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Dynamic Analysis and Design of Offshore Structures

Second Edition

Springer

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To
My parents, teachers, family members and friends

Foreword

I consider it a great privilege to write a "Foreword" for this excellent book authored by Prof. Chandrasekaran of Indian Institute of Technology Madras. He has succeeded in closing a very evident gap namely unavailability of a suitable textbook dealing with the dynamic analysis and design of offshore structures for undergraduate and graduate students. As he has included elements of recent research into the topics, this book becomes ideal for research students also. Inclusion of large number of worked examples, objective/subjective type exercises with solution keys and MATLAB programs make it more valuable. I have recommended this book to undergraduate students in civil engineering majoring on "offshore structures", postgraduate students doing M.Sc. in "offshore engineering" as well as postgraduate research students working on related topics at my University.

Chapter 1 on "Introduction to Offshore Platforms" is very much informative dealing with all basic information needed. The excellent quality of illustrative figures and the large number of objective and subjective exercises with solutions make it very much valuable. Chapter 2 deals with "Environmental Forces". The various components of wind, wave, current, ice/snow, marine growth, earthquake loads as well as the mass/additional mass/damping effects have been dealt with. All other loads such as dead, live, fabrication, installation, lifting, load-out, transportation, launching, upending, and accidental components are explained. The chapter on "Introduction to Structural Dynamics" is exhaustive starting from the fundamentals and covering all aspects related to the dynamic equations and solutions. There are about 90 solved numerical examples and two MATLAB programs along with many additional exercises and examples to facilitate the understanding. The important aspect of "Damping" is covered in Chap. 4. "Hydrodynamic Response of Perforated Offshore Members" is covered in Chap. 5, where results of experimental and numerical studies are explained and compared in detail. The chapter on "Stochastic Dynamics" deals with very important topics like response spectrum, reliability, fatigue, and stress concentration factor. The final chapter on "Applications" describes detailed studies on Triceratops as well as TLP, dealing with the significance of springing and ringing responses. The experimental

investigations on VIV suppression systems and Buoyant Leg Storage and Regasification Platforms are of great research interest recently.

Based on my 50 years of academic/research/consultancy experience, I am very glad to recommend this book for the senior undergraduate and postgraduate students of civil, structural, applied mechanics, mechanical, naval arch, ocean, offshore, and marine engineering programs. Also, this book will serve as a very good reference book for practicing engineers working on related topics.

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Preface to Second Edition

The book titled Dynamic Analysis and Design of Offshore Structures: Second Edition is updated with recent advancements in the field of research in deep-water offshore platforms. The author felt the necessity to update the contents by including experimental and numerical investigations carried out on new-generation offshore platforms. This edition includes many solved examples and exercise for self-learning, in addition to computer codes for various applications in dynamic analyses. Basic intention is to make it a widely accepted textbook for the senior under graduate and postgraduate students of civil, structural, applied mechanics, mechanical, aerospace, naval arch, and ocean engineering program. This new edition will also have valuable contents with respect to new and recent research carried out by the author in structural dynamics. Each chapter is updated with a section of frequently asked Q&A in the form of exercise, which is likely to enhance understanding of this complex subject, through easy and self-explanatory text.

To encourage easy learning and a better tool for classroom teaching, this edition is also supported with slide presentation to conduct the course in a complete classroom mode. This edition is also an outcome of a few short courses conducted by the author in the recent past, which were well attended by practicing engineers, both from India and abroad. New sections in almost all chapters are included with authentic research findings, which are verified by wide publications in various journals in the recent past.

My sincere thanks are due to my research scholars, colleagues, and my students who have given their valuable input and feedback to develop the contents of this book. In particular, I wish to express my thanks to Ms. Indira, Mr. Lognath, Mr. Kiran, and Ms. Nagavinothini for their editorial assistance and graphic art support extended during the preparation of manuscript of the book.

Chennai, India — Srinivasan Chandrasekaran

Preface to First Edition

Offshore structures are unique in the field of engineering, as they pose many challenges in the development and conceptualization of the design. As innovative platform geometries are envisaged to alleviate the encountered environmental loads efficiently, detailed understanding of their analysis and basic design becomes inevitable. Structural dynamics, being an important domain of offshore engineering, require an intensive teaching and guidance to illustrate the fundamental concepts as applied to ocean structures in particular. With the vast experience of teaching this subject and guiding research, a humble attempt is made to present the basics in a closed form, which will be useful for the graduate students and researchers. The chapters in the book are organized such that the reader gets an overall idea of various types of offshore plants, basic engineering requirements, fundamentals of structural dynamics and their applications to preliminary design. Numerical examples and application problems are chosen to illustrate the use of experimental, numerical, and analytical studies in the design and development of new structural form for deep-water oil exploration. This book is a repetitive effort in the direction of capacity building of practicing and consulting offshore structural engineers who need to understand the basic concepts of dynamic analysis of offshore structures through a simple and straightforward approach.

Video lectures of the courses available at the following websites: (i) http://nptel.ac.in/courses/114106035; (ii) http://nptel.ac.in/courses/114106036; and (iii) http://nptel.ac.in/courses/114106037, which also substitute the classroom mode of understanding of the contents of this book.

My sincere thanks are due to my professors, colleagues, and my students who have given their valuable input and feedback to develop the contents of this book. In particular, I wish to express my thanks to Ms. Ezhil, Ms. Indira, and Ms. Madhavi for their editorial assistance and graphic art support extended during the preparation of manuscript of the book.

I also owe a lot of thanks to all the authors and publishers who have earlier attempted to publish books on structural dynamics and allied topics, based on which I developed my concepts on the said subject.

Srinivasan Chandrasekaran

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About the Author

Srinivasan Chandrasekaran is a Professor in the Department of Ocean Engineering at the Indian Institute of Technology Madras, Chennai, India. He has 23 years of teaching, research, and industrial experience, during which he has supervised many sponsored research projects and offshore consultancy assignments both in India and abroad. His current areas of research are dynamic analysis and design of offshore platforms, development of geometric forms of compliant offshore structures for ultra-deep water oil exploration and production, subsea engineering, rehabilitation and retrofitting of offshore platforms, structural health monitoring of ocean structures, seismic analysis and design of structures, and risk analyses and reliability studies of offshore and petroleum engineering plants. He has also been a Visiting Fellow at the invitation of the Ministry of Italian University Research to the University of Naples Federico II, Italy, for a 2-year period, during which he conducted research on the advanced nonlinear modeling and analysis of structures under different environment loads with experimental verifications. He has published 110 research papers in international journals and refereed conferences organized by professional societies around the world. He has also authored three textbooks which are quite popular among graduate students of civil and ocean engineering. He is a member of many national and international professional bodies and has delivered many invited lectures and keynote addresses at international conferences, workshops, and seminars organized in India and abroad.

Abbreviations

API	American Petroleum Institute
BLS	Buoyant Leg Structure
BOP	Blow Out Preventer
CDF	Cumulative distribution function
CFD	Computational Fluid Dynamics
DBE	Design basis earthquake
DNV	Det Norske Veritas
DPS	Dynamic Position Keeping Systems
FEED	Front-End Engineering Design
FFFP	Film Forming Fluoro Protein
FLS	Fatigue Limit State
FOSM	First-Order Second Moment Method
FPS	Floating Production Systems
FPSO	Floating Production, Storage and Offloading
FPU	Floating Production Unit
FSI	Fluid Structure Interaction
FSO	Floating Storage and Offloading
FSRU	Floating, Storage and Regasification Units
GBS	Gravity-Based Structure
GoM	Gulf of Mexico
ISSC	International Ship Structures Congress
JONSWAP	Joint North Sea Wave Project
KT	Kanani-Tajimi
LNG	Liquid Natural Gas
LRFD	Load Resistance Factor Design
MARIN	Maritime Research Institute Netherlands
MATLAB	Matrix Laboratory
MCE	Maximum credible earthquake
MF	Magnification Factor
MSL	Mean Sea Level
ODE	Ordinary Differential Equation

PC	Perforated Cover
PDF	Probability Density Function
PLS	Progressive Collapse Limit State
PM	Pierson Moskowitz
SALM	Single Anchor Leg Mooring system
SCF	Stress Concentration factor
SDOF	Single Degree of Freedom System
SHM	Simple Harmonic Motion
SLS	Serviceability Limit State
SSS	Subsea systems
THT	Tetra-hydrothiophene
TLP	Tension Leg Platform
ULS	Ultimate Limit State
VIV	Vortex induced Vibration
WSI	Wave Structure Interaction

Symbols

A	Cross-sectional area in mm^2
α	Philip's constant
$\overline{\alpha}$	Modified Philip's constant
a_n	Acceleration of water particle
β	Reliability Index
c	Damping element
C_c	Critical damping
C_H	Force coefficient in horizontal direction
C_V	Force coefficient in vertical direction
C_w	Wind pressure coefficient
C_D	Drag Coefficient
C_L	Lift Coefficient
$C_x(\tau)$	Auto-covariance function
d	Water depth
dA	Exposed area
dV	Disposed volume of water per unit length
D	Diameter of the ice cone
D_{max}	Maximum Dynamic amplification factor
D_g	Fatigue damage
δ	Surface drag coefficient/drag coefficient
δ_a	Crack growth
Δx	Centre-to-Centre distance between the column members of TLP
Δt	Dynamic tether tension variation
E	Young's modulus of steel
F	Cyclic frequency
F_i	Inertia force
F_w	Wind force
F_D	Drag Force
F_g	Average gust factor
F_L	Lift Force
F_r	Froude Number
Φ	Velocity Potential

f_{H}	Force on horizontal cylinder
$\overline{F}_o$	Force amplitude on the structure
$F(t)$	Excitation force
g	Acceleration due to gravity
$g(x)$	Limit state function
γ	Peakedness parameter
γ_{R}	Resistance factor
$\overline{F}_0$	Force amplitude on the structure
H	Wave Height
H_{s}	Significant Wave Height
h	Ice thickness
$h_{FX(t)}$	Impulse Response function
$H(\omega)$	Transfer function or frequency response function
K	Wave Number
k	Stiffness
Λ	Wavelength
L	Live loads
L_u	Integral length scale
L_b	Ice-breaking length
L_{c}	Characteristic length of ice
M	Margin of Safety
m	Mass element
M_{o}, M_1	Spectral moments
m_{n}	nth moment
μ	Coefficient of absolute viscosity of the film
$N(t)$	Number of upcrossings
n_g	Number of cycles
ω	Circular frequency
ω_d	Damped vibration frequency
ω_p	Peak frequency
ω_g	Natural frequency of the ground
P	Permanent loads
p_{f}	Probability of failure
R	Resistance of the structure
r	Radius of the cylinder
$R_x(\tau)$	Autocorrelation function
ρ	Density of fluid
ρ_{a}	Mass density of air (1.25 kg/m^3)
ρ_w	Density of water
S	Load effects
$S_F^+(\omega)$	One-sided power spectral density function
$S_U^+(\omega)$	Wind spectrum
S_0	Intensity of earthquake
σ_g^2	Variance of the ground acceleration

σ_u^2	Variance of wind speed at a reference height of 10 m
$\overline{\sigma}$	Spectral width parameter
σ_f	Bending strength of ice
T	Wave period
T_{p}	Peak Wave period
$\overline{T}'$	Period of ice
t_{f}	Time of first failure
Θ	Phase angle
$\overline{U}_{10}$	Mean wind speed at a height of 10 m above Mean Sea Level
$\dot{u}$	Horizontal water particle velocity
$\ddot{u}$	Horizontal water particle acceleration
u_{c}	Current velocity
u_{w}	Mean wave period
$\dot{v}$	Vertical water particle velocity
$\ddot{v}$	Vertical water particle acceleration
V	Submerged volume of the structure
v	Velocity of air in m/s
v_n	Velocity of water particle
V_{S1}, V_{S2}	Load factors
v_{10}	Wind speed at 10 m above MSL
v_{z}	Wind speed at an elevation of z m above MSL
$\overline{v}$	Mean wind velocity in m/s
$v(t)$	Gust component
$\dot{x}$	Velocity of the structure
$\ddot{x}$	Acceleration of the structure
$x(t)$	Instantaneous response vector of TLP
$x_{\mathrm{g}}(t)$	Ground displacement vector
x_{1g}	Horizontal ground displacement
x_{3g}	Vertical ground displacement
Z_{s}	Thickness of the surface layer
ξ	Damping ratio
Y	Crack and geometry-dependent factor
ξ_g	Damping of the ground

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