

# Contents

Preface .....	xv
Preface to the First Edition .....	xvii

## PART I. RANDOM SEA WAVES AND ENGINEERING APPLICATIONS

### Chapter 1 Introduction

1.1 Waves in the Sea .....	3
1.2 Outline of Design Procedures against Random Sea Waves .....	5
1.2.1 Wave Transformation .....	5
1.2.2 Methods of Dealing with Random Sea Waves .....	9

### Chapter 2 Statistical Properties and Spectra of Sea Waves

2.1 Random Wave Profiles and Definitions of Representative Waves ...	12
2.1.1 Spatial Surface Forms of Sea Waves .....	12
2.1.2 Definition of Representative Wave Parameters .....	14
2.2 Distributions of Individual Wave Heights and Periods .....	17
2.2.1 Wave Height Distribution .....	17
2.2.2 Relations between Representative Wave Heights .....	21
2.2.3 Distribution of Wave Period .....	24
2.3 Spectra of Sea Waves .....	25
2.3.1 Frequency Spectra .....	25
2.3.2 Directional Wave Spectra .....	31
2.4 Relationship between Wave Spectra and Characteristic Wave Dimensions .....	39
2.4.1 Relationship between Wave Spectra and Wave Heights .....	39
2.4.2 Relationship between Wave Spectra and Wave Periods .....	42

### Chapter 3 Transformation and Deformation of Random Sea Waves

3.1 Wave Refraction .....	45
3.1.1 Introduction .....	45
3.1.2 Refraction Coefficient of Random Sea Waves .....	47

3.1.3	Computation of Random Wave Refraction by Means of the Energy Flux Equation .....	52
3.1.4	Wave Refraction on a Coast with Straight, Parallel Depth-Contours .....	55
3.2	Wave Diffraction .....	57
3.2.1	Principle of Random Wave Diffraction Analysis.....	57
3.2.2	Diffraction Diagrams of Random Sea Waves.....	59
3.2.3	Random Wave Diffraction of Oblique Incidence.....	66
3.2.4	Approximate Estimation of Diffracted Height by the Angular Spreading Method .....	69
3.2.5	Applicability of Regular Wave Diffraction Diagrams.....	72
3.3	Equivalent Deepwater Wave .....	73
3.4	Wave Shoaling .....	75
3.5	Wave Deformation Due to Random Breaking .....	78
3.5.1	Limiting Wave Height of Regular Waves by Breaking.....	78
3.5.2	Computational Model of Random Wave Breaking .....	79
3.5.3	Computation of the Change in Wave Height Distribution Due to Random Wave Breaking .....	81
3.5.4	Diagrams for the Estimation of Wave Height in the Surf Zone .....	85
3.5.5	Formulas for Wave Height Estimation Within the Surf Zone.....	94
3.5.6	Wave Setup at Shoreline by Random Wave Breaking .....	95
3.5.7	Other Models of Random Wave Breaking .....	97
3.6	Wave Reflection and Dissipation .....	98
3.6.1	Coefficient of Wave Reflection .....	98
3.6.2	Propagation of Reflected Waves .....	100
3.6.3	Superposition of Incident and Reflected Waves .....	103
3.7	Spatial Variation of Wave Height along Reflective Structures.....	105
3.7.1	Wave Height Variation near the Tip of a Semi-infinite Structure .....	105
3.7.2	Wave Height Variation at an Inward Corner of Reflective Structures .....	107
3.7.3	Wave Height Variation along an Island Breakwater .....	110
3.8	Wave Transmission over Breakwaters .....	112
3.8.1	Wave Transmission Coefficient .....	112
3.8.2	Propagation of Transmitted Waves in a Harbor.....	115
3.9	Longshore Currents by Random Waves on Planar Beach .....	116

3.9.1 Longshore Currents by Unidirectional Irregular Waves . . . . . 116  
 3.9.2 Longshore Currents by Directional Random Waves . . . . . 120

Chapter 4 Design of Vertical Breakwaters

4.1 Vertical Breakwaters in Japan . . . . . 126  
 4.2 Wave Pressure Formulas for Upright Sections . . . . . 132  
     4.2.1 Overview of Development of Wave Pressure Formulas . . . . . 132  
     4.2.2 Formulas of Wave Pressure under Wave Crests . . . . . 134  
     4.2.3 Pressure under a Wave Trough . . . . . 141  
     4.2.4 Accuracy of Wave Pressure Formulas . . . . . 144  
 4.3 Design of Upright Sections . . . . . 146  
     4.3.1 Stability Condition for an Upright Section . . . . . 146  
     4.3.2 Width of Upright Section . . . . . 148  
     4.3.3 Precautions against Impulsive Breaking Wave Pressure . . . . . 153  
     4.3.4 Comments on Design of Concrete Caissons . . . . . 159  
 4.4 Design of Rubble Mound Foundation . . . . . 160  
     4.4.1 Dimensions of Rubble Mound . . . . . 160  
     4.4.2 Foot-Protection Blocks and Armor Units . . . . . 161  
     4.4.3 Protection against Scouring of the Seabed in Front of a  
         Breakwater . . . . . 164

Chapter 5 Design of Seawalls

5.1 Wave Overtopping Rate of Seawalls . . . . . 167  
     5.1.1 Overtopping Rate by Random Sea Waves . . . . . 167  
     5.1.2 Wave Overtopping Rate of Vertical Revetments and Block  
         Mound Seawalls . . . . . 169  
     5.1.3 Influence of Various Factors upon the Rate of Wave  
         Overtopping . . . . . 176  
 5.2 Crest Elevation . . . . . 177  
     5.2.1 Design Principles for the Determination of Crest Elevation . . 177  
     5.2.2 Tolerable Rate of Wave Overtopping . . . . . 179  
     5.2.3 Determination of Crest Elevation of a Seawall . . . . . 181  
 5.3 Additional Design Problems Related to Seawalls . . . . . 185

Chapter 6 Harbor Tranquility

6.1 Parameters Governing Harbor Tranquility . . . . . 188

6.2 Estimation of the Probability of Wave Height Exceedance Within a Harbor . . . . .	191
6.2.1 Estimation Procedure . . . . .	191
6.2.2 Joint Distribution of Significant Wave Height, Period and Direction Outside a Harbor . . . . .	193
6.2.3 Selection of the Points for the Wave Height Estimation . . . . .	195
6.2.4 Estimation of Wave Height in a Harbor Incident Through an Entrance . . . . .	195
6.2.5 Estimation of Waves Transmitted over a Breakwater . . . . .	197
6.2.6 Estimation of the Exceedance Probability of Wave Height Within a Harbor . . . . .	198
6.2.7 Estimation of Storm Wave Height in a Harbor . . . . .	202
6.3 Graphical Solution of the Distribution of Wave Height in a Harbor . . . . .	202
6.4 Some Principles for Improvement of Harbor Tranquility . . . . .	207
6.5 Motions of Ships at Mooring . . . . .	212
6.5.1 Modes and Equations of Ship Motions . . . . .	212
6.5.2 Ship Mooring and Natural Frequency of Ship Mooring System . . . . .	215
6.5.3 Dynamical Analysis of Ship Mooring . . . . .	217
6.5.4 Acceptable Ship Motions at Mooring for Safe Working Conditions . . . . .	217
6.5.5 Some Remarks on Ship Mooring . . . . .	219

## Chapter 7 Hydraulic Model Tests with Irregular Waves

7.1 Similarity Laws and Model Scales . . . . .	223
7.2 Generation of Irregular Waves and Data Analysis . . . . .	225
7.2.1 Irregular Wave Generator . . . . .	225
7.2.2 Preparation of Input Signal to the Generator . . . . .	228
7.2.3 Input Signals to a Multidirectional Wave Generator . . . . .	232
7.2.4 Data Recording and Analysis . . . . .	233
7.3 Experimental Techniques for Irregular Wave Tests . . . . .	233
7.3.1 Model Tests on Harbor Tranquility . . . . .	233
7.3.2 Model Tests for Breakwater Stability . . . . .	236
7.3.3 Model Tests for Wave Overtopping and Reflection of Seawalls and Other Structures . . . . .	240
7.4 Model Tests Using Multidirectional Wave Generators . . . . .	241

PART II. STATISTICAL THEORIES OF RANDOM SEA WAVES

Chapter 8 Description of Random Sea Waves

8.1 Profiles of Progressive Waves and Dispersion Relationship . . . . . 247  
 8.2 Description of Random Sea Waves by Means of Variance Spectrum 249  
 8.3 Stochastic Process and Variance Spectrum . . . . . 252

Chapter 9 Statistical Theory of Irregular Waves

9.1 Distribution of Wave Heights . . . . . 259  
 9.1.1 Envelope of Irregular Wave Profile . . . . . 259  
 9.1.2 The Rayleigh Distribution of Wave Heights . . . . . 261  
 9.1.3 Probability Distribution of Largest Wave Height . . . . . 265  
 9.2 Wave Grouping . . . . . 268  
 9.2.1 Wave Grouping and Its Quantitative Description . . . . . 268  
 9.2.2 Probability Distribution of Run Length for Uncorrelated Waves . . . . . 271  
 9.2.3 Correlation Coefficient between Successive Wave Heights . . . 272  
 9.2.4 Theory of Run Length for Mutually Correlated Wave Heights . . . . . 277  
 9.3 Distribution of Wave Periods . . . . . 280  
 9.3.1 Mean Period of Zero-upcrossing Waves . . . . . 280  
 9.3.2 Marginal Distribution of Wave Periods and Joint Distribution of Wave Heights and Periods . . . . . 282  
 9.4 Maxima of Irregular Wave Profiles . . . . . 292  
 9.5 Nonlinearity of Sea Waves . . . . . 297  
 9.5.1 Nonlinearity of Surface Elevation . . . . . 297  
 9.5.2 Asymmetry of Wave Profiles . . . . . 299  
 9.5.3 Effects of Wave Nonlinearity on Wave Heights and Periods . . 302  
 9.5.4 Nonlinear Components of Wave Spectrum . . . . . 304  
 9.6 Sampling Variability of Sea Waves . . . . . 307

Chapter 10 Techniques of Irregular Wave Analysis

10.1 Statistical Quantities of Wave Data . . . . . 316  
 10.1.1 Analysis of Analog Data . . . . . 316  
 10.1.2 Analysis of Digital Data . . . . . 318

10.2	Frequency Spectrum of Irregular Waves . . . . .	323
10.2.1	Theory of Spectral Analysis . . . . .	323
10.2.2	Spectral Estimate with Smoothed Periodograms . . . . .	331
10.3	Directional Spectra of Random Sea Waves . . . . .	336
10.3.1	Relation between Directional Spectrum and Covariance Function . . . . .	338
10.3.2	Estimate of Directional Spectra with a Wave Gauge Array .	340
10.3.3	Estimate of Directional Wave Spectra with a Directional Buoy and with a Two-axis Current Meter . . . . .	348
10.3.4	Advanced Theories of Directional Spectrum Estimates . . . . .	351
10.4	Resolution of Incident and Reflected Waves of Irregular Profiles . . .	356
10.4.1	Measurement of the Reflection Coefficient in a Wave Flume . . . . .	356
10.4.2	Measurement of the Reflection Coefficient of Prototype Structures . . . . .	361
10.5	Numerical Simulation of Random Sea Waves and Numerical Filters . . . . .	363
10.5.1	Principles of Numerical Simulation . . . . .	363
10.5.2	Selection of Frequency and Wave Angle Components . . . . .	364
10.5.3	Pseudorandom Number Generating Algorithm . . . . .	365
10.5.4	Simulation of Time Series Data . . . . .	366
10.5.5	Preparation of Control Signals for Multidirectional Wave Generator . . . . .	368
10.5.6	Numerical Filtering of Wave Record . . . . .	369

## PART III. STATISTICAL ANALYSIS OF EXTREME WAVES

### Chapter 11 Statistical Analysis of Extreme Waves

11.1	Introduction . . . . .	377
11.1.1	Data for Extreme Wave Analysis . . . . .	377
11.1.2	Distribution Functions for Extreme Waves . . . . .	380
11.1.3	Return Period and Return Value . . . . .	383
11.2	Estimation of Best-Fitting Distribution Function . . . . .	384
11.2.1	Selection of Fitting Method . . . . .	384

- 11.2.2 Plotting Position Formulas . . . . . 386
- 11.2.3 Parameter Estimation by the Least Squares Method . . . . . 387
- 11.2.4 Selection of Most Probable Parent Distribution . . . . . 390
- 11.3 Estimation of Return Value and Its Confidence Interval . . . . . 397
  - 11.3.1 Statistical Variability of Samples of Extreme Distributions . 397
  - 11.3.2 Confidence Interval of Parameter Estimates . . . . . 401
  - 11.3.3 Return Value and Its Confidence Interval . . . . . 404
  - 11.3.4 Treatment of Mixed Populations . . . . . 411
- 11.4 Design Waves and Related Problems . . . . . 413
  - 11.4.1 Encounter Probability and  $L$ -year Maximum Height . . . . . 413
  - 11.4.2 Some Remarks for Extreme Wave Data Analysis . . . . . 418
  - 11.4.3 Selection of Design Wave Height and Period . . . . . 421

Appendix

- List of Wavelength and Celerity for a Given Wave Period and Water Depth . . . . . 427
- Index . . . . . 433