PIANC Sydney Seminar 9-10 May 2019

Previously presented at ICCE2019 International Conference on Coastal Engineering Baltimore USA 30 June to 3 August 2018

UPGRADING BREAKWATERS IN RESPONSE TO SEA LEVEL RISE:

PRACTICAL INSIGHTS FROM PHYSICAL MODELLING

NEW TECHNOLOGY – HIGH DENSITY CONCRETE ARMOUR UNITS

Ron Cox. Daniel Howe, Ben Modra

MANY OTHERS – CRC low carbon , NSWPorts Port Kembla

Overview

Implications of sea level rise

Designing new structures

Upgrading existing structures

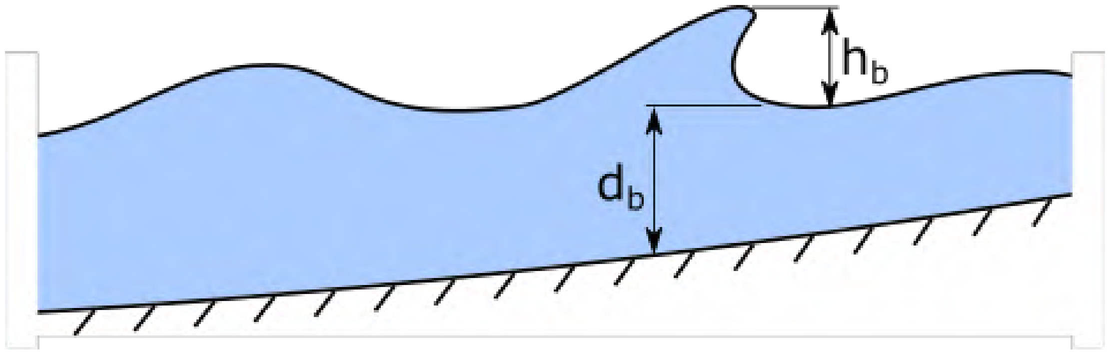
Photo: Frank Redward

Design wave conditions

Worst case: waves plunging on structure

Breaking wave height (h_b) governed by water depth (d_b)

$h_b \approx 0.55\ d_b$ (typical value for NSW)

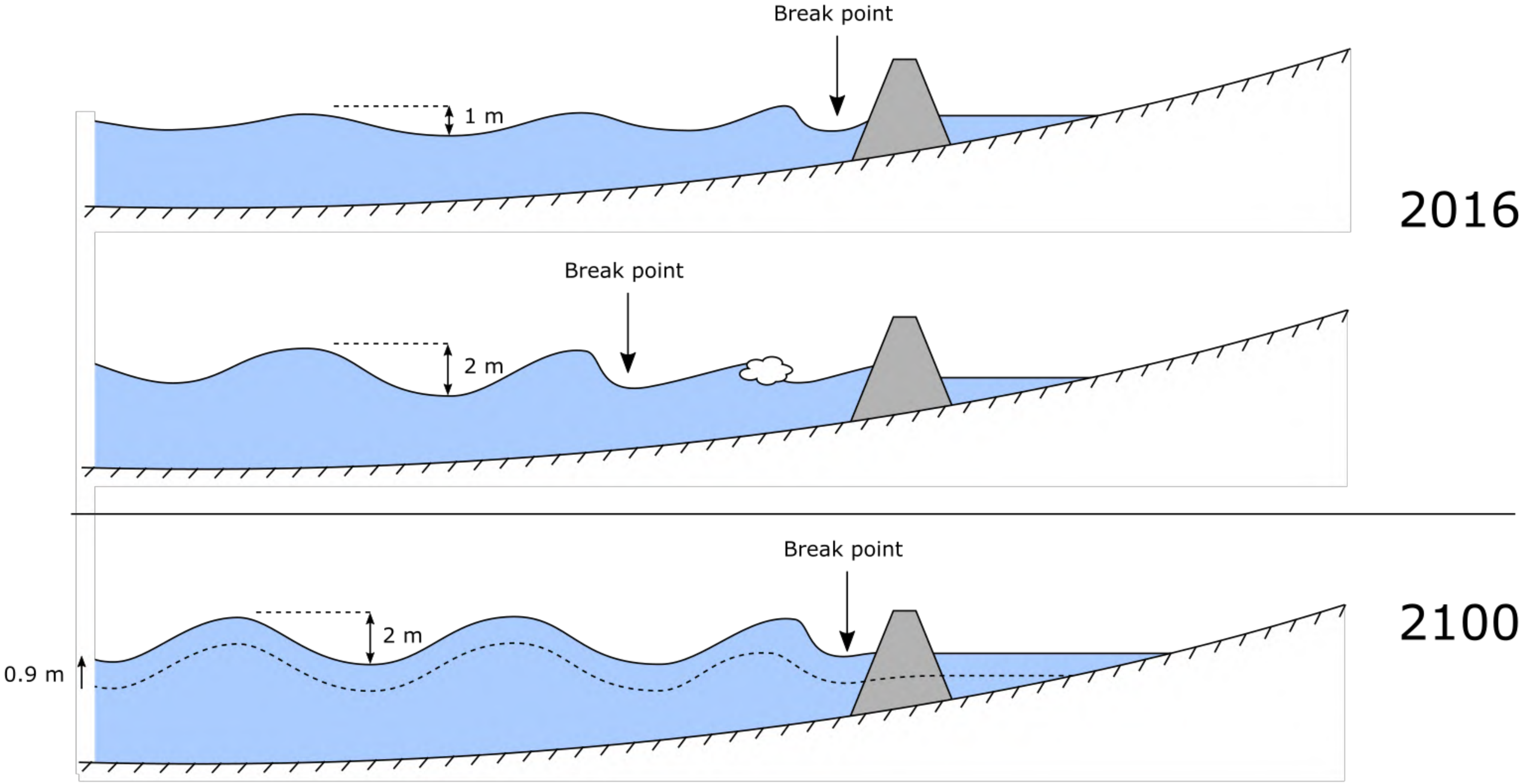


Depth-limited wave conditions

Wave height dependent on water depth

Larger waves break further offshore

Sea level rise brings larger waves close to shore

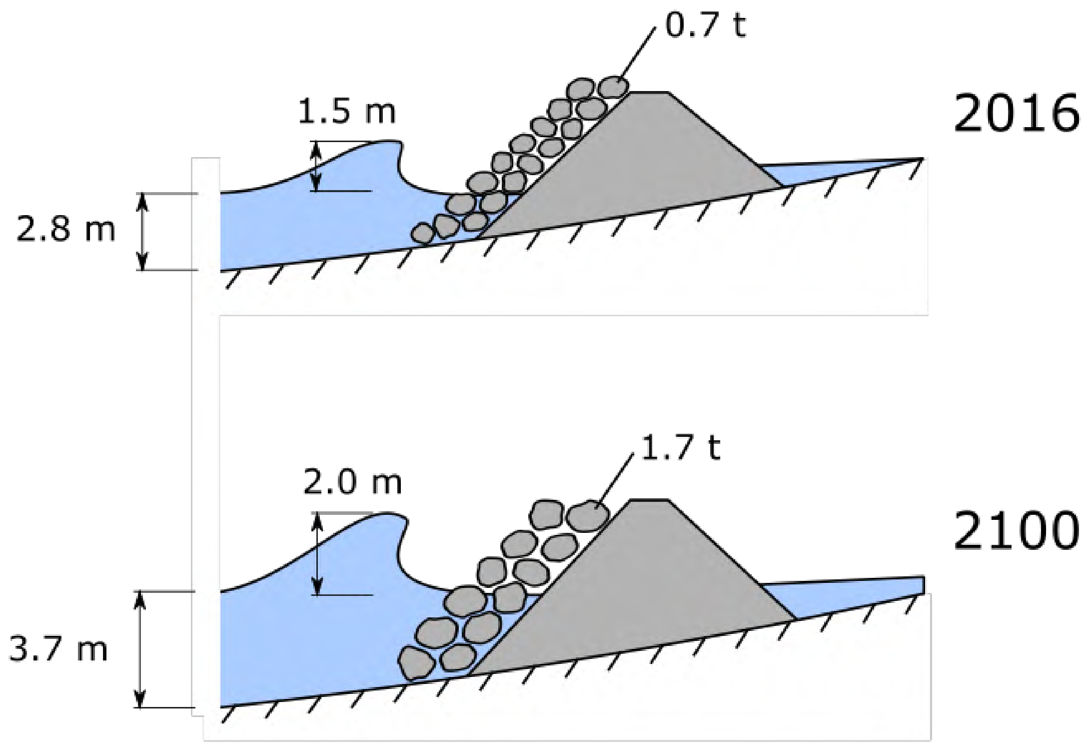


Design armour size

Case study: Tweed Heads breakwater

With sea level rise:

- wave height increases 30%
- armour size increases 140%



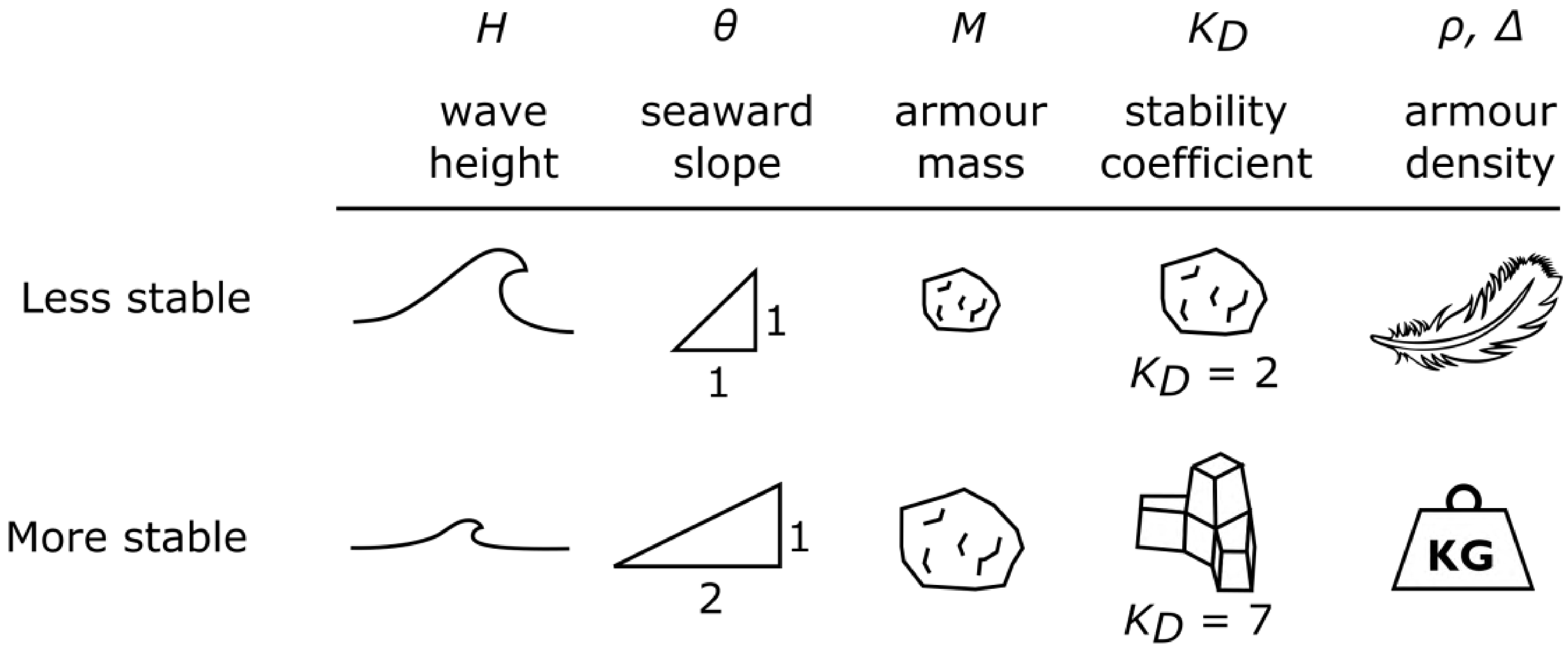
Breakwater stability equation

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

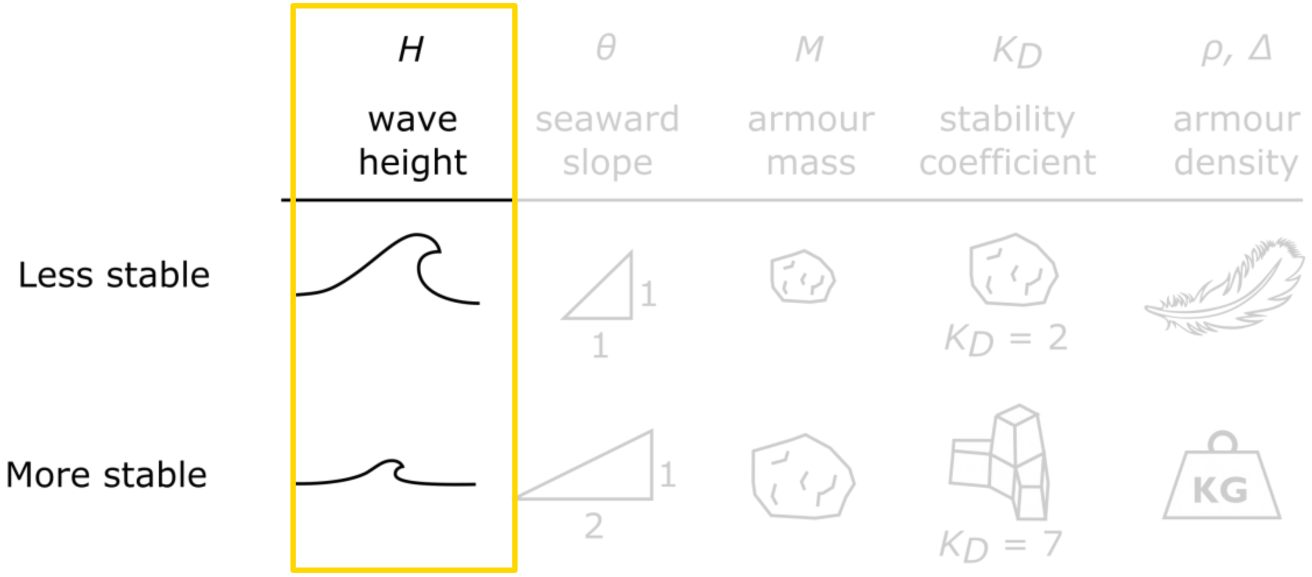
M	armour mass
ρ_a	armour density
H	wave height
K_D	stability coefficient
Δ	submerged relative density
$\cot\theta$	slope

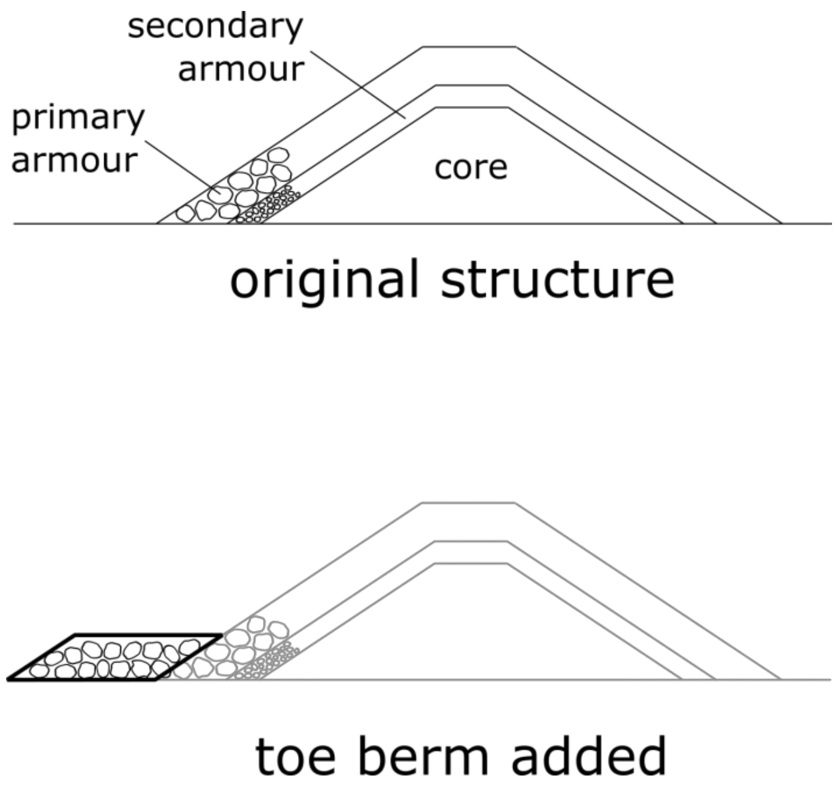
Photo: NSW Public Works

Parameters affecting armour stability

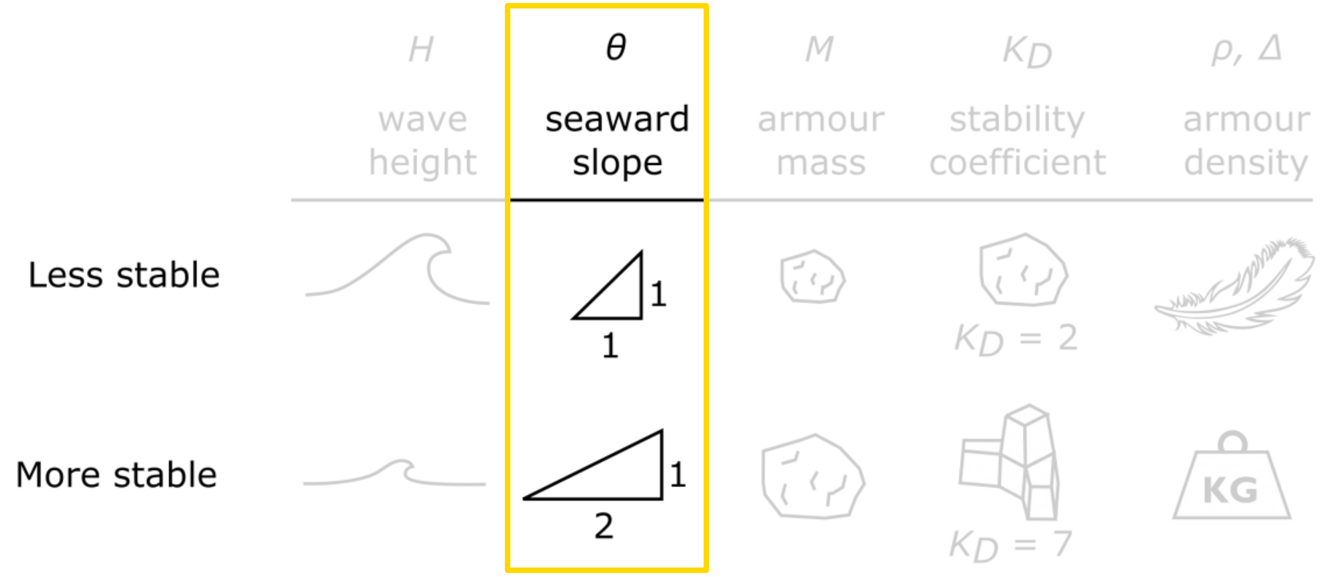


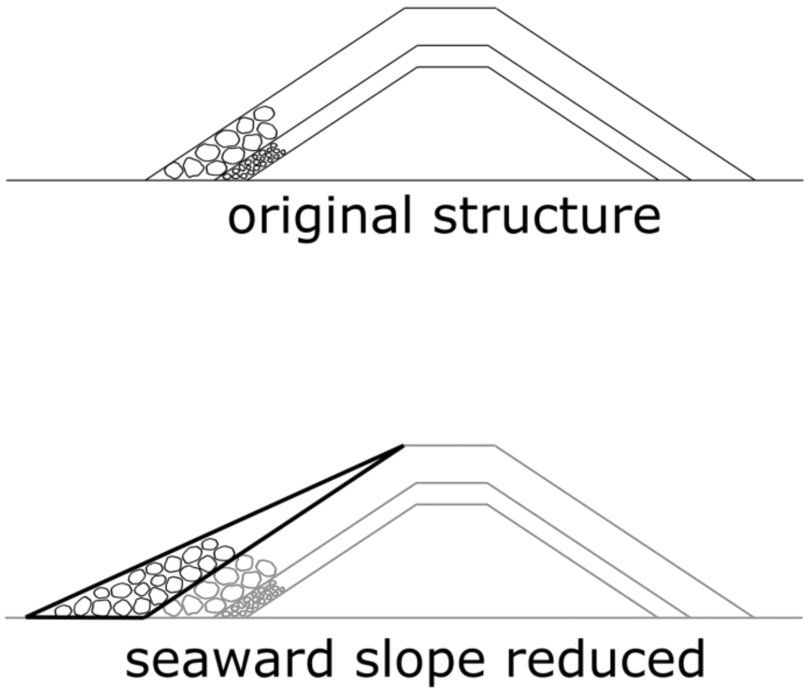
Reduce wave height (toe berm)



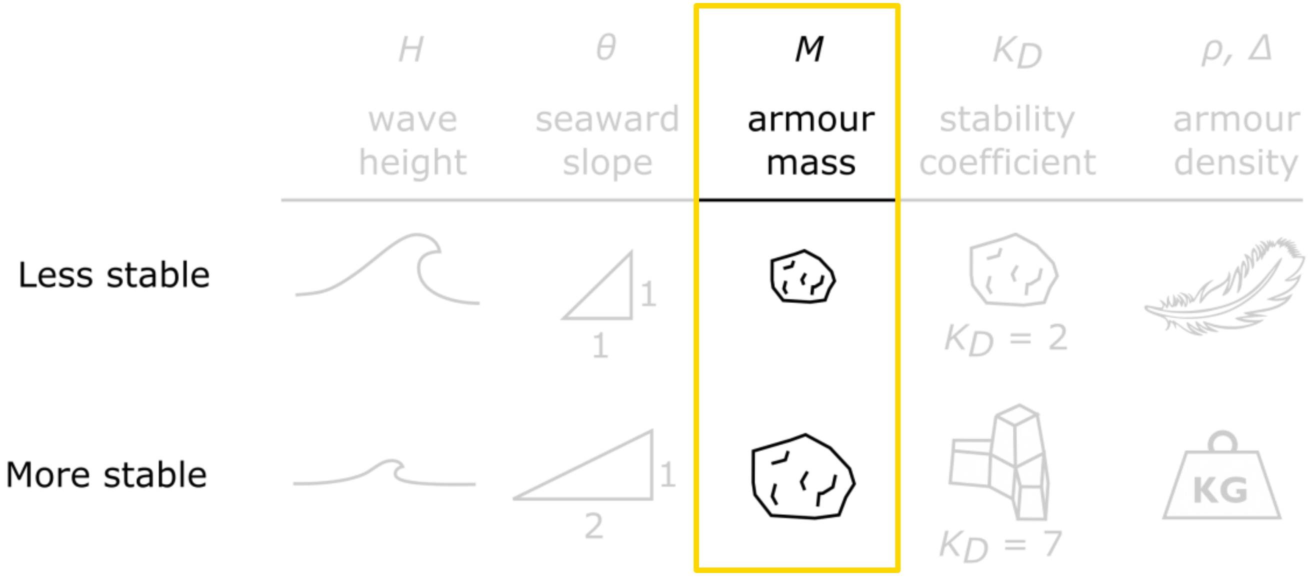


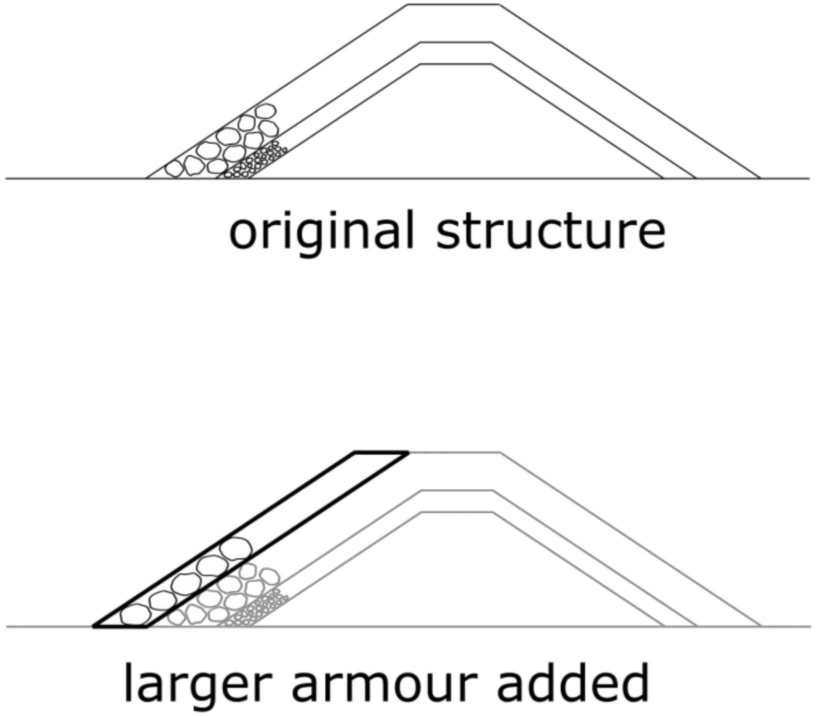
Reduce seaward slope



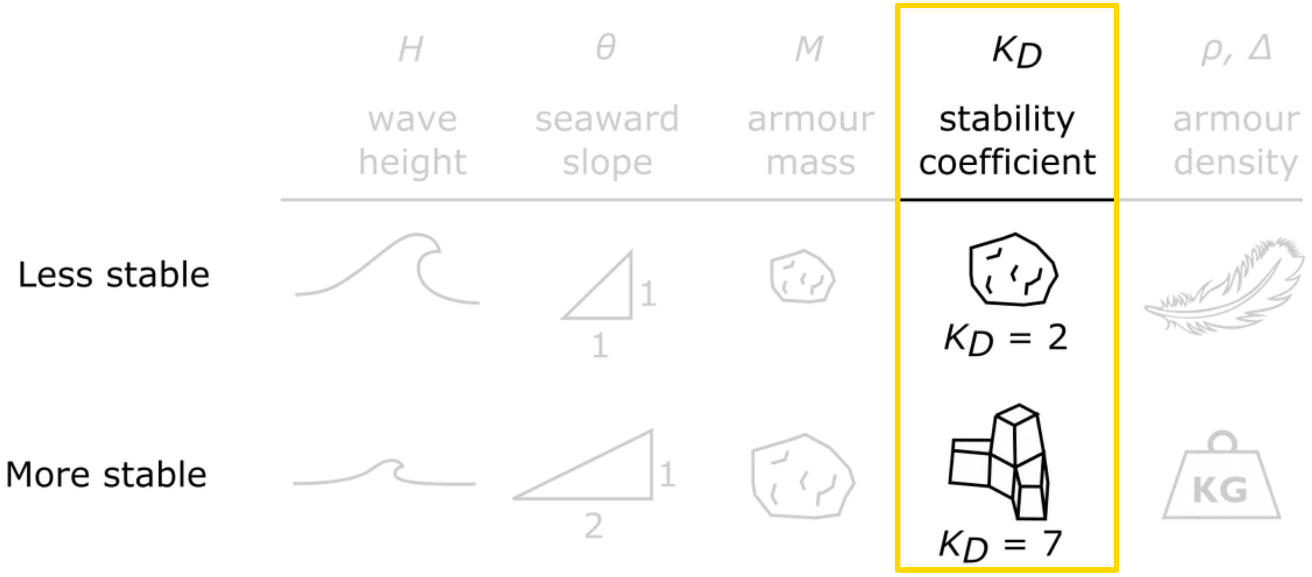


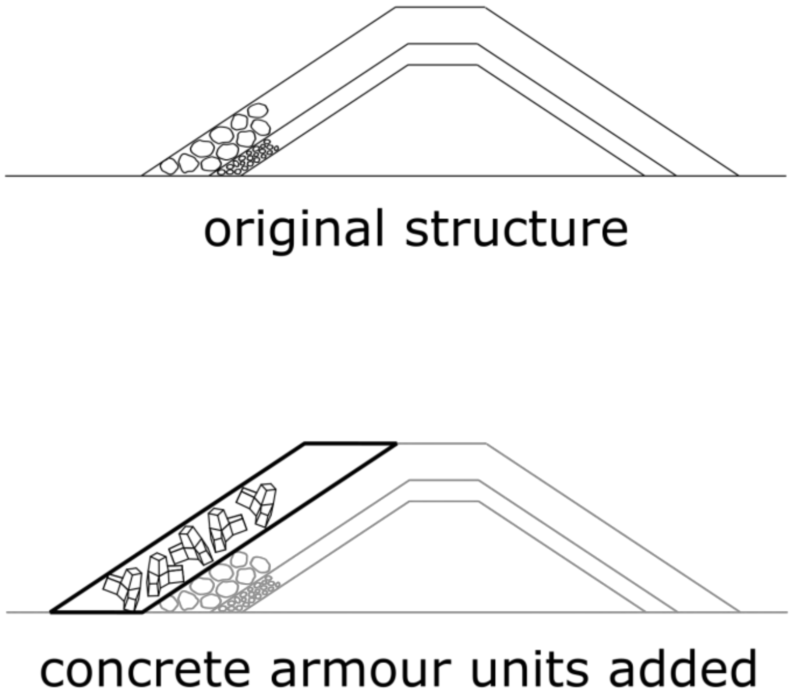
Increase armour mass



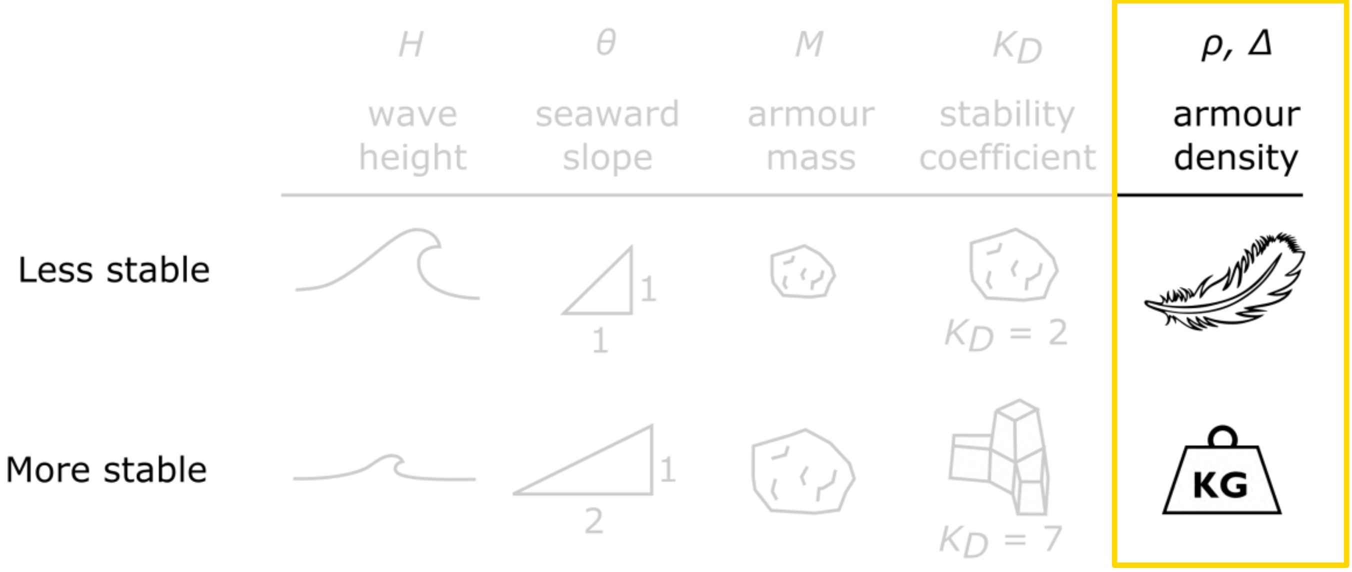


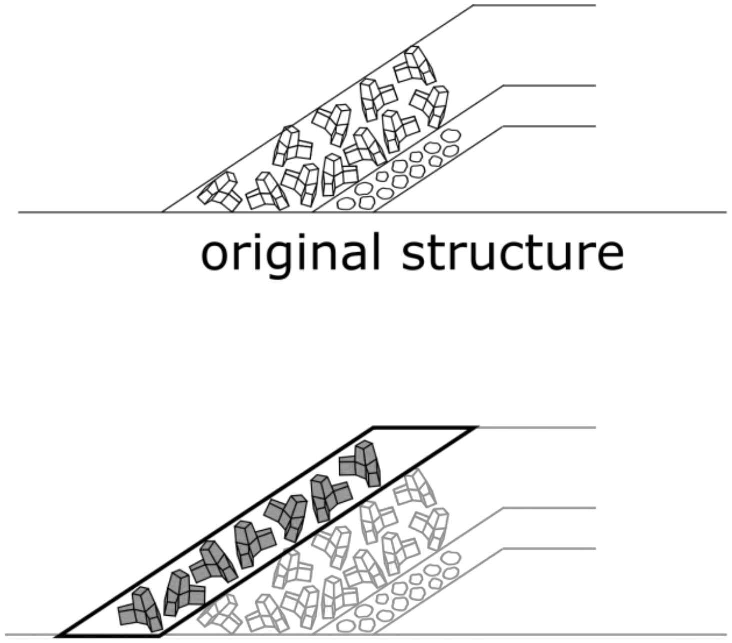
Increase stability coefficient (use concrete armour)





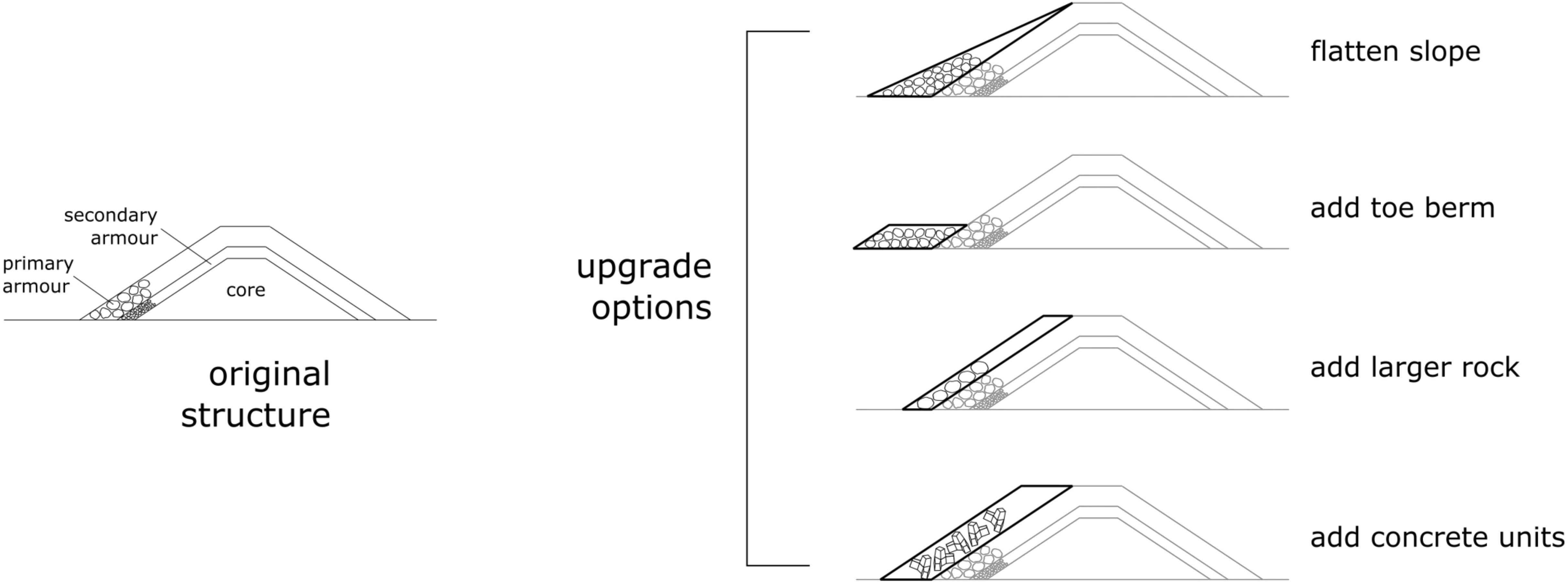
Increase armour density





Physical modelling at WRL – upgrading for climate change

Upgrade options - rock

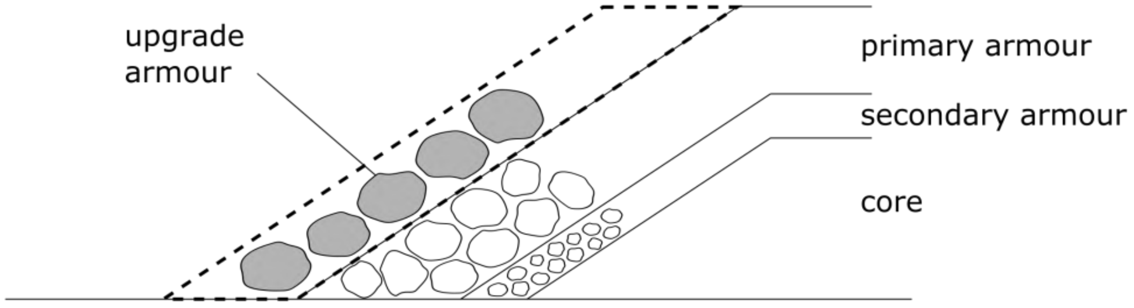


Previous work – Alice Harrison

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

Single layer armour was effective

Rock structures depend on mass for stability (not interlocking)

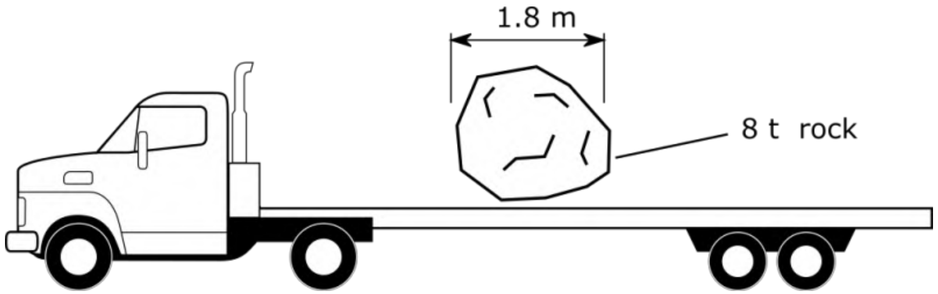


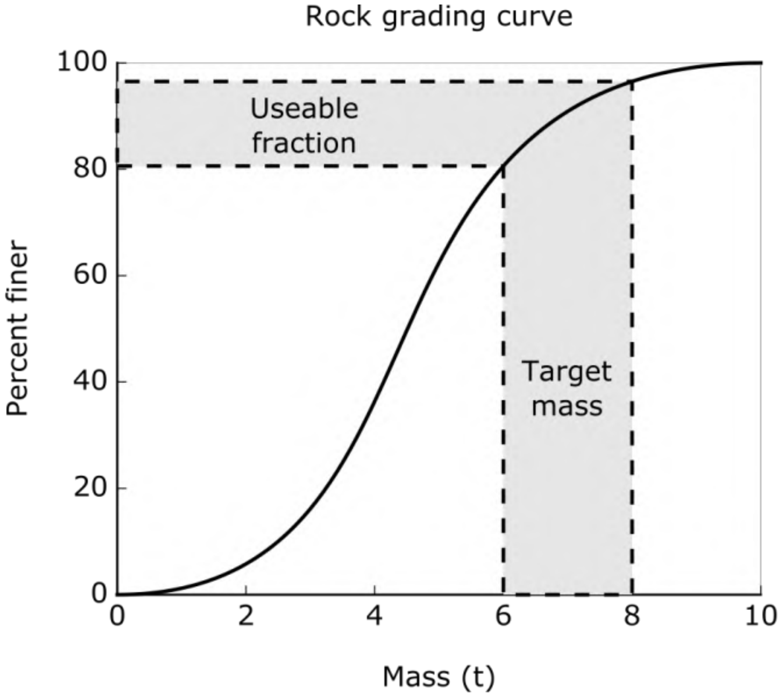
Alice Harrison: Rock armour

Rock size limit

Current economic size limit: 5 – 8 t

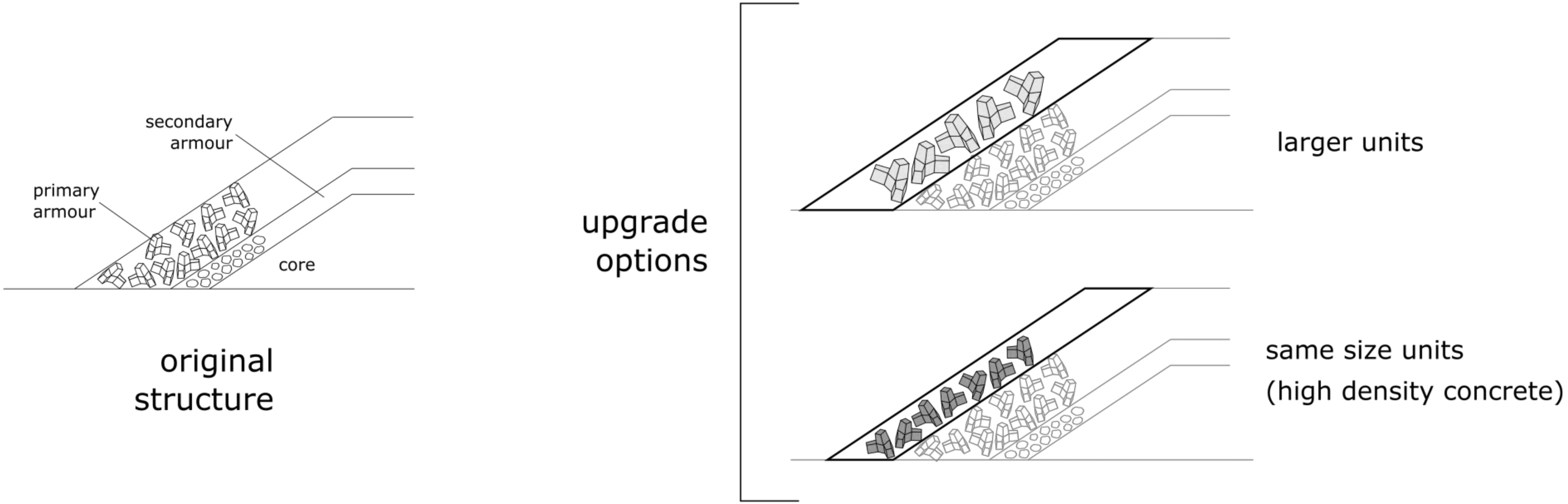
- Lack of nearby quarries
- Larger rock target reduces total yield
- Transportation challenges





CIRIA, 2007

Upgrade options – concrete armour units



Previous work – Calvin Li

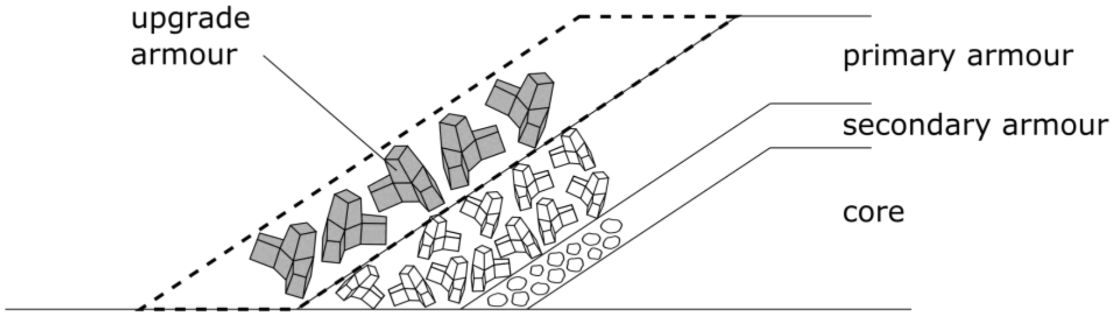
Poor interlocking between different-sized units

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

Source: NSW Public Works

ECONOMIC ANALYSIS: Upgrade strategies

Current treasury interest rate 7%

- Scenario 2: Design for 2075, upgrade in 2065
- Encourages higher risk of failure

Interest rates below 4%

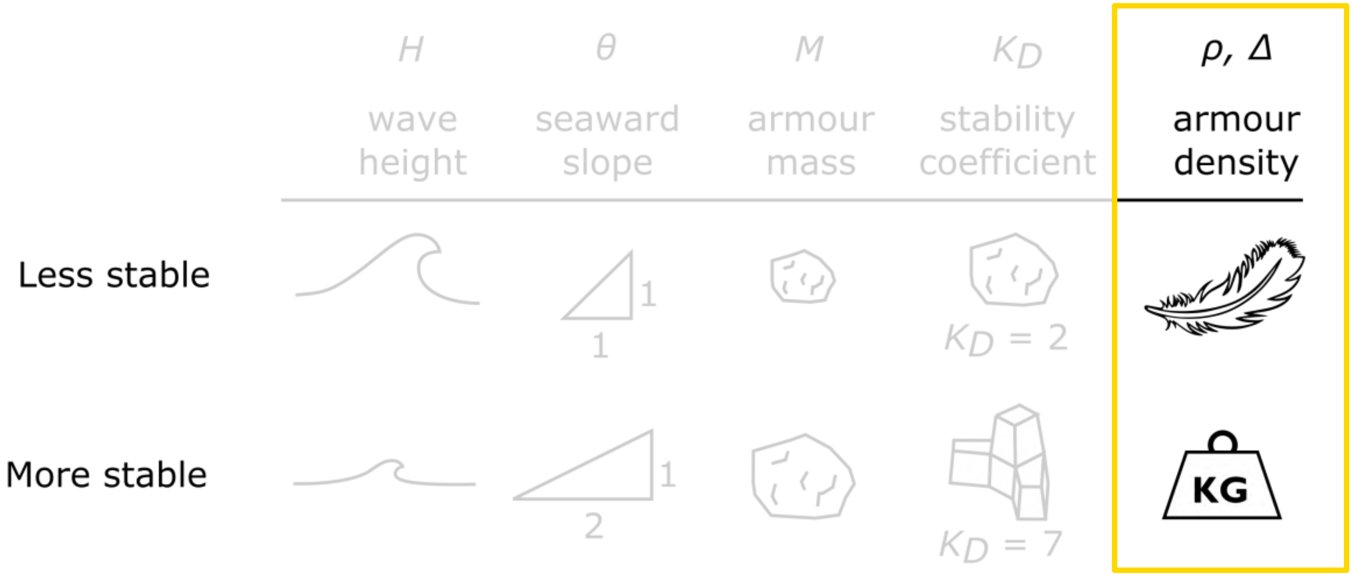
- Scenario 1: Design for 2115, no planned upgrades
- Lowest risk of failure

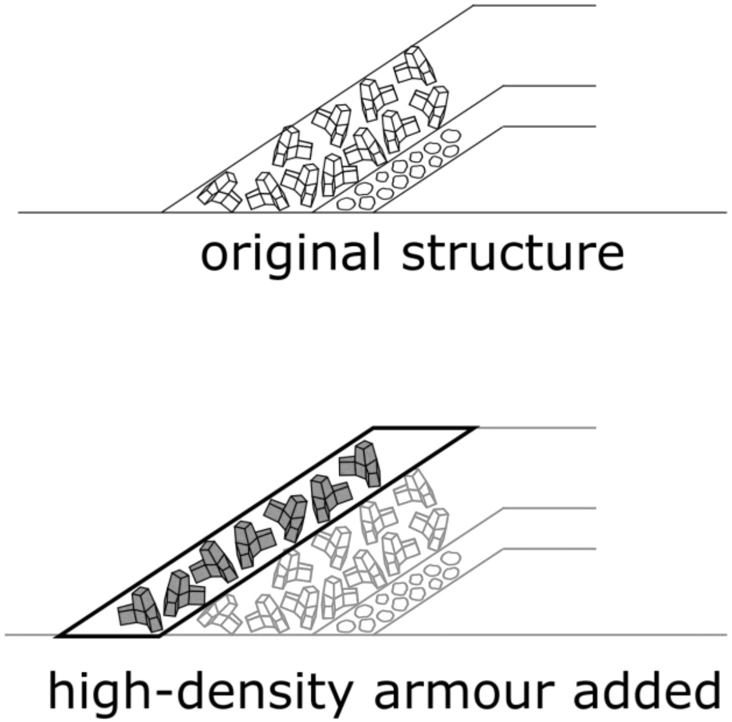
Asset value

- Important for low value and high interest rates

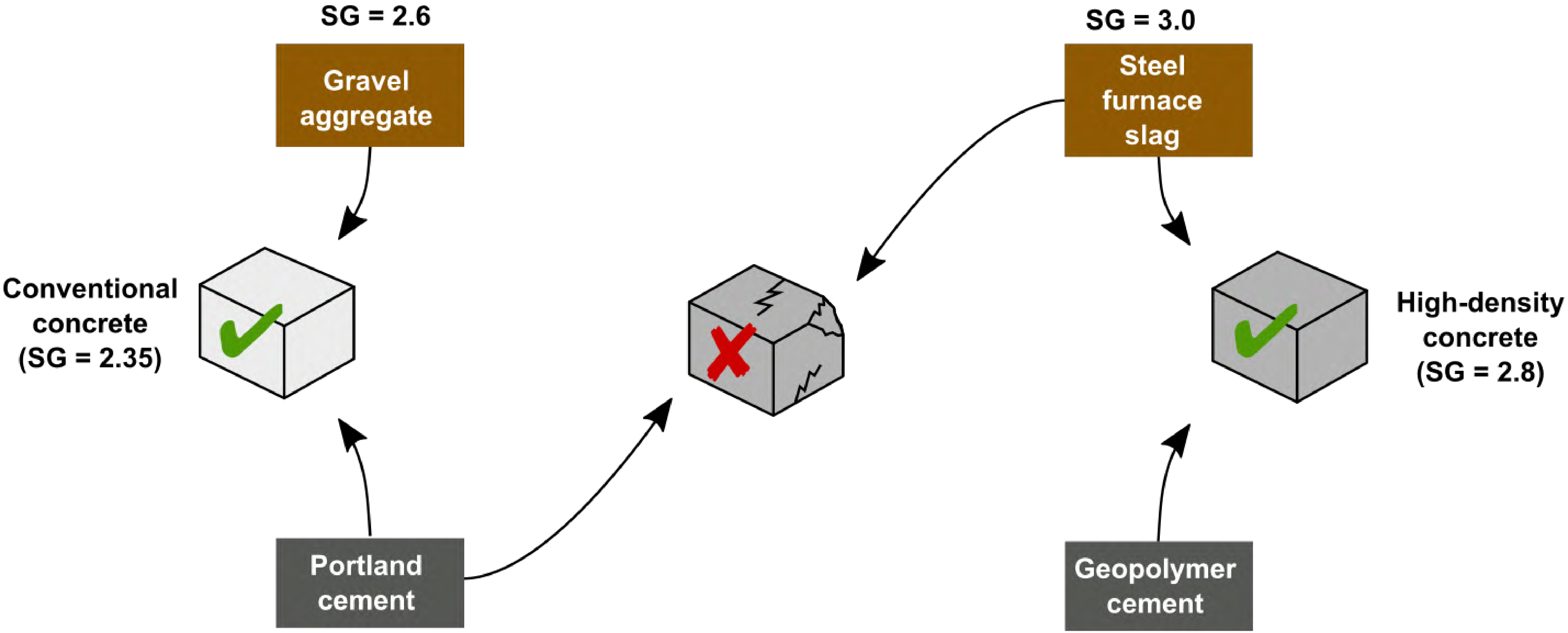
Harrison, A., and Cox, R. Physical and economic feasibility of rubble mound breakwater upgrades for sea level rise, Coasts & Ports Conference 2015.

Increase armour density



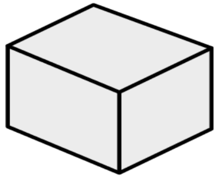


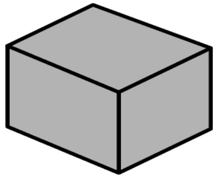
High-density concrete



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

Importance of Δ^3 = submerged relative density cubed



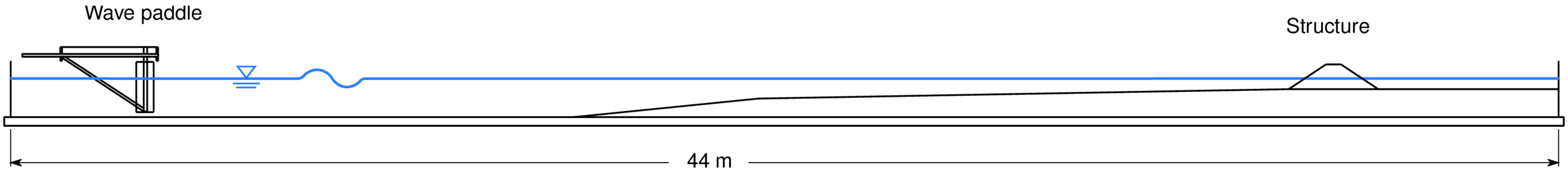


$$\Delta = \frac{\rho_a}{\rho_w} - 1$$

	Conventional concrete	High-density concrete	High - density/ conventional
SG	2.3	2.7	1.2
Δ	1.3	1.7	1.4
Δ^3	2.2	5.3	**2.5**

Experimental setup

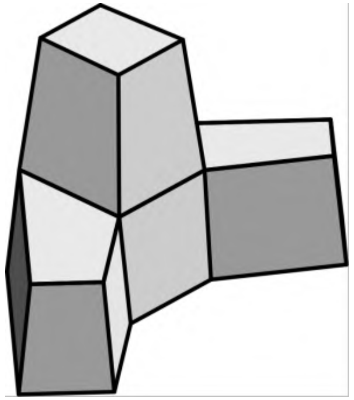
Facility:	1.2 m wide wave flume
Scale:	1:33
T_p :	9, 11, 13 s
$H_{sig\ (max)}$:	5.5 m (depth limited)



Present investigation

SG: 2.35, 2.8

Unit: Hanbar



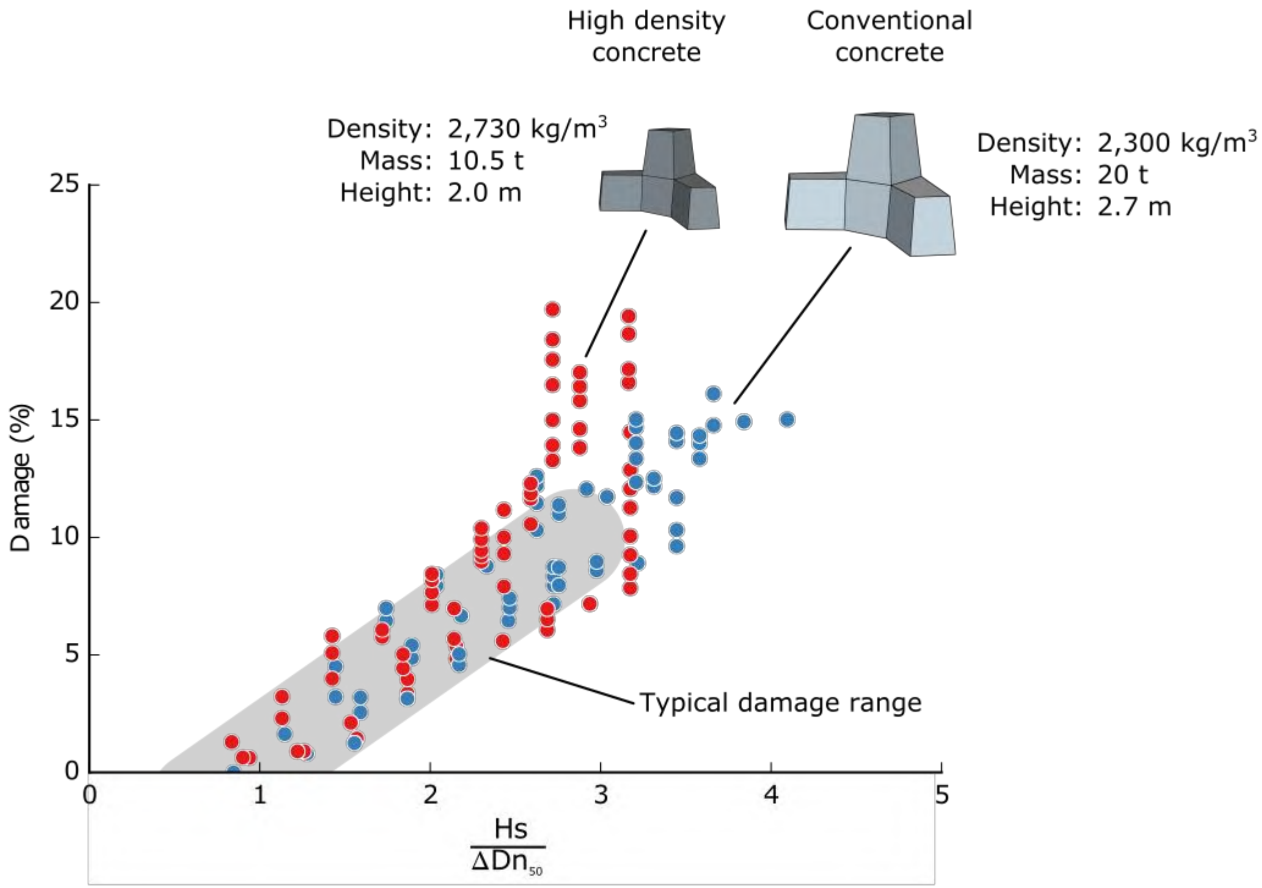
	Conventional concrete	High-density concrete
Mass (t)	20	10.5
Height (m)	2.7	2.0
Density (kg/m3)	2300	2730

High density Hanbars

Hudson's equation remains valid for moderate levels of damage

0% damage

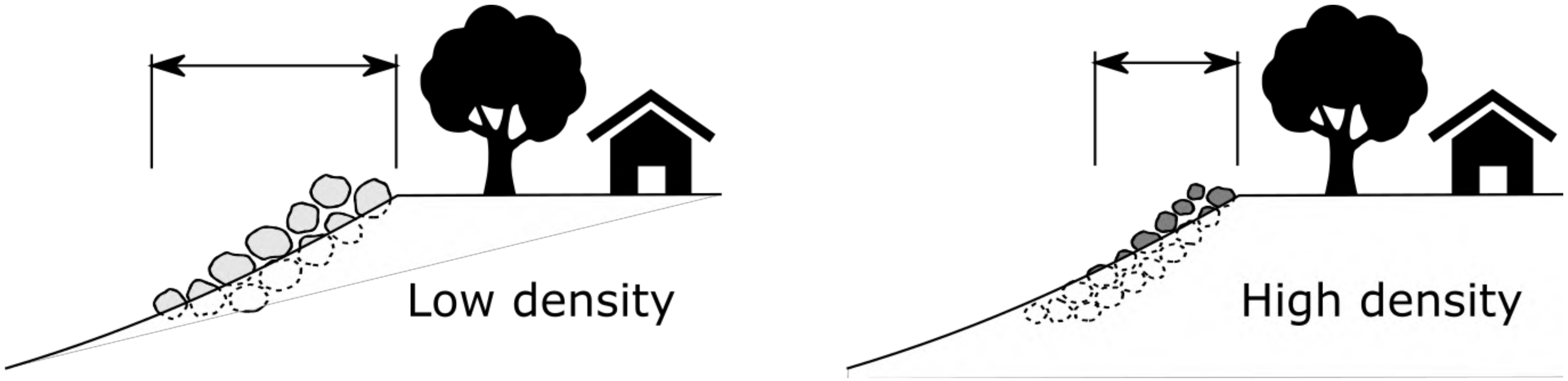
11% damage



Applications

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

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



Next steps

- Improve concrete workability
- Conduct field trial

High Density Geopolymer 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 plan for up to 16 HD Hanbars to be cast and installed at Port Kembla

Existing Ordinary Portland Cement Hanbars	16t, 7m^3, 2.3 t/m^3
Trial HD Geopolymer Hanbars	18t, 7m^3, 2.6 t/m^3

Δ^3 = submerged relative density cubed = $\{(2.6-1)/(2.3-1)\}^3 = 1.86$

Trial casting – phase 1 – 11 April 2018 – 3 HD 18 t Hanbar units

Subsequent casting of further 11 units and placement of 14 Hanbars on 2 July 2018 Port Kembla Northern Breakwater for performance monitoring

Questions

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