Ultimate Limit State Design of Steel-Plated Structures

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Preface

Steel-plated structures are important in a variety of marine and land-based applications, including ships, offshore platforms, box girder bridges, power/chemical plants, bins, bunkers and box girder cranes. The basic strength members in steel-plated structures include support members (such as stiffeners, plate girders), plates, stiffened panels/grillages, and box girders. During their lifetime, the structures constructed using these members are subjected to various types of loading which is for the most part operational, but may in some cases be extreme or even accidental.

In the past, criteria and procedures for the design of steel-plated structures were primarily based on allowable stresses and simplified buckling checks for structural components. However, it is now well recognized that the limit state approach is a better basis for design since it is difficult to determine the real safety margin of any structure using linear elastic methods alone. It also readily follows that it is of crucial importance to determine the true limit state if one is to obtain consistent measures of safety which can then form a fairer basis for comparisons of structures of different sizes, types and characteristics. An ability to better assess the true margin of safety would also inevitably lead to improvements in related regulations and design requirements as well.

The design of marine structures such as FPSOs (floating, production, storage and offloading systems), mobile offshore drilling units, the deck structures of jacket platforms and even relatively novel concepts such as tension leg platforms by and large now tends to be perhaps less limit state oriented than land-based structures such as bridges, where the preference is now clearly for limit state design.

To obtain a safe and economic structure, the limit-state-based capacity as well as structural behavior under known loads must be assessed accurately. The structural designer can perform such a relatively refined structural safety assessment even at the preliminary design stage if there are simple expressions available for predicting the limit state behavior accurately. A designer may even desire to do this not only for the intact structure, but also for structures with premised damage, in order to assess their damage tolerance and survivability.

Most structural engineers in the industry are very skilled and well experienced in the practical structural design aspects based on the traditional criteria, but may need a better background in the concept of limit state design and related engineering tools and data. Hence there is a need for a relevant engineering book on the subject, which has an exposition of basic knowledge and concepts. Many structural specialists in research institutes continue to develop more advanced methodologies for the limit state design of steel-plated structures, but may sometimes lack the useful engineering data to validate them. Students in universities want to learn more about the fundamentals and practical

procedures regarding the limit state design, and thus need a book that provides useful insights into the related disciplines.

This book reviews and describes both fundamentals and practical design procedures for the ultimate limit state design of ductile steel-plated structures. Serviceability limit state based on buckling and accidental limit state based on collision and grounding accidents are also described. Existing mechanical model test results as well as nonlinear finite element solutions are included where relevant. The book is basically designed as a textbook so that the derivation of the basic mathematical expressions is presented together with a thorough discussion of the assumptions and the validity of the underlying expressions and solution methods.

It is the intention of the authors that the reader should be able to obtain an insight into a wider spectrum of limit state design considerations in both an academic and a practical sense. The present book is also to be seen in part as an easily accessed design tool box that hopefully facilitates learning by applying the concepts of the limit state for practice. Selected computer software which automates design methodologies or expressions presented in the book will hence be made available on an as-is basis through an internet web site. The user's manuals for the software, including illustrative example data sheets, will also be provided at the web site as noted in the appendices to this book.

The present book is primarily based on the two authors' own insights and developments obtained over more than a total of 40 years of professional experience, as well as existing information and findings by numerous other researchers and limit state practitioners. Wherever possible, we have tried our best to acknowledge the invaluable efforts of other investigators and practitioners, and if we have failed anywhere in this regard, it was solely inadvertent. Any additional information brought to our notice in this regard will of course be included in the future editions of this book.

The initiation of this book originated from a desire to summarize existing knowledge and also bring more advanced developments and insights obtained through various research projects undertaken by the Pusan National University, the American Bureau of Shipping (ABS), and of course many others in the past several years. In this regard, sincere thanks are given to many ABS staff members including Dr. Donald Liu, Dr. John Spencer, Dr. Yung Sup Shin and Dr. Ge Wang. Dr. Anil K. Thayamballi formerly worked for ABS for a number of years.

We are very pleased to acknowledge all those individuals who helped make this book possible. Dr. Ge Wang (American Bureau of Shipping, USA) and Prof. Manolis Samuelides (National Technical University of Athens, Greece) were involved in writing major sections of Chapter 9, while Prof. Weicheng Cui (Shanghai Jiaotong University, China) was involved in writing major sections of Chapter 10.

A number of experts kindly reviewed the draft manuscript and provided quite valuable and comprehensive comments to improve it at an earlier stage. Prof. Rene Maquoi (University of Liege, Belgium) reviewed Chapter 7. Prof. Norman Jones (University of Liverpool, UK) reviewed Chapter 9. Prof. Susumu Machida (Chiba University, Japan) reviewed Chapter 10. Mr. Hwa Soo Kim (Hyundai Heavy Industries, Korea) reviewed major parts of the entire draft manuscript. Prof. Toshiyuki Kitada (Osaka City University, Japan) and Prof. Norman Jones (University of Liverpool, UK) provided a number of useful references for Chapters 7 and 9, respectively. Dr. Ge Wang (American Bureau of Shipping, USA) provided some illustrations for Chapter 8, while Dr. Shengming Zhang

(Lloyd's Register of Shipping, UK) and Prof. Preben T. Pedersen (Technical University of Denmark, Denmark) provided some illustrations for Chapter 9.

In the initial stage of organizing the table of contents for this book, a number of experts, colleagues and friends provided valuable comments and interests. These individuals, in alphabetical order of their names include: Prof. Bilal M. Ayyub (University of Maryland, USA), Dr. Yong Bai (Doris Inc., USA), Prof. Wolfgang Fricke (University of Hamburg, Germany), Dr. Paul A. Frieze (PAFA Consulting Engineers, UK), Prof. Owen F. Hughes (Virginia Polytechnic Institute and State University, USA), Prof. Toshiyuki Kitada (Osaka City University, Japan), Prof. Jae Wook Lee (Inha University, Korea), Prof. Alaa E. Mansour (University of California at Berkeley, USA), Prof. Robert E. Melchers (The University of Newcastle, Australia), Prof. Preben T. Pedersen (Technical University of Denmark, Denmark), Dr. Sherif M. H. Rashed (MSC Software Japan Ltd., Japan), Dr. Philippe Rigo (University of Liege, Belgium), Prof. Yutaka Toi (Tokyo University, Japan), Prof. Yasumitsu Tomita (Osaka University, Japan), Prof. Yukio Ueda (Kinki University, Japan), Prof. Tomasz Wierzbicki (Massachusetts Institute of Technology, USA) and Prof. Tetsuya Yao (Osaka University, Japan).

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Jeom Kee Paik
Anil Kumar Thayamballi
February 2002

About the Authors

Jeom Kee Paik is Professor of Ship Structural Mechanics at the Pusan National University, Korea. He received his Bachelor of Science degree from the Pusan National University in 1981 and both the Master of Engineering (1984) and Doctor of Engineering (1987) degrees from Osaka University, Japan, from the faculties of naval architecture and ocean engineering. He has 20 years experience in teaching and research in the areas of limit state design, ultimate strength, impact mechanics (e.g. collision and grounding), fracture mechanics, age related degradation models and reliability of steel and aluminum alloy structures. Currently he is a standing committee member of the Royal Institution of Naval Architects in London. He has taken part in the activities of the International Ship and Offshore Structures Congress (ISSC). He has been a member of the ISSC Technical Committee on Ultimate Strength, and he currently chairs the ISSC Specialist Committee on Collision and Grounding. Prof. Paik is the author or co-author of over 300 publications in journals, conference proceedings and research reports. He is also the author of several textbooks and book chapters including *Computational Analysis of Complex Structures* published by the American Society of Civil Engineers (ASCE). He has received outstanding paper awards from the Royal Institution of Naval Architects (1995), the Society of the Naval Architects of Korea (1996), the Association of the Korea Science and Engineering Societies (1996) and the (US) Society of Naval Architects and Marine Engineers (2000). He is listed in the *Marquis Who's Who in Science and Engineering*, and *Who's Who in the World*. He was recently elected by the *Barons Who's Who* as one of the 500 new-century leaders for technology in the world as well as in Asia. Prof. Paik's e-mail address is `jeompaik@pusan.ac.kr`.

Anil K. Thayamballi is a senior staff consultant with the Marine Services Group of the Chevron Shipping Company, San Ramon, California, specializing in marine structural design and life cycle care. He obtained his Bachelor of Technology degree, with honors, from the Indian Institute of Technology at Kharagpur, and his Masters and Ph.D. degrees from the University of California at Berkeley, from the departments of naval architecture and offshore engineering. During and subsequent to his graduate studies, he worked for Mansour Engineering Consultants in Berkeley, California, and Imodco Offshore in Calabasas, California, in addition to a long stint at the marine classification society, American Bureau of Shipping, in New York. He was also Visiting Lecturer in Naval Architecture and Offshore Engineering at the University of California at Berkeley for two years. Dr. Thayamballi's professional experience spans 20 years. He has served on the ASCE Committee for Fatigue and Fracture Reliability, the American Petroleum Institute Resource Group RG-4 on Structural Element Behavior, and on the International Ship and Offshore

Structures Congress Technical Committee on Design Procedures and Philosophy, including as its Chairman. He currently serves on the Marine Technology Committee of the Society of Naval Architects and Marine Engineers (SNAME) in New York. Dr. Thayamballi is the author or co-author of over 60 refereed technical publications in the areas of limit state design, ultimate strength, fracture mechanics, fatigue technology, and reliability of steel structures. He received an outstanding paper award from SNAME in 2000 for a joint paper with Prof. Paik. He currently lives in Lafayette, California, in the San Francisco Bay area. Dr. Thayamballi's e-mail address is athayamballi@compuserve.com.

How to Use This Book

The intention behind writing this book is to develop a textbook and handy source to the principles of limit state design of steel-plated structures. This book has been designed to be well suited to university students who would be approaching the limit state design technology of steel-plated structures perhaps for the first time. In terms of more advanced and sophisticated design methodologies being presented, the book should also meet the needs of structural designers or researchers who are involved in the field of naval architecture, offshore, civil, architectural and mechanical engineering.

Hence, apart from its value as a ready reference and an aid to continuing education for the established practitioners, this book can be used as a textbook in teaching courses on limit state design of steel structures at the university level. The book in fact perhaps covers a wide enough range of topics which may be considered for more than one semester course! A teaching course of 45 hours for undergraduate students in structural mechanics or thin-walled structures may cover Chapter 1, Principles of Limit State Design, Chapter 2, Buckling and Ultimate Strength Behavior of Plate–Stiffener Combinations: Beams, Columns and Beam–columns, Chapter 3, Elastic and Inelastic Buckling of Plates, Chapter 5, Elastic and Inelastic Buckling of Stiffened Panels and Grillages, and Chapter 7, Ultimate Strength of Plate Assemblies: Plate Girders, Box Columns/Girders and Corrugated Panels. During that course, it is suggested that the student should carry out practice problems related to the design of steel-plated structures using the computer programs introduced in this book and available from the web site given in the appendices.

For graduate students who pass the teaching course for the undergraduate students noted above, a more advanced course of 45 hours may cover Chapter 1, Principles of Limit State Design (repeated), Chapter 4, Post-buckling and Ultimate Strength Behavior of Plates, Chapter 6, Post-buckling and Ultimate Strength Behavior of Stiffened Panels and Grillages, Chapter 8, Ultimate Strength of Ship Hulls (for students on a naval architecture course), Chapter 9, Impact Mechanics and Structural Design for Accidents, Chapter 10, Fracture Mechanics and Ultimate Strength of Cracked Structures, and together with hands-on practice of ultimate limit state design using in part the related computer programs.

Chapters 11, 12 and 13 as well as the rest of the chapters may be utilized by practitioners in industry or research institutes both for their work and for continuing education where desired. The computer programs together with more sophisticated design methodologies presented in this book will certainly be very useful for those researchers who want to study, facilitate and develop more advanced design concepts. The authors, in any event, have attempted to serve these many lofty aims in developing this book. They sincerely hope that their effort has been successful, however modestly!

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