

# Dynamic analysis of buildings for earthquake-resistant design<sup>1</sup>

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 (inélastiques). Bien que les deux types d'analyse (linéaire et non-linéaire) requièrent une modélisation analytique soignée, cette dernière requiert 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 a été 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.

<sup>1</sup>This article is one of a selection of papers published in this Special Issue on the Proposed Earthquake Design Requirements of the National Building Code of Canada, 2005 edition.

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# Dynamic Analysis Of Buildings For Earthquake Resistant Design

**J Dewey**



## **Dynamic Analysis Of Buildings For Earthquake Resistant Design:**

**Dynamic Analysis and Earthquake Resistant Design** ,1997 **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 **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 Modal Analysis Methods in Seismic Design for Buildings William K. Stockdale,1975 Dynamic Analysis and Earthquake Resistant Design: Methods of dynamic analysis

,1997 **Dynamic Analysis and Earthquake Resistant Design** ,2000 Earthquake Resistant Building Design and Construction Norman B. Green,1981 *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

**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

*Dynamic Analysis and Earthquake Resistant Design* Japanese Society of Civil Engineers,2000-01-01 The second volume in a projected series on dynamic analysis and earthquake resistant design this text includes topics such as dynamic analysis of soil structure interaction system rupture of ground due to earthquake and its prediction basic method response calculations and nonlinear problems

**Computer Analysis and Design of Earthquake Resistant Structures** ,1997 *Dynamic Analysis And Earthquak* ,1997-01-01 *Dynamic Analysis of Buildings for Earthquake Design* José M. Roesset,American Society of Civil Engineers. Boston Society of Civil Engineers Section,Massachusetts Institute of Technology. Department of Civil Engineering,1975 *Design of Earthquake-resistant Buildings* Minoru Wakabayashi,1986 **Building Technology Publications** ,1978 **Building Technology Publications: 1976** Center for Building Technology (U.S.),1977 *Concrete Buildings in Seismic Regions* George G. Penelis,Gregory G. Penelis,2014-03-24 Bearing in mind that reinforced concrete is a key component in a majority of built environment structures Concrete Buildings in Seismic Regions combines the scientific knowledge of earthquake engineering with a focus on the design of reinforced concrete buildings in seismic regions This book addresses practical design issues providing an integrated comprehensible and clear presentation that is suitable for design practice It combines current approaches to seismic analysis and design with a particular focus on reinforced concrete structures and includes an overview of structural dynamics analysis and design of new R C buildings in seismic regions post earthquake damage evaluation pre earthquake assessment of buildings and retrofitting procedures seismic risk management of R C buildings within urban nuclei extended numerical example applications Concrete Buildings in Seismic Regions determines guidelines for the proper structural system for many types of buildings explores recent developments and covers the last two decades of analysis design and earthquake engineering Divided into three parts the book specifically addresses seismic demand issues and the basic issues of structural dynamics considers the capacity of structural systems to withstand seismic effects in terms of strength and deformation and highlights existing R C buildings under seismic action All of the book material has been adjusted to fit a modern seismic code and offers in depth knowledge of the background upon which the code rules are based It complies with the last edition of European Codes of Practice for R C buildings in seismic regions and includes references to the American Standards in effect for seismic design

**Building Technology Publications** Center for Building

Technology,1979      **NBS Special Publication** ,1968      **Structural Dynamics in Earthquake and Blast Resistant Design** B. K. Raghu Prasad,2020 Focusing on the fundamentals of structural dynamics required for earthquake blast resistant design Structural Dynamics in Earthquake and Blast Resistant Design initiates a new approach of blending a little theory with a little practical design in order to bridge this unfriendly gap thus making the book more structural engineer friendly This is attempted by introducing the equations of motion followed by free and forced vibrations of SDF and MDF systems D Alembert s principle Duhammel s integral relevant impulse pulse and sinusoidal inputs and most importantly support motion and triangular pulse input required in earthquake and blast resistant designs respectively Responses of multistorey buildings subjected to earthquake ground motion by a well known mode superposition technique are explained Examples of real size structures as they are being designed and constructed using the popular ETABS and STAAD are shown Problems encountered in such designs while following the relevant codes of practice like IS 1893 2016 due to architectural constraints are highlighted A very difficult constraint is in avoiding torsional modes in fundamental and first three modes the inability to get enough mass participation and several others In blast resistant design the constraint is to model the blast effects on basement storeys below ground level The problem is in obtaining the attenuation due to the soil Examples of inelastic hysteretic systems where top soft storey plays an important role in expending the input energy provided it is not below a stiffer storey as also required by IS 1893 2016 and inelastic torsional response of structures asymmetric in plan are illustrated in great detail In both cases the concept of ductility is explained in detail Results of response spectrum analyses of tall buildings asymmetric in plan constructed in Bengaluru using ETABS are mentioned Application of capacity spectrum is explained and illustrated using ETABS for a tall building Research output of retrofitting techniques is mentioned Response spectrum analysis using PYTHON is illustrated with the hope that it could be a less expensive approach as it is an open source code A new approach of creating a fictitious imaginary boundary to obtain blast loads on below ground structures devised by the author is presented with an example Aimed at senior undergraduates and graduates in civil engineering earthquake engineering and structural engineering this book Explains in a simple manner the fundamentals of structural dynamics pertaining to earthquake and blast resistant design Illustrates seismic resistant designs such as ductile design philosophy and limit state design with the use of capacity spectrum Discusses frequency domain analysis and Laplace transform approach in detail Explains solutions of building frames using software like ETABS and STAAD Covers numerical simulation using a well known open source tool PYTHON

## **Dynamic Analysis Of Buildings For Earthquake Resistant Design** Book Review: Unveiling the Power of Words

In a global driven by information and connectivity, the ability of words has become more evident than ever. They have the capacity to inspire, provoke, and ignite change. Such could be the essence of the book **Dynamic Analysis Of Buildings For Earthquake Resistant Design**, a literary masterpiece that delves deep to the significance of words and their affect our lives. Compiled by a renowned author, this captivating work takes readers on a transformative journey, unraveling the secrets and potential behind every word. In this review, we shall explore the book is key themes, examine its writing style, and analyze its overall impact on readers.

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