HIGH-DENSITY COASTAL ARMOUR UNITS FOR MANAGING INCREASED RISK WITH CLIMATE CHANGE

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Presentation – Ron Cox

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Overview

Implications of Climate Change

-wave climate and sea level rise

Upgrading existing structures

Low carbon, high density GPC CAUs

Field trials

Further research

Future opportunities

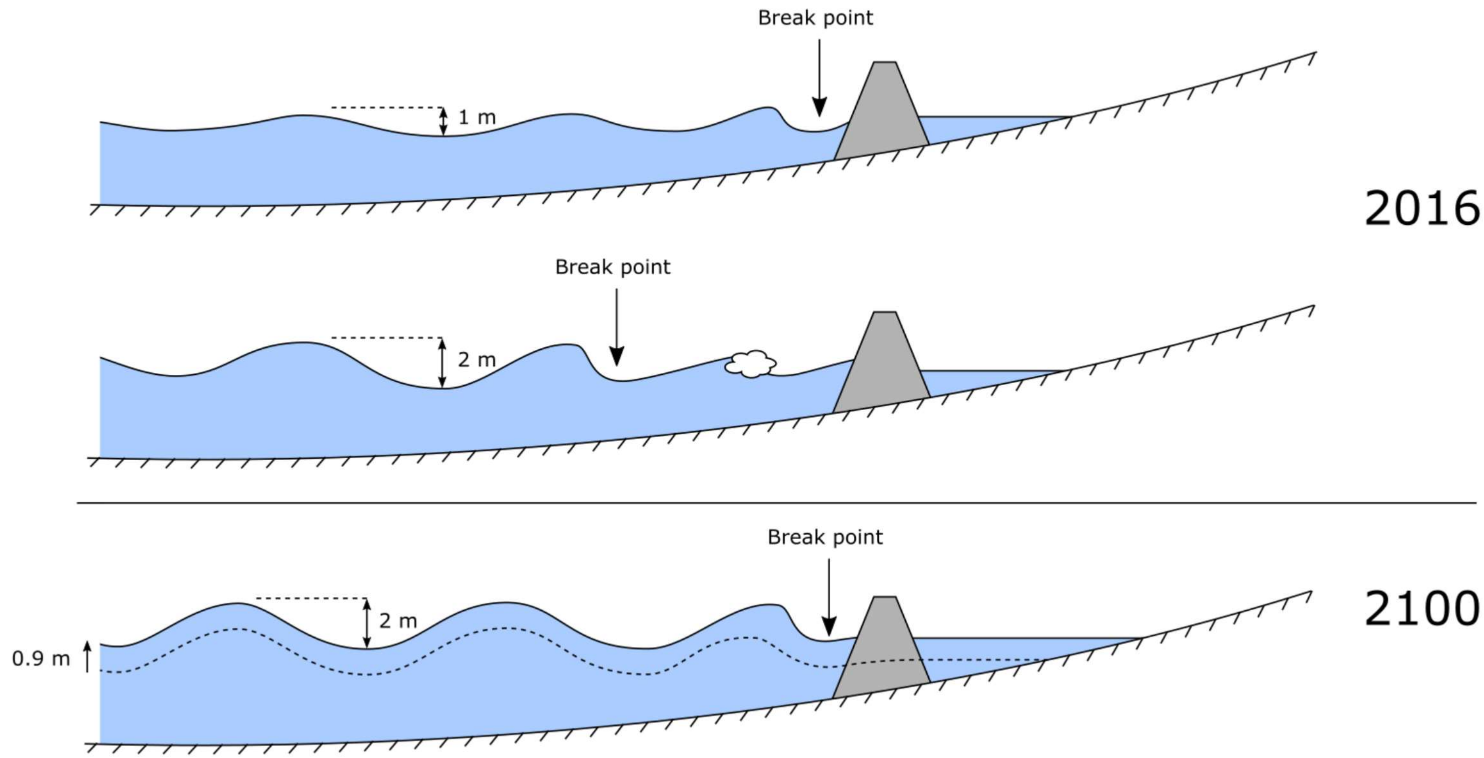
Photo: Frank Redward

Depth-limited wave conditions

Wave height dependent on water depth

Larger waves break further offshore

Sea level rise brings larger waves close to shore



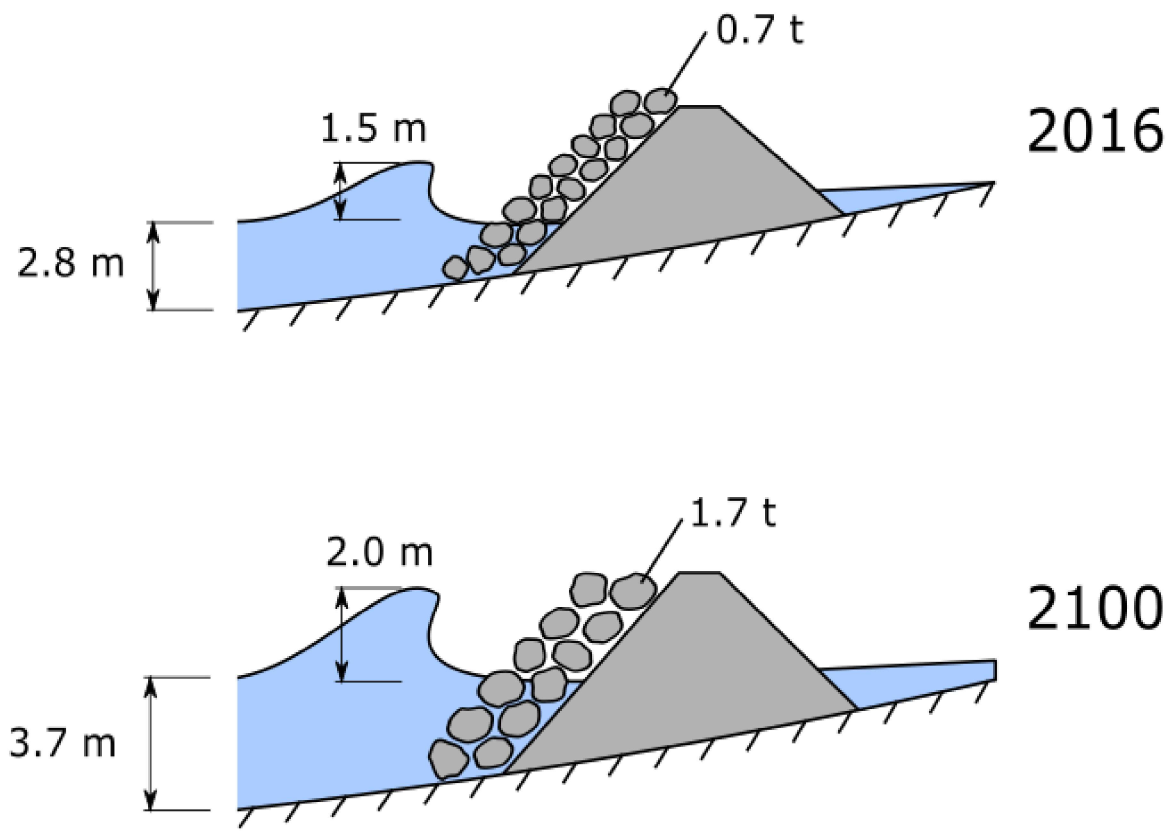
Design armour size

Case study: Tweed Heads
breakwater

With sea level rise:

- wave height increases 33%

- armour size increases 240%



Breakwater stability equation – Hudson

$$M = \frac{\rho_a \, \boldsymbol{H^3}}{K_d \, \boldsymbol{\Delta^3} \cot \alpha}$$

M is the mass of the rock armour or CAU

H is the incident wave height

α is the structure slope

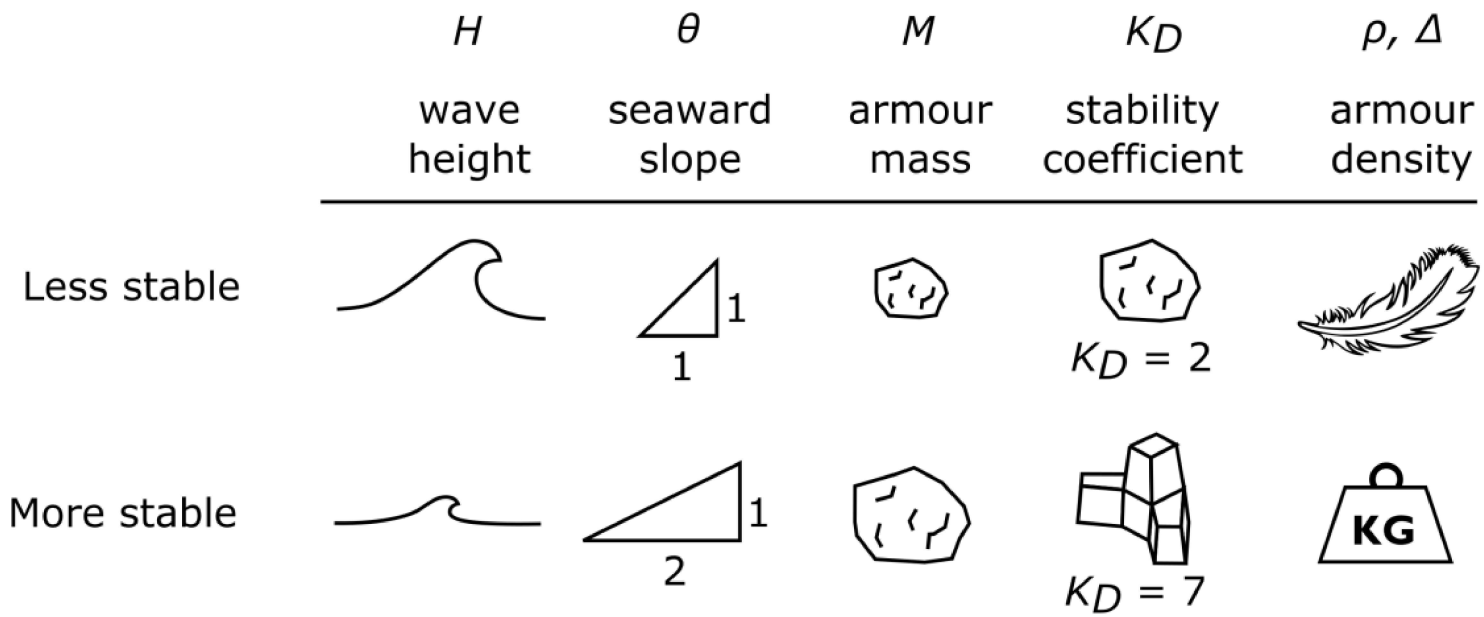
ρ_a is the rock armour or CAU density

ρ_w is the water density

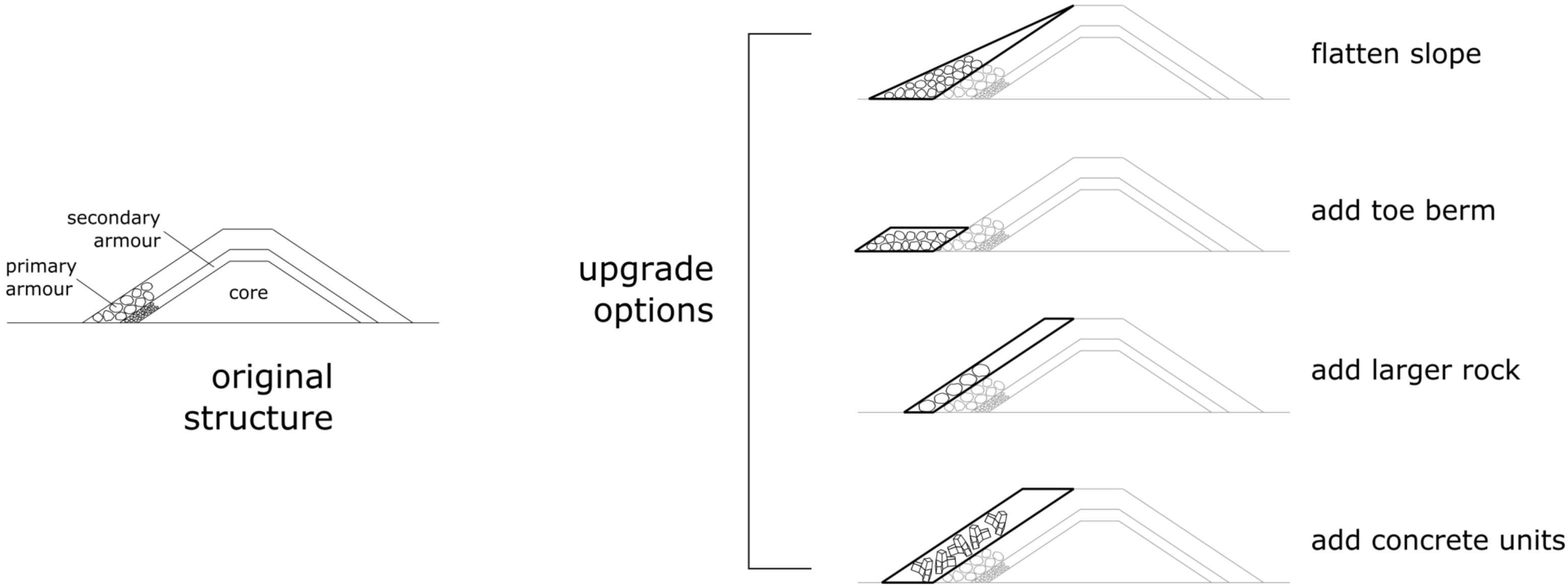
$\Delta = \frac{\rho_a}{\rho_w} - 1$ is the relative submerged density

K_D is the Hudson damage coefficient

Parameters affecting armour stability



Upgrade options - rock

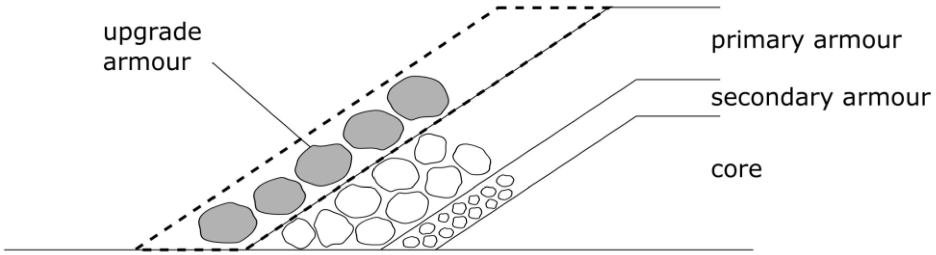


Previous work – Alice Harrison

Single layer armour was effective

Harrison, A., and Cox, R. Physical and economic feasibility of rubble mound breakwater upgrades for sea level rise, Coasts & Ports Conference 2015.

Rock structures depend on mass for stability (not interlocking)



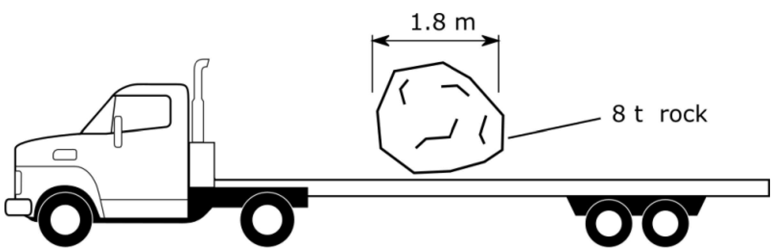
Alice Harrison: Rock armour

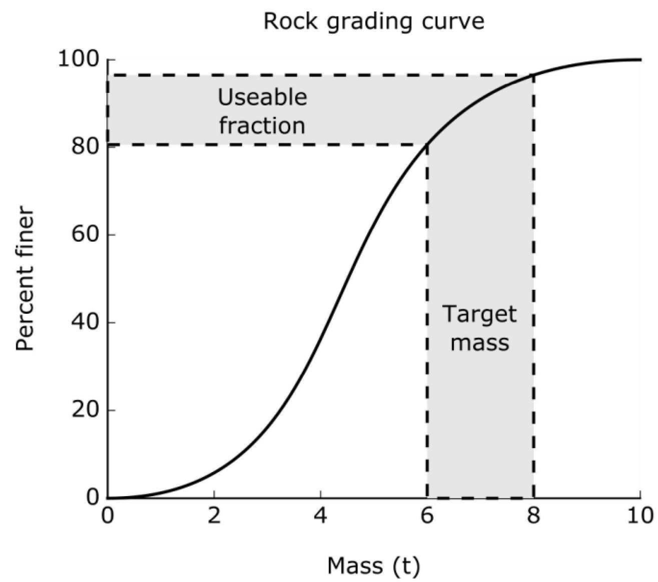
Physical modelling at WRL – upgrading for climate change

Rock size limit

Current economic size limit: 5 – 8 t

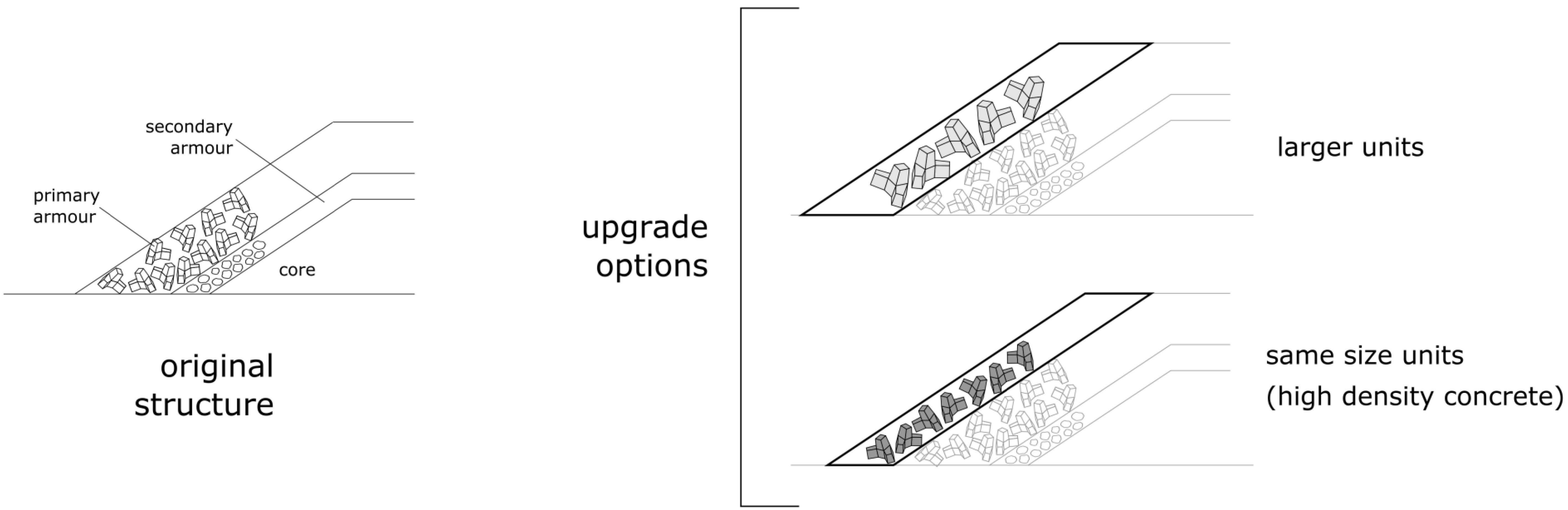
- Lack of nearby quarries
- Larger rock target reduces total yield
- Transportation challenges





CIRIA, 2007

Upgrade options – concrete armour units



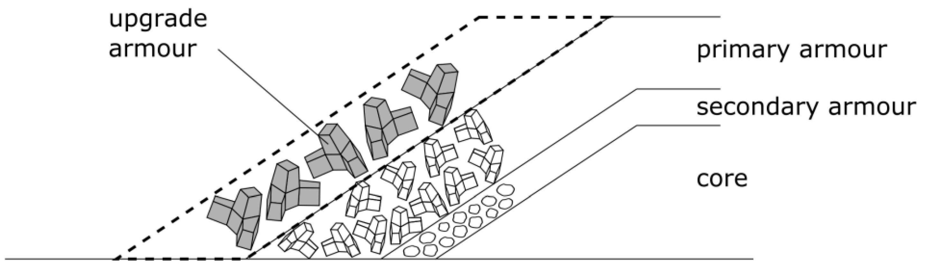
Previous work – Calvin Li

Poor interlocking between different-sized units

Single layer armour upgrade could be effective, (but):

Li, C., and Cox, R. Stability of Hanbars for upgrading of breakwaters with sea level rise. Coasts and Ports Conference 2013

- Stability sensitive to placement density
- Difficult to construct



Single layer Hanbar upgrade not recommended

Calvin Li: Hanbar armour

Physical Model

Scale 1:51.2

Model seaside slope 1:2

Bathymetry slope 1:50

1000 random waves

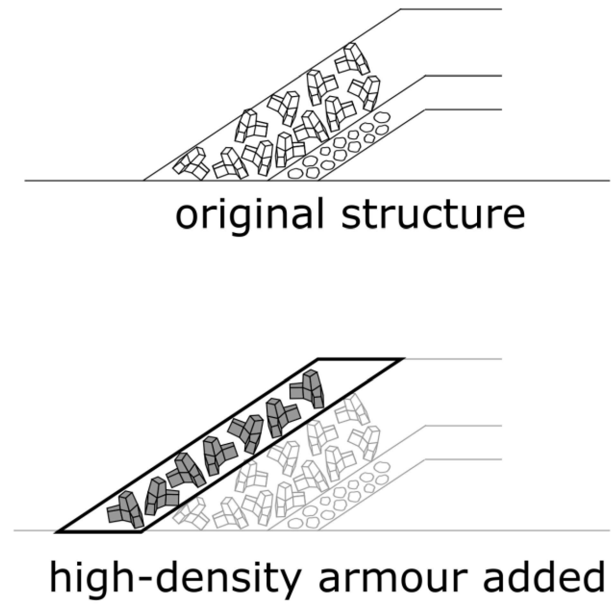
Hs measured with 3 probe array

Constructability considerations

Current random placement cannot achieve the required density

May be achieved by computer aided construction systems

Increase armour density



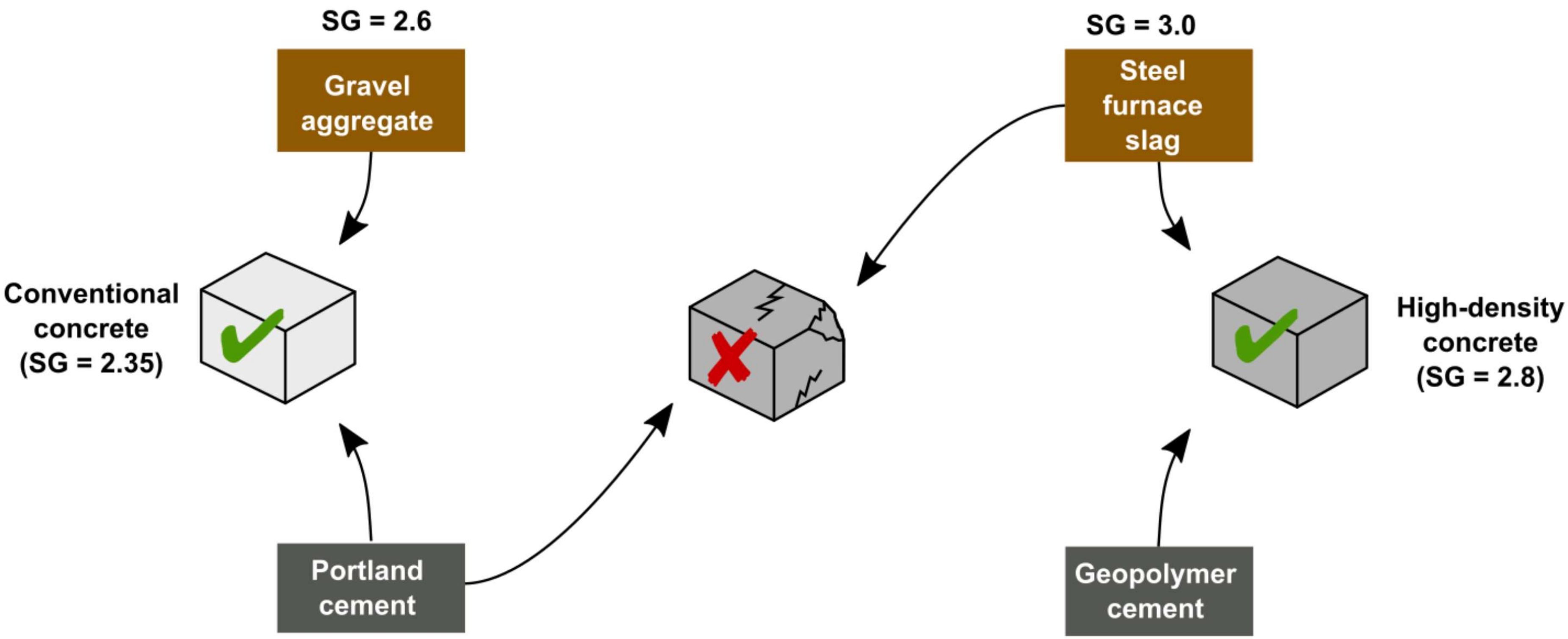
Hudson equation $\mathbf{M = \frac{\rho_a \, H^3}{K_D \, \Delta^3 \cot\theta}}$

Importance of Δ^3 = submerged relative density cubed

$$\Delta = \frac{\rho_a}{\rho_w} - 1$$

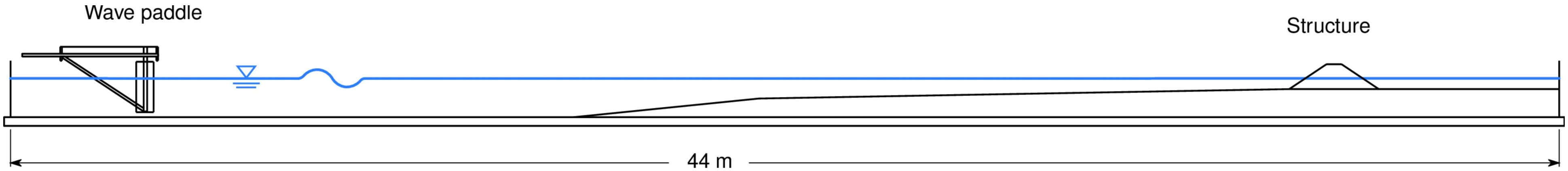
	Conventional concrete	High-density concrete	High - density/ conventional
SG	2.3	2.6 to 2.8	1.1 to 1.2
Δ	1.3	1.6 to 1.8	1.2 to 1.4
Δ^3	2.2	4.1 to 5.8	**1.9 to 2.6**

High-density GPC concrete (50% less carbon than OPC)

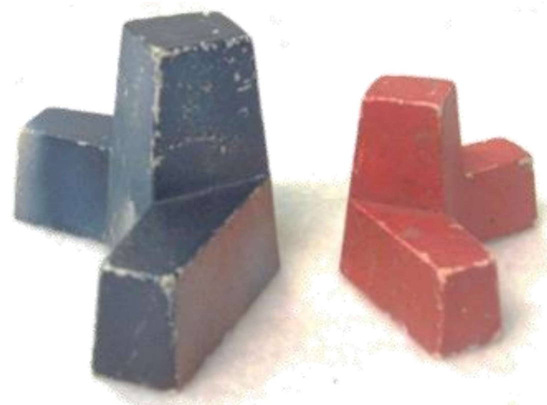


Experimental setup

Facility:	1.2 m wide wave flume
Scale:	1:33
T_p :	9, 11, 13 s
$H_{sig\ (max)}$:	5.5 m (depth limited)

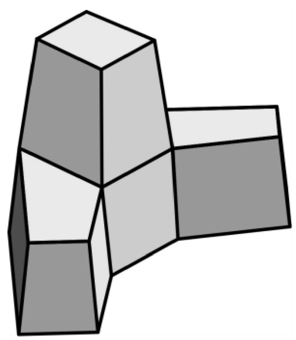


Present investigation



SG: 2.35, 2.8

Unit: Hanbar



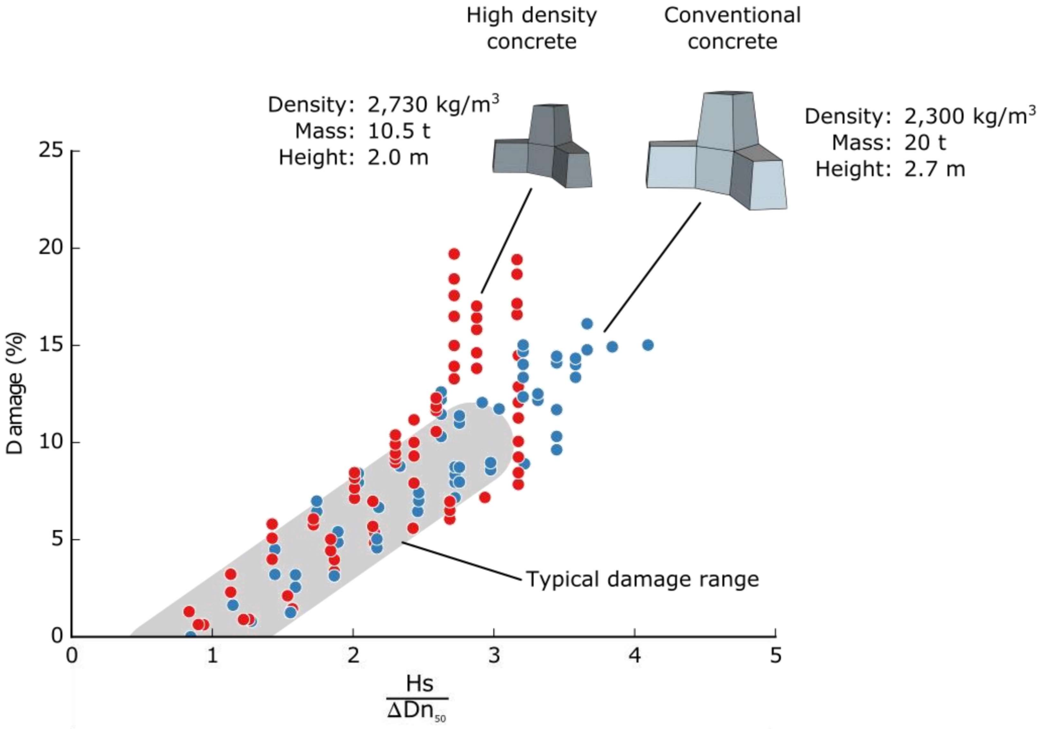
	Conventional concrete	High-density concrete
Mass (t)	20	10.5
Height (m)	2.7	2.0
Density (kg/m3)	2300	2730

High density Hanbars

Hudson's equation remains valid for moderate levels of damage

0% damage

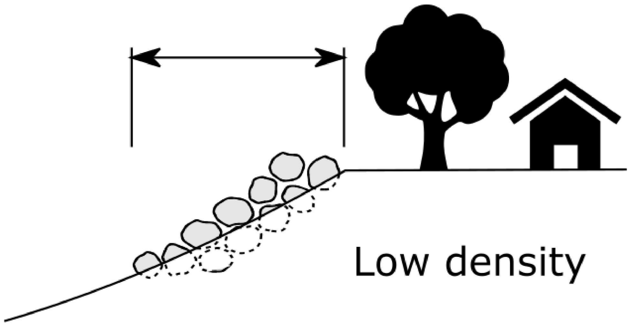
11% damage

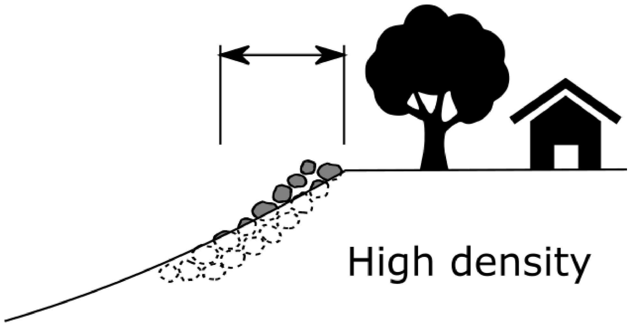


Applications

1. **Retrofit existing structures**
   - Interlock with existing armour
   - Increase stability

2. **Build new structures**
   - Reduce concrete requirements
   - Reduce carbon cost
   - Reduce footprint





Development steps

- Improve GPC concrete workability at laboratory scale
- Conduct field trial to prove batching, transport, casting and placement at scale
- Monitor for concrete durability in harsh marine environment
- Further wave flume testing of different CAUs
- Further field scale seawall installations

High Density Geopolymer Concrete field trials

2 years of laboratory mix design to improve strength and workability

Port Kembla significantly damaged in July 2016 East Coast Low storm

Trial to prove batching, transport, casting at scale and placement on Northern Breakwater at Port Kembla– 13 x 18 t GPC Hanbars placed on 2 July 2018

Existing Ordinary Portland Cement OPC Hanbars 16t, 7m^3, 2.3 t/m^3

Trial Low Carbon HD GPC Hanbars (same mould) 18t, 7m^3, 2.6 t/m^3

Δ^3 = submerged relative density cubed = $\{(2.6-1)/(2.3-1)\}^3 = 1.9$

GPC has 50% lower carbon footprint than the OPC

Ongoing monitoring of durability in harsh marine environment

Trial batch and casting – 11 April 2018 – 3 HD GPC 18 t Hanbars

Two further GPC batches and casting of extra 10 GPC units - placement of 13 x 18 t Hanbars on 2 July 2018 - Port Kembla Northern Breakwater

Performance Monitoring

May 2021 - Detailed monitoring with core samples and laboratory analysis - strength retained at 40 Mpa after 3 years – some durability issues due to poor quality of some fly ash and slag source material

February 2023 – site inspection revealed some brown staining, but no cracking of units even after rough placement

Northern Breakwater with 16 tonne OPC Hanbars has performed well - showing little damage even though exposed to storms of 5, 10 and 18 year ARI in the period since 2018.

The trial low carbon 18 tonne high density GPC Hanbar CAUs have also performed well with some superficial discoloration, no structural breakage and some displacement caused by the poor initial placement.

Further research and scale installation

The trial has demonstrated that low carbon high density GPC Hanbar CAUs have progressed from a laboratory scale concept to a real opportunity for full scaled application – for upgrades or new structures.

Next step in "proof of concept" - construction of a small seawall section in a relatively sheltered environment with relatively small 2 to 5 tonne low carbon high density GPC Hanbar CAUs.

Ongoing laboratory wave flume stability testing of different CAUs to the simpler Hanbar is needed. This should include application of high density GPC CAUs to new construction and upgrading of existing structures for increased wave exposure with climate change.

Questions

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