



Contents

Section 1

1	Introduction, General Framework and Organization of the ROM 1.1	19
	19	
1.1	General Framework	19
1.1.1	Ports of general interest, current legislation	20
1.1.2	Public domain, service zone, urban structure of the port	21
1.1.3	Port Planning: Analysis and Documents	21
1.1.4	Investment projects and port construction	22
1.1.5	Objectives of the ROM Program and MEIPOR	23
1.2	Layout of the harbor area and breakwaters	26
1.3	Tasks and milestones in a breakwater project design	28
1.4	Classification of construction projects and development levels	29
1.4.1	Development levels of the breakwater project	30
1.4.2	Objects and activities, depending on the development level of the project .	31
1.5	Contents and organization of the ROM 1.1 in sections	38
1.5.1	Organization of the ROM 1.1	38
1.6	Relation with other ROM recommendations, instructions , and standards	41

Section 2

2	Specific Project Bases	47
2.1	General approach to breakwater planning and design	47
2.2	Spatial and temporal organization of the project	49
2.2.1	Temporal organization: project phases	49
2.2.2	Spatial organization: subsets	51
2.3	Subset performance according to construction states	53
2.3.1	Sample and event space	53
2.3.2	Failure and stoppage modes	53
2.3.3	Complete set of modes	55
2.3.4	Event spaces and component diagrams	55
2.4	Characterization of the evolution of damage	57
2.4.1	Conceptual model of the temporal progress of the level of cumulative damage	59
2.4.2	Curves of the mean cumulative damage	61
2.4.3	Trajectory of cumulative damage in a loading cycle	66
2.4.4	Time dependency of the probability model of cumulative damage	68
2.4.5	Temporal progress of other cumulative variables	72
2.4.6	Operational stoppage levels and temporal evolution of the operational stoppage	74
2.5	Failure probability at an advanced damage level	75
2.5.1	Conceptions for breakwater design	76
2.5.2	Indicators of the temporal evolution of reliability	78
2.6	Analysis of the spatial evolution of the damage	82
2.6.1	Triggering and propagation trees	82
2.6.2	Decision tree	83
2.7	Identification of project factors and critical components	84
2.8	Variant in the conception and design of a breakwater	86

Section 3

3	Procedure for breakwater projects	91
3.1	Conception of the structure and design sequence	91
3.1.1	Tools for the conception of the breakwater	92

3.1.2	Logical sequence of activities	94
3.2	Typology and selection criteria	97
3.2.1	Description of a typology	98
3.2.2	Environmental and technical factors affecting the selection of breakwater typologies	99
3.2.3	Economic factors for the selection of breakwater typologies	101
3.3	Breakwater performance and the configuration of diagrams	101
3.3.1	Component diagrams for safety purposes	101
3.3.2	Component diagrams for operationality purposes	107
3.4	Principal failure and stoppage modes in a breakwater	110
3.4.1	Subset with a straight alignment	110
3.4.2	Subsets with non-straight alignments and transitions	114
3.4.3	Principal failure modes caused by other agents at the breakwater site	116
3.4.4	Failure modes in the construction, maintenance and repair phases	117
3.4.5	Stoppage modes related to the activities of the harbor area	117
3.5	Joint probability distribution of failure and stoppage in the subset	118
3.5.1	Selection of principal and non-principal modes	118
3.6	Triggering and propagation trees and the propagation of failure or stoppage	119
3.6.1	Design for safety purposes (extreme work and operating conditions)	120
3.6.2	Design for operational purposes (normal work and operating conditions)	125
3.6.3	Design for post-exceptional work and operating conditions	125
3.7	Design of the evolution of damage and repair strategies	125
3.7.1	Elaboration of repair strategies	126
3.7.2	Decision tree for selecting repair strategies	127
3.8	Organization of the construction, processes, and resources	129
3.8.1	Preliminary studies	129
3.8.2	Description of construction subphases and procedures	130
3.8.3	Planning of the construction strategy	130

Section 4

4	Verification of the breakwater in a project phase	133
4.1	Objectives and requirements of a breakwater project in the ROM Program	133
4.1.1	Nature of the subset in a project phase	134
4.2	General verification procedure	139
4.2.1	Evaluation of the behavior of a mode	139
4.2.2	Verification equation: concept and formulation	141
4.2.3	Integrated verification of the principal modes of a subsystem	142
4.2.4	Verification methods	143
4.3	Verification of the project phase requirements	146
4.3.1	Spatial and temporal scales for the verification of project requirements	146
4.3.2	Recommendations for verification with Level I methods	149
4.3.3	Recommendations for verification with Level II and III methods	150
4.3.4	Verification of exceptional work and operating conditions, WOC_3	153
4.4	Verification methods and project development stage	161
4.4.1	Verification methods, depending on the project development stage	162
4.4.2	Working hypotheses and simplifications, depending on the stage of project development	162
4.5	Sensitivity analysis according to the project factors	168

Section 5

5	Evaluation of costs, optimization, and risk level	173
5.1	Context of cost evaluation in Spain	173
5.2	Cost-evaluation objectives and the dual optimization system	174
5.2.1	Capitalization costs of a breakwater	175
5.3	Construction project costs of a breakwater	176
5.3.1	Organization of the calculation of the total costs	176
5.3.2	Cost evaluation procedure	177
5.3.3	Calculation of the descriptor of the total costs	180
5.4	Optimization of the sensitivity analysis	185
5.4.1	Elements that define a technical-economic optimization method	185

5.4.2	Analytical optimization method	187
5.4.3	Sensitivity analysis of the breakwater design	188
5.4.4	Sequence for the optimization and sensitivity analysis	189
5.4.5	Recommended optimization model of the accumulated cost	190
5.5	Analysis of the profitability and risk level of the investment project	191
5.5.1	ROM 1.1-MEIPOR connectivity	191
5.5.2	Suitability and optimization of the investment project	192
5.5.3	Dual optimization system and acceptable risk level	193
5.5.4	Summary of the investment project and its indicators	193
5.6	Exceptional work and operating conditions and analysis of the accident rate	201

Appendices

Symbols and definitions	207
Símbolos	207
Acronyms	212
Definitions	213
Observations and examples	223
Bibliography	225
MEIPOR Financial-Economic Indicators	229
Drafting the ROM 1.1	235



List of Figures

Section 1

1.1	Conditioning factors for harbor infrastructure decision-making	20
1.2	Legal entities for the administration of port land area	21
1.3	Planning instruments and requirements for environmental impact evaluation	22
1.4	Flowchart for the design of basic infrastructure projects	23
1.5	Integration of the breakwater in the harbor area	26
1.6	Breakwater sections and parameters representing vertical, composite, and sloping breakwaters.	27
1.7	Organization of a breakwater project	29
1.8	Project classification	30
1.9	ROM 1.1 levels of project development	31
1.10	Table of contents of the ROM 1.1	39

Section 2

2.1	Workflow for breakwater design, verification, and optimization, considering the spatial and temporal evolution of modes	48
2.2	Hierarchy of the time scales of the project	51

2.3	Cascade distribution of the performance of a breakwater subset	53
2.4	Event space for a set of three components	56
2.5	Typology of component diagrams	57
2.6	Diagram that evaluates the cumulative damage and its consequences	58
2.7	State curves of the mean cumulative damage	62
2.8	Iso-duration curves, based on the predominant agent and damage	63
2.9	Iso-mean-damage-value curves, based on the predominant agent and the duration	64
2.10	Iso-characteristic-value curves of the characteristic agent, based on the duration and cumulative damage	65
2.11	Example of cumulative damage in a loading cycle	67
2.12	Iso-value curves of the fitted model	67
2.13	Experiments on measured cumulative damage and data fitting	68
2.14	Sequence of states of the characteristic cycle analyzed	69
2.15	Temporal evolution of cumulative damage probability for the two PDFs of initial damage: the first PDF represents a conservative repair strategy, whereas the second PDF represents a riskier repair strategy	70
2.16	Temporal evolution of the probability of cumulative damage, considering agent variability	72
2.17	Experimental results for the cumulative overtopping volume	74
2.18	The probability density functions (PDFs) of cumulative damage during the structure's useful life for project designs with and without a repair strategy	78
2.19	Example of a triggering and propagation tree	83
2.20	Classification algorithm of the total cost of repairs, depending on the initial repair strategies and their duration.	85
2.21	Relative importance of the predictors that define the different repair strategies	85
2.22	Interconnection between variants, verification methods, and project classes.	88

Section 3

3.1	General sequence for the conception and design of a breakwater	92
3.2	Tools for the planning and design of the breakwater	94
3.3	Logical sequence for the planning and design of the breakwater	96
3.4	Subsets in the breakwater and harbor extension of the Motril port	97
3.5	Subsystems of a sloping breakwater subset	98
3.6	Conventional breakwater typologies	99
3.7	(Left panel: diagram of the breakwater subsets. Right panel: diagram of the subsystems in a subset.	105
3.8	Diagram of breakwater components	105

3.9	Component diagram of each subset	106
3.10	<i>Failure tree</i> (PIANC, 2016) and component diagram corresponding to excessive wave transmission through a sloping breakwater with a crown wall (ROM 1.1)	109
3.11	<i>Failure tree</i> (PIANC, 2016) and component diagram corresponding to excessive wave transmission onto a sloping breakwater with a crown wall (ROM 1.1)	109
3.12	Principal elements and modes, organized by subsystems in a sloping breakwater	110
3.13	Triggering and propagation trees in the transition and head subsets	121
3.14	Triggering and propagation tree of the failure affecting the subsystems in the following subsets: breakwater land connection, secondary alignment, and transition. This is a consequence of the deformations and movements of the foundations and soil.	122
3.15	Triggering and propagation tree of the failure affecting the subsystems of the following subsets: breakwater land connection, secondary alignment, and transition. This is a consequence of the erosion and displacement of the unit pieces of the outer perimeter.	123
3.16	Triggering and propagation tree of the failure in subsystems of the principal alignment as a consequence of the deformations and movements in the foundation and soil	124
3.17	Triggering and propagation trees of the failure between subsystems of the main alignment as a consequence of the erosion and displacement of the unit pieces of the outer perimeter.	124
3.18	Example of a decision tree	128
3.19	Example of decision strategies	129

Section 4

4.1	Relations between spatial and temporal scales for the verification of a breakwater	148
4.2	Diagram of the structure	154
4.3	Diagram of the hydrodynamic variables of the study	155
4.4	Time series of the free surface and force in the regions defined and the total force on the structure	156
4.5	Cumulative distribution functions of the free surface, wave heights, and wave periods in defined regions	156
4.6	Probability density and cumulative distribution functions of the total force on the structure	157
4.7	Zero up-crossings in the time series of the total force and (landward) positive peaks and (seaward) negative peaks in each of them	158
4.8	Cumulative distribution function of the landward force peaks and seaward force peaks	159
4.9	Cumulative distribution functions of the maximum wave height values and the values of the maximum landward and seaward forces in each simulation	160

4.10	Cumulative distribution function of the minimum value of the safety margin in each simulation	161
------	---	-----

Section 5

5.1	Calculation sequence of the descriptor of the total construction and dismantling cost	178
5.2	Calculation sequence of the descriptor of the total repair cost	179
5.3	Calculation of the descriptor of the total cost of exploitation	180
5.4	Characterization of climate agents at the site and typology of the sloping breakwater	181
5.5	Diagram of the input data necessary to calculate the repair costs with a Monte Carlo numerical simulation	182
5.6	Example of a triggering and propagation tree of failure propagation.	183
5.7	Fit parameters of the power curve of cumulative damage for the failure mode, erosion of the toe berm.	183
5.8	Boxplots with the accumulated repair costs in euros over a five-year period for the failure mode, erosion of the toe berm.	184
5.9	Fit parameters of the power curve of the repairs for the failure mode, toe berm erosion.	185
5.10	Sequence of tasks of the optimization process of the design of a breakwater	190
5.11	Workflow of the example	194
5.12	Sketch of berths and dimensions.	195
5.13	Service levels compared to average annual productivity.	195
5.14	Variation in total costs in relation to the design damage level.	196
5.15	Temporal evolution of fulfillment probabilities, based on decision-making. . .	197
5.16	Probability density function of the repair costs for a design that envisages Iribarren-level damage.	198
5.17	Probability density function of the IFPR for the three cases considered.	199
5.18	Density function of the IFPR of the Operator for the three cases considered.	199
5.19	Probability density function of the IEPR for the three cases considered.	200
5.20	Results of the sensitivity analysis for optimistic and pessimistic scenarios. . . .	201
5.21	Flow chart of the interconnection of the three instruments.	203



List of Tables

Section 1

1.1	Summary table of preliminary studies	32
1.2	Summary of the study of alternatives and solutions	34
1.3	Summary table of the blueprint	36
1.4	Indicative values for technical personnel, qualifications, and estimated number of work hours in the construction project (Spain)	43

Section 4

4.1	Minimum useful life based on the ERI	135
4.2	Maximum joint probability in the in-service phase	135
4.3	Minimum operability in the in-service phase	138
4.4	Average number of annual stoppages, based on the OSERI	138
4.5	Maximum probable duration of a stoppage based on the OERI and OSERI	138
4.6	Recommended resolution based on the general nature of the subset	161

