
BRIDGE ENGINEERING

Construction and Maintenance

EDITED BY
Wai-Fah Chen
Lian Duan



CRC PRESS

Boca Raton London New York Washington, D.C.

The material in this book was previously published in *Bridge Engineering Handbook*, W.F. Chen and L. Duan, Eds., CRC Press, Boca Raton, FL, 2000.

Library of Congress Cataloging-in-Publication Data

Catalog record is available from the Library of Congress

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the authors and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage or retrieval system, without prior permission in writing from the publisher.

All rights reserved. Authorization to photocopy items for internal or personal use, or the personal or internal use of specific clients, may be granted by CRC Press LLC, provided that \$1.50 per page photocopied is paid directly to Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923 USA The fee code for users of the Transactional Reporting Service is ISBN 0-8493-1684-7/03/\$0.00+\$1.50. The fee is subject to change without notice. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

The consent of CRC Press LLC does not extend to copying for general distribution, for promotion, for creating new works, or for resale. Specific permission must be obtained in writing from CRC Press LLC for such copying.

Direct all inquiries to CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431.

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

Visit the CRC Press Web site at www.crcpress.com

© 2003 by CRC Press LLC

No claim to original U.S. Government works

International Standard Book Number 0-8493-1684-7

Printed in the United States of America 1 2 3 4 5 6 7 8 9 0

Printed on acid-free paper

Foreword

Among all engineering subjects, bridge engineering is probably the most difficult on which to compose a handbook because it encompasses various fields of arts and sciences. It not only requires knowledge and experience in bridge design and construction, but often involves social, economic, and political activities. Hence, I wish to congratulate the editors and authors for having conceived this thick volume and devoted the time and energy to complete it in such short order. Not only is it the first handbook of bridge engineering as far as I know, but it contains a wealth of information not previously available to bridge engineers. It embraces almost all facets of bridge engineering except the rudimentary analyses and actual field construction of bridge structures, members, and foundations. Of course, bridge engineering is such an immense subject that engineers will always have to go beyond a handbook for additional information and guidance.

I may be somewhat biased in commenting on the background of the two editors, who both came from China, a country rich in the pioneering and design of ancient bridges and just beginning to catch up with the modern world in the science and technology of bridge engineering. It is particularly to the editors' credit to have convinced and gathered so many internationally recognized bridge engineers to contribute chapters. At the same time, younger engineers have introduced new design and construction techniques into the treatise.

This handbook is divided into four volumes, namely:

Superstructure Design

Substructure Design

Seismic Design

Construction and Maintenance

There are 67 chapters, beginning with bridge concepts and aesthetics, two areas only recently emphasized by bridge engineers. Some unusual features, such as rehabilitation, retrofit, and maintenance of bridges, are presented in great detail. The section devoted to seismic design includes soil-foundation-structure interaction. Another section describes and compares bridge engineering practices around the world. I am sure that these special areas will be brought up to date as the future of bridge engineering develops.

I advise each bridge engineer to have a desk copy of this volume with which to survey and examine both the breadth and depth of bridge engineering.

T. Y. Lin

*Professor Emeritus, University of California at Berkeley
Chairman, Lin Tung-Yen China, Inc.*

Preface

The *Bridge Engineering Handbook* is a unique, comprehensive, and the state-of-the-art reference work and resource book covering the major areas of bridge engineering with the theme “*Bridge to the Twenty-First Century*.” It has been written with practicing bridge and structural engineers in mind. The ideal reader will be an M.S.-level structural and bridge engineer with a need for a single reference source to keep abreast of new development and the state-of-the-practice, as well as review standard practices.

The areas of bridge engineering include planning, analysis and design, construction, maintenance and rehabilitation. To provide engineers a well organized and user-friendly, easy to follow resource, the handbook is divided and printed into four Volumes: I Superstructure Design, II Substructure Design, III Seismic Design, and IV Construction and Maintenance.

Volume IV Construction and Maintenance contains constructions of steel and concrete bridges, substructures of major overwater bridges, construction inspections, construction control for cable-stayed bridges, maintenance inspection and rating, strengthening and rehabilitation.

The handbook stresses professional applications and practical solutions. Emphasis has been placed on ready-to-use materials. It contains many formulas and tables that give immediate answers to questions arising from practical works. It describes the basic concepts and assumptions omitting the derivations of formulas and theories. It covers traditional and new, innovative practices. An overview of the structure, organization, and content of the book can be seen by examining the table of contents presented at the beginning of the volume while an in-depth view of a particular subject can be seen by examining the individual table of contents preceding each chapter. References at the end of each chapter can be consulted for more detailed studies.

The chapters have been written by many internationally known authors in different countries covering bridge engineering practices, and research and development in North America, Europe, and Pacific Rim countries. This handbook may provide a glimpse of rapid global economy trend in recent years toward international outsourcing of practice and competition of all dimensions of engineering. In general, the handbook is aimed at the needs of practicing engineers, but materials may be re-organized to accommodate several bridge courses at the undergraduate and graduate levels. The book may also be used as a survey of the practice of bridge engineering around the world.

The authors acknowledge with thanks the comments, suggestions and recommendations during the development of the handbook, by Fritz Leonhardt, Professor Emeritus, Stuttgart University, Germany; Shouji Toma, Professor, Horrai-Gakuen University, Japan; Gerard F. Fox, Consulting Engineer; Jackson L. Durkee, Consulting Engineer; Michael J. Abrahams, Senior Vice President, Parsons Brinckerhoff Quade & Douglas, Inc.; Ben C. Gerwick, Jr., Professor Emeritus, University of California at Berkeley; Gregory F. Fenves, Professor, University of California at Berkeley; John M. Kulicki, President and Chief Engineer, Modjeski and Masters; James Chai, Supervising Transporta-

tion Engineer, California Department of Transportation; Jinrong Wang, Senior Bridge Engineer, California Department of Transportation; David W. Liu, Principal, Imbsen & Associates, Inc.

Wai-Fah Chen
Lian Duan

Editors



Wai-Fah Chen is presently Dean of the College of Engineering at the University of Hawaii. He was a George E. Goodwin Distinguished Professor of Civil Engineering and Head of the Department of Structural Engineering at Purdue University from 1976 to 1999.

He received his B.S. in civil engineering from the National Cheng-Kung University, Taiwan, in 1959, M.S. in structural engineering from Lehigh University, Pennsylvania, in 1963, and Ph.D. in solid mechanics from Brown University, Rhode Island, in 1966. He received the Distinguished Alumnus Award from the National Cheng-Kung University in 1988 and the Distinguished Engineering Alumnus Medal from Brown University in 1999.

Dr. Chen's research interests cover several areas, including constitutive modeling of engineering materials, soil and concrete plasticity, structural connections, and structural stability. He is the recipient of several national engineering awards, including the Raymond Reese Research Prize and the Shortridge Hardesty Award, both from the

American Society of Civil Engineers, and the T. R. Higgins Lectureship Award from the American Institute of Steel Construction. In 1995, he was elected to the U.S. National Academy of Engineering. In 1997, he was awarded Honorary Membership by the American Society of Civil Engineers. In 1998, he was elected to the Academia Sinica (National Academy of Science) in Taiwan.

A widely respected author, Dr. Chen authored and coauthored more than 20 engineering books and 500 technical papers. His books include several classical works such as *Limit Analysis and Soil Plasticity* (Elsevier, 1975), the two-volume *Theory of Beam-Columns* (McGraw-Hill, 1976–77), *Plasticity in Reinforced Concrete* (McGraw-Hill, 1982), and the two-volume *Constitutive Equations for Engineering Materials* (Elsevier, 1994). He currently serves on the editorial boards of more than 10 technical journals. He has been listed in more than 20 *Who's Who* publications.

Dr. Chen is the editor-in-chief for the popular 1995 *Civil Engineering Handbook*, the 1997 *Handbook of Structural Engineering*, and the 1999 *Bridge Engineering Handbook*. He currently serves as the consulting editor for McGraw-Hill's *Encyclopedia of Science and Technology*.

He has been a longtime member of the Executive Committee of the Structural Stability Research Council and the Specification Committee of the American Institute of Steel Construction. He has been a consultant for Exxon Production Research on offshore structures, for Skidmore, Owings, and Merrill in Chicago on tall steel buildings, and for the World Bank on the Chinese University Development Projects, among many others.

Dr. Chen has taught at Lehigh University, Purdue University, and the University of Hawaii.



Lian Duan is a Senior Bridge Engineer with the California Department of Transportation (Caltrans), U.S., and Professor of Structural Engineering at Taiyuan University of Technology, China. He received his B.S. in civil engineering in 1975, M.S. in structural engineering in 1981 from Taiyuan University of Technology, and Ph.D. in structural engineering from Purdue University, West Lafayette, Indiana, in 1990. Dr. Duan worked at the Northeastern China Power Design Institute from 1975 to 1978.

Dr. Duan's research interests cover areas including inelastic behavior of reinforced concrete and steel structures, structural stability, and seismic bridge analysis and design. With more than 60 authored or coauthored papers, chapters, and reports, his research focuses on the development of unified interaction equations for steel beam-

columns, flexural stiffness of reinforced concrete members, effective length factors of compression members, and design of bridge structures.

Dr. Duan is also an esteemed practicing engineer and a registered P.E. in California. He has designed numerous building and bridge structures. He was lead engineer for the development of the seismic retrofit design criteria for the San Francisco-Oakland Bay Bridge West Spans and made significant contributions to the project. He is co-editor of the *Structural Engineering Handbook* CRCnetBase 2000 (CRC Press, 2000) and the *Bridge Engineering Handbook* (CRC Press, 2000), winner of *Choice Magazine's* Outstanding Academic Title Award for 2000. He received the ASCE 2001 Arthur M. Wellington Prize for his paper "Section Properties for Latticed Members of San Francisco-Oakland Bay Bridge." He currently serves as Caltrans Structural Steel Committee Chairman and a member of the Transportation Research Board A2C02 Steel Bridge Committee.

Contributors

Masoud Alemi

California Department of
Transportation
Sacramento, California

Michael M. Blank

U.S. Army Corps of Engineers
Philadelphia, Pennsylvania

Simon A. Blank

California Department of
Transportation
Walnut Creek, California

Jackson Durkee

Consulting Structural Engineer
Bethlehem, Pennsylvania

Mahmoud Fustok

California Department of
Transportation
Sacramento, California

Ben C. Gerwick, Jr.

Ben C. Gerwick, Inc.
Consulting Engineer
San Francisco, California

Danjian Han

Department of Civil Engineering
South China University of
Technology
Guangzhou, China

F. Wayne Klaiber

Department of Civil Engineering
Iowa State University
Ames, Iowa

Luis R. Luberas

U.S. Army Corps of Engineers
Philadelphia, Pennsylvania

Murugesu

Vinayagamoorthy
California Department of
Transportation
Sacramento, California

Terry J. Wipf

Department of Civil Engineering
Iowa State University
Ames, Iowa

Quansheng Yan

College of Traffic and
Communication
South China University of
Technology
Guangzhou, China

Contents

1	Steel Bridge Construction	<i>Jackson Durkee</i>	1-1
2	Concrete Bridge Construction	<i>Simon A. Blank, Michael M. Blank, and Luis R. Luberas</i>	2-1
3	Substructures of Major Overwater Bridges	<i>Ben C. Gerwick, Jr.</i>	3-1
4	Bridge Construction Inspection	<i>Mahmoud Fustok and Masoud Alemi</i>	4-1
5	Maintenance Inspection and Rating	<i>Murugesu Vinayagamoorthy</i>	5-1
6	Strengthening and Rehabilitation	<i>F. Wayne Klaiber and Terry J. Wipf</i>	6-1
7	Cable Force Adjustment and Construction Control	<i>Danjian Han and Quansheng Yan</i>	7-1