Dipartimento di Ingegneria
Dottorato in Ingegneria Civile - Ciclo XXXIV

ROMA TRE UNIVERSITÀ DEGLI STUDI

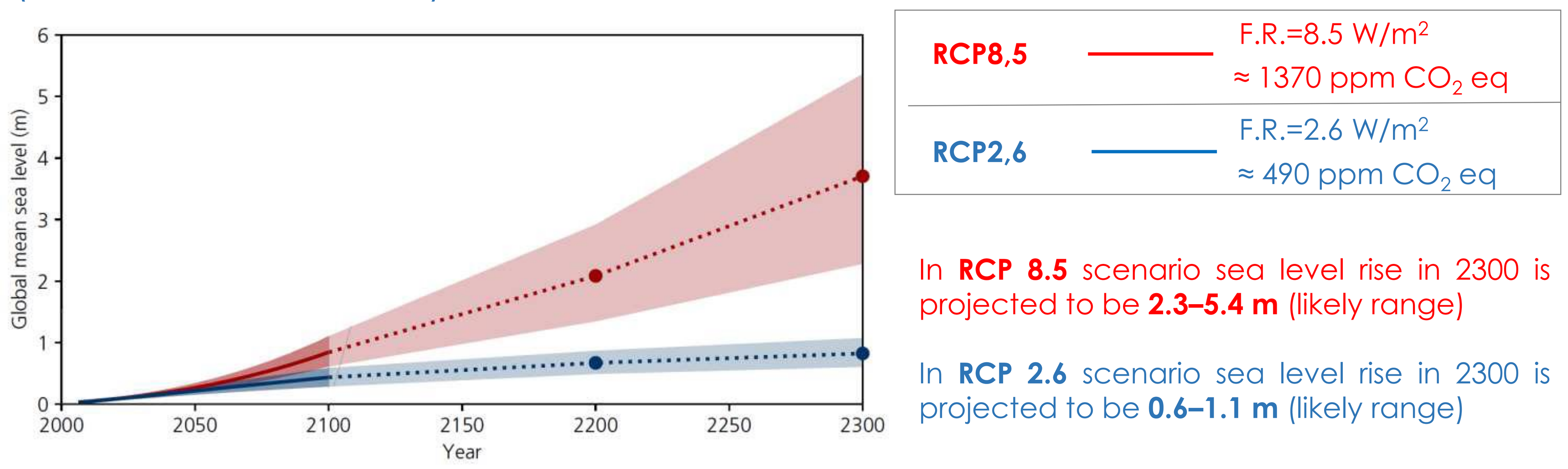
Upgrade of coastal defence structures

Yuri Pepi
Docente guida Prof. Leopoldo Franco

Nowadays one of the most challenging problem for engineers is to **adapt** existing coastal structures to climate changes. **Wave overtopping** and **armour stability** are highly sensitive to the increasing extreme water depths due to **higher storm surges** coupled with **sea level rise** (and the relative increase in breaking wave heights). One way to face these problems for rubble mound breakwaters is to **add one or more layers** to the existing armour (see *Burcharth et al.* (2014)). One example of this solution is presented in *Cecioni et al.* (2019) where a further tetrapod double layer has been added to the existing tetrapod armour at Piombino breakwater.
My PhD studies aim to analyze the effect of **mitigation measures** for the upgrade of rubble mound breakwater against increasing future marine hazards. The study is focused on **two types of armour** (rocks and tetrapod), the **number of layers** (1 to 4) on **different slope angles** and other structural characteristics on the wave overtopping and armour stability. The main effects of **porosity** and **roughness** will be investigated. During my first year I have analyzed the results of several new physical model tests reproduced since summer 2019 at the new medium scale random wave flume of the Engineering Department of Roma Tre University.

Sea level rise

(IPCC, SROCC 25/9/2019)

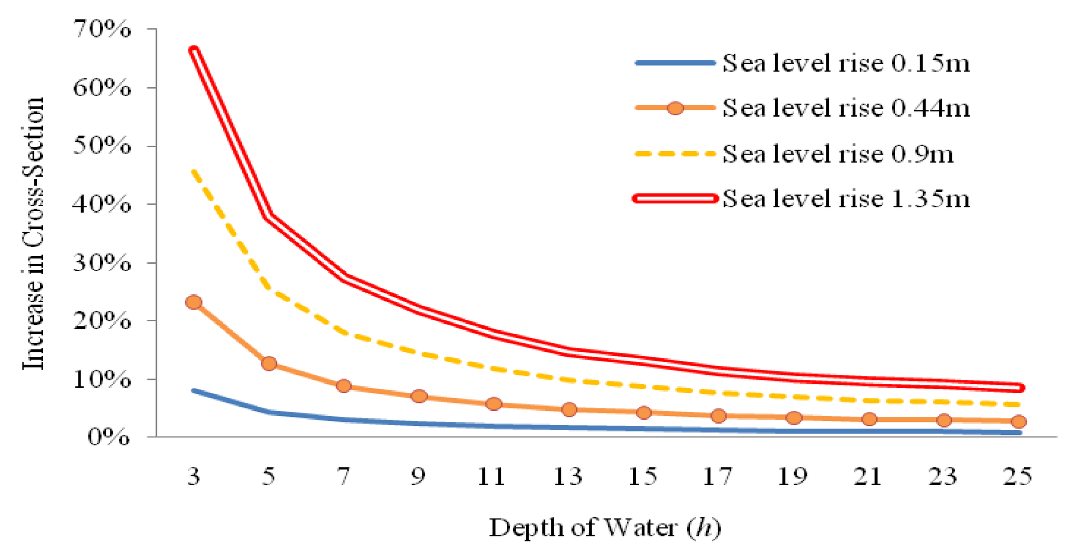


In **RCP 8.5** scenario sea level rise in 2300 is projected to be **2.3–5.4 m** (likely range)

In **RCP 2.6** scenario sea level rise in 2300 is projected to be **0.6–1.1 m** (likely range)

Breakwater future costs

(Esteban et al., 2013)



Breakwater costs in 2050 (SLR +1,3m):

- Deep water: **+8%**
- Shallow water: **+66%**

Armour stability and wave overtopping

Long Beach Harbor - Los Angeles (USA)

Marina del Este Port – Granada (Spain)

Wave overtopping discharge formula

(EurOtop manual – 2018)

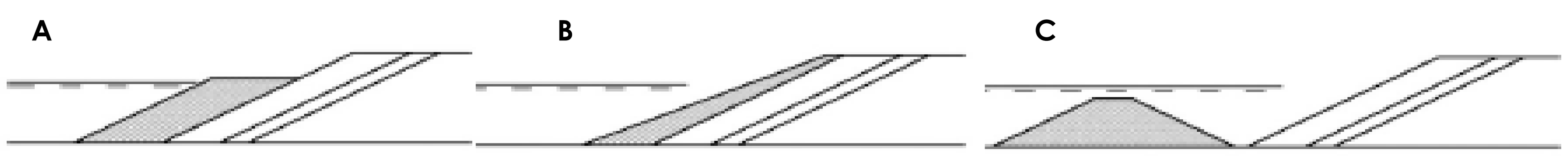
$$\frac{q}{\sqrt{g\,H_{m0}^3}} = Q = 0.09 \exp\left[-\left(1.5\,\frac{R_c}{H_{m0}\,\gamma_f\,\gamma_\beta}\right)^{1.3}\right]$$

Armour type	Layers	γ_f (EurOtop, 2018)
Rock	2	0.40
Tetrapod	2	0.38
Rock	3	No guidance; would have to rely upon linear assumptions and Judgement
Tetrapod	4	
Rock + Tetrapod	4	

q [l/s/m] average wave overtopping discharge
Rc [m] Crest height with respect to SWL
H_{m0} [m] Significant wave height
Influence factors:
γ_β influence factor for the oblique wave attack, if β = 0° γ_β = 1
γ_f influence factor for the permeability and roughness of the slope

Reinforcement options for rubble mound breakwaters

(Burcharth H. F. et al., 2014)



Addition of a berm — Addition of an armour layer — Construction of a submerged detached breakwater

Reinforcement options	Mean overtopping discharge Armour stability	Confidence in predictions for design or Assessment
Addition of a berm (**A**)	Reduction factor γ_b for berm	Reasonably robust, less verified at large scale or in the field
Addition of an armour layer (**B**)	Reduction by the additional armor layer	No experiments; no guidance; would have to rely upon linear assumptions and Judgement
Construction of a submerged detached breakwater (**C**)	Reduction of incident waves	Robust and extremely well-established

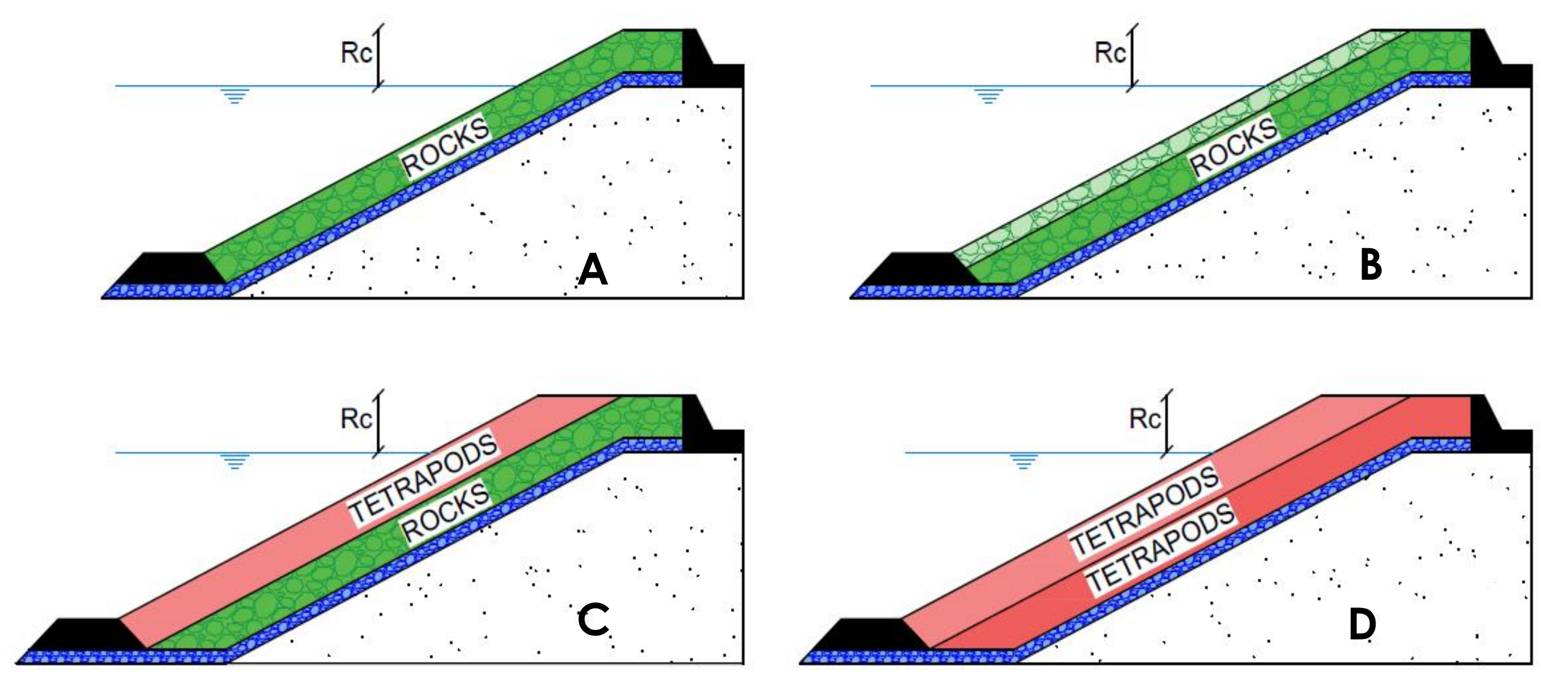
Laboratory model set-up

Dimensions:

20 m long
0.6 m wide
1 m high

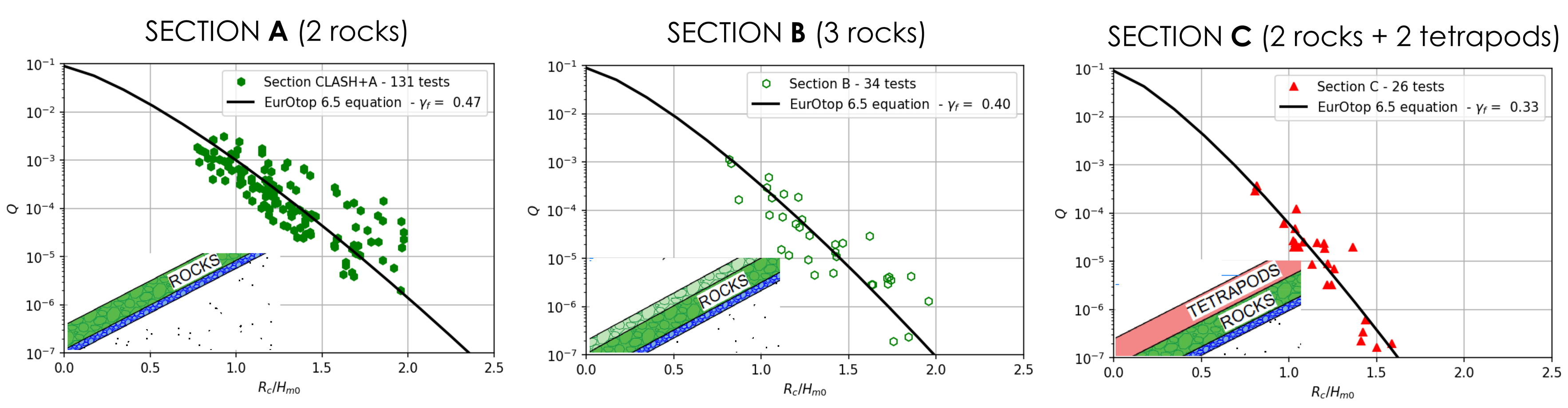
- **Wave paddle**, piston stroke 1.35 m
- 7 resistive level **probes** (5 along the and 2 at the paddle).
- Active wave absorption using the *Awasys* software
- Incident and reflected waves using the *WaveLab™* software.

Physical models (Scale: 1:30)



Model cross-section and device for measuring overtopping volumes

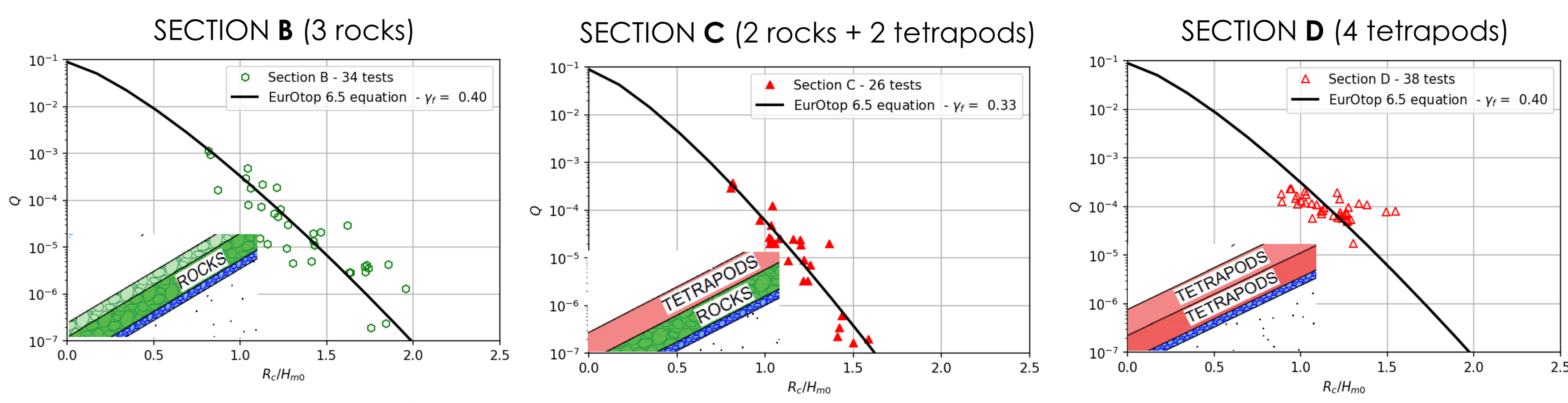
Experimental results



Section	Armour	γ_f	$\Delta\gamma_f$	ΔQ
A	2 rocks	0.47	0 %	0 %
B	3 rocks	0.40	15 %	71 %
C	2 rocks+2 tetrapods	0.33	30 %	92 %

These results shows that **adding an extra layer** is a valid option to reduce the overtopping on breakwaters.
It is possible to say that the overtopping discharge reduction in these tests is just affected by the γ_f because:

- Perpendicular wave attack (**No wave direction**)
- Simple armoured slope (**No berm**)
- ξm-10 < 4 (**No long wave influence**)



Also these tests shows that **3 rocks** and **4 tetrapods** have the same overtopping performance while **2 rocks + 2 tetrapods** is better than both of them. So adding a layer is a good option but it's better if the **porosity of the armour decreases from external to inside.** In these configurations the dissipation of the wave energy is higher due to:

Section	Armour	γ_f	$\Delta\gamma_f$	ΔQ
A	2 rocks	0.47	0 %	0 %
B	3 rocks	0.40	15 %	71 %
C	2 rocks+2 tetrapods	0.33	30 %	92 %
D	4 tetrapods	0.40	15%	71%

- **Heterogeneity – discontinuity**
- **Trajectories distortion**
- **Increase of dispersion phenomena**

Courses and other activities

Online course on *Machine Learning* (Standford University, Prof. Andrew Yan-Tak Ng)
Course on *Numerical methods for coastal engineering* (Roma Tre University, Prof. Giorgio Bellotti)
Course on *Generation and Analysis of Waves in Physical Models* (Aalborg University, Prof. Thomas Lykke Andersen)

Seawater intrusion and mitigation in Chennai region (Prof. Elango Lakshmanan)
Tsunami run-up in real geometries. Key concept, mathematical modelling and risk management (Prof. Rui Ferreira)
Characterization of turbulent flows within wall-mounted cylindrical obstacles (Prof. Rui Ferreira)
Modeling the impact of extreme storms on coastal local communities and the associated risk at the residential scale. Case study in Rhode Island USA (Prof. Annette Grilli)
Recent progress in the modeling of the 1908 Messina tsunami, and recent historical and hypothetical events (Prof. Stephan Grilli)

References

Cecioni C., Franco L., Bellotti G., 2019: *Wave forces at the crown wall of rubble mound breakwater measured and predicted at 2D physical models*. Proceedings Coastal Structures 2019.

Esteban, M. & Takagi, H. & Shibayama, T.. (2013). Sea level rise and the increase in rubble mound breakwater damage.

Burcharth H. F., Andersen T. L., Lara J. L., 2014: *Upgrade of coastal defence structures against increased loadings caused by climate change: A first methodological approach*, Coastal Engineering, Volume 87, 2014, Pages 112-121

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Van der Meer, J. W., NWH Allsop, T. Bruce, Julien De Rouck, Andreas Kortenhaus, T. Pullen, H. Schüttrumpf, Peter Troch, and B. Zanuttigh. 2018. *EurOtop: Manual on Wave Overtopping of Sea Defences and Related Structures : an Overtopping Manual Largely Based on European Research, but for Worlwide Application*. 2nd ed.