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Seismic Design of RC Buildings

Theory and Practice

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Foreword

In recent years, earthquake engineering has been introduced as a subject at undergraduate and postgraduate levels. However, a beginner, with only an elementary knowledge of the theory of vibrations, finds it difficult to grasp the concepts of inertia forces, ductility, etc. Secondly, because of the vastness of the subject and its complexity, most practicing engineers find it difficult to access and comprehend the analytical process. Thus, at present, there is a clear need for a book which will explain the fundamentals of earthquake-resistant design in such a manner that students as well as practicing engineers can absorb them with ease. It is my strong belief that this book will meet such a requirement.

The authors are well known for their ability to present complex concepts in a simple manner. Mr. Manohar is known for his consultancy work at both national and international levels and is the recipient of the Indian Concrete Institute's Lifetime Achievement Award. He has also trained a large cross-section of professional engineers, architects, students, and supervisors in concepts of structural engineering and earthquake-resistant design. Professor Madhekar is dedicated to her work as a faculty for this subject. It is not without reason that she is held in high esteem by her students and employers. In addition, both authors have delivered lectures under the "Capacity Development Programme" of the Government of Maharashtra, sponsored by UNDP as well as by many other organisations. Teaching is a passion for both authors, and these qualities are effectively reflected in this publication.

Some of the attractive features of this book are as follows:

1. The fundamentals of structural dynamics and their practical applications to earthquake-resistant design of buildings are dealt with side by side. This unified approach is very useful to fully understand the practical implications of theoretical concepts. I am confident that students and practicing engineers will appreciate this approach.

2. In this book, the reader is initiated into the subject of response evaluation of structures' under ground motion excitation through an "easy-to-understand" concept, namely, simple harmonic motion. This simple theoretical approach is gradually extended to cover linear single-degree-of-freedom systems under earthquake excitation and then continues systematically right up to the nonlinear analysis of multistorey buildings. The mathematical content is highly focused and comprehensive. In my opinion, the book satisfies virtually all the needs of students, teaching faculty, and professional engineers.
3. There are several solved examples which cover the evaluation of forces and moments for which various types of practical structures, such as RC buildings, masonry structures, shear walls, retaining walls, and piles, need to be designed. Also included are members such as drag struts and collectors. It also deals with the subjects of soil-structure interaction and the effect of passive base isolation on the response of a building. This will definitely assist the professional engineers reading this book.
4. Earthquake engineering is a multifaceted subject requiring inputs from various disciplines to create a sound earthquake-resistant structure. For instance, it encompasses subjects such as inelastic material properties of primary building materials, important geotechnical aspects that play a role in soil-structure coupling and lateral loads on retaining walls, and importance of ductility, to name just a few. The authors have done well to include the right quantum of information from such topics to aid the designer in the design process.
5. It covers the subject of modal analysis in depth including the important missing mass correction approach. The authors have also provided a theoretical background to formulae used for evaluation of modal mass, participation factor, etc. This highly mathematical topic is developed in a systematic and easy-to-understand fashion which will benefit faculty and students alike.
6. The authors have drawn readers attention to a possible tension shift in shear walls and beams. This has an important bearing on reinforcement detailing.
7. Brick adobes are often badly hit during an earthquake because of their heavy weight and inadequate attention paid to incorporate anti-seismic measures. I am glad the authors have included requirements for "confined brickwork," as these are relatively inexpensive to implement and can certainly improve a building's performance during an earthquake.
8. The authors have used the medium of an illustrative example to explain the manner of conducting a nonlinear time history analysis for both a SDOF as well as a MDOF system. As a result, this difficult area is presented in a very clear, step-by-step manner, which is very easy to follow for a student.
9. The student as well as the professional designer will benefit greatly from coverage of topics such as (1) pushover analysis, (2) soil structure coupling, (3) piles exposed to lateral loads, (4) limit state design of brick masonry, and (5) performance-based design.

This book is well suited for senior-level graduate and postgraduate courses in Structural Dynamics and Earthquake Engineering. The book contains a wealth of information which is very difficult to obtain, and thus it will be an excellent reference document for both students and practicing professionals. It will provide a vital link between theory and practice.

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15 September 2014

Preface

The writing of this book has been both a joy and a challenge. Decades of our combined experience in consulting and teaching at postgraduate level in earthquake-resistant design has given us an opportunity to bring the complex theoretical concepts of earthquake engineering within easy reach of students, teaching faculty, and practicing professionals in a user-friendly manner. It is our belief that when theoretical concepts are well understood, it gives an impetus to put them into practice. The real challenge has been to address a wide spectrum of readers ranging from architects to structural engineers and from students to teaching faculty.

Over the centuries, mankind has had to deal with many natural hazards, such as cyclones, floods, droughts, and volcanic eruptions, which cause huge losses in terms of lives lost and property destroyed, but the one most feared is an earthquake. This fear stems principally from the totally unpredictable nature of this hazard, its suddenness, and the colossal destruction of life and property that it can cause. Contrary to common belief, a very large number of detectable earthquakes occur annually in the world, of which only about 20 % are felt and cause varying degrees of damage. That one can build an earthquake-proof structure is only an idealistic thought. Apart from the fact that such a structure could be economically unviable, one cannot guarantee the safety of a structure against a motion whose characteristics at best can only be an informed guess. Hence, in seismic-resistant design, the primary aim is to minimize damage and thus also save lives.

The Indian subcontinent is under a real threat of a moderate or major earthquake, and over the years, the country has experienced its share of seismic activity. Some of these have caused severe damage to property and loss of life. For a country as densely populated as ours, the need for affordable space for urban expansion will drive human habitat into regions with high seismic risk. It is therefore very important that we develop a clear understanding of the concepts of earthquake-resistant design and implement the correct design and construction practices in order to minimize damage and loss of life, should an earthquake strike.

Adobes are at a disadvantage during an earthquake because of their heavy weight. Secondly, in rural areas, where brick housing is common, there is still considerable lack in understanding of the provisions required to improve their seismic resistance. However, such structures would continue to be built in large measure because of their relatively low cost, availability of materials locally, and their thermal insulation and fire-resistant properties. It is for this reason that we have included a chapter dealing with confined masonry. Such masonry can bring about improvement in seismic resistance of such abodes, at minimal extra cost. The subject is then extended to cover design aspects of reinforced brickwork to tackle higher-end masonry buildings.

The primary user group envisaged includes students, teaching faculty, and professional engineers. This book is our small contribution towards achieving good quality in the design and construction of buildings and for students and professionals to clearly understand the concepts of sound earthquake engineering. Some recent developments, as far as India is concerned, have also been included to provide the student and practicing engineer an insight into these areas, comprising (1) base-isolated buildings, (2) strength design of brick masonry, (3) concepts of performance-based design, (4) principles of capacity-based design, etc.

This book deals with the design and detailing requirements for seismic resistance of new buildings. The normal design of buildings is well understood. Hence, this book focuses only on seismic engineering aspects of the design process. A large number of examples on important topics are included for the benefit of students and practicing engineers. The examples are chosen to illustrate specific areas of design fundamentals. It is not the intention of this book to present exhaustive step-by-step calculations while solving examples. We believe that understanding the right approach to problem solution is more important. The illustrative examples are structured accordingly.

There are two important relatively recent developments which are covered in this book: (1) There is a growing demand to move away from strength-based design towards performance-based design. This subject has been introduced in the book. (2) There is greater awareness among owners to minimize earthquake-related damage to property and consequently prevent loss of life. As a result, there are increasing calls for checking the adequacy of existing buildings to meet current seismic codal stipulations. For this purpose, the pushover analysis technique is handy. Literature on this subject is very limited and, moreover, not readily available. The methodology of undertaking such an exercise is presented in the book with solved examples.

We have delivered many presentations across the country to a wide cross-section of technical personnel in an effort to disseminate knowledge in this field and to provide solutions to practical problems faced by designers, contractors, and architects while implementing theoretical concepts in their designs. From exchanges with participants, we realized that there was a definite need to translate the concepts of earthquake-resistant design from the laboratories to students, teaching faculty, and practicing professionals in a manner they would readily relate to. That is what this book attempts to achieve.

We wish to acknowledge that this book builds its foundations on the technical works of veritable giants such as Prof. James M. Kelly, Prof. Gary C. Hart and Kevin Wong as well as Prof. Tushar Kanti Datta and others. Many of the publications are referenced in the bibliography, but space restrictions do not permit inclusion of all. We also wish to express our gratitude to Prof. R.S. Jangid of IIT Bombay for his kind words of appreciation in his Foreword to this book. We are grateful to those who may have been of help but whose names have been inadvertently left out. Some photographs have been included to highlight certain key aspects of earthquake damage as well as concepts. We are grateful to Mr. C.M. Dordi and M/s Ambuja Cements Ltd. for making most of them available for use in this book.

Every effort has been made to ensure the correctness of various facets of earthquake-resistant design and detailing and examples covered in this book. In spite of that, it is inevitable that some errors or misprints may still be found. We will be grateful to the users of this book for conveying to us any error that they may find. We would also welcome any suggestions and comments offered. We would like to thank the M.Tech. students from the College of Engineering Pune who assisted in solving some of the example problems.

We would like to express our gratitude to our respective families for their unstinted support and encouragement without which this publication would not have been possible.

Pune, India
15 September 2014

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Suhasini N. Madhekar

About the Authors

Sharad Manohar holds an MSc (Structural Engineering) degree from Imperial college, University of London. He is a graduate of the College of Engineering Pune, FIE (India), and was Chief Civil Engineer with Tata Consulting Engineers. He has extensive experience of over five decades in the construction, design, management, and handling of national and international contracts of a wide range of structures, including those in high seismic areas. He has worked with Gammon India Ltd. and Tata Consulting Engineers as Chief Civil Engineer and continues to provide consulting services and training in Structural Engineering and Management. He played a key role in the implementation of training centers for the entire cement industry in India. Mr. Manohar is a recipient of the Lifetime Achievement Award from the Indian Concrete Institute and a Gourav award from Association of Consulting Civil Engineers (India) for outstanding contribution over a lifetime of achievement. He has authored a book *Tall Chimneys – Design and Construction* and published several technical journal papers. He is a member of a national committee appointed by the Reserve Bank of India to develop guidelines for assessment of the structural safety of their existing buildings.

Suhasini Madhekar holds a PhD in Structural Engineering from IIT Bombay. She is presently working as a faculty member in the Department of Applied Mechanics at the College of Engineering Pune. She is FIE (India) and life member of ISTE, ISSE, INDIAN ASTR, IIBE, and ICI. Dr. Madhekar has teaching experience of over 24 years at undergraduate and postgraduate levels. She has published several papers in reputed journals and proceedings. She is the recipient of the COEP Star Award, an Excellence in Teaching Award from the College of Engineering Pune. She was awarded the Alumni Distinguished Faculty Fellowship by the Alumni Association of the College of Engineering Pune.

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