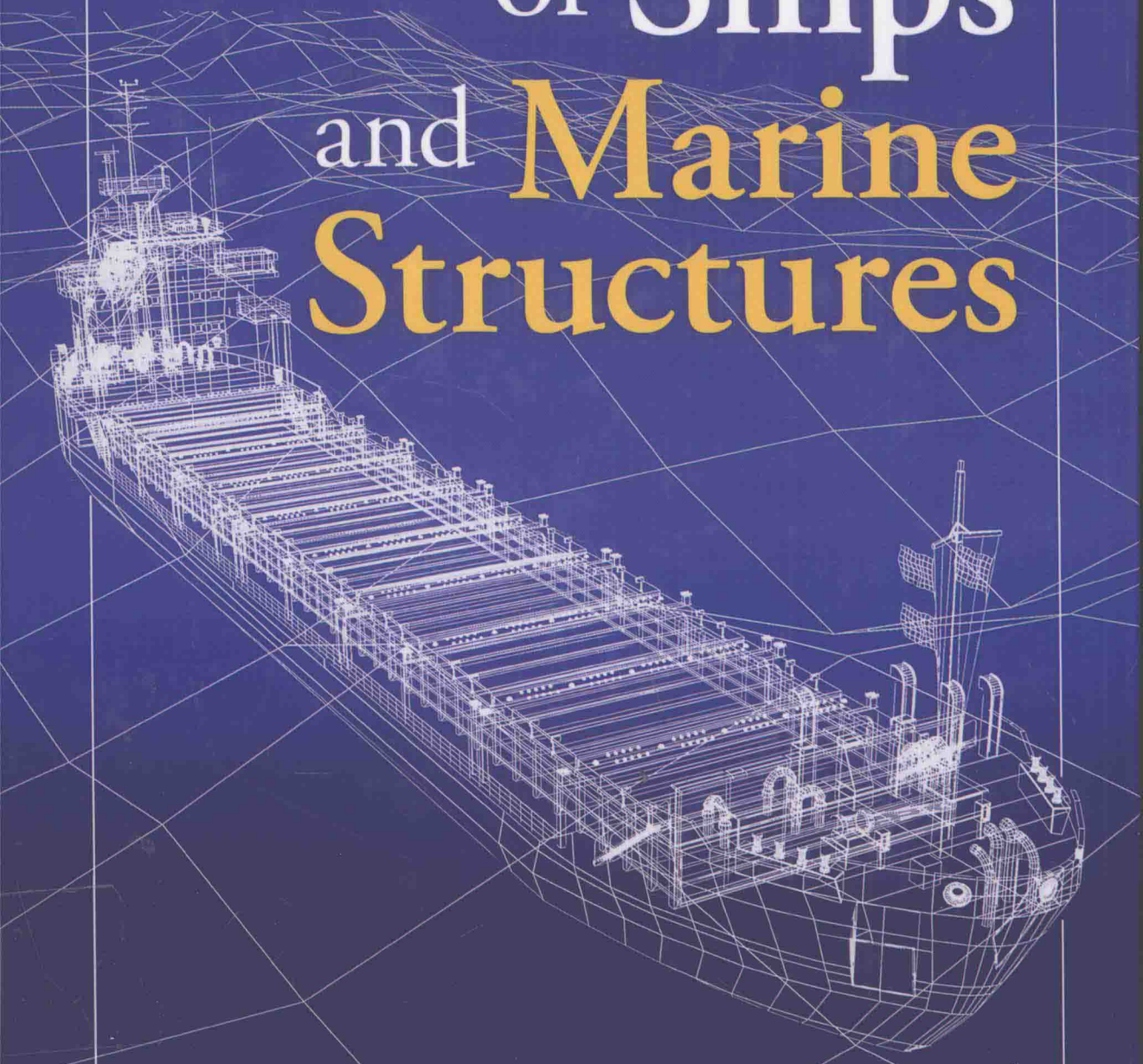
Design Principles of Ships and Marine Structures



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Preface

In the last 40 years, the author has been involved in teaching ship design and associated subjects, stability and hydrodynamics and industrial activity related to marine design. During this period, design methodology underwent tremendous changes and improvements. With the availability of high-speed computing and many sophisticated software, advanced numerical techniques are being applied to maritime design procedure at the concept design stage. The use of empirical formulations has reduced. Also, in recent years, concerns of energy consumption, environment, safety and reliability have increased. Designers are increasingly incorporating such aspects at the design stage to reduce these concerns. With increasing competition, it has become necessary to look at the effectiveness of design from the economic point of view such as project profitability and shipbuilding cost. With these varied requirements, the system design aspects in large complex products have become important and it is necessary to evaluate alternatives for each system or unit, as well as the final product. Systems engineering applications try to integrate technical, environmental or societal and economic systems, making a final complex marine platform. The management of design activities has also become increasingly important and complex, providing space for creativity and innovation. This book intends to make the reader aware of all these aspects of design and their integration.

As the title of the book indicates, the subjects deal with the many and varied principles of design. The chapters of the book are fairly varied in nature, the intention being to focus on the importance of each of the topics covering the entire sphere of marine design. For each chapter, there are enough books written by renowned authors and the reader is advised to refer to those books if needed, to produce good design work. With the author's experience of more than 40 years in marine design applications, the book is written focussing on marine design with examples of ships wherever necessary. He believes that the principles described in this book can be applied to successful designs of any other marine structure or vehicle, the details being different in each case.

The book has 16 chapters starting with an introduction of marine design which includes a description of various marine products which are used for transportation, defence and exploitation of marine resources. Chapter 2 introduces the reader to marine environment in which the product has to work. Chapter 3 discusses various design methodologies such as sequential design process with the application of concurrent engineering. Set-based design, which has been successfully implemented in the automobile industry, has been introduced in the book, and it is expected that this will be useful in marine applications also. Chapter 4 discusses applications of engineering economics to marine design, highlighting the effect of design parameters on the profitability over the life of the ship and building cost based on shipyard facilities. Chapter 5 addresses the issue of parameter estimation using different techniques such as statistical data and empirical formulae for parameter estimation, as well as the performance prediction at the concept design stage. Chapter 6 discusses intact and damage stability issues applied to ship design. Hydrodynamic issues of resistance, propulsion, sea keeping and manoeuvring and their effects on design are discussed in Chapter 7. We do not go into the fundamental or advanced details of these subjects in this chapter, but the application of computational fluid dynamics (CFD) and experimental fluid dynamics (EFD) in these areas have been highlighted. Chapter 8 discusses hull form design and is purely based on vehicles, particularly ships. The use of

computer-aided design techniques has been highlighted. Machinery systems consisting of main and auxiliary machinery, redundancies, piping systems and energy consumption patterns have been discussed in Chapter 9. Structural design is a subject by itself. But without the fundamentals of materials, loads and design techniques, a marine platform design remains incomplete. Chapter 10 briefly discusses structural design, including materials. Space layout for payload, equipment and machinery and accommodation for personnel on board on the platform, commonly known as general arrangement, is discussed in Chapter 11. Safety has become an important aspect of design of complex products and systems these days. In Chapter 12, design aspects related to safety, including risk assessment, are discussed. Design for sustainability includes protection of air and water environment and protection against invasive species. These issues have brought to the fore a number of innovative ideas. These are discussed in Chapter 13. Chapter 14 discusses designs for production to reduce construction cost and time. Standardisation and modularisation are the main issues discussed here. Chapter 15 states the principles of numerical optimisation for decision-making. The importance of heuristic optimisation and multi-objective decision-making processes are highlighted. Chapter 16 is on design management, the crucial factors being the encouragement of creativity and innovation in marine design.

S. C. Misra

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Some material in the book has been taken from other publications. I am thankful to the publishers for their permission.

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More than 35 years of interaction with students of naval architecture and ocean engineering at the Indian Institute of Technology, Kharagpur, and the Indian Maritime University at Visakhapatnam campus has been the prime motivating factor for undertaking the project of writing this book. I am grateful to all my students for that.

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Author

S. C. Misra earned a B.Tech. (Hons.) degree in naval architecture from IIT Kharagpur, India, in 1970, and his PhD from the University of Newcastle upon Tyne, United Kingdom, in 1976. After serving for a few years as design engineer in Hindustan Shipyard Ltd., Visakhapatnam, he joined the Indian Institute of Technology, Kharagpur, as assistant professor in naval architecture. He became professor there and also served three years as head of the Department of Ocean Engineering and Naval Architecture and finally retired from active service in 2013. During his service period, he spent six months at Glasgow University, United Kingdom, two years as visiting professor at IIT Madras and five years as the director of the Indian Maritime University, Visakhapatnam Campus, where he initiated undergraduate and postgraduate programs in naval architecture and ocean engineering and dredging and harbour engineering. Subsequent to his retirement, he has been involved in a number of research and consultancy projects in the areas of design of ships, marine structures and inland water transportation.

Nomenclature

A	Annual repayment/attained subdivision index
B	Breadth
D	Depth/propeller diameter
E	Energy/Young's modulus
F	Future sum of money
I	Moment of inertia
J	Advance coefficient/polar moment of inertia
L	Length/load
M	Bending moment
N	Revolutions per minute/number of years
P	Present sum of money/principal amount of investment/engine power
Q	Torque
R	Required subdivision index/resistance
S	Wetted surface
T	Draught/wave period in seconds/thrust
U	Free stream velocity in x-direction
V	Speed
W	Weight in tonnes
c	Wave celerity = $\omega/k = \lambda/T$
cgt	Compensated gross tonnes
dwt	Deadweight
f	Frequency in Hz
g	Acceleration due to gravity = 9.81 m/s^2/Limit state function
g	Limit state function
h	Water depth below surface/height above water
i	Interest rate/effective rate of return/discount rate
k	Wave number = $2\pi/\lambda$/form factor
k_s	Surface roughness
n	Revolutions per second
p	Pressure
q	Shear flow
t	Thrust deduction fraction
u, v and w	Perturbation velocities in x, y and z directions, respectively
w	Wake fraction
z	Number of propeller blades
Δ	Displacement in tonnes
∇	Volume of displacement
ε	Phase angle
ζ	Wave elevation
$\zeta_{a1/3}$	Significant wave height
ζ_ω or ζ_a	Wave amplitude with frequency ω
η	Efficiency
θ	Trim angle
λ	Wave length/model scale

λ_c	Average wavelength in a seaway
ν	Kinematic coefficient of viscosity
ξ	Motion response
ρ	Density
σ	Cavitation number/bending or flexural stress
σ_ζ	Standard deviation of ζ distribution
σ_ζ^2	Variance of ζ distribution
τ	Shear stress
τ_c	Thrust loading coefficient
φ	Velocity potential/heel angle
ω	Circular wave frequency in rad/s = $2\pi/T$
ω_e	Encounter frequency
A_P, A_E, A_D, A_0	Propeller projected, expanded, developed and disc area, respectively
A_x	Midship area
A_{WP}	Water plane area
BAR	Blade area ratio = A_E/A_0
C_B	Block coefficient
C_F	Frictional resistance coefficient
C_P	Prismatic coefficient
C_{PV}	Vertical prismatic coefficient
C_R	Residuary resistance coefficient
C_T	Total resistance coefficient
C_{WP}	Water plane area coefficient
C_x	Midship area coefficient
Fn	Froude number = $V/\sqrt{(g \cdot L)}$
$F_{n\nabla}$	Displacement Froude number = $V/\sqrt{(g \cdot \nabla^{1/3})}$
$F(x)$	Probability distribution function
$f(x)$	Probability density function
H_ω	Wave height of wave frequency ω
h_0	Standard height above water
i_e	Half angle of entrance
K_Q	Torque coefficient
K_T	Thrust coefficient
L_{BP}	Length between perpendiculars
L_{OA}	Length overall
L_{WL}	Length on water line
p_v	Vapour pressure
P/D	Pitch ratio
R_F	Frictional resistance
R_n	Reynolds number
R_P	Pressure resistance
R_R	Residuary resistance
R_T	Total resistance
R_V	Viscous resistance
R_{VP}	Viscous pressure resistance
R_W	Wave making resistance
S_ζ	Energy spectrum
$S_\zeta(\omega)$	Energy spectrum ordinate at circular frequency ω
T_c	Average zero-crossing period

V_0	Standard speed
V_A	Speed of advance
V_c	Critical speed
AAC	Average annual cost
AAW	Anti-aircraft warfare
AIS	Automatic identification system
ALARP	As low as possible
AP	After perpendicular
ASD	Allowable stress design
ASW	Anti-submarine warfare
AUV	Automatic underwater vehicle
BM	Metacentric radius
CA	Compound amount factor
CB	Centre of buoyancy with coordinates LCB, TCB and VCB or KB
CAD	Computer-aided design
CAM	Computer-aided manufacturing
CESA	Community of European Shipbuilders Association
CFC	Chlorofluorocarbon
CFD	Computational fluid dynamics
CG	Centre of gravity with coordinates LCG, TCG and VCG or KG
CIM	Computer-instructed manufacturing
CR	Capital recovery factor
CRV	Coastal research vessel
CSD	Cutter suction dredger
CSR	Common structural rules
DCF	Discounted cash flow
DE	Diesel engine
ECA	Emission control areas
EEDI	Energy efficiency design index
EEZ	Exclusive economic zone
FEM	Finite element methods
FFA	Fire-fighting appliance
FORM	First-order reliability method
FP	Forward perpendicular
FRP	Fibre-reinforced plastic
FPSO	Floating production storage and offloading unit
FSA	Formal safety assessment
FSO	Floating storage and offloading unit
FSU	Floating storage unit
GA	General arrangement
GM	Metacentric height
GT	Gross tonnage
GZ	Statistical stability lever or arm
HFO	Heavy fuel oil
IACS	International Association of Classification Societies
IBC	International Regulations for Carriage of Dangerous Chemicals in Bulk
IGC	The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
ILO	International Labour Organisation

IMDG	International Regulations for Carriage of Dangerous Goods
IMO	International Maritime Organisation
INCOSE	International Council on System Engineering
IRR	Internal rate of return
ITTC	International Towing Tank Conference
KN	Perpendicular distance from keel to the perpendicular through CB to LWL
KSA	Korean Shipbuilders Association
LCF	Longitudinal centre of floatation
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LSA	Life-saving appliances
LRFD	Load and resistance factor design
LWL	Load water line
MARPOL	International Convention on Prevention of Pollution from Ships
MCT 1 cm	Moment to change trim 1 centimetre
MDO	Marine diesel oil
MSI	Motion sickness index
MSL	Mean sea level
NCCV	Non-cargo carrying vessels
NESDIS	National Environmental Satellite, Data and Information Service
NOAA	National Oceanic and Atmospheric Administration
NPV	Net present value
NPVI	Net present value index
NT	Net tonnage
OECD	Organisation of Economic Co-operation and Development
ODS	Ozone depleting substances
ORV	Ocean research vessel
OTEC	Ocean thermal energy conversion
OWC	Oscillating water column
QPC	Quasi propulsive coefficient
PSF	Partial safety factor
PSSA	Particularly sensitive sea areas
PW	Present worth factor
RAO	Response amplitude operator
RFR	Required freight rate
ROI	Return on investment
ROLO	Roll on load off
RORO	Roll on roll off
SAJ	Shipbuilders Association of Japan
SCA	Series compound amount factor
SOFAR	Sound fixing and ranging
SOLAS	Safety of life at sea
SPW	Series present worth factor
ST	Steam turbine
SWATH	Small water plane area twin hull vessel
TBT	Tri-butyl tin
TEU	Twenty feet equivalent unit
TLP	Tension leg platform
TP 1 cm	Tonnes per centimetre immersion

TSHD	Trailing suction hopper dredger
UI	Unmanned installation
ULCC	Ultra-large crude carrier
UNCLOS	United Nations Conference on Law of the Sea
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Program
VDR	Voyage data recorder
VLCC	Very large crude carrier
VLOC	Very large ore carrier
WSD	Working stress design

Contents