Compound flood modelling of wave overtopping and surge overflow under the dynamic surge and wave circumstances

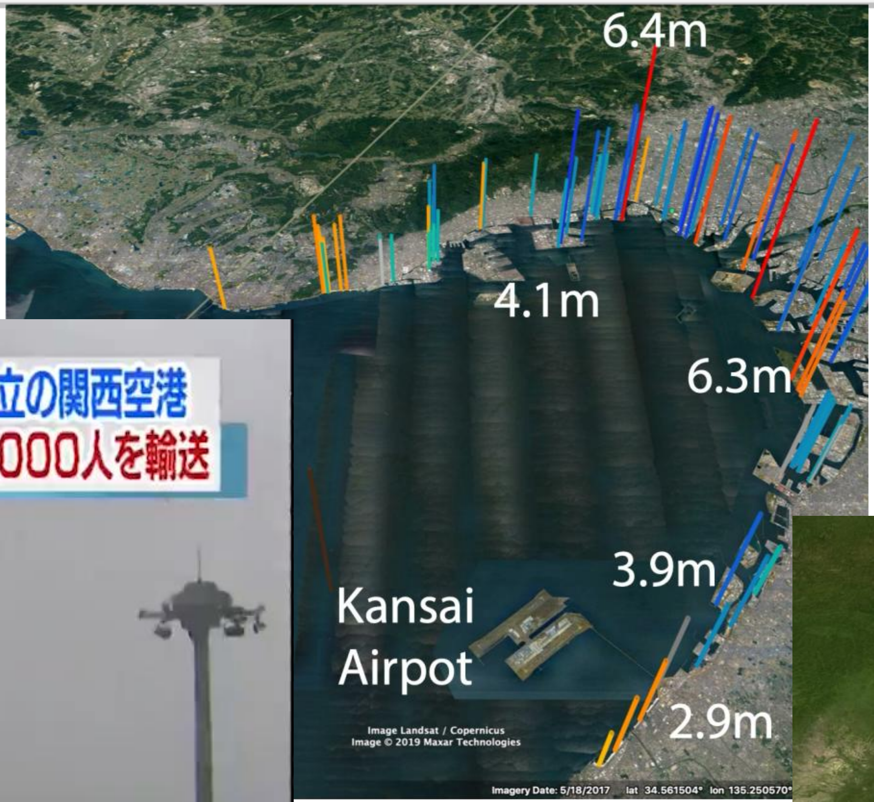
Sooyoul Kim[1], Junbeom Jo[2], Tomohiro Yasuda[3], Nobuhito Mori[2]

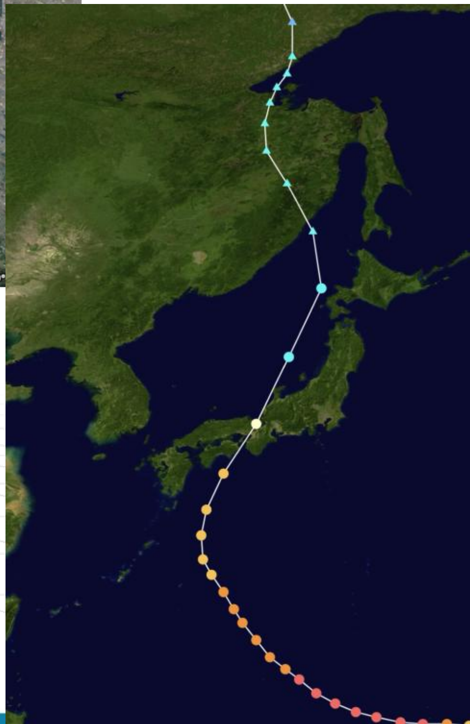
[1]Center of Water Cycle Marine Environment and Disaster Management, Kumamoto University
[2]Disaster Prevention Research Institute, Kyoto University
[3]Faculty of Environmental and Urban Engineering, Kansai University

熊本大学
Kumamoto University

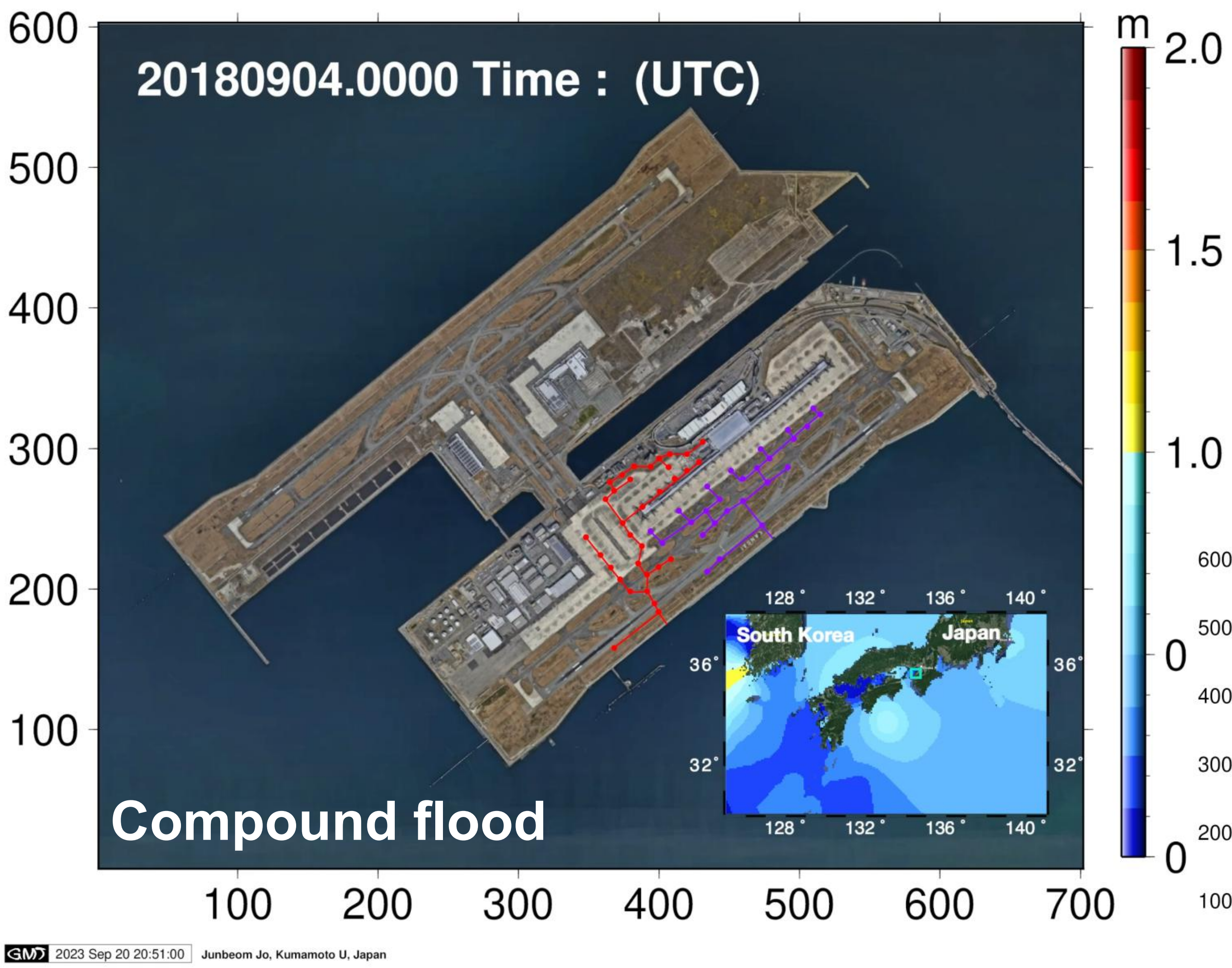
Background and Motivation

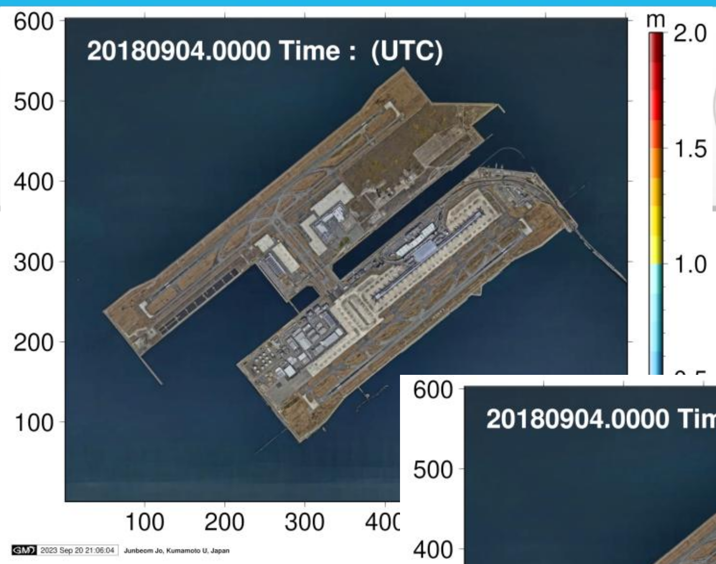
Flooding at Kansai International Airport due to Jebi (2018)



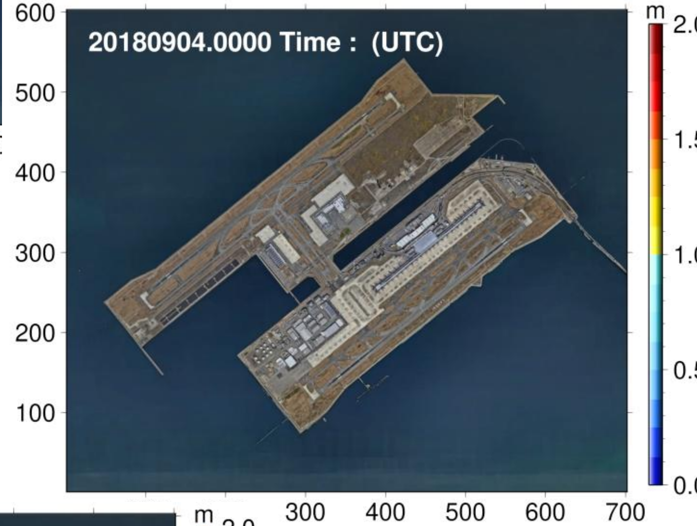


Contributions to floods

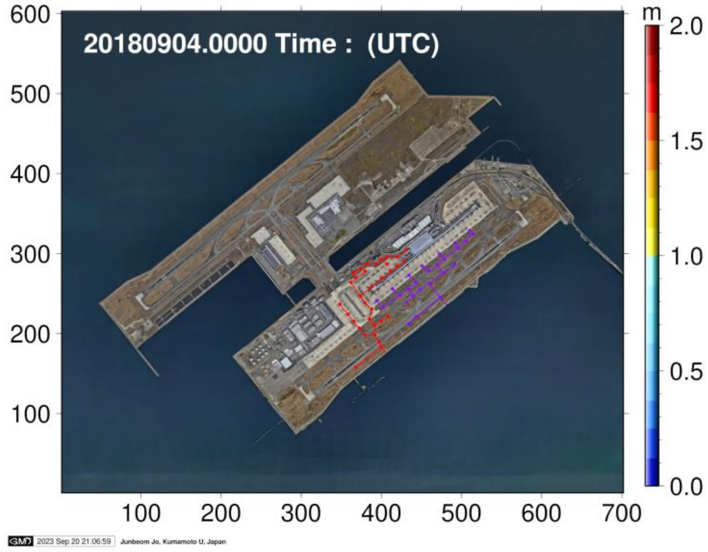




Wave overtopping: 90.8%

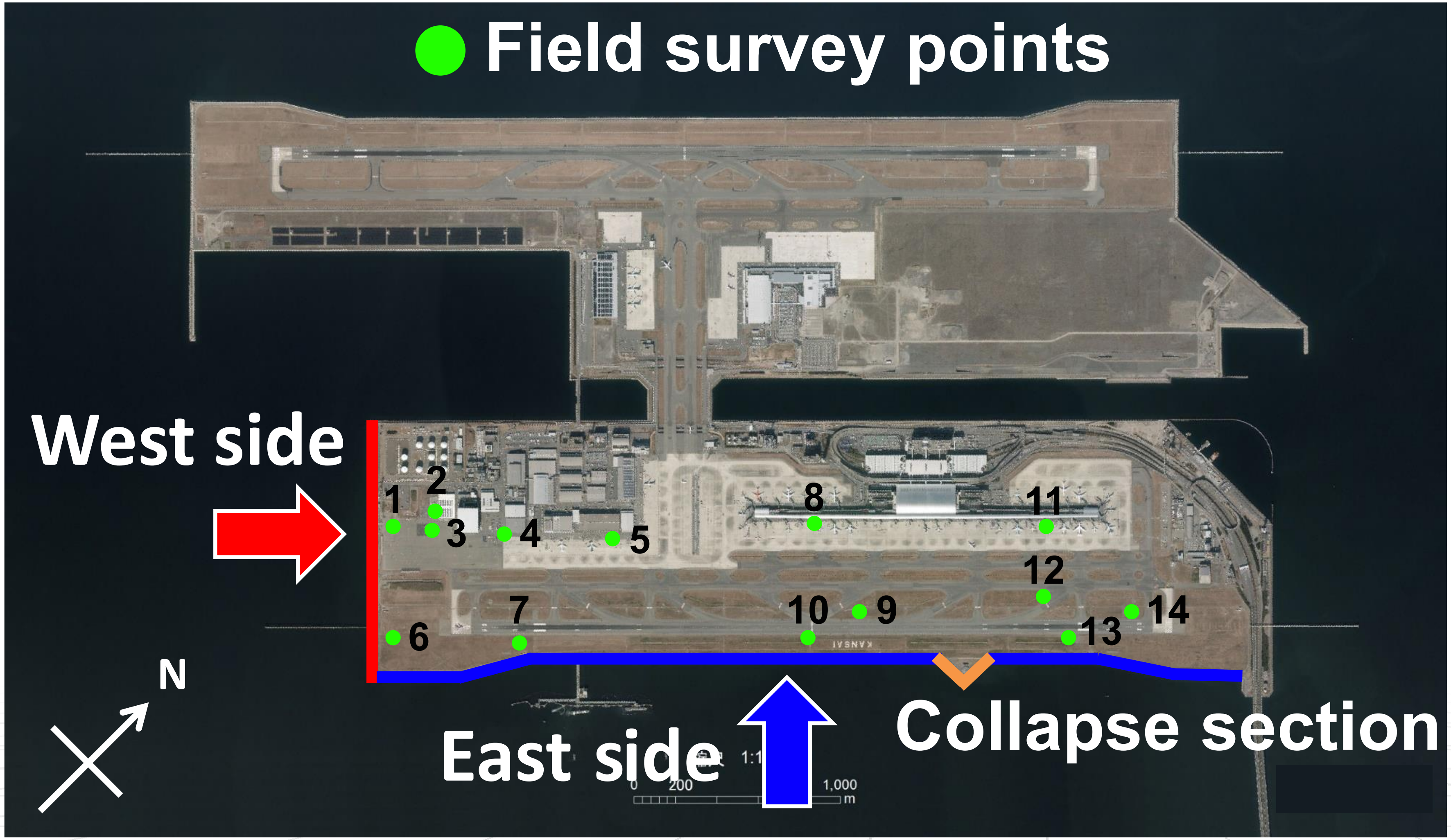


Breakwater Failure: 7.5%

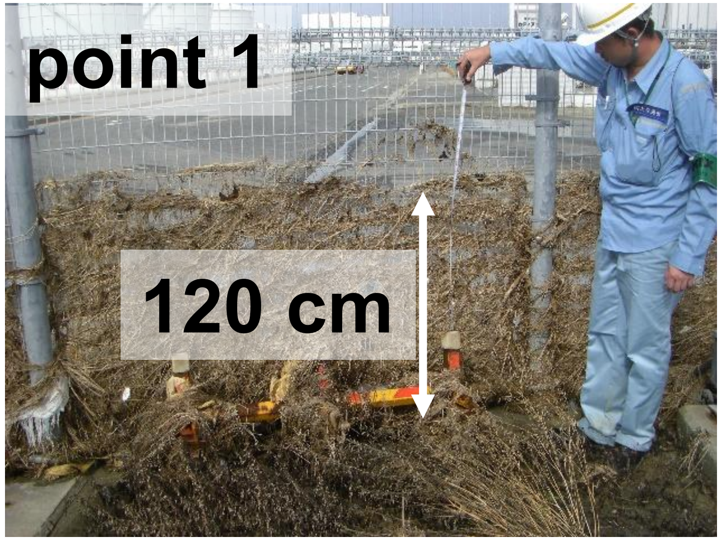


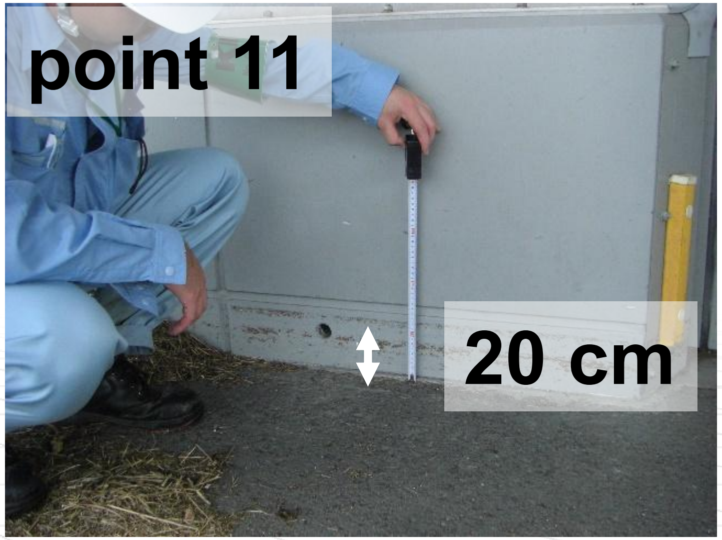
Backflow of sewer system: 1.7%

Calculation VS field survey



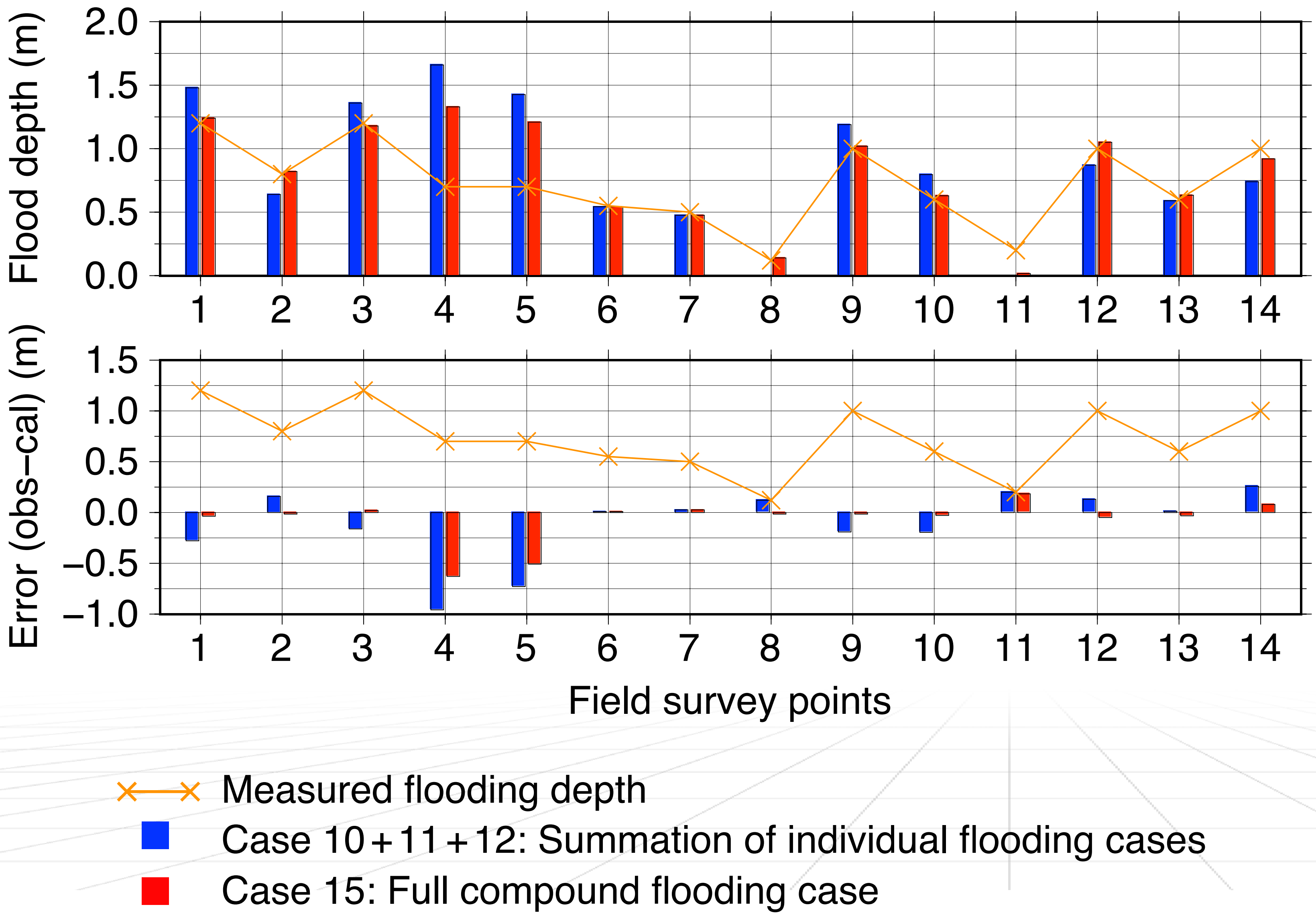
< Location of field survey points (total 14 points) >





< Field survey overview >

Calculation VS field survey Jo. Et al. 2025 Journal of Hydrology



- **Summation of Individual factors**
  - Wave overtopping + Breakwater failure + Backflow of sewer system
- **Compound hazards**
  - **All factors**
- **All factors included in the calculation for compound hazards-induced floods**

Wave overtopping and runup modeling

Wave overtopping Rate estimation diagram

Goda et al. (1973, 1976)

Wave overtopping Rate estimation flowchart

Takayama et al. (1982)

Integrated Formula of Overtopping and Runup Modeling (IFORM)

Mase et al. (2013)

Typhoon Jebi (2018)

Dynamic modeling of compound hazards-induced floods

1) Wave overtopping formula

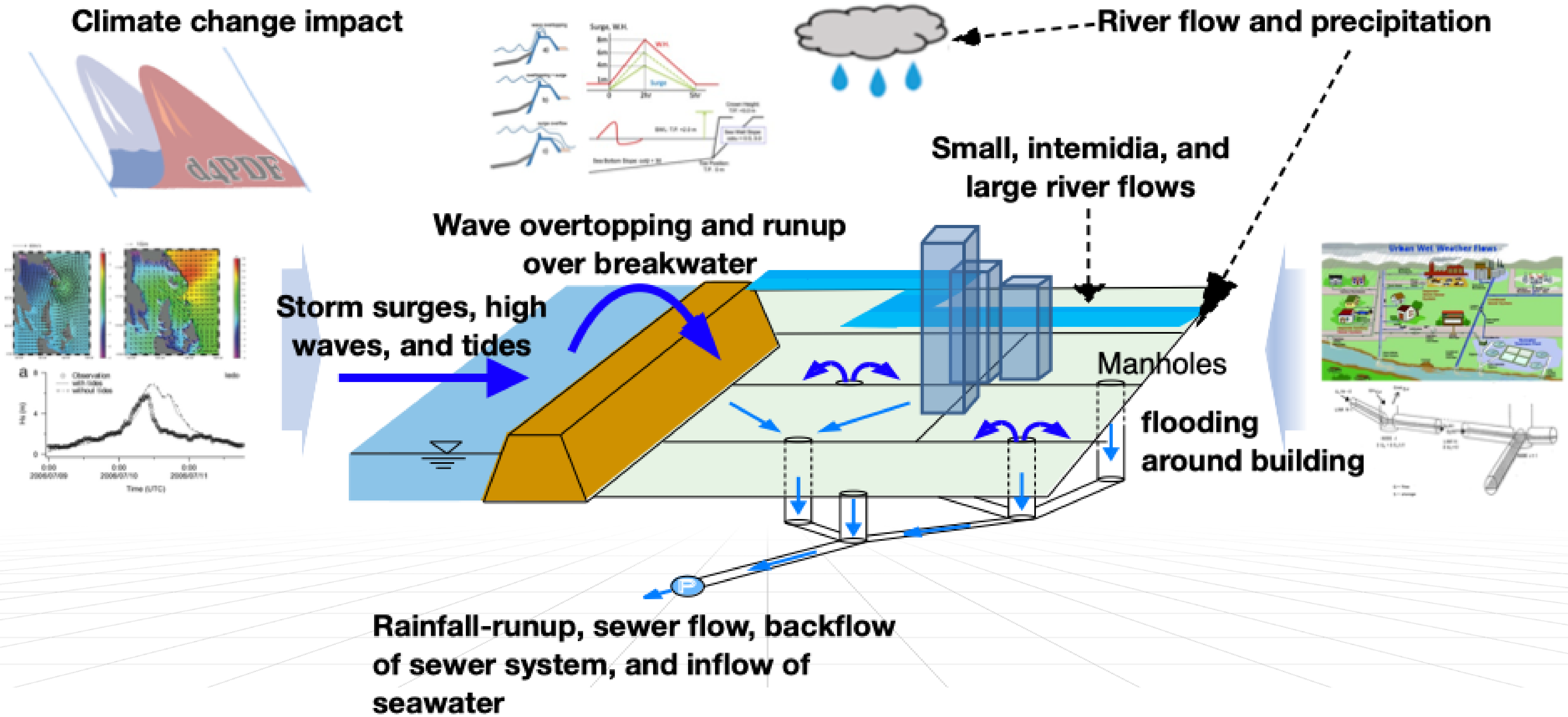
$$q_{overtopping} = C\left[\Gamma\left(\frac{R_{max}}{H_0'}\right)^{\frac{3}{2}}\left\{1-\frac{R_c}{H_0'}\Big/\left(\frac{R_{max}}{H_0'}\right)^{\frac{3}{2}}\right\}^{\Omega}\right]$$

$$R_{max} = 1.54\,R_{2\%}$$

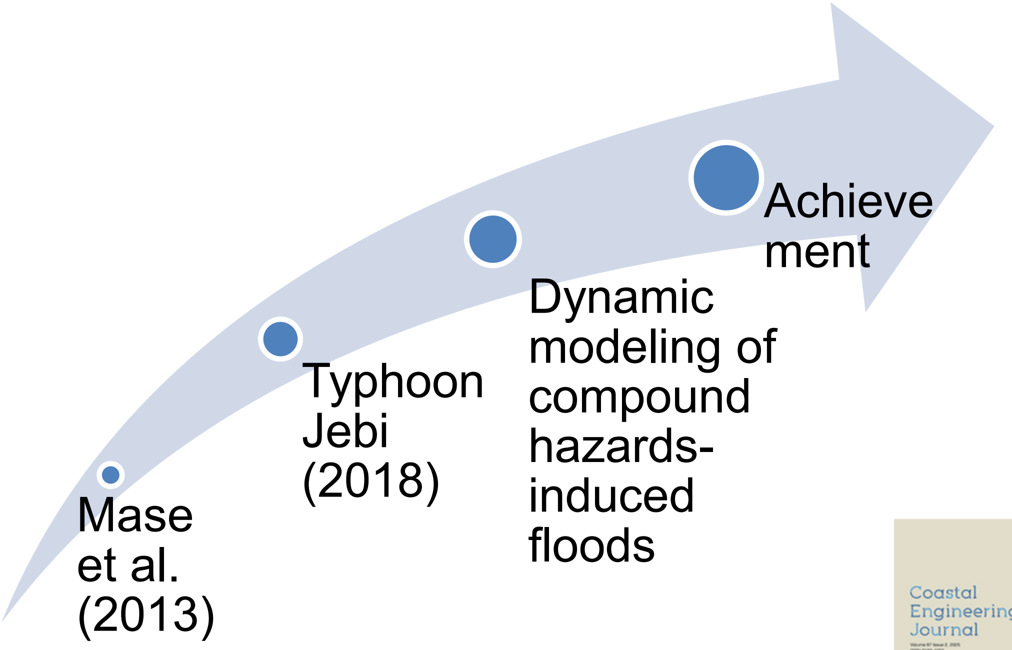
2) Wave runup formula

$$R_{2\%} = H_0'\,[2.99 - 2.73\exp(-0.57\tan\beta\,/\sqrt{H_0'/L_o})]$$

Dynamic modeling of compound hazards-induced floods



Compound hazards modeling



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Combined storm surge and wave overtopping inundation based on fully coupled storm surge-wave-tide model

Junbeom Jo [a], Sooyoul Kim [b,*], Nobuhito Mori [c,d], Hajime Mase [c,e,f]

Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/coastaleng

Application of a subgrid-scale urban inundation model for a storm surge simulation: Case study of typhoon Haiyan

Nobuki Fukui [a,*], Nobuhito Mori [b,c], Sooyoul Kim [d], Tomoya Shimura [b], Takuya Miyashita [b]

Coastal Engineering Journal
ISSN: (Print) (Online) Journal homepage: www.tandfonlir

Assessment of climate change impact on compound flooding considering typhoon intensification and astronomical tide in Ise Bay, Japan: a typhoon track ensemble approach

Masaya Toyoda, Nobuhito Mori, Sooyoul Kim, Jun Yoshino & Kazuki Haruyama

Ocean Engineering 220 (2021) 108350
Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/oceaneng

Refinement of integrated formula of wave overtopping and runup modeling

Masatoshi Yuhi [a,*], Hajime Mase [b,c,d,e], Sooyoul Kim [f], Shinya Umeda [a], Corrado Altomare [g]

Journal of Hydrology
journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Coastal and pluvial compound flooding of surge, wave, tide, rainfall-runoff, sewer flow, and seawall failure at coastal urban areas

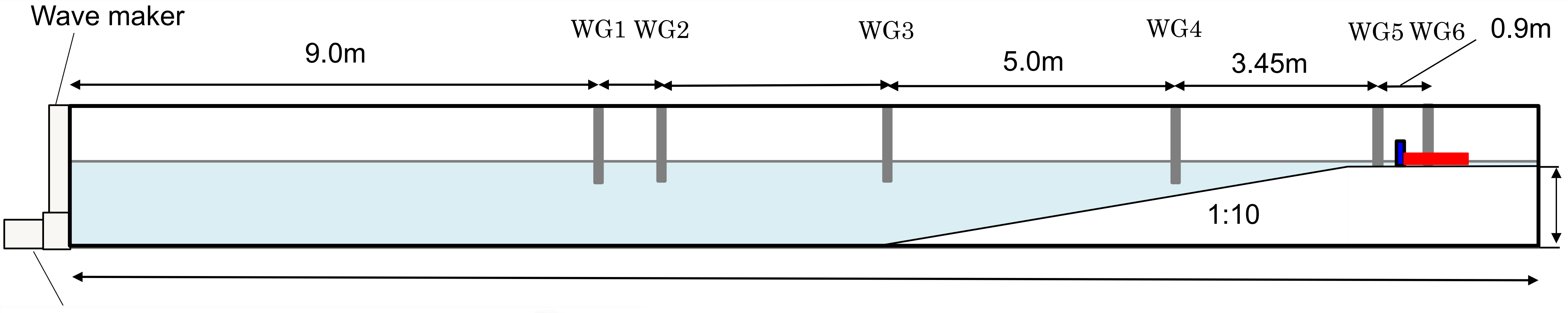
Junbeom Jo [a,*], Sooyoul Kim [b], Jungsoo Kim [c], Nobuhito Mori [a,d,e]

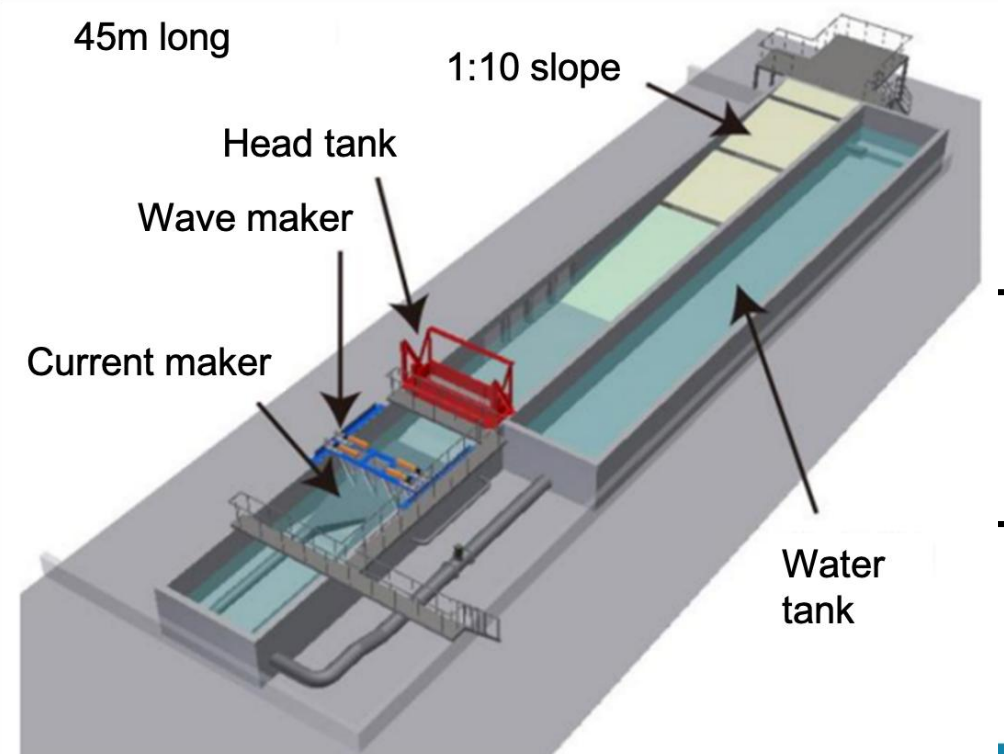
Purpose of the study

Purpose of the study: Validation of process-based model, SuWAT

  - Validated in the real world: flood depths compared to field survey
- Not validated for time-sequence average volumes of wave overtopping, surge overflow, and transient process
- Physical experiments for flooding volumes on a wave flume with
  - changes of water level (tides), and wave information
- Fully coupled model of surge, wave, and tide (SuWAT), integrating Formula of Overtopping and Runup Modeling (IFORM)
  - Shallow water equations + spectral wave model (SWAN) with a formula derived from data of experiments on a constant water level
    - Commonly, nonlinear shallow water equations (e.g., SWASH) or the full Navier-Stokes equations (e.g., DualSPHysics, FLOW-3D).

Schematics of wave flumes at DPRI, Kyoto U

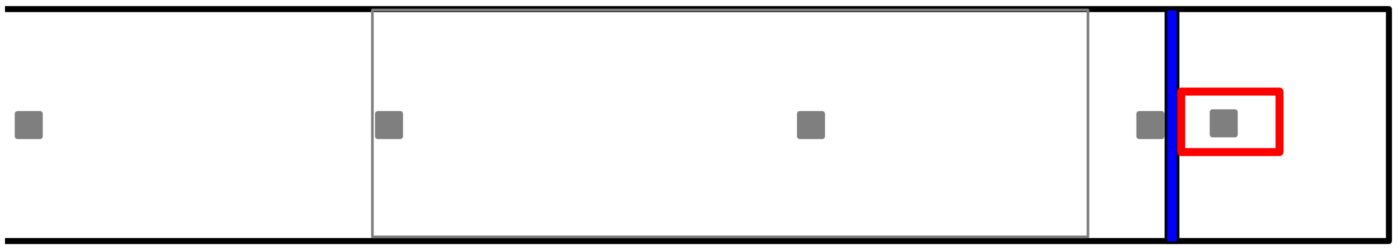




WG : Wave gauges

Crest width of BW H=0.25m

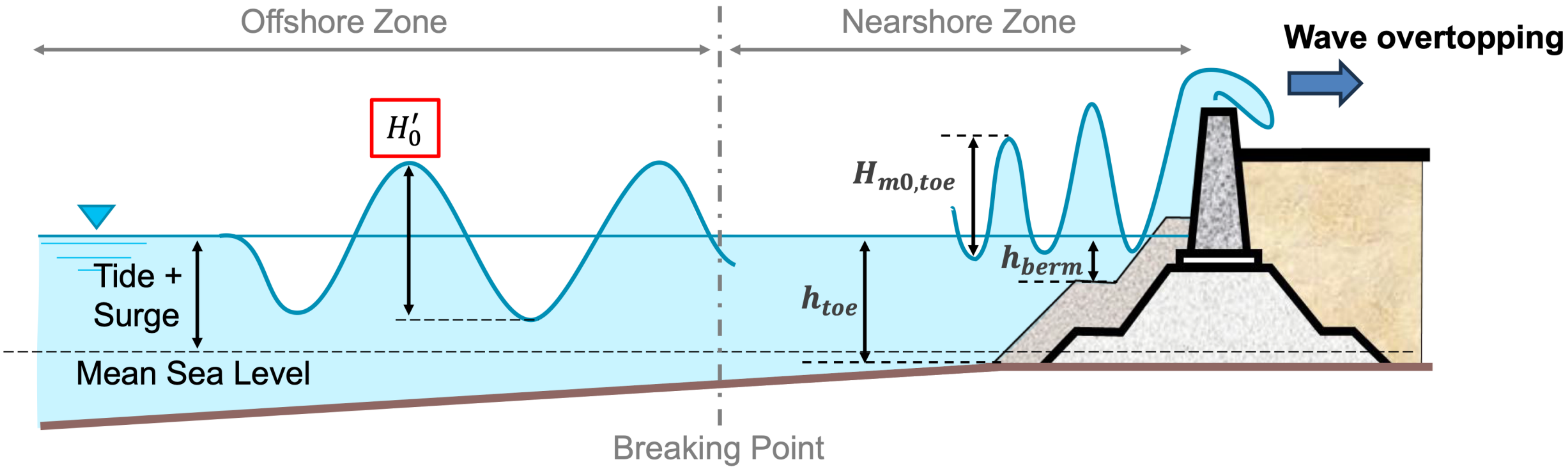
Catchment



Experiment conditions

Scale	1:25
Bottom slope	1:10
Front slope of BW	Vertical, 1:1, 1:2

Constant water depth h_0 (m)	0.89
Crest height h_c(m)	0.16
Run time (s)	480

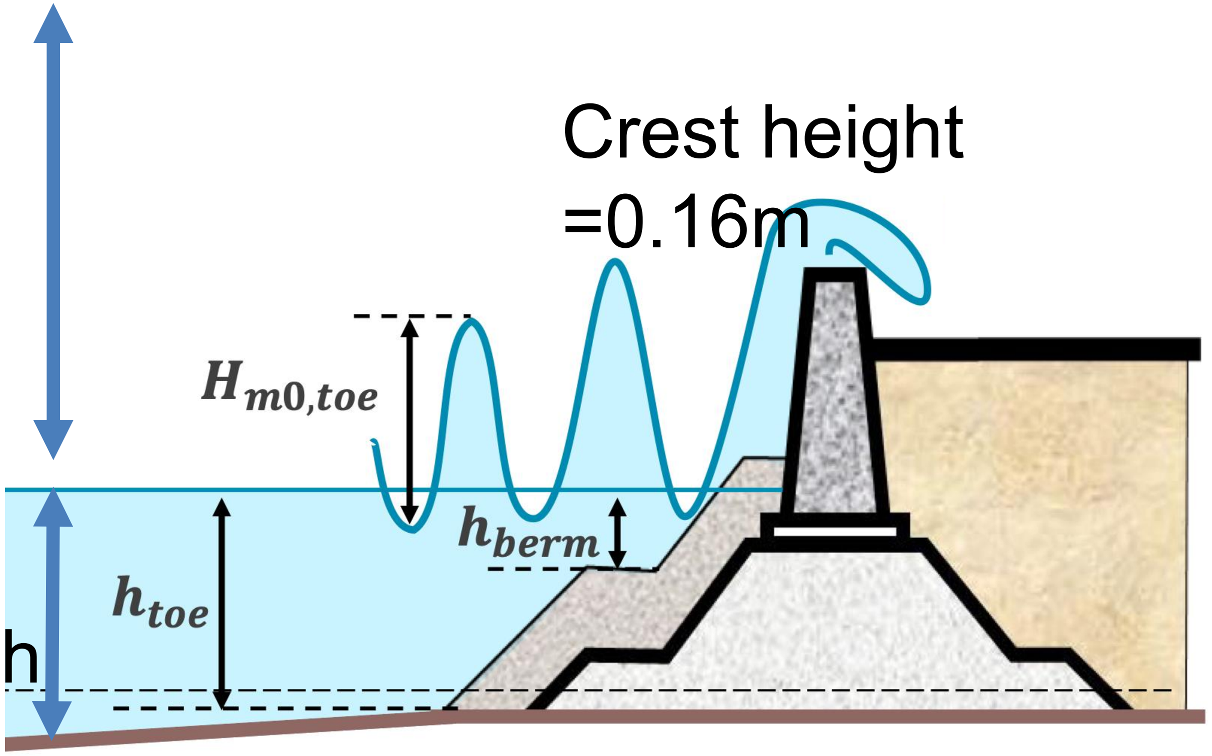


Wave Information at boundary and Tide conditions at WG5

108 cases in total

Inflow volume Q(m³/s)	Offshore Hs, H_0'(m)	Sig. wave period $T_{1/3}$(s)	Wave length L_0(m)	Slope of wave H_0'/L_0
0.03 ~ 0.36 (18 cases)	0.068	1.6	3.99	0.017
	0.106	2.0	6.24	
	0.153	2.4	8.99	
	0.081	1.2	2.25	0.036
	0.144	1.6	3.99	
	0.225	2.0	6.24	

Tidal height range
(=Inflow volume Q(m³/s)
=0.052m – 0.25m, 18 heights



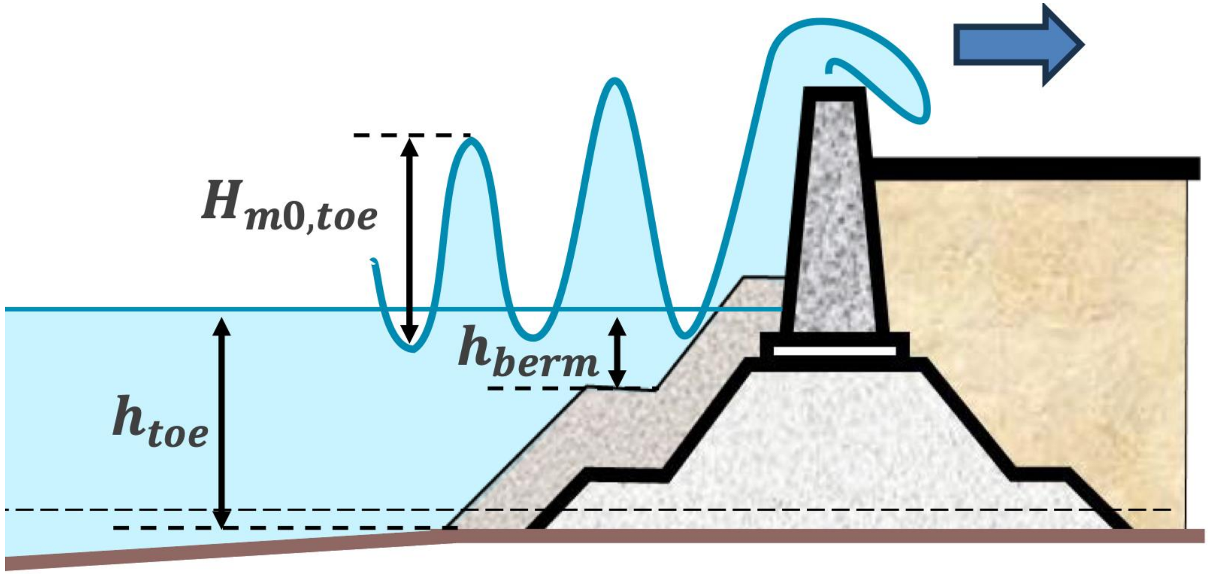
Constant water depth
=0.89m

Numerical experiments

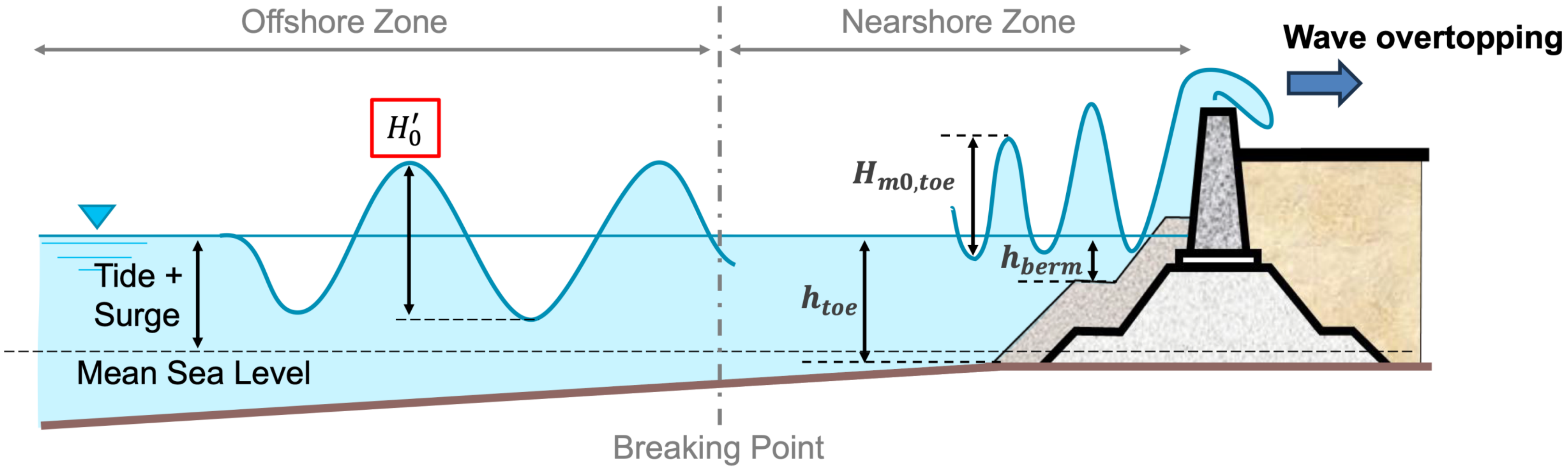
Numerical experiments

Dimension	Horizontal 2D
Grid size (m)	0.1
Time step (s)	0.005
Coupling time step (s)	1
Manning Number	0.025
Surge overflow formula	EurOtop

$$q_s = 0.6\sqrt{g}|-R_c|^{\frac{3}{2}}$$

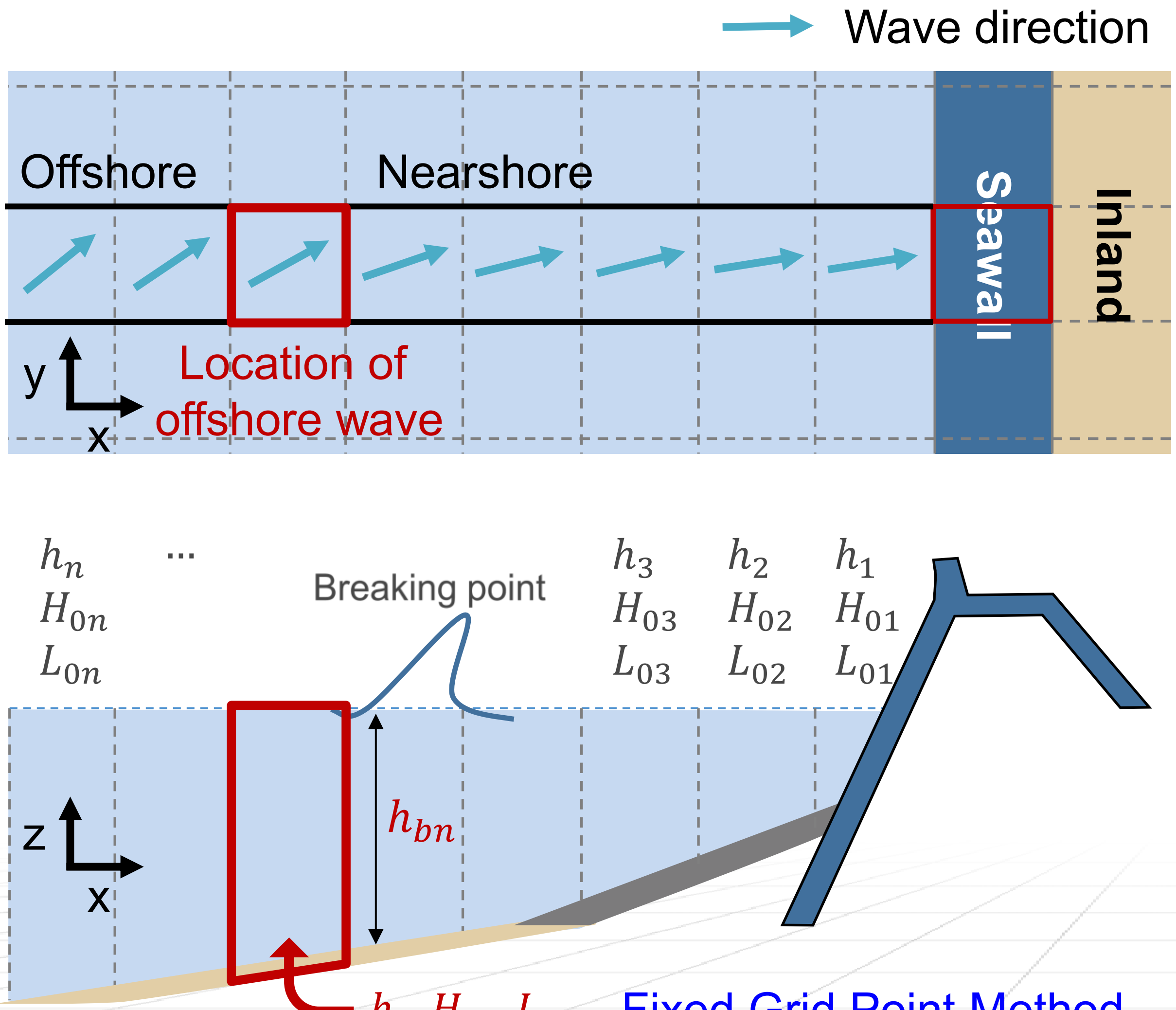


Numerical experiments



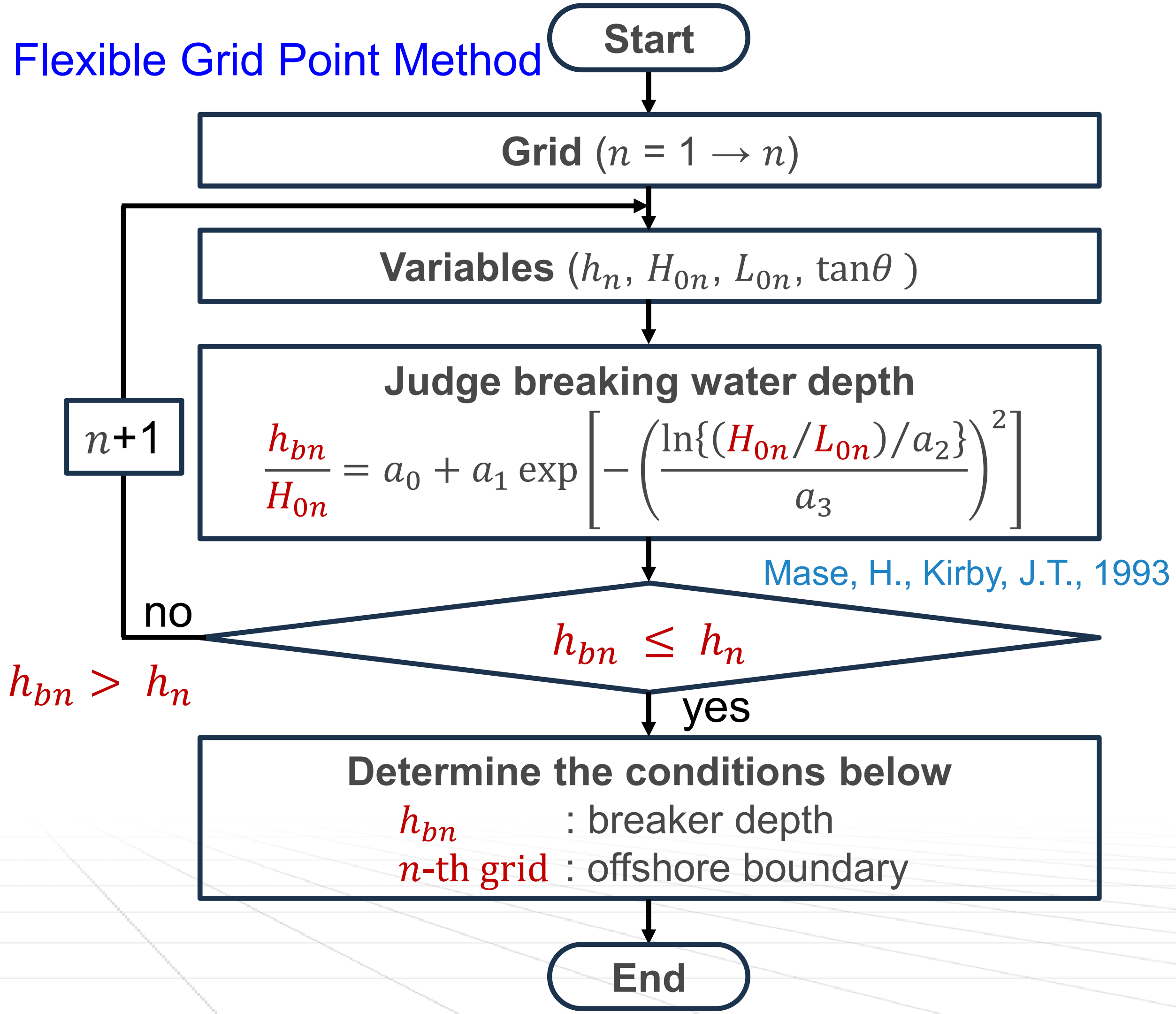
- Essential information for IFORM
  - Water depth + water surface level change
  - Wave breaking-depth
  - H_0' : H_s at offshore before breaking
  - T_s : T_s at offshore before breaking
  - W_{dir}: Wave direction at offshore before breaking

Flexible VS Fixed Grid Point methods



Fixed Grid Point Method

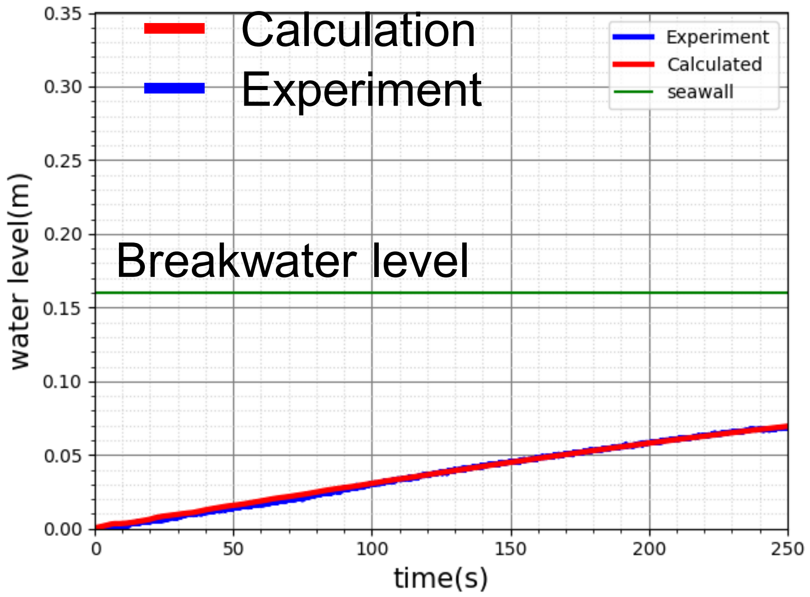
Flexible Grid Point Method



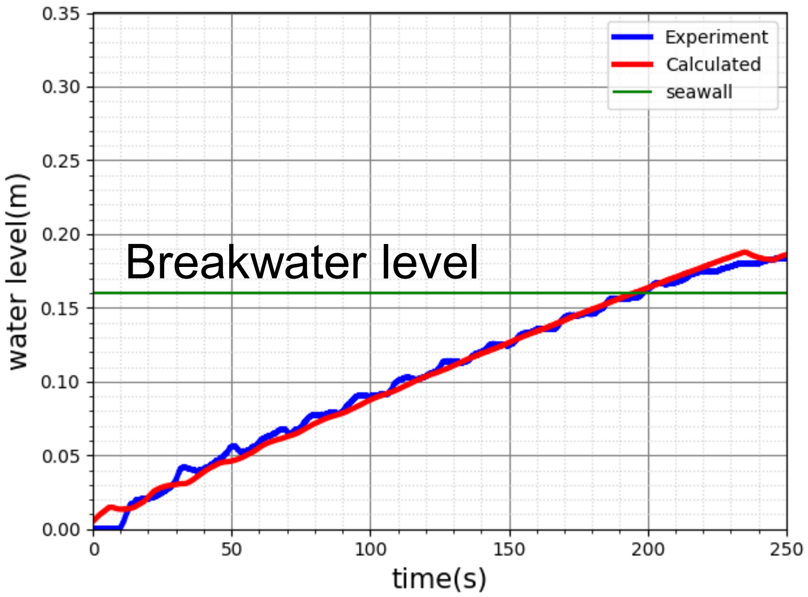
h_n : water depth, H_{0n} : Hs, L_{0n} : Period, $\tan\theta$: Bottom slope on the $n\,th$ grid

Results: Comparisons
Calculations VS Experiments

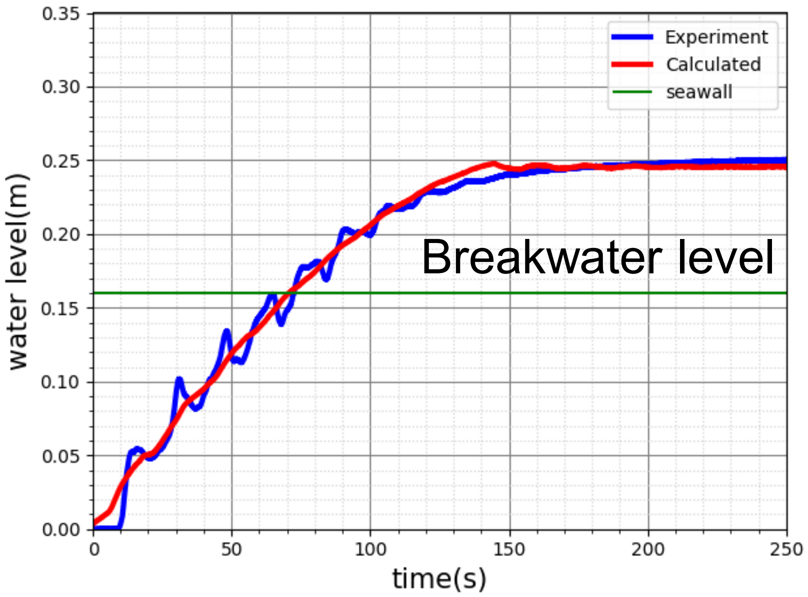
Only tides at WG5



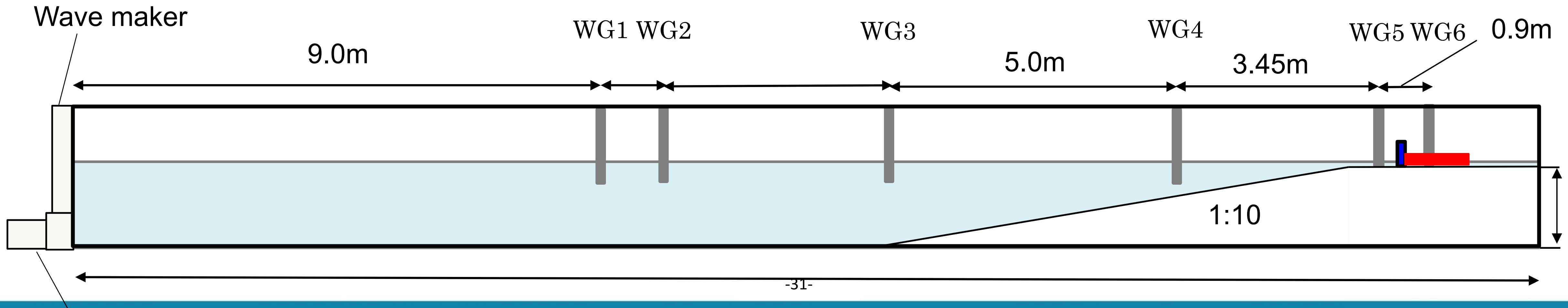
Q=0.05(m^3/s)



Q=0.12(m^3/s)



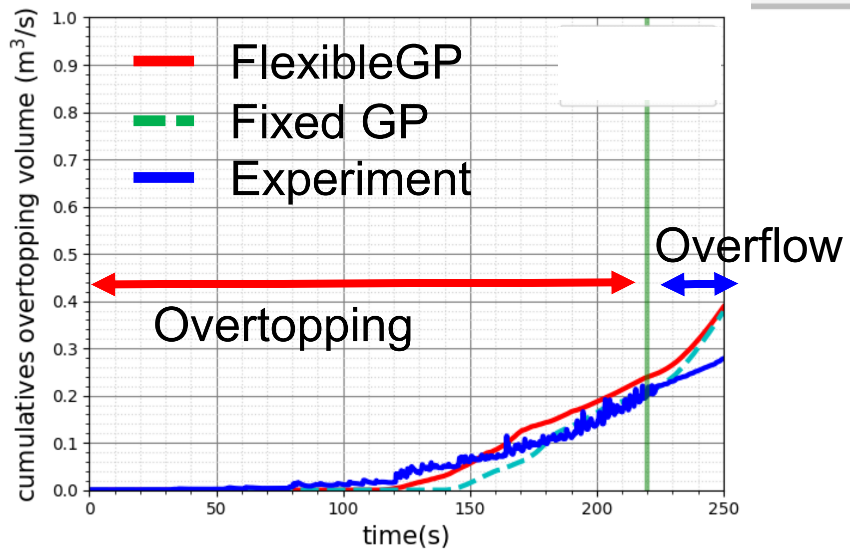
Q=0.24(m^3/s)



Volumes of wave overtopping and surge overflow at WG6

Vertical slope

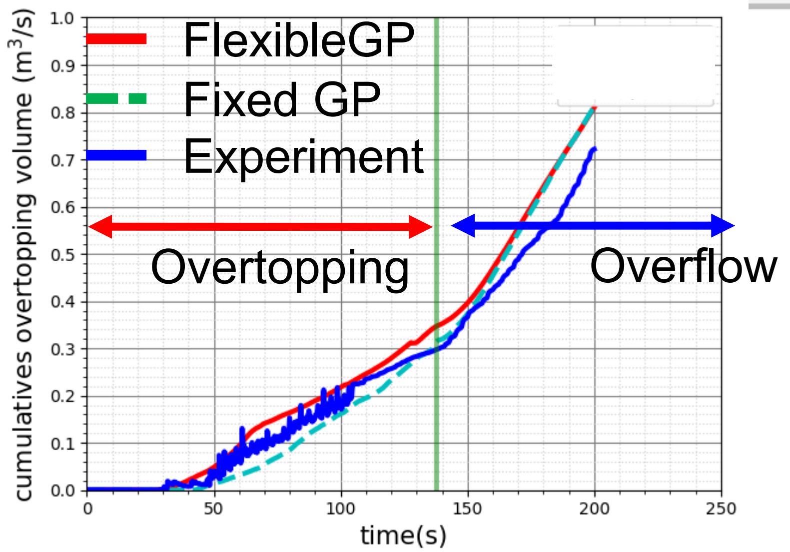
Small tidal condition



Q=0.11(m^3/s) , H_0'=0.068(m), $cot\alpha$=0

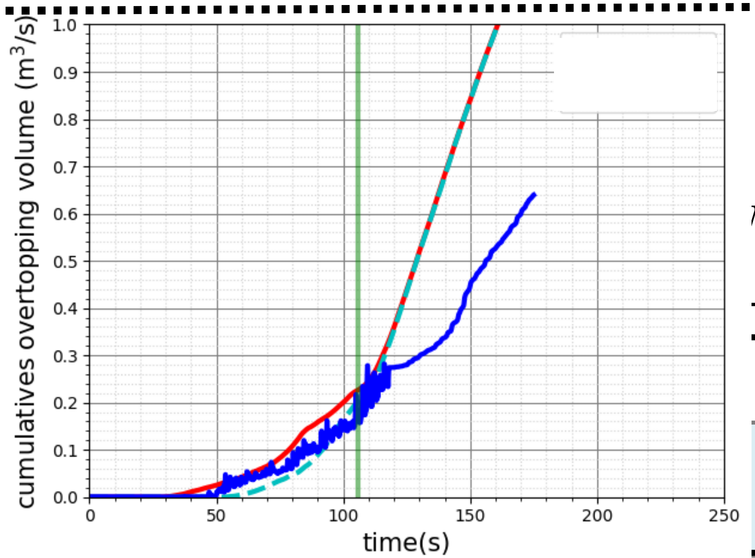
1:1 slope

Small tidal condition



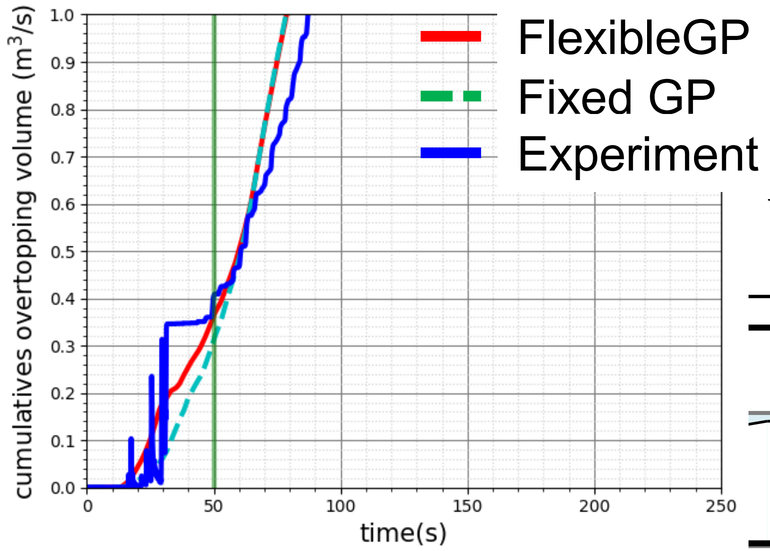
Q=0.15(m^3/s) , H_0'=0.106(m), $cot\alpha$=1

Large tidal condition



Q=0.18(m^3/s) , H_0'=0.106(m), $cot\alpha$=0

Large tidal condition



Q=0.33(m^3/s) , H_0'=0.153(m), $cot\alpha$=1

mak

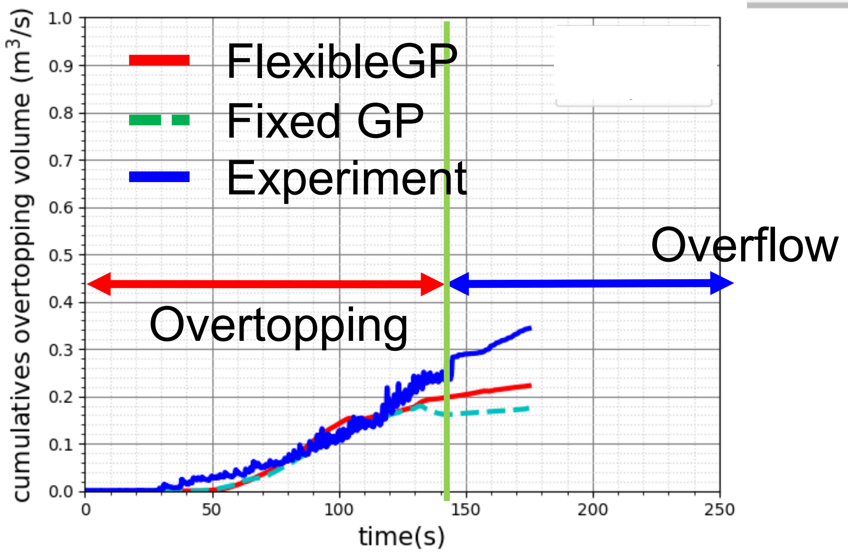
'G2

WG5 WG6 0.9m

Volumes of wave overtopping and surge overflow at WG6

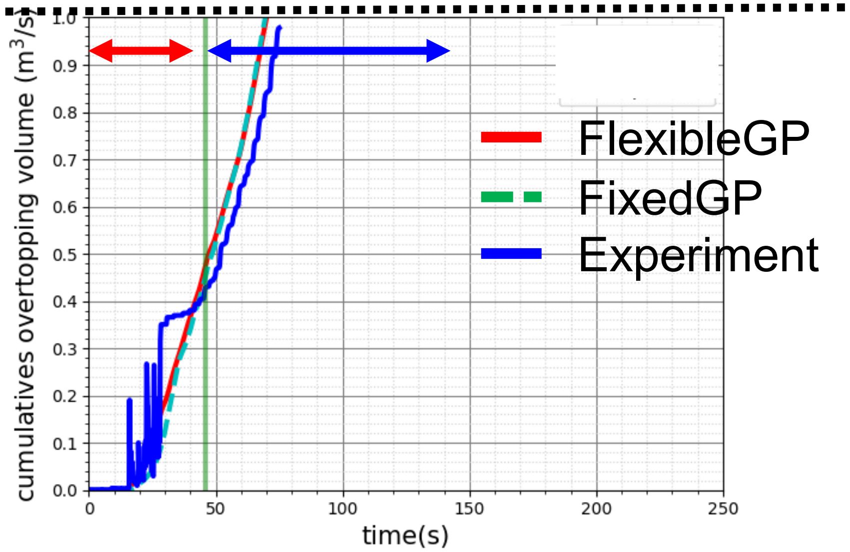
1:2 slope

Small tidal condition



Q=0.07(m^3/s) , H_0'=0.144(m), $cot\alpha$=2

Large tidal condition

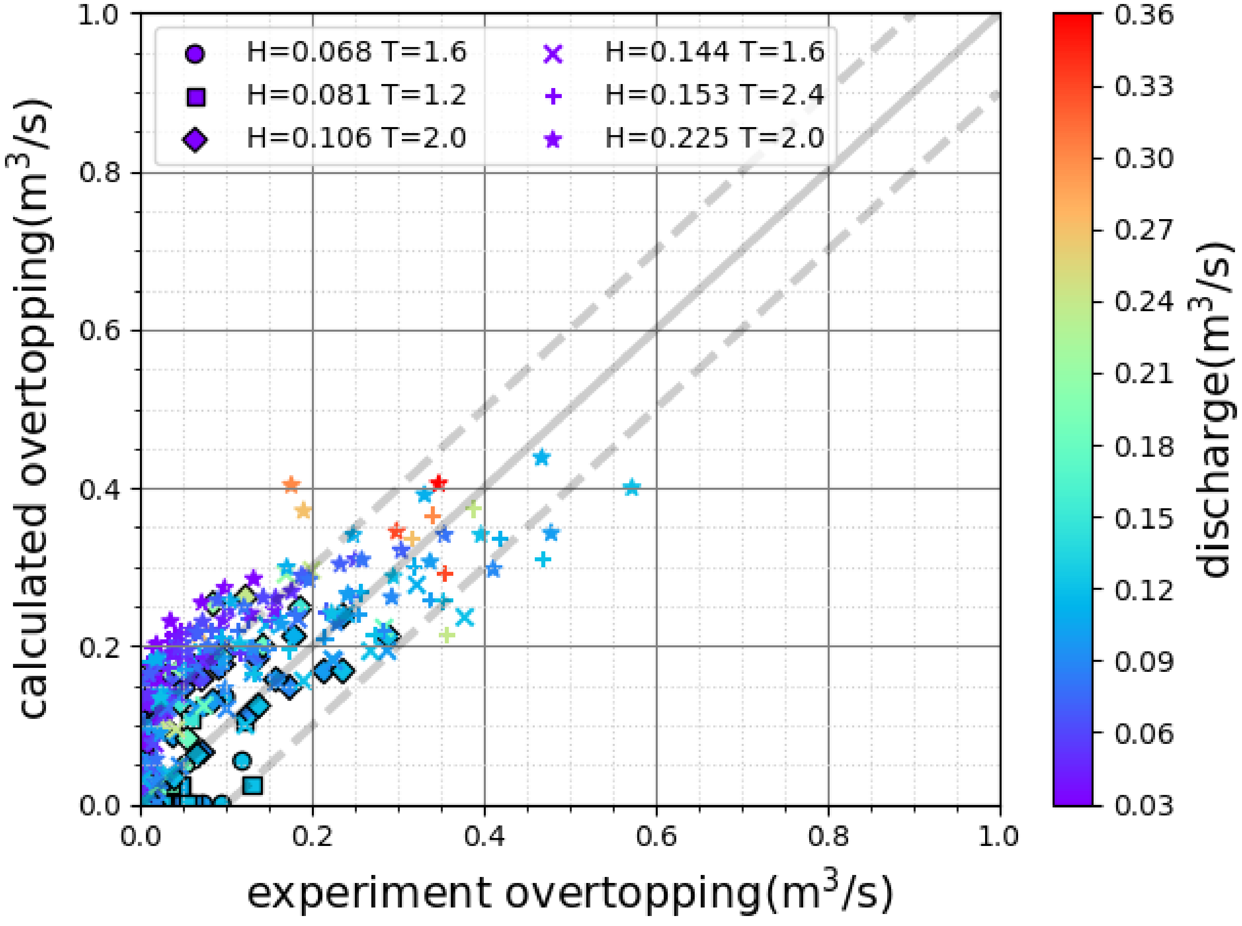


Q=0.36(m^3/s) , H_0'=0.225(m), $cot\alpha$=2

- Summary
  - Timing of the beginning of wave overtopping is identical
  - Flexible GP is better than Fixed GP
  - Fixed GP has higher uncertainties on estimating the volume of overtopping
    - Importance of the designation of offshore grids
  - Overestimated surge overflow volumes for Flexible and Fixed GP methods

A trend of Wave overtopping / Surge overflow on the vertical slope

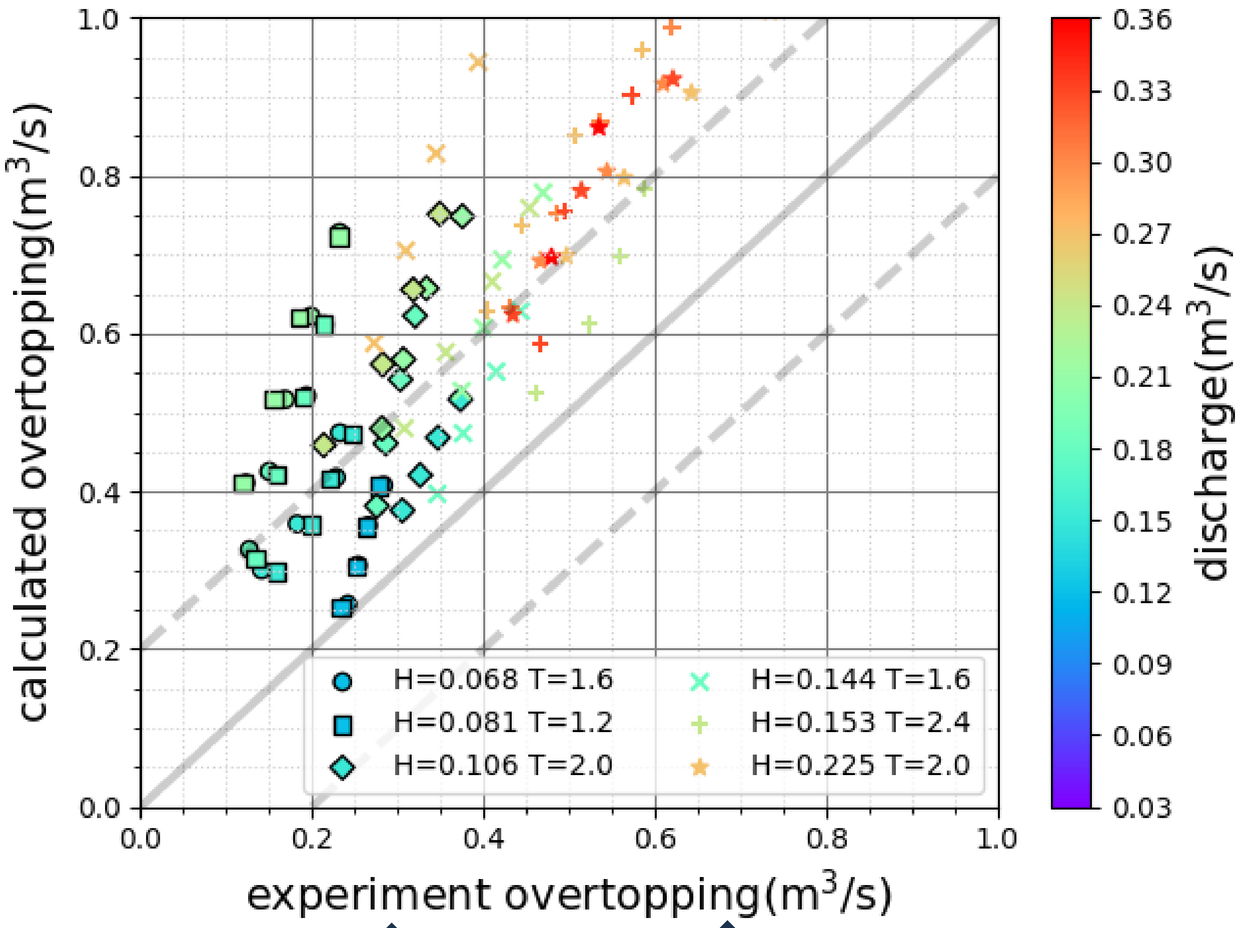
Overtopping dominated-regime



Higher Hs

Errors

Overflow dominated-regime

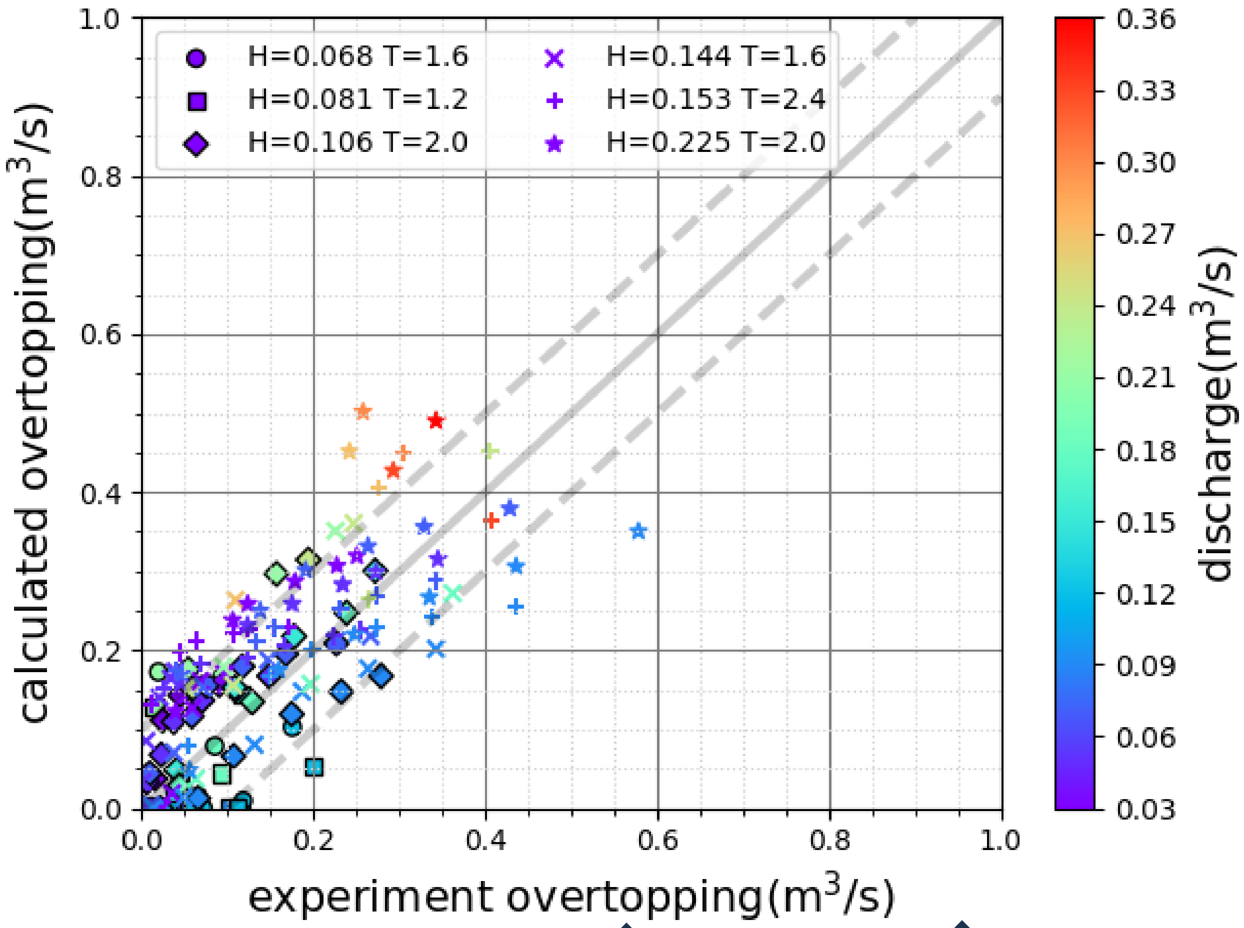


Higher Hs

Errors

A trend of Wave overtopping / Surge overflow on the 1:1 slope

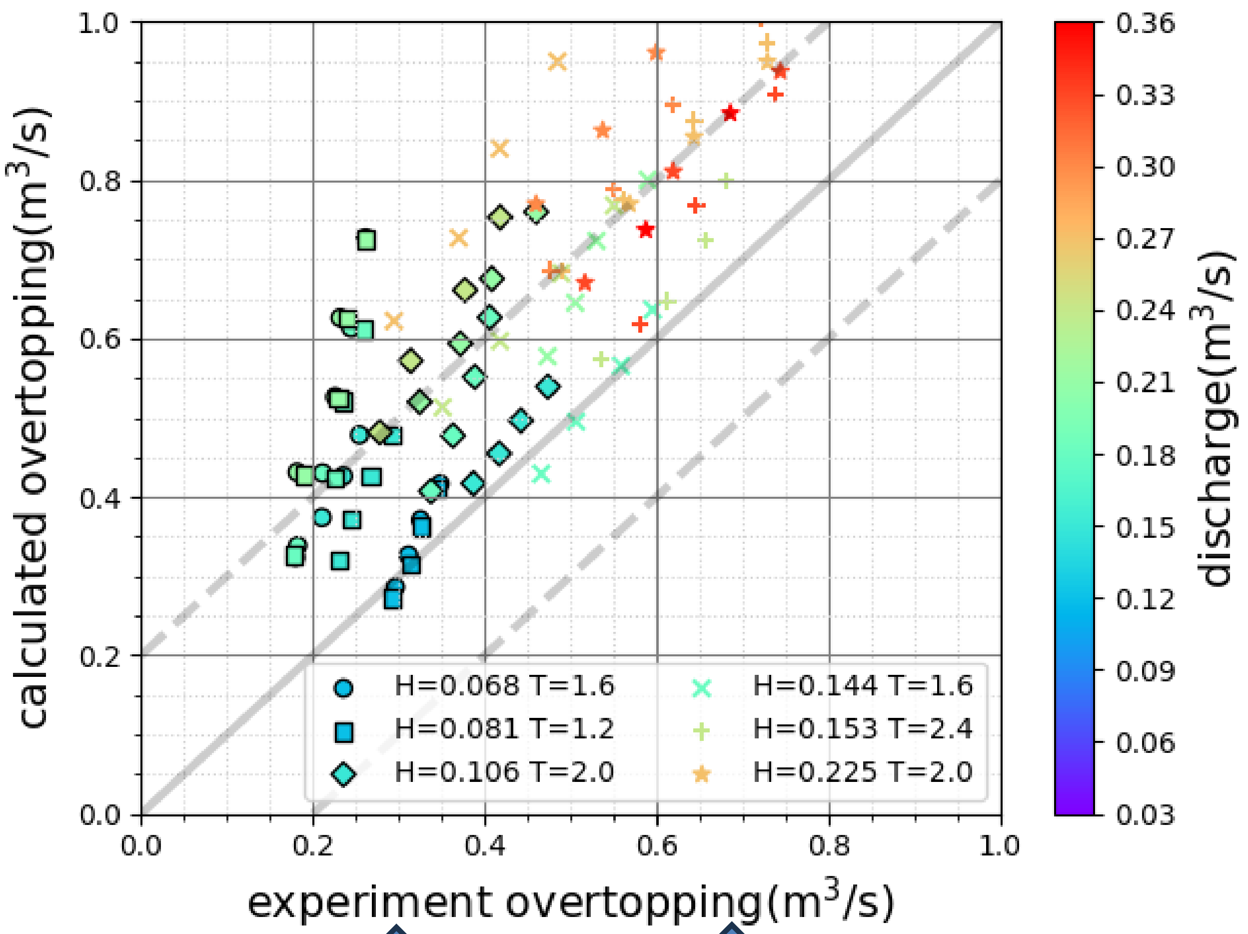
Overtopping dominated-regime



Higher Hs

Errors

Overflow dominated-regime

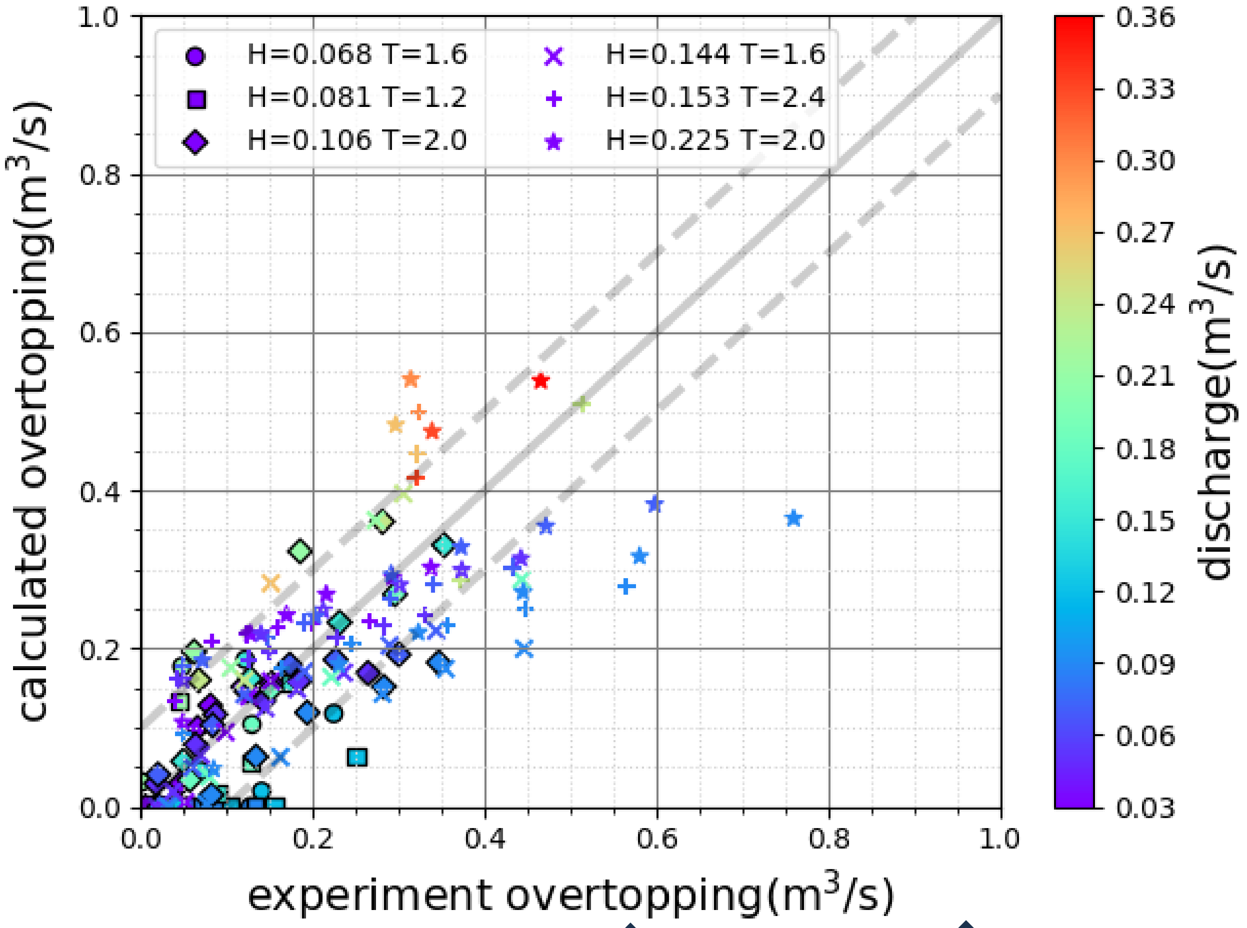


Higher Hs

Errors

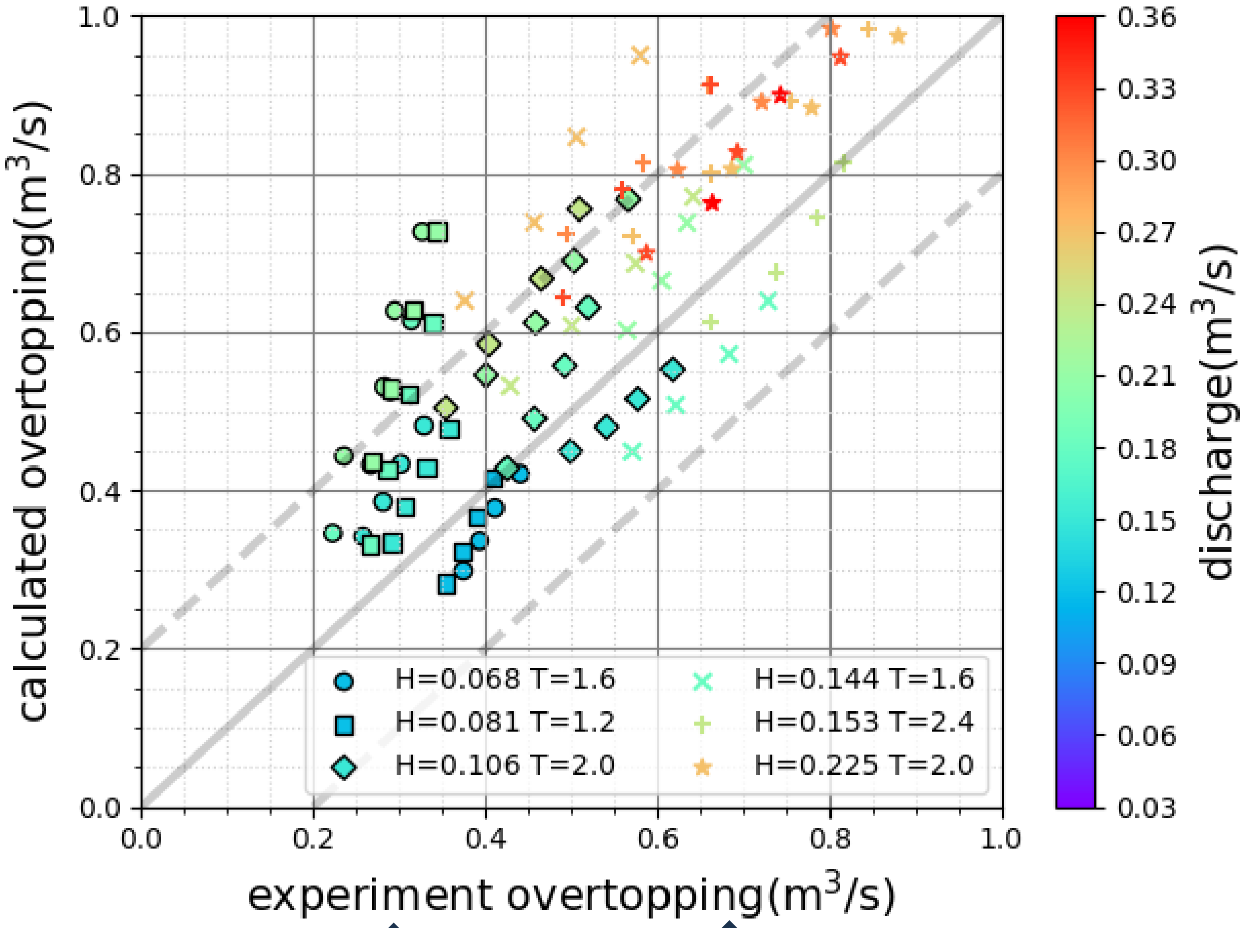
A trend of Wave overtopping / Surge overflow on the 1:2 slope

Overtopping dominated-regime



Higher Hs　Errors

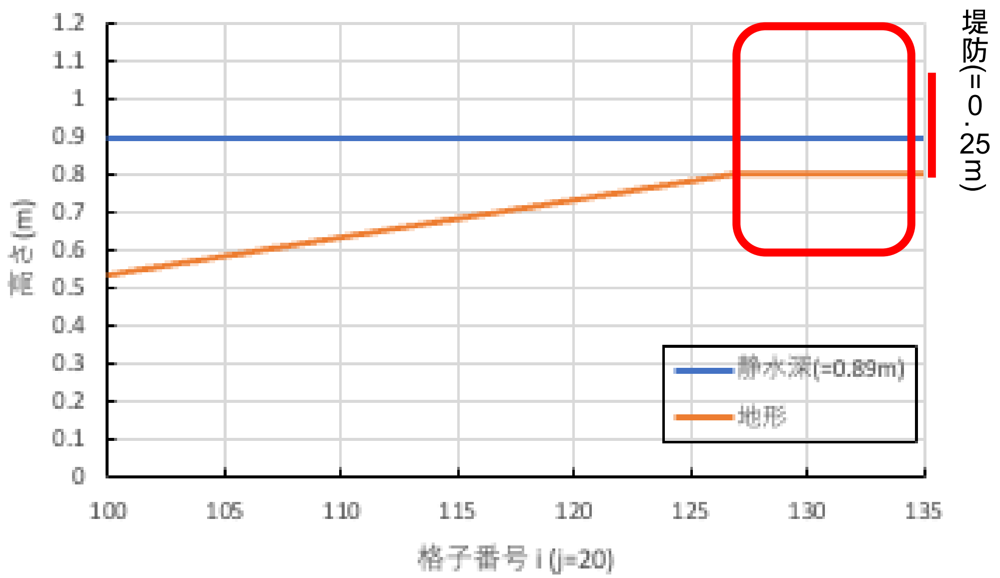
Overflow dominated-regime



Higher Hs　Errors

Improvement

Improvement: Berm-type IFORM



IFORM has a trend of underestimation on the shallow water, so we implemented the berm-type IFORM. (Yuhi et al. 2022)

$$\frac{R_{2\%}}{H_0'} = C(W_B^*, S^*)\left[2.99 - 2.73\exp\left(-\frac{0.57\tan\beta}{\sqrt{\frac{H_0'}{Lo}}}\right)\gamma_{runup}\right]$$

$$C(W_B^*, S^*) = 1 - \beta(S^*)\tanh(\gamma(S^*)\cdot W_B^*)$$

$$\beta = \begin{cases} 0.29[1+\tanh(10.6(S^*+0.41))] \\ (S^* \le 0.1) \\ 0.58[1-\tanh(0.7(S^*-0.1))] \\ (S^* > 0.1) \end{cases}$$

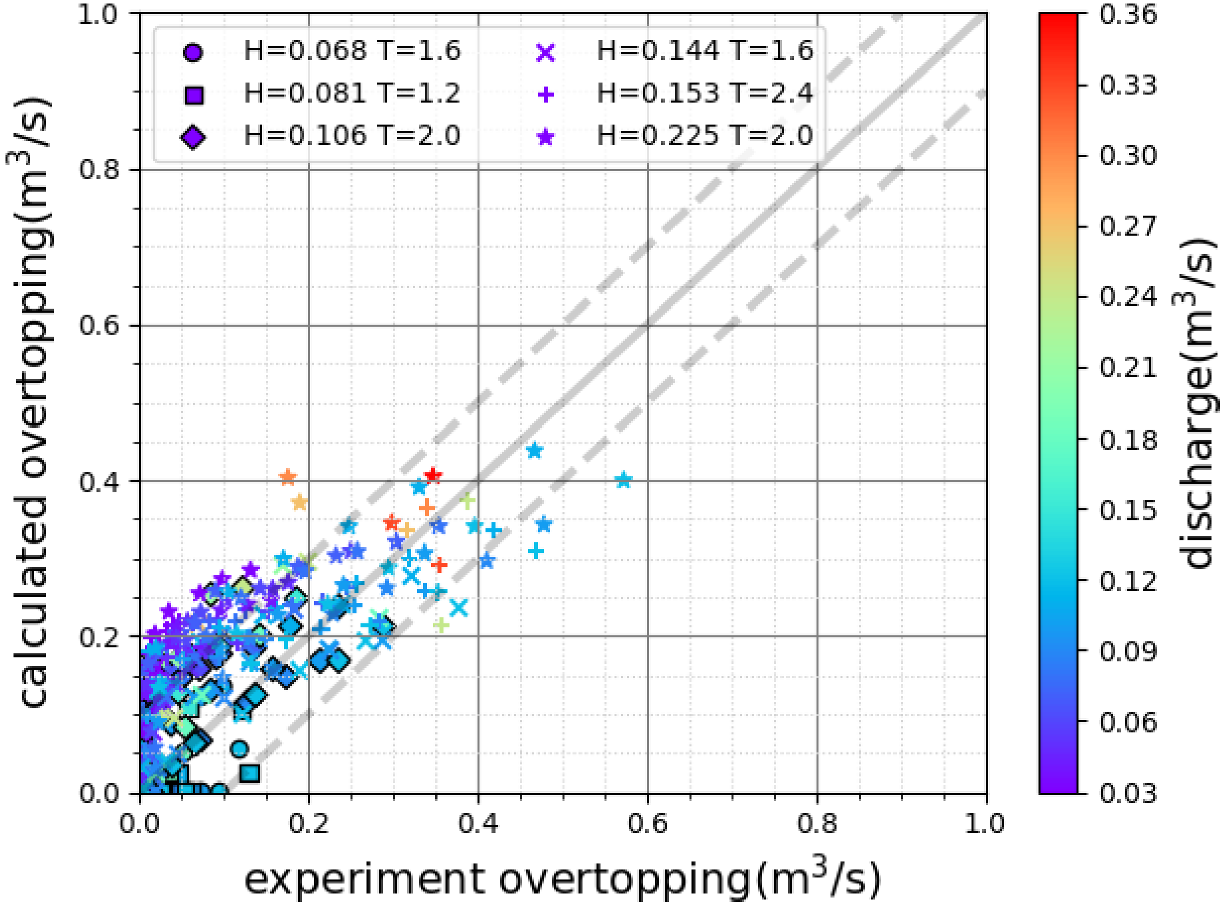
$$\gamma = -5\tanh(10(S^*+0.3)) + 7.5$$

4) 富永侑歩, 伍井稔, 加藤憲一, 金洙列, 間瀬肇：越波越流遷移モデルを用いた高潮浸水計算手法の精度検証,土木学会論文集B2(海岸工学), Vol.77,No2,I_265-I_270,2021.

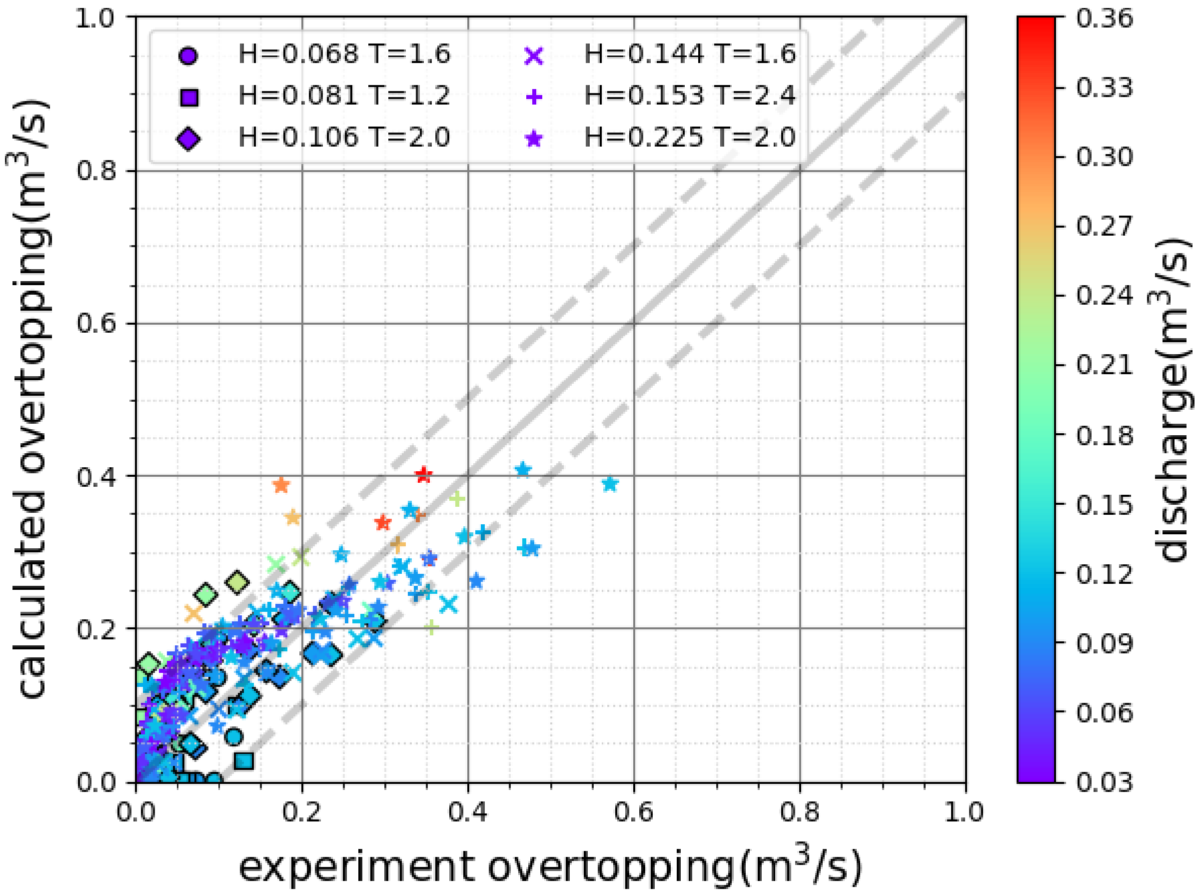
5) 由比政年, 市村友希乃, 間瀬肇, 平石哲也, 川崎浩司, 水谷英朗：バーム地形による遡上高の低減効果特性およびIFORMへの取り組み,土木学会論文集B2(海岸工学), Vol.75,No2,I_757-I_262,2019.

Non-berm-typed IFORM VS Berm-typed IFORM on the vertical slope

Non-berm-typed IFORM



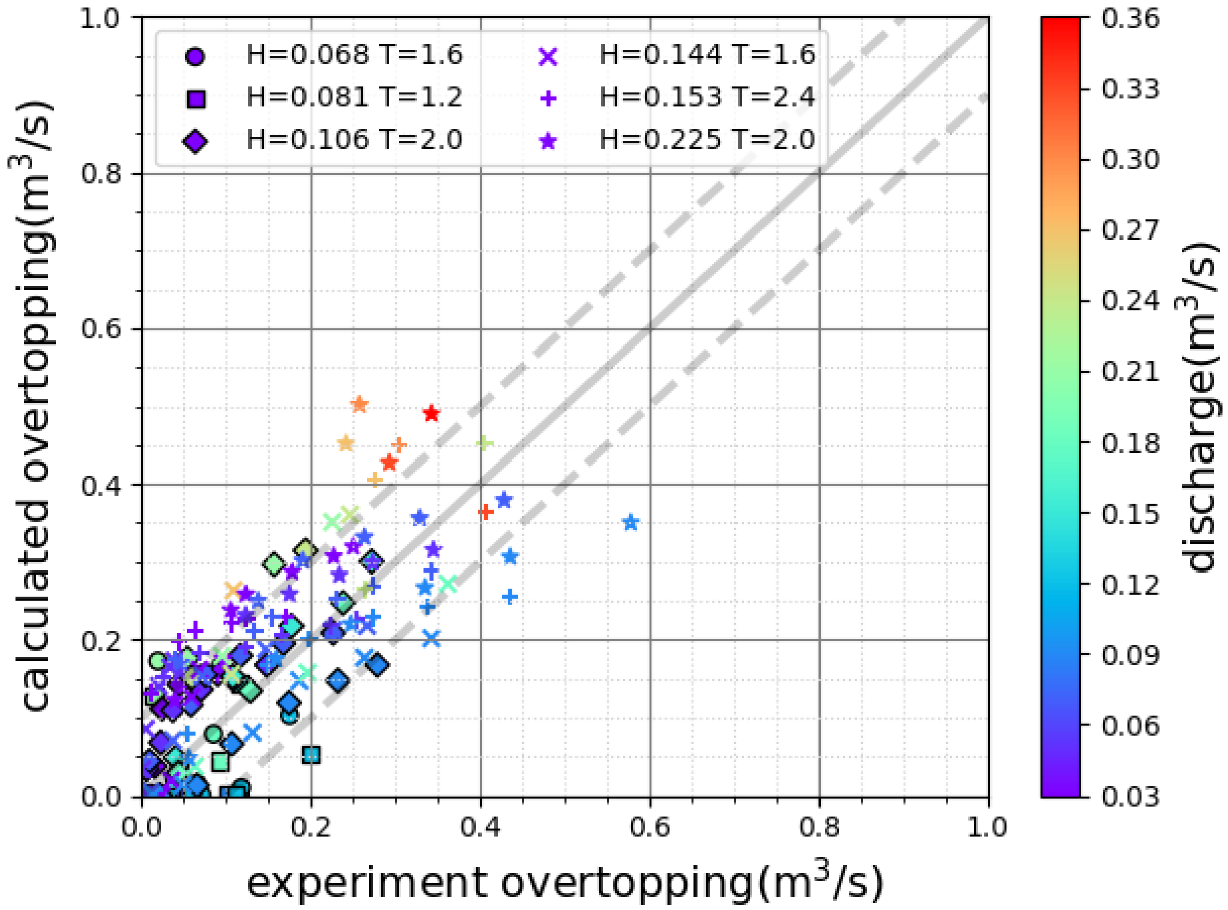
Berm-typed IFORM



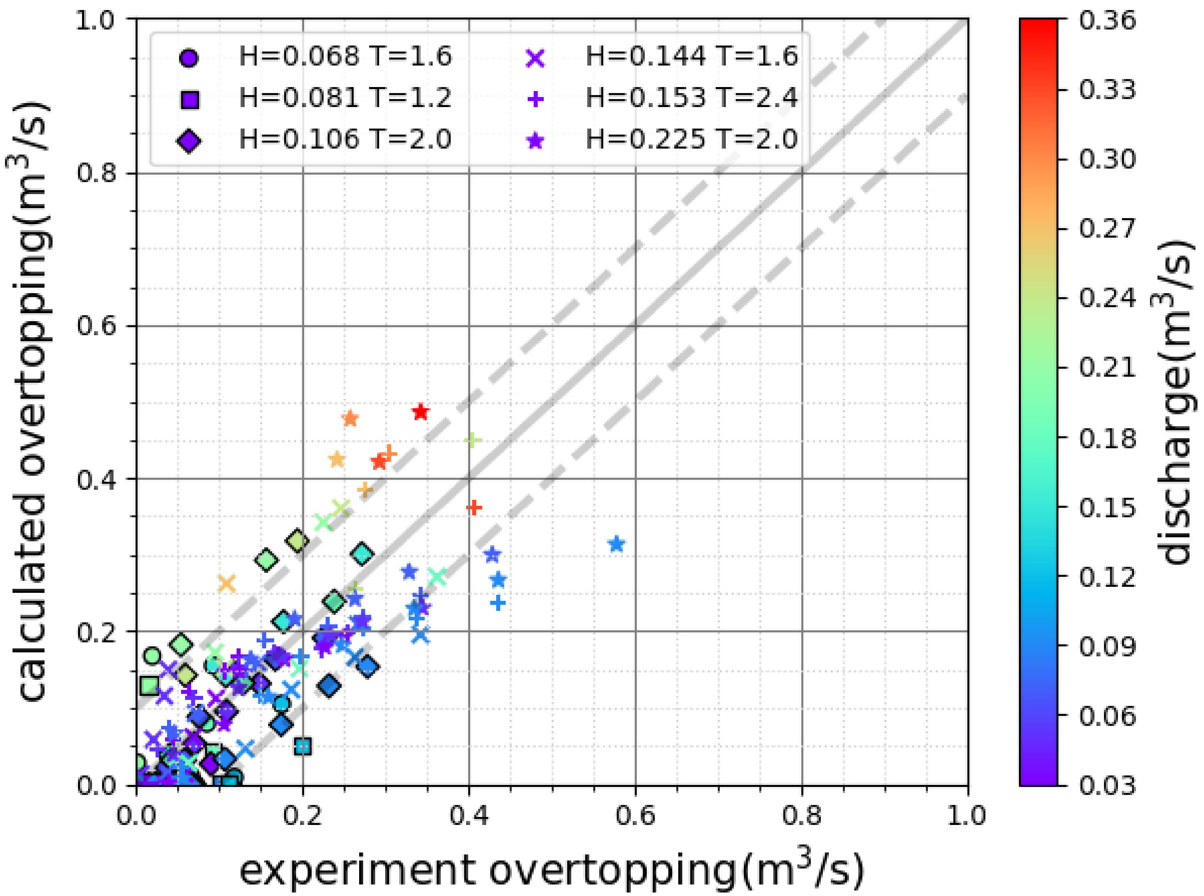
Improvement

Non-berm-typed IFORM VS Berm-typed IFORM on the 1:1 slope

Non-berm-typed IFORM



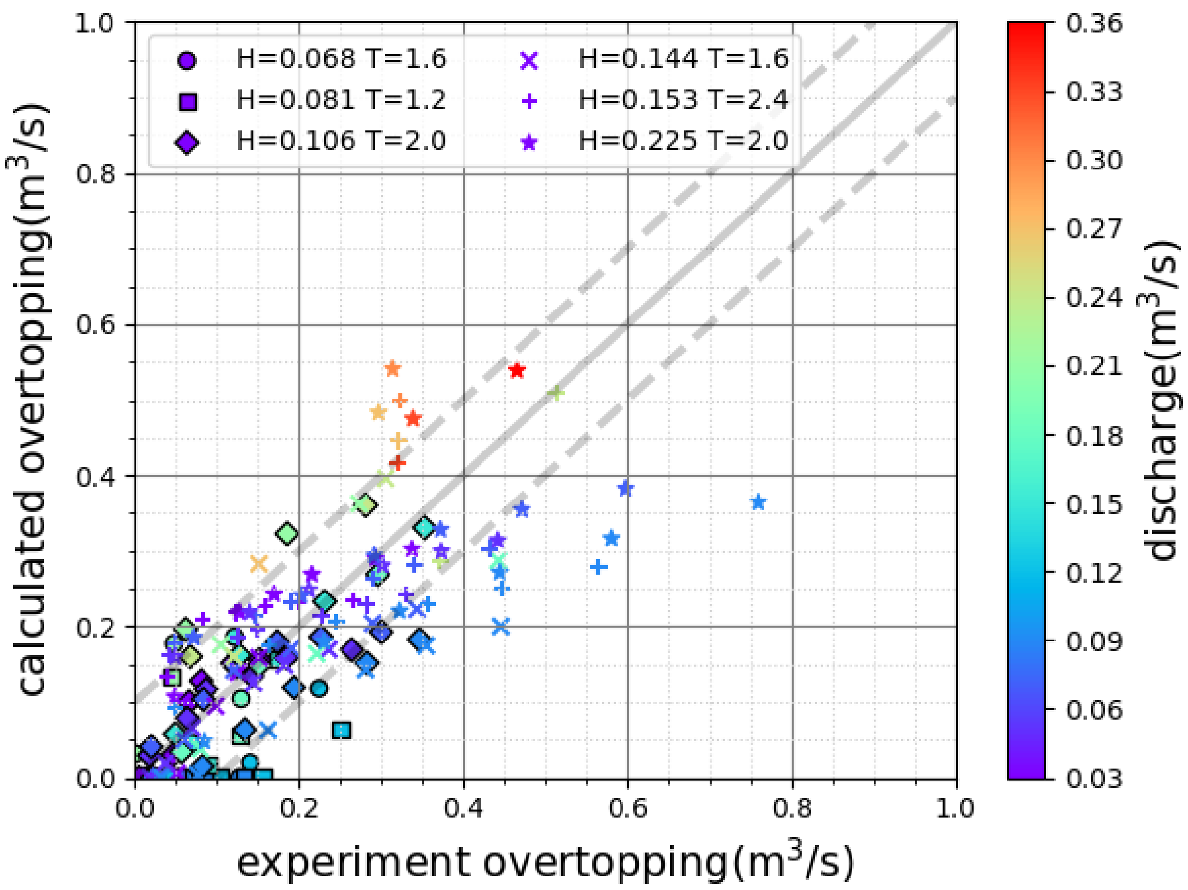
Berm-typed IFORM



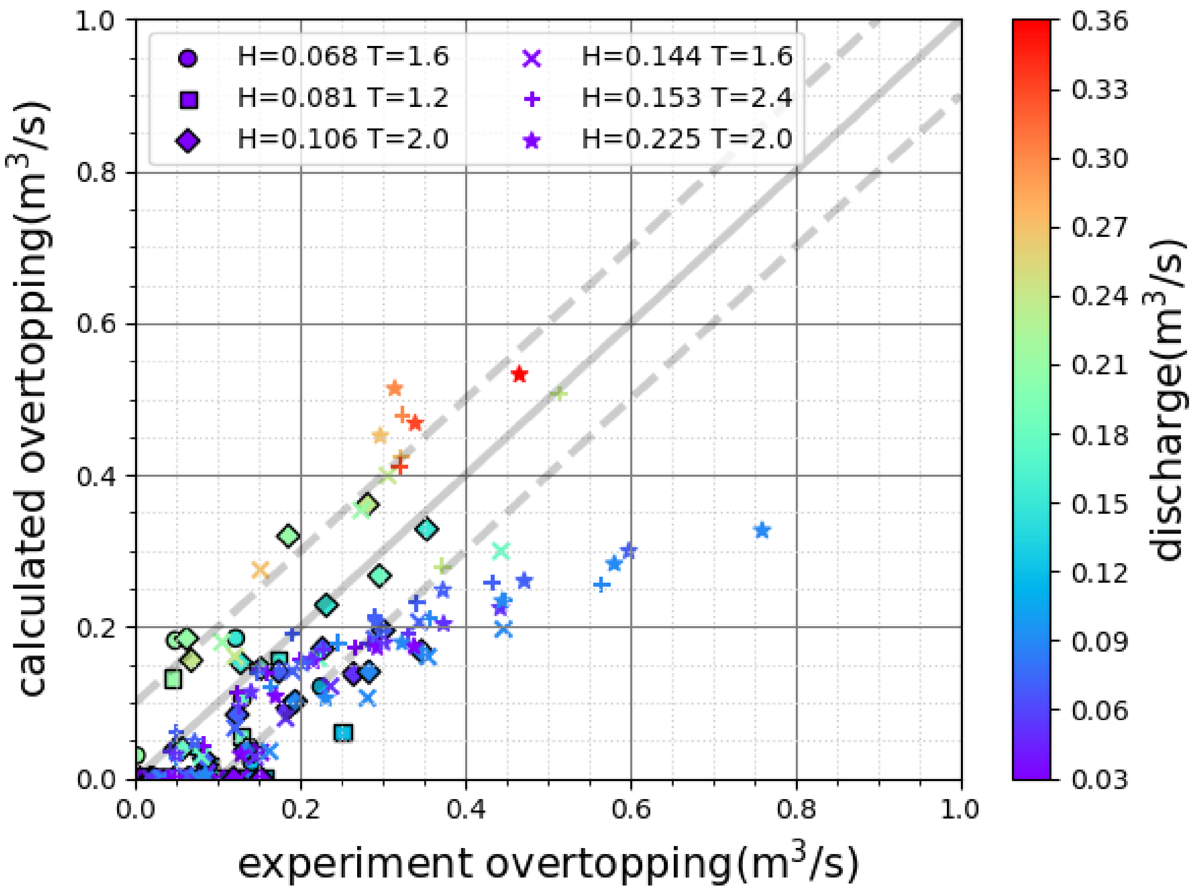
Improvement

Non-berm-typed IFORM VS Berm-typed IFORM on the 1:2 slope

Non-berm-typed IFORM



Berm-typed IFORM



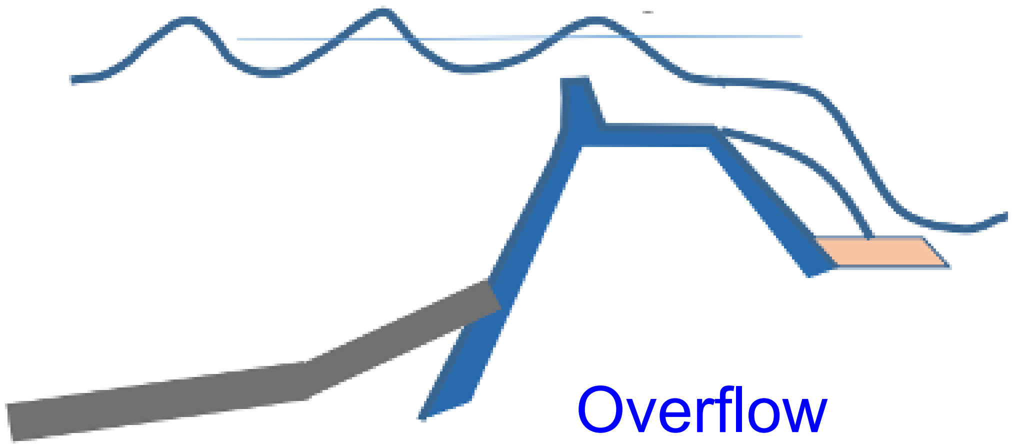
Improvement not much

Improvement: Correction factor to surge overflow rate

- Implement a correction factor to surge overflow rates (C_s).

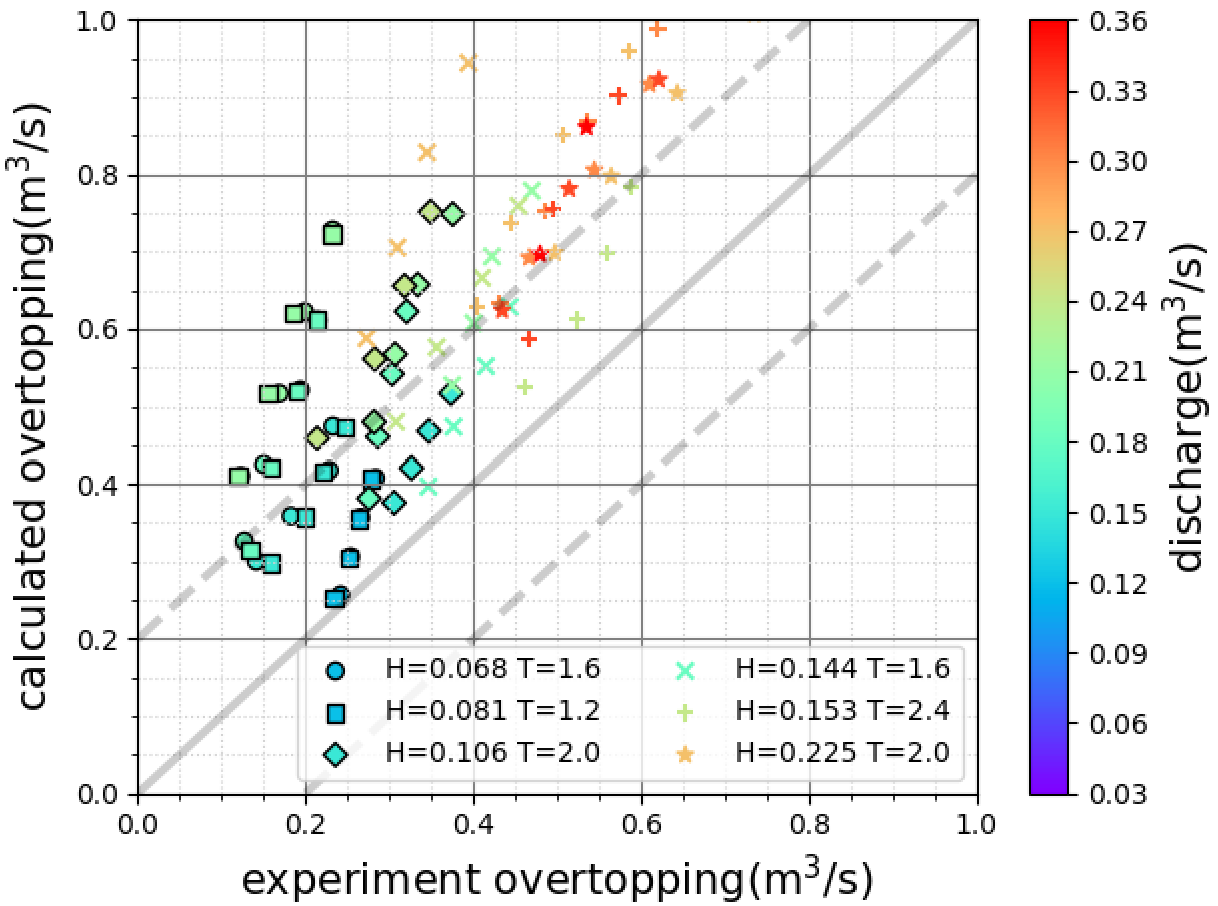
- $q = q_w \times \mathrm{Raito} + C_s q_s$
  - $q_s = 0.6\sqrt{g}|-R_c|^{\frac{3}{2}}$

- Method
  - C_s= differences of regression lines between calculations and experiments
  - C_s =0.6

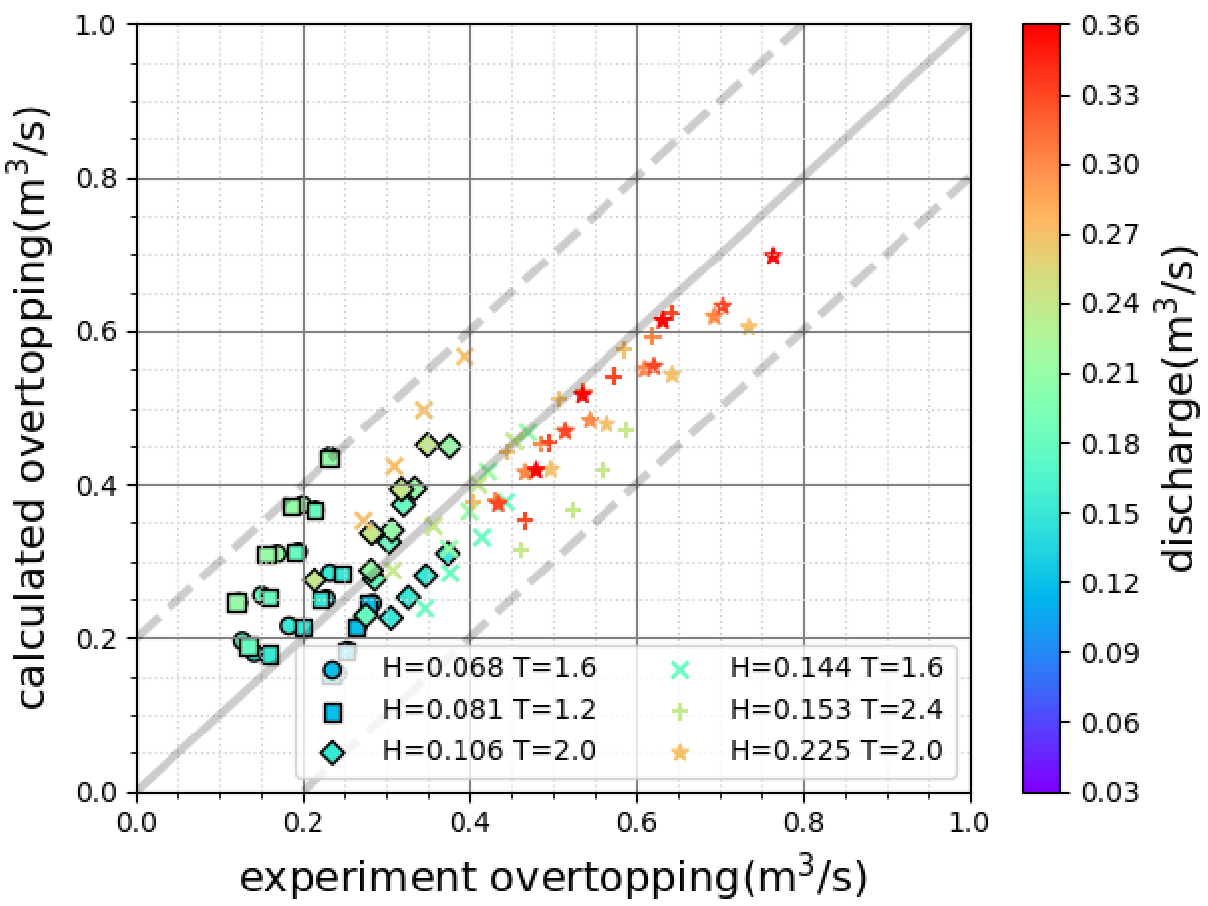


IFORM VS IFORM with C_s on the vertical slope

IFORM with C_s =1.0

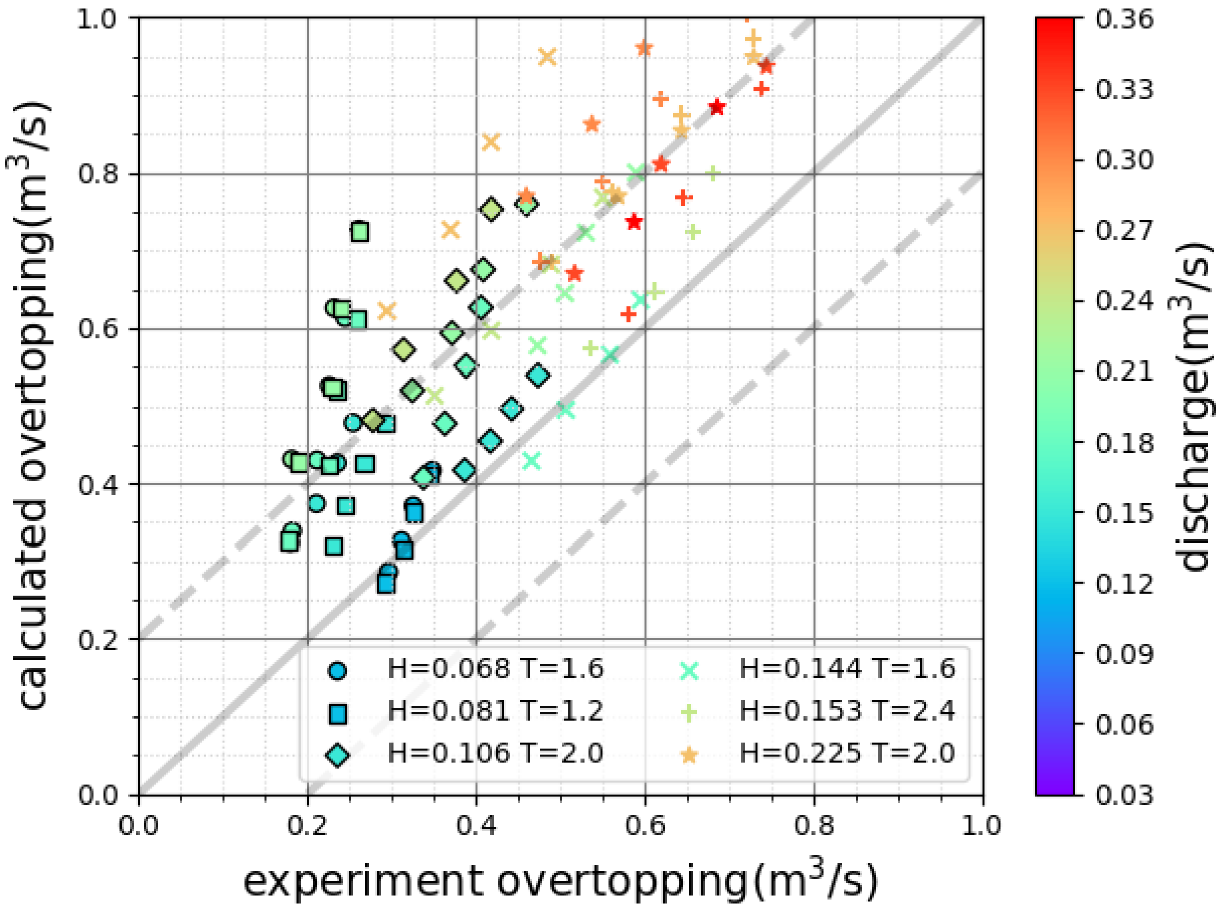


IFORM with $C_s = 0.6$

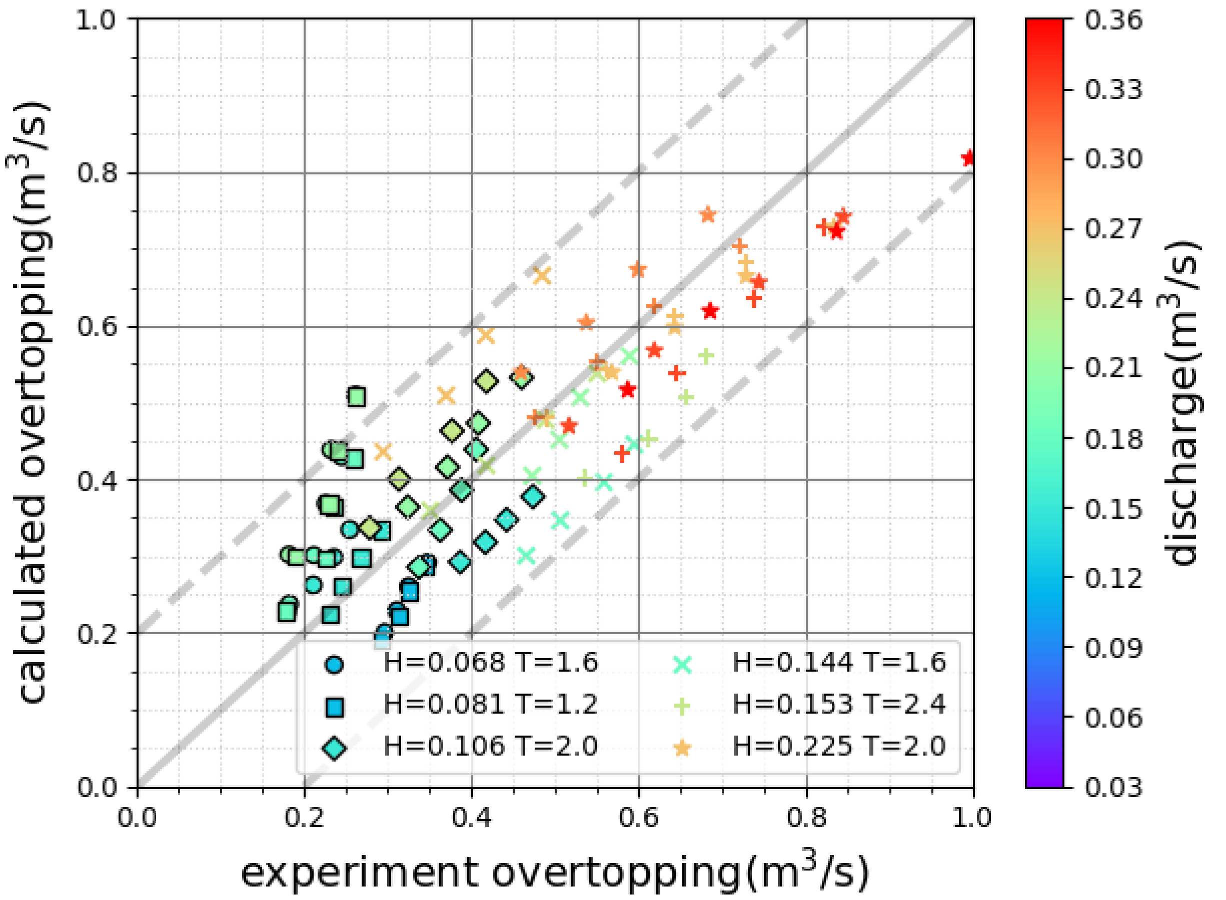


IFORM VS IFORM with C_s on the 1:1 slope

IFORM with C_s =1.0

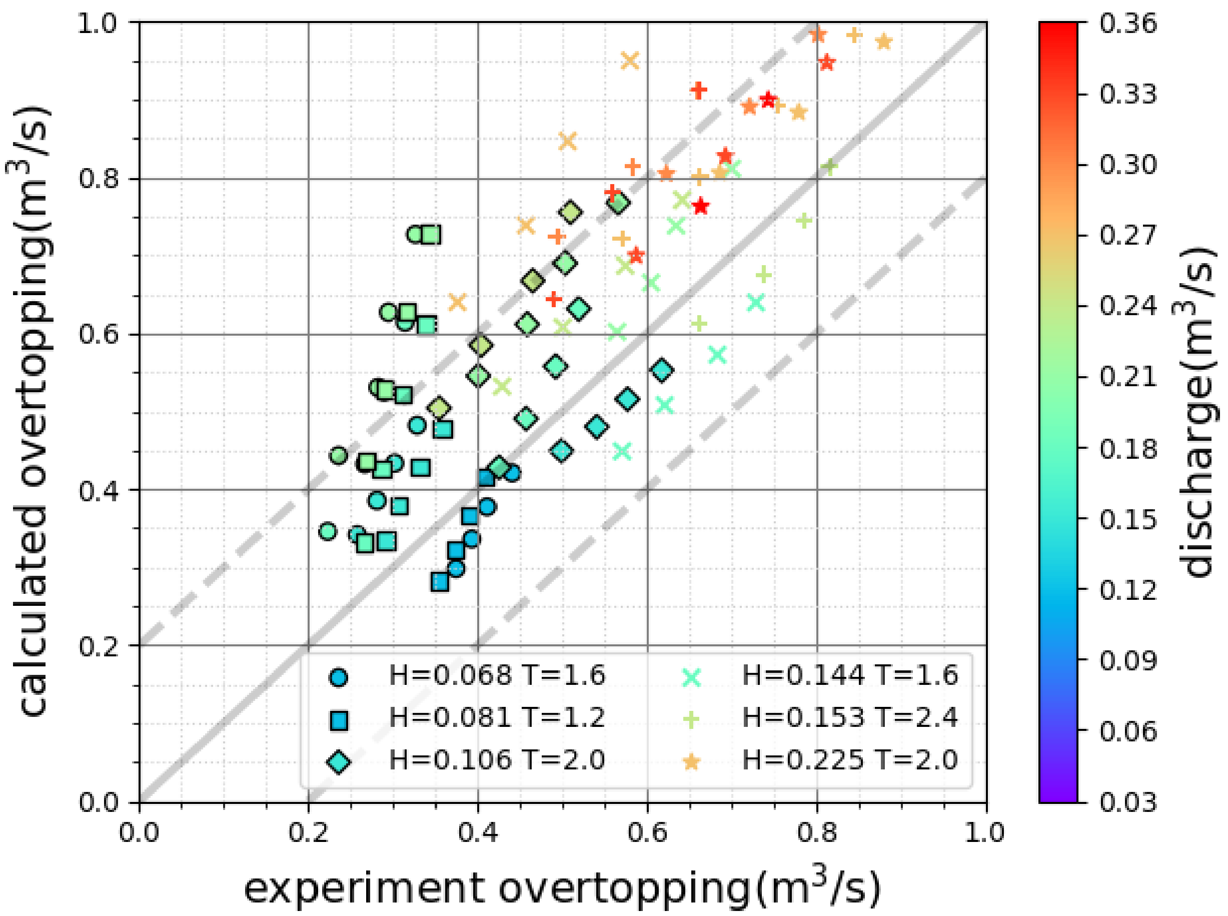


IFORM with C_s = 0.6



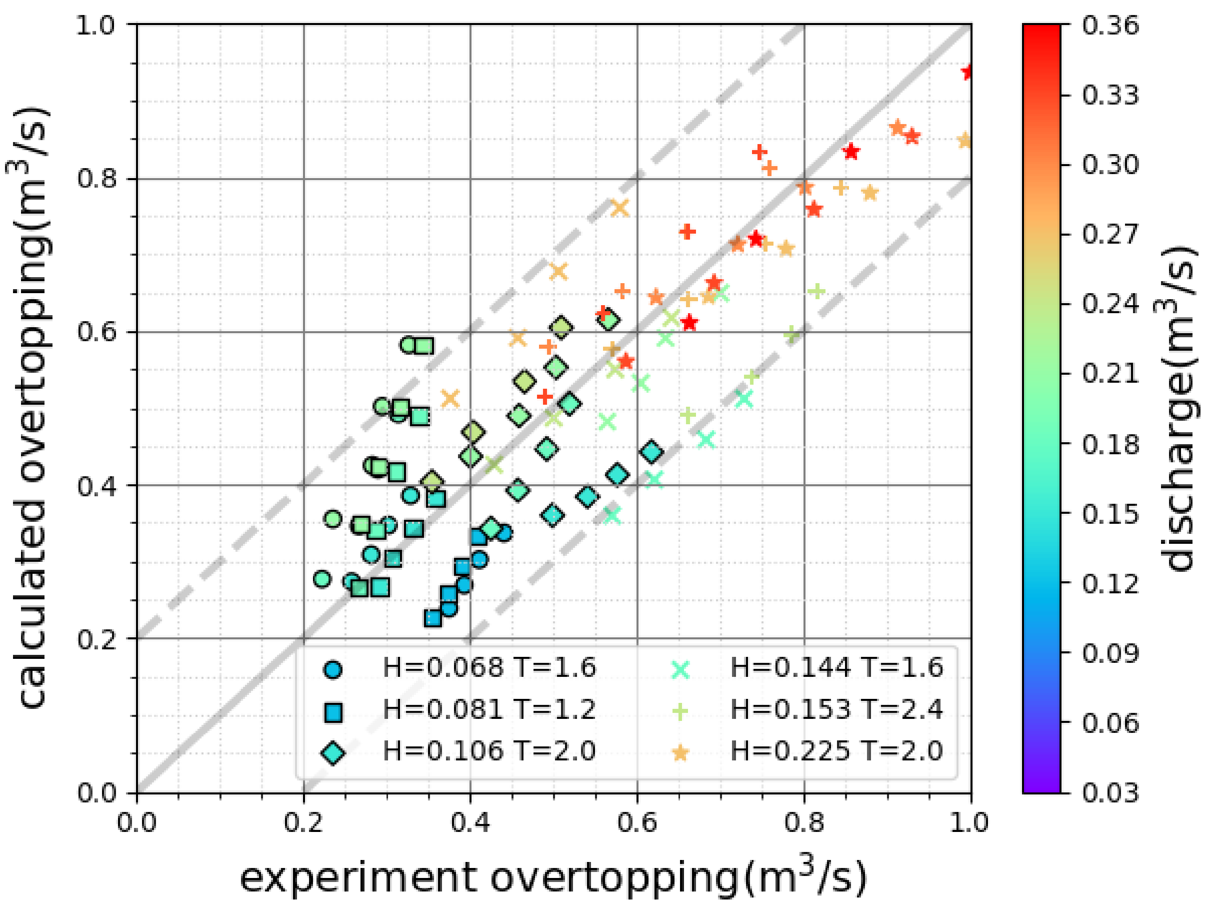
IFORM VS IFORM with C_s on the 1:2 slope

IFORM with C_s =1.0



C_s =1.0

IFORM with C_s = 0.6



C_s =0.6

Summary

Summary and conclusions

- Validation of the model with the experimental data
    - Considering Waves and water level changes
    - Good agreement with the experimental data
- Further work for improving
    - Mean rates of wave overtopping considering two bimodal sea conditions
    - Mean rates of surge overflow
    - Considering wave-dissipating revetments
    - Comparing IFORM to EuroTop

Sooyoul Kim[1]
sooyoulkim@kumamoto-u.ac.jp

Thank you!

Any question?

sooyoulkim@kumamoto-u.ac.jp

熊本大学
Kumamoto University