

Essentials of
Offshore Structures
Framed and Gravity Platforms

D.V. Reddy and A.S.J. Swamidas

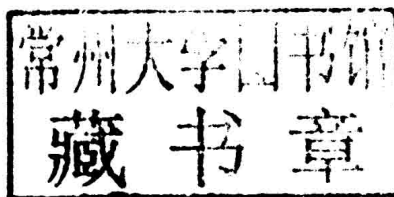


CRC Press
Taylor & Francis Group

Essentials of Offshore Structures

Framed and Gravity Platforms

D.V. Reddy
A.S.J. Swamidas



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

Cover photo courtesy of Hibernia Management and Development Company Ltd.

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2014 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed on acid-free paper
Version Date: 20130412

International Standard Book Number-13: 978-1-4200-6882-5 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Reddy, D. V.
Essentials of offshore structures : framed and gravity platforms / D.V. Reddy and A.S.J. Swamidias.
pages cm
Includes bibliographical references and index.
ISBN 978-1-4200-6882-5 (hardcover : alk. paper)
1. Offshore structures. I. Swamidias, A. S. J. II. Title.

TC1665.R43 2013
627'.98--dc23

2013002998

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

Essentials of Offshore Structures

Framed and Gravity Platforms

*To the Almighty Creator of Planet Ocean, with its
vast resources and mighty challenges.*

Preface

This textbook provides comprehensive coverage of the engineering concepts and design of off-shore drilling platforms for exploration and production. The book is intended to provide the senior undergraduate or graduate student with a clear and adequate presentation of both the theory and application of the fundamental principles of structural, fluid, and geotechnical mechanics to off-shore structures. Since the main focus is on the emphasis on pragmatic engineering applications for offshore structural design, research, and development, the text will also be very useful to those working in the design industry. In contradistinction to other books in the field, this text has numerous example and homework problems.

It is a pleasure to thank all the authors and publishers of the many books and articles, listed in the bibliography but too numerous to list here, who kindly permitted the reproduction of many figures and tables in the chapters. Thanks are due to Ms. Caroline Cynthia, who worked diligently for the processing of the figure and table permission requests and the typing of the manuscript. The publisher has been exceedingly cooperative in helping to meet the submission deadlines.

Finally, we must record our gratitude to our wives, Geetha and Melly, who stoically provided moral support to make this book possible.

Suggested Method of Coverage for a 16-Week Course

Lectures	
Date	Topic
Week 1	Chapter 1 and Chapter 2, Reading Assignment, Assignment 1 Chapter 3: Sections 3.3, 3.4, 3.5, and 3.8 Chapter 3: Sections 3.3, 3.4, 3.5, and 3.8—continued
Week 2	Chapter 3: Sections 3.3, 3.4, 3.5, and 3.8—continued Chapter 3: Sections 3.3, 3.4, 3.5, and 3.8—continued Chapter 3: Sections 3.3, 3.4, 3.5, and 3.8—continued
Week 3	Chapter 3: Sections 3.3, 3.4, 3.5, and 3.8—continued Chapter 3: Sections 3.3, 3.4, 3.5, and 3.8—continued, Assignment 2 Chapter 4: Sections 4.2 and 4.5
Week 4	Chapter 4: Sections 4.2 and 4.5—continued Chapter 4: Sections 4.2 and 4.5—continued Chapter 4: Sections 4.2 and 4.5—continued
Week 5	Chapter 4: Sections 4.2 and 4.5—continued, Assignment 3 Chapter 5: Sections 5.1 and 5.3 Chapter 5: Sections 5.1 and 5.3—continued
Week 6	Chapter 5: Sections 5.1 and 5.3—continued Chapter 5: Sections 5.1 and 5.3—continued, Assignment 4 Chapter 6: Sections 6.3.1 to 6.3.5, and 6.3.8
Week 7	Chapter 6: Sections 6.3.1 to 6.3.5, and 6.3.8—continued Chapter 6: Sections 6.3.1 to 6.3.5, and 6.3.8—continued Chapter 6: Sections 6.3.1 to 6.3.5, and 6.3.8—continued
Week 8	Chapter 6: Sections 6.3.1 to 6.3.5, and 6.3.8—continued Chapter 6: Sections 6.3.1 to 6.3.5, and 6.3.8—continued Chapter 6: Sections 6.3.1 to 6.3.5, and 6.3.8—continued

Week 9	Chapter 6: Sections 6.3.1 to 6.3.5, and 6.3.8—continued, Assignment 5 Chapter 7: Sections 7.2 to 7.4 Chapter 7: Sections 7.2 to 7.4—continued
Week 10	Chapter 7: Sections 7.2 to 7.4—continued Chapter 7: Sections 7.2 to 7.4—continued Chapter 7: Sections 7.2 to 7.4—continued
Week 11	Chapter 7: Sections 7.2 to 7.4—continued Chapter 7: Sections 7.2 to 7.4—continued, Assignment 6 Chapter 8: Sections 8.2, 8.3.2.2, and 8.4
Week 12	Chapter 8: Sections 8.2, 8.3.2.2, and 8.4—continued Chapter 8: Sections 8.2, 8.3.2.2, and 8.4—continued Chapter 8: Sections 8.2, 8.3.2.2, and 8.4—continued
Week 13	Chapter 8: Sections 8.2, 8.3.2.2, and 8.4—continued Chapter 8: Sections 8.2, 8.3.2.2, and 8.4—continued Chapter 8: Sections 8.2, 8.3.2.2, and 8.4—continued, Assignment 7
Week 14	Chapter 9: Sections 9.2, 9.3, and 9.4 Chapter 9: Sections 9.2, 9.3, and 9.4—continued Chapter 9: Sections 9.2, 9.3, and 9.4—continued
Week 15	Chapter 9: Sections 9.2, 9.3, and 9.4—continued Chapter 9: Sections 9.2, 9.3, and 9.4—continued Chapter 9: Sections 9.2, 9.3, and 9.4—continued, Assignment 8
Week 16	Review Review

Dr. D. V. Reddy

Florida Atlantic University

Boca Raton, FL

USA

Dr. A. S. J. Swamidas

Memorial University of Newfoundland

St. John's, Newfoundland and Labrador

Canada

Authors

D. V. Reddy, PhD (Liverpool), MS (Northwestern), DIC (Imperial College, London) BE (Madras), professor of civil, environmental, and geomatics engineering and director of the Center for Marine Structures and Geotechnique, Florida Atlantic University, is a registered professional engineer in Florida, Newfoundland and Labrador, and Alberta and a chartered engineer in the United Kingdom with a long and distinguished research, teaching, and administrative career on three continents. He has held professorships at the Indian Institute of Technology, Madras; Memorial University of Newfoundland, St. John's, Newfoundland; and the University of Florida, Gainesville, Florida, and visiting professorships at the University of Calgary, Alberta; South Dakota School of Mines and Technology, Rapid City, South Dakota; the Technical University of Hannover, Germany; and Chulalongkorn University (Fulbright scholar), Bangkok, Thailand. He has taught courses on offshore and coastal structures for over 30 years and worked in the industry (including consultancies) in India, the United Kingdom, and the United States. His research interests are in the areas of marine structures, materials, and geotechnical engineering, with particular focus on concrete technology and computational and analytical mechanics. He has authored over 370 papers, 3 books, and 3 conference volumes. He is a fellow of the American Concrete Institute and an active member of several of its technical committees. He was recognized as Distinguished Teacher of the Year 1988–1989 by Florida Atlantic University and Government Civil Engineer of the Year by the ASCE, South Florida Chapter in 1988. He is also the recipient of a number of outstanding research paper awards.

A. S. J. Swamidas, PhD (Indian Institute of Technology, Chennai), MSc (Madras University) and BEng (Hons) (Madras University) is an honorary research professor of engineering, Memorial University, St. John's, Newfoundland and Labrador, Canada. He has held professorships at the Indian Institute of Technology, Chennai, India, and at Memorial University, Newfoundland and Labrador (NL), Canada, with a distinguished academic, teaching, and research career. He has taught offshore structures to graduate and undergraduate students for more than 20 years and acted as a consultant to a number of companies. His research interests are in the area of dynamics of offshore and onshore structures with particular focus on computational mechanics and damage detection. He has authored over 210 papers/reports and two conference volumes. He was a registered professional engineer in Newfoundland and Labrador, Canada.

Contents

Preface.....	xv
Authors.....	xvii
 Chapter 1 Offshore Operations and Structural Development.....	1
1.1 Introduction	1
1.2 Current State of the Industry	3
1.3 Commercial Projections for the Offshore Industry	6
1.4 Structural Concept Evaluation and Innovative Developments	15
1.5 Legal Jurisdiction	30
1.6 History of Offshore Structural Development	32
Exercise Problems	35
Appendix	39
References	43
 Chapter 2 Components of a Typical Offshore Structure.....	47
2.1 Introduction	47
2.2 Functional and Structural Requirements of an Offshore Platform	50
2.3 Components of a Fixed Jacket Steel Platform	51
2.3.1 Jacket Substructure.....	53
2.3.2 Pile Foundation	58
2.4 Components of a Steel Jack-Up Platform	60
2.5 Components of a Concrete Gravity Platform	63
2.6 Components of a Ship Structure.....	70
2.6.1 Modern Trends	75
2.7 Components of a Semi-Submersible.....	75
Exercise Problems	81
References	83
 Chapter 3 Ocean Environment: Wind, Wave, Current, Tides, Ice, and Seismic Effects.....	85
3.1 Introduction	85
3.2 Description of the Ocean Environment.....	85
3.2.1 Winds	85
3.2.2 Currents.....	88
3.2.3 Waves.....	89
3.2.4 Tides.....	90
3.2.5 Earthquakes.....	92
3.2.6 Sea Ice and Other Forms of Ice in the Ocean	95
3.2.6.1 Icebergs.....	97
3.3 Ocean Winds and Wind Statistics	100
3.3.1 Introduction to Wind	100
3.3.2 Theoretical Characterization of Wind Regime	102
3.3.2.1 Probabilistic Nature of Wind Regime	103
3.3.3 Wind Velocity Profile	107

3.4	Ocean Waves and Wave Statistics	110
3.4.1	Introduction to Waves.....	110
3.4.2	Airy's Two-Dimensional Small Amplitude Linear Wave Formulation	111
3.4.2.1	Wave Particle Velocity, Acceleration, and Orbit	115
3.4.2.2	Wave Pressure, Energy, and Flux (or Power).....	117
3.4.3	Nonlinear Wave Formulation	120
3.4.4	Wave Statistics and Spectral Characterization.....	124
3.4.4.1	Theoretical Prediction Based on Statistical Characterization of Waves	125
3.4.4.2	Wave Prediction from Wind Characteristics	132
3.5	Ocean Currents.....	135
3.5.1	Introduction to Ocean Currents.....	135
3.5.2	Current Velocity Profile	136
3.6	Solar and Lunar Ocean Tides	139
3.6.1	Introduction to Solar and Lunar Ocean Tides.....	139
3.6.2	Theory of Tidal Formation.....	140
3.6.3	Water Level Fluctuations Including Tides	142
3.7	Seismological Considerations, Earthquakes, and Seaquakes.....	147
3.7.1	Introduction to Seismological Considerations, Earthquakes, and Seaquakes	147
3.7.2	Characteristic Features of Earthquake Phenomena	147
3.7.3	Magnitude and Intensity of Earthquakes	150
3.8	Ice Environment and Properties	153
3.8.1	Introduction to Ice Environment and Properties.....	153
3.8.2	Ice Properties.....	154
3.8.3	Modes of Possible Ice–Structure Interaction	157
	Exercise Problems	160
	References	167

Chapter 4	Seabed Mechanics	171
4.1	Introduction	171
4.2	Ocean Floor Characteristics and Characterization	171
4.3	Offshore Site Investigation and Equipment Used.....	177
4.3.1	Introduction	177
4.3.2	High-Resolution Geophysical Surveys.....	178
4.3.3	Drill and Wire-Line Coring Techniques Using Surface Support Vessel	179
4.3.3.1	Drill and Wire-Line Coring Using Surface Support Vessel	179
4.3.3.2	Sea Bottom-Located Rotary Drills with Wire-Line Corers and Operated by Divers	180
4.3.3.3	Vibro-Coring or Flexo-Coring (with Equipment at Sea Bottom) from Surface Support Vessel	180
4.3.3.4	Using Remote-Controlled Rotary Corers	181
4.3.3.5	Use of Gravity or Stationary Piston Corers	181
4.3.4	Remote In Situ Measurements	184
4.3.4.1	Modular Seacalf Cone Penetrometers	184
4.3.4.2	Wire-Line Vane Shear Test Equipment	190

4.4	Ocean Bed Soil Mechanics	195
4.4.1	Introduction	195
4.4.2	Identification of Marine Soil Characteristics	196
4.4.3	Structure of Soil	196
4.4.4	Atterberg Limits	199
4.4.5	Permeability of Soils	201
4.4.6	Stresses in Ocean Soils and Effective Stress Principle	202
4.4.7	Shear Strength and Failure of Ocean Soils	205
4.4.7.1	Laboratory Tests to Measure Shear Strengths	206
4.4.7.2	Stress–Strain Curves and Shear Strength Computation	207
4.4.7.3	Simple Methods for Estimating Undrained Cohesion	210
4.4.8	Consolidation (or Compressibility) of Ocean Soils	212
4.4.9	Stiffness of Soils	217
4.5	Bearing Capacities of Offshore Platforms	220
4.5.1	General	220
4.5.1.1	Scour	220
4.5.1.2	Mudslides	220
4.5.1.3	Sand Waves, Dunes, Banks	221
4.5.1.4	Seabed Subsidence	221
4.5.2	Bottom-Fixed Jacket Platforms on Piles	221
4.5.2.1	Stability of Fixed Platforms in Piles	221
4.5.2.2	Bearing Capacity of Piles in Compression and Tension	224
4.5.3	Bottom-Supported Gravity Platforms	228
4.5.3.1	Geotechnical Issues Related to Installation of Platform Structure on Site	229
4.5.3.2	Stability of Gravity Platform Structure under Static Loads and under Cyclic Environmental Loads	229
4.5.3.3	Settlement of Soil beneath Gravity Platform Foundations	231
4.5.4	Stress Distribution beneath Gravity Platform Foundation	231
4.5.5	Computation of Stability of Gravity Platform Structure	232
4.5.5.1	Installation Requirements	233
4.5.5.2	Slip (or Sliding) of Foundation Structure	235
4.5.5.3	Vertical Bearing Capacity of Soil beneath Gravity Platform Structure	236
4.5.5.4	Stability of Gravity Platform Structure with Respect to Overturning	236
	Exercise Problems	242
	References	245

Chapter 5 Materials and Their Behavior in the Ocean Environment 249

5.1	Material Requirements for Offshore Structures	249
5.1.1	Introduction	249
5.1.2	Ocean Environment and Materials	252
5.1.2.1	Ocean Water Chemistry	253
5.1.2.2	Biological Considerations	254
5.1.2.3	Marine Atmosphere	254
5.1.3	Development of Materials for Ocean Structures	255
5.1.3.1	Material Issues Relating to Construction Phase	255
5.1.3.2	Material Issues Relating to Operation Phase	260

5.2	Mechanical Properties for Ocean Use.....	266
5.2.1	Introduction.....	266
5.2.2	Properties Related to Strength and Deformation	269
5.2.3	Properties Related to Failure, Fatigue, and Fracture.....	274
5.2.3.1	Failure Strength of Materials.....	275
5.2.3.2	Fracture Mechanics	277
5.2.3.3	Fatigue Failure and Crack Initiation.....	284
5.2.3.4	Fatigue Failure and Crack Propagation	286
5.2.4	Introduction to Properties of a Range of Materials Used in the Ocean	295
5.2.4.1	Alloys of Iron and Steel.....	296
5.2.4.2	Low-Carbon Steels	296
5.2.4.3	Medium-Strength Steels	296
5.2.4.4	High-Strength Steels.....	296
5.2.4.5	Aluminum Alloys	300
5.2.4.6	Titanium Alloys.....	300
5.2.4.7	Nonmetallic Materials	300
5.3	Range of Material Properties and Material Selection	306
5.3.1	Introduction.....	306
5.3.2	Range of Material Properties for Ocean Structures.....	307
5.3.3	Selection of Materials for Ocean Structures	307
5.4	Marine Corrosion and Biodegradation.....	311
5.4.1	Introduction.....	311
5.4.2	Basic Mechanisms in Corrosion.....	311
5.4.3	Corrosion and Microbial Effects of Ocean Environment	315
5.4.3.1	Ocean Atmosphere	315
5.4.3.2	Seawater.....	316
5.4.3.3	Mineral, Mud, and Hydrocarbon Products.....	317
5.4.3.4	Carbon Dioxide.....	318
5.4.3.5	Biological and Microbiological Environments.....	318
5.4.4	Forms of Corrosion	320
5.4.4.1	General Corrosion.....	320
5.4.4.2	Galvanic Corrosion.....	320
5.4.4.3	Crevice Corrosion.....	321
5.4.4.4	Pitting Corrosion.....	321
5.4.4.5	Intergranular Corrosion	322
5.4.4.6	Differential Environmental Influences	322
5.4.4.7	Fretting Corrosion.....	322
5.4.4.8	Corrosion–Erosion.....	322
5.4.4.9	Stress Corrosion Cracking	322
5.4.4.10	Corrosion Fatigue	323
5.4.5	Corrosion Protection	324
5.4.5.1	Protective Coatings.....	324
5.4.5.2	Cathodic Protection	325
5.4.5.3	Anodic Protection.....	326
5.4.5.4	Corrosion Inhibition and Electrolyte Modification	326
	Exercise Problems	327
	References	332

Chapter 6	Environmental Forces on Offshore Structures.....	337
6.1	Introduction	337
6.1.1	Permanent (or Dead) Loads.....	337
6.1.2	Operating (or Live) Loads	337
6.1.3	Environmental Loads (Forces).....	338
6.1.4	Construction and Installation Loads (Forces).....	338
6.1.4.1	Lifting Forces	339
6.1.4.2	Load-Out Forces	340
6.1.4.3	Transportation Forces	340
6.1.4.4	Launching and Upending Forces.....	342
6.1.5	Accidental Loads (Forces).....	344
6.2	Design Conditions for Loads (Forces) Acting on the Structure	345
6.2.1	Limit State, Probability, and Safety	345
6.2.2	Limit State Design.....	347
6.3	Environmental Forces.....	350
6.3.1	Introduction	350
6.3.2	Wind Forces	351
6.3.3	Wave Forces	362
6.3.3.1	Wave Statistics	363
6.3.4	Wave Forces on Offshore Structures.....	363
6.3.4.1	Wave Forces on Slender Vertical Cylindrical Members....	364
6.3.4.2	Linearization of Nonlinear Wave Drag Force	366
6.3.4.3	Wave Forces Obtained from Airy's Linear Wave Theory	368
6.3.4.4	Effects of Relative Motion of the Structure.....	370
6.3.4.5	Wave Forces on Arbitrarily Oriented Cylindrical Members...	373
6.3.4.6	Wave Forces on Large Diameter Structures	376
6.3.5	Current Forces.....	378
6.3.5.1	Current Velocity Profiles	378
6.3.5.2	Current Forces Exerted on the Structure.....	382
6.3.5.3	Forces Exerted on the Structure due to Current–Wave Interaction	382
6.3.6	Earthquake Forces.....	386
6.3.7	Ice Forces on Ocean Structures.....	388
6.3.7.1	Ice Loads on Vertical Cylindrical Structures	389
6.3.7.2	Ice Loads on Sloping Structures.....	392
6.3.7.3	Limit Loads due to Environmental Interaction	395
6.3.8	Tides	400
6.3.9	Marine Growth.....	400
	Exercise Problems	401
	References	415
Chapter 7	Fundamental Considerations for Framed Offshore Structural Analysis.....	419
7.1	Introduction	419
7.2	Site Characteristics and Modeling Procedures for Analyses	419
7.2.1	Structural Skeleton for Force Application and Analysis.....	419
7.3	Hydrostatic Pressure and Buoyancy	429
7.4	Preliminary Considerations for Static Analysis and Design.....	431
7.5	Finite Element Applications for Framed Offshore Structural Analyses	438
7.5.1	Introduction	438
7.5.2	Use of Truss Elements in Offshore Structural Modeling.....	439

7.5.3	Plane Trusses.....	439
7.5.4	Space Trusses	449
7.5.5	Use of Beam Elements in Offshore Structural Modeling	452
7.5.5.1	Plane Frames.....	453
7.5.5.2	Member Stiffness Matrix for Horizontal Beam Member	453
7.5.5.3	Member Stiffness Matrix for Arbitrarily Oriented Member	456
7.5.5.4	Relating Member Stiffness Matrix to System Axes	458
7.5.5.5	Space Frames	463
7.6	Formulation of Solid–Fluid Interaction Problems.....	471
7.7	Simplified Lumped Mass/Stiffness Considerations for Dynamic Analyses.....	474
7.7.1	Introduction	474
7.7.2	Characterization of Offshore Structure as an SDOF System.....	477
7.7.3	SDOF Models in Offshore Structures	480
7.7.4	MDOF Systems	485
7.7.4.1	Two-Degrees-of-Freedom System	485
7.7.4.2	Three-Degrees-of-Freedom System	486
7.7.4.3	Many-Degrees-of-Freedom System.....	487
7.7.4.4	Solution Procedures	488
	Exercise Problems	492
	References	503

Chapter 8 Analysis and Design Considerations for Framed Steel Offshore Platforms 507

8.1	Introduction	507
8.1.1	Design Considerations.....	508
8.1.2	Design Codes and Provisions.....	510
8.2	Preliminary Design Considerations for Steel Jacket Offshore Structures	511
8.2.1	Typical Preliminary Design	511
8.2.2	Minimum Embedment Length of Piles (of Columns).....	513
8.2.2.1	Embedment Length	513
8.2.2.2	Equivalent Short Pile Length.....	515
8.2.2.3	Sufficiency of Selected Column Pile Section for Short Pile	516
8.2.3	Top Deck Analysis for Imposed Loads	516
8.2.3.1	Sufficiency of Vertical Column below Top Deck	517
8.2.3.2	Analysis and Design of Deck Framing Members.....	520
8.2.3.3	Truss Structures in the Top Deck	526
8.2.3.4	Reassessing Sufficiency of Vertical Column below the Top Deck.....	531
8.2.3.5	Tubular Members in Jacket Structure	532
8.2.3.6	Miscellaneous Considerations for Jacket Platform.....	535
8.3	Analysis of Pile Foundations for Offshore Structures.....	536
8.3.1	Introduction	536
8.3.2	Soil–Structure Interaction	536
8.3.2.1	Beam-on-Elastic (due to Hetenyi) Foundation	538
8.3.2.2	Beam-on-Winkler Foundation: p – y Curve Approach	540
8.3.2.3	Elastic Continuum Approach.....	541
8.3.2.4	Finite Element Approaches.....	541
8.4	p – y Curve Approach.....	541
8.5	Classical Derivations for Pile–Soil Interaction	546