RISK ANALYSIS IN PORT FACILITIES

Risk analysis in maritime structures

The Spanish Maritime Works Recommendations

Recomendaciones para Obras Marítimas (ROM)

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Spanish Maritime Works Recommendations

ROM PROGRAM (1987)

Series 0: General recommendations
- ROM 0.2. Actions in design and maritime harbour structures(1990)

Series 1: Outer Structures : Breakwaters

Series 2: Inner structures: docks and mooring and anchoring structures

Series 3: Maritime and ground configurations harbours

Series 4: Harbour Superstructures

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Spanish Maritime Works Recommendations

ROM PROGRAM (1999)

Series 0. Description and characterization of projects factors of harbour and maritime structures

0.0 General Procedure and Project Design (2001)

Series 1. Maritime structures against sea oscillations

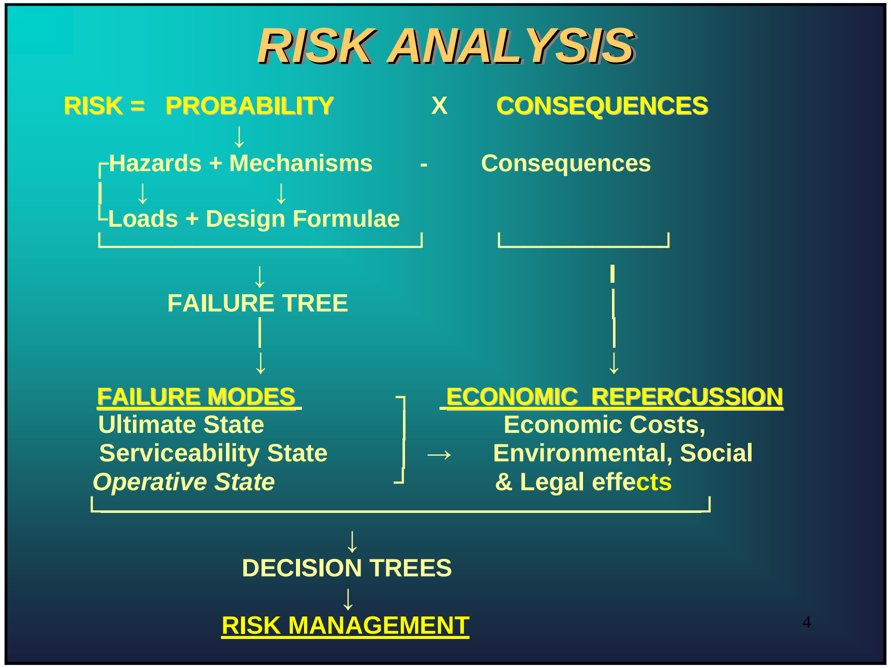
Series 2 Inner harbour structures

Series 3 Planning, management and exploitation of harbour areas

Series 4 Superstructure and ground installations of harbour areas.

Series 5 Maritime and harbour structures in the physical environment

Series 6 Technical, administrative, and legal specifications



RISK ANALYSIS

DESIGN CRITERIA a decision with Uncertainties *(Level Risk)*

ADMISSIBLE LEVEL RISK = Referred to the *occurrence probability* of the worst load conditions that a given structure is likely to be exposed during its Useful Life

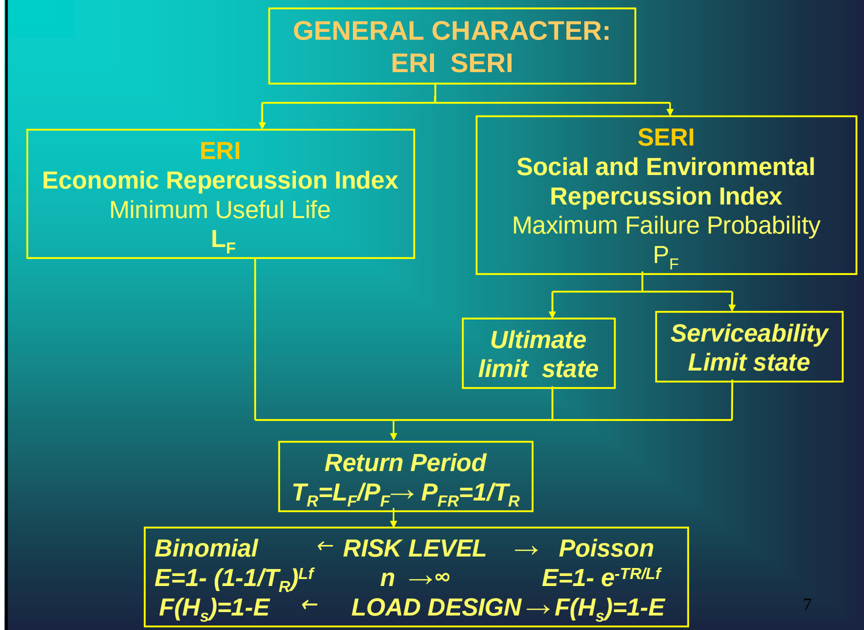
Probability: can be assessed rather objectively by means of a failure tree and the available environmental information.

Consequences: An objective quantitative determination of the losses is not easy

RISK ANALYSIS IN MARITIME STRUCTURE

MARITIME STRUCTURE →Built for creating possibilities for or facilitating economic activities within its immediate context. Consequently , project design alternative should be:

- Reliable: in regards to its safety
  Functional: in regards to its serviceability
  → GENERAL CHARACTER
- Operational: In regards to its use and exploitation → OPERATIVE CHARACTER



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SPANISH MARITIME WORKS RECOMMENDATIONS ROM 0.0

ERI.⇒ Economic Repercussion Index

$$ERI = \frac{C_{RD} + C_{RI}}{C_O}$$

1) Structure rebuilding (C_{RD})

2) Economic activities consequences (C_{Ri})

3) Dimensionalization parameter (C_O) . Depends on the economic development in the country.

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Economic Repercussion Index (ERI)

- $C_{RD} \rightarrow$ Initial investment duly updated to year in question
- $C_0 \rightarrow$ Function of economic country development . For Spain 3 Million of euros for the horizon year in which the cost are valued.
- $C_{RI} \rightarrow$

$$C_{RI}/C_O = (C)*[(A)+(B)]$$

Economic and Production Importance		
A Context of the system	1	Local
	2	Regional
	3	National / International
B Strategic importance	0	Irrelevant
	2	Relevant
	5	Essential
C Structure Relevance	0	Irrelevant
	2	Relevant
	5	Essential

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SPANISH MARITIME WORKS RECOMMENDATIONS
Economic Repercussion Index (ERI)

ERI.⇒ ***MINIMUM USEFUL LIFE. L_f***

$$ERI = \frac{C_{RD} + C_{RI}}{C_O}$$

$$C_{RI}/C_O = (C)*[(A)+(B)]$$

ERI	≤ 5	6-20	≥20
Minimum Useful Life years	15	25	50

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SPANISH MARITIME WORKS RECOMMENDATIONS

Environmental and Social Repercussion Index (SERI)

$$SERI = \sum_{i=1}^{3} SERI_i$$

- $SERI_1$: **Human losses possibility related with the failure of the construction**
- $SERI_2$: **Environmental , historical and heritage damages prone by failure of the structure**
- $SERI_3$: **Social Alarm due to the construction failure**

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SERI ESTIMATION (ROM 0.0)

SERI1: Human losses

0 Non probable ***(Remote)***
3 Accidentally, few people affected***(Low)***
10 High probability but few people affected ***(High)***
20 Affection to regional medical response capacity ***(Catastrophic)***

SERI2: Environmental and patrimony affections

0 Damages to elements of great historical and artistic value improbable ***(Remote)***
2 Slight and Reversible damages ***(Low)***
4 Important damages and effects but reversibility is kept***(Middle)***
8 irreversible damages with few losses of patrimony elements***(High)***
15 Irreparable damages with extinction of protected species and destruction of natural resources ***(Very high)***

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SERI ESTIMATION (ROM 0.0)

SERI3 Social Alarm

0 ***Low*: Failure does no prone any significant social alarm**

5 ***Moderate*: Minimum Social alarm. Associated to *Moderate* SERI1, and High SERI2 values**

10 ***High*: Social alarm caused by a *High* SERI1 value, and a *Very high* SERI2 value**

15 ***Maximum*: Maximum Social Alarm**

$$\mathrm{SERI} = \sum_{i=1}^{3} \mathrm{SERI}_i$$

↓

MAXIMUN FAILURE PROBABILITY (ROM 0.0)

↓ ↓

Ultimate Limit State | **Serviceability Limit State**

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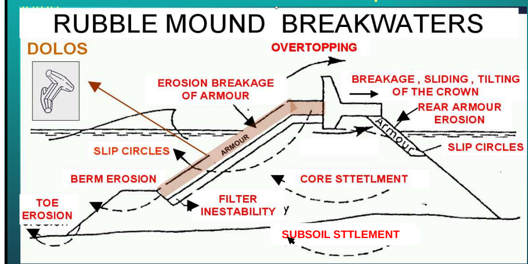
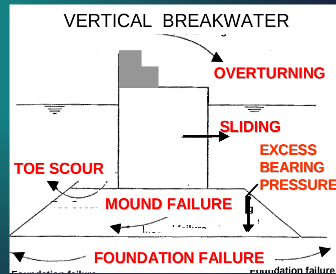
ULTIMATE LIMIT STATES

- **Static Equilibrium lost**: overturning, sliding..
- **Breakage or Exhaustion**: cap wall sliding, foundation failure….
- **Instability:** buckling of all of a part of structure element
- **Fatigue:** in slender pieces of the main layer of rubble mound breakwate
- **Deformation**: erosion of the toe berm, subsoil settlement.
- **Progressive Collapse**: defined by means of the serial, parallel of compound fault trees





SERI	≤ 5	5 - 19	20-29	≥30
PF_{ELU}	0.20	0.10	0.01	0.0001

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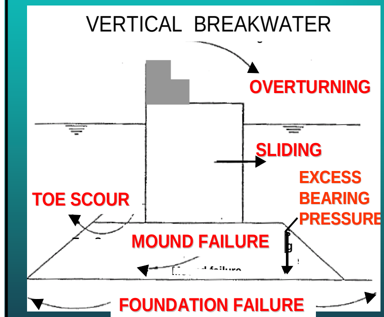
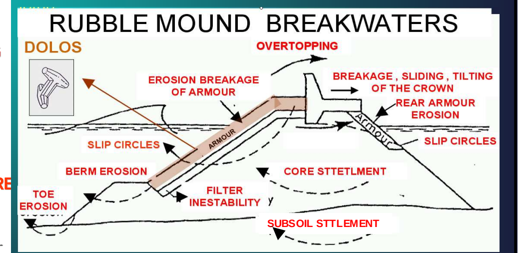
SERVICEABILITY LIMIT STATES

- ***Durability:*** *loss of impermeability and porosity,…*
- ***Deformation****: surface erosion by cap overtopping,..*
- ***Vibration:*** *vibration in the crown due to waves impact,…*
- ***Aesthetic Environmental Legal****: (deformation on the front dock beam,..)*





SERI	≤ 5	5- 19	20-29	≥30
PF_{ELS}	0.20	0.10	0.07	0.007

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OPERATIVE CHARACTER :

OPERATIVE LIMIT STATES:

- ***Threshold level exceedance*** **by one or several agents related with physic environment , in particular the climatic one.**
- ***Environmental effect or social repercussion unacceptable*****, such us the amount and time discharge of specific product with winds of a specific directions.**
- ***Legal requisites*****, such as the aparition of new legal environmental prescriptions that oblige to make internal modifications that affect to working operations.**

OIER
Operative Index of Economic Repercussion

OISER
Operative Index of Social & Environmental Repercussion

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Operational Index of Economic Repercussion (OIER)

ANSWER CAPACITY TO THE DEMAND

OIER= [(D)+(E)] (F)

	STATUS OF SITUATIONS	Value	Reference
OIER	D Simultaneity	0	No simultaneous
		5	Simultaneous
	E Intensity	0	Low Intensive
		3	Intensive
		5	Very Intensive
	F adaptability	0	High adaptability
		1	Middle adaptability
		3	Low adaptability

Operational Index of Social and Environmental Repercussion (OISER)

Similar to SERI :

$$\text{OISER} = \sum_{i=1}^{3} \text{OISER}_i$$

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OPERATIVE CHARACTER : OIER, OISER

Minimum operationally in the useful life

OIER	≤5	6-20	>20
Operative Time (%)	0.85	0.95	0.99

Average number of stoppages per time interval (Usually a year)

OISER	<5	5 -19	20-29	≥30
Number	10	5	2	0

Maximum duration of a stoppage mode (hours)

	OISER			
OIER	≤5	5 -19	20-29	≥30
≤ 5	24	12	6	0
6-20	12	6	3	0
20	6	3	1	0

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LIMIT OPERATING CONDITIONS IN JETTIES and QUAYS (ROM 3.1-1999)

	Absolute wind velocity $V_{10.1\ min}$	Absolute current velocity $V_{c.1\ min}$	Wave height H_s
1. *Vessel berthing*			
• Forces longitudinal to the quay	17.0 m/s	1.0 m/s	2.0 m
• Forces transversel to the quay	10.0 m/s	0.1 m/s	1.5 m
2. *Loading and unloading operation stoppage (for conventional equipment)*			
• Forces longitudinal to the quay			
– Oil tankers			
<30,000 DWT	22 m/s	1.5 m/s	1.5 m
30,000-200,000 DWT	22 m/s	1.5 m/s	2.0 m
>200,000 DWT	22 m/s	1.5 m/s	2.5 m
– Bulk carriers			
Loading	22 m/s	1.5 m/s	1.5 m
Unloading	22 m/s	1.5 m/s	1.0 m
– Liquid Gas Carriers			
<60,000m³	22 m/s	1.5 m/s	1.2 m/s
>60,000m³	22 m/s	1.5 m/s	1.5 m/s
– General cargo merchant ships, Deep sea fishing boats and refrigerated vessels.	22 m/s	1.5 m/s	1.0 m
– Container ships, Ro-Ros and Ferries	22 m/s	1.5 m/s	0.5 m
– Liners and Cruise vessels (1)	22 m/s	1.5 m/s	0.5 m
– Fresh fish fishing boats	22 m/s	1.5 m/s	0.6 m
• Forces transversal to the quay			
– Oil tankers			
<30,000 DWT	20 m/s	0.7 m/s	1.0 m
30,000-200,000 DWT	20 m/s	0.7 m/s	1.2 m
>200,000 DWT	20 m/s	0.7 m/s	1.5 m
– Bulk carriers			
Loading	22 m/s	0.7 m/s	1.0 m
Unloading	22 m/s	0.7 m/s	0.8 m

LIMIT OPERATING CONDITIONS IN JETTIES and QUAYS (ROM 3.1-1999)

	Absolute wind velocity $V_{10.1\ min}$	Absolute current velocity $V_{c.1\ min}$	Wave height H_s
• Forces transversal to the quay			
– Liquid Gas Carriers			
<60,000m³	16 m/s	0.5 m/s	0.8 m/s
>60,000m³	16 m/s	0.5 m/s	1.0 m/s
– General cargo merchant ships, Deep sea fishing boats and refrigerated vessels.	22 m/s	0.7 m/s	0.8 m
– Container ships, Ro-Ros and Ferries	22 m/s	0.5 m/s	0.3 m
– Liners and Cruise vessels (1)	22 m/s	0.5 m/s	0.3 m
– Fresh fish fishing boats	22 m/s	0.7 m/s	0.4 m
3. *Vessel staying at quay*			
• Oil tankers and Liquid Gas Carriers			
– Actions longitudinal to the quay	30 m/s	2.0 m/s	3.0
– Actions transversal to the quay	25 m/s	1.0 m/s	2.0 m
• Liners and Cruise vessels (2)			
– Actions longitudinal to the quay	22 m/s	1.5 m/s	1.0 m
– Actions transversal to the quay	22 m/s	0.7 m/s	0.7 m
• Recreational boats (2)	22 m/s	1.5 m/s	0.4 m
– Actions longitudinal to the quay	22 m/s	1.5 m/s	0.4 m
– Actions transversal to the quay	22 m/s	07 m/s	0.2 m
• Other types of vessel	Limitations imposed by the quay design loads		

NOTES:

$V_{10.1\ min}$ = Mean wind velocity at 10 m high and 1 minute gust
$V_{c.1\ min}$ = Mean current velocity at a depth of 50% of the vessel's draught in a 1 minute interval.
H_s = Significant wave height (the period's influence will be taken into account for more precise studies).
Longitudinal = The wind, current or waves will be taken as acting longitudinally when their direction lies in the sector of ± 45° with the vessel's longitudinal axis.
Transversal = The wind, current or waves will be taken as acting transversally when their direction lies in the sector of ± 45° with the vessel's transversal axis.
(1) = Conditions refer to passenger embarking and disembarking.
(2) = Conditions refer to the limits for maintaining acceptable habitableness with passengers on board.

WORKING CONDITIONS AND LIMIT STATES

Maritime structures are built for:

- Supply the necessary conditions to carry out normal operations of use and exploitation
- Withstand, without damage or structural deformation, extreme (or extraordinary) actions cause by the mutual interaction of the structure and its immediate environment

Working and Operating Conditions (WOC´s)

Characterized by the occurrence of certain *project factors* in terms of this :
- Simultaneity
- Compatibility.

Generally, WOC´s are specified in terms of predominant agents.

Verification of the failure modes
- Normal working conditions
- Extreme working conditions
- Exceptional working conditions

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AGENTS CLASIFICATION

AGENTS : Any entity that can act or significantly affect the Reliability, Functionality and Operationally of a maritime structure and its context.

PERDOMINANT AGENTS: Those which have a determining effect on the occurrence of the failure mode under consideration

ORIGIN

_ Gravitational : (Own weight , dead weight)
_ Soil** (soil movements, stress against sea walls)
_ Physical Environment (climatic, hydraulic, Seismic, Bio-geochemical)
_ Use and Exploitation: (Goods storage, traffic movement, ship docking, mooring)
_ Building materials: (thermal, rheological)
_ Construction method

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WORKING OPERATIONS CONDITIONS: (WOC´s)

Normal WOC: Predominant agents are those of use and exploitation (i.e. Goods storage, traffic movement, ship docking, mooring..) Other agents can simultaneously act being necessary to specific and delimit its compatible values.

Extreme WOC: The predominant agents , (usually climatic factors) takes extreme values. The maritime structure is generally out of service. So, agents of use and exploitation are not simultaneous with climatic environmental agents or there compatibility values are insignificant.

Exceptional WOC: consider conditions with ,(1) very low probability of exceedance , or (2) associated to unexpected or accidental occurrence , or (3) foreseen occurrences promoted by use and exploitation.

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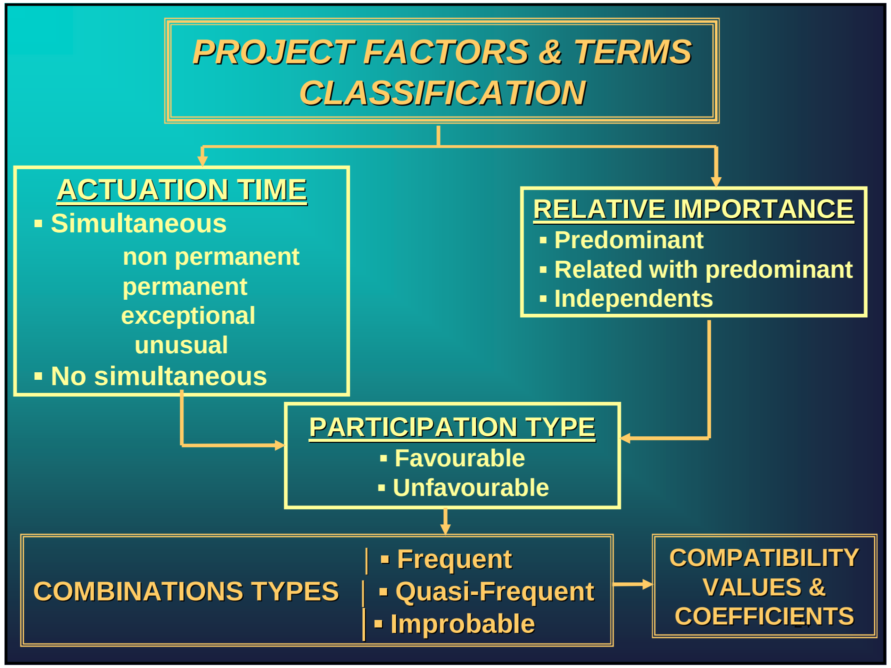

COMPATIBILITY: CLASS OF VALUES

DETERMINISTIC DEFINITION
Nominal Value
(Average, Minimum, Maximum)

STATISTICAL DEFINITION
Characteristic Value
(Centred, Lower and Upper tail)

Lower class values: lower tail values of representative distribution function, in statistical description , or minimum nominal value in deterministic definition. This class of values have a high probability to be exceeded.

Centred class values: Central values (mean, median, mode, ..) of the distribution function (mean or extreme). Average nominal value in deterministic form.

Upper class values: Values with low probability to be exceeded. In statistical description these values belong to the upper tail of the mean or extreme distribution function. Maximum nominal value for deterministic terms and factors.

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COMPATIBILITY VALUES

- **Fundamental combinations**:
  - For extreme work conditions:
    The value of the concomitant term is referred to quantil of probability of not exceeding 0.70, taken the extreme distribution.
  - For Operational work conditions:
    The concomitant term value is the operational threshold value.

- **Frequent combinations:**
  - For extreme work conditions:
    The value of the concomitant term is the quantil of the probability of no exceeding (0.50-0.60) referred to the extreme distribution.
  - For Operational work conditions:
    The value of the concomitant term is the operational threshold.

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COMPATIBILITY VALUES

- **Quasi-permanent combinations:**

The value of the concomitant term is

- The quantil of the probability of no exceeding 0.5-0.60 (centred class) of the mean distribution

Or

- The quantile value with the probability of not exceeding 0.25 (class of the lower tail) of the extreme distribution

In each case, the criteria to be adopted should be that which the best represents the normal and extreme operational working conditions that are being verified.

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METHODS OF DESIGN EQUATION VERIFICATION SPANISH- RECOMMENDATIONS(2001)

VERIFICATION METHODS

- LEVEL_I
  - Global Security Coefficient
  - Partials Security Coefficients
- LEVEL_II
  - First Order Reliability Method
- LEVEL_III
  - Direct and Numerical Integration Techniques
  - Numerical Simulations Techniques

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DETERMINISTIC VERIFICATION METHODS (*LEVEL _O and I)*

1. GLOBAL SAFETY COEFFICIENT (level 0)

$$Z = \frac{R}{L} > Z_C$$

Centred Coefficient	Characteristic Coefficient
$Z_E = \frac{E[R]}{E[L]} > Z_C$	$Z_K = \frac{R_K}{L_K} > Z_C$

- Nominal values
- Compatibility coefficients
- Reducing Coefficient
  (unfavorable mechanicals properties)
- Minimum acceptable safety coefficient, $Z_{C,}$ (specific ROM)

2. PARTIALS SAFETY COEFFICIENTS (level I)

$$S = \sum_{i=1}^{I} a_i R_i - \sum_{j=1}^{J} b_j L_j > 0$$

- Characteristic values
- Compatibility coefficients
- Reducing Coefficient
  (unfavorable mechanicals properties)
- Weighting coefficients

RESULTS:
Verification of the established limits (failure probability)

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PROBABILISTIC VERIFICATION METHODS: (*LEVEL II)*

1. FIRST ORDER RELIABILITY METHOD

- Nominal values for deterministic factors
- Class of values recommend for combination types
- Marginal distribution functions

Resolution methods

- Transformation of variables ,R,L, into uncorrelated reduced normal variables:
  Normal distributed : $Z_R' = (R-\mu_R)/\sigma_R$, $Z_L' = (L-\mu_L)/\sigma_L$
  No Normal distributed (Rosenblat transformation)

$$\left.\begin{array}{l} \sigma'_{xi} = \dfrac{\varphi\left(\Phi^{-1}(F_{xi}(X_i^d))\right)}{f_{xi}(x_i^d)} \\ \mu'_{xi} = X_i^d - \sigma'_{xi}\Phi^{-1}(F_{xi}(X_i^d)) \end{array}\right) \xrightarrow{X=R,\text{or } L} Z_X = \frac{X - \mu'_{xi}}{\sigma'_{xi}}$$

- Linearization of the limit state function $g_z(R_1', R_2', .., L_1', ..) = 0$
- Estimation of initial critical point $\beta = \min_{g(z)=0} \left(\sum_{i=1}^{n} Z_i^2\right)^{1/2}$
- Optimization

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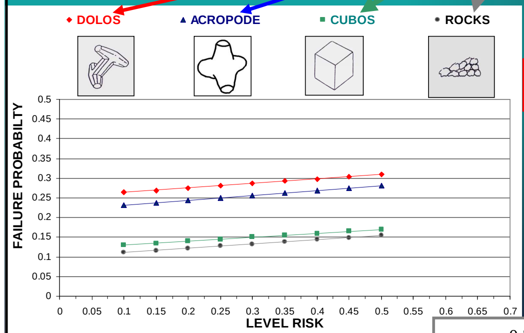
LEVEL II

HYDRAULIC STABILITY OF MAIN ARMOUR OF RUBBLE MOUND BREAKWATER



FAILURE FUNCTION

$$g = Z\Delta D\ (43-66r)\varphi R^{1/3}\ N_Z^{-0.1} - H_S$$

$$g = Z\Delta D\ R - H_S$$

$$g = Z\left(6.7\frac{R^{0.4}}{N_z^{0.3}} + 1.0\right)S^{-0.1}\Delta D - H_S$$

$$g = ZR^{0.2}\,P^{-0.13}\,\Delta D\cot\alpha^{(0.5-P)}S^{-0.5P}\ N_Z^{-0.1} - H_S$$

PROBABILISTIC ESTIMATION OF THE PARTIAL COEFFICIENTS

- Define failure modes
- Select the code format (design equations and its uncertainties
- Group terms in favourable and unfavourable (only two coefficients were considered)
- Define intervals of the parameters, their statistical proprieties and combinations
- Select target probabilities of failure (i.e., in terms of a target reliability index (Maximum failure probability (ERI, SERI)
- Calculate the partial coefficients
- Optimize and calibrate the system
- Verify the partials coefficients system against the observed behaviour of existing structure.

PROBABILISTIC VERIFICATION METHODS:*(LEVEL III)*

Representatives design values

- Nominal values for deterministic factors
- Class of values recommend for combination types
- Joint, Conditional and Marginal distribution functions

Resolution methods

a) - Failure region Integration from joint density function

b) - Numerical simulation Techniques

RESULTS OF LEVEL II AND LEVEL III

- Failure probability associate to failure mode under consideration
- Reliability index of the Structure: $\beta \rightarrow P_F=\Phi(-\beta)$
- Sensibility index: α (relative importance on reliability of the factor)

$$\alpha_i = \frac{\partial g}{\partial Z_i} \Big/ \left[\sum_{i=1}^{n} \left(\frac{\partial g}{\partial Z_i} \right)^2 \right]^{1/2}$$

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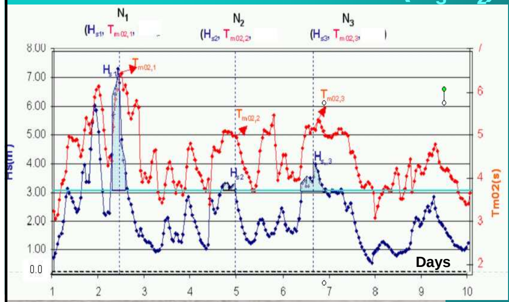
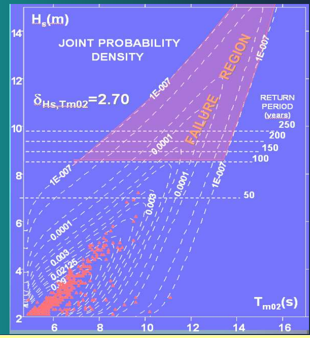
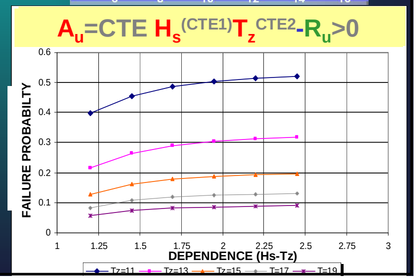
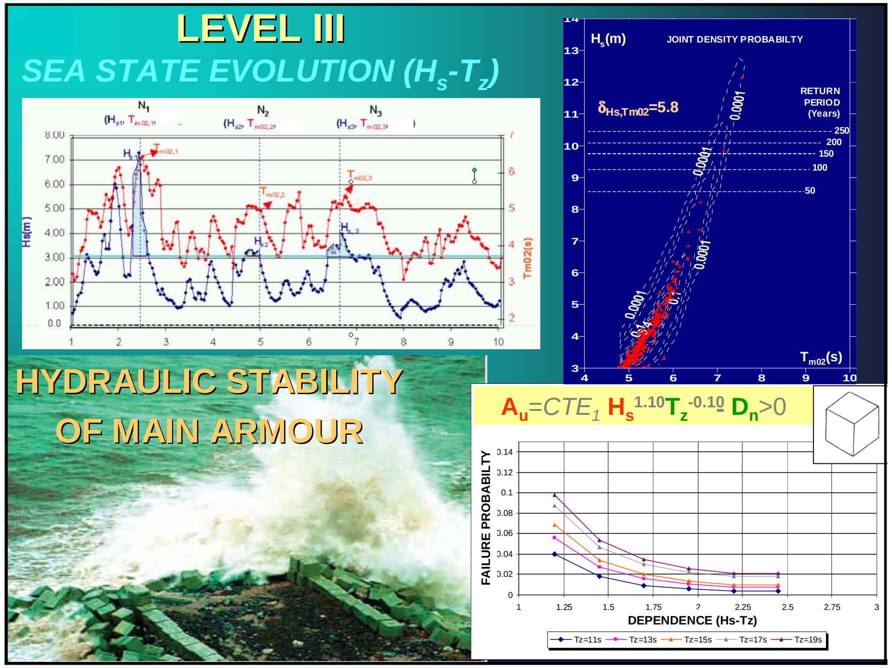
LEVEL III

SEA STATE EVOLUTION (H_s-T_z)









RECOMMENDED USE OF THE VERIFICATION METHODS

SPANISH MARITIME WORKS RECOMMENDATIONS (ROM 0.0-2001)

ERI	SERI			
	S_1	S_2	S_3	S_4
R_1	0 **)	I	I & II or III	I & II or III
R_2	I	I	I & II or III	I & II or III
R_3	I & II or III	I & II or III	I & II or III	I & II or III

**)It is referred to the Global safety coefficient

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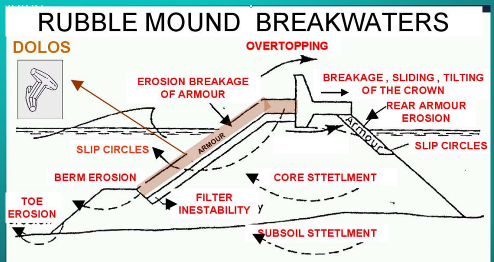
JOINT PROBABILITY CALCULATION (*PARALLEL CONNECTION*)

FAILURE OF THE SYSTEM ONLY IF ALL ELEMENTS FAILS



- Displacement at main armor
- Erosion of toe berm
- Sea bed Scour

Upper Bound

$$P_{Fp}^{U} = \min\{P_{F,i}, i = 1,..n\}$$

Full correlation between failure modes

Lower Bound

$$P_{Fp}^{L} = P_{F,1}\,P_{F,2}......P_{F,n}$$

No correlation between failure modes

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JOINT PROBABILITY CALCULATION (*SERIES CONNECTION*)

FAILURE OF THE SYSTEM IF ANY OF ELEMENTS FAILS

Toe Scour — Sliding of parapet wall — Rear slope erosion

No correlation between failure modes

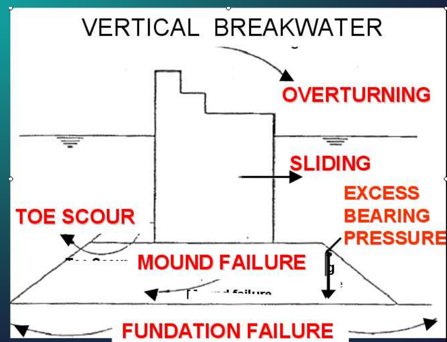
Upper Bound

$$P_{Fs}^{U} = 1 - \prod_{i=1}^{n} (1 - P_{F,i}) \approx \sum_{i=1}^{n} P_{F,i}$$

Total dependence between failure modes

Lower Bound

$$P_{Fs}^{L} = \max\{P_{F,i}, i = 1,..n\}$$



ECONOMIC OPTIMIZATION

Socioeconomic Optimization: Maximization of the objective function defined in terms of the total cost/benefit of the structure, B, and the total cost of the project , C_T

Objective function: $\text{Max}\ \{B(X)-C_T(X)\},\ \ X=\{x_1,x_2,\ldots.x_n\}$

Restriction
$C_T(X)<C_{MAX}$
$E(X)>E_{MAX}$
$P_{f,ELU} < P_f$ SERI _ ULS
$P_{f,ELS} < P_f$ SERI _ SLS
$P_{f,ELO} < P_f$ OISER _ OLS

In all cases the optimization of objective function should be coherent with the Investment Evaluation Manual of Puertos del Estado (Spain)

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ASPECTS INVOLVED IN A GLOBAL RISK MANAGEMENT

1. *Elaboration of a potential hazards list (fault trees)*
2. *Evaluation of their probability of occurrences and consequences (fault & events trees)*

3. Development of <u>alert systems</u> (*data networks & Nested numerical models*) for dynamic application of hazards control through <u>prevention techniques</u> (*events simulations)*. Decision trees.

4 Development of <u>contingency plans</u> according to risk type

5. Approval of the established <u>actuation protocols</u> by government (the responsible of the appropriate risk management)

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