Wave overtopping mitigation by a vertical wall or a wave return wall at the end of a pitched rock slope

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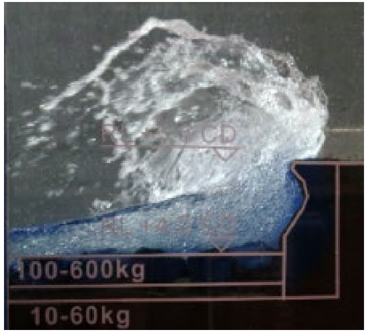

Contents

- Objective
- Mitigation options for sea level rise and wave overtopping
- Stability of pitched rock slopes
- Analysis on wave overtopping
- Practical results along EurOtop

Objective

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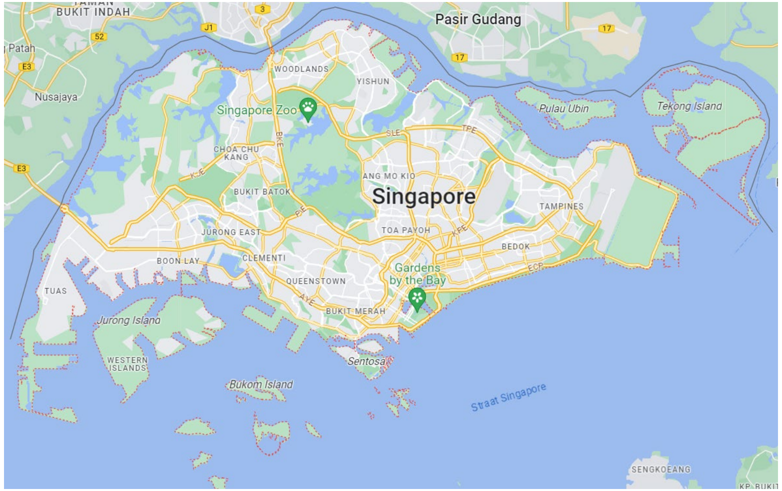
Situation in Singapore

- Relatively mild (design) wave conditions: H_s = 1-2.5 m
- Locally generated: steep waves with $s_{m-1,0} > 0.035$
- Deep water (generally 10-20 m)
- Crest level low and equal to industrial area



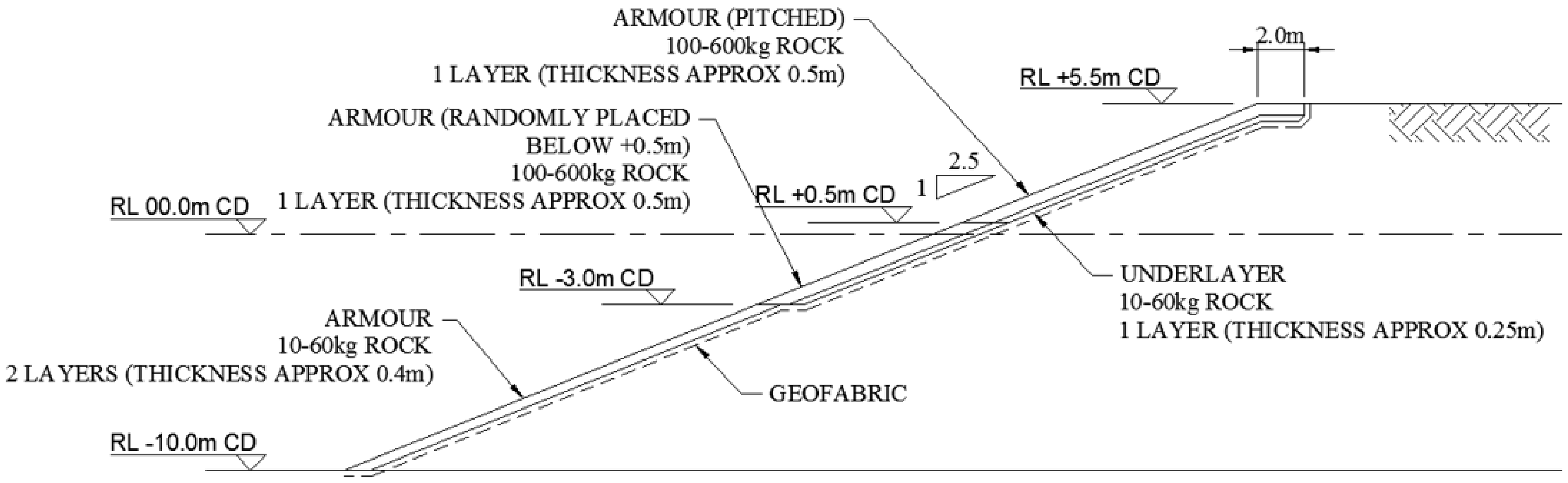
Sea level rise will have a significant influence on wave overtopping

What are efficient and practical mitigation options?

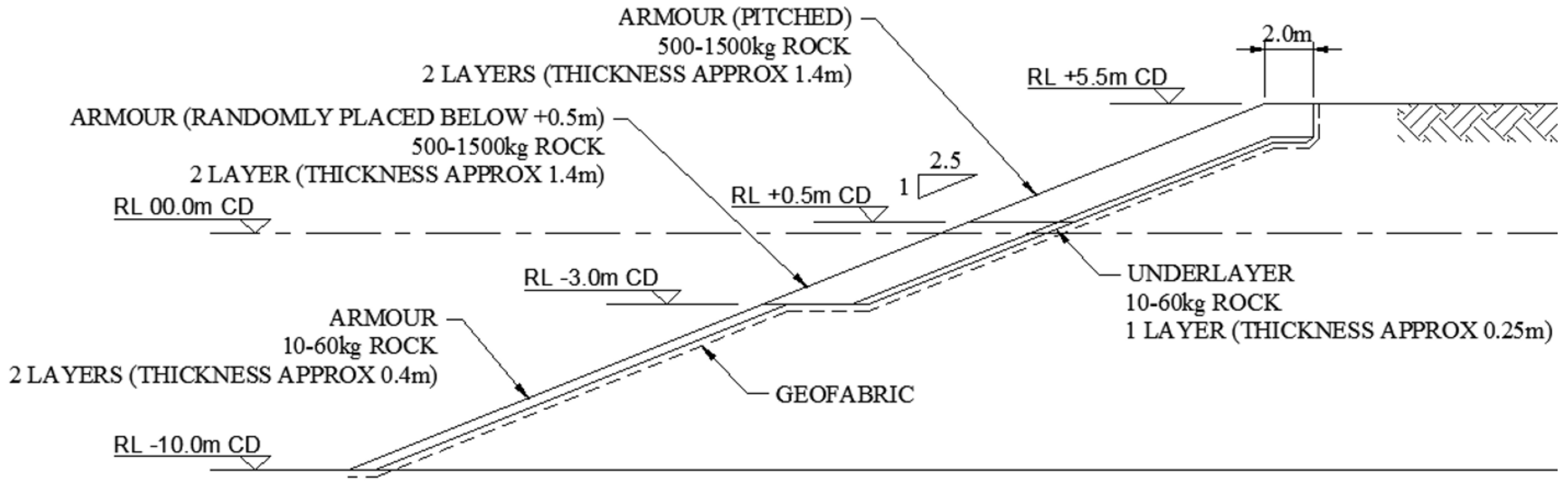
Pitched rock slopes

Pitched rock slopes

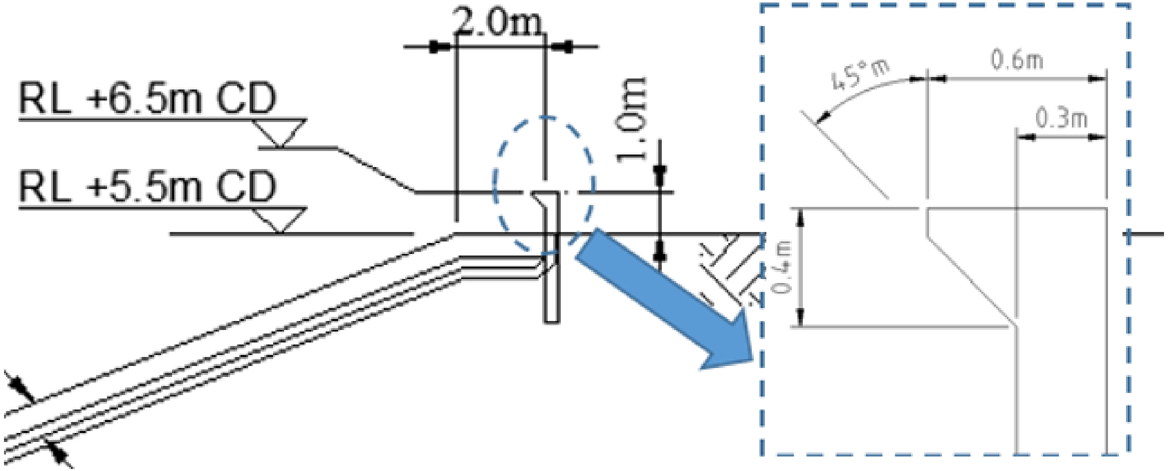
Pitched rock slopes – single layer, Structure 1



Pitched rock slopes – double layer, Structure 2



Mitigation: wave wall

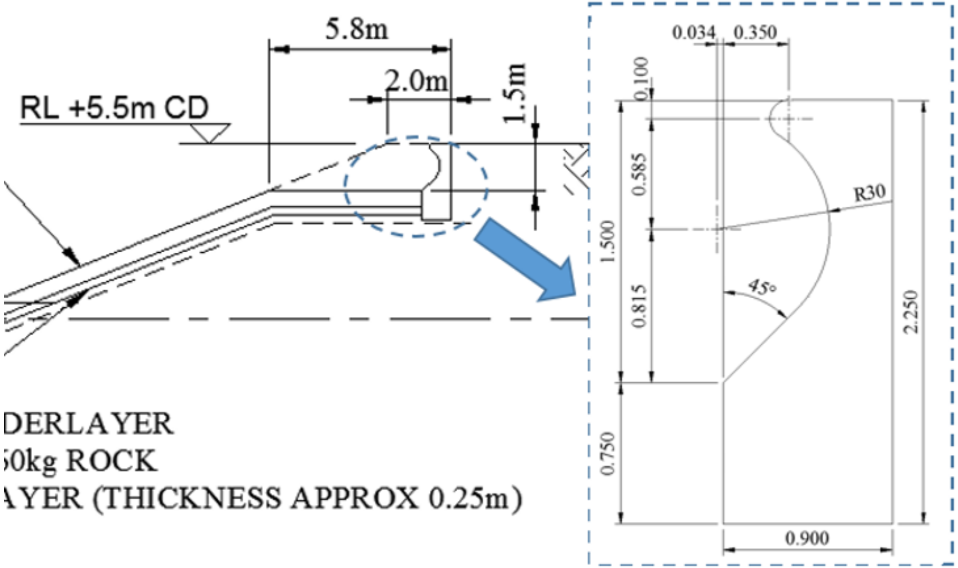


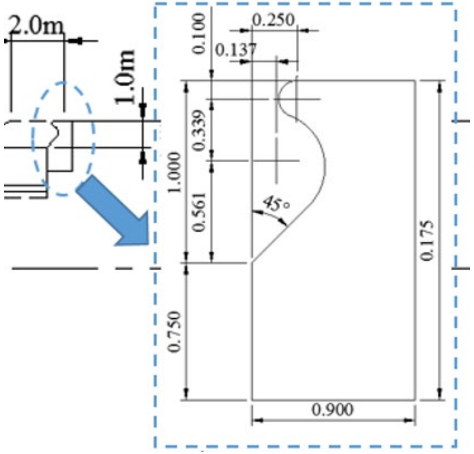
1.0 or 1.5 m high

with or without bullnose

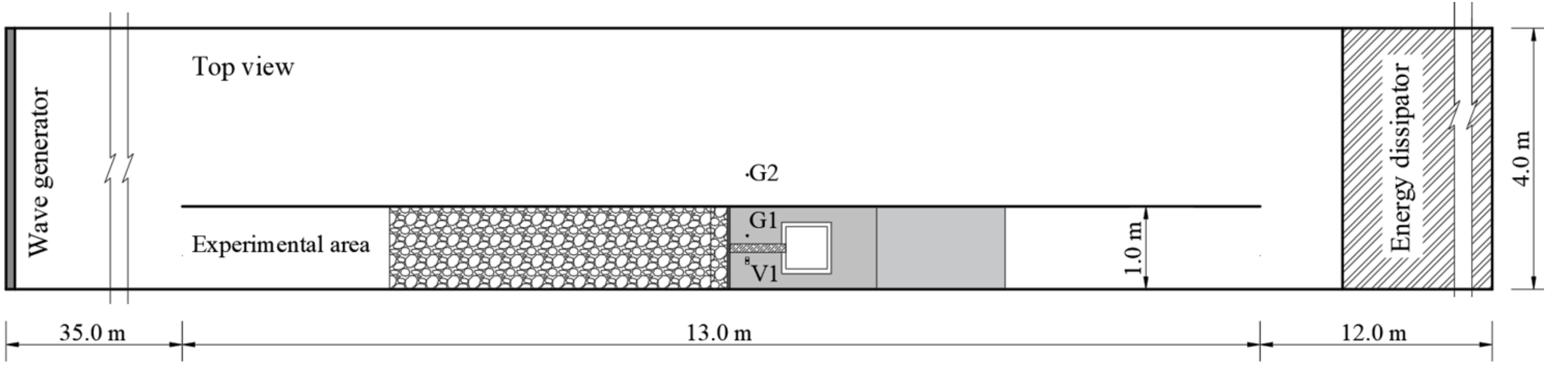
Mitigation: wave return wall

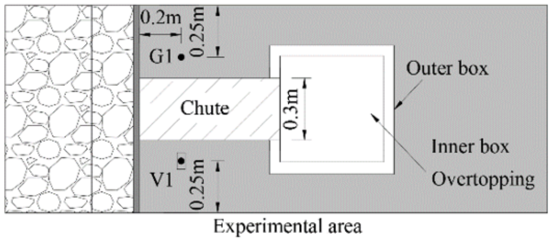
1.0 or 1.5 m high





Model tests in China, Dalian University of Technology





Model tests in China, Dalian University of Technology

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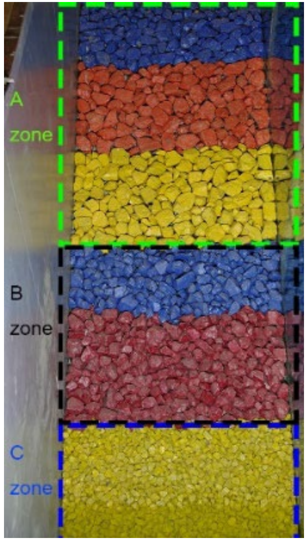
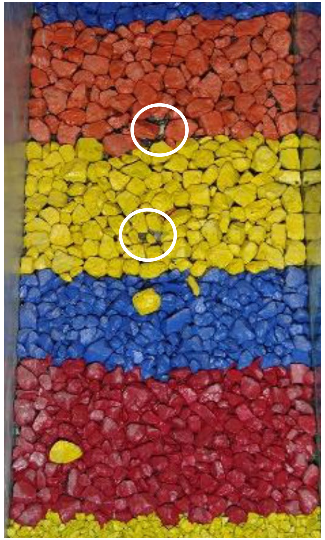
Single layer



Before

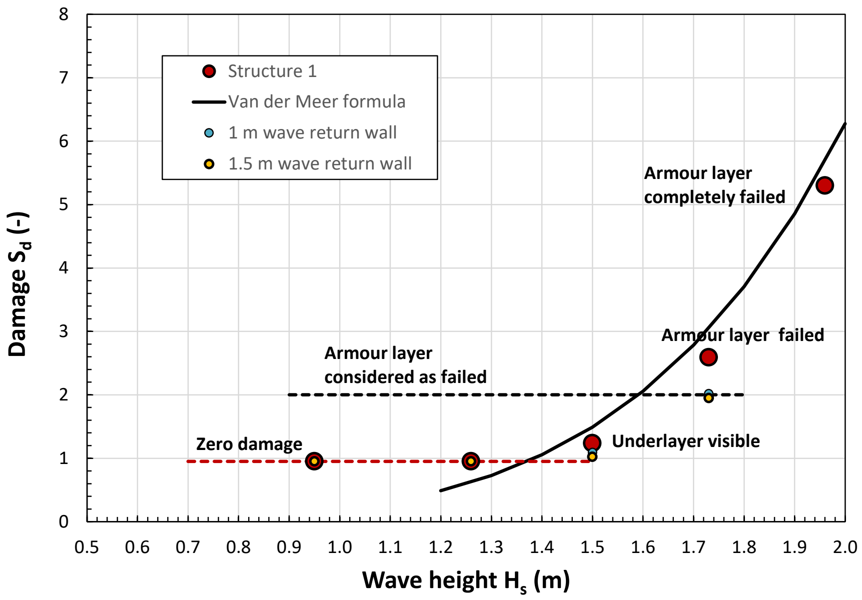


S_d=1.2

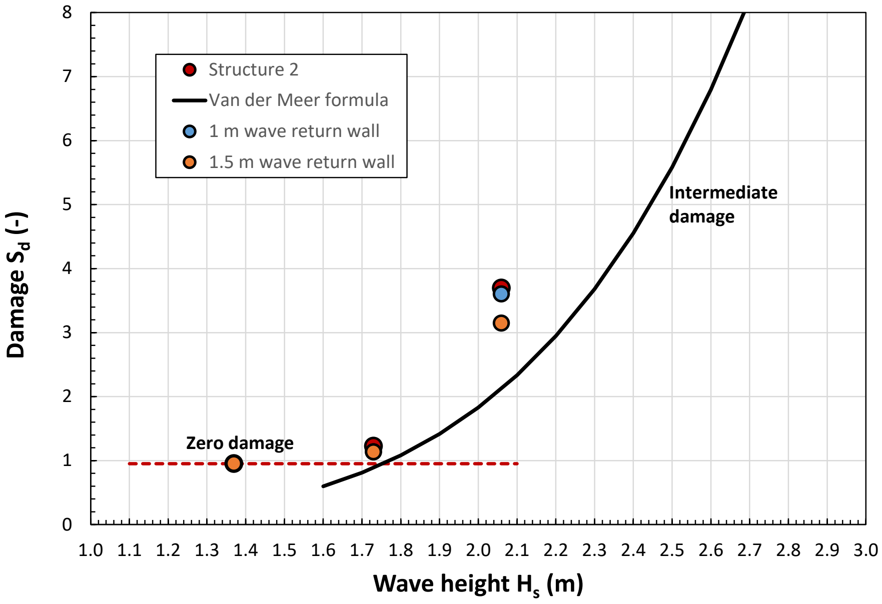
S_d=2.3
Failure

S_d=4.6
Structure failed

Stability – Van der Meer formula



Single layer pitched rock



Double layer pitched rock

Wave overtopping tests

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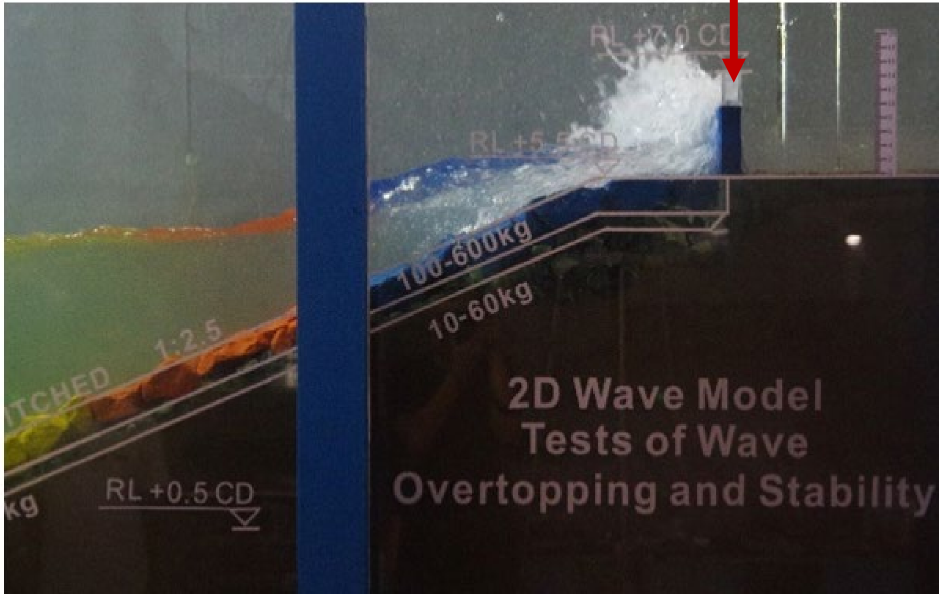
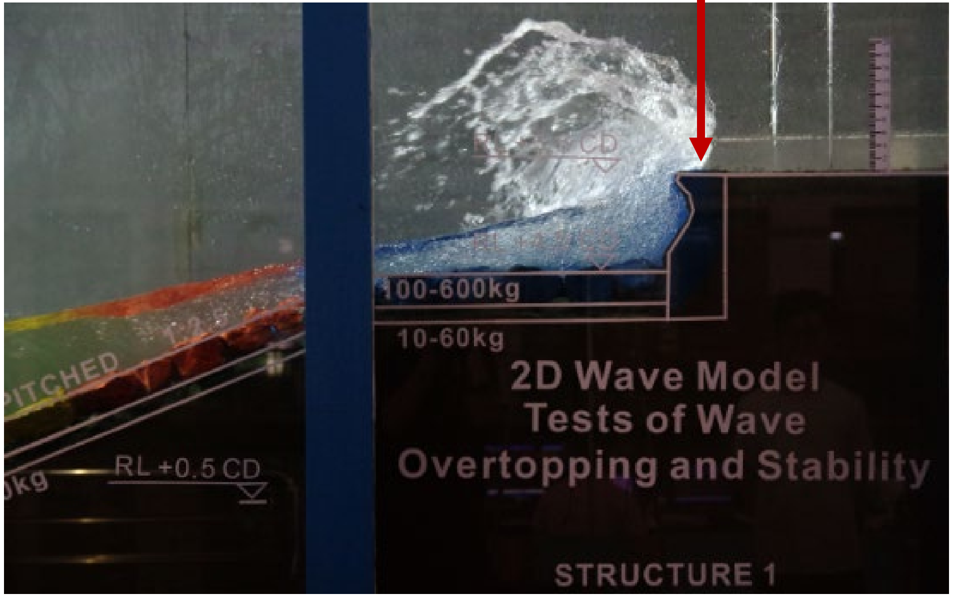
Wave wall, with or without bullnose

Wave return wall



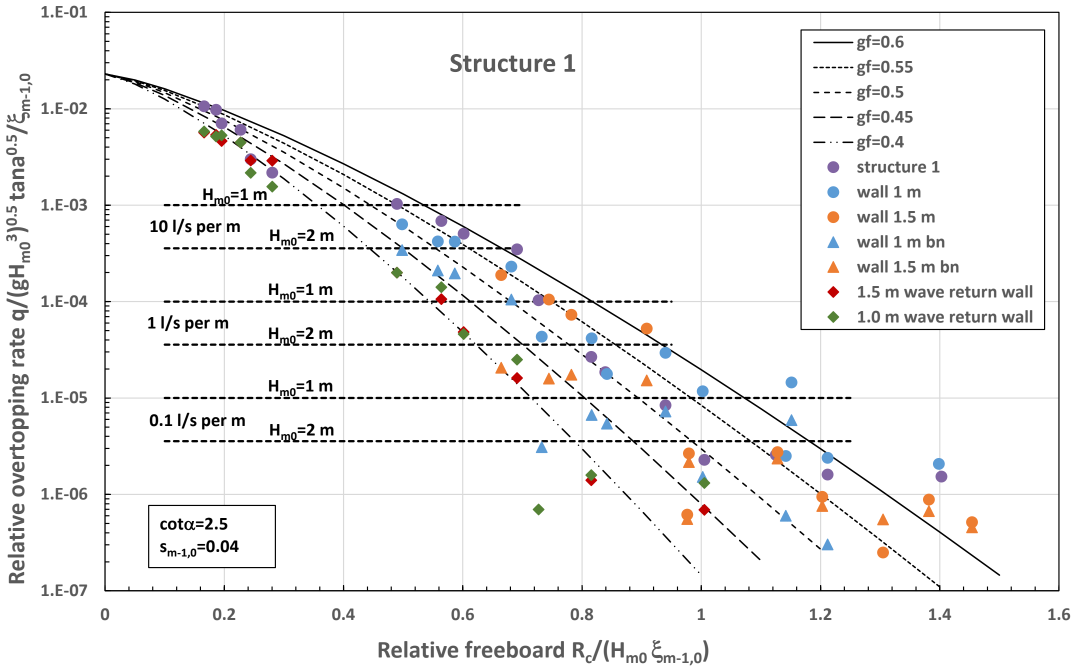


EurOtop equations (gentle slope)

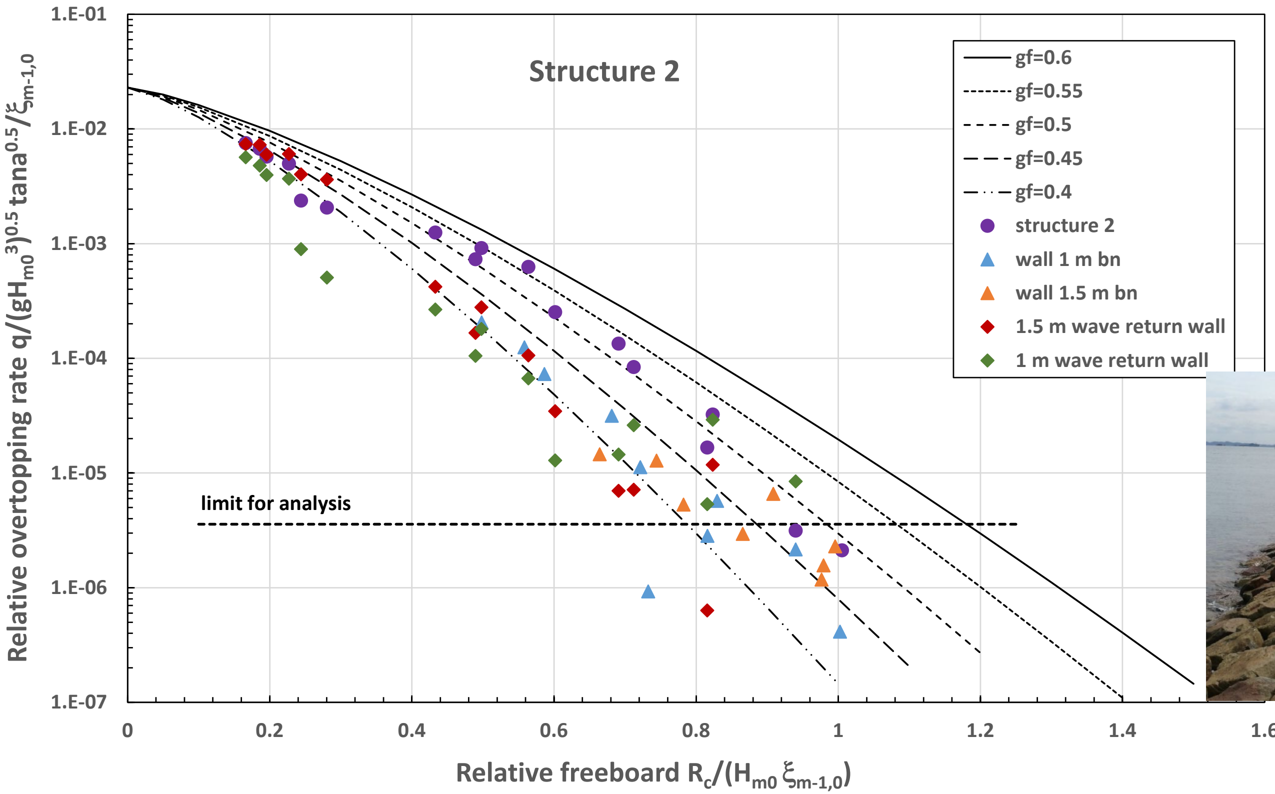
Influence factor for roughness/wall

$$\frac{q}{\sqrt{g \cdot H_{m0}^{3}}} = \frac{0.023}{\sqrt{\tan\alpha}} \gamma_b \cdot \xi_{m-1,0} \cdot \exp\left[-\left(2.7 \frac{R_c}{\xi_{m-1,0} \cdot H_{m0} \cdot \gamma_b \cdot \gamma_f \cdot \gamma_\beta \cdot \gamma_v}\right)^{1.3}\right]$$

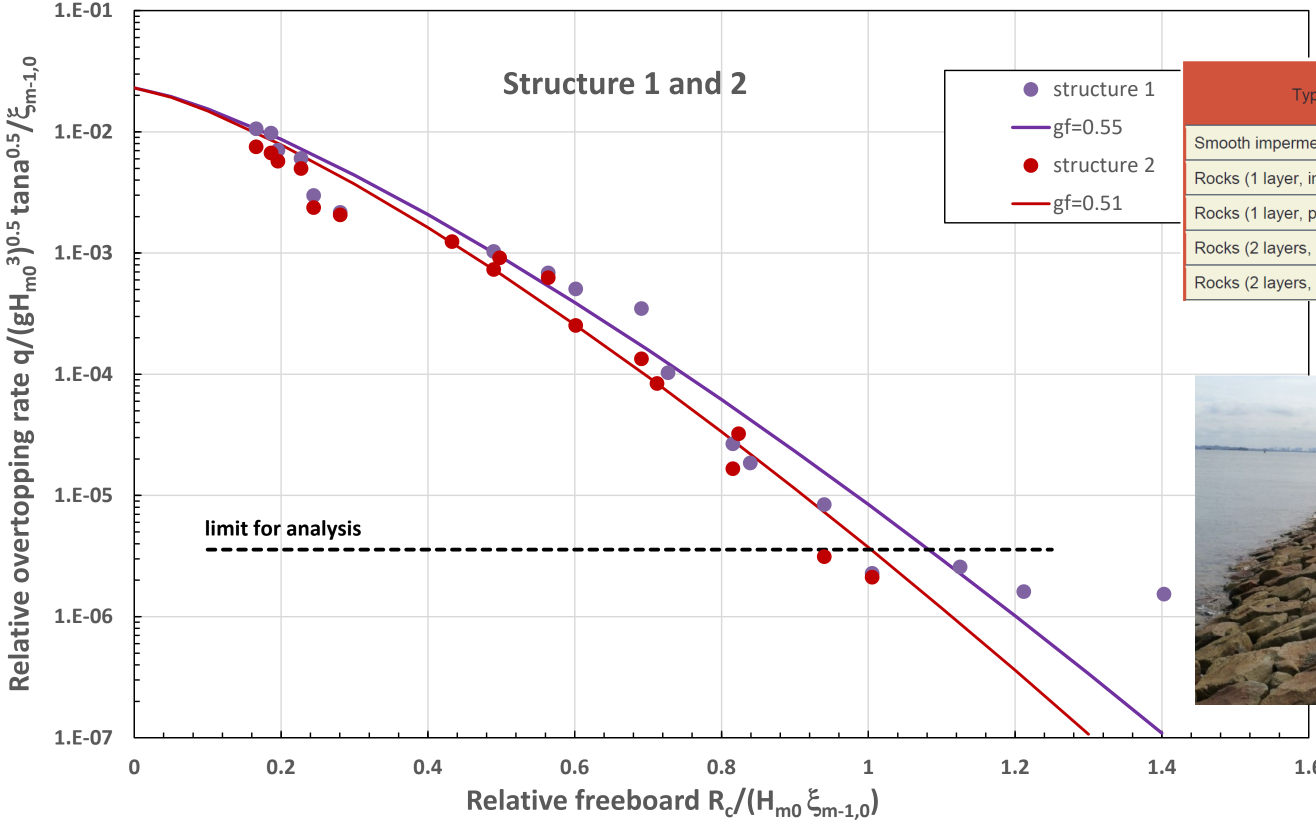
EurOtop 5.10



Double pitched, all data



Single or double pitched - comparison



Type of armour layer	γ_f
Smooth impermeable surface	1.00
Rocks (1 layer, impermeable core)	0.60
Rocks (1 layer, permeable core)	0.45
Rocks (2 layers, impermeable core)	0.55
Rocks (2 layers, permeable core)	0.40

Single pitched; wave wall

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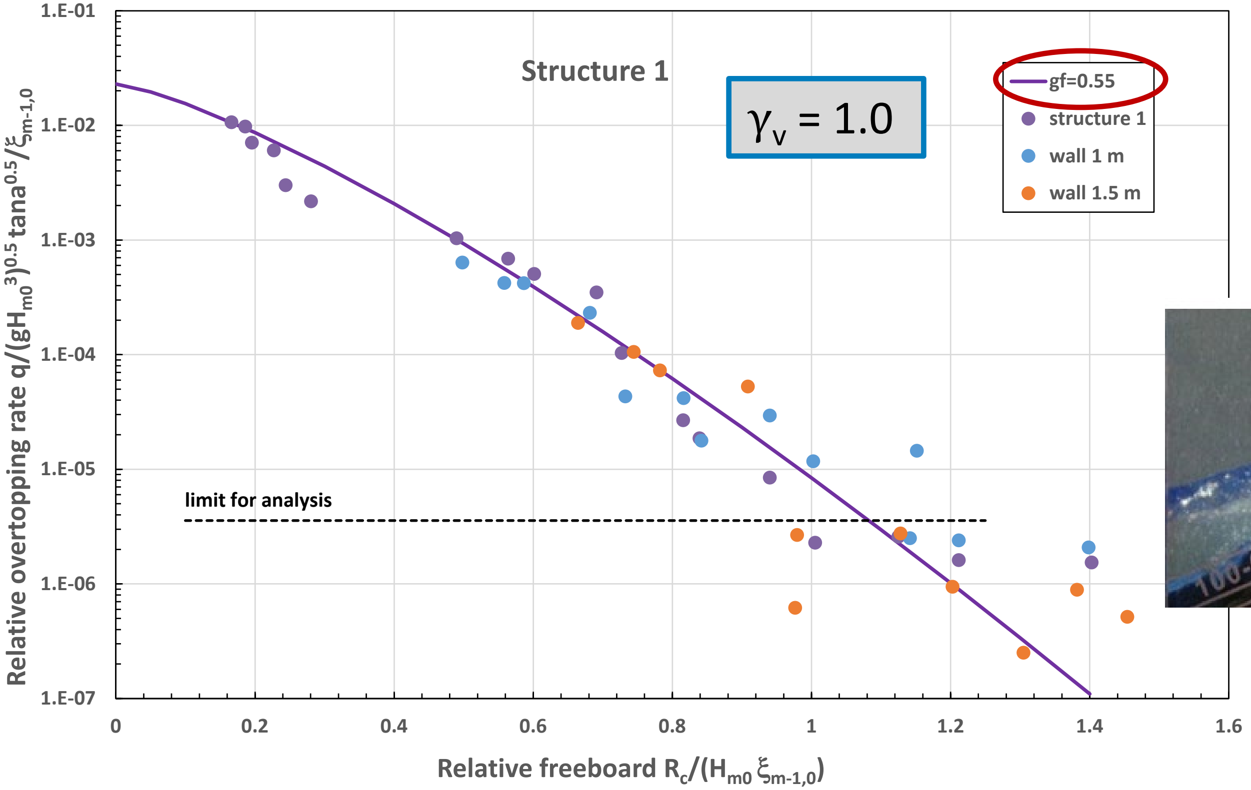
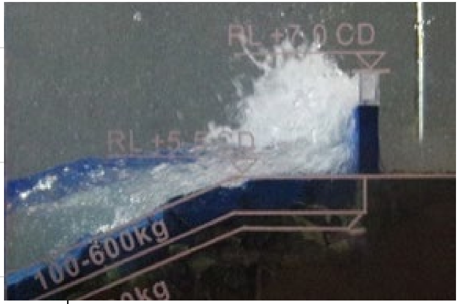
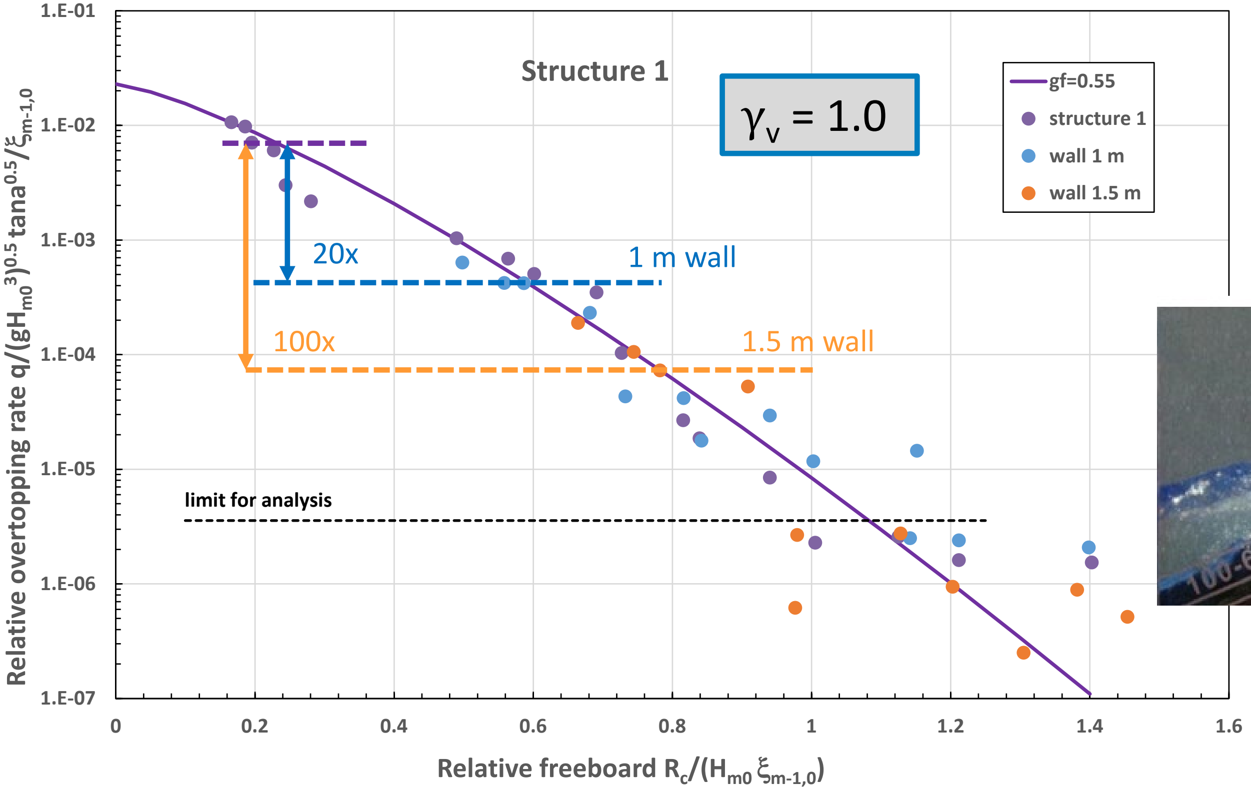
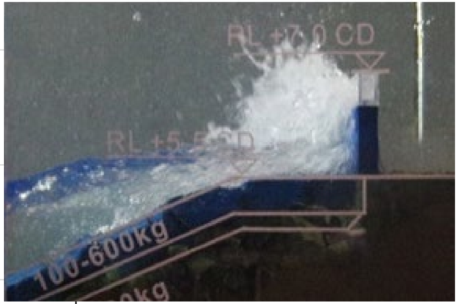


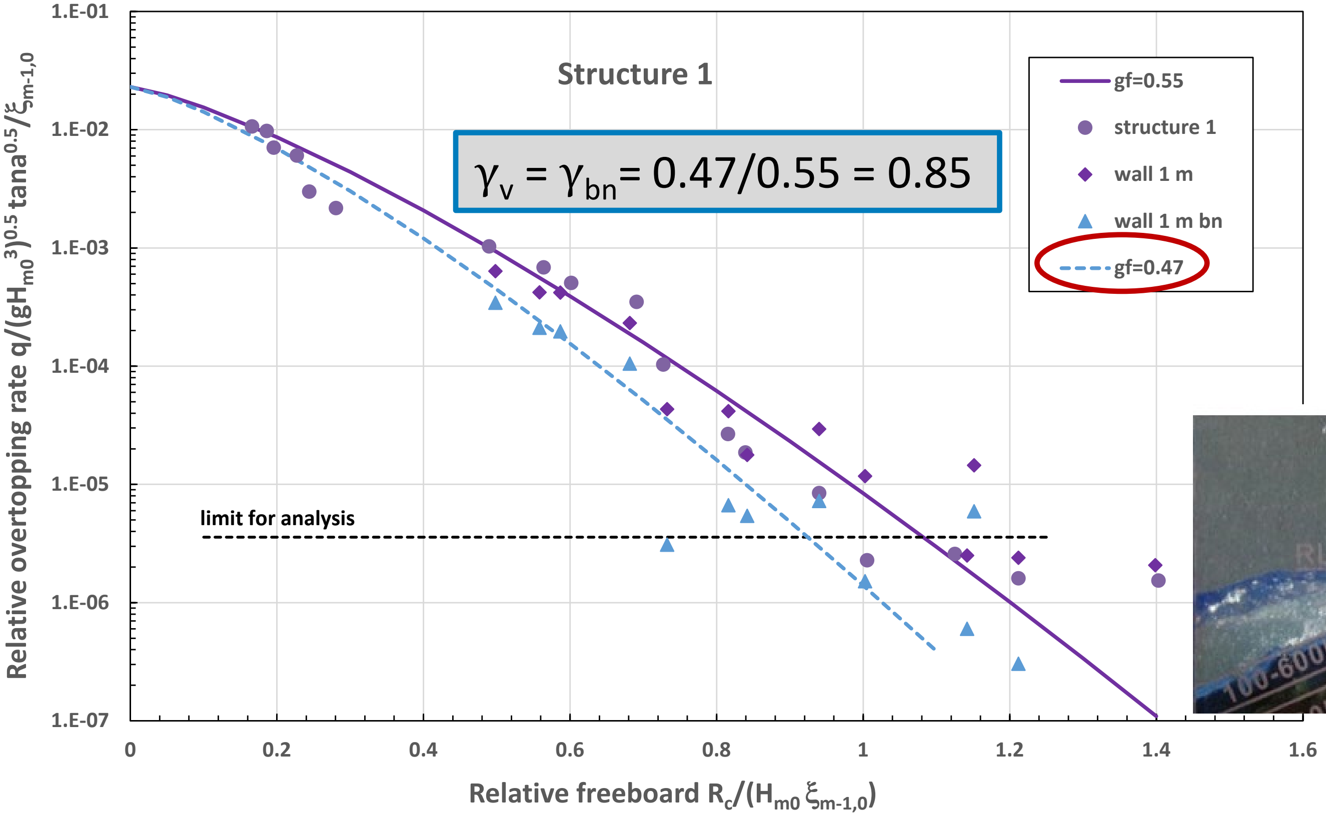


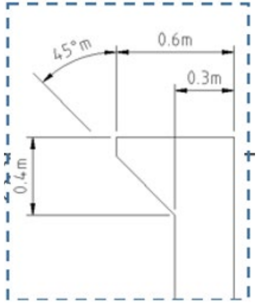
Single pitched; wave wall





Single pitched; wall and bullnose 1 m





Single pitched; wall and bullnose 1.5 m

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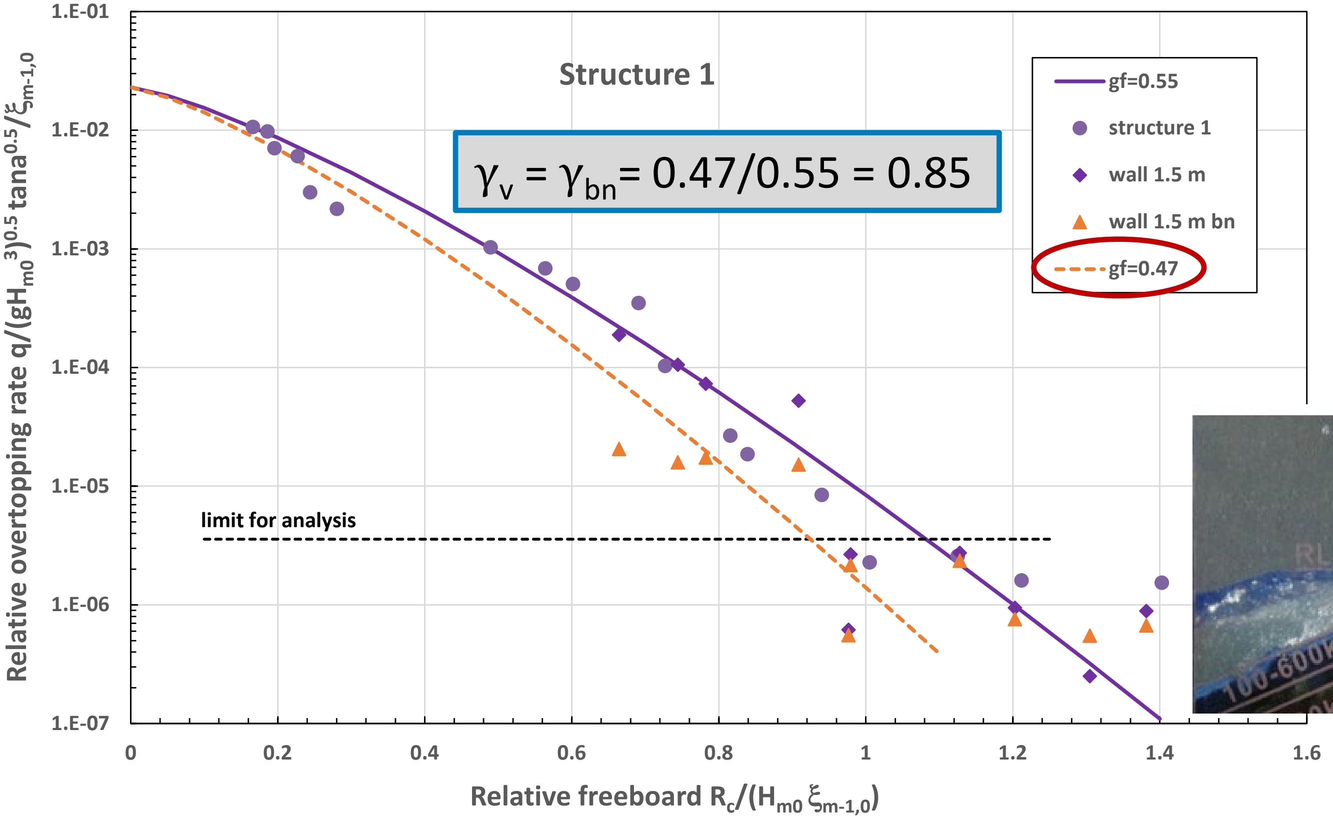
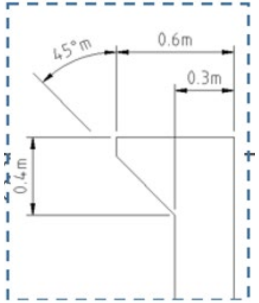
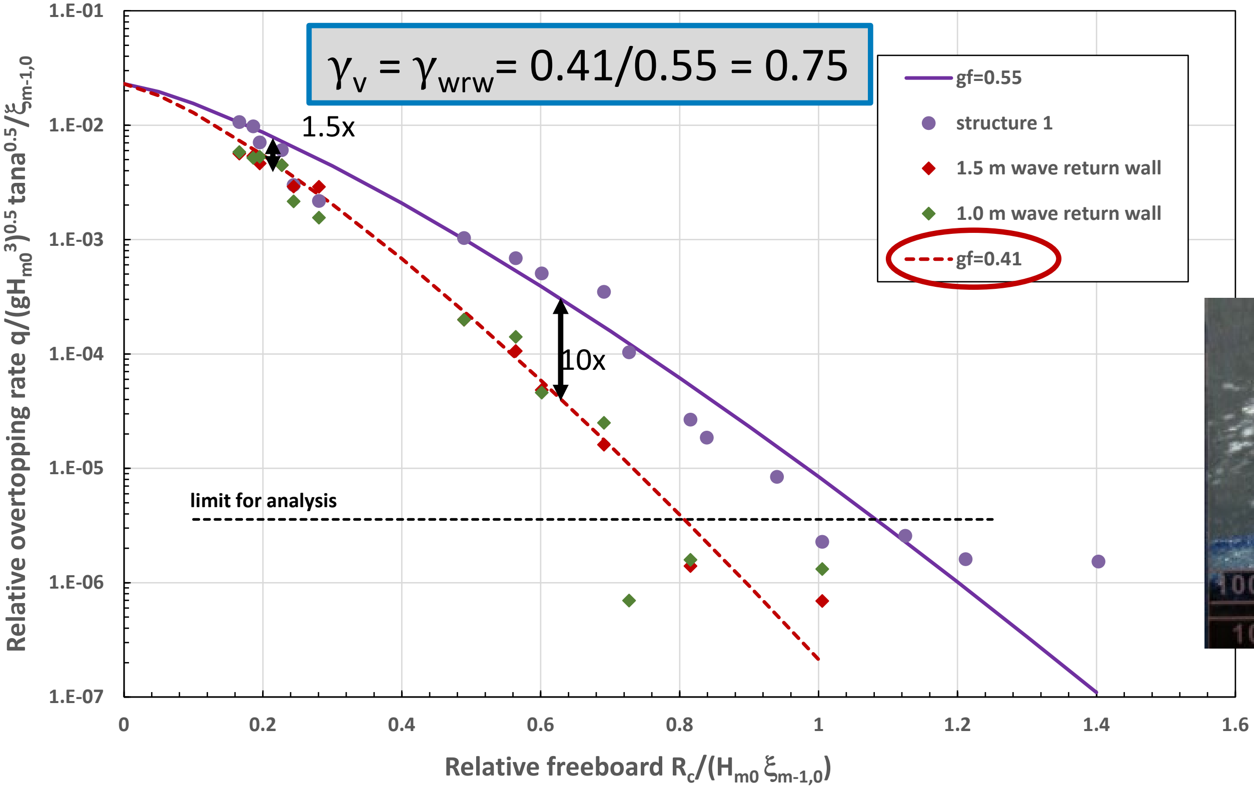
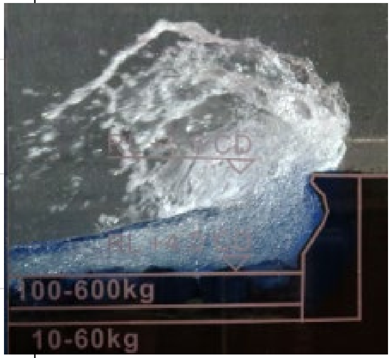


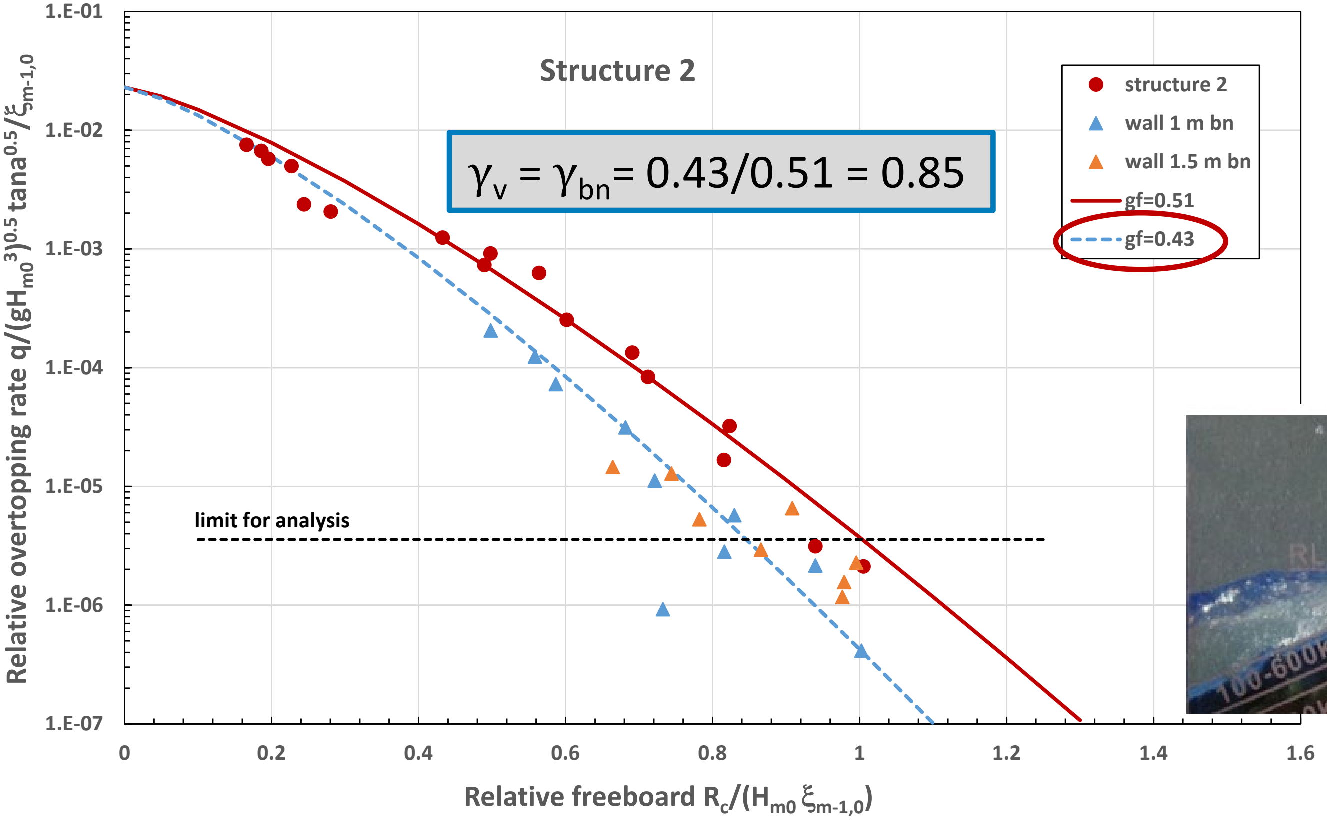


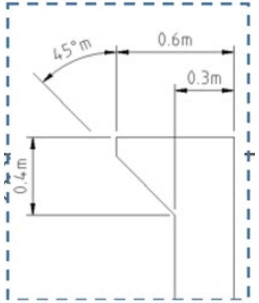
Single pitched; wave return wall





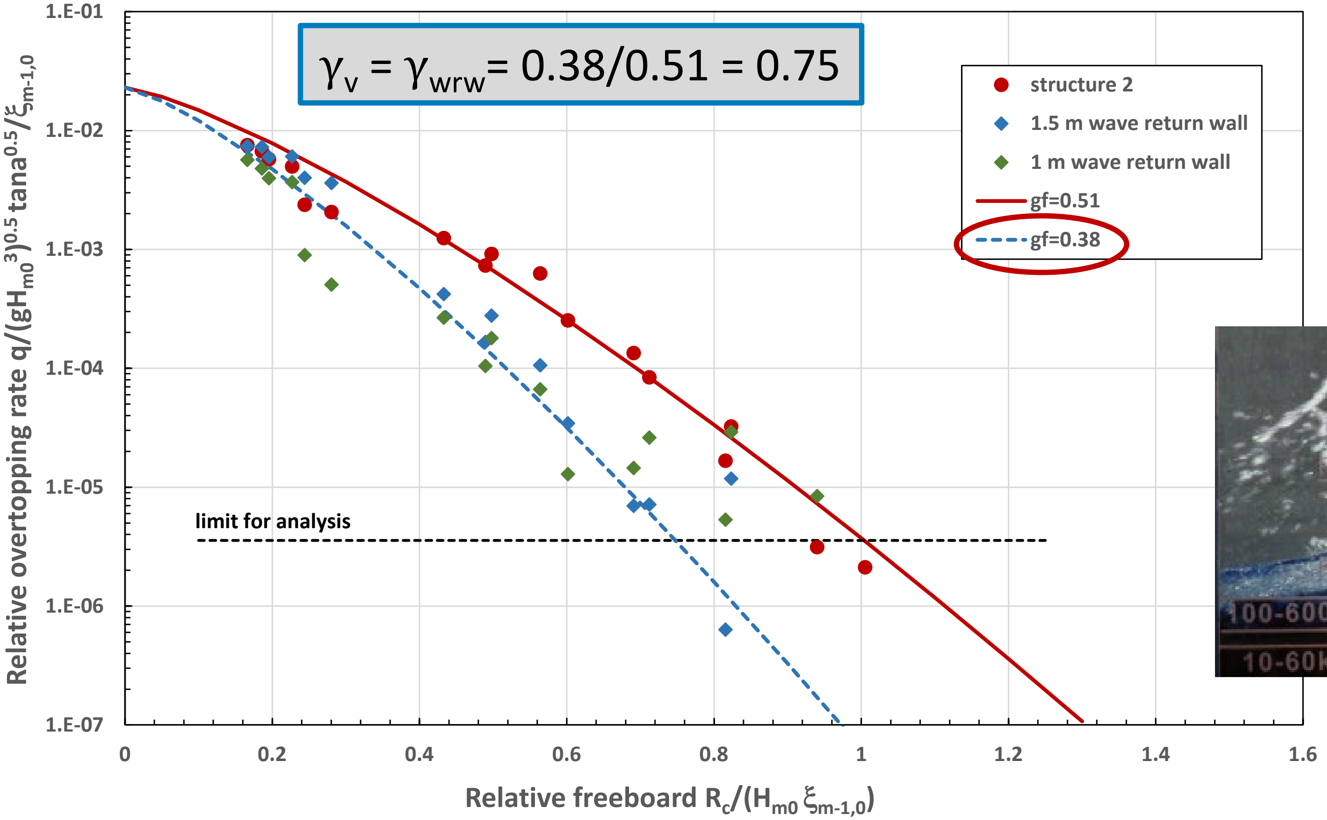
Double pitched; wall 1 m and 1.5 m + bullnose

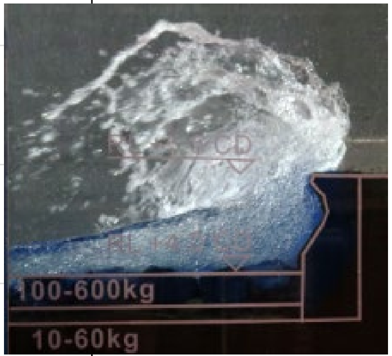




Double pitched, wave return wall

Knowledge





Conclusions on mitigation options

Restrictions

- (Pitched) rock slopes, one or two layers: mild design wave heights
- Only for high wave steepness: $s_{m-1,0} > 0.035$

Conclusions

- Pitched slopes (above water only) have similar stability as randomly placed rock
- Failure for a single pitched slope occurs at $S_d = 2$!
- Wave wall is very effective, but is an obstacle
- Wave return wall is effective at same crest height
- Model testing gives new influence factors γ_f and γ_v in EurOtop equations

Conclusions on mitigation options

Vertical walls, with or without bullnose; wave return wall; a wave steepness $s_{m-1,0}$ > 0.035:

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = \frac{0.023}{\sqrt{\tan\alpha}} \gamma_b \cdot \xi_{m-1,0} \cdot \exp[-(2.7 \frac{R_c}{\xi_{m-1,0} \cdot H_{m0} \cdot \gamma_b \cdot \gamma_f \cdot \gamma_\beta \cdot \gamma_v})^{1.3}]$$

EurOtop 5.10

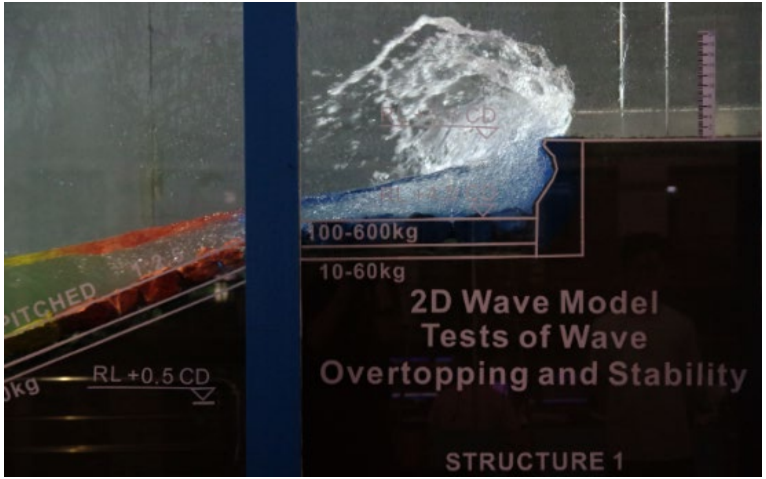
EurOtop random

Single layer of pitched rock:	γ_f = 0.55	0.6
Double layer of pitched rock:	γ_f = 0.51	0.55
A vertical wall on top:	γ_v = 1.0	
A bullnose on the vertical wall:	$\gamma_v = \gamma_{bn}$= 0.85	
A wave return wall	$\gamma_v = \gamma_{wrw}$= 0.75	

Use as max, but do not apply for surging waves

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = 0.09 \cdot \exp[-(1.5 \frac{R_c}{H_{m0} \cdot \gamma_f \cdot \gamma_\beta \cdot \gamma *})^{1.3}]$$

Thank you



100-600kg
10-60kg
2D Wave Model
Tests of Wave
Overtopping and Stability
RL +0.5 CD
STRUCTURE 1

Relationship S_d and N_{od} (Van der Meer, JCHS 2021)

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$$S_{d-approx} = 1.32 * N_{od} + 0.95$$