

# 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 (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.

<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

**Leslie E. Robertson, Takeo Naka**



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

**Dynamic Analysis and Earthquake Resistant Design** Dobuku Gakkai, 2001-01-01 The third volume in this series this deals with dams which generate electricity and maintain the natural resources and industrial facilities including power generating stations storage tanks and piping of nuclear power stations 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 Simplified Dynamic Analysis of High-Rise Buildings Hideo Takabatake, Yukihiro 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 A Complete Earthquake Resistant Design of Four-Story Regular Office Building for Pakistan Region Faheem A. Gul, 2022-08-25 The overall objective of this work program is to enhance the awareness of the public against vulnerability of upcoming earthquakes The specific objective of this work is To make our students capable to design a regular building independently The above mentioned specific goal is achieved with

the help of following three tasks defining the scope of current work i To calculate the external stability checks problem ii To design the superstructure of the building project by using SAP Structure analysis program software in order to create and analyze FEM Finite Element Model The analysis results will be used for the drawings of structural members of the building iii To Design the substructure of the building project by using SAFE software The analysis results of the building foundation will be used for the structural drawings of isolated footings

#### EARTHQUAKE RESISTANT DESIGN OF STRUCTURES

AGRAWAL, PANKAJ ,SHRIKHANDE, MANISH ,2006-01-01 This comprehensive and well organized book presents the concepts and principles of earthquake resistant design of structures in an easy to read style The use of these principles helps in the implementation of seismic design practice The book adopts a step by step approach starting from the fundamentals of structural dynamics to application of seismic codes in analysis and design of structures The text also focusses on seismic evaluation and retrofitting of reinforced concrete and masonry buildings The text has been enriched with a large number of diagrams and solved problems to reinforce the understanding of the concepts Intended mainly as a text for undergraduate and postgraduate students of civil engineering this text would also be of considerable benefit to practising engineers architects field engineers and teachers in the field of earthquake resistant design of structures

*Design of Earthquake-resistant Buildings* Minoru Wakabayashi,1986

**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

*Tall Building Criteria and Loading* Leslie E. Robertson,Takeo Naka,1980-01-01 Prepared by the Council on Tall Buildings and Urban Habitat of ASCE

This report examines the loads to which tall buildings are subjected so that engineers can precisely define the related structural elements that are necessary before translating a client s needs into a safe design The report explores five different classes of loads gravity loads and temperature affects earthquake loads wind loading and wind effects fire and accidental loads as well as quality control and overall safety considerations Steel buildings which hold the record for height tax the designer s ingenuity to provide adequate resistance to lateral loading Concrete buildings are both more numerous and widely distributed and for them vertical gravity loads may be the chief problem Both steel and concrete buildings and lateral and vertical loads are addressed Other subjects covered include dead live cyclic snow construction and combined loads code requirements meteorological and environmental factors in design firefighting provisions and modeling Contributions came from more than 800 contributors all international and professional and heavily representing design and industrial firms

Condensed references follow each chapter and a glossary is included *Earthquake Resistant Design* Mr. Rohit Manglik, 2024-07-29 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 *NBS Special Publication*, 1968 **Building Technology Publications**, 1983 *Nuclear Science Abstracts*, 1974 **Building Technology Publications** Center for Building Technology, 1978 **Earthquake Resistant Design and Risk Reduction** David J. Dowrick, 2009-07-20 Earthquake Resistant Design and Risk Reduction 2nd edition is based upon global research and development work over the last 50 years or more and follows the author's series of three books Earthquake Resistant Design 1st and 2nd editions 1977 and 1987 and Earthquake Risk Reduction 2003 Many advances have been made since the 2003 edition of Earthquake Risk Reduction and there is every sign that this rate of progress will continue apace in the years to come Compiled from the author's wide design and research experience in earthquake engineering and engineering seismology this key text provides an excellent treatment of the complex multidisciplinary process of earthquake resistant design and risk reduction New topics include the creation of low damage structures and the spatial distribution of ground shaking near large fault ruptures Sections on guidance for developing countries response of buildings to differential settlement in liquefaction performance based and displacement based design and the architectural aspects of earthquake resistant design are heavily revised This book Outlines individual national weaknesses that contribute to earthquake risk to people and property Calculates the seismic response of soils and structures using the structural continuum Subsoil Substructure Superstructure Non structure Evaluates the effectiveness of given design and construction procedures for reducing casualties and financial losses Provides guidance on the key issue of choice of structural form Presents earthquake resistant design methods for the main four structural materials steel concrete reinforced masonry and timber as well as for services equipment plant and non structural architectural components Contains a chapter devoted to problems involved in improving retrofitting the existing built environment This book is an invaluable reference and guiding tool to practising civil and structural engineers and architects researchers and postgraduate students in earthquake engineering and engineering seismology local governments and risk management officials *Promoting the Adoption and Enforcement of Seismic Building Codes* Robert B. Olshansky, 1998 *Nuclear Safety*, 1973 *Fifth World Congress on Disaster Management: Volume IV* S. Anand Babu, 2023-04-27 World Congress on Disaster Management WCDM brings researchers policy makers and practitioners from around the world in the same platform to discuss various challenging issues of disaster risk management enhance understanding of risks and advance actions for reducing risks and building resilience to disasters The fifth WCDM deliberates on three critical issues that pose the most serious challenges as well as hold the best possible promise of building resilience to disasters These are Technology Finance and Capacity WCDM has emerged as the largest global conference on

disaster management outside the UN system The fifth WCDM was attended by more than 2500 scientists professionals policy makers practitioners all around the world despite the prevalence of pandemic      **Scientific and Technical Aerospace Reports** ,1982 Lists citations with abstracts for aerospace related reports obtained from world wide sources and announces documents that have recently been entered into the NASA Scientific and Technical Information Database      **Stahlbau Kalender 2020** Ulrike Kuhlmann,2020-05-12 Der Stahlbau Kalender dokumentiert verl sslich und aus erster Hand den aktuellen Stand der Stahlbau Regelwerke Seit der Ausgabe 2011 werden systematisch alle Teile von Eurocode 3 mit ihren Nationalen Anh ngen kommentiert In dieser Ausgabe werden neben der Aktualisierung von Teil 1 1 Allgemeine Bemessungsregeln und Regeln f r den Hochbau auch Erl uterungen f r die neuen Regeln der zuk nftigen Eurocode Generation pr sentierte Au erdem wird f r den Metallleichtbau auf die sich abzeichnenden nderungen und Erg nzung in Eurocode 3 Teil 1 3 f r kaltgeformte Bauteile und Bleche und in Eurocode 9 Teil 1 4 eingegangen Der Stahlbau ist in grundlegender Weise mit dem Leichtbau und der Anwendung von faserverst rkten Kunststoffen verbunden Die funktionalen und wirtschaftlichen Vorteile wie z B geringes Eigengewicht hohe mechanische Festigkeit einfache Montage niedrige thermische Leitf higkeit und vielf ltige architektonische Gestaltungsm glichkeiten werden f r Sandwichelemente im Membranbau f r tempor re und f r fliegende Bauten bis hin zu Leichtbaubr cken genutzt Zu diesen Themen enth lt das Buch Beitr ge ber die ingenieurm ige Auslegung von Bauteilen mit Erl uterungen zu den Konstruktionsregeln Bei Leichtbau Konstruktionen gilt es ein besonderes Augenmerk auf das Schwingungsverhalten zu legen Dieses wird in zwei Beitr gen neben der Erdbebenbemessung besonders vertieft Ein weiteres grundlegendes Thema des Stahlbaus der Korrosionsschutz wird in zwei ausf hrlichen Beitr gen mit allen Aspekten und M glichkeiten umfassend und aktuell behandelt Das Buch ist ein Wegweiser f r die richtige Berechnung und Konstruktion im gesamten Stahlbau mit neuen Themen in jeder Ausgabe Es stellt anwendungsbereites Wissen mit zahlreichen Beispielen zur Verf gung Herausragende Autoren aus der Industrie aus Ingenieurb ros und aus der Forschung vermitteln Grundlagen und geben praktische Hinweise      Building Technology Publications: 1976 Center for Building Technology (U.S.),1977

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