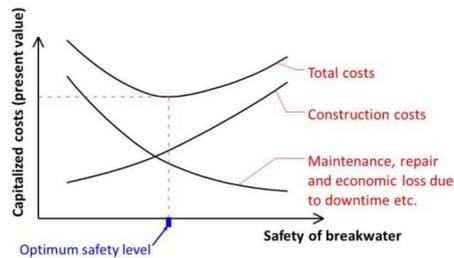




PIANC

Report n° 196 - 2016



CRITERIA FOR THE SELECTION OF BREAKWATER TYPES AND THEIR RELATED OPTIMUM SAFETY LEVELS

The World Association for Waterborne Transport Infrastructure



PIANC
The World Association for
Waterborne Transport Infrastructure

PIANC REPORT N° 196
MARITIME NAVIGATION COMMISSION

**CRITERIA FOR THE SELECTION OF
BREAKWATER TYPES AND THEIR RELATED
OPTIMUM SAFETY LEVELS**

2016

PIANC has Technical Commissions concerned with inland waterways and ports (InCom), coastal and ocean waterways (including ports and harbours) (MarCom), environmental aspects (EnviCom) and sport and pleasure navigation (RecCom).

This report has been produced by an international Working Group convened by the Maritime Navigation Commission (MarCom). Members of the Working Group represent several countries and are acknowledged experts in their profession.

The objective of this report is to provide information and recommendations on good practice. Conformity is not obligatory and engineering judgement should be used in its application, especially in special circumstances. This report should be seen as an expert guidance and state-of-the-art on this particular subject. PIANC disclaims all responsibility in case this report should be presented as an official standard.

PIANC Secrétariat Général
Boulevard du Roi Albert II 20, B 3
B-1000 Bruxelles
Belgique

<http://www.pianc.org>

VAT BE 408-287-945

ISBN 978-2-87223-239-0

© All rights reserved

DOCUMENT HISTORY

Criteria for the Selection of Breakwater Types and Their Related Optimum Safety Levels

Report No. 196

Edition No..	Date	Notes
0.1	December 9, 2016	First edition published

TABLE OF CONTENTS

1	General	7
1.1	Introduction.....	7
1.2	Objectives and Terms of Reference.....	7
1.3	Target Readers.....	8
1.4	Working Group 47 Members.....	8
1.5	WG History.....	8
2	Scope and Organisation of the Report and its Relation to the Breakwater Design Process .10	
3	Types of Breakwater	12
4	General Characteristics of Breakwater Types	16
4.1	Rubble Mound Structures.....	16
4.2	Caisson Structures.....	16
4.3	Breakwaters with Overspill Reservoir.....	17
5	Selection of Breakwater Type Based on Functional Criteria	18
6	Selection of Breakwater Type Based on Site Environmental Conditions and Conditions for Construction	22
7	Example of Breakwater Types Conforming to Equal Functional and Environmental Criteria	25
8	Safety Aspects Related to Design of Breakwaters	29
8.1	Failure Modes, Design Equations and Fault Trees.....	29
8.1.1	Failure Modes.....	29
8.1.2	Failure Mode Design Equations.....	31
8.1.3	Fault Trees and Their Application in Reliability Analysis.....	31
8.2	Design Methods and Related Principles of Safety Implementation.....	33
8.2.1	Deterministic Design.....	33
8.2.2	Design Based on Conventional Partial Safety Factors. Limit State Functions.....	33
8.2.3	The PIANC and the EU – MAST 2 Partial Safety Factor Systems for Breakwaters..	34
8.2.4	Probabilistic Design.....	35
8.3	Safety Classification, Working Life and Safety Levels in Recent Codes and Recommendations.....	35
8.4	Observed Service Lifetimes.....	39
8.5	Conclusions on Choice of Design Method and Applicability of Existing Codes and Design Recommendations.....	40
9	Design of Breakwaters Based on Life-Cycle Analyses	41
10	Introduction to Parametric Study of Breakwater Safety Levels Based on Life-Cycle Cost Optimisation	45
11	Summary of Optimum Safety Level Study: Rock and Cube Armoured Rubble Mound Breakwaters	48
11.1	Cross Sections.....	48
11.2	Definition of Limit State Structure Performance, Repair Strategy and Costs.....	48
11.3	Case Studies.....	49
11.4	Example Results of Case Studies.....	49
11.5	Conclusions.....	50
12	Summary of Optimum Safety Level Study: Berm Breakwaters	51
12.1	Failure Modes and Classification of Structures.....	51
12.2	Cross Sections.....	52
12.3	Definition of Limit State Structure Performance, Repair Strategy and Costs.....	53
12.4	Case Studies.....	53
12.5	Main Results on Optimum Safety Levels.....	57
13	Summary of Optimum Safety Level Study: Single Layer Complex Armour Type Breakwaters	59
13.1	Complex Types of Single Layer Armour Blocks.....	59
13.2	Cross Section.....	59
13.2.1	Armour Layer Stability Prediction.....	59
13.3	Case Studies and Costs.....	60
13.4	Main Results on Optimum Safety Levels.....	62
14	Summary of Optimum Safety Level Study: Caisson Breakwaters	63
14.1	Introduction.....	63
14.2	Cross Sections and Failure Modes.....	63
14.3	Limit State Performances and Repair Strategy.....	64
14.4	Costs of Construction and Repairs.....	65
14.5	Stability Calculations.....	65
14.6	Summary of Optimum Safety Level Study: Caissons on Hard Seabeds.....	67
14.6.1	Overview of Case Studies.....	67

14.6.2	Example Case Studies of Caissons on Hard Seabeds.....	68
14.7	Summary of Optimum Safety Level Study: Caissons on Rubble Foundation Sandy Sea Beds 72	
14.7.1	Overview of Case Studies	72
14.7.2	Example Case Studies of Caissons on Rubble Foundation on Sand Seabeds	73
14.8	Main Results on Optimum Safety Levels Related to Caissons on Hard Seabed.....	76
14.8.1	Water depth $h =$ approx. 15 m. $H_s^{100y} = 5 - 6$ m. Interest rate 5 % p.a.	76
14.8.2	Water depth $h =$ approx. 25 m. $H_s^{100y} = 8 - 9$ m. Interest rate 5 % p.a.	76
14.8.3	Large water depth $h = 40$ m. Very large waves, $H_s^{100y} = 12 - 13$ m. Interest rate 5 % p.a.....	76
14.8.4	Large water depth $h = 40$ m, small to moderate waves, $H_s^{100y} = 5 - 6$ m. Interest rate 5 %.....	77
14.9	Main Results on Optimum Safety Levels Related to Caissons on Sandy Seabeds.....	77
14.9.1	Water depth $h = 15$ m. $H_s^{100y} = 5 - 6$ m. Interest rate 5 % p.a.	77
14.9.2	Large water depth $h = 25$ m. Large waves, $H_s^{100y} = 8 - 9$ m. Interest rate 5 % p.a.	77
14.9.3	Water depth, $h = 40$ m. $H_s^{100y} = 13 - 14$ m. Interest rate 5 % p.a.	77
15	Conclusions: Optimum Breakwater Safety Levels.....	79
15.1	Rock and Cube Armoured Outer Rubble Mound Breakwaters	79
15.2	Icelandic-Type Berm Breakwaters.....	79
15.3	Outer Breakwaters Armoured with Single Layer Interlocking Armour Units.....	80
15.4	Outer Caisson Breakwaters.....	81
16	Methods of Probabilistic Design to Target Safety Levels: Example Application of the PIANC Partial Safety Factor System.....	83
	References	85
	Appendices	87
A	Downtime Costs	87
B	Parametric Study of Breakwater Safety Levels Based on Life-Cycle Cost Optimisation	90
C	The PIANC Safety Factor System for Breakwaters	154
D	Glossary	178

List of Figures

Figure 2.1:	Steps in selection of type of breakwater.....	10
Figure 3.1:	Conventional multi-layer rubble-mound breakwater without superstructure.....	12
Figure 3.2:	Multi-layer rubble-mound breakwater with superstructure	12
Figure 3.3:	Single layer rubble-mound breakwater with interlocking concrete armour units.....	12
Figure 3.4:	Main types of rubble mound berm breakwaters.....	13
Figure 3.5:	Conventional caisson breakwater with vertical front on hard seabed.....	13
Figure 3.6:	Caisson breakwater with high foundation (vertical composite)	13
Figure 3.7:	Caisson breakwater with mound in front (horizontal composite) on hard seabed	14
Figure 3.8:	Caisson breakwaters with sloping top on hard seabed.....	14
Figure 3.9:	Caisson breakwater with perforated front and wave dissipation chamber on hard seabed	14
Figure 3.10:	Blockwork breakwaters on hard seabed.....	14
Figure 3.11:	Tandem-breakwater.....	15
Figure 3.12:	Rubble mound breakwater with overspill reservoir	15
Figure 5.1:	Functional classification of breakwaters related to wave transmission, wave overtopping and demand for access and space. [Burcharth, 2005].....	19
Figure 5.2:	Examples of moorings behind breakwaters.....	20
Figure 5.3:	Examples of crossing waves at harbour entrances due to wave reflection	20
Figure 5.4:	Beach erosion caused by waves reflected from neighbour breakwater	20
Figure 5.5:	Illustration of high wave reflection from caisson breakwater to improve bypassing of sediments.....	21
Figure 7.1:	Breakwater Option 1: 1:3.5 with rock 8-12 t, mass density 2,800 kg/m ³ . 10 m wide berm at +5.3 m CD. Crest level at +16.8 m CD.	26
Figure 7.2:	Breakwater Option 2: 1:2 with cubes 48 tonnes. Crest at +21 m CD	26
Figure 7.3:	Breakwater Option 3: 1:1.5 with single layer of cubes of 33 t to +10 m CD. At +11.5 m CD a berm of 10 m with rock and then a slope 1:2 of rock up to +21 m CD.....	26
Figure 7.4:	Breakwater Option 4: 1:1.5 with Accropode 28.8 tonnes up to +22 m CD. Or seawall 1:1.5 with Xbloc 24 tonnes up to + 22 m CD	26
Figure 7.5:	Option 5: Tandem breakwater. 40 t low-crested structure up to +1 m CD. Seawall 1:2.5 with rock 6-10 t up to +10 m CD, a rock berm 10 m wide and then asphalt up to +16.5 m CD	27
Figure 7.6:	Option 6: Open caisson with perforated front. Reflection less than 30 %	27
Figure 7.7:	Option 7 Icelandic berm breakwater. Largest rock 20-30 tonnes, berm at +10 m, 16 m wide. Crest at +15 m CD.....	27
Figure 7.8:	Option 8: Seawall design with re-used 40 t cubes in a bermed profile.....	28
Figure 7.9:	Option 9: Final constructed design with a low-crested structure with 40 t cubes and a cobble beach	28
Figure 7.10:	Trial section of the low-crested structure with 40 t re-used cubes	28
Figure 8.1:	Failure modes for a conventional rubble mound breakwater [Burcharth, 1992]	29
Figure 8.2:	Overall stability failure modes for a conventional caisson breakwater [PIANC WG 28, 2003].....	30
Figure 8.3:	Examples of local stability failure modes [PIANC WG 28, 2003]	30
Figure 8.4:	Fault tree showing six failure modes for a conventional rubble mound breakwater [Burcharth, 1992].....	31
Figure 8.5:	Fault tree related to the caisson failure modes shown in Figure 8.2.	32

Figure 9.1: Illustration of principle of determination of safety level corresponding to minimum lifetime costs	41
Figure 11.1: Shallow and deep water cross sections	48
Figure 11.2: Case 2. Total costs in 50-year lifetime as function of interest rate and armour unit mass used in deterministic design.....	50
Figure 12.1: Definition of the failure modes recession and front erosion	51
Figure 12.2: Cross section of the Årvikssand berm breakwater in Norway	52
Figure 12.3: Cross section of the Sirevåg berm breakwater in Norway	52
Figure 12.4: Parameterised cross section of the berm breakwater	53
Figure 12.5: Case 1.2 results.....	55
Figure 12.6: Case 1.4 results.....	55
Figure 12.7: Case 2.2 results.....	56
Figure 12.8: Case 2.4 results.....	57
Figure 13.1: Accropode	59
Figure 13.2: Parameterised cross section.....	59
Figure 13.3: Stability of Accropode armour on slope 1:1.33 Range for minimum stability, $\xi_p = 3.5 - 4.5$ corresponding to wave steepness $s_{op} = 0.03 - 0.05$ [Burcharth et al., 1998].....	60
Figure 13.4: Case 1. Total costs in 50 year lifetime as function of interest rate and armour unit mass used in deterministic design. Damage accumulation included. No downtime costs included.....	61
Figure 13.5: Case 2. Total costs in 50 year lifetime as function of interest rate and armour unit mass used in deterministic design. Damage accumulation included. Downtime costs included.....	62
Figure 14.1: Cross sections of outer caisson breakwaters on bedding layer (top) and high mound foundation (bottom).....	64
Figure 14.2: Failure modes included in the optimisation.	64
Figure 14.3: Armour blocks in front of caisson and rubble mound behind caisson as means of repair	64
Figure 14.4: Illustration of resistance of mound to sliding.....	66
Figure 14.5: Diagrams for the estimation of caisson sliding distance.	67
Figure 14.6: Case F1-b-40. Dependence of lifetime costs on relative height of caisson rubble foundation and on return period applied in deterministic design.....	69
Figure 14.7: Case B1-b-40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on return period applied in deterministic design.....	70
Figure 14.8: Case S1-b-40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on return period applied in deterministic design.....	71
Figure 14.9: Case FD-b-40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on return period applied in deterministic design.....	72
Figure 14.10: Case F1-s35-r40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on return period applied in deterministic design.....	73
Figure 14.11: Case B1-s35-r45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on return period applied in deterministic design.....	74
Figure 14.12: Case S1-s35-r45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on return period applied in deterministic design.....	75
Figure B.2.1: Failure modes	98
Figure B.2.2 Cross section of the Årvikssand berm breakwater in Norway.....	99
Figure B.2.3: Cross section of the Sirevåg berm breakwater in Norway	99
Figure B.2.4: Parameterised cross section of the berm breakwater	99
Figure B.2.5: Built-in unit price cost function for rock	103
Figure B.2.6: Case 1.1 results	104
Figure B.2.7: Case 1.2 results	105
Figure B.2.8: Case 1.3 results	106
Figure B.2.9: Case 1.4 results	107
Figure B.2.10: Case 2.1 results	108
Figure B.2.11: Case 2.2 results	109
Figure B.2.12: Case 2.3 results	110
Figure B.2.13: Case 2.4 results	111
Figure B.3.1: Accropode.....	113
Figure B.3.2: Parameterised cross section.....	113
Figure B.3.3: Stability of Accropode armour on slope 1:1.33. Range for minimum stability, corresponding to wave steepness $s_{op} = 0.03 - 0.05$ [Burcharth et al., 1998]	114
Figure B.3.4: Case 1. Total costs in 50 years lifetime as function of interest rate and armour unit mass used in deterministic design. Damage accumulation included. No downtime costs included.....	115
Figure B.3.5: Case 2. Total costs in 50 years lifetime as function of interest rate and armour unit mass used in deterministic design. Damage accumulation included. Downtime costs included.....	115
Figure B.4.1: Cross sections of outer caisson breakwaters on bedding layer (left) and on high mound foundation (right)	117
Figure B.4.2: Failure modes included in the optimisation	117
Figure B.4.3: Armour blocks in front of caisson and rubble mound behind caisson as means of repair	118
Figure B.4.4: Illustration of resistance of mound to sliding	120
Figure B.4.5: Diagrams for the estimation of caisson sliding distance	121
Figure B.4.6: Case F1-a-37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	122
Figure B.4.7: Case F1-b-37. Dependence of lifetime costs on relative height of caisson rubble foundation and on wave return period applied in deterministic design.....	123
Figure B.4.8: Case F1-b-40. Dependence of lifetime costs on relative height of caisson rubble foundation and on wave return period applied in deterministic design.....	124

Figure B.4.9: Case F1-b-45. Dependence of lifetime costs on relative height of caisson rubble foundation and on wave return period applied in deterministic design.....	125
Figure B.4.10: Case B1-a-37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	126
Figure B.4.11: Case B1-b-37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	127
Figure B.4.12: Case B2-b-37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	128
Figure B.4.13: Case B1-b-40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	129
Figure B.4.14: Case B1-b-45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	130
Figure B.4.15: Case S1-b-37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	131
Figure B.4.16: Case S2-b-37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	132
Figure B.4.17: Case S1-b-40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	133
Figure B.4.18: Case S2-b-40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	134
Figure B.4.19: Case S1-b-45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	135
Figure B.4.20: Case S2-b-45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	136
Figure B.4.21: Case FD-b-40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	137
Figure B.4.22: Case F1-s30-r37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	139
Figure B.4.23: Case F1-s35-r37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	140
Figure B.4.24: Case F1-s35-r40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	141
Figure B.4.25: Case F1-s35-r45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	142
Figure B.4.26: Case F2-s35-r45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	143
Figure B.4.27: Case B1-s30-r37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	144
Figure B.4.28: Case B1-s35-r37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	145
Figure B.4.29: Case B2-s35-r37. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	146
Figure B.4.30: Case B1-s35-r40. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	147
Figure B.4.31: Case B1-s35-r45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	148
Figure B.4.32: Case B2-s35-r45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	149
Figure B.4.33: Case S1-s35-r45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	150
Figure B.4.34: Case S2-s35-r45. Dependence of lifetime costs on relative height of caisson rubble mound foundation and on wave return period applied in deterministic design.....	151

List of Tables

Table 7.1: Environmental conditions.....	25
Table 7.2: Preliminary functional design criteria.....	25
Table 7.3 Breakwater options considered.....	25
Table 8.1: Proposed classification of design working life [ISO 2394].....	36
Table 8.2: Definition of consequences classes [EN 1990, 2002].....	36
Table 8.3: Recommended minimum values of reliability index β and related failure probabilities P_f for construction works (ultimate limit states),	36
Table 8.4: Indicative values for the target reliability index β and related approximate values of P_f related to class RC2.....	37
Table 8.5: Consequence classes and tentative target reliability indices β (and associated target failure probabilities) related to one-year reference period and ultimate limit states [JCSS, 2000].....	37
Table 8.6: Tentative target reliability indices (and associated failure probabilities) related to one-year reference period and irreversible serviceability limit states [JCSS, 2000].....	37
Table 8.7: Proposal for safety classification for coastal structures	38
Table 8.8: Safety classes and design working life. Italian Guidelines (1996).....	38
Table 8.9: Maximum probability of admissible damage P_f in the period of working life. Italian guidelines (1996).....	38
Table 8.10: Economic repercussion values and related minimum design working life, ROM 0.0 (2002).....	39
Table 8.11: Social and Environmental Repercussion Index (SERI) and related maximum P_f (and minimum β -values) within working life. ROM 0.0 (2002)	39

Table 8.12: Comparison of limit state tentative target structure failure probabilities corresponding to 50 year working life	40
Table 10.1: Characteristics of wave statistics applied in cost optimisation simulations.....	47
Table 11.1: Applied repair policy as function of damage levels	49
Table 11.2: Case study data.....	49
Table 11.3: Case 2. Optimum safety levels for cube armoured breakwater.....	50
Table 11.4: Approximate ranges of optimum annual reliability levels for rock and cube armoured outer breakwaters, with and without downtime costs included	50
Table 12.1: Classification of berm breakwaters	51
Table 12.2: Classification of berm breakwaters based on 100-year return period wave conditions [Sigurdarson and Van der Meer, 2013].....	52
Table 12.3: Limit state performance and related repair strategy	53
Table 12.4: Bulk volume built-in unit prices for rock.....	53
Table 12.5: Case studies.....	54
Table 12.6: Case study 1.2 results. 11 m water depth,	54
Table 12.7: Case study 1.4 results. 11 m water depth. Lykke Andersen et al. (2014) formula. All data. 50-year service lifetime.....	55
Table 12.8: Case study 2.2 results. 20 m water depth, Sigurdarson et al. (2008) formula. 50-year service lifetime.....	56
Table 12.9: Case study 2.4 results. 20 m water depth, Lykke Andersen et al. (2014) formula. 50-year service lifetime.....	57
Table 12.10: Ranges of optimum design conditions for shallow and deep water cases. 50-year lifetime.....	58
Table 13.1: Case study data.....	60
Table 13.2: Case 1. Optimum safety levels for Accropode armoured breakwater. 50-year service lifetime. 10 m water depth.....	61
Table 13.3: Case 2. Optimum safety levels for Accropode armoured breakwater. 50-year service lifetime. 20 m water depth. Damage accumulation included.	61
Table 14.1: Limit state performances and repair strategy	65
Table 14.2: Average built-in bulk unit prices in euro/m ³ (approx. 2007).....	65
Table 14.3: Case studies: Caissons on hard seabed.	68
Table 14.4: Case F1-b-40. Optimum safety levels for outer breakwater in 15 m water depth. Hard seabed. RLS repair by mound behind caisson. Depth limited waves. $H_s^{100y} = 5.64$ m. Rubble foundation friction angle 40°. 100 year service life	68
Table 14.5: Case B1-b-40. Optimum safety levels for outer breakwater in 25 m water depth on hard bottom. RLS repair by mound behind caisson. Non-depth limited large waves, $H_s^{100y} = 8.76$ m. Rubble foundation friction angle 40°. 100-year service life.....	69
Table 14.6: Case S1-b-40. Optimum safety levels for outer breakwaters in 40 m water depth. Hard bottom. Caisson depth h' restricted to 24 m. Non-depth limited very large waves, $H_s^{100y} = 13.2$ m. RLS repair by mound behind caisson. Rubble foundation friction angle 40°. 100-year service life.....	70
Table 14.7: Case FD-b-40. Optimum safety levels for outer breakwater in 40 m water depth on hard bottom. Caisson depth h' restricted to 24 m. Non-depth limited small waves, $H_s^{100y} = 5.64$ m. RLS repairs by mound behind caisson. Rubble foundation friction angle 40°. 100-year service life	71
Table 14.8: Case studies. Caissons on sand sea beds.....	72
Table 14.9: Case F1-s35-r40. Optimum safety level for outer caisson breakwater in 15 m water depth Sand seabed. 100-year lifetime. Sand friction angle 35°. Rubble friction angle 40°. Depth limited waves, $H_s^{100y} = 5.64$ m. RLS repairs by mound behind caisson. 100-year service life	73
Table 14.10: Case B1-s35-r45. Optimum safety level for outer caisson breakwater in 25 m water depth on sand seabed. Sand friction angle 35°. Rubble friction angle 40°. Non-depth limited waves, $H_s^{100y} = 8.76$ m. RLS repairs by mound behind caisson. 100-year service life	74
Table 14.11: Case S1-s35-r45. Optimum safety level for outer caisson breakwater in 40 m water depth on sand seabed. Caisson depth h' restricted to 24 m. Sand friction angle 35°. Rubble friction angle 40°. Non-depth limited waves, $H_s^{100y} = 13.2$ m. RLS repairs by mound behind caisson. 100-year service life	75
Table 14.12: Optimum probability of occurrence of limit states in 100-year lifetime.....	76
Table 14.13: Optimum probability of occurrence of limit states in 100-year lifetime.....	76
Table 14.14: Optimum probability of occurrence of limit states in 100-year lifetime.....	76
Table 14.15: Optimum probability of occurrence of limit states in 100-year lifetime.....	77
Table 14.16: Optimum probability of occurrence of limit states in 100-year lifetime.....	77
Table 14.17: Optimum probability of occurrence of limit states in 100-year lifetime.....	77
Table 14.18: Optimum probability of occurrence of limit states in 100-year lifetime.....	78
Table 15.1: Optimum number of occurrences of limit states in 50-year lifetime.....	79
Table 15.2: Optimum probability of limit state occurrences in 50-year lifetime	80
Table 15.3: Optimum probabilities of occurrence of limit states for caissons in outer breakwaters. Quarry rock foundation on hard seabed. 100-year lifetime	81
Table 15.4: Optimum probabilities of occurrence of limit states for caissons in outer breakwaters. Quarry rock foundation on sand seabed. 100-year lifetime	81
Table 16.1: Optimum damage levels and related safety factors.....	84
Table 16.2: Optimum mass of cube corresponding to each limit state.....	84