

# Contents

<i>Preface to the Third Edition</i>	v
<i>Preface to the Second Edition</i>	ix
<i>Preface to the First Edition</i>	xi
<b>Part I. Random Sea Waves and Engineering Applications</b>	
1. Introduction	3
1.1 Waves in the Sea . . . . .	3
1.2 Overview of Historical Development of Random Waves Applications . . . . .	5
1.3 Outline of Design Procedures Against Random Sea Waves . . . . .	10
1.3.1 Wave Transformation . . . . .	10
1.3.2 Methods of Dealing with Random Sea Waves . . . . .	13
2. Statistical Properties and Spectra of Sea Waves	19
2.1 Random Wave Profiles and Definitions of Representative Waves . . . . .	19
2.1.1 Spatial Surface Forms of Sea Waves . . . . .	19
2.1.2 Definition of Representative Wave Parameters . . . . .	21
2.2 Distributions of Individual Wave Heights and Periods . . . . .	24
2.2.1 Wave Height Distribution . . . . .	24
2.2.2 Relations Between Representative Wave Heights . . . . .	27
2.2.3 Distribution of Wave Period . . . . .	30
2.3 Spectra of Sea Waves . . . . .	31
2.3.1 Frequency Spectra . . . . .	31
2.3.2 Directional Wave Spectra . . . . .	37

2.4	Relationship Between Wave Spectra and Characteristic Wave Dimensions . . . . .	48
2.4.1	Relationship Between Wave Spectra and Wave Heights . . . . .	48
2.4.2	Relationship Between Wave Spectra and Wave Periods . . . . .	53
2.5	Long-Period Waves Accompanying Wind Waves and Swell . . . . .	54
3.	Generation, Transformation and Deformation of Random Sea Waves . . . . .	63
3.1	Simplified Forecasting Method of Wind Waves and Swell . . . . .	63
3.1.1	Simplified Forecast of Wave Height and Period . . . . .	63
3.1.2	Simplified Forecast of Swell Height and Period . . . . .	66
3.1.3	Relationship Between Significant Height and Period of Wind Waves and Swell . . . . .	67
3.2	Wave Refraction . . . . .	68
3.2.1	Introduction . . . . .	68
3.2.2	Refraction Coefficient of Random Sea Waves . . . . .	70
3.2.3	Computation of Random Wave Refraction by Means of the Energy Balance Equation . . . . .	75
3.2.4	Wave Refraction on a Coast with Straight, Parallel Depth-Contours . . . . .	78
3.3	Wave Diffraction . . . . .	80
3.3.1	Principle of Random Wave Diffraction Analysis . . . . .	80
3.3.2	Diffraction Diagrams of Random Sea Waves . . . . .	82
3.3.3	Random Wave Diffraction of Oblique Incidence . . . . .	89
3.3.4	Approximate Estimation of Diffracted Height by the Angular Spreading Method . . . . .	92
3.3.5	Application of Regular Wave Diffraction Diagrams . . . . .	95
3.4	Equivalent Deepwater Wave . . . . .	96
3.5	Wave Shoaling . . . . .	99
3.6	Wave Deformation Due to Random Breaking . . . . .	102
3.6.1	Breaker Index of Regular Waves . . . . .	102
3.6.2	Hydrodynamics of Surf Zone . . . . .	104
3.6.3	Wave Height Variations on Planar Beaches . . . . .	117
3.6.4	Prediction of Random Wave Breaking Process on Beaches of Complicated Profiles . . . . .	128

3.7	Reflection of Waves and Their Propagation and Dissipation . . . . .	131
3.7.1	Coefficient of Wave Reflection . . . . .	131
3.7.2	Propagation of Reflected Waves . . . . .	133
3.7.3	Superposition of Incident and Reflected Waves . . . . .	137
3.8	Spatial Variation of Wave Height Along Reflective Structures . . . . .	139
3.8.1	Wave Height Variation Near the Tip of a Semi-Infinite Structure . . . . .	139
3.8.2	Wave Height Variation at an Inward Corner of Reflective Structures . . . . .	141
3.8.3	Wave Height Variation Along an Island Breakwater . . . . .	144
3.9	Wave Transmission of Breakwaters and Low-Crested Structures . . . . .	146
3.9.1	Wave Transmission of Coefficient of Composite Breakwaters . . . . .	146
3.9.2	Wave Transmission Coefficient of Low-Crested Structures . . . . .	148
3.9.3	Propagation of Transmitted Waves in a Harbor . . . . .	153
4.	Design of Vertical Breakwaters . . . . .	161
4.1	Overview of Vertical and Composite Breakwaters . . . . .	161
4.2	Wave Pressures Exerted on Upright Sections . . . . .	168
4.2.1	Overview of Development of Wave Pressure Formulas . . . . .	168
4.2.2	Goda Formulas of Wave Pressure Under a Wave Crests . . . . .	170
4.2.3	Impulsive Breaking Wave Pressure and Its Estimation . . . . .	180
4.2.4	Sliding of Upright Section by Single Wave Action . . . . .	185
4.3	Preliminary Design of Upright Sections . . . . .	188
4.3.1	Stability Condition for an Upright Section . . . . .	188
4.3.2	Stable Width of Upright Section . . . . .	190
4.4	Several Design Aspects of Composite Breakwaters . . . . .	194
4.4.1	Wave Pressure Under a Wave Trough . . . . .	194
4.4.2	Uplift on a Large Footing . . . . .	197
4.4.3	Wave Pressure on Horizontally-Composite Breakwaters and Other Special Breakwaters . . . . .	198
4.4.4	Comments on Design of Concrete Caissons . . . . .	200

4.5	Design of Rubble Mound Foundation of Composite	
	Breakwaters . . . . .	201
4.5.1	Dimensions of Rubble Mound . . . . .	201
4.5.2	Foot-Protection Blocks . . . . .	202
4.5.3	Protection Against Scouring of the Seabed in Front of a Breakwater . . . . .	206
5.	Design of Coastal Dikes and Seawalls	211
5.1	Random Wave Run-Up on Coastal Dikes and Seawalls . .	211
5.1.1	Run-Up Height by Standing Waves at Vertical Wall . . . . .	211
5.1.2	Run-Up Height on Smooth Slopes and Coastal Dikes . . . . .	212
5.2	Wave Overtopping Rate of Coastal Dikes and Seawalls . .	216
5.2.1	Overtopping Rate by Random Sea Waves . . . . .	216
5.2.2	Mean Rate of Wave Overtopping at Vertical and Block-Mound Seawalls . . . . .	218
5.2.3	Mean Rate of Wave Overtopping at Coastal Dikes of Plane Slope . . . . .	225
5.2.4	Unified Formulas for Wave Overtopping Rate of Vertical and Inclined Seawalls . . . . .	229
5.3	Influence of Various Factors on Wave Overtopping Rate .	233
5.4	Tolerable Rate of Wave Overtopping and Determination of Crest Elevation . . . . .	238
5.4.1	Design Principles for the Determination of Crest Elevation . . . . .	238
5.4.2	Tolerable Rate of Wave Overtopping . . . . .	239
5.4.3	Examples of Determining Crest Elevation of Seawalls . . . . .	241
5.5	Additional Design Problems Related to Seawalls . . . . .	246
6.	Probabilistic Design of Breakwaters	253
6.1	Uncertainty of Design Values . . . . .	253
6.1.1	Overview . . . . .	253
6.1.2	Examples of Uncertainty of Design Parameters for Breakwater Design . . . . .	255
6.1.3	Uncertainty of Offshore Significant Wave Height .	258

6.2	Reliability-Based Design of Breakwater . . . . .	260
6.2.1	Classification of Reliability-Based Design Method . . . . .	260
6.2.2	Evaluation of External Safety by Level II Method . . . . .	261
6.2.3	Design of Breakwaters with Partial Factor System . . . . .	270
6.3	Performance-Based Design of Breakwaters . . . . .	274
6.3.1	Outline of Performance-Based Design Method . .	274
6.3.2	Performance-Based Design with Expected Sliding Distance Method . . . . .	276
6.3.3	Vertical Breakwater Design with Modified Level I Method . . . . .	285
7.	Harbor Tranquility . . . . .	291
7.1	Parameters Governing Harbor Tranquility . . . . .	291
7.2	Estimation of the Probability of Wave Height Exceedance Within a Harbor . . . . .	294
7.2.1	Estimation Procedure . . . . .	294
7.2.2	Joint Distribution of Significant Wave Height, Period and Direction Outside a Harbor . . . . .	296
7.2.3	Selection of the Points for the Wave Height Estimation . . . . .	298
7.2.4	Estimation of Wave Height in a Harbor Incident Through an Entrance . . . . .	298
7.2.5	Estimation of Waves Transmitted Over a Breakwater . . . . .	300
7.2.6	Estimation of the Exceedance Probability of Wave Height Within a Harbor . . . . .	301
7.2.7	Estimation of Storm Wave Height in a Harbor . .	304
7.3	Graphical Solution of the Distribution of Wave Height in a Harbor . . . . .	305
7.4	Some Principles for Improvement of Harbor Tranquility .	309
7.5	Motions of Ships at Mooring . . . . .	314
7.5.1	Modes and Equations of Ship Motions . . . . .	314
7.5.2	Ship Mooring and Natural Frequency of Ship Mooring System . . . . .	317
7.5.3	Time-Domain Analysis of Moored Ships . . . . .	319
7.5.4	Some Remarks on Ship Mooring . . . . .	321

7.6	Allowable Ship Movements and Mitigation of Mooring Troubles . . . . .	322
7.6.1	Allowable Movements of Moored Ships . . . . .	322
7.6.2	Mitigation of Mooring Troubles . . . . .	323
8.	Hydraulic Model Tests with Random Waves	331
8.1	Similarity Laws and Scale Effects . . . . .	331
8.1.1	Selection of Model Scales with the Froude Similarity Law . . . . .	331
8.1.2	Possible Scale Effects in Model Tests . . . . .	333
8.2	Necessity of Hydraulic Model Tests with Random Waves .	335
8.3	Generation of Random Waves in Test Basins . . . . .	337
8.3.1	Random Wave Generator . . . . .	337
8.3.2	Preparation of Input Signal to the Generator . . .	340
8.3.3	Input Signals to a Multidirectional Random Wave Generator . . . . .	343
8.3.4	Non-Reflective Wave Generator . . . . .	344
8.3.5	Other Topics on Wave Generation in Test Flumes	344
8.4	Model Tests Using Multidirectional Radom Waves . . . .	347
8.5	Some Remarks on Execution of Random Wave Tests . . .	348
8.5.1	Number of Test Runs and Their Durations . . . .	348
8.5.2	Calibration of Test Waves . . . . .	349
8.5.3	Resolution of Incident and Reflected Waves in a Test Flume . . . . .	350
8.5.4	Statistical Variability of Damage Ratio of Armor Units . . . . .	351

## **Part II. Statistical Theories of Random Sea Waves**

9.	Description of Random Sea Waves	357
9.1	Profiles of Progressive Waves and Dispersion Relationship	357
9.2	Description of Random Sea Waves by Means of Variance Spectrum . . . . .	360
9.3	Stochastic Process and Variance Spectrum . . . . .	362
10.	Statistical Theory of Irregular Waves	369
10.1	Distribution of Wave Heights . . . . .	369
10.1.1	Envelope of Irregular Wave Profile . . . . .	369
10.1.2	The Rayleigh Distribution of Wave Heights . . . .	371
10.1.3	Probability Distribution of Largest Wave Height .	376

10.2	Wave Grouping . . . . .	379
10.2.1	Wave Grouping and Its Quantitative Description .	379
10.2.2	Probability Distribution of Run Length for Uncorrelated Waves . . . . .	382
10.2.3	Correlation Coefficient Between Successive Wave Heights . . . . .	383
10.2.4	Theory of Run Length for Mutually Correlated Wave Heights . . . . .	388
10.3	Distribution of Wave Periods . . . . .	391
10.3.1	Mean Period of Zero-Upcrossing Waves . . . . .	391
10.3.2	Marginal Distribution of Wave Periods and Joint Distribution of Wave Heights and Priods . . . . .	393
10.4	Maxima of Irregular Wave Profiles . . . . .	402
10.5	Nonlinearity of Sea Waves . . . . .	407
10.5.1	Nonlinearity of Surface Elevation . . . . .	407
10.5.2	Effects of Wave Nonlinearity on Characteristic Wave Heights and Periods . . . . .	414
10.5.3	Nonlinear Components of Wave Spectrum . . . . .	419
10.6	Sampling Variability of Sea Waves . . . . .	424
11.	Techniques of Irregular Wave Analysis	433
11.1	Statistical Quantities of Wave Data . . . . .	433
11.1.1	Analysis of Analog Data . . . . .	433
11.1.2	Analysis of Digital Data . . . . .	435
11.2	Frequency Spectral Analysis of Irregular Waves . . . . .	440
11.2.1	Theory of Spectral Analysis . . . . .	440
11.2.2	Spectral Estimate with Smoothed Periodograms .	447
11.3	Directional Spectral Analysis of Random Sea Waves . . .	453
11.3.1	Relation Between Directional Spectrum and Covariance Function . . . . .	454
11.3.2	Estimate of Directional Spectrum with a Wave Gauge Array . . . . .	456
11.3.3	Estimate of Directional Wave Spectra with a Directional Buoy or with a Two-Axis Current Meter . . . . .	464
11.3.4	Advanced Theories of Directional Spectrum Estimates . . . . .	467

11.4	Resolution of Incident and Reflected Waves of Irregular Profiles . . . . .	472
11.4.1	Measurement of the Reflection Coefficient in a Wave Flume . . . . .	472
11.4.2	Measurement of the Reflection Coefficient of Prototype Structures . . . . .	476
11.5	Numerical Simulation of Random Sea Waves and Numerical Filters . . . . .	478
11.5.1	Principles of Numerical Simulation . . . . .	478
11.5.2	Methods of Numerical Simulation . . . . .	479
11.5.3	Pseudo-Random Number Generating Algorithm . . . . .	484
11.5.4	Numerical Filtering of Wave Record . . . . .	485
12.	2-D Computation of Wave Transformation with Random Breaking and Nearshore Currents . . . . .	491
12.1	Overview of Numerical Computation Models for 2-D Wave Transformations . . . . .	491
12.2	Outline of Phase-Averaged Type Wave Transformation Models . . . . .	494
12.3	Outline of Phase-Resolving Type Wave Transformation Models . . . . .	497
12.4	Wave Transformation Analysis with PEGBIS Model . . . . .	501
12.5	Outline of Numerical Computation of Nearshore Currents . . . . .	511
12.6	Prediction of Wave Setup and Longshore Currents on Planar Beaches . . . . .	520

### **Part III. Statistical Analysis of Extreme Waves**

13.	Statistical Analysis of Extreme Waves . . . . .	537
13.1	Introduction . . . . .	537
13.1.1	Data for Extreme Wave Analysis . . . . .	537
13.1.2	Distribution Functions for Extreme Data Analysis . . . . .	539
13.1.3	Characteristics of Selected Distribution Functions . . . . .	542
13.1.4	Return Period and Return Value . . . . .	545
13.1.5	Spread Parameter of Distribution Functions . . . . .	546

13.2	Estimation of Best-Fitting Distribution Function . . . . .	549
13.2.1	Selection of Plotting Position . . . . .	549
13.2.2	Estimation of Return Values with the Least Squares Method . . . . .	553
13.2.3	Selection of Most Probable Parent Distribution . . . . .	559
13.2.4	Rejection of Distribution Function . . . . .	563
13.3	Confidence Interval of Return Value . . . . .	568
13.3.1	Statistical Variability of Samples of Extreme Distributions . . . . .	568
13.3.2	Confidence Interval of Parameter Estimates . . . . .	570
13.3.3	Confidence Interval of Return Value . . . . .	571
13.4	Several Topics on Extreme Wave Statistics . . . . .	579
13.4.1	Treatment of Mixed Populations . . . . .	579
13.4.2	Encounter Probability . . . . .	581
13.4.3	<i>L</i> -Year Maximum Wave Height and Its Confidence Interval . . . . .	582
13.5	Design Waves and Related Problems . . . . .	586
13.5.1	Database of Extreme Waves and Its Analysis . . . . .	586
13.5.2	Selection of Design Wave Height and Period . . . . .	590

## Part IV. Waves and Beach Morphology

14.	Coastline Change and Coastal Reconnaissance . . . . .	599
14.1	Introduction . . . . .	599
14.2	Overview of Historical Coastline Change . . . . .	600
14.2.1	Geological View of Coastline Change . . . . .	600
14.2.2	Geological Features of Sandy Coast . . . . .	603
14.2.3	Natural Process of Shoreline Change . . . . .	607
14.2.4	Examples of Estimated Rate of Littoral Sediment Transport . . . . .	609
14.3	Anthropogenic Influence on Coastal Morphology . . . . .	613
14.3.1	Outline . . . . .	613
14.3.2	Typical Cases of Significant Shoreline Recession by Anthropogenic Influence . . . . .	614
14.3.3	Patterns of Shoreline Changes Caused by Structure Construction on Sandy Coast . . . . .	618
14.4	Coastal Reconnaissance for Beach Protection Project . . . . .	624
14.4.1	Collection and Analysis Documents Before Coastal Reconnaissance . . . . .	624

14.4.2	Field Inspection Works . . . . .	629
14.4.3	Guidelines for Search of Sediment Supply and Longshore Transport Direction . . . . .	635
15.	Prediction and Control of Shoreline Evolution	643
15.1	Introduction . . . . .	643
15.2	State of the Art of Beach Morphological Prediction . . . . .	644
15.2.1	Overview of Studies on Sediment Movement . . . . .	644
15.2.2	Problems Inherent to Beach Morphological Prediction . . . . .	648
15.2.3	Sediment Suspension Rate in Surf Zone . . . . .	652
15.2.4	Fall Velocity and Equilibrium Beach Profile . . . . .	655
15.3	Overview of Beach Morphology Models . . . . .	657
15.3.1	Prediction Formulas for Longshore Sediment Transport . . . . .	657
15.3.2	Shoreline Change Models . . . . .	661
15.3.3	Numerical Models for 3-D Beach Deformation . . . . .	665
15.3.4	Quantitative Assessment of Sediment Impoundment by Groin . . . . .	667
15.4	A Case Study of Shoreline Change Prediction by One-Line Model . . . . .	670
15.5	Overview of Shore Protection Facilities . . . . .	676
	<i>Appendix</i>	687
	<i>Author Index</i>	693
	<i>Subject Index</i>	699