

Esa Eranti • George C. Lee



COLD REGION STRUCTURAL ENGINEERING



COLD REGION STRUCTURAL ENGINEERING

E. ERANTI

G. C. LEE

MCGRAW-HILL BOOK COMPANY

**New York St. Louis San Francisco Auckland Bogotá
Hamburg Johannesburg London Madrid Mexico
Montreal New Delhi Panama Paris São Paulo
Singapore Sydney Tokyo Toronto**

Library of Congress Cataloging-in-Publication Data

Eranti, Esa M.

Cold region structural engineering.

Bibliography: p.

Includes index.

1. Structural engineering—Cold weather conditions.

I. Lee, George C. II. Title.

TA636.E73 1986 624.1'0911 85-16797

ISBN 0-07-037034-6

Copyright © 1986 by McGraw-Hill, Inc. All rights reserved.
Printed in the United States of America. Except as permitted
under the United States Copyright Act of 1976, no part of this
publication may be reproduced or distributed in any form or by
any means, or stored in a data base or retrieval system, without
the prior written permission of the publisher.

1234567890 DOC/DOC 8932109876

ISBN 0-07-037034-6

*The editors for this book were Joan Zselezky and Ingeborg M. Stochmal,
the designer was Naomi Auerbach, and the production supervisor
was Sally Fliess. It was set in Caledonia by Progressive Typographers.*

Printed and bound by R. R. Donnelley & Sons, Inc.

CONTENTS

Preface ix

Chapter 1	ENVIRONMENT AND DEVELOPMENT	1
1.1	Introduction	1
1.2	The Climate	4
1.3	The Environment	8
1.4	Engineering Considerations	12
Chapter 2	SNOW AND ICING PROBLEMS	16
2.1	Characteristics of Snow Covers	16
2.2	Snow Loads	18
2.3	Snow Control	24
2.4	Construction on Snowfields	27
2.5	Avalanches	32
2.6	Icing on Structures	36
Chapter 3	ICE PROBLEMS	45
3.1	Ice and Engineering	45
3.2	Description of Ice Covers	50
3.2.1	Ice Classification	50
3.2.2	Some Features of Lake and Sea Ice Covers	53
3.2.3	Ice Covers in Rivers	60
3.3	Deformation and Strength Properties of Ice	65
3.3.1	Microstructure and Mechanical Properties	65
3.3.2	Elastic Behavior	67
3.3.3	Viscoelastic Behavior	69
3.3.4	Strength of Ice	72
3.4	Bearing Capacity of Ice Cover	76
3.4.1	General Considerations	76
3.4.2	Analytical Solutions	77

3.4.3	Moving Loads	81
3.4.4	Behavior of the Ice Cover under Static Loads	85
3.4.5	Methods to Thicken and Strengthen the Ice Cover Artificially	89
3.5	Ice Forces on Structures	91
3.5.1	Vertical Ice Forces Due to Water-Level Fluctuations	91
3.5.2	Thermal Ice Pressures	98
3.5.3	External Forces on Ice Cover	105
3.5.4	Static Ice Forces on Isolated Structures Due to Slow Horizontal Movements of the Ice Cover	111
3.5.5	Dynamic Ice Forces on Isolated Narrow Vertical Structures	117
3.5.6	Ice Forces on Sloping Structures	124
3.5.7	Pressure Ridges	127
3.5.8	Ice Forces against Wide Structures	131
3.5.9	Icebergs, Ice Islands, and Other Multiyear Ice Features	136
3.5.10	Local Ice Pressures	139
3.6	Ice Control and Structural Design	141
3.6.1	Ice Control in Rivers	141
3.6.2	Ice Problems in Power Generation	145
3.6.3	Some Aspects of Harbor Design	149
3.6.4	Some Engineering Problems Related to Winter Navigation	164
3.6.5	Ice and Offshore Hydrocarbon Development	169
Chapter 4	FROST	186
4.1	Seasonal Frost and Permafrost	186
4.1.1	Frozen Soil Classification	188
4.1.2	Frost Features	188
4.1.3	Frost and Engineering	195
4.2	Properties of Frozen Ground	198
4.2.1	Strength Properties	201
4.2.2	Deformation Properties	203
4.2.3	Thermal Properties	212
4.3	Ground Thermal Regime	215
4.3.1	Steady-State Solutions	215
4.3.2	Progress of Freeze-Thaw Boundary	215
4.4	Frost Action	224
4.4.1	Frost Heaving	226
4.4.2	Thaw Consolidation	229
4.4.3	Thaw Weakening	231
4.5	Measurement of Frost-Related Properties of Soils	234
4.6	Foundation Design	235
4.6.1	Foundations for Seasonal Frost Areas	235
4.6.2	Foundations for Permafrost Areas	251
4.7	Frost Action on Roads	270
4.7.1	Pavement Failures	270
4.7.2	Design against Frost Action	271
4.7.3	Drainage	288
4.8	Utility Lines	295
4.8.1	Utility Lines in Seasonal Frost	296
4.8.2	Utility Lines in Permafrost Areas	301

4.9	Special Constructions in Permafrost Areas	303
4.9.1	Pipelines	305
4.9.2	Tunnels	309
4.9.3	Dams	311
4.9.4	Coastal and Offshore Structures	315
4.10	Numerical Method for Frost Problems	320
4.10.1	Equation of Simultaneous Heat and Moisture Flux	322
4.10.2	Finite Element Formulation	330
4.10.3	Examples of Numerical Solutions	331
Chapter 5	CONSTRUCTION MATERIALS	342
5.1	Steel	343
5.1.1	Fracture Toughness and Other Considerations	343
5.1.2	Methods to Measure Fracture Toughness	344
5.1.3	Manufacturing Effects	347
5.1.4	Design Based on Fracture Mechanics	350
5.1.5	General Design Criteria	357
5.2	Concrete	360
5.2.1	Freezing of Fresh Concrete	361
5.2.2	Admixtures	366
5.2.3	Cracking and Drying	370
5.2.4	Effects of Low Temperatures on the Properties of Hardened Concrete	371
5.2.5	Effects of Freeze-Thaw Cycles on the Properties of Concrete	373
5.2.6	Special Applications	375
5.3	Wood	377
5.4	Aluminum	380
5.5	Plastics	381
5.6	Other Materials	382
Chapter 6	OTHER DESIGN CONSIDERATIONS	387
6.1	Thermal Insulation	387
6.1.1	Conduction	387
6.1.2	Air Leaks	391
6.1.3	Optimum Insulation	392
6.2	Moisture and Condensation	393
6.2.1	Vapor Diffusion and Condensation	393
6.2.2	Other Moisture Sources	399
6.2.3	Practical Moisture Control	399
6.3	Thermal Stresses	400
6.4	Fire	403
6.5	Some Roof Design Considerations	404
6.6	Some General Design Aspects	406
Chapter 7	COLD WEATHER CONSTRUCTION: TECHNIQUES AND RESTRICTIONS	409
7.1	Feasibility Considerations	409

7.2	Earthworks and Foundation Construction	410
7.2.1	Winter Excavation Operations in Seasonal Frost Areas	414
7.2.2	Excavation in Permafrost Areas	423
7.2.3	Earth Handling and Placement	425
7.2.4	Foundation Construction and Seasonal Frost	437
7.2.5	Foundation Construction in Permafrost Areas	439
7.3	Concrete Construction in Winter Conditions	446
7.3.1	Manufacturing	446
7.3.2	Delivery and Pouring	448
7.3.3	Protecting, Heating, and Curing	452
7.3.4	Quality Control	460
7.3.5	Joining Precast Concrete Elements	461
7.3.6	New Developments	463
7.4	Other Considerations	465
7.4.1	Steel Construction	465
7.4.2	Masonry Work	465
7.4.3	Roofing	468
7.4.4	Interior Work in Buildings	469

Chapter 8 CONSTRUCTION PROJECTS IN COLD ENVIRONMENTS 473

8.1	Year-Round Construction in Developed Subarctic Areas	473
8.2	Construction Projects in Arctic Environment	479
8.2.1	Seasonal Restrictions	479
8.2.2	Problems in Project Management	486
8.2.3	Project Execution and Construction Methods	489

Bibliography 502

Unit Conversion Table 519

Index 523

PREFACE

Because of the many research interests among its faculty, the Center for Cold Regions Engineering, Science, and Technology (CREST) was formally established at the State University of New York at Buffalo in 1979. The areas of expertise of the participants at the Center cover a wide range of fields in engineering and in the natural sciences. Shortly after the formation of CREST, the first author joined the engineering school as a research associate, working with the second author on a cold region structural engineering research project. During 1979 we held extensive discussions and concluded that there is a lack of published material summarizing available information on structural design and construction in cold regions. This led to our collaborative effort to collect and review available information and to the publication of two summary reports, "Introduction to Ice Problems in Civil Engineering" and "Introduction to Cold Regions Structural Design and Construction," which formed the basis of this book.

The field of cold region engineering covers a wide range of topical areas; however, it is not possible to summarize all the information in a single volume. Therefore, we do not claim that this book is, in any way, all inclusive. We have concentrated our efforts on some of the cold region engineering areas that have relatively practical significance. Special attention has been given to alternative engineering solutions and practical approaches, including simple design formulas, graphs, and tables. The theoretical backgrounds of selected problem areas are also briefly discussed as introductions to the subjects.

Because cold region engineering is multidisciplinary and international in nature, we have attempted to include most of the relevant information from North America, Scandinavia, and, to the extent possible, the Soviet Union, in order to provide the reader with a relatively uniform view of

some of the most feasible approaches and solutions to cold region engineering problems.

Although much emphasis has been given to practical engineering approaches, this book can also be used as a reference book in cold region engineering courses. The list of references contained in this book is fairly extensive, and it should be useful for those interested in furthering their understanding of the current state of the art.

In our effort to collect and digest the available information, we received invaluable assistance from the U.S. Army Cold Regions Research and Engineering Laboratory and the Technical Research Centre of Finland. It would not have been possible for us to complete the manuscript without the technical information provided to us by these two organizations. Further, we would like to acknowledge the support of the State University of New York at Buffalo and of Erkki Juva Consulting Engineers and Finn-Stroi Ltd. of Finland. We would also like to express our appreciation to a number of individuals who assisted us in various capacities during the preparation of the manuscript, including Jenn-Shin Hwang, Helen Liu, Liisa Viitanen, Leena-Marjut Rautio, and Pat Doeing.

Esa Eranti
George C. Lee

Cold region structural engineering Hardcover " January 1, 1986. by. E Eranti (Author). Best-sellers rank #5,239,946 in Books (See Top 100 in Books) #1,842 in Structural Engineering #454,666 in Reference (Books). Tell the Publisher! I'd like to read this book on Kindle. The Cold Regions Research and Engineering Laboratory (CRREL) is a United States Army Corps of Engineers, Engineer Research and Development Center research facility headquartered in Hanover, New Hampshire, that provides scientific and engineering support to the U.S. government and its military with a core emphasis on cold environments. CRREL also provides technical support to non-government customers. Cold region Structural Engineering. January 1986. Edition: II. Because of the many research interests among its faculty, The Center for Cold Regions Engineering, Science, and Technology (CREST) was formally established at the State University of New York at Buffalo in 1979. the areas of expertise of the participants at the Center cover a wide range of fields in engineering and in the natural sciences. Shortly after the formation of CREST, the first author joined the engineering school as a research associate, working with the second author on a cold region structural engineering research project. During 1979 we held extensive discussions and concluded the Structural Design for Cold Region Engineering Lecture 14 Theory of Plates Shunji Kanie. Theory of Plates Kirchhoff Plate Kirchhoff Plate Pure Bending Such as Bernoulli Euler Assumptions Isotropic and homogeneous The thickness of the plate is thin (Comparatively to the length and width) Linear filaments of the plate (Even after the deformation) Kirchhoff hypothesis. Technological advances for cold regions in research, development, and engineering practice are relevant to the journal. Theoretical papers must include a detailed discussion of the potential application of the theory to address cold regions problems. The journal serves a wide range of specialists, providing a medium for interdisciplinary communication and a convenient source of reference. Benefits to authors We also provide many author benefits, such as free PDFs, a liberal copyright policy, special discounts on Elsevier publications and much more.