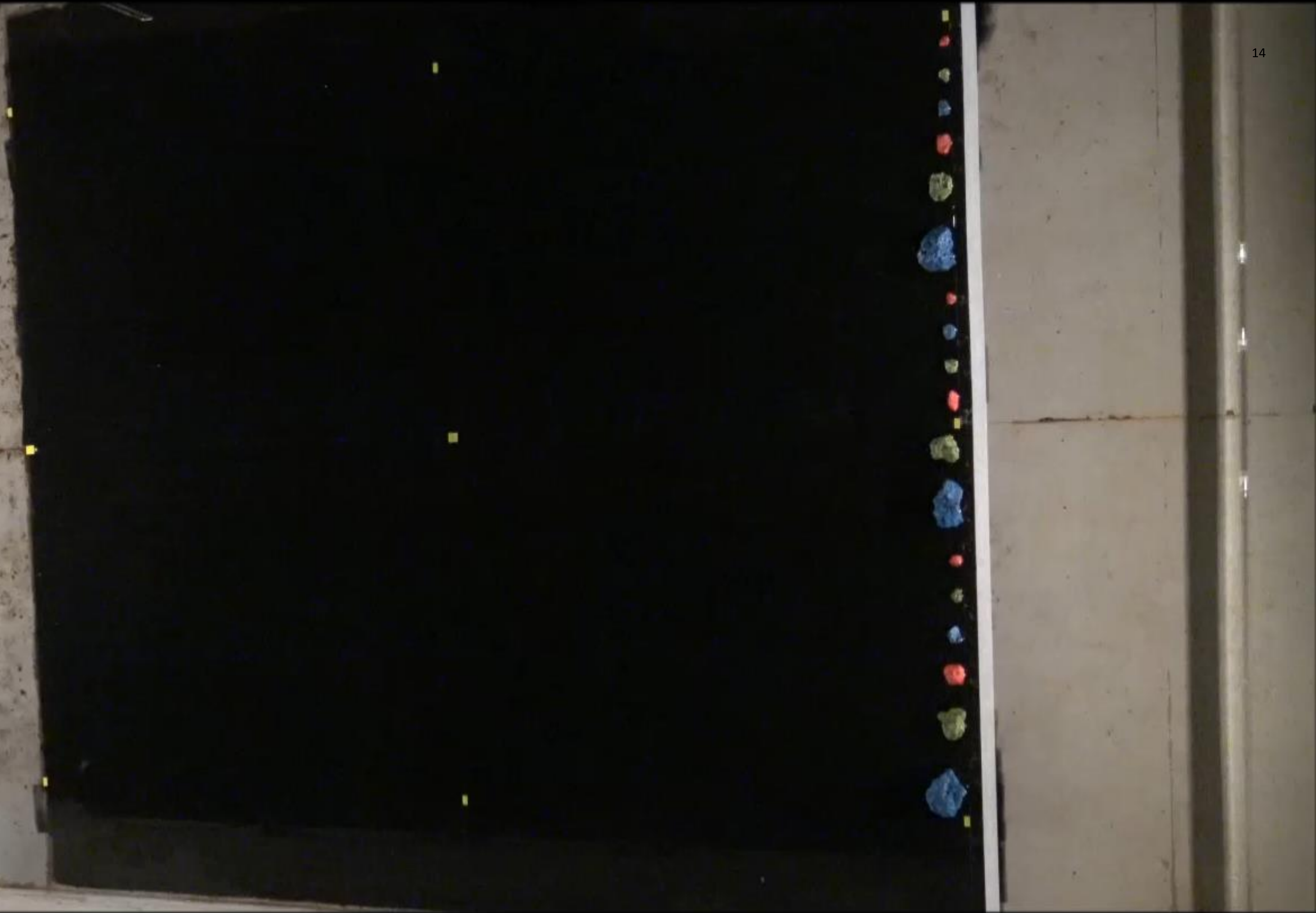
Generate waves.

Solitary wave	Irregular wave

↓

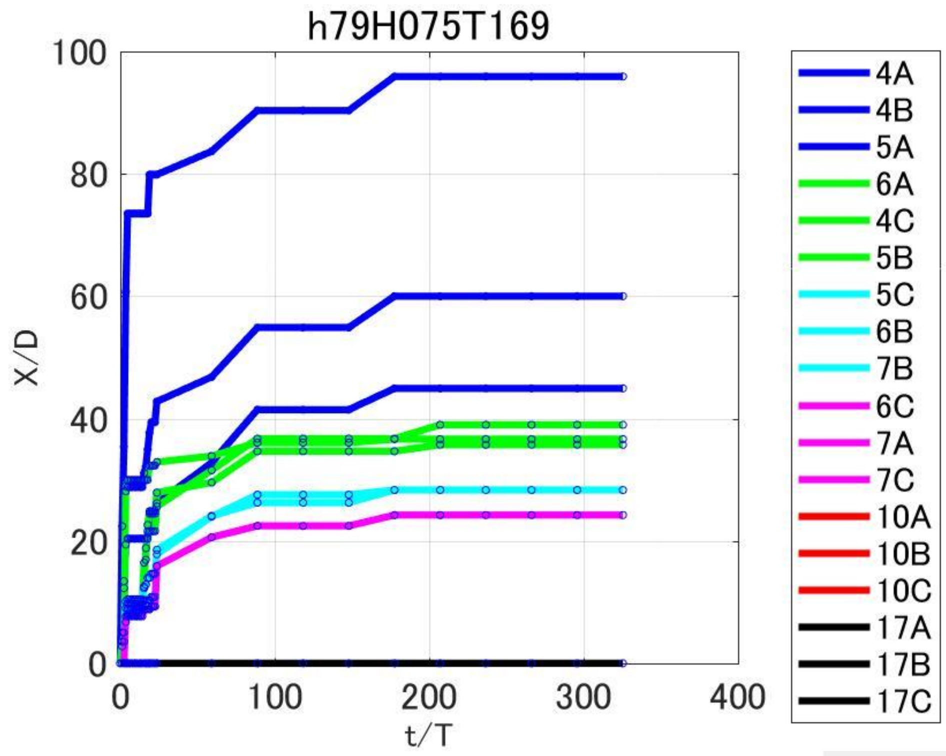
Measure the distance from initial position to final position.

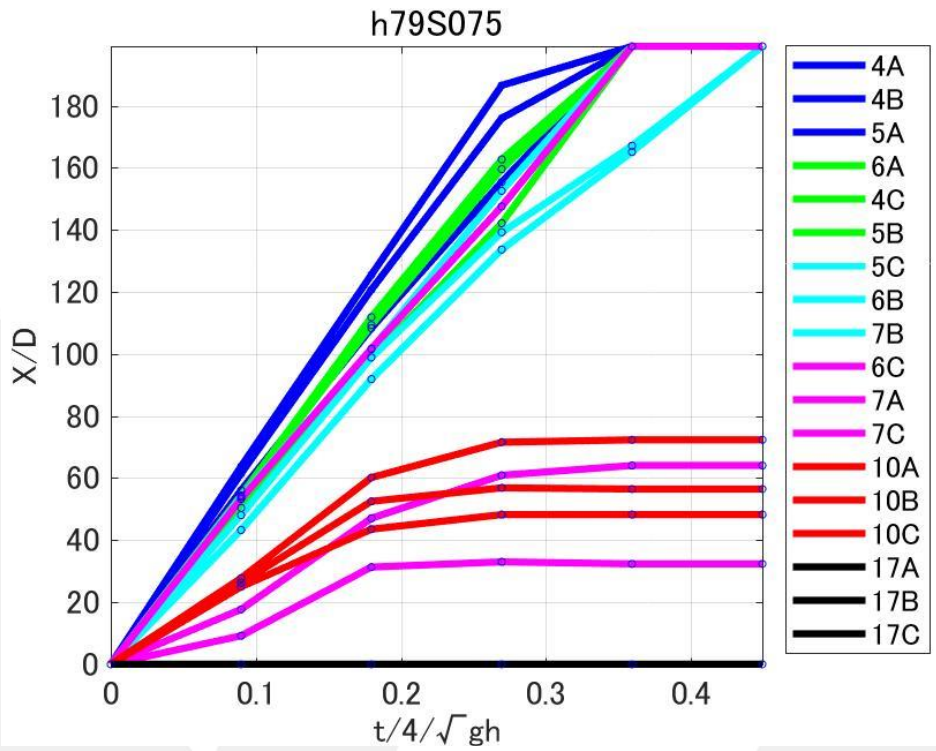
Final position	Sequence of movement



Results and discussion

Time series of boulders motion

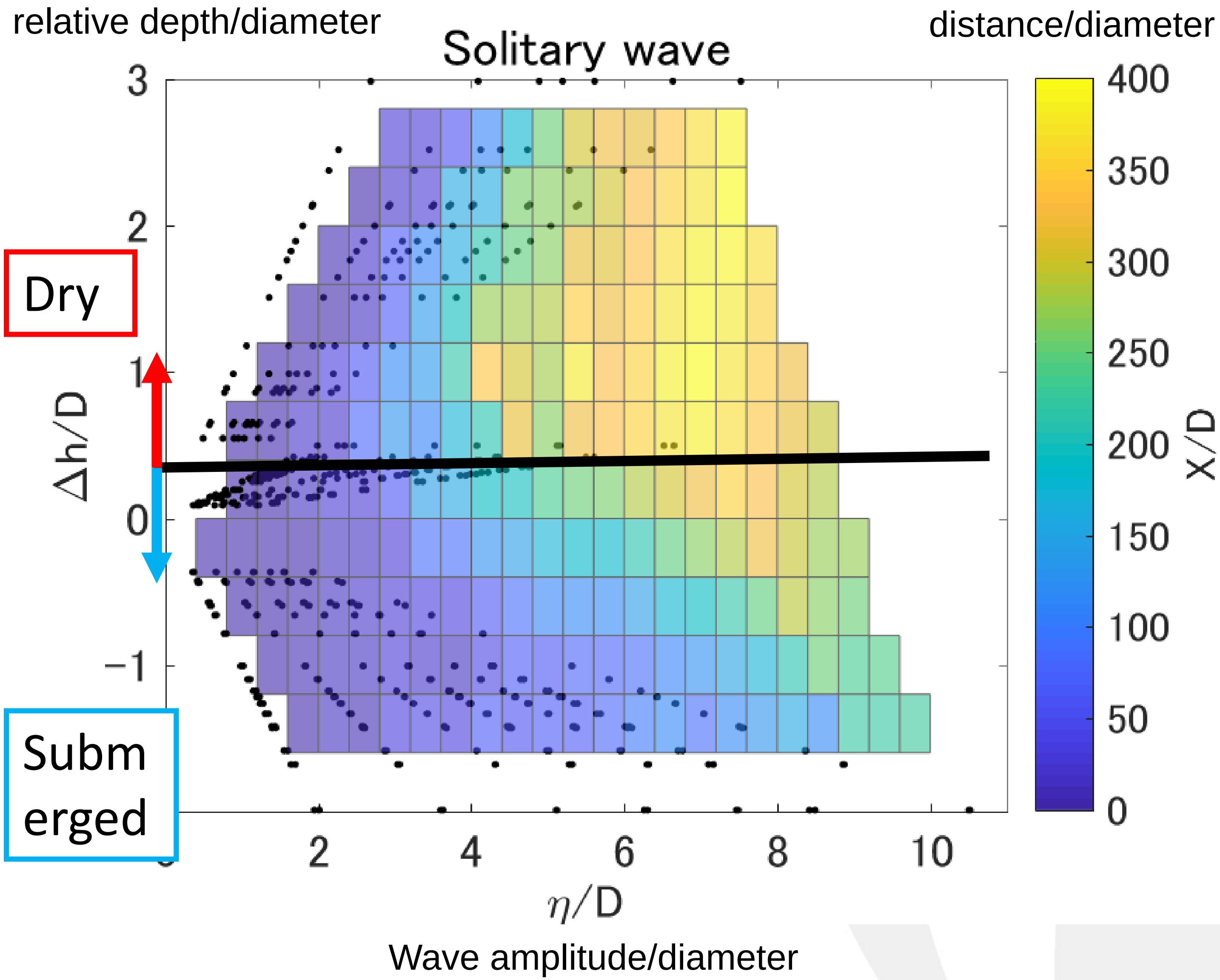




In irregular wave conditions, time series of motion showed more for and shows strong mobility in the early stages.

In solitary wave conditions, time series of motion showed almost linearly in proportion to the time-lapse.

Boulder distributions



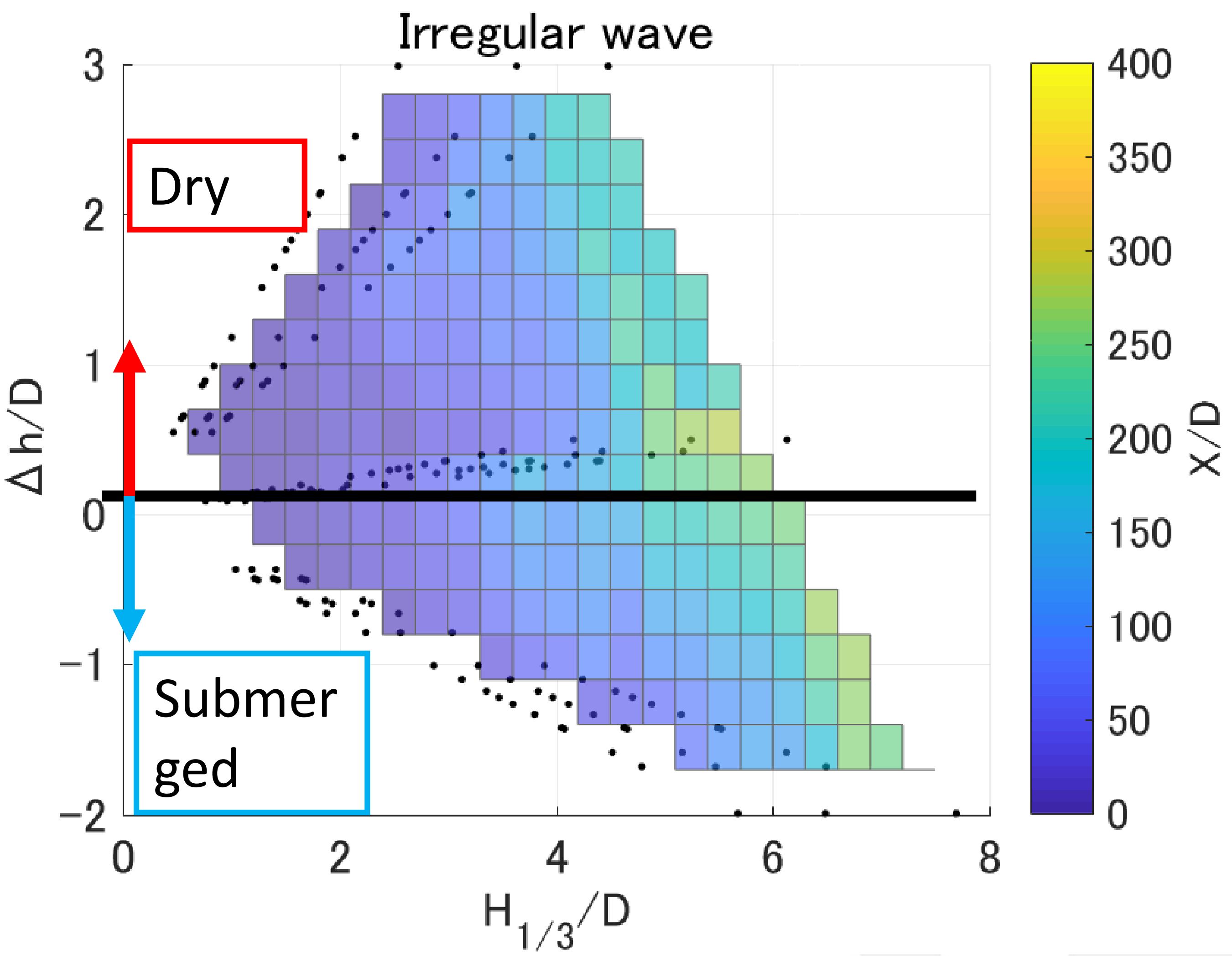
Summarized by water level (h), wave height (η or Hs), and final position of boulder(X).

Δh=Grand Level(0.8m)-Water Level (0.74,0.79,0.84m)

Transport distance increases when the reef is dry.

- Strongly affected by wave breaking point of solitary wave.

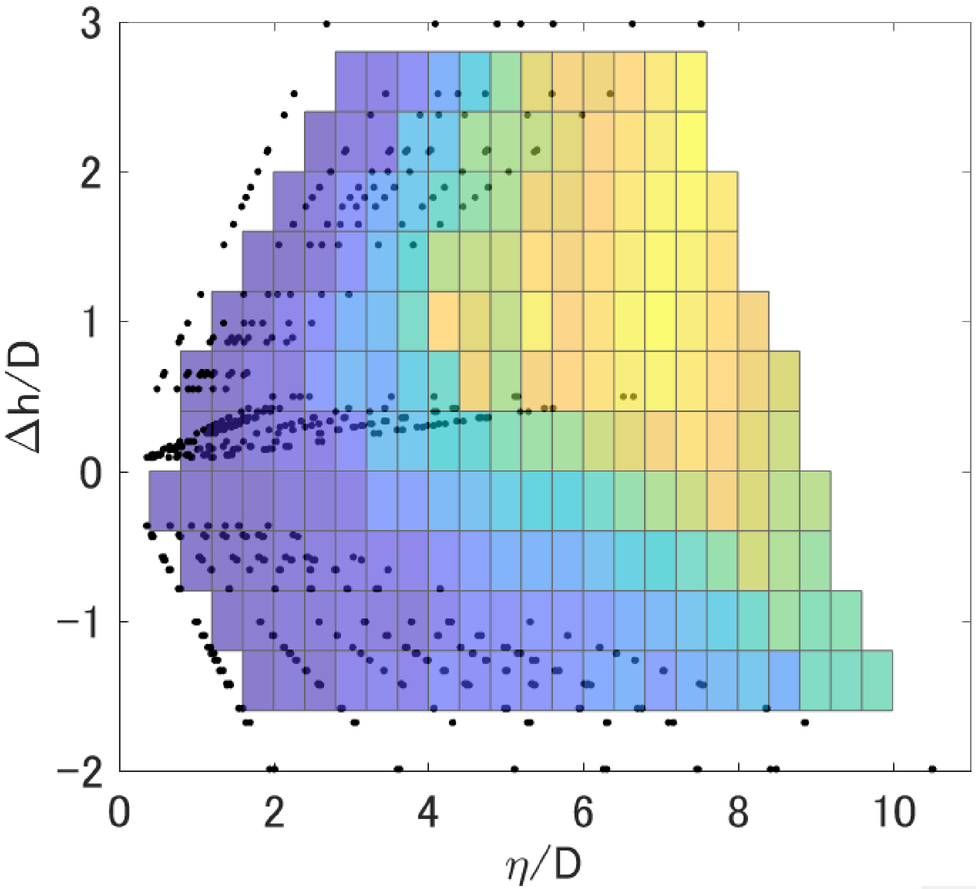
Transport characteristics



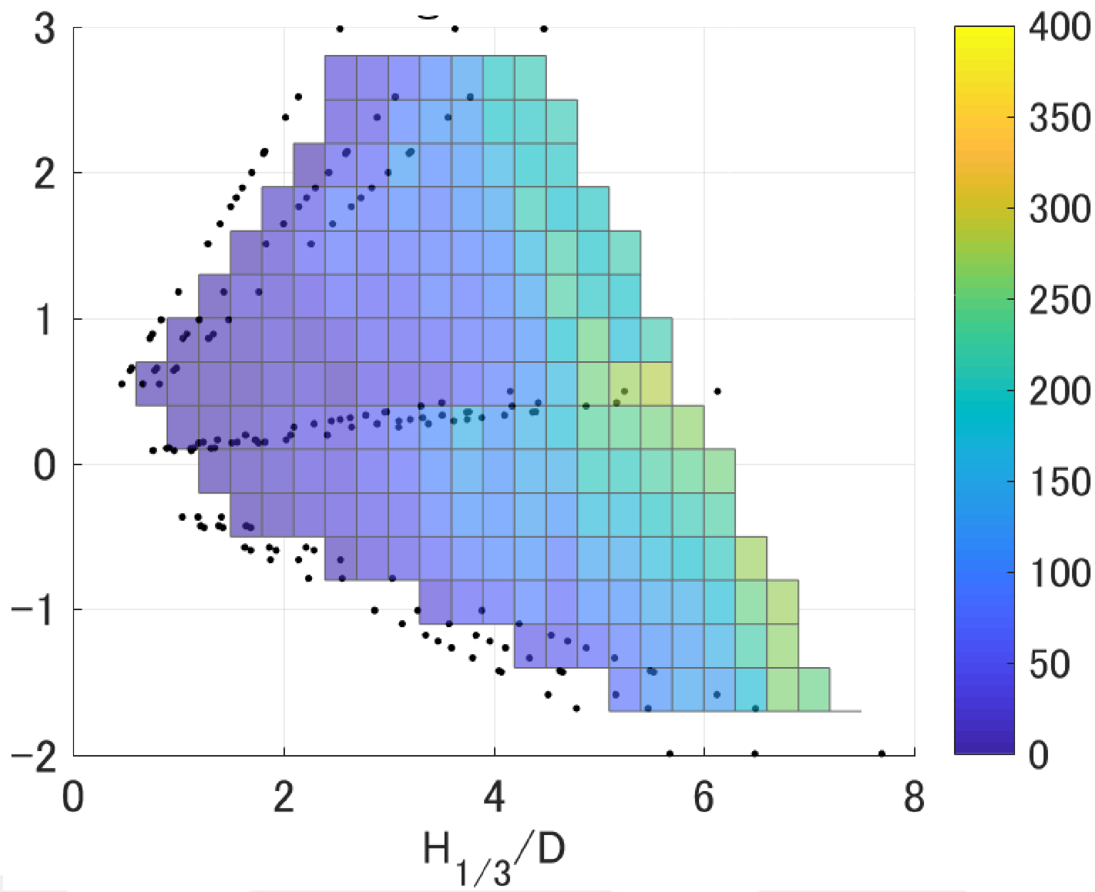
Transport distance increases when the reef is submerged.

- ➢ Irregular waves repeatedly force to the boulders, and apparent weight become light in the submerged condition by set up.
- ➢ Resulting smaller friction and movable condition.

Transport characteristics



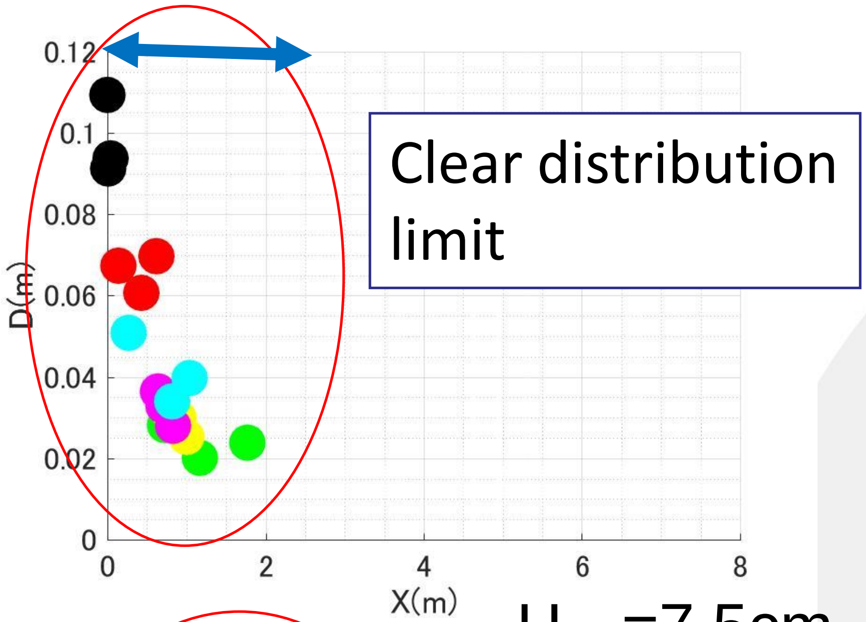
Solitary wave

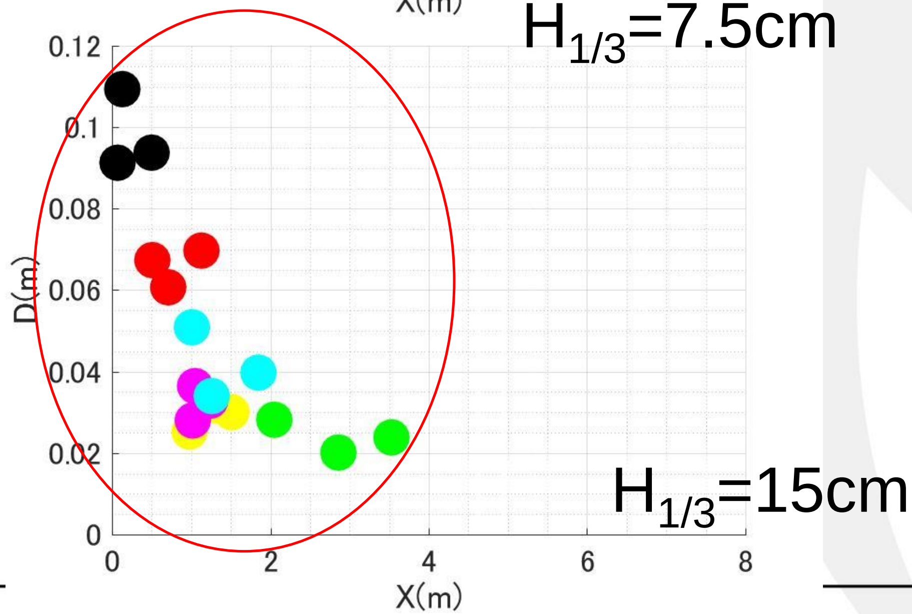


Irregular wave

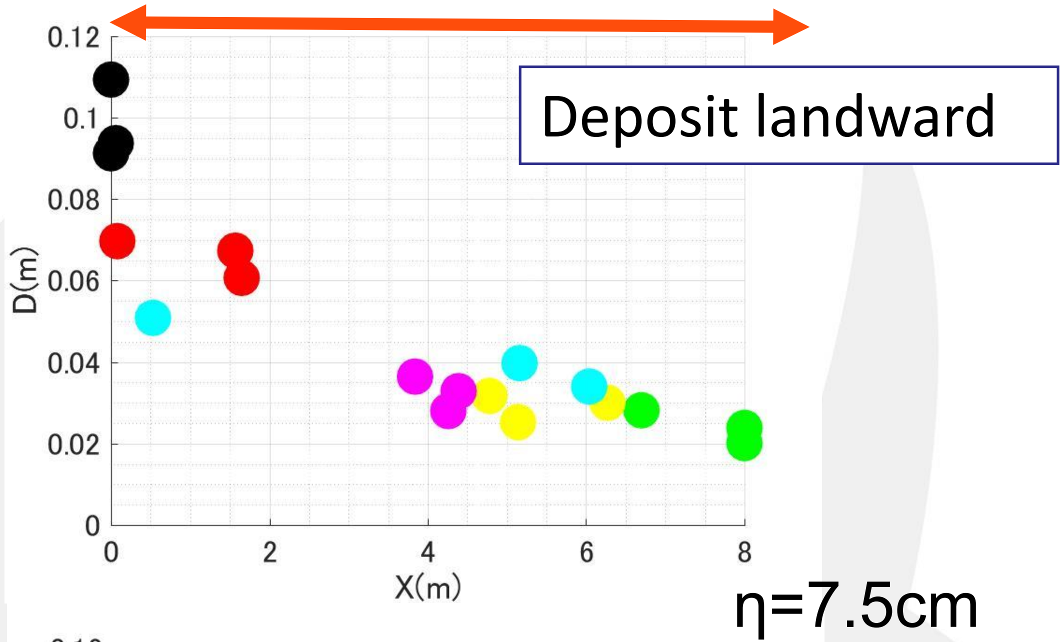
Transport distance of different size boulders

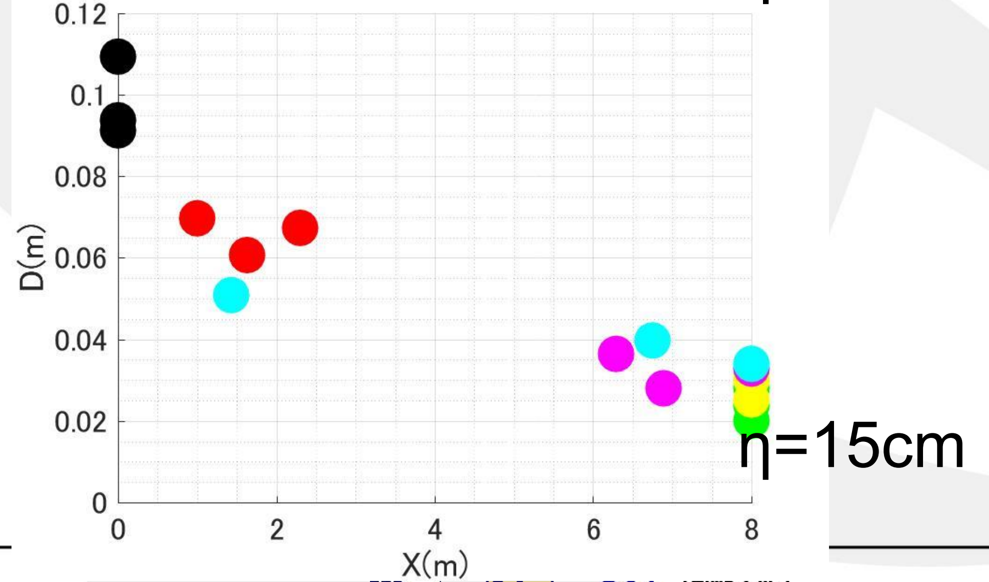
Irregular wave



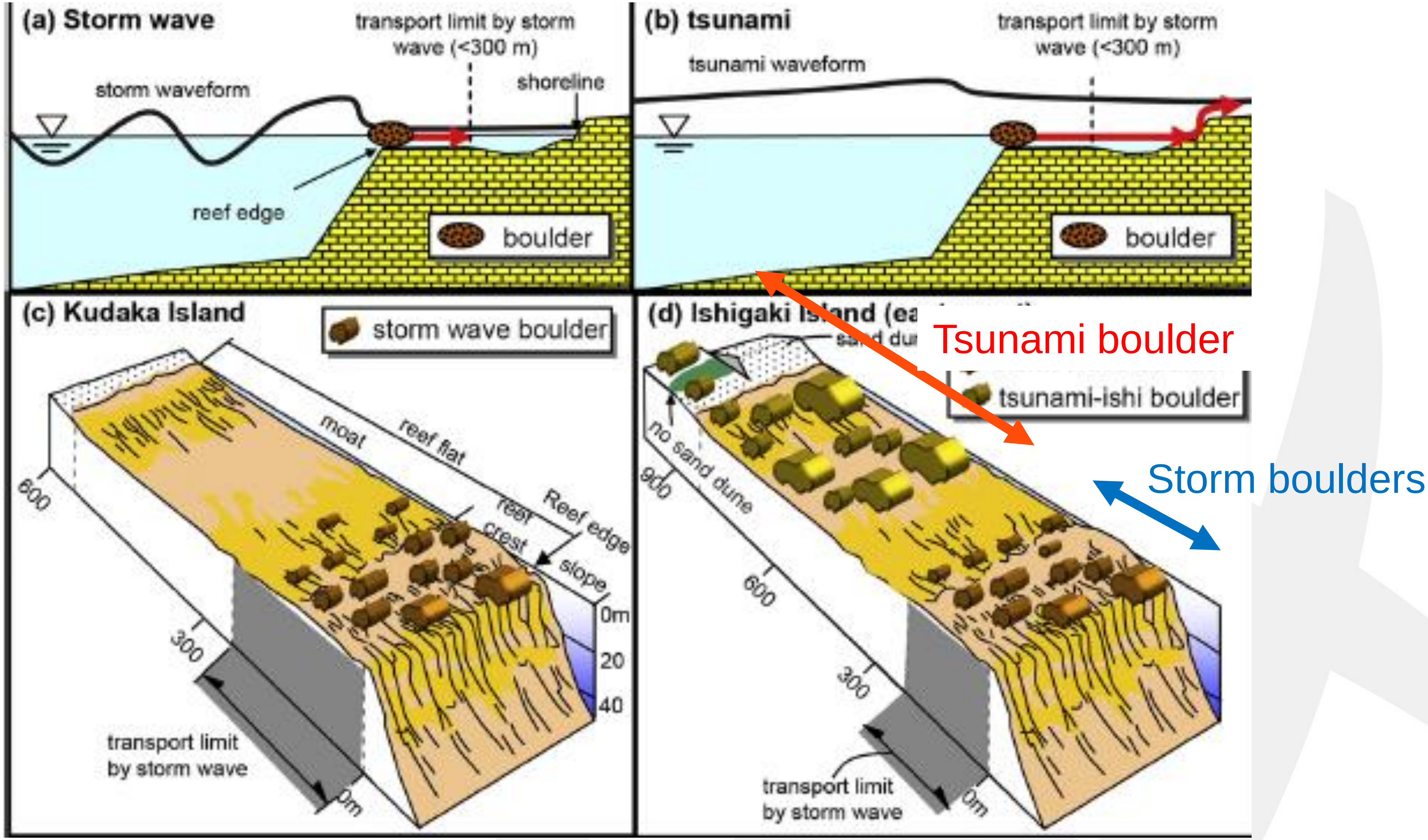


Solitary wave





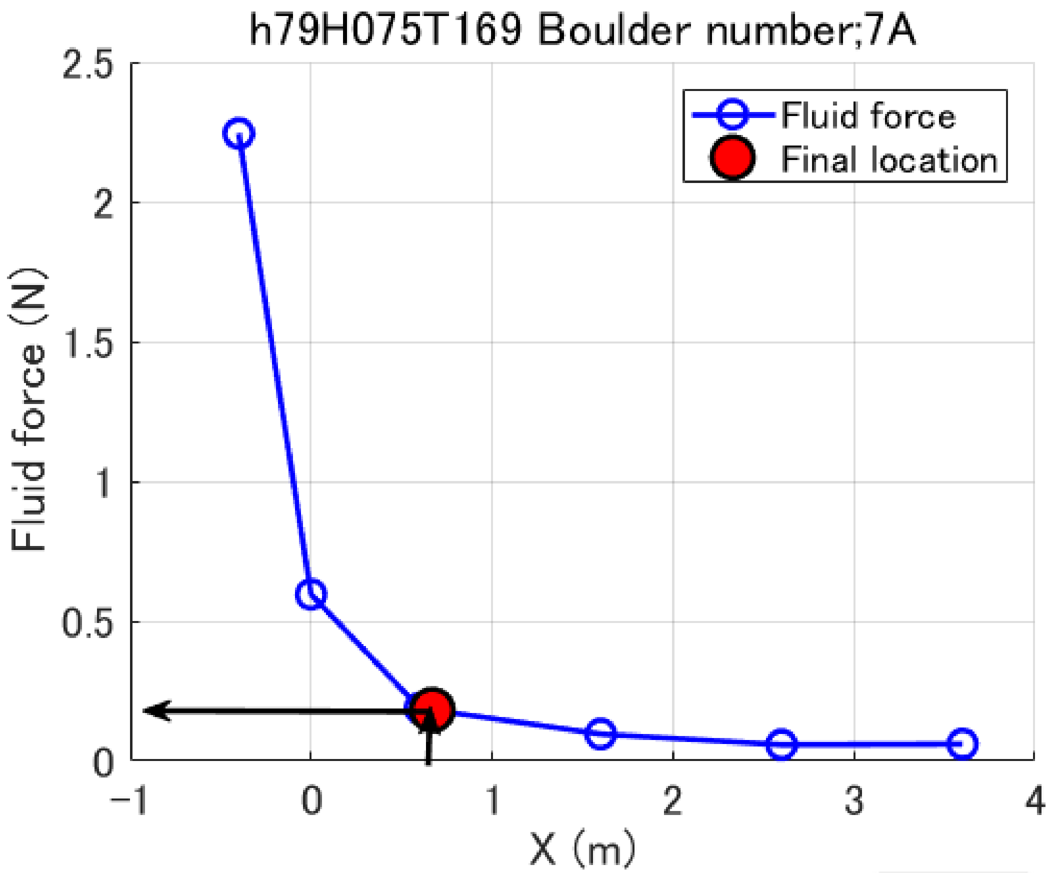
Boulder distributions in the fields



Experimental results indicate

- Storm boulders range narrow area
- Tsunami boulder are widely spread

Stability analysis: outline



Fluid force at the final position in case of irregular wave.
（Blue line ： Fluid force,
Red point ： Final position）

Sakakiyama.(2014) reported the fluid force acting on oil tank by tsunami.

$$F_d = \frac{1}{2}\rho C_R u^2 A$$

C_R=1.0 for our condition.

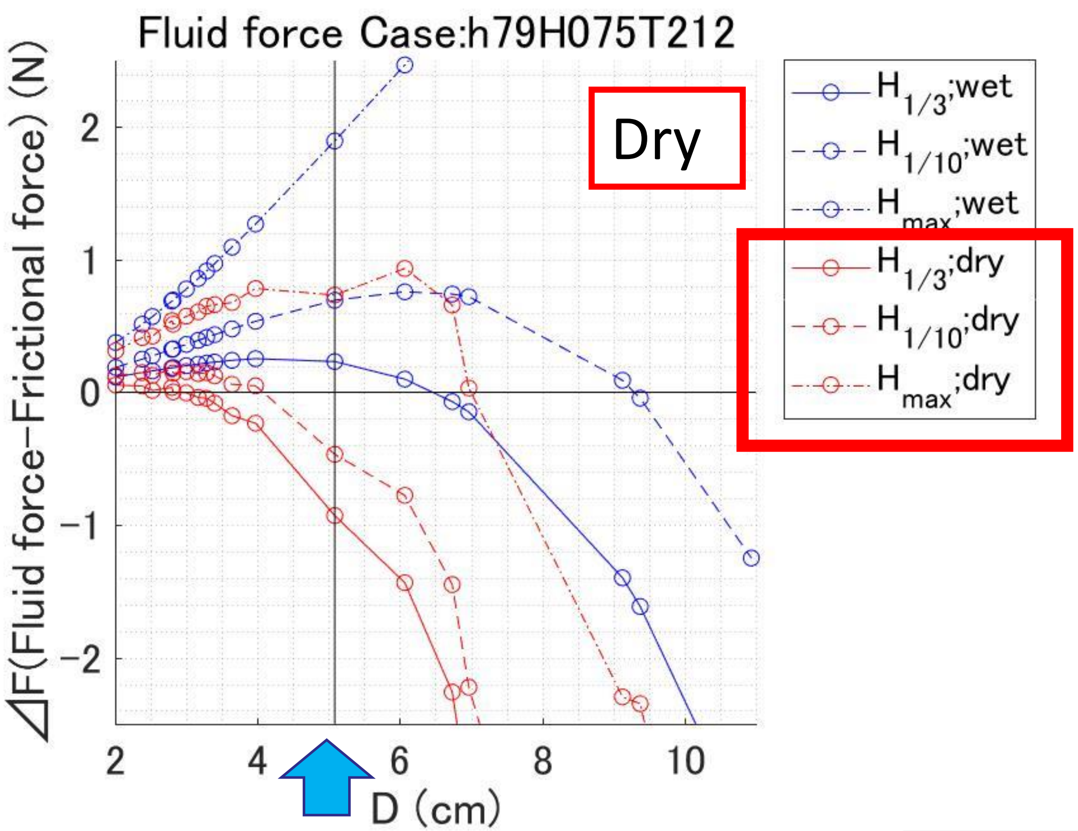
Fluid velocity (u) is calculated assuming small amplitude waves theory.

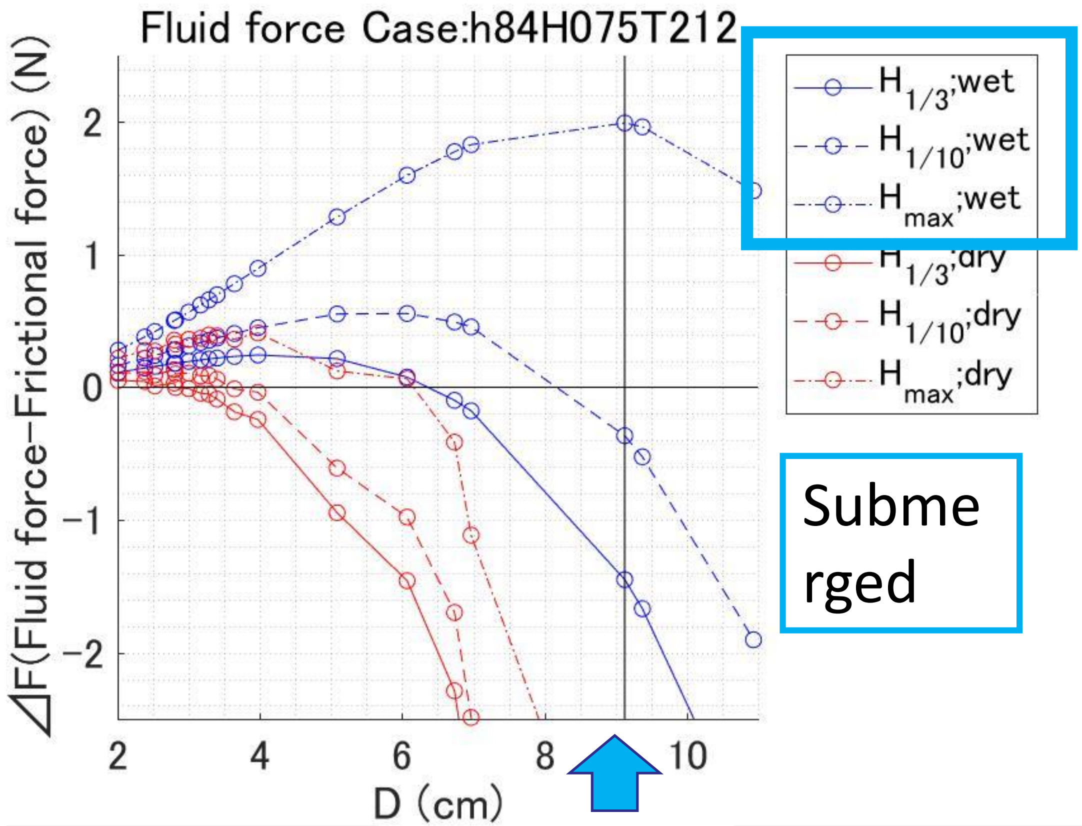
$$u = \pi \frac{H}{T}\frac{1}{kh_s}$$

Fluid force is in proportion to wave height.
When the frictional force becomes larger than the fluid force, the boulders reach the movement limit.

➢ The force required to move.

Stability analysis 1/2





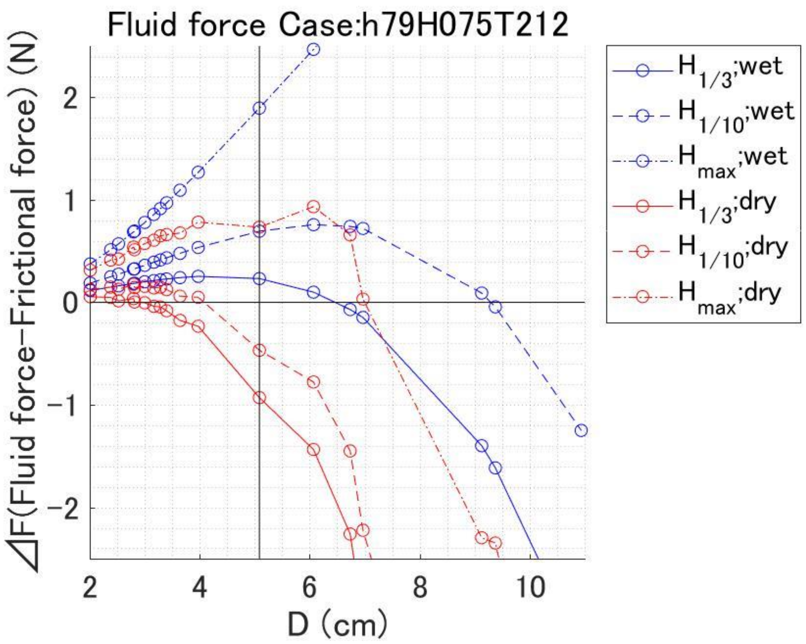
Representative diameter between movable and stationary

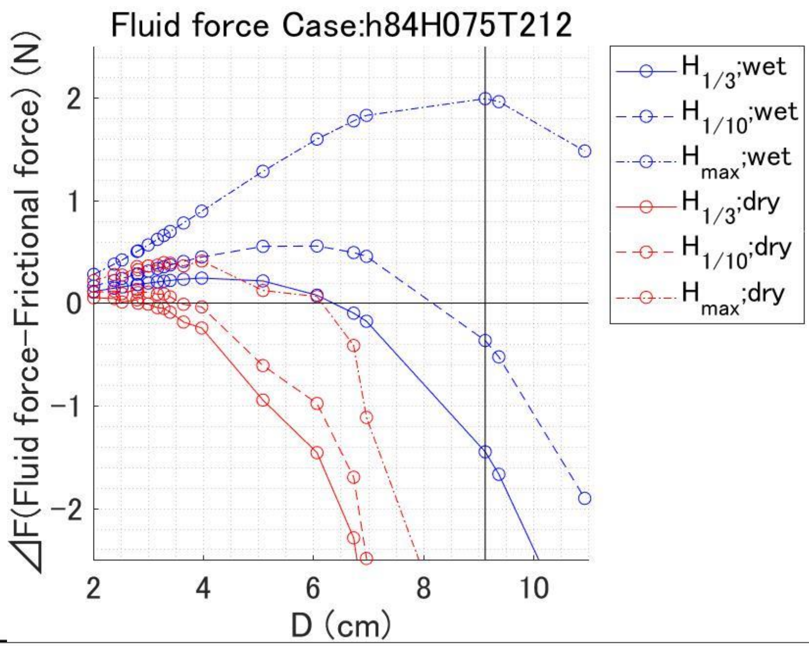
$$\Delta F = F_d - F_f$$

F_d : Fluid force (N)

F_f : Maximum static friction force (N)

Stability analysis 2/2





Because the boulders move with occasional large waves, evaluate the fluid force with $H_{1/10}$ and H_{max}.

- Fluid force should be evaluated with $H_{1/10}$.
- Consider the weight of the boulders which are changed by buoyancy depending on the condition of the reef.

Although these results vary depending on how fluid force is given, these simple theories are evaluated with these.

Conclusions

- This study conducted to measure transport characteristics of coastal boulders through a series of experiments in a Hybrid Tsunami Open Flume .

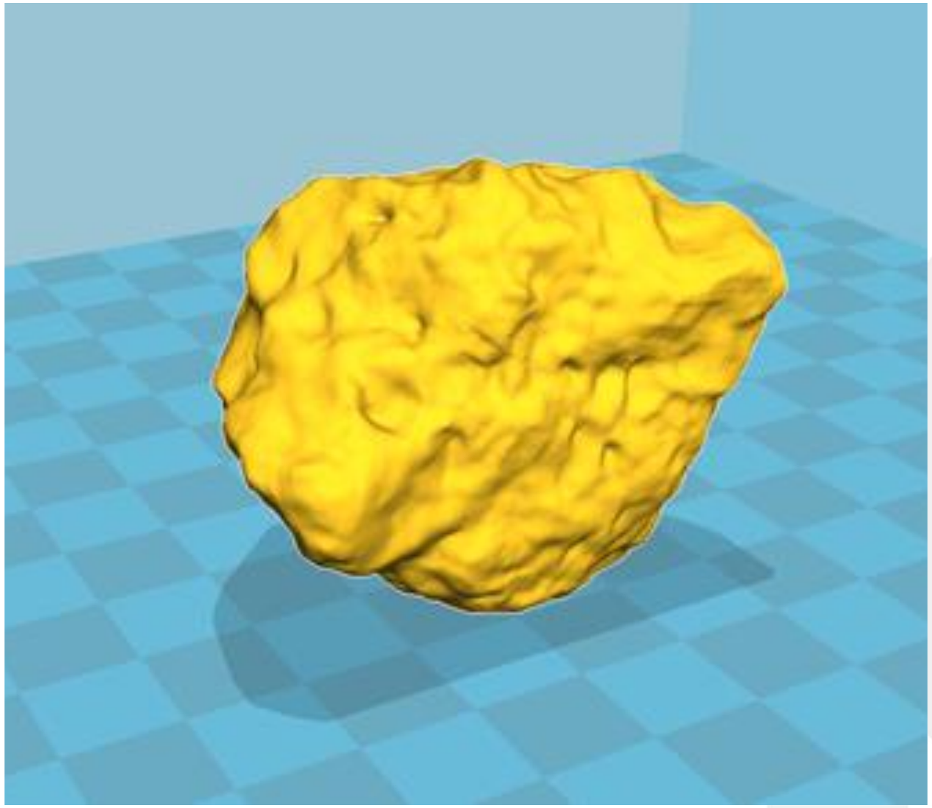
Conclusions

- The dynamics of boulder transport show a strong dependence on both detailed hydrodynamics and boulder properties, some of which have never been observed in the field.
- Largest transport distances are found for still water levels just below a flat shelf, and one long tsunami waves will transport boulders for much greater distances than many irregular storm waves.

Thank you for your attention.

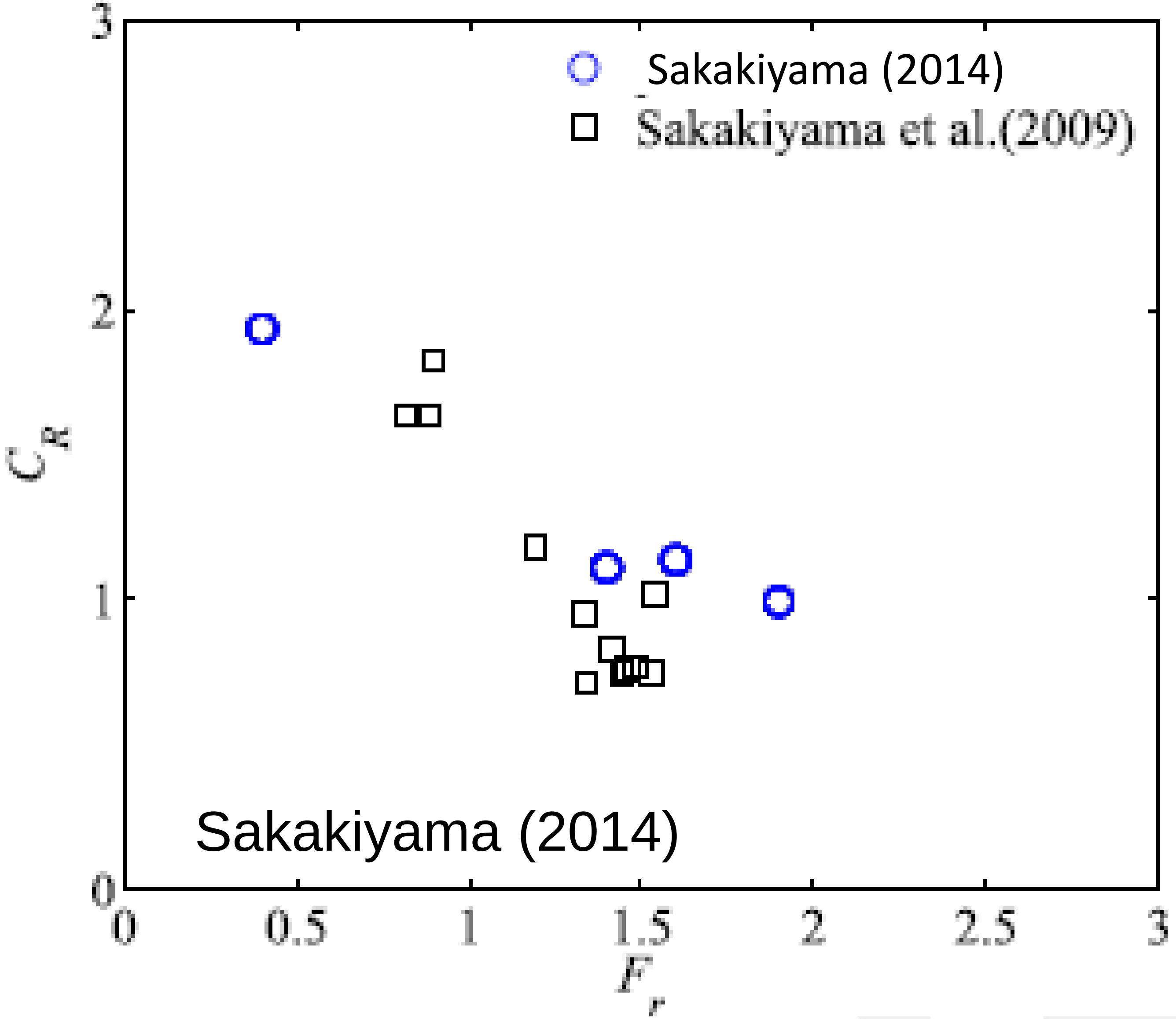
Do you have any questions?

STL (Stereolithography) data of boulders.



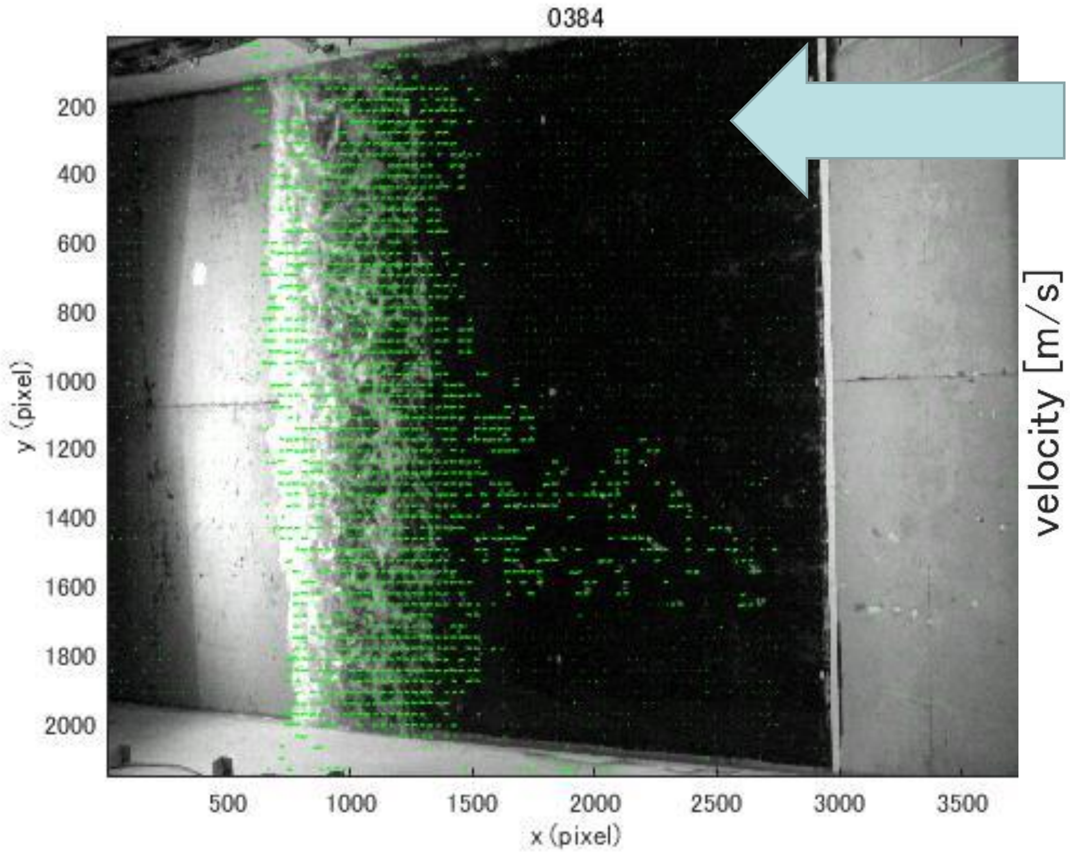
- Boulder various factors (Diamter, Volume) are given by STL data .
- STL data of boulders can be obtained from 3D printer.

Resistance coefficient



- C_R means resistance coefficient (combine drag coefficient with surface coefficient) depending on Froude number.
- Based on the relationship between the C_R of the experiment result of Sakakiyama and the Fr, C_R = 1.0 is set because Fr is 1.2 to 1.5 in this experiment .

PIV


0384
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y (pixel)
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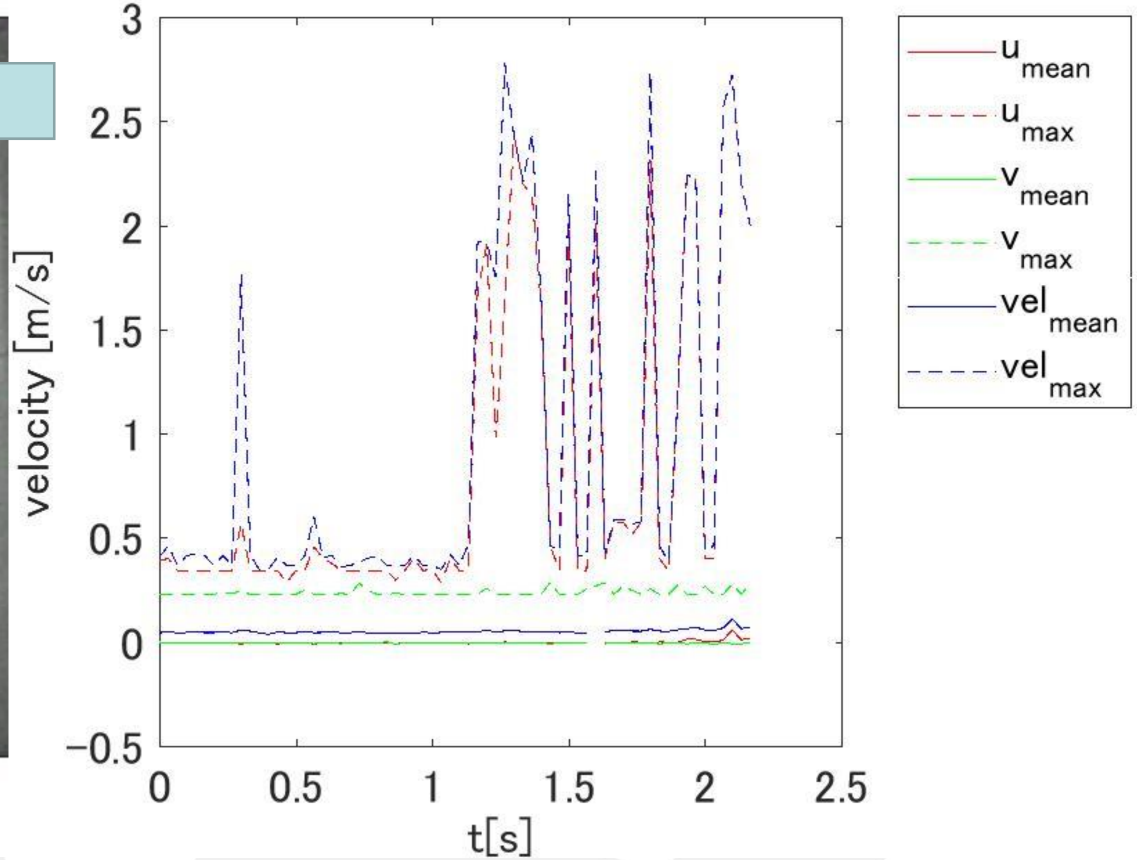
3
2.5
2
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1
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velocity [m/s]
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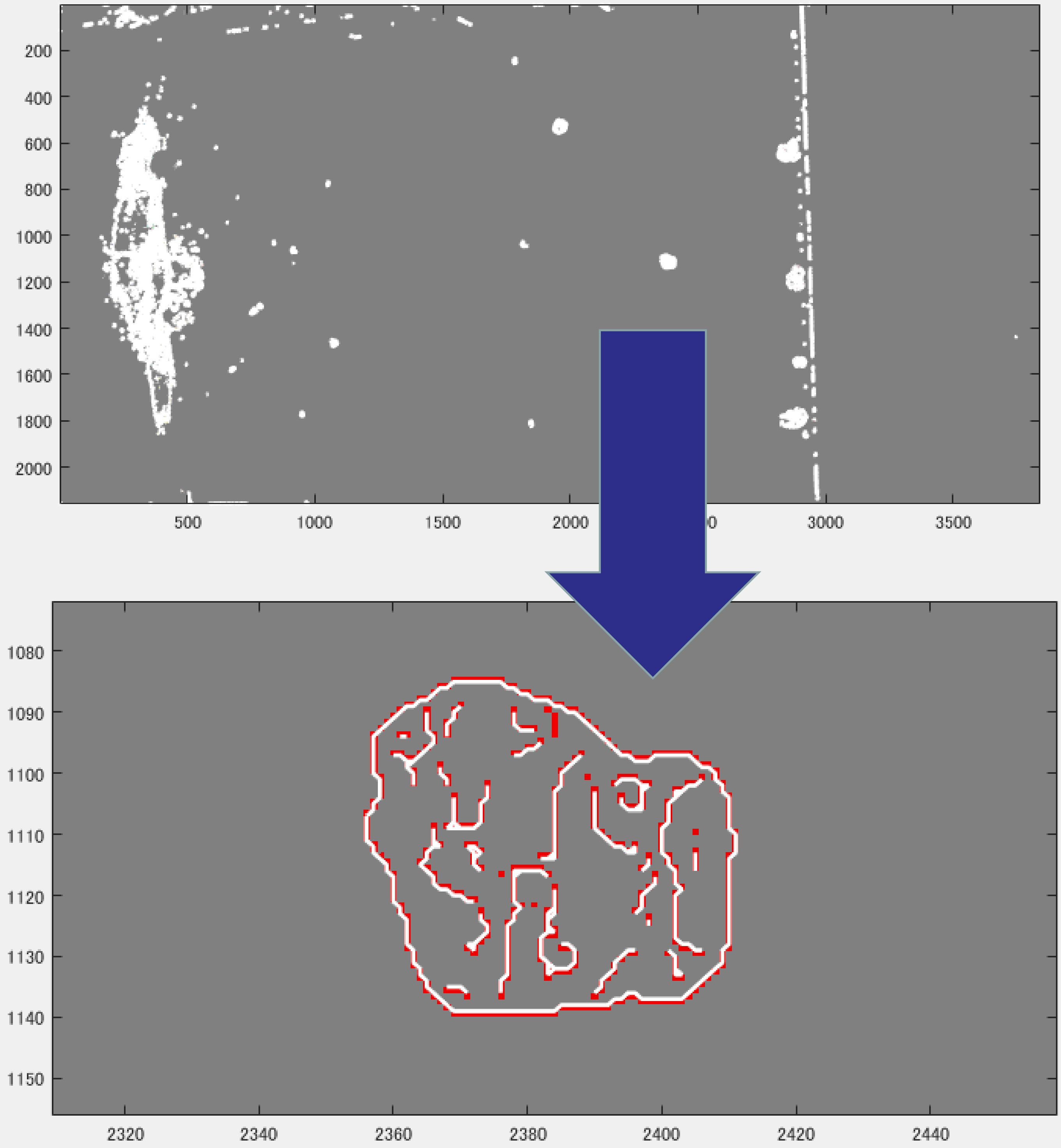

Enlarge the whole drawing and read the number of pixels.

- ➢ Convert to meters from there.

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	Wet	Dry
Coefficient of static friction	0.650	0.601
Coefficient of dynamic friction	0.270	0.424