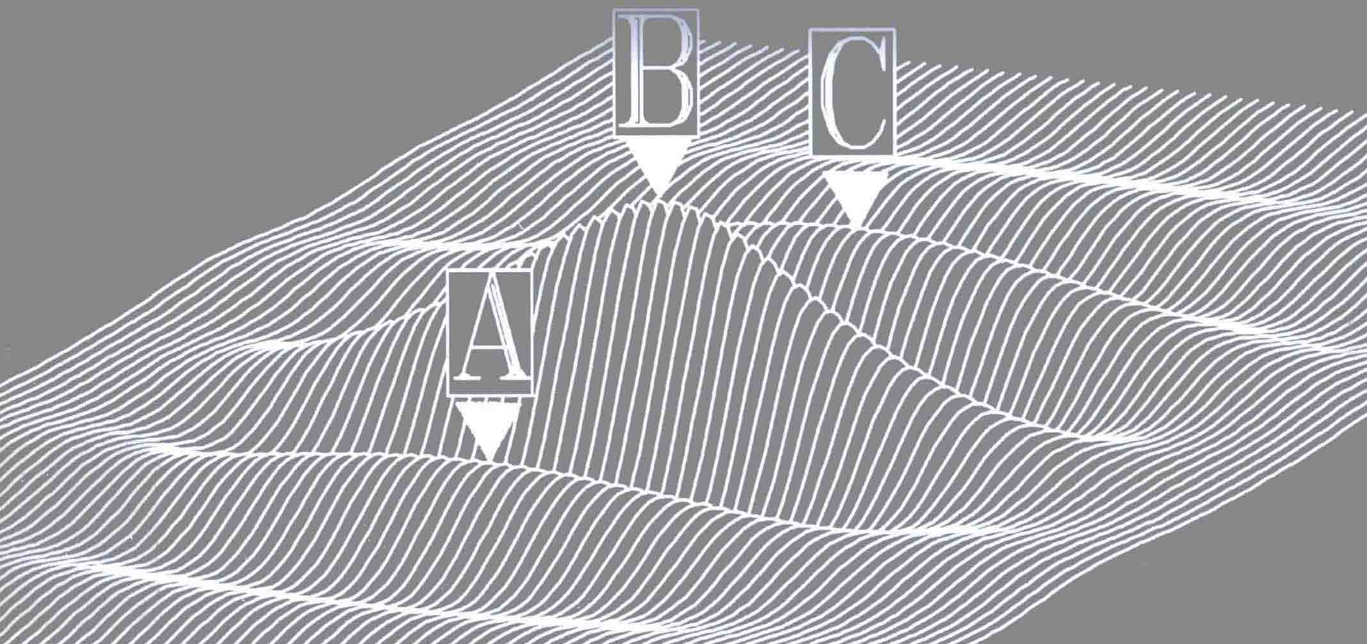
Wave Mechanics and Wave Loads on Marine Structures

Paolo Boccotti



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To B.V. Maria

Preface

A science calls for a unifying idea capable of yielding a powerful synthesis. In particular, ocean engineering science calls for unification of

1. the deterministic and the stochastic approach to wave theory;
2. the approach of field measurements, and the approach of experiments in wave tanks.

This unification is obtained through quasi-determinism (QD) theory and small-scale field experiments (SSFEs).

With the QD theory, a deterministic wave mechanics is born by the theory of probability. The SSFEs are experiments performed, like in a big wave tank, in sea areas or lakes where wind seas have some small size.

An ocean engineering science may be founded on QD theory and SSFEs. This is an important novelty, because in all the books I have consulted the deterministic approach and the stochastic approach to wave theory are conceptually separated; and, similarly, there are two distinct experimental activities: field measurements and wave tank experiments.

In 15 papers published in Ocean Engineering, J. Waterway, Port, Coastal, and Ocean Engineering, J. Fluid Mechanics, Probabilistic Engineering Mechanics, and J. Offshore Mechanics and Artic Engineering, and in a previous book published by Elsevier (2000), I presented the QD theory and many results of SSFEs. However, I did not point out openly that an ocean engineering science may be founded on these two pillars. Here, I intend to do this; and for this aim I shall present the QD theory in a simpler form, and devote a larger room to calculation of wave loads.

This book covers a wide area of potential interest: civil engineering, naval architecture, and mechanical engineering (because of the large room reserved to the problem of wave energy conversion). The area of greatest potential interest is civil engineering, and more specifically: ocean engineering, offshore engineering, port engineering, and coastal engineering. The book has been conceived to be read by students, researchers, and engineers.

The software illustrated in this book and given in the companion website is original and has only the didactic scope to make the new concepts clearer.

Wave Mechanics and Wave Loads on Marine Structures is a prerequisite to books like *Handbook of Offshore Engineering by Chakrabarti* (Elsevier, 2005), roughly, as a book on solid mechanics is a prerequisite to books on steel design or concrete design.

Paolo Boccotti
Reggio Calabria, Italy
March 2014

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Paolo Boccotti

Symbols

(Some symbols used in only one section are not included in the list.)

a	Wave amplitude
a	Triangle (ETS) height
A	Absorption coefficient
a_x, a_y, a_z	Particle acceleration
b	Width
b	Threshold or given value of the surface elevation
b	Threshold or given value of a wave crest height
b	Triangle (ETS) base
c	Wave propagation speed
C	Height of a wave crest
C	Energy-flux/energy factor
C_d	Diffraction coefficient
C_r	Refraction coefficient
C_s	Shoaling coefficient
C_{dg}	Drag coefficient
C_{in}	Inertia coefficient
c_G	Group velocity
c_R	Propagation speed of the reflected wave energy
d	Water depth
D	Diameter
D	Directional distribution
D	Persistence above a fixed threshold
$\mathscr{E}$	Mean wave energy per unit surface
$\mathscr{E}$	Dimensionless frequency spectrum
E	Frequency spectrum (omnidirectional spectrum)
EP	Electrical power
f	Frequency
f	General function
F	General function
F	Function in the diffraction theory
f_x, f_y, f_z	Force per unit length
F_x, F_y, F_z	Force, or force per unit length
$\mathscr{F}_{\mathscr{R}}$	Phase-speed reduction factor
g	Acceleration due to gravity
G	Function in the diffraction theory
h	Threshold or given value of the significant wave height
h	Energy per unit weight at various locations of a converter
H	Wave height
H_s	Significant wave height
H_{s0}	Significant wave height on deep water

k	Wave number
k	Exponent in the gas law
K	Constant
K	Head loss factor
K', K''	Parameters regression base height of ETS
K_1, K_2	Parameters distribution wave heights in a sea state
K_0	Parameter relationship between T_p and H_s for wind seas
K_E	Keleugan−Carpenter number
$K(n)$	Normalizing factor directional distribution
L	Lifetime of a structure
L	Wavelength
L_0	Wavelength on deep water
L_p	Wavelength relevant to wave period T_p
L_{p0}	Wavelength, on deep water, relevant to wave period T_p
m_j	jth spectral moment (with angular frequencies)
m_0	Variance of the surface elevation of a sea state
M	Determinant of a covariance matrix
M	Moment of a force
M_a	Air mass
M_{ij}	i,j cofactor of a covariance matrix
n_p	Width parameter of the directional distribution at the peak frequency
p	Pressure
p	Probability density function
P	Probability of exceedance
$\mathscr{P}$	Probability
p_a	Absolute pressure air
Q	Flow rate per unit length
r	Polar coordinate
R	Radius
R	Return period
R	Resonance coefficient
s	Local propagation axis
S	Directional spectrum
t	Time
t_o	Special time instant
T	Wave period
T	Time lag
T^*	Lag of the absolute minimum of the autocovariance
T_p	Peak period
T_h	Period of a very large wave
T_m	Mean wave period
u	Dummy variable
u	Current velocity
u	Wind speed at an elevation of 10 m above the mean sea surface
u	Velocity in the vertical duct of a U-OWC

u	Parameter of the Weibull 2-parameter distribution
v_x, v_y, v_z	Particle velocity
w	Dummy variable
w	Dimensionless frequency $(=\omega/\omega_p)$
w	Parameter of the Weibull 2-parameter distribution
x	Dummy variable
x	Horizontal coordinate axis
x_o	Fixed value of x
X	Space lag
y	Horizontal coordinate axis
y_o	Fixed value of y
Y	Space lag
$\mathscr{Y}$	Fetch
z	Vertical coordinate axis with origin at the still water level
α	Angle between x-axis and direction of wave advance
α	Quotient between wave height and RMS surface elevation of a sea state
A	Energy scale parameter JONSWAP spectrum (α in the original paper)
β	Dimensionless wave height with a universal distribution
β	Polar coordinate
β	Ratio between the wave height at a U-OWC and the wave height at a vertical breakwater
γ	Specific weight of water
Δp	Wave pressure
$\Delta\omega$	Angular frequency resolution
ε	Phase angle
ζ	Vertical coordinate axis with origin at the seabed
η	Surface elevation (assumed to have a zero mean)
θ	Angle between the y-axis and the direction of wave advance
θ_d	Angle of the dominant direction
λ	Sea bottom slope
ν	Chinematic viscosity
ξ	Dummy variable whose domain is (0,1)
ξ	Ratio between crest height and wave height
ξ	Height of the air pocket of a U-OWC
ρ	Water density
σ	RMS surface elevation of a sea state
τ	Time lag between crest and trough
τ	Ratio between a time lag T and peak period T_p
τ	Time lag covariance pressure-discharge in a converter
ϕ	Velocity potential
Φ	Cross-covariance of surface elevation and velocity potential
Φ	Mean energy flux per unit length
χ	Ratio between c_R and c_G
χ_1	Shape parameter JONSWAP spectrum (γ in the original paper)

χ_2 Shape parameter JONSWAP spectrum (σ in the original paper)
ψ Autocovariance function
ψ^* Narrow bandedness parameter (= absolute value of the ratio between the minimum and the maximum of the autocovariance function)
Ψ Cross-covariance of surface elevation
$\widehat{\Psi}$ Cross-correlation of surface elevation
ω Angular frequency
ω_p Dominant angular frequency of the spectrum

Mathematical Symbols

$\langle f(t) \rangle$ Time average of function $f(t)$
$f(t)$ Time derivative of function $f(t)$

Symbols Used in All the FORTRAN Programs

PG = π
DPG = 2π

Abbreviations and Acronyms

CV	Control volume
DSSP	Design sea state pattern
DWR	Duration of a wave record
ETS	Equivalent triangular storm
GA	Gauge array
GM	Goda's model
LHS	Left-hand side
MWL	Mean water level
NDBC	National Data Buoy Center of NOAA
NOAA	National Oceanic and Atmospheric Administration, USA
NOEL	Natural Ocean Engineering Laboratory, Italy
OWC	Oscillating water column
pdf	Probability density function
POT	Peaks over threshold
QD	Quasi-determinism
RHS	Right-hand side
RMS	Root mean square
RPP	Random point process
SSFE	Small-scale field experiment
U-OWC	U-shaped OWC
VHM	Virtual-height model

Contents