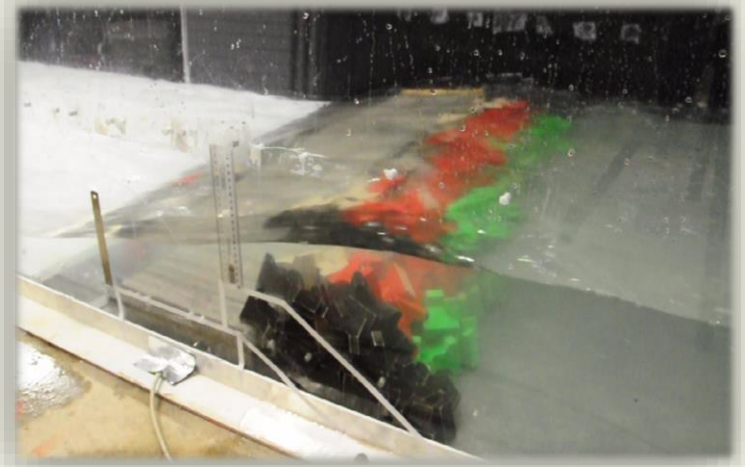
THE UNIVERSITY OF AUCKLAND
NEW ZEALAND

Composite Breakwaters Under Tsunami Attack



Zhonghou Xu, Bruce Melville, Liam Wotherspoon, N.A.K. Nandasena

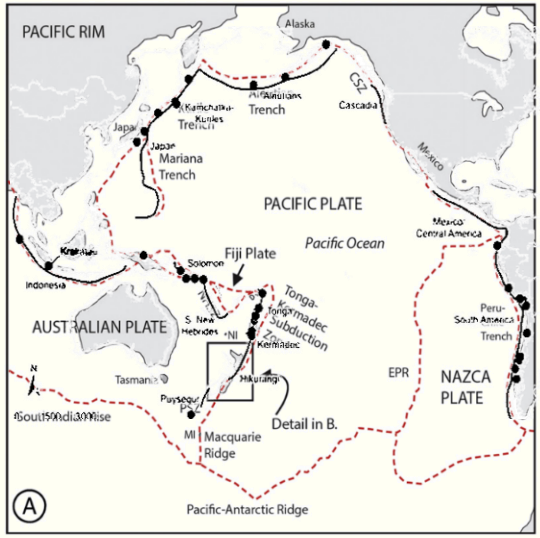
The University of Auckland

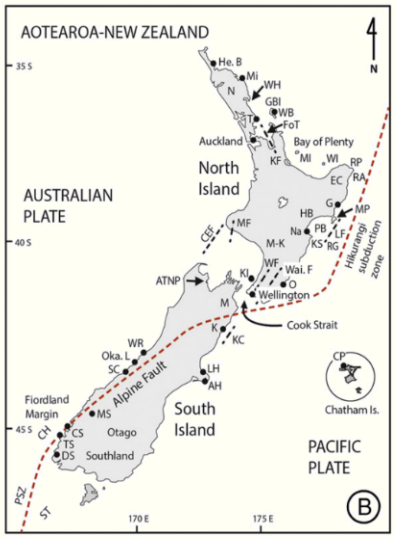
12 August, 2019

Introduction

Recent major tsunamis

- Indian Ocean tsunami, 2004
- South Pacific tsunami, 2009
- Chile tsunami, 2010
- Great East Japan tsunami, 2011





New Zealand tsunamis

Year	Source
1855	Wairarapa (earthquake)
1868	Southern Peru (earthquake)
1877	Northern Chile (earthquake)
1883	Krakatoa, Indonesia (volcano)
1895	Pigeon Bay, Canterbury (landslide)
1924	Chatham Islands (unknown source)
1931	Hawke's Bay (earthquake and landslide)
1947	Poverty Bay (tsunami earthquake)
1960	Chile (earthquake)
1964	Alaska (earthquake)
2003	Charles Sound, Fiordland (earthquake and landslide)
2010	Chile (earthquake)
2011	Japan (earthquake)

- 2016, Kaikoura (earthquake)

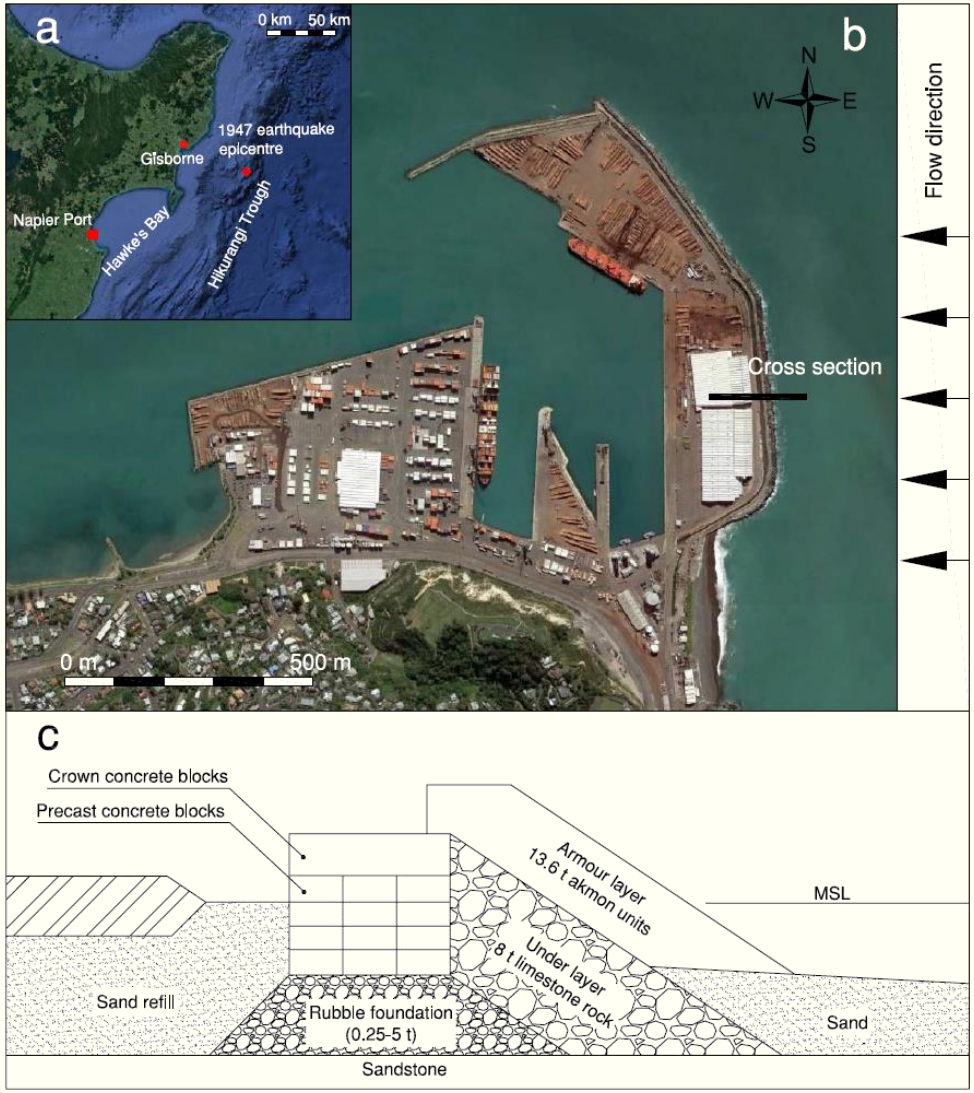
New Zealand's tectonic location in the South Pacific with major plate boundaries (adapted from D.N. King, 2015 and G. Downes et al, 2017)

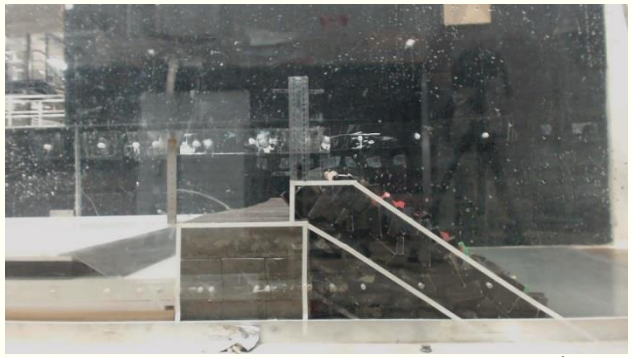
Introduction

Tsunami damage

Ghobarah, et al. (2006); Jayaratne, et al (2016)

Introduction

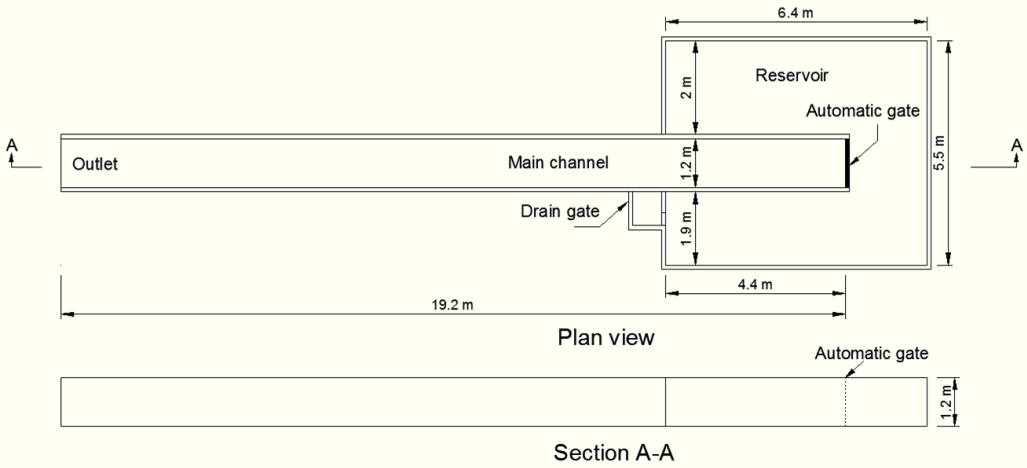




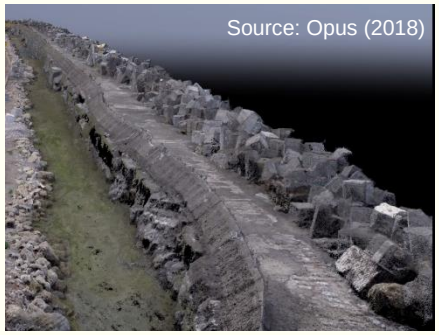
Sources: Google earth, GeoNet, Opus (2018)

Facility

Tsunami flume



Model set-up



Froude number similarity

Scale

Length scale=λ_L=40

Time scale=λ_T=6.32

Weight scale =λ_W=56303 (Akmon units, limestone rocks and concrete blocks)

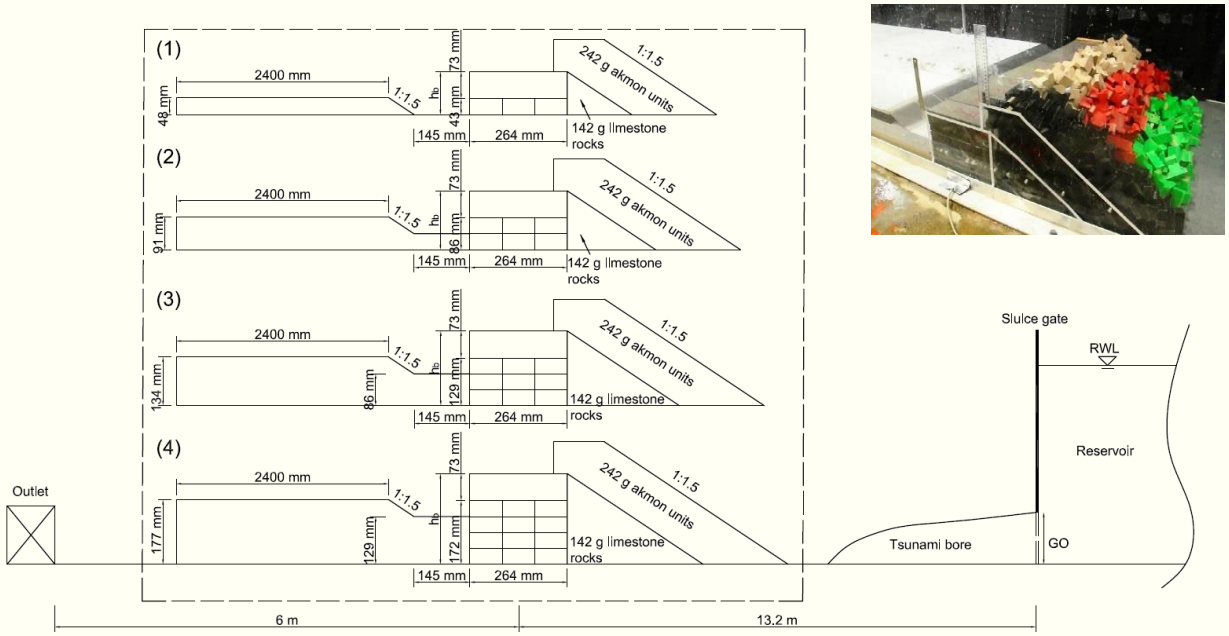
$$\lambda_W = (\lambda_L^3)\frac{(\gamma_r)_m}{(\gamma_r)_p}\left[\frac{(\gamma_r)_p/(\gamma_W)_p - 1}{(\gamma_r)_m/(\gamma_W)_m - 1}\right]^3$$

Table 1 Summary of units and blocks used in experiments.

Units	Density (kg/m^3)	Model weight (g)	Dimension (mm), (a b c)	Number
Akmon units	2400	242	-	298
Limestone rocks	2400	142 (W_{50})	-	621
Crown concrete blocks	2400	4394	264×95×73	12
Precast concrete blocks	2400	436	88×48×43	288

a, *b*, and *c* are the lengths of longitudinal, lateral, and height axes of the concrete blocks respectively.

Model set-up



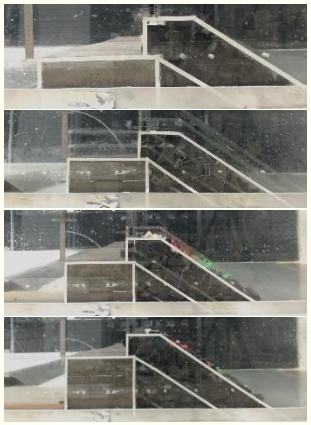


Table 2 Composition of models

Breakwater height h_b	Number of Akmon units (two layers)					Number of limestone rocks			Number of precast concrete blocks	Number of precast blocks layers
mm	Yellow (upper centre)	Red (middle centre)	Green (lower centre)	Black (both sides)	Total	White (centre)	Black (both sides)	Total		
116	38	38	38	54	168	101	50	151	72	1
159	48	48	48	78	222	178	88	264	144	2
202	55	57	57	83	252	250	130	380	216	3
245	66	66	66	100	298	405	216	621	288	4

Damage assessment methodology

$$N_s = \frac{h_0}{\Delta D_{n50}}$$

$$F_n = \frac{h_b}{h_0}$$

$$F_b = \frac{(h_b \Delta D_{n50})^{0.5}}{h_0}$$

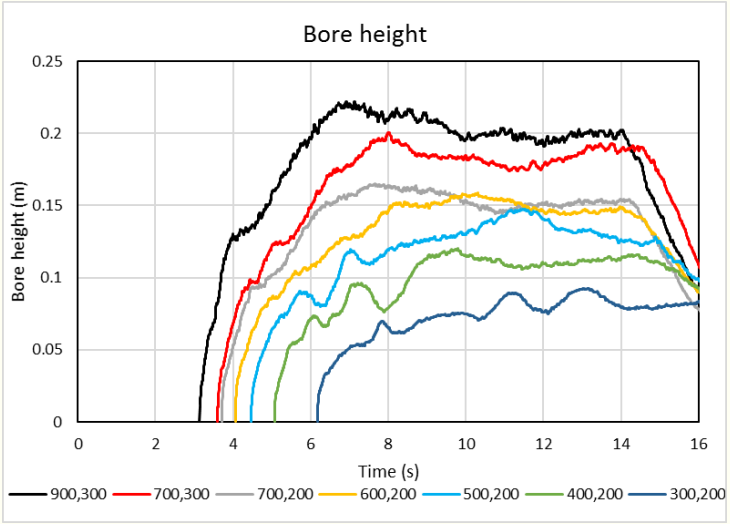
Damage parameter S

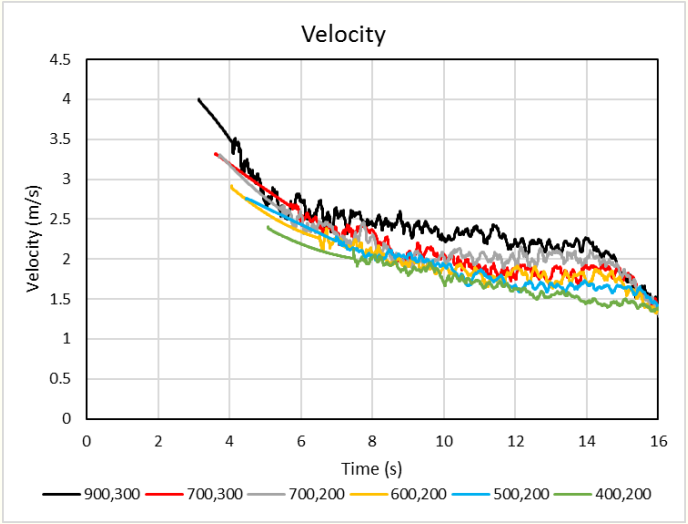
$$S = \frac{A_e}{D_{n50}^2} \qquad A_e = \frac{N_e D_{n50}^3}{(1-n)L} \qquad n = \frac{dA - mV}{dA}$$

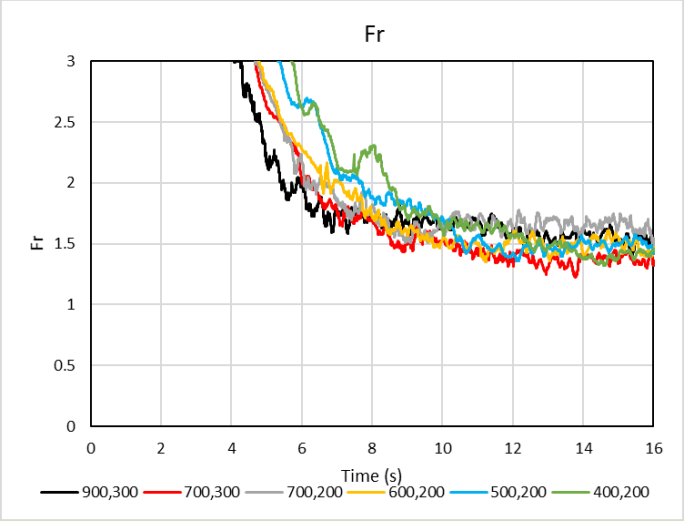
Damage ratio R_d

$$R_d = \frac{N_{displaced}}{N_{total}} \times 100\%$$

Results


Bore height
Bore height (m)
0.25
0.2
0.15
0.1
0.05
0
0 2 4 6 8 10 12 14 16
Time (s)
900,300 700,300 700,200 600,200 500,200 400,200 300,200


Velocity
Velocity (m/s)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0 2 4 6 8 10 12 14 16
Time (s)
900,300 700,300 700,200 600,200 500,200 400,200

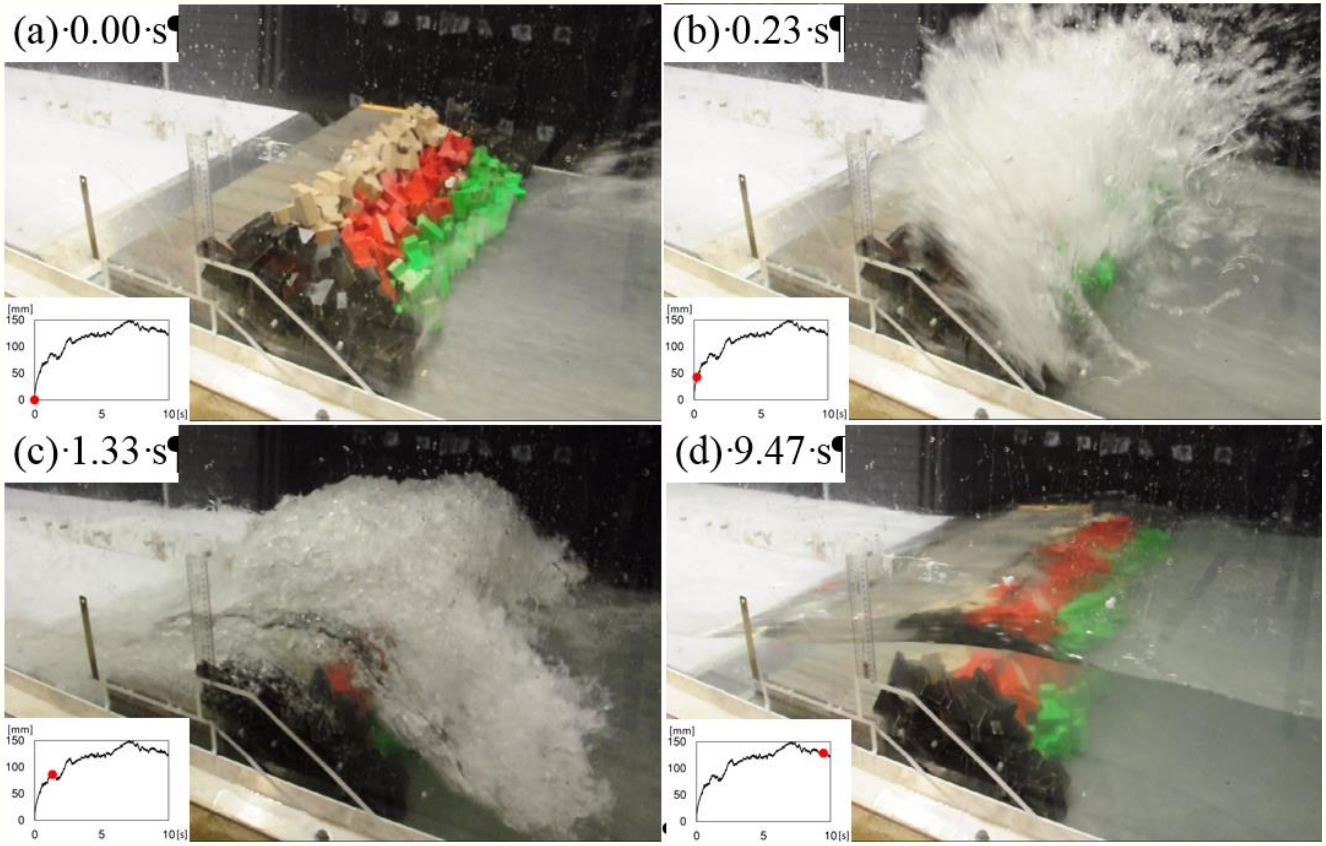

Fr
Fr
3
2.5
2
1.5
1
0.5
0
0 2 4 6 8 10 12 14 16
Time (s)
900,300 700,300 700,200 600,200 500,200 400,200

Results

https://youtu.be/bYB_tfanpsw

20% actual speed.

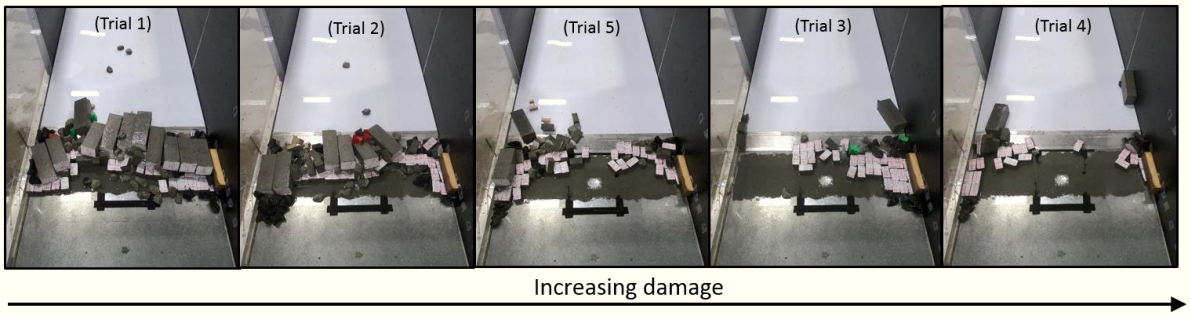
Results



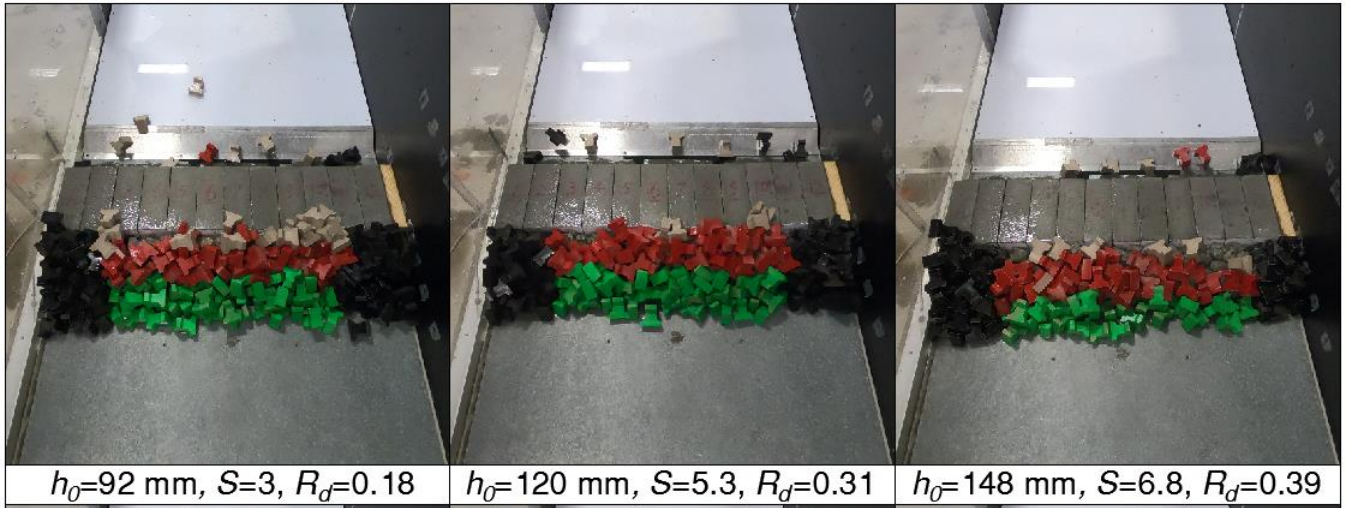
(a) Initial impact at 0.00 s.
(b) Splash up at 0.23 s.
(c) Overtopping at 1.33 s.
(d) Quasi-steady overflow at 9.47 s.
The height of the breakwater is 116 mm. h_0=148 mm.

Results

Variability in damage for the same set-up



Results



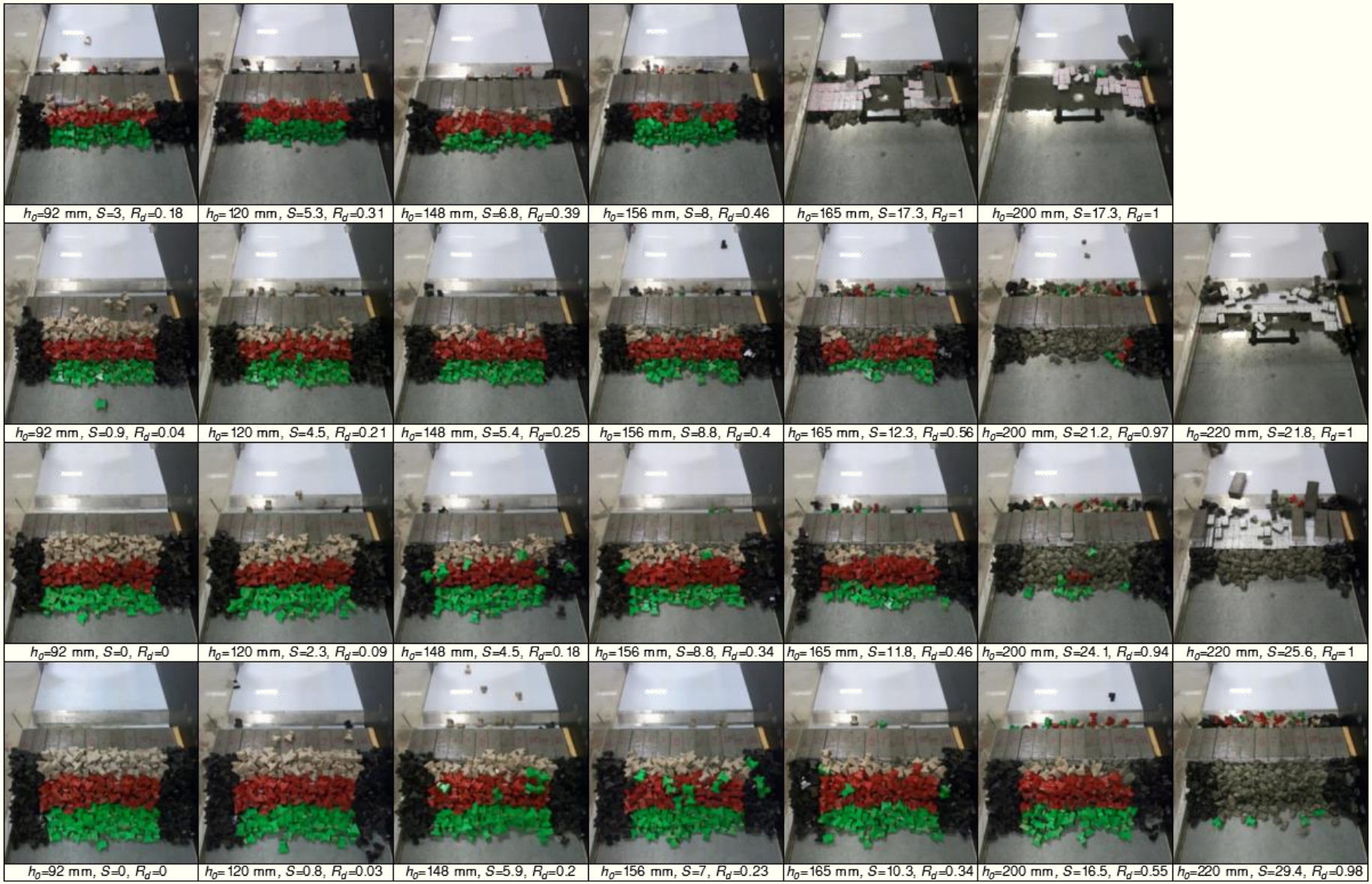
h_0=92 mm, S=3, R_d=0.18 | h_0=120 mm, S=5.3, R_d=0.31 | h_0=148 mm, S=6.8, R_d=0.39

h_0=156 mm, S=8, R_d=0.46 | h_0=165 mm, S=17.3, R_d=1 | h_0=200 mm, S=17.3, R_d=1

Breakwater height h_b=116 mm.

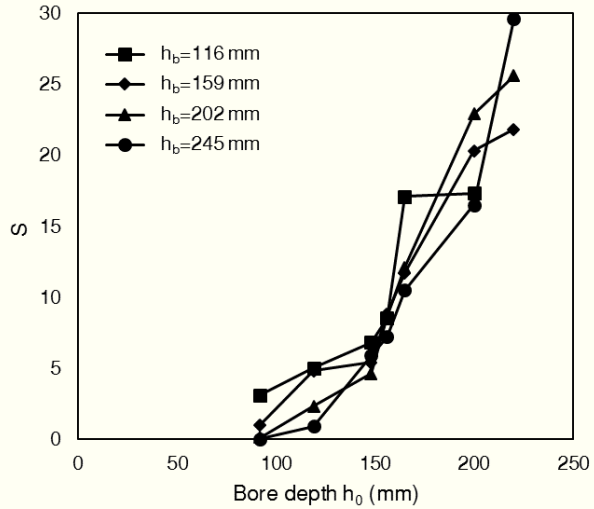
Increasing bore height

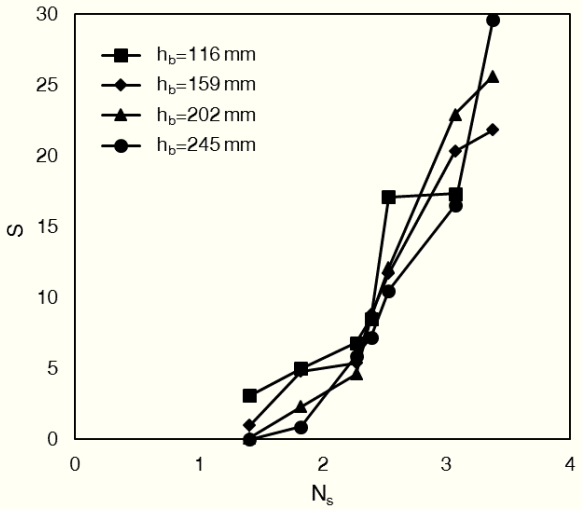
Increasing breakwater height

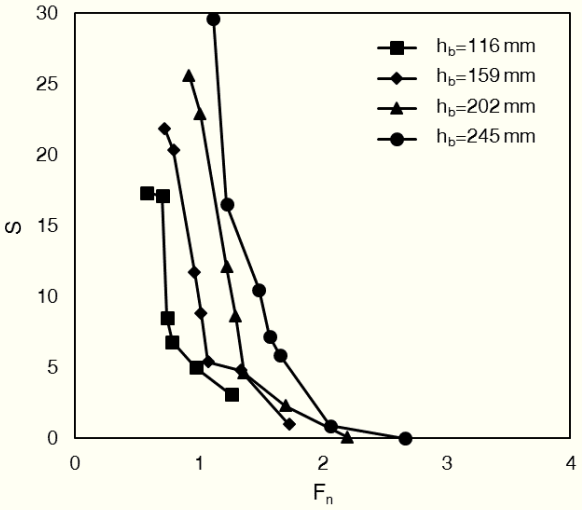


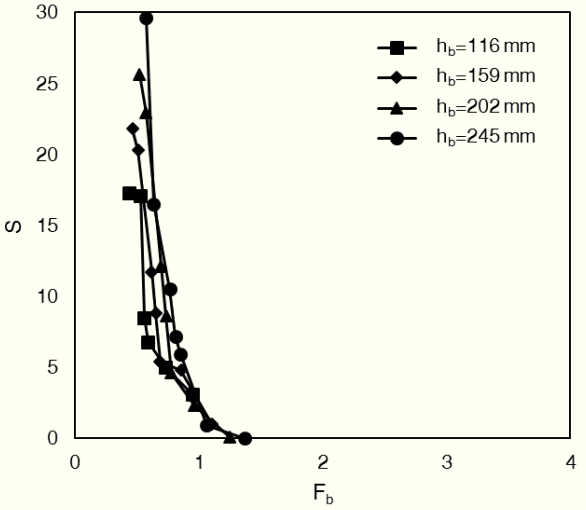
Results

$$S = \frac{A_e}{D_{n50}^2}$$



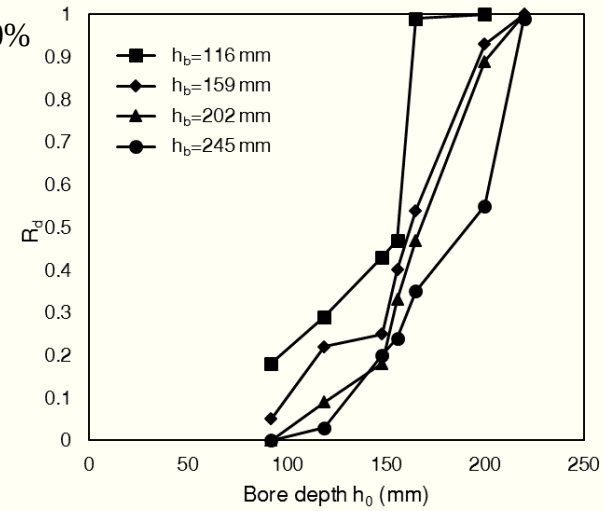


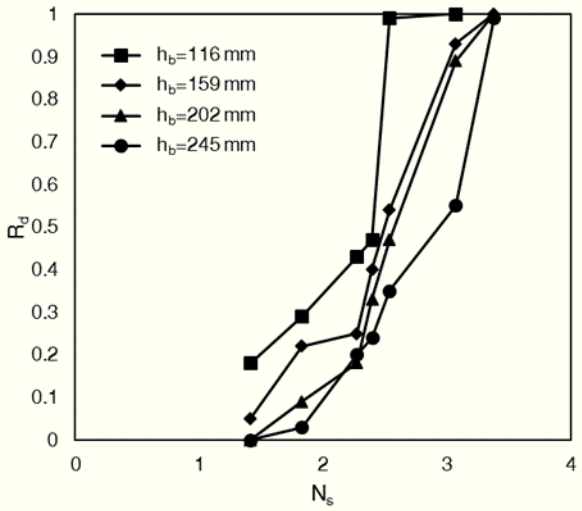


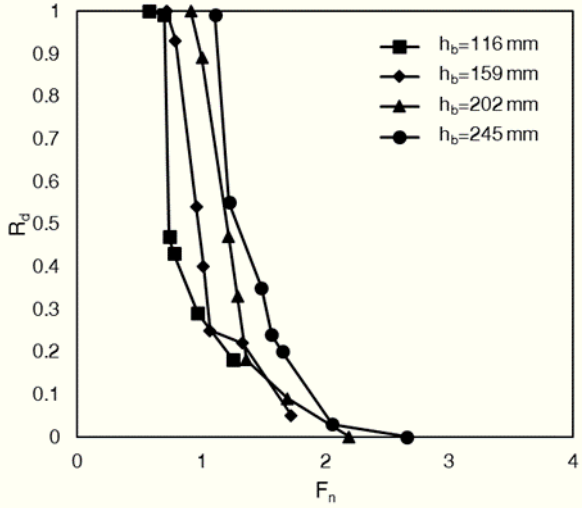


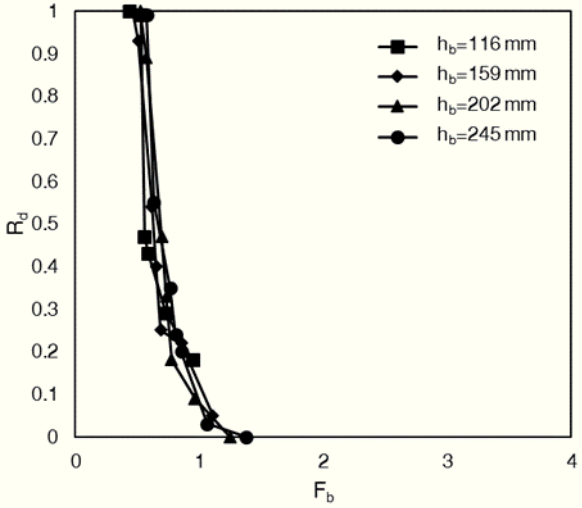
Results

$$R_d = \frac{N_{displaced}}{N_{total}} \times 100\%$$









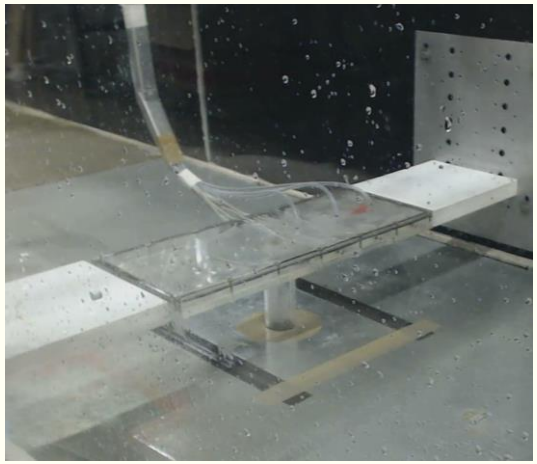
Conclusion

- Once the precast concrete blocks underneath the crown blocks are exposed, they will be quickly displaced by the tsunami flow. The higher breakwaters experienced delayed initiation of the same damage ratio levels (R_d).
- The damage parameter S and the damage ratio R_d increase with bore depths. The proposed parameter F_b is a good parameter for assessing the damage of the armour layer under tsunami flow。
- Little damage of armour layer was observed when F_b>1 while destruction occurred when F_b approached 0.5.

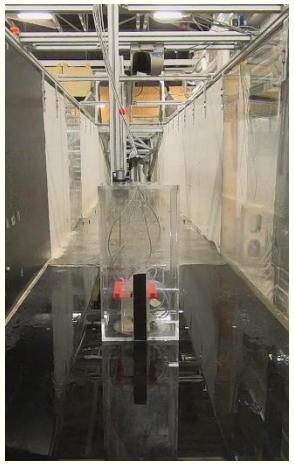
Previous and ongoing research

Wharf

Bridge

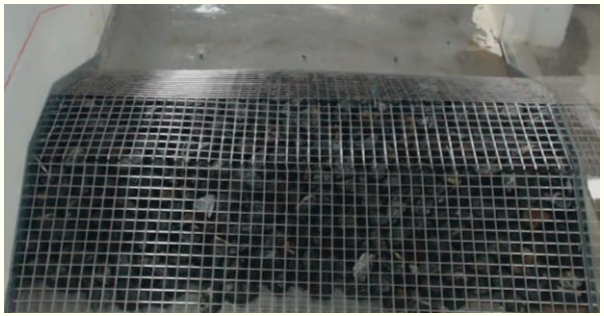


Building

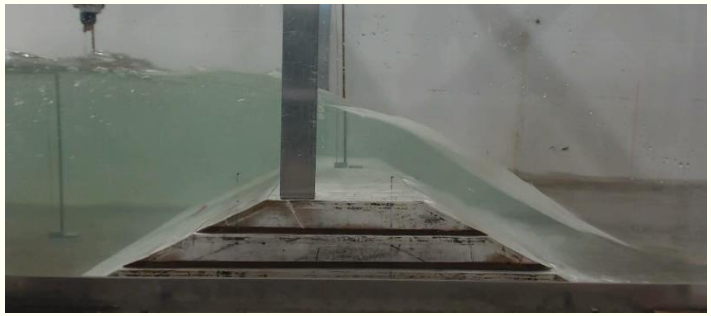


Power pole

Rubble mound



Sea wall



Thank you

E-mail: zxu159@aucklanduni.ac.nz