Climate change and sea level rise ; coastal vulnerability ans societal impacts,
10-11 June 2013, Collège de France, Paris (France)

From Climate Change Hypothesis to the Sizing of Coastal Infrastructures. An experimental study

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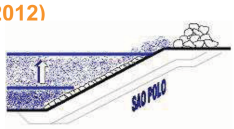
Outline

- Context: the SAO POLO project
- Purpose of the experimental study
- Experimental setup, hydrodynamic conditions, measurements
- Structure 1 : smooth concrete sloping seawall
- Structure 2 : rock-armoured shoreline structure
- Test results and analysis
- Conclusions

The SAO POLO R&D project (2009-2012)



SAO POLO : Adaptation strategies for marine protection works and coastlines tenure face to sea levels rise.

Stratégies d'Adaptation des Ouvrages de Protection marine ou des modes d'Occupation du Littoral vis-à-vis de la montée du niveau des mers et des Océans

- Part of R&D programme "Management and Impacts on Climate Change", partially supported by the French Ministry in charge of Ecology, Sustainable Development and Energy. GICC
- Project leader: Philippe Sergent (CETMEF)

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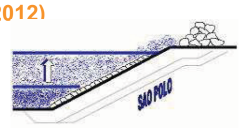
The SAO POLO R&D project (2009-2012)



SAO POLO : Adaptation strategies for marine protection works and coastlines tenure face to sea levels rise.

- Purpose: providing a coherent system of technical tools enabling to study and evaluate adaptation strategies (e.g. reinforcement of coastal defenses, sustainable development of land in the coastal area)
- Workpackages:
  1. Define parameters, structures and sites of the project
  2. Estimate present and future performances of coastal structures
  3. Study reinforcement/modifications of structures
  4. Estimate costs of works and modifications.
  5. Develop a decision-support system to help in choosing a strategy

Effects of sea level rise on coastal structures performances

- **Purposes of the study**
  - Evaluation of performance of structures, in terms of **overtopping rate** and **stability**, under the hypothesis of a future sea level rise.
  - Test and comparison of **reinforcement solutions in the future scenarios**.
  - Suggesting reinforcement solutions having the **same performance in the future scenarios as the original structures in the present conditions**.
- **Methodology** : experiments in a physical scale model (wave flume) (scale 1:30 – Froude similitude)
- Study of **two shallow water costal protection structures** :

Smooth concrete sloping seawall

Two-layer rock-armoured shoreline structure

Experimental setup : the wave flume

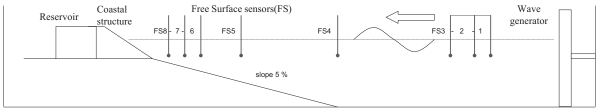
Wave flume characteristics at LNHE and Saint-Venant Lab. in Chatou:

- Total length: 45 m
- Width: 0.6 m
- Maximum water depth: 0.6 m
- Wavemaker : piston-type. Electrical motor, computer controlled.
  Regular or irregular waves. Active wave absorption system (limit spurious reflections).

View of the wave flume

Experimental setup: bottom profile and water levels

- Bathymetry:
  - **5% plane sloping bottom** over a distance of 180 m
  - Bottom made of concrete.
  - Water depth at the toe of the structure : **3.0 m (present scenario)**



Scheme of the experimental set-up (not in scale)

- Sea level rises for future scenarios:
  - **+0.5 m** => water depth at the toe of the structure : **3.5 m**
  - **+1.0 m** => water depth at the toe of the structure : **4.0 m**

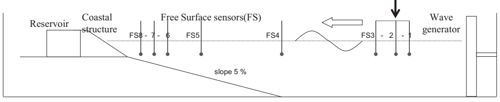
Experimental setup : incident wave conditions

- Wave conditions:
  - Consider that offshore wave conditions will not be significantly modified for future scenarios ...but wave conditions at the toe of the structures will change due to the increase of water depth.
    => so same *offshore* wave conditions for present and future scenarios.
  - Irregular wave conditions:
    - JONSWAP wave spectrum (with peak enhancement factor γ = 3.3)
    - Significant wave height: H_{m0} = 2.0 ; 3.0 ; 4.0 m
    - Peak period: T_p = 9.0 ; 10.3 ; 12.9 s
- Duration of each sea-state (test): **3 h**
  (= 33 min at model scale)

Experimental setup: measurements

- Wave characteristics at various locations:

Incident wave height



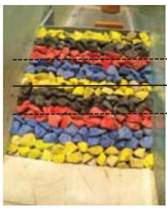
- Overtopping rate:

Reservoir

Pump + flowmeter

=> mean discharge per unit width q ($m^3/s/m = m^2/s$)

- Stability of armour stones:



MSL + 1.5Hmo

MSL

MSL - 1.5Hmo

=> fraction of displaced rocks D (%)

Structure 1 : smooth concrete sloping seawall

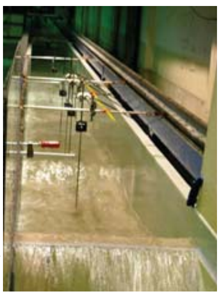
Seawall : design and performance

Design of the smooth concrete sloping seawall:

- Slope of the concrete seawall: **1:2**
- Design criterion: mean overtopping discharge of $5 \cdot 10^{-3}$ $m^3/s/m$ in the present scenario

→ Crest elevation: **9.6 m above MSL** for present conditions (water depth at the toe: 3 m)

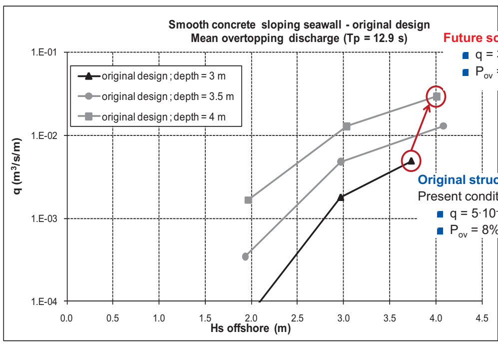
Seawall physical model



Snapshot of overtopping wave during test in the flume

Seawall : increase of overtopping with mean sea level

(results for the period T_p = 12.9 s)



Future scenario (+1 m MSL):

- q = $3 \cdot 10^{-2}$ m^2/s
- P_{ov} = 27%

Original structure performance

Present conditions:

- q = $5 \cdot 10^{-3}$ m^2/s
- P_{ov} = 8%

Seawall : 3 reinforcements tested

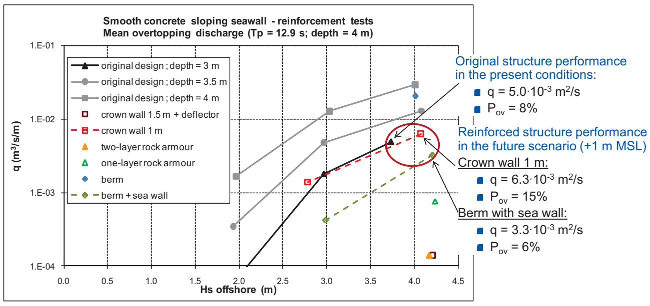
- **Crown wall:**
  - 1.5 m crown wall, with deflector 0.6 m high
  - 1.0 m crown wall
- **Armour layer on the concrete slope:**
  - Tests with 1 and 2 layers (4-6 T armour rocks)
- **Berm with sea wall on the sea side**
  - Berm width/elevation: 5.0 m/5.0 m
  - Parapet height: 1.2 m
  - Two sea wall porosities tested (12.5%; 25%)

Crown wall with deflector

Armour layer

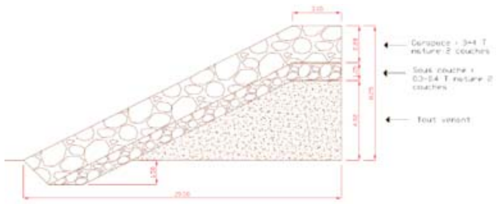
Berm with sea wall

Seawall reinforcement tests: results (period T_p = 12.9 s)



- Best reinforcement solutions : crown wall or berm with sea wall
- Armour stones decrease the overtopping discharge, but have poor stability
- Crown wall with deflector: a too "strong" reinforcement

Structure 2 : rock-armoured shoreline structure



Shoreline structure : design and performance

Design of the shoreline structure:

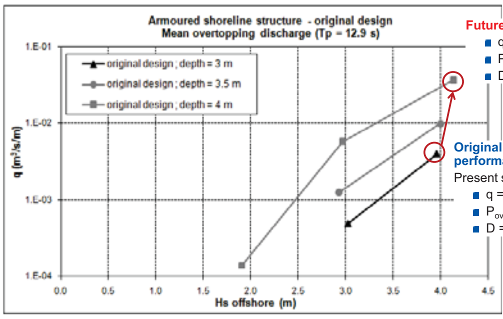
- Design criteria:
  - maximum mean overtopping discharge of q = $5 \cdot 10^{-3}$ m³/s/m in the present scenario (as for the seawall)
  - stability: start of damage (D < 5%, in the area within MSL ± 1.5 H_s)
- Slope of the structure: **1:2**

→ Double layer of armour stones**: 3-4 T**

→ Crest elevation: **5.3 m above MSL** for present conditions (water depth at the toe: 3 m)

Physical model of the rock-armoured shoreline structure

Shoreline structure : increase of overtopping with mean water level (results for the period T_p = 12.9 s)



Future scenario (+1 m MSL):

- q = $3.7 \cdot 10^{-2}$ m²/s
- P_{ov} = 30%
- D = 6.2%

Original structure performance

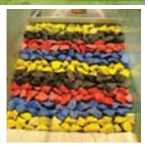
Present scenario:

- q = $4.0 \cdot 10^{-3}$ m²/s
- P_{ov} = 4.7%
- D = 1.5%

Shoreline structure : 4 reinforcements tested (1/2)

- **Crown wall**
  - Height: 1.0 m

→ Better overtopping performance, but poorer stability of the armour stones (due to reflection on the wall)



Reinforcement with a 1.0 m crown wall

- **Third layer of armour stones + crown wall**
  - 5 solutions tested varying:
    - stone size: 3-4 T ; 5-6 T
    - crown wall height : 1.0 m; 1.5 m; 2.0 m

→ The stone size affects the stability, but has a small influence on the overtopping discharge

→ The higher the crown wall, the smaller the overtopping discharge, but the worse the stability.

Reinforcement with a 2.0 m crown wall and a third layer of armour stones of 5-6 T

Shoreline structure : 4 reinforcements tested (2/2)

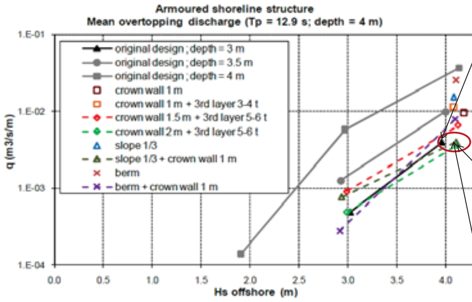
- **Milder armour slope**
  - Slope 1:3
  - Armour stones: 3-4 T
  - Tests with and without a 1.0 m high crown wall
  - → Good stability and good overtopping performance with the crown wall

Reinforcement with a milder structure slope (1:3) and a crown wall

- **Composite profile including a berm**
  - Same type and number of blocks used for the milder slope reinforcement
  - Berm elevation: 1.0 m (corresponding to the future scenario water level)
  - Berm width: 8.4 m
  - Tests with and without a 1.0 m high crown wall
  - → Poorer stability and overtopping performances than milder structure slope case

Reinforcement with a berm and a crown wall

Shoreline structure : test results (period T_p = 12.9 s)



Original structure performance in the **present scenario**
- $q = 4.0 \cdot 10^{-3}$ m²/s
- P_{ov} = 4.7%
- D = 1.5%

Reinforced structure performance in the **future scenario** (+1 m MSL)

3rd layer 5-6 T + crown wall 2 m:
- $q = 3.1 \cdot 10^{-3}$ m²/s
- P_{ov} = 7.5%
- D = 2%

Slope 1:3 + crown wall 1 m:
- $q = 4.7 \cdot 10^{-3}$ m²/s
- P_{ov} = 6.2%
- D = 2.9%

- **Best reinforcement solutions:**
  - Third layer of armour stones 5-6 T with a crown wall of 2 m
  - Milder slope (1:3) with a crown wall of 1 m

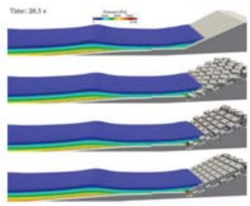
Conclusions of the experimental study

- Two physical models of costal protection structures were built at 1:30 scale to test reinforcement solutions against climate change-induced sea level rise of up to +1 m
- Target : reinforced structures should have the same performances in the future scenario as the original structures in the present conditions.

- In terms of overtopping discharge:
  - The use of a parapet on a berm on the sea side or on the structure crest (crown wall) is necessary to limit the overtopping discharge, independently from the structure considered.
  - The stone size does not have a significant impact on the overtopping performance of the structure (among the values considered in the tests).

- In terms of stability (rock-armoured shoreline structure), two viable solutions :
  - the use of a third layer of larger size stones
  - the construction of a milder slope.

Thank you for your attention !



Code SPHysics
C. Altomare, X.F. Gironella, A.J.C. Crespo, J.M. Domínguez, M. Gómez-Gesteira, B.D. Rogers (2012), *Improved accuracy in modelling armoured breakwaters with SPH*, Proc. 7th SPHERIC International workshop, Prato (Italy).