

Dynamic analysis of buildings for earthquake-resistant design¹

Murat Saatcoglu and Jag Mohan Humar

Abstract: The proposed 2005 edition of the National Building Code of Canada specifies dynamic analysis as the preferred method for computing seismic design forces and deflections, while maintaining the equivalent static force method for areas of low seismicity and for buildings with certain height limitations. Dynamic analysis procedures are categorized as either linear (elastic) dynamic analysis, consisting of the elastic modal response spectrum method or the numerical integration linear time history method, or nonlinear (inelastic) response history analysis. While both linear and nonlinear analyses require careful analytical modelling, the latter requires additional considerations for proper simulation of hysteretic response and necessitates a special study that involves detailed review of design and supporting analyses by an independent team of engineers. The paper provides an overview of dynamic analysis procedures for use in seismic design, with discussions on mathematical modelling of structures, structural elements, and hysteretic response. A discussion of the determination of structural period to be used in association with the equivalent static force method is presented.

Key words: dynamic analysis, earthquake engineering, elastic analysis, fundamental period, hysteretic modelling, inelastic analysis, National Building Code of Canada, seismic design, structural analysis, structural design.

Résumé : L'édition 2005 du Code National du Bâtiment du Canada spécifie l'analyse dynamique comme méthode de calcul de préférence afin de déterminer les forces de conception sismiques et les déflexions, tout en maintenant la méthode de force statique équivalente pour les régions à faible sismicité et pour les bâtiments ayant certaines limitations en hauteur. Les procédures d'analyse dynamique sont catégorisées comme étant linéaire (élastique) avec des méthodes de spectre de réponse modale élastique et des méthodes temporelles d'intégration numérique linéaire, ou des méthodes temporelles non-linéaires (inelastiques). Bien que les deux types d'analyse (linéaire et non-linéaire) requièrent une modélisation analytique soignée, cette dernière requière des considérations additionnelles afin de simuler correctement la réponse d'hystérésis et nécessite une étude spéciale, qui comporte une révision détaillée de la conception et des analyses secondaires provenant d'équipes indépendantes d'ingénieurs. Cet article procure un survol des procédures d'analyse dynamique utilisées pour la conception sismique, avec des discussions sur les modèles mathématiques des structures, éléments structurels et réponse d'hystérésis. Une discussion sur la détermination de la période structurale à être utilisée en association avec la méthode de force statique équivalente est présentée.

Mots clés : analyse dynamique, génie sismique, analyse élastique, période fondamentale, modèle d'hystérésis, analyse inélastique, Code National du Bâtiment du Canada, conception sismique, analyse structurale, conception structurale.

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Introduction

Structural response to earthquakes is a dynamic phenomenon that depends on dynamic characteristics of structures

and the intensity, duration, and frequency content of the exciting ground motion. Although the seismic action is dynamic in nature, building codes often recommend equivalent static load analysis for design of earthquake-resistant buildings due to its simplicity. This is done by focusing on the predominant first mode response and developing equivalent static forces that produce the corresponding mode shape, with some empirical adjustments for higher mode effects. The use of static load analysis in establishing seismic design quantities is justified because of the complexities and difficulties associated with dynamic analysis. Dynamic analysis becomes even more complex and questionable when non-linearity in materials and geometry is considered. Therefore, the analytical tools used in earthquake engineering have been a subject for further development and refinement, with significant advances achieved in recent years.

The seismic provisions of the 1995 edition of the National Building Code of Canada (NBCC 1995) are based on the equivalent static load approach with dynamic analysis permitted for obtaining improved distribution of total static base

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Written discussion of this article is welcomed and will be received by the Editor until 31 August 2003.

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Dynamic Analysis Of Buildings For Earthquake Resistant Design

William K. Stockdale



Dynamic Analysis Of Buildings For Earthquake Resistant Design:

Dynamic Analysis and Earthquake Resistant Design, 1997 *Simplified Dynamic Analysis of High-Rise Buildings* Hideo Takabatake, Yukihiko Kitada, Izuru Takewaki, Akiko Kishida, 2019-04-30 This book presents a simple analytical method based on the extended rod theory that allows the earthquake resistance of high rise buildings to be easily and accurately evaluated at the preliminary design stage It also includes practical software for applying the extended rod theory to the dynamic analysis of actual buildings and structures High rise buildings in large cities built on soft ground consisting of sedimentary rock tend to have low natural frequency If ground motion due to an earthquake occurs at distant hypocenters the vibration wave can be propagated through several sedimentary layers and act on skyscrapers as a long period ground motion potentially producing a resonance phenomenon that can cause severe damage Accordingly there is a pressing need to gauge the earthquake resistance of existing skyscrapers and to improve their seismic performance This book was written by authors who have extensive experience in tall building seismic design in Japan The software included enables readers to perform dynamic calculations of skyscrapers resistance to vibrations As such it offers a valuable resource for practitioners and engineers as well as students of civil engineering Earthquake Resistant Buildings M.Y.H. Bangash, 2011-08-19 This concise work provides a general introduction to the design of buildings which must be resistant to the effect of earthquakes A major part of this design involves the building structure which has a primary role in preventing serious damage or structural collapse Much of the material presented in this book examines building structures Due to the recent discovery of vertical components it examines not only the resistance to lateral forces but also analyses the disastrous influence of vertical components The work is written for Practicing Civil Structural and Mechanical Engineers Seismologists and Geoscientists It serves as a knowledge source for graduate students and their instructors DESIGN OF CONCRETE STRUCTURES BANDYOPADHYAY, J. N., 2008-07-07 This text primarily analyses different methods of design of concrete structures as per IS 456 2000 Plain and Reinforced Concrete Indian Standard Code of Practice 4th revision Bureau of Indian Standards It gives greater emphasis on the limit state method so as to illustrate the acceptable limits for the safety and serviceability requirements of structures Besides dealing with yield line analysis for slabs the book explains the working stress method and its use for designing reinforced concrete tension members theory of redistribution of moments and earthquake resistant design of structures This well structured book develops an effective understanding of the theory through numerous solved problems presenting step by step calculations The use of SP 16 Design Aids for Reinforced Concrete to IS 456 1978 has also been explained in solving the problems KEY FEATURES Instructional Objectives at the beginning of the chapter highlight important concepts Summary at the end of the chapter to help student revise key points Sixty nine solved illustrative examples presenting step by step calculations Chapter end exercises to test student s understanding of the concepts Forty Tests to enable students to gauge their preparedness for actual exams This comprehensive text is suitable for undergraduate

students of civil engineering and architecture It can also be useful to professional engineers *Post-Earthquake Fire Analysis in Urban Structures* Behrouz Behnam, 2017-02-03 Post earthquake fire is one of the most complicated problems resulting from earthquakes and presents a serious risk to urban structures Most standards and codes ignore the possibility of post earthquake fire thus it is not factored in when determining the ability of buildings to withstand load This book describes the effects of post earthquake fire on partially damaged buildings located in seismic urban regions The book quantifies the level of associated post earthquake fire effects and discusses methods for mitigating the risk at both the macro scale and micro scale The macro scale strategies address urban regions while the micro scale strategies address building structures covering both existing buildings and those that are yet to be designed **Modal Analysis Methods in Seismic Design for Buildings** William K. Stockdale, 1975 **Simplified Methods of Analysis for Earthquake Resistant Design of Buildings** Ernesto Cruz, Anil K. Chopra, 1985 **Dynamic Analysis and Earthquake Resistant Design: Methods of dynamic analysis**, 1997 **Nonlinear Dynamic Analysis of Building Frameworks Using a Continuum Model** Michael Joseph Chajes, 1990 **Nonlinear Structural Dynamic Analysis Procedures for Category I Structures**, 1979 **Design of Earthquake-resistant Buildings** Minoru Wakabayashi, 1986 Capacity design and nonlinear dynamic analysis of earthquake-resistant structures : [reprint of the keynote lecture, held at the 10th European Conference on Earthquake Engineering, Vienna, Austria, August 28 - September 2, 1994] Hugo Bachmann, Peter Linde, Thomas Wenk, European Conference on Earthquake Engineering, 1994 *Earthquake Analysis and Design* Mr. Rohit Manglik, 2024-04-06 EduGorilla Publication is a trusted name in the education sector committed to empowering learners with high quality study materials and resources Specializing in competitive exams and academic support EduGorilla provides comprehensive and well structured content tailored to meet the needs of students across various streams and levels Nuclear Science Abstracts, 1974 **Inelastic Dynamic Analysis of Mixed Steel-concrete Space Frames** Sherif M. El-Tawil, 1996 **Proceedings of the Symposium on the High-rise and Long-span Structures** Doboku Gakkai, 1964 **Earthquake Resistant Engineering Structures III** C. A. Brebbia, A. Corz, 2001 Third International Conference on Earthquake Resistant and Engineering Structures ERES III P facing t p **Proceedings of the Symposium** Nihon Gakujutsu Kaigi. Kyōryō kōzō kōgaku kenkyū Renraku Inkai, 1963 **Earthquake Analysis and Design of Industrial Structures and Infra-structures** Indrajit Chowdhury, Shambhu P. Dasgupta, 2018-10-06 Despite significant development in earthquake analysis and design in the last 50 years or more different structures related to industry infra structure and human habitats get destroyed with monotonic regularity under strong motion earthquake Even the recent earthquake in Mexico in September 2017 killed a number of people and destroyed national assets amounting to hundreds of millions of dollars Careful evaluation of the technology reveals that despite significant development in earthquake engineering most of the books that are available on the market for reference are primarily focused towards buildings and framed type structures

It is accepted that during an earthquake it is buildings that get destroyed most and has been the biggest killers of human life. Yet there are a number of structures like retaining walls, water tanks, bunkers, silos, tall chimneys, bridge piers, etc. that are equally susceptible to earthquake and if damaged can cause serious trouble and great economic distress. Unfortunately, many of these systems are analyzed by techniques that are too simplified, unrealistic, obsolete, or nothing is done about them, ignoring completely the seismic effects as no guidelines exist for their analysis and design like seismic analysis of counterfort retaining walls or dynamic pressures on bunker walls, etc. This highly informative book addresses many of these items for which there exists a significant gap in technology and yet remain an important life line of considerable commercial significance. The book is an outcome of authors' academic research and practice across the four continents: USA, Europe, Africa, and Asia in the last thirty-two years where many of these technologies have been put in practice that got tested against real time earthquakes. All methods presented herein have been published previously in peer-reviewed research journals and international conferences of repute before being put to practice. Professionals working in international EPC and consulting engineering firms, graduates taking advanced courses in earthquake engineering, doctoral scholars pursuing research in earthquake engineering in the area of dynamic soil structure interaction (DSSI) and advanced undergraduates wanting to self-learn and update themselves on earthquake analysis and design are greatly benefited from this book.

Computer Analysis and Design of Earthquake Resistant Structures D. E. Beskos, S. A. Anagnostopoulos, 1997

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