NON-LINEAR STATIC AND CYCLIC ANALYSIS OF STEEL FRAMES WITH SEMI-RIGID CONNECTIONS

S.L. CHAN and P.P.T. CHUI

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ELSEVIER
2000
Amsterdam – Lausanne – New York – Oxford – Shannon – Singapore – Tokyo

ELSEVIER SCIENCE Ltd
The Boulevard, Langford Lane
Kidlington, Oxford OX5 1GB, UK

First edition 2000
Library of Congress Cataloging-in-Publication Data

Non-linear static and cyclic analysis of steel frames with semi-rigid connections/edited by Siu-Lai Chan and Pui-Tak Chui.
p.cm.
ISBN 0-08-042998-X
1. Structural frames - - Design. 2. Structural analysis (Engineering) 3. Steel, Structural. I. Chan, Siu-Lai. II. Chui, Pui-Tak.

TA660.F7 N66 2000
624.1'773 - - dc21

99-046371

British Library Cataloguing in Publication Data
A catalogue record from the British Library has been applied for.

ISBN: 0 08 042998 X

∞The paper used in this publication meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).

Printed in The Netherlands.

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FOREWORD

Since introduction of the limit state design philosophy focussing on the structural behaviour at limit states instead of controlling the allowable material stress used in the old permissible stress design concept, the true structural behaviour is ever sought by large-scale testing and numerical modelling. For the ultimate limit state, the collapse behaviour is of paramount importance under the action of static or dynamic loads. The safety of a structure can then be insured by inspecting the response of a structure under the action of design or expected loads during the life of a structure.

Based on second-order analysis allowing for the practical nature of external forces and structures such as load eccentricity and initial imperfections, the "Nonlinear Integrated Design and Analysis (NIDA)" concept has been applied by the authors in the design of a number of unconventional structures such as steel trusses, space frames, steel and bamboo scaffolding and pre-tensioned steel trusses. In NIDA, the linear structural model can be used since it allows modelling by a single element for each member and the uncertainty in assuming an effective length and for checking of structural instability is eliminated. However, this approach relies on the currently used first-plastic-hinge concept and collapse behaviour allowing for geometrical and material non-linearities of an indeterminate structure is not studied. As a result, the advantages of indeterminacy and reserve in strength after the first plastic hinge cannot be fully exploited.

The availability of low-cost personal computers in the past decade or so has provided a golden opportunity for the use of sophisticated and refined methods of analysis requiring extensive computational time and effort. This includes the collapse analysis of steel frames allowing for geometrical and material non-linearities and under time-dependent loads. On the other hand, reliable and simple kinematic formulations for geometrical change and material yielding are still essential along with the powerful computing machines of huge memory and high speed, not only because of saving in computer time, but they also will provide the practitioners with a physical insight into the structural behaviour. Engineers may like to have a physical grasp and to examine the significance of varying some parameters such as the effect of adopting more flexible joints on the overall response of a structure. This study is trivial by the present method but becomes too coarse and uncertain for the linear analysis with empirical formulae such as the Rankine–Merchant equation and too complicated by the finite shell element analysis. A general feel is that the mathematical computer model should be a true reflection of the overall structural characteristics so that the finite plate elements should be used to model a plate structure with two lateral dimensions much larger than the third dimension or thickness. Similarly a skeletal structure should be modelled by the one-dimensional beam-column element instead of a patch of shell elements. On the other hand, the shell elements should be more appropriate for study of local effects and stress concentration, but not for overall structural design and analysis in a design office.

This book is devoted to the discussion and studies of simple and efficient numerical procedures used in a personal computer for large deflection and elasto-plastic analysis of steel frames under the attack of static and dynamic loads. The text is designed for use by senior undergraduates and post-graduate students specialised in non-linear analysis of steel structures. This includes B.Eng., B.Sc. and M.Sc. students taking courses in related subject and M.Ph. and Ph.D. students researching advanced structural engineering and steel structures. This text can be used by practising engineers involved in advanced structural analysis and design of steel structures. The arrangement of this text is in the order of complexity. In Chapter 1, the basic fundamental behaviour and philosophy for design of structural steel is discussed. Emphasis is placed on different modes of buckling and the inter-relationship between different types of analysis. An introduction to the well-known P-δ and P-Δ effects is also given. Different levels of refinement for non-linear analysis are described and their limitations and advantages are summarised. In Chapter 2, the basic matrix method of analysis is presented. The linear stiffness and transformation matrices are derived from the first principle. Several examples of linear analysis of semi-rigid jointed frames are included. It is evident that one must have a good understanding of linear analysis before handling a second-order non-linear analysis. In Chapter 3, the linearized bifurcation and second-order large deflection are compared and the detailed procedure for a second-order analysis based on the Newton–Raphson scheme is described with the aid of a flow-chart. This load control iterative scheme can be used in the investigation of the structural response at design load level, but it is handicapped by divergence at limit load. In Chapter 4, various solution schemes for tracing of post-buckling equilibrium paths are introduced and the Minimum Residual Displacement control method with arc-length load step control is employed for the post-buckling analysis of two and three dimensional structures. Connections play an important role in the behaviour of moment-resistant steel frames. Chapter 5 is addressed to the non-linear behaviour and modelling of semi-rigid connections. Several numerical functions for description of moment versus rotation curves of typical connection types are introduced. The inclusion of semi-rigid connections and material yielding to the static analysis of steel frames is described in Chapter 6. The scope of the work in this Chapter is of general practical interest since the "Advanced Analysis" can be implemented by the described solution method with incorporation of design requirements stipulated in various design codes such as out-of-plumbness and member initial imperfections. In Chapter 7, the cyclic response of steel frames with semi-rigid joints but elastic material characteristics is studied. This assumption allows us to concentrate on the influence of semi-rigid connections over the global structural response and the effects of using various connection types on the structural behaviour. In the last Chapter 8, the combined effects of semi-rigid connections and plastic hinges on steel frames under time-dependent loads are studied using a simple springs-in-series model. For computational effectiveness and efficiency, the concentrated plastic hinge concept is used throughout these studies. The plastic hinge model adopts the section assemblage concept in which material in web takes axial force and in flange takes bending moments. This model is general, does not require pre-requisite plastic moment-axial force interactive function and can be applied to many types of sections.

This book is structured to study the non-linear behaviour of steel frames under static and time-dependent loads in a way of increasing difficulty with the first few Chapters covering simple material and the last few Chapters dealing with more complicated problems with various sources of non-linearity. The text is hoped to make a contribution to the implementation of the fascinating and elegant non-linear analysis and design concept to practical steel structures. With this computational skill and technique, better understanding of structural behaviour can be modelled and obtained, based on which more innovative structural schemes can be invented and constructed safely and economically.

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ACKNOWLEDGEMENTS

We are thankful to the Hong Kong Polytechnic University for providing resources in the completion of this book. We would also like to thank our overseas colleagues, who include Professors W.F. Chen, S. Kitipornchai, D.A. Nethercot and N.S. Trahair, for their encouragement and discussion. Special thanks should go to the students of the first author, who include but are not limited to Dr. G.W.M. Ho, Dr. A.K.W. So, Mr. C.Y. Yau and Dr. Z.H. Zhou, for their valuable contributions to his research partly described in this book. The authors are further indebted to Ove Arup and Partners (Hong Kong) Limited, for their encouragement. Appreciation should further be honoured to Miss Louisa McAra for her patience in proof-reading the text and Miss Freda Chow for the typing of some of this text. The first author would further like to express his gratitude to his wife, Shui-Wai, and his two sons, Lok-Man and Lok-Yan, for their bearance in allowing him to use their leisure time in writing this book. Without their support, this book would never have been completed. The second author would like to thank Miss Freda Chow, for her support in the course of writing this book. The first author is thankful to the Research Grant Council of the Hong Kong Special Administrative Region on the projects "Stability and non-linear analysis of glased frames" (B-Q080/95), "Static and dynamic advanced analysis for design of steel structures" (B-Q193/97) and "Nonlinear analysis of steel–concrete composite frame structures under gravity and lateral cyclic loads" (B-Q035/94), of which part of the findings are contained in this book. Finally, we gratefully acknowledge our pleasant cooperation with the publisher, Elsevier Science Ltd. and its Publisher Dr. J. Milne and his assistant Mrs. R. Davies and Dr. R. Maliukevičius of VTEX Ltd.

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