Port Designer's Handbook

This book is dedicated to my family, in acknowledgement of their understanding and encouragement that have helped me so much in my research. Without their support I would neither have been able to start nor finish this book.

Port Designer's Handbook

Fourth edition

Carl A. Thoresen

Published by ICE Publishing, One Great George Street, Westminster,
London SW1P 3AA.

Full details of ICE Publishing representatives and distributors can be found at:
www.icebookshop.com/bookshop_contact.asp

Other titles by ICE Publishing:

Port Designer's Handbook.

Carl A. Thoresen. ISBN 978-0-7277-3228-6

Port Designer's Handbook, Second edition

Carl A. Thoresen. ISBN 978-0-7277-4086-1

Port Designer's Handbook, Third edition

Carl A. Thoresen. ISBN 978-0-7277-6004-3

www.icebookshop.com

A catalogue record for this book is available from the British Library

ISBN 978-0-7277-6307-5

© Thomas Telford Limited 2018

ICE Publishing is a division of Thomas Telford Ltd, a wholly-owned subsidiary of the Institution of Civil Engineers (ICE).

All rights, including translation, reserved. Except as permitted by the Copyright, Designs and Patents Act 1988, no part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior written permission of the Publisher, ICE Publishing, One Great George Street, Westminster, London SW1P 3AA.

This book is published on the understanding that the author is solely responsible for the statements made and opinions expressed in it and that its publication does not necessarily imply that such statements and/or opinions are or reflect the views or opinions of the publishers. While every effort has been made to ensure that the statements made and the opinions expressed in this publication provide a safe and accurate guide, no liability or responsibility can be accepted in this respect by the author or publishers.

While every reasonable effort has been undertaken by the author and the publisher to acknowledge copyright on material reproduced, if there has been an oversight please contact the publisher and we will endeavour to correct this upon a reprint.

Commissioning Editor: James Hobbs

Production Editor: Madhubanti Bhattacharyya

Market Development Executive: Elizabeth Hobson

Typeset by Academic + Technical, Bristol

Index created by Laurence Errington

Printed and bound in Great Britain by Bell and Bain, Glasgow

Contents

	Foreword	xi
	Preface	xiii
	Acknowledgements	xv
	About the author	xvii
01	Port planning	1
	1.1. Introduction	1
	1.2. Planning procedures	1
	1.3. Subsurface investigations	14
	1.4. Hydraulic laboratory studies	23
	1.5. Life-cycle management	27
	1.6. Safety management and risk assessment	28
	1.7. The International Ship and Port Facility Security (ISPS) Code and the Container Security Initiative (CSI)	31
	References and further reading	36
02	Environmental forces	39
	2.1. General	39
	2.2. Wind	39
	2.3. Waves	52
	2.4. Floating wave breakwater	68
	2.5. Current	71
	2.6. Ice forces	79
	References and further reading	83
03	Channels and harbour basins	85
	3.1. Channels and waterways	85
	3.2. Harbour basin	90
	3.3. Anchorage areas	99
	3.4. Area of refuge	102
	3.5. Grounding areas	103
	References and further reading	104
04	Berthing requirements	105
	4.1. Operational conditions	105
	4.2. Navigation	109
	4.3. Tugboat assistance	117
	4.4. Wind and wave restrictions	126
	4.5. Ship movements	137
	4.6. Passing ships	145
	4.7. Visibility	146
	4.8. Port regulations	146
	4.9. Availability of a berth	146
	References and further reading	147
05	Impact from ships	149
	5.1. General	149
	5.2. The theoretical or kinetic method	149
	5.3. The empirical method	157
	5.4. The statistical method	157
	5.5. Abnormal impacts	158

	5.6. Absorption of fender forces	159
	5.7. Ship 'hanging' on the fenders	161
	References and further reading	162
06	Design considerations	163
	6.1. General	163
	6.2. Design life	166
	6.3. Standards, guidelines and design codes	168
	6.4. Load combinations and limit states	169
	6.5. Load and concurrency factors	171
	6.6. Material factors and material strength	171
	6.7. Characteristic loads from the sea side	171
	6.8. Vertical loads on berth structures	173
	6.9. Horizontal loads on the berth	178
	6.10. Characteristic loads from the land side	178
	6.11. Summary of loads acting from the sea side	179
	References and further reading	179
07	Safety considerations	181
	7.1. General	181
	7.2. Specification safety	181
	7.3. Design safety	181
	7.4. Construction safety	185
	7.5. Personnel safety	185
	7.6. Operational safety	185
	7.7. Total safety	186
	References and further reading	186
08	Types of berth structures	189
	8.1. General	189
	8.2. Vertical loads	191
	8.3. Horizontal loads	193
	8.4. Factors affecting the choice of structures	199
	8.5. Norwegian and international berth construction	203
	References and further reading	203
09	Gravity wall structures	205
	9.1. General	205
	9.2. Block wall berths	205
	9.3. Caisson berths	209
	9.4. Cell berths	211
	References and further reading	222
10	Sheet pile wall structures	223
	10.1. General	223
	10.2. Driving of steel sheet piles	224
	10.3. Simple anchored sheet pile wall berths	230
	10.4. Solid platform berths	234
	10.5. Semi-solid platform berth	239
	10.6. Drainage of steel sheet piles	240
	10.7. Berth structures in arctic conditions	240
	References and further reading	240

11	Open berth structures	243
	11.1. General	243
	11.2. Column berths	249
	11.3. Pile berths	256
	11.4. Lamella berths	271
	11.5. Open berth slabs	272
	References and further reading	301
12	Floating berth structures	303
	12.1. General	303
	12.2. Mooring systems	311
	12.3. Floating quays and load levels	321
	References and further reading	324
13	Berth details	325
	13.1. General	325
	13.2. Traditional mooring system	325
	13.3. Automatic mooring system	337
	13.4. Lighting	340
	13.5. Electric power supply	340
	13.6. Potable and raw water supply	342
	13.7. Water drainage system	342
	13.8. Sewage disposal	343
	13.9. Oil and fuel interceptors	343
	13.10. Access ladders	344
	13.11. Handrails and guardrails	344
	13.12. Kerbs	345
	13.13. Lifesaving equipment	346
	13.14. Pavements	346
	13.15. Crane rails	354
	References and further reading	357
14	Container terminals	359
	14.1. Site location	359
	14.2. Existing areas	360
	14.3. Container ships	362
	14.4. Container terminal areas	365
	14.5. Container handling equipment	370
	14.6. Container handling systems in the container stacking area	377
	14.7. Container berth and terminal area requirements and capacity	391
	14.8. Hinterland	396
	14.9. The world's largest container ports	398
	References and further reading	398
15	Fenders	399
	15.1. General	399
	15.2. Fender requirements	400
	15.3. Surface-protecting and energy-absorbing fenders	401
	15.4. Different types of fender	406
	15.5. Installation	407
	15.6. Effects of fender compression	409

	15.7. Properties of a fender	412
	15.8. Single- and double-fender systems	419
	15.9. Fender wall	421
	15.10. Hull pressure	424
	15.11. Spacing of fenders	425
	15.12. Cost of fenders	426
	15.13. Damage to fender structures	427
	15.14. Calculation examples	429
	15.15. Information from fender manufacturers	433
	References and further reading	445
16	Erosion protection	447
	16.1. General	447
	16.2. Erosion due to wave action	451
	16.3. Erosion due to the main propeller action	452
	16.4. Erosion due to thrusters	455
	16.5. The required stone protection layer	458
	16.6. Erosion protection systems	459
	16.7. Operational guidelines	468
	References and further reading	469
17	Steel corrosion	471
	17.1. General	471
	17.2. Corrosion rate	473
	17.3. Astronomical low water corrosion	473
	17.4. Corrosion protection systems	474
	17.5. Stray current corrosion	479
	References and further reading	479
18	Underwater concreting	481
	18.1. General	481
	18.2. Different methods of underwater concreting	481
	18.3. The tremie pipe method	483
	18.4. The production of concrete for use in tremie pipes	495
	18.5. Anti-washout (AWO) concrete	497
	18.6. Damage during construction of new structures	501
	18.7. Repairs of new concrete	504
	18.8. Concrete plant and supervision	505
	References and further reading	508
19	Concrete deterioration	509
	19.1. General	509
	19.2. Durability of concrete berth structures	510
	19.3. Freezing and thawing	511
	19.4. Erosion	512
	19.5. Chemical deterioration	512
	19.6. Corrosion of reinforcement	514
	19.7. Resistivity	519
	19.8. Condition survey	519
	19.9. Concrete cover	521
	19.10. Surface treatments	522

	19.11. Condition survey	522
	19.12. Overloading of the berth structure	523
	19.13. In situ quality control	524
	References and further reading	524
20	Concrete maintenance and repair	525
	20.1. General	525
	20.2. Assessment	526
	20.3. Maintenance manual and service inspection	526
	20.4. Condition of a structure	527
	20.5. Repairs of concrete	528
	20.6. Repairs in zone 1 (permanently submerged)	531
	20.7. Repairs in zone 2 (tidal zone)	535
	20.8. Repairs in zone 3 (the splash zone or the area above highest astronomical tide (HAT))	537
	20.9. Cathodic protection	542
	20.10. Chloride extraction	547
	20.11. Cost of repairs	547
	References and further reading	548
21	Port maintenance	549
	21.1. Responsibility for maintenance	549
	21.2. Spares	549
	21.3. Management information	549
	21.4. Maintenance personnel	550
	21.5. Plant and equipment	550
	21.6. Infrastructure	551
	21.7. Optimisation of design to reduce future maintenance costs	553
	21.8. Maintenance management	556
	21.9. Maintenance strategy	556
	21.10. Inspections	557
	21.11. Rating and prioritisation	559
	21.12. Condition assessment ratings	559
	21.13. Post-event condition ratings	560
	21.14. Recommendations and follow-up actions	561
	21.15. Repair prioritisation	562
	20.16. Maintenance data management	562
	References and further reading	563
22	Ship dimensions	565
	22.1. General	565
	22.2. Ship dimensions	565
	22.3. Recommended design dimensions	579
	22.4. Recommendations	596
	References and further reading	596
23	Definitions	597
	References and further reading	606
24	Conversion factors	607
	24.1. Length	607

24.2.	Speed	607
24.3.	Area	607
24.4.	Volume	608
24.5.	Weight	608
24.6.	Force	608
24.7.	Force per unit length	608
24.8.	Force per unit area	608
24.9.	Moment	609
24.10.	Temperatures	609
24.11.	Useful data	609
	Index	611

Foreword

The fourth edition of this handbook on port and harbour design will, in my opinion, give our harbour colleagues around the world an opportunity not only to study Norwegian practices and solutions in the construction of everything from traditional berth structures to complicated oil and gas berths but also to gain knowledge and understanding of this fast-changing field.

The invitation to write the foreword to the fourth edition of the *Port Designer's Handbook*, which has been updated to cover the latest developments and standards, provides the ideal opportunity for me to express my belief that harbour experts around the world should share their knowledge and learning more frequently and widely with their colleagues.

This new edition will contribute to this important endeavour and make new information based on the author's long experience and knowledge available to others within the harbour and port sector, so that the field can continue to develop.

I feel, therefore, that this handbook will be invaluable both to practising harbour and port engineers and to postgraduate and senior university students as a survey of the state of the art.

Kirsti L. Slotsvik
Director General of the Norwegian Coastal Administration

Preface

The purpose of the fourth edition of the *Port Designer's Handbook* is to update its coverage, particularly regarding the berthing of large vessels and the design and construction of berth structures due to new developments in construction and the use of new materials. Over the last 5–10 years there have been considerable improvements as well as much new thinking in the design and construction of port and harbour structures. The main aim of the fourth edition is not to cover the full scope of port design and construction but to give guidelines and recommendations pertaining to the principal issues in the layout, design and construction of modern port structures, and the forces and loadings acting on them.

The use of new concrete technology for berth structures in the marine environment is dealt with in detail, as are the types of deterioration and methods of repair of these structures. Safety considerations and maintenance problems have also been extensively covered.

The book is mainly based on the author's more than 50 years' experience gained from practical engineering and research while working on some 850 port and harbour projects, big and small, both in Norway and abroad. For much of this time, he worked as chief engineer, with technical responsibility for the port and harbour division, for the largest Norwegian consulting company, Norconsult AS. After retiring, he started his own company, PORT-CAT.

This book includes material from the many lectures given by the author over the years on berth and port structures at the Norwegian University of Science and Technology, and at the Chalmers University of Technology, Sweden, as well as on postgraduate courses arranged by the Norwegian Society of Chartered Engineers.

In recent decades the growing interest in the design of port and harbour structures has produced a huge number of research reports and technical papers, especially from the International Navigation Association (PIANC). Much of this latest information has been evaluated and summarised in this handbook.

The author hopes that this book will be as readable as it is useful, providing practical guidance for engineers who are responsible for the design of port and harbour structures, and that it will contribute to the further development of the area. Many of the subjects mentioned in the text are worthy of further study, and there are further reading lists at the end of each chapter to direct readers to other detailed sources of information.

Acknowledgements

The author would like to express his deepest thanks to the many friends and colleagues who have contributed to this fourth edition, offering helpful encouragement, information, comments and suggestions. In particular, his sincere thanks go to the following people, whom the author has drawn upon for their experience and knowledge and who therefore deserve special mention:

Senior Geotechnical Engineer **Bjørn Finborud**, Norconsult AS, Norway:

Chapter 1

Late Senior Geotechnical Engineer **Odd Gregersen**, Norwegian Geotechnical Institute, Norway: Chapters 1 and 11

Senior Port Consultant **George R. Steel**, Scott Wilson Group, UK:

Chapters 1 and 14 and co-author of Chapter 21

Special Adviser **Arne Lothe**, Norconsult AS, Norway: Chapters 1 and 2

Senior Port Consultant **José Ricardo López Biagi**: Chapter 2

Professor **Shigeru Ueda**, Tottori University, Japan: Chapters 4, 15 and 22

Project Manager **Sergi Ametller**, Panama Canal Enlargement, Grupo Unidos por el Canal, Panama: Chapter 2

Professor **Knut V. Høyland**, The Norwegian University of Science and Technology, Norway: Chapter 2

Professor **Han Ligteringen**, Delft University of Technology, the Netherlands: Chapter 2

Project Manager **Frederic J. L. Hannon**, TOTAL Tour Atlantique, France: Chapter 3

Manager **Andy Dogherty**, OCIMF (Oil Companies International Marine Forum), UK: Chapters 1 and 3

Senior Marine Advisor **Graeme Robertson**, Shell Shipping Technology, UK: Chapters 3 and 4

Dr **Mark McBride**, HR Wallingford, UK: Chapters 3, 4 and 22

Consulting Engineer **Svein Ove Nyvoll**, Nyvoll Consult AS, Norway: Chapters 6, 11, 19, 20 and 21

Sector Head Structures **Steinar Leivestad**, Norwegian Council for Building Standardization: Chapter 6

Consulting Engineer **Hans Petter Jensen**, Sivilingeniør Hans Petter Jensen AS, Norway: Chapters 9, 10 and 11

Technical Director Dr **Svein Fjeld**, Dr techn. Olav Olsen AS, Norway: Chapters 3, 10 and 15

Structural Engineer **Knut-Ola Lunde**, Dr tech. Olav Olsen AS, Norway: Chapter 12

Senior Adviser and Strategy and Research Manager **Per G. Rekdal**, Oslo Port Authority, Norway: Chapter 13

Manager **Marc Sas**, IMDO International Marine and Dredging Consultants, the Netherlands: Chapter 16

Senior Hydraulic Engineer **Henk J. Verheij**, Delft Hydraulics, the Netherlands: Chapter 16

Port Director **Tore Lundestad**, Borg Port Authority, Norway: co-author of Chapter 14, and a general contributor to the book

Jari Pirhonen, Pirhonen Consulting Oy, Finland: Chapter 14

Technical Director **Stephen Cork**, HR Wallingford, UK: Chapter 14

Director **Gisli Viggosson**, Icelandic Maritime Administration, Iceland:
Chapter 15
Senior Adviser **Reidar Kompen**, Norwegian Public Road Administration,
Norway: Chapters 18, 19 and 20
Concrete Technologist **Bernt Kristiansen**, AF Gruppen ASA, Norway:
Chapters 18, 19 and 20
Chief Engineer **Trygve Isaksen**, Norconsult AS, Norway: Chapter 20.

In addition, the author's thanks go to the following friends and colleagues whom he has known for many years and has had the privilege of exchanging experiences with in the field of port and harbour engineering:

Senior Port Engineer **Hans Magnus Rossebø**, Norconsult AS, Norway
Late Professor **Alf Tørum**, Sintef Coastal and Ocean Engineering, Norway
President Harbour and Marine Construction **Lars Gunnar Andersen**,
Altiba Construction Company AS, Norway
Professor **Øivind A. Arntsen**, The Norwegian University of Science and
Technology, Norway
Manager and Discipline Lead Coastal Engineering **Rune Jerstad**, M.Sc.,
Dr techn. Olav Olsen AS, Norway
Regional Director **Fritjof Wangsvik**, The Norwegian Coastal Administration,
Region Nordland, and first delegate of PIANC Norway
Senior Project Manager Harbour Facilities, **Rikard Karlstrøm**,
Multiconsult AS, Norway
Senior Advisor **J. U. Broelsma**, Rijkswaterstaat, the Netherlands
Director **José Llorca Ortega**, Department of Technology and Standards,
Puertos del Estado, Spain
Technical Director **Svein-Inge Larsen**, Kristiansand Port Authority, Norway
Chief Engineer **Roar Johansen**, Borg Port Authority, Norway
Senior Port Engineer **Riyad Zen Al-Den**, Oslo Port Authority, Norway
Consulting Engineer **Kjell Thorvald Sørensen**, Oslo, Norway
Vice-President **Ron Heffron**, Moffatt and Nichol, Long Beach, CA, USA
Director **S. Ghosh**, Consulting Engineering Service, India.

The author would finally like to thank PIANC for permission to use information and materials from their publications and ICE Publishing for all of its help and assistance during the preparation of the typescript for the fourth edition of the *Port Designer's Handbook*.

About the author

Carl A. Thoresen graduated from the University of Strathclyde, Glasgow, in 1963. During more than 50 years as a professional consulting engineer he has been involved in practical engineering and research for some 850 different port and harbour projects, both in Norway and overseas as chief engineer and responsible consultant for the largest Norwegian consulting company, Norconsult AS. For the last decade he has run his own company, PORT-CAT. In addition, he has worked for the Norwegian Agency for International Development, the World Development Bank, the Asian Development Bank and the African Development Bank.

He has been involved in projects relating to waterways, complicated oil and gas harbours, commercial multi-purpose and container terminals, breasting and mooring dolphins, lighthouses, breakwaters, ferry berths, fishing harbours, marinas and small-craft harbours. His involvement in these projects has included planning, technical and economic evaluations, design, preparation of tender documents, tender evaluations and negotiation, construction supervision, maintenance and rehabilitation work.

In addition to authoring the four editions of the *Port Designer's Handbook* (2003, 2010, 2014 and 2018), he is the author of *Port Design: Guidelines and Recommendations* and the co-author of the *Norwegian Recommendations for Waterfront Structures* and the *Norwegian Recommendations for Concrete Construction in Water*.

He has been a member of many official technical committees for harbour design, constructions and waterfront structures, and actively involved in many working groups of the International Navigation Association (PIANC), including Working Group 33, *Guidelines for the Design of Fender System 2002*; Working Group 48, *Guidelines for Port Construction Related to Thrusters*; Working Group 116 (as chairman), *Safety Aspects Affecting the Berthing Operations of Large Tankers to Oil and Gas Terminals*; Working Group 135, *Design Principles for Container Terminals in Small and Medium Ports*; Working Group 145, *Berthing Velocity and Fender Design*; and Working Group 153, *Recommendation for the Design of Marine Oil Terminals*.