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Accumulated damage evolution and investment costs of breakwaters

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OUTLINE

- An academic question or an engineering obligation?
- Technical and economic design criteria: ROM 0.0, PIANC 2016, ...
- Overall objectives
- Temporal accumulated damage, spatial propagation and triggering other modes
- Total costs and investments
- CONCLUSIONS

An Academic Question or an Engineering Obligation?

REGIONAL CONSTRAINTS

Socio - economic and environmental features

High demand and occupation (opportunity cost)

Use of coastal public land (legality)

RISKS

Natural hazards, vulnerability,

Global warming and rising sea

SUSTAINABILITY

Environmental,

Financial and Economic

COST QUANTIFICATION

Development, construction, maintenance, repair, dismantling, restoration

MEIPOR (2016): Methodology for **Decision-making** in Harbor Investment Projects

(*adaptation of EU Guide to Cost-Benefit Analysis of Investment Projects*)


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Revisión y Actualización del Método de Evaluación de Inversiones Portuarias (MEIPOR 2016)

(Versión preliminar para la evaluación de su aplicación práctica)

Mayo de 2016

Objective of MEIPOR

financial and economical optimum investment costs

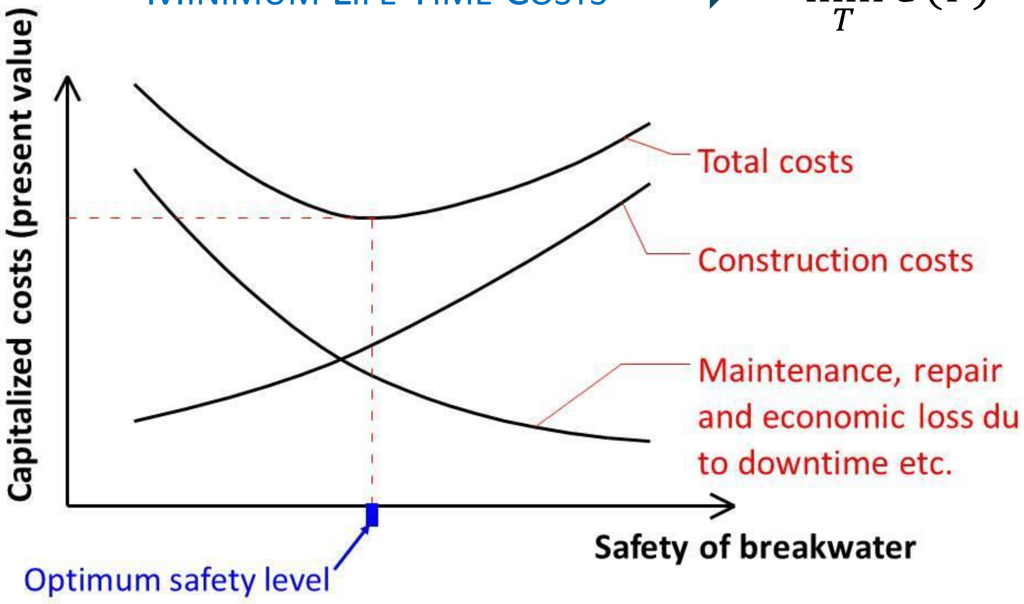
Regional constraints, financial sustainability and risk

TECHNICAL-ECONOMICAL DESIGN CRITERIA ➡ ROM 0.0 (2000) and PIANC (2016)

MINIMUM LIFE TIME COSTS ➡

$$\min_{T} C(T) = C_I(T) + \sum_{t=1}^{T_L} \{C_{R_1}(T)P_{R_1}(t) + C_{R_2}(V)P_{R_2}(t) + C_F(T)P_F(t)\}\frac{1}{(1+r)^t}$$

construction *repair* *maintenance* *failure*



➡ Optimization against a **single mode of failure** in the **useful life** of the breakwater

Based, among others, on two assumptions

Modes of failure are **independent** => (doubtful and possibly not optimum)

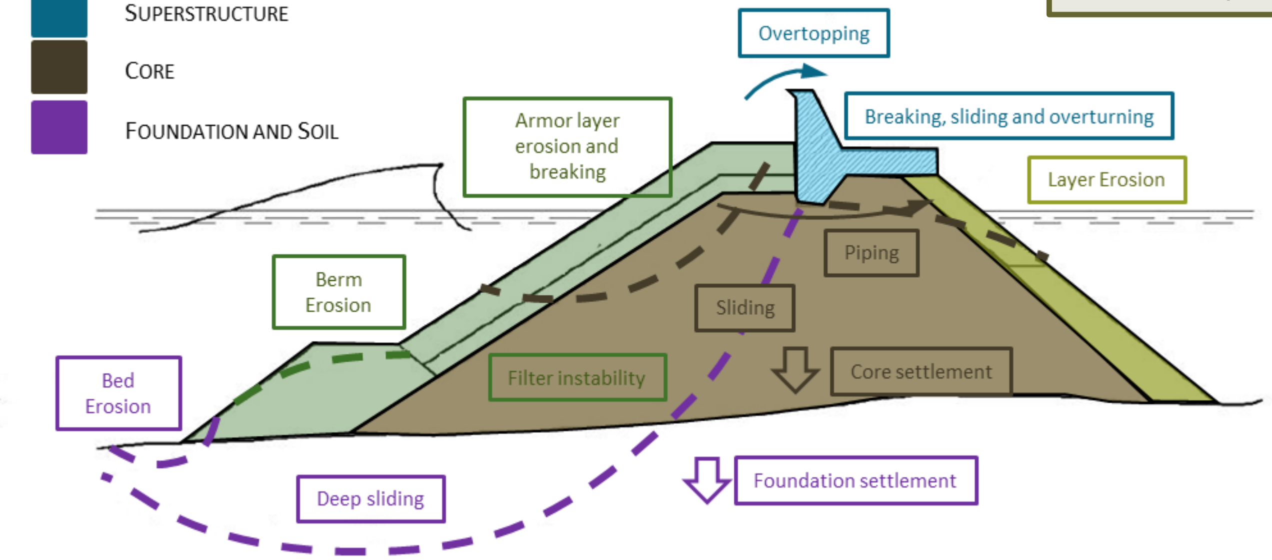
Immediate reparation is possible => (facilities and money available)

Optimization in the **useful life time** => (payback time, duration of the licence, subventions?)

Technical-Economical Design Criteria

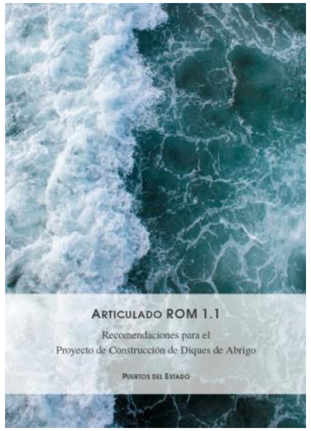
Principal Failure modes in rubble mound breakwaters

- Armor Layer and Berm (Seawards)
- Armor Layer (Leeward)
- Superstructure
- Core
- Foundation and Soil



ROM (2018): *Recommendations for the desin and construction of breakwaters*

(adaptation to ROM 0.0 and MEIPOR 2016)



Objective of ROM

Technical - economic optimum safety and operational constraints and other requirements: legal, environmental, ...

(1) Correlated, concomitant, triggering other modes of… ?

(2) Analyzing the reparation costs along the useful life ... ?

(3) Regarding the cash flow and financial sustenability to pay for ... ?

So far reparation is a COST but should be an INVESTMENT → Repair Policy (when and how) must be included in the Optimization Process!!

Overall Objectives

To design, construct and manage a brekwater
technical - economic optimum safety and operational constraints regarding the financial and economical optimum investment costs!

Engineering Objectives and Challenges

To estimate the probability distribution function of the investment costs in the useful life of a breakwater.

- Time series simulations of **multivariate storms** in the useful life → *Methods for simulation of Multivariate Storm Evolution (ICCE 2018): Solari and Losada 2018, and Lira et al. 2018*
- Methods for the analysis of the **temporal evolution of the damage**
- Description of the **spatial damage propagation and triggering** of other modes of failure
- **Mantainance and repairing strategies** and and derived processes including duration
- Tools for calculation of the **total costs** of the breakwater and of the **investment costs**

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Temporal accumulated Damage Equation

Challenge: To develop an accumulation model of concomitant and triggered modes of failure

Van der Meer (1988)
Medina (1996)
Melby and Kobayashi (1998)
Melby and Kobayashi (1999)
Melby (1999)

Castillo et al. (2012)

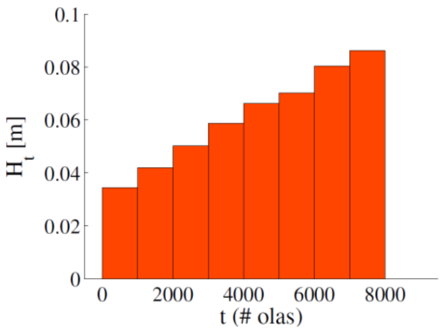
Any accumulation model must follow an ADDITIONAL compatibility condition

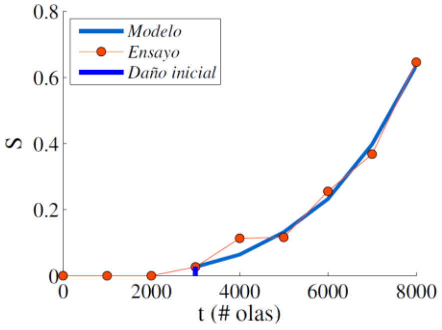
$$S(S_0;\ t = t_1 + t_2) = S(S_0;\ t_1) + S[S(S_0;\ t_1); t_2]$$

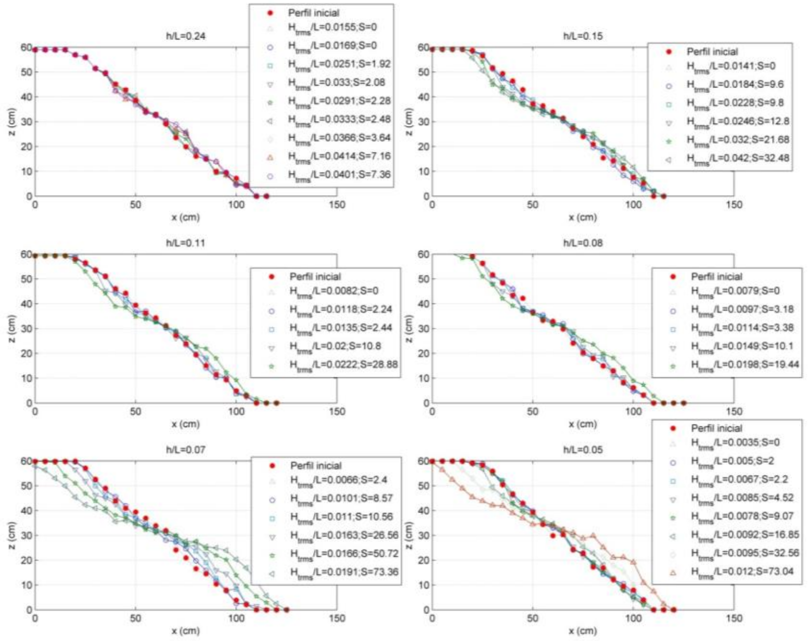
$$S(t, S_0, H) = g[g^{-1}(S_0, H) + t, H]$$

Potential model for damage accumulation: $\boldsymbol{S^{1/b} = S_0^{1/b} + (a \cdot H_t^c)^{1/b} \cdot t}$

Parameters (a, b, c)



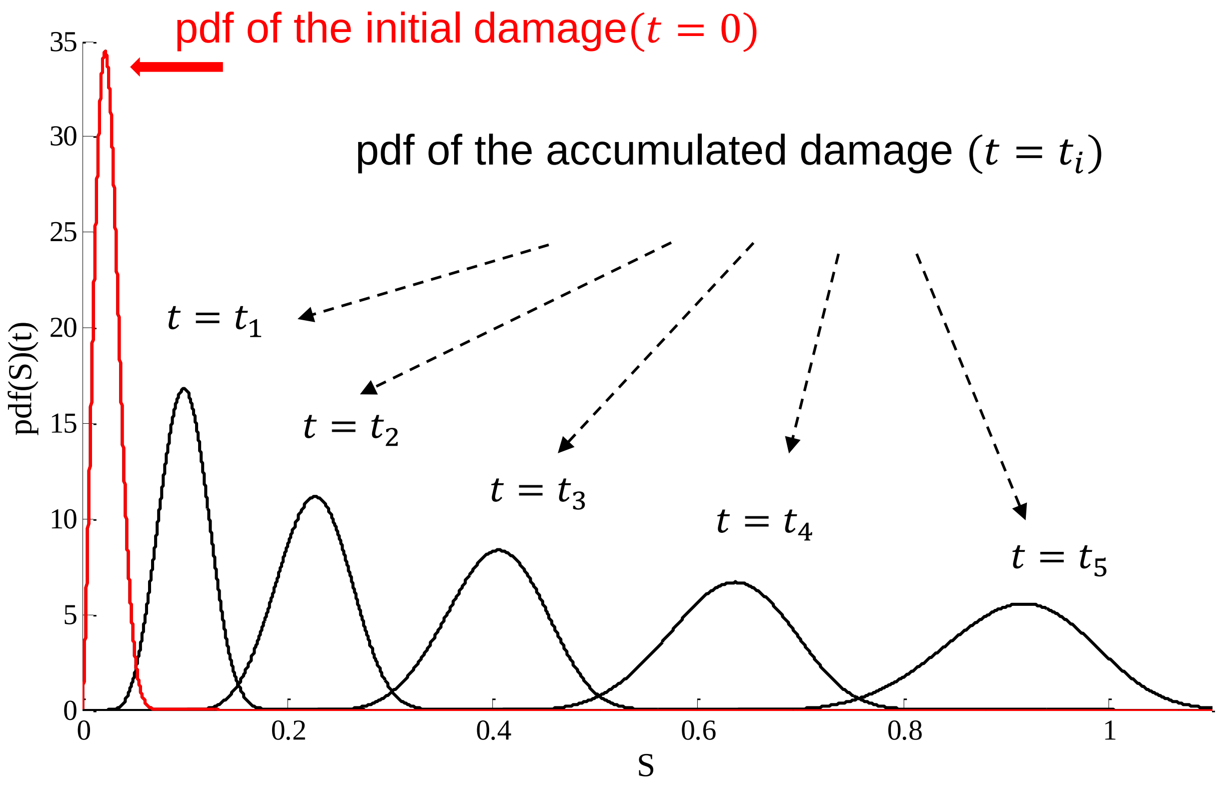


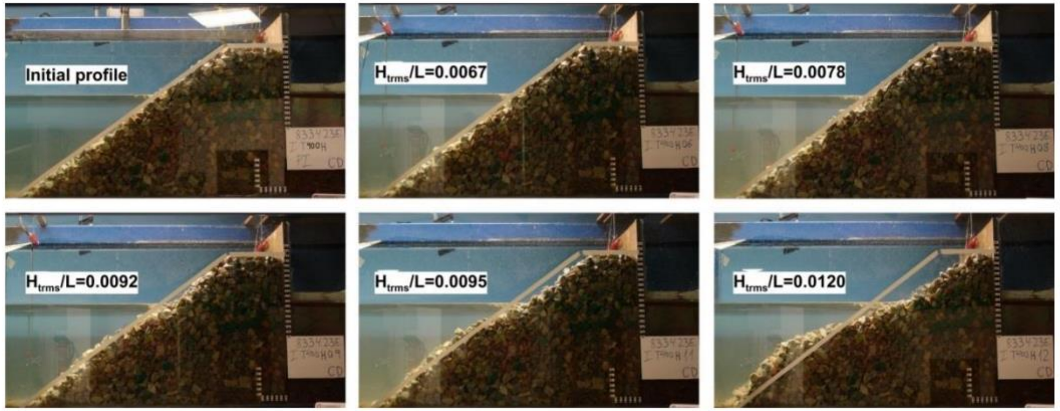


Evolution of the profile depending on the wave slope, the incoming wave train and the typology

TEMPORAL ACCUMULATED DAMAGE EQUATION

Design based on the temporal accumulated damage: probability of failure after time t_i





Damage Accumulation Tests in rubble mound breakwater *(UGR)*

pdf of the initial damage

Accumulated damage model

Sequence of states (H_t, T_z, t)

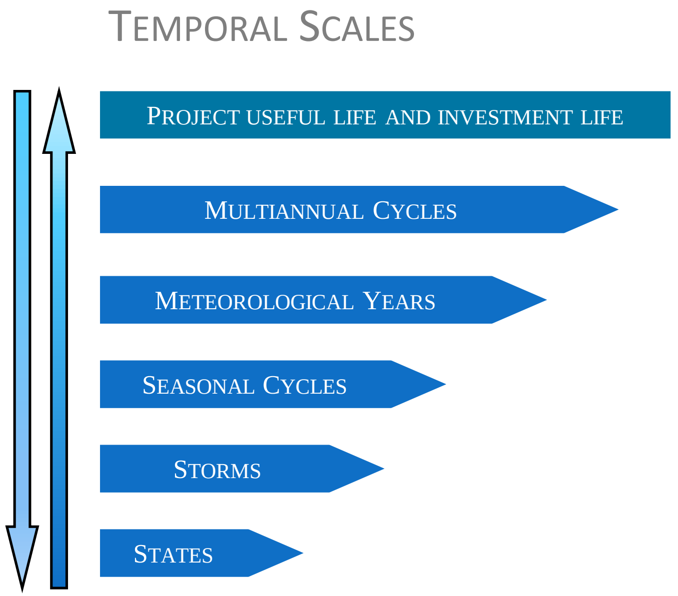
pdf accumulated damage after time t_i

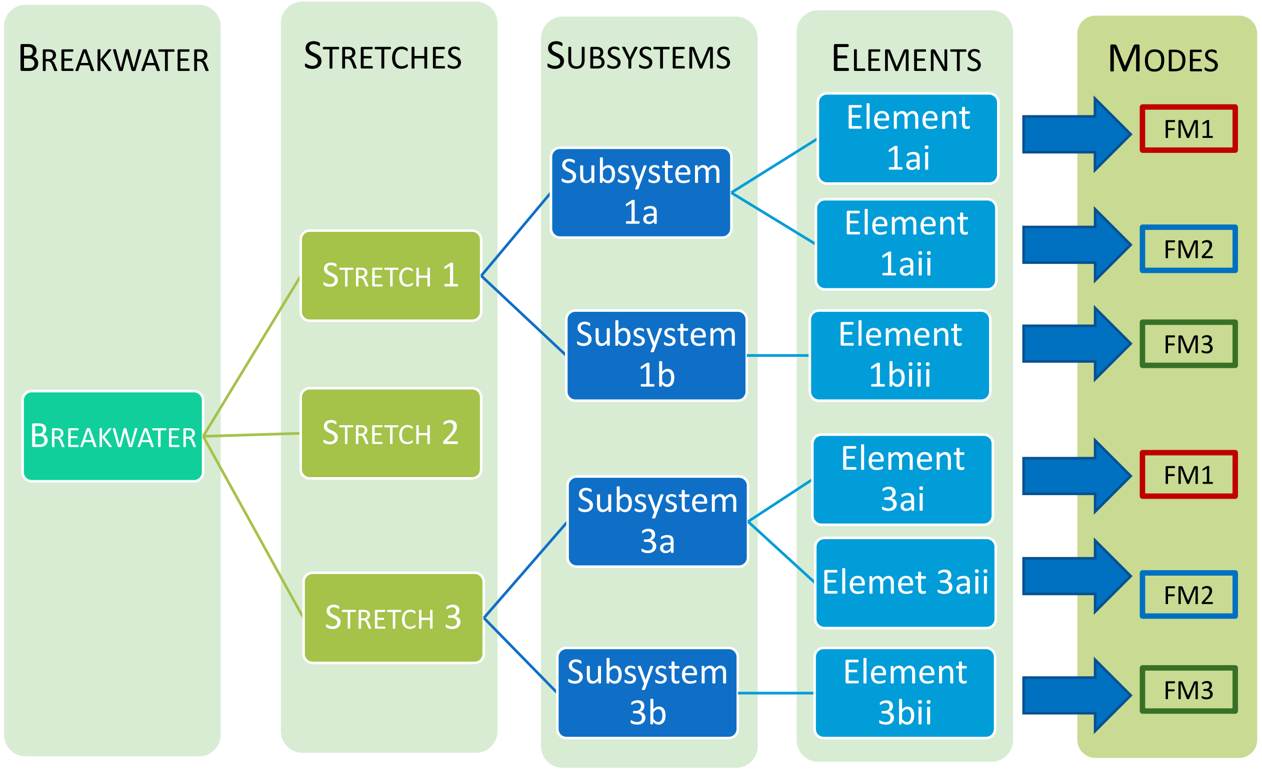
Probability of failure after time t_i

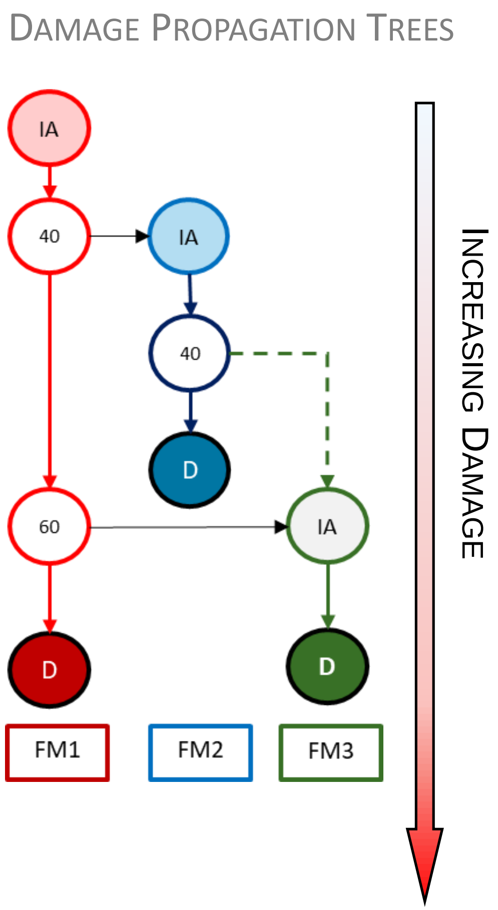
Decision: REPARATION

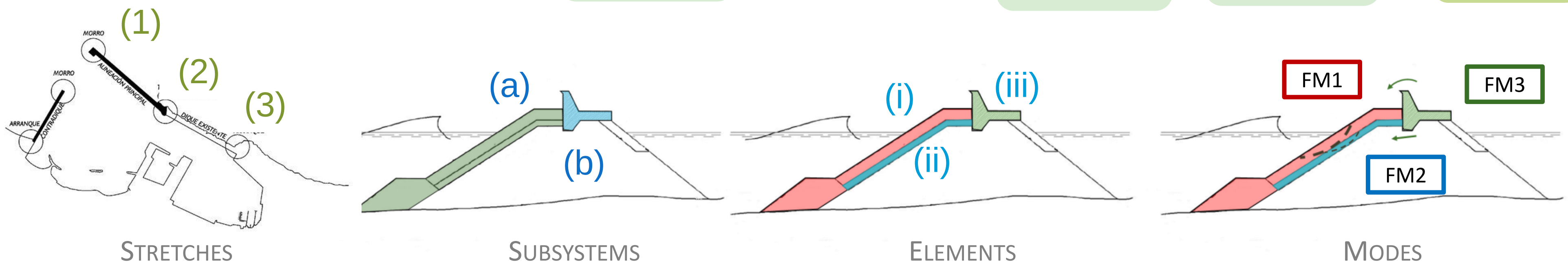
Temporal and Spatial Scales for Damage Analysis

Challenge: to develope methods to quantify the consequences of the failure in one or more components on the performance of the system





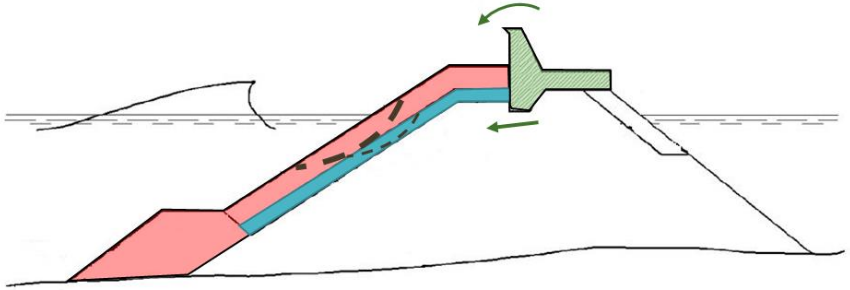


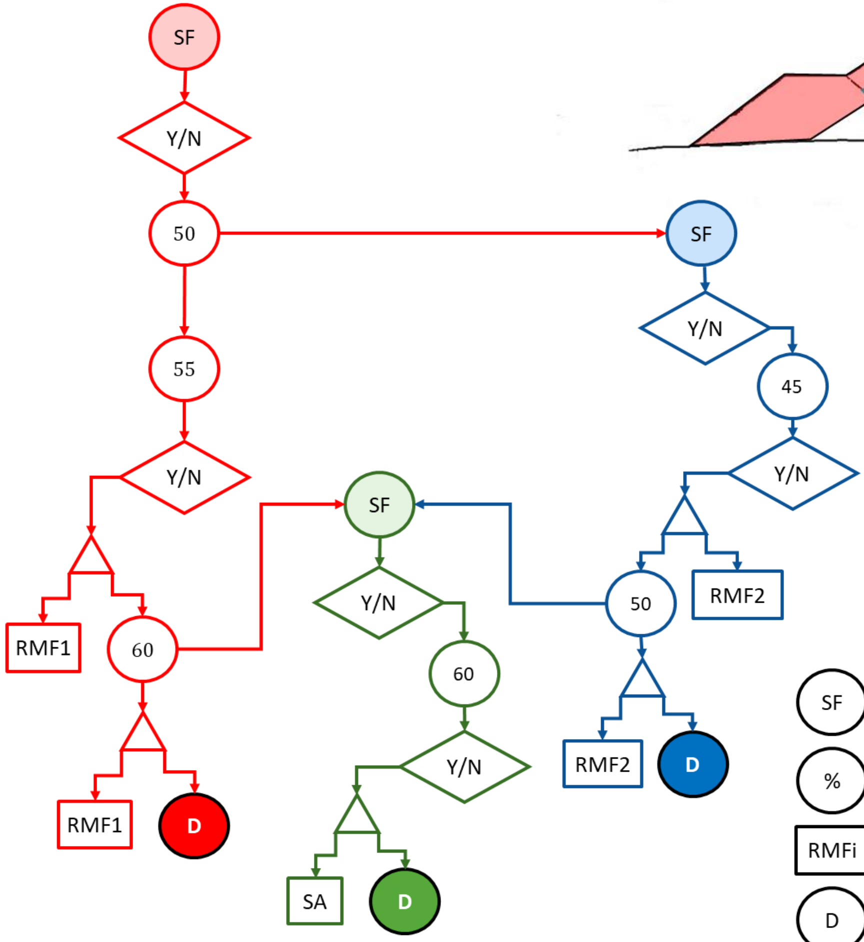


Maintenance and Repair Strategies and Decision Trees

<u>Challenge</u>: to develope methods to detect dominant processes of triggering other modes of failure

Decision Trees





FM1: Main Armor Layer Erosion

FM2: Secondary Armor Layer Erosion

FM3: Crown Sliding / Overturning

SF *Start of Failure*

% *Damage*

RMFi *Repaired Failure Mode*

D *Destruction*

Repair Strategies: Content

- Damage level to start the repair
- Sea climate thresholds to stop
- Actions after stoppage
- Resources for the repair
  - Availability
  - Operationality
  - Efficiency
- Priority for concurrent reapartion
- Costs
- …

\+

Climatic Agents

PROBABILITY OF SUCCESS

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Total Costs and Investments

General structure of the overall construction/reparation costs during an specific stretch of breakwater

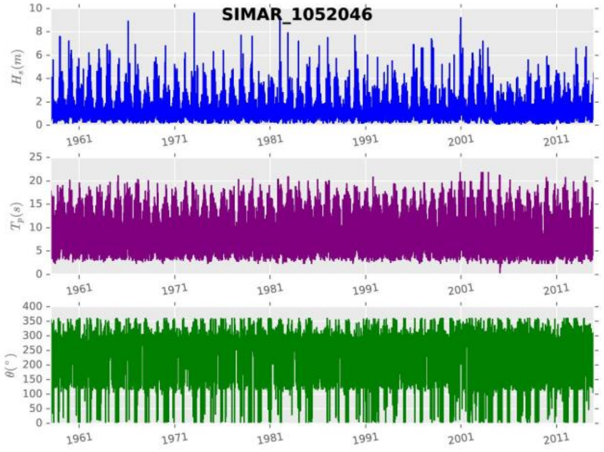
$$C_T^f = \underbrace{\sum_{sf=1}^{n}\sum_{uo=1}^{m} Vol_{sf,uo}\left(1+\underbrace{k_{sf}}_{\text{Damages and losses}}\right)C_{uo}}_{\text{Execution of the Milestones}} + \underbrace{\sum_{sfp=1}^{m}\sum_{uo=1}^{m} Vol_{sfp,uo}C_{uo}}_{\text{Protections}} + \underbrace{\sum_{sf=1}^{m}\tau_{sf}\sum_{ac=1}^{n} C_{ac_{sf}}}_{\text{Afections}} + \underbrace{C_t}_{\text{Others}}$$

Segregation of the Overall Costs

Direct Costs	*Facilities* *Equipment* *Labor costs*
Indirect Costs	
Costs of operational stoppage	

TOTAL COSTS AND INVESTMENTS

OBTAINING MULTIVARIATE LOCAL TIME SERIES

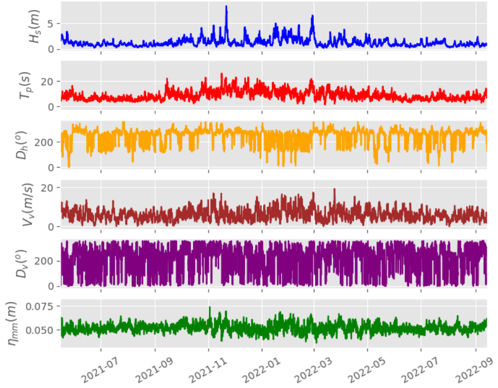


Data/SIMAR

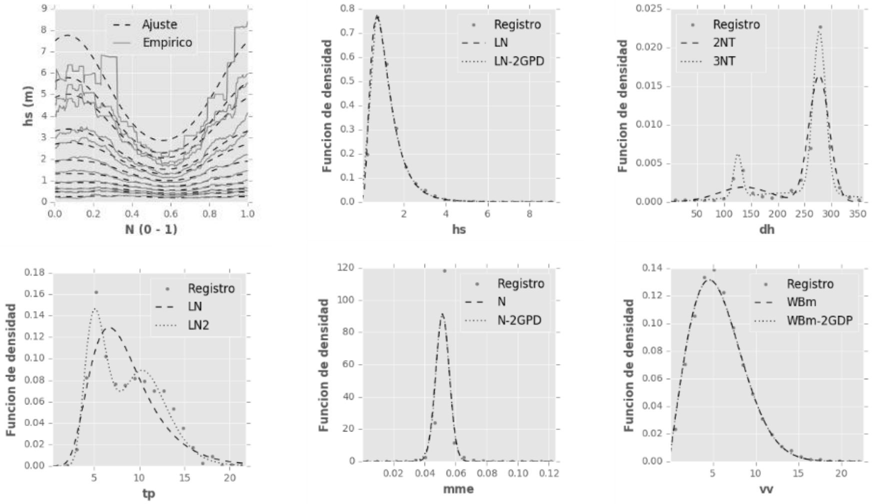
Checking time series

Downscaling

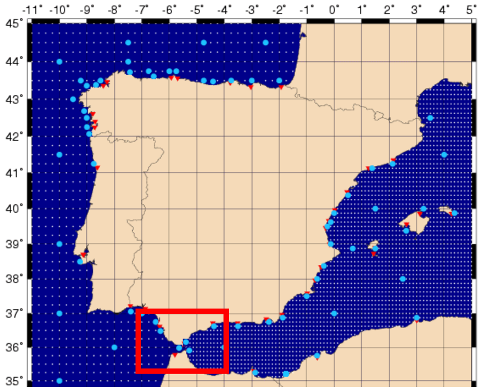
Reconstruction



Local time series



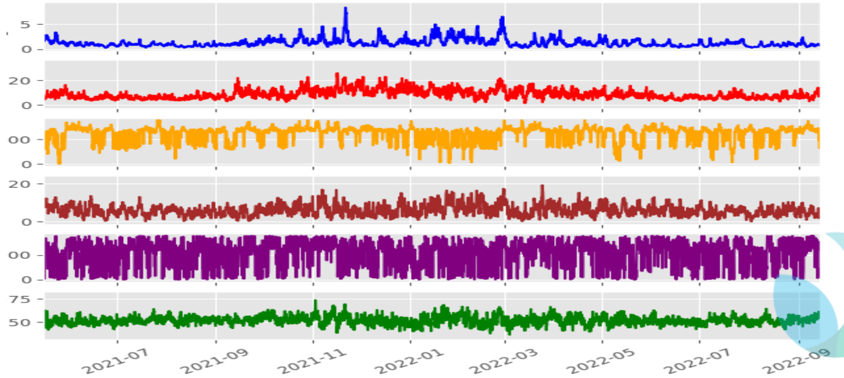
STATISTICAL CHARACTERIZATION



Cádiz Breakwater

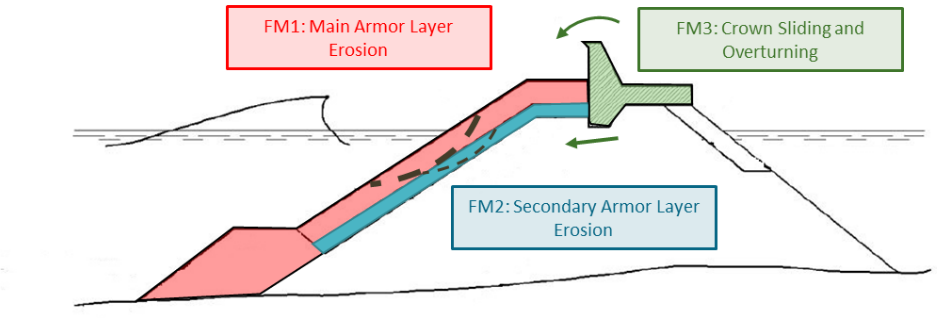
MULTIVARIATE SIMULATIONS

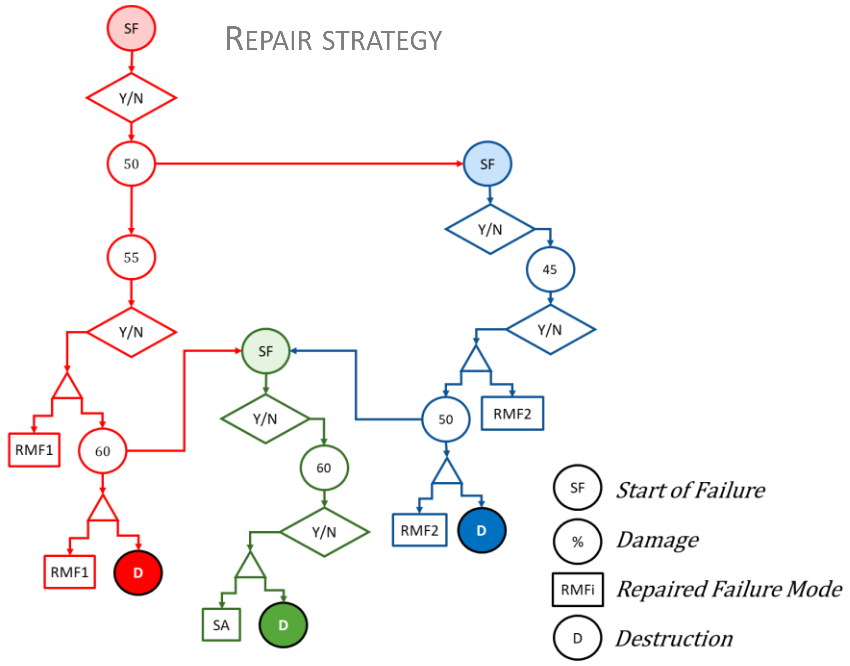
Methods for simulation of Multivariate Storm Evolution (ICCE 2018)
Solari and Losada 2018, and Lira et al. 2018



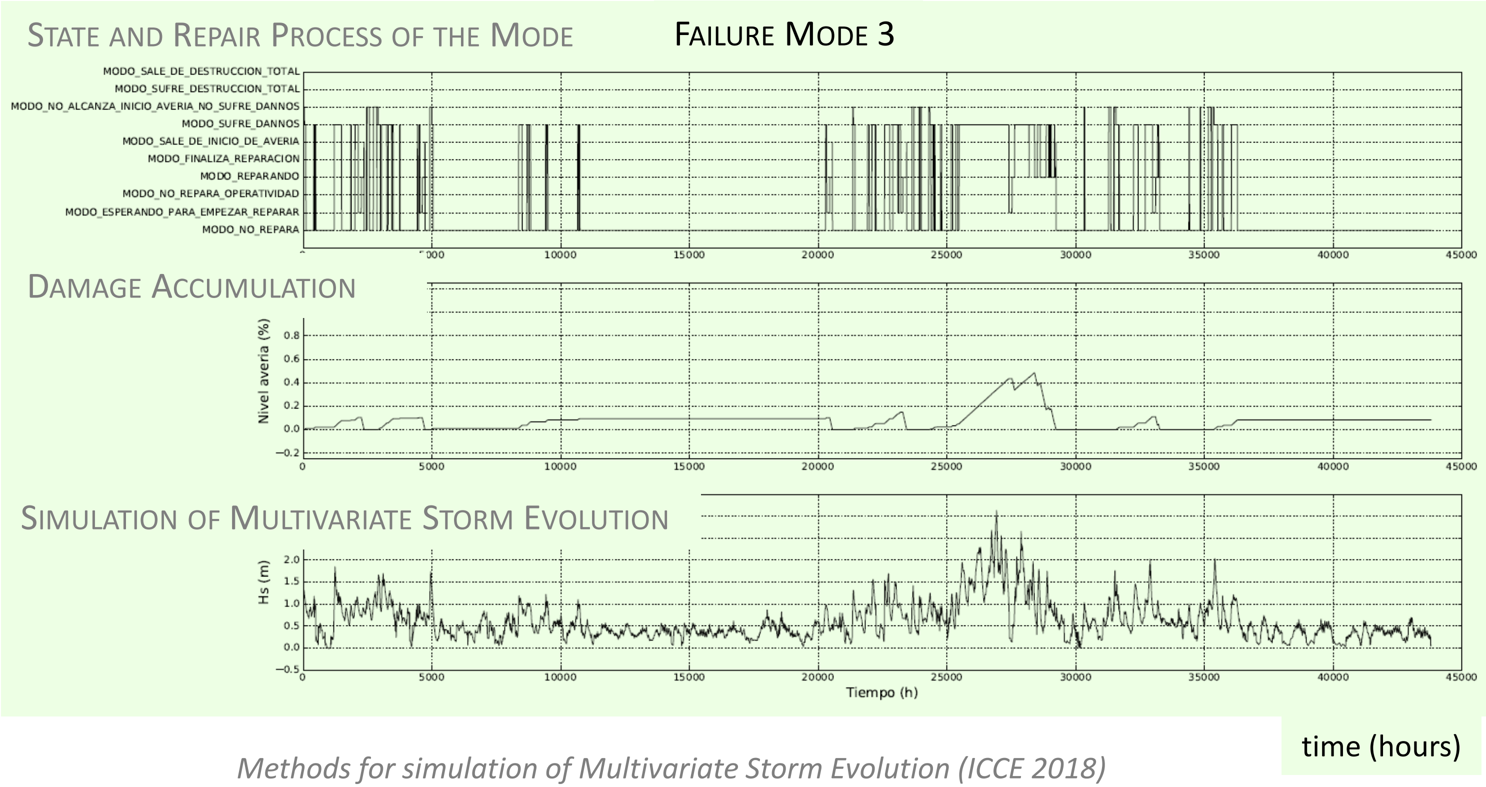
Total Costs and Investments

Simulation of multivariate storm evolution, damage evolution and state and repair process





<u>Series failure diagram</u>: breakwater fail when one mode of failure occur



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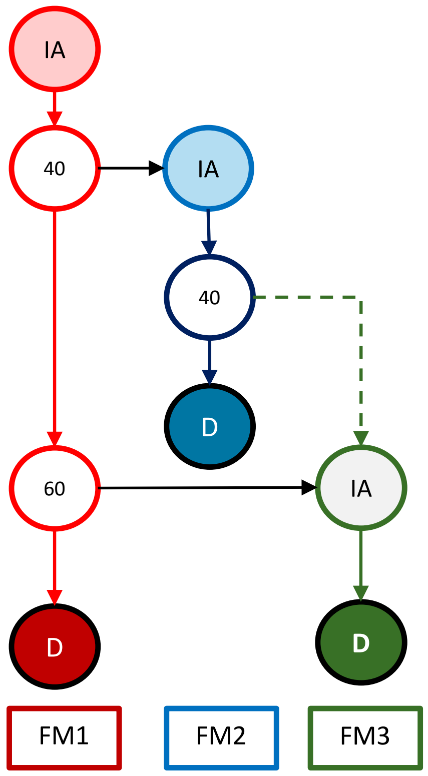
Total Costs and Investments

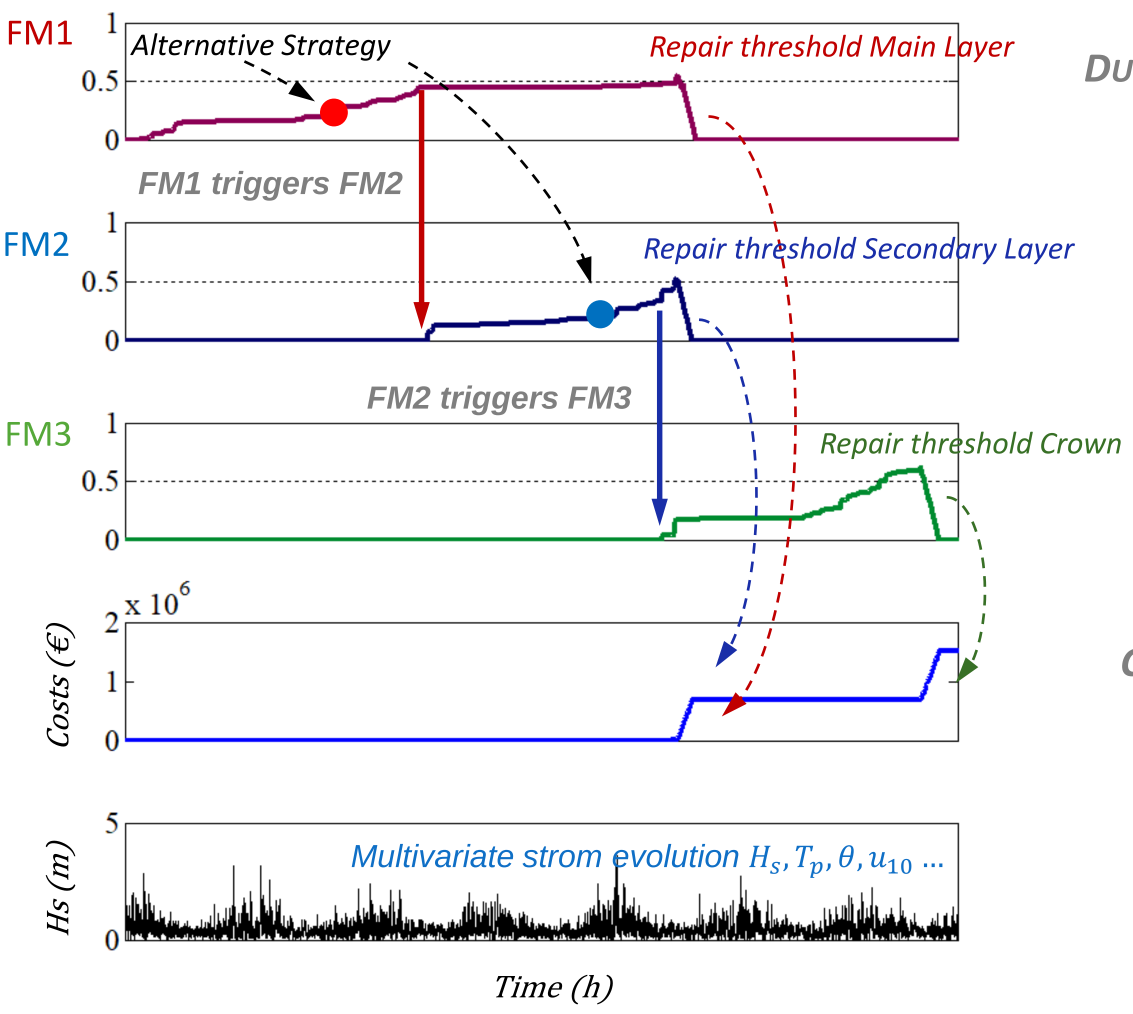
Probability density functions of the reparation time and of the costs split by mode of failure after **N simulations of useful life**

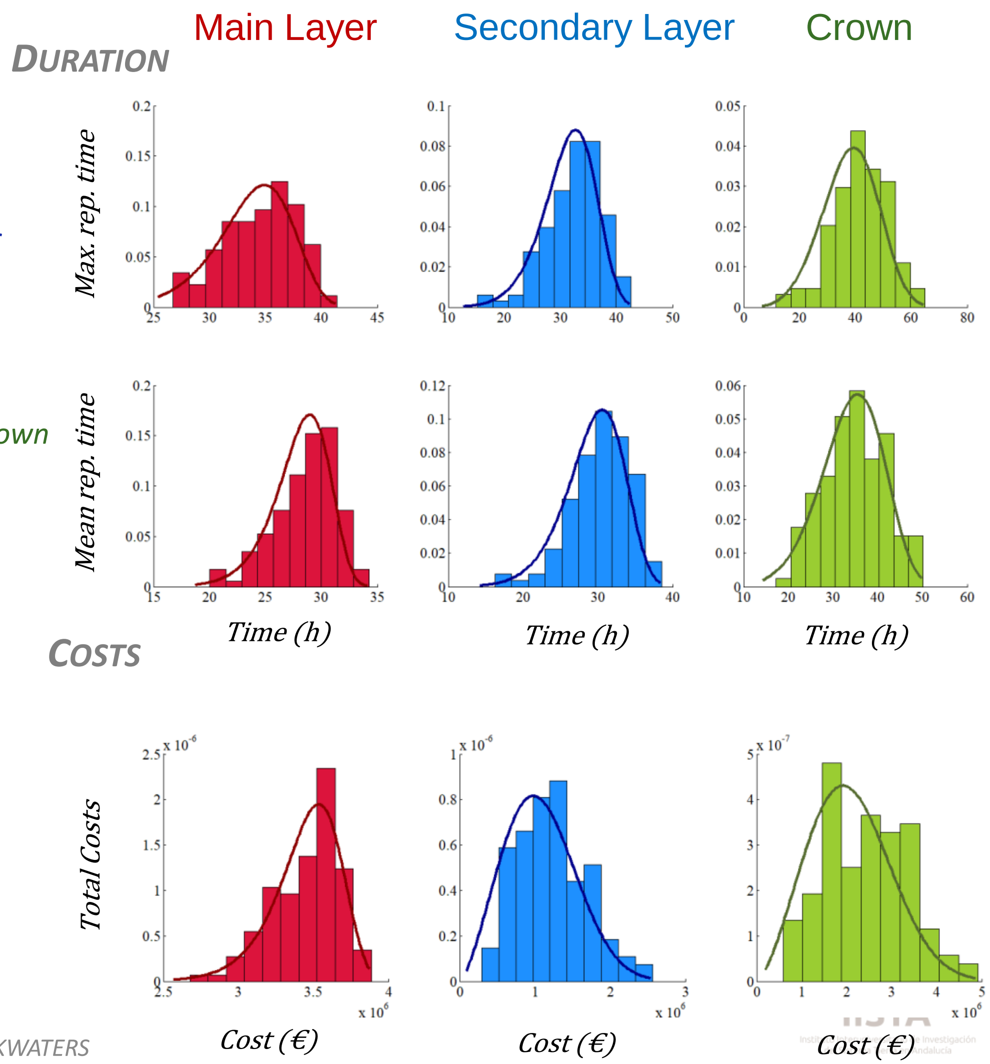
Damage Propagation Sequence (Simulation i)

After N simulations



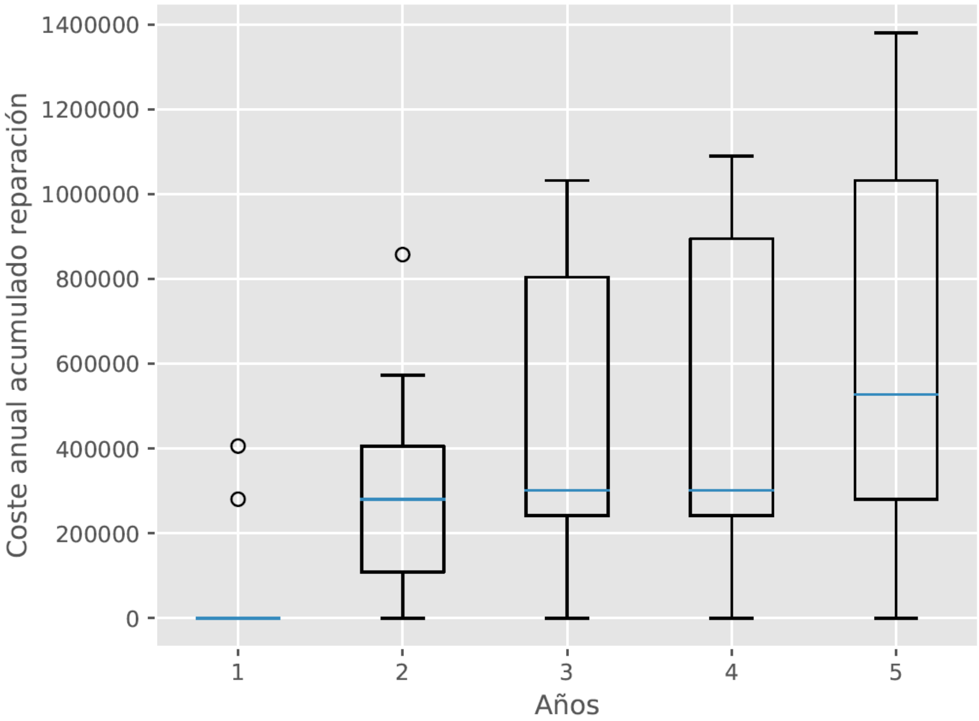
Damage Propagation Tree
+
Reparation Strategy



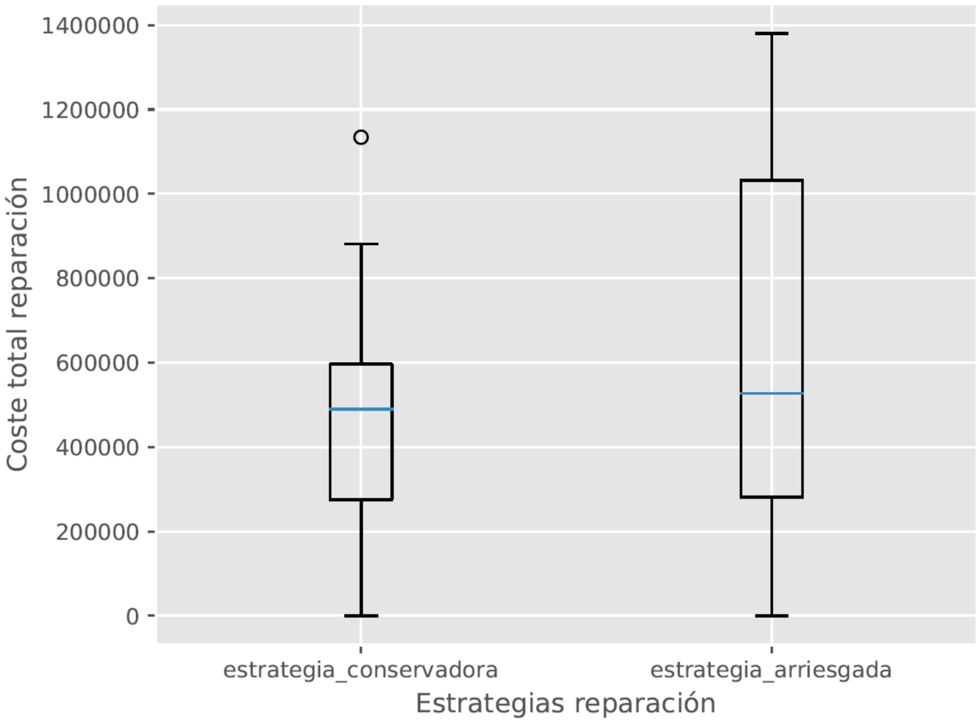


Total Costs and Investments

Accumulated and Total Reparation Costs after 5 years: Conservative versus Risky Strategy



Evolution of the Accumulated Reparation Costs (€) in 5 years (12 simulations)



Total Reparation Costs (€) after 5 years two strategies: conservative and risky

CONCLUSIONS

AN OVERALL CHALLENGE: ADVANCED DESIGN CONCEPTS AND TOOLS TO OPTIMIZE THE INVETSMENT COST OF MARITIME STRUCTURES (BREAKWATERS TOO)

1. Why we need to built a breakwater and purpose

2. Design based on "How it works", "how it operates" and "how it affects its purposes and objectives" and on the total costs of the investmente

3. Integral and integrated design of the breakwater alignments and sections

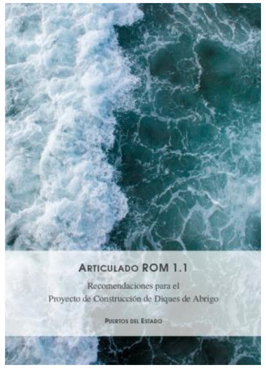
4. Decisions based on acceptable risk of the investment, based on a dual optimization problem,

   (a) technical-economic optimization (ROM 1.1, 2016)

   (b) economic-financial optimization (MEIPOR, 2016)

   (c) environmental constraints, (WFD, Coastal Law, mainly)

FULFILMENT OF PURPOSES AND OBJECTIVES → DUAL OPTIMIZATION PROBLEM

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Conclusions

1. Because of social, economical and environmental reasons,
the maritime engineers has to calculate the investment costs of the project and to prove that it is environmental and financial sustainable while fulfills safety requirements and operational efficiency.

2. New challenges to the maritime engineering community related with, (1) the design based on damage evolution and concomitant modes of failure that could trigger other mode of failures, and (2) to define and decide when to repair to avoid the collapse of the structure.

3. To achieve these challenges the engineers have to start to change course to the design of the breakwater, based on the understanding of the global behavior and objective of the breakwater, and not in formulae.

Thank you!

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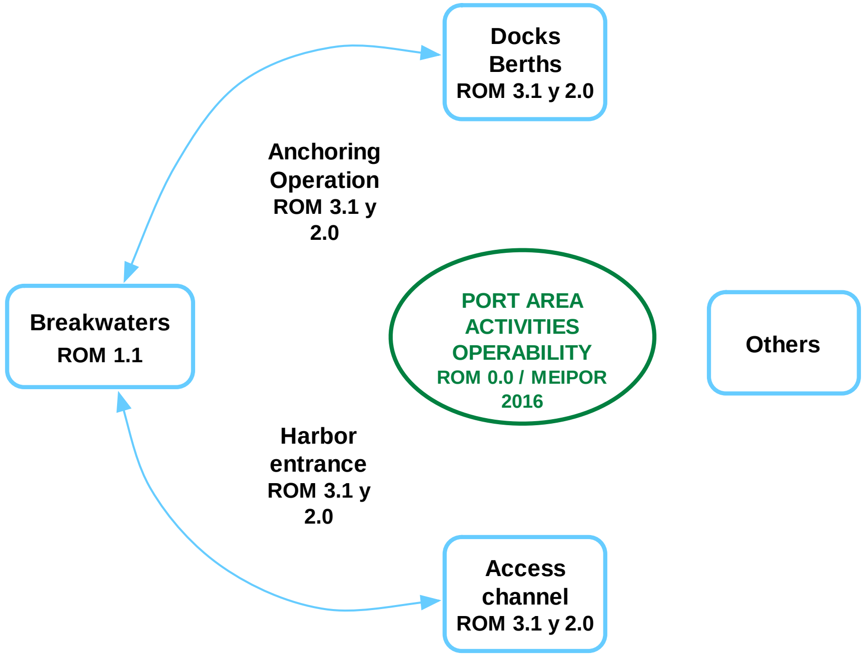

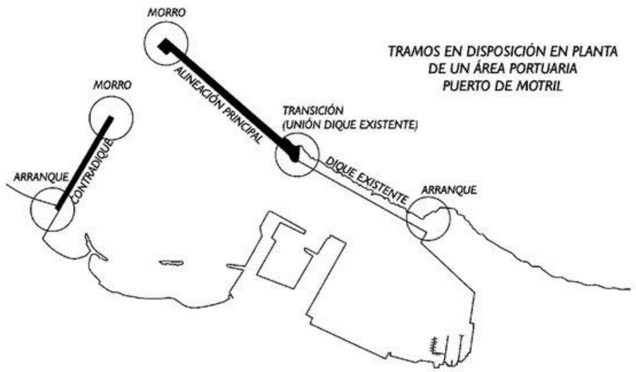

Some engineering questions

- Of the initial cost,
  how much is the breakwater construction cost?
- Of the estimated total cost investment in the useful life of the port,
  how much is associated to maintenance, reparation en dismantling?
- How important is,
  the performance of breakwater in the operational of the Port?
- How much depend,
  the financial and economical results on the breakwater performance?
- When the total cost of the breakwater can not be paid by the operational activity of the harbor,
  which should be the attitude of the consultant engineer?

CONSTRUCTION STRATEGY

- Framework for the construction process (Stretches, Subphases, Failure Modes)
- Schedule of activities
- Protection strategies
  - *Winter stops*
  - *Temporal protections*
- Restrictions
- Resources and Costs

CONSTRUCTION PHASES
SF0: Dredging works
SF1: Bedding layer
SF2: Core
SF3: Secondary Layer
SF4: Main Layer
SF5: Berm
SF6: Crown

Graphical output of the construction/reparation process