

Preface

Earthquakes are among the most destructive natural disasters on our planet. Over history, enormous engineering and research efforts have been devoted to the study of causes and consequences of earthquakes, the prediction and forecasting of future earthquakes, the determination of ground motion intensities in a particular site, and the seismic response assessment and the mitigation measures for various types of structures and foundations. All these efforts have been intended simply to keep structures and their contents from falling down and causing damage and to keep people safe during earthquakes.

During the last century, through a synergy of various pieces of know-how associated with the contents above, a unique scientific topic, earthquake engineering, has finally been formed. It is essentially focused on finding solutions to problems posed by seismic hazards. During its development, earthquake engineering has borrowed much from other engineering disciplines in its understanding of seismic wave propagations and ground motion characteristics, in considering nonlinear soil and structural responses and engineering dynamics, and in developing probability-based design approaches. Although earthquake engineering as a scientific topic is by no means fully understood (and perhaps never will be), the great amount of activity in this field has made it possible to form a practical subject in a fairly systematic, coherent, and quantitative manner.

The development of modern earthquake engineering has been closely linked to advances in computer technology, allowing engineers to solve problems of increasing complexity in two aspects: First, it allows for the calculation of results based on classical solutions but with numerical evaluation of certain terms that cannot be expressed in a closed form; second, it also allows for the modeling of complex systems (structures, foundations, soils, or faults) using approximation methods such as finite element method and to perform numerical calculations to obtain the system's response. However, even though engineers and researchers are using computers to solve many seismic problems with great complexity, many of them lack an actual understanding of the essential principles in earthquake engineering, and their capability to properly evaluate seismic ground motions and structural responses is thus limited and even weaker than that of those working

on this subject decades ago. This is also partly because the complexity of the analyzed seismic problems has dramatically increased in recent decades, which is more case-dependent, and therefore, less general conclusions can be drawn. Eventually, this has led to many engineers and researchers losing the “big picture” and intuition toward original problems and principles. Moreover, the division of responsibilities between seismologists and civil engineers has become more “clear,” thus *“eliminating the previously critical need for engineers to get involved ‘up front’ in the seismic input characterization for a project”* (CA Cornell). In many cases, professional structural and geotechnical engineers are not able to qualify the seismic input ground motions with respect to their seismological features, and seismologists and geotechnical and structural engineers often understand each other only poorly. Furthermore, students who study earthquake engineering are given canned class exercises and deterministic projects, which are often far different from the real-world seismic engineering problems that have a great diversity in various aspects. Therefore, in spite of increased knowledge on earthquake engineering, the problems of seismic design are in many cases handled without success despite large expenditures of investment. This leads to an insurmountable barrier to efficiently manage the risk of structures and to further improve the design, potentially posing a significant safety hazard, and may also result in significant economic loss. Such considerations motivated me to write this book.

The objective of this book is to offer a methodical presentation of essentials of earthquake engineering, based on “understandable” mathematics and mechanics with an emphasis on engineering application aspects; to present the most useful methods for determining seismic ground motions and loading on structures; to apply both the well-accepted and emerging methods to perform seismic design and analysis for real-world engineering structures; and to implement various types of mitigation measures to increase the seismic resistance of structures. Instead of being generic, the book is filled with concrete explanations from real-world engineering practices.

The background assumed for reading this book includes a basic knowledge of matrix algebra, differential and integral calculus, structural dynamics or engineering vibrations, structural mechanics, strength of materials, and a working knowledge of probability theory.

Chapter 1 provides a review of and introduction to historical earthquakes and consequences; the cause of earthquakes, with a special focus on tectonic-related earthquakes and fault rupture mechanism; earthquake prediction and forecasting; and the relevance of earthquake engineering with offshore structures. Chapter 3 presents the seismic wave propagation, earthquake magnitude and intensity measures, measurements and characterizations of seismic motions, etc. These two chapters together introduce readers to basic knowledge of engineering seismology necessary for civil engineers.

Note that previous earthquake engineering efforts have mainly focused on land-based structures. More offshore structures with large capital investment are being placed in areas with active seismicity, and many existing offshore structures are regarded as having inadequate seismic resistance due to increased/updated

knowledge on seismic hazard and assessment methods, as well as due to original deficiencies and damages that took place during manufacturing, construction, and operation of structures. Therefore, Chap. 2 is dedicated to introducing different types of offshore structures, their dynamic characteristics, and their similarities with and differences from land-based structures. This serves as an introduction for further exploring their seismic responses and resistance discussed in later chapters.

Since the determination of ground motions is of great importance for both geotechnical and structural engineers to assess a particular design to be installed at a specific site/location, Chaps. 4 through 7 present the representation and the determination of earthquake ground motions for civil engineering applications.

As the ground motions at two locations more than hundreds of meters apart can differ to certain extent, thus potentially magnifying the response of extended structures with multiple supports or structures sensitive to torsional vibrations, Chap. 8 discusses the characterization, determination, and influence of spatial varied ground motions.

Based on the knowledge of engineering seismology and ground motion determination and representation presented in previous chapters, Chap. 9 presents the determination of seismic hazard and risk, of which the former is an essential part for seismic design, and the latter describes the social, economic, and environmental consequences of earthquakes.

As seismic analysis and design for offshore structures are important topics in this book, Chap. 10 presents relevant knowledge of hydrodynamic load effects and ice loading effects on offshore structures, which may occur simultaneously and be combined with seismic loading applied on structures. This is followed by a brief introduction to shock wave due to seaquakes and its effects on floating offshore structures as discussed in Chap. 11. In Chap. 12, causes, calculation, characterization, and mitigations of tsunami waves are presented.

Note that the contents presented from Chap. 3 through Chap. 12 are mainly focused on the ground motion and loading generated or triggered by earthquakes, Chap. 13 discusses damages of structures and foundations due to ground motions. In addition, the human safety and motion-induced interruptions are also briefly discussed in this chapter.

Chapter 14 presents the essential design philosophy and its realization in prescriptive codes and performance-based design. The former, prescriptive codes have gained a great deal of popularity by placing a strong focus on characterizing uncertainties associated with both load and resistance; the latter, performance-based design, is promoted by many professionals as a tool for future structural and geotechnical design.

From Chap. 15, the contents of the book move into various topics on seismic structural analysis and design, as well as mitigation measures. Chapter 15 presents traditional and recent seismic analysis methods, among which the traditional methods mainly aim for pursuing accuracy of calculated seismic responses, while the recently developed methods place more focus on the compatibility between the structural response calculation and the evaluation of detailed performance demand, on revealing a structure's intrinsic seismic response and essential performance

characteristics and on improving the robustness of seismic load estimation and analysis results.

The majority of the contents in the first 15 chapters provide readers a “big picture” to determine the seismic motions and to evaluate their effects on engineering structures, in the aspects of fault rupture, wave propagation (path effects), local geotechnical site effects, soil structure interactions, and structural dynamics.

Chapter 16 describes the response assessment methods of offshore structures due to potential sudden subsidence accidents. In Chap. 17, available methods to assess hydrodynamic impacts of liquid inside tanks and their influence on the structural integrity are presented.

As inexpensive digital computers and user-friendly geotechnical and structural engineering software have extensively been used in the practice of civil engineering, Chap. 18 presents a selection of computer systems for improving numerical analysis efficiencies. It also details how to manage computation precision during either analytical or numerical analysis, the later of which is often ignored by researchers and engineers.

Chapters 19 through 29 discuss various mitigation measures and strategies to decrease the negative influence of earthquakes. These include the avoidance of significant dynamic amplifications, ductility design, increasing damping by using either structural damping or direct damping devices, base and hanging isolation system, dynamic absorber, load- and energy-sharing mechanism, structural health monitoring, resistance of non-structural elements, and seismic rehabilitation.

While the book does not seek to promote any specific “school of thought,” it inevitably reflects this author’s “best practice” and “own interpretations.” This is particularly apparent in the topics selected and level of detail devoted to each of them, their sequences, and the choices of many mathematical treatments and symbol notations, etc. The author hopes that this does not deter the readers from seeking to find their own “best practice” and dive into the vast knowledge basin of modern earthquake engineering, which is extremely enjoyable as readers go deeper and wider. Moreover, the book is densely referenced to allow readers to explore more detailed information on each topic presented.

Seismic design comprises a combination of decisions made from an environment of partial truth, partial knowledge, and partial uncertainties. In this process, both academic know-how and professional experience play equally important roles. By incorporating more advanced (but not necessarily more complicated) knowledge of earthquake engineering into the experiences accumulated from engineering applications, there is a margin to further reduce uncertainties. As a result, more cost-effective and safer designs can then be achieved. Moreover, engineering applications for designing earthquake-resistant structures are, in many ways, more of an art than a science. Even though seismic designs must be thoroughly checked in a rigorous scientific manner, intuition, imagination, and a synthesis of experience and knowledge play essential roles in the process of design.

It must be admitted that the development of earthquake engineering is far from mature. To further develop this subject, researchers and engineers are motivated to

propose more dedicated and new theories and apply them to mitigate the associated risks due to earthquakes.

In preparing such a text, it is rather difficult to acknowledge all the help given to the author. First, I am indebted to the earthquake, offshore, and civil engineering communities who have undertaken extensive research and development that has led to accumulated knowledge, methods, and engineering applications in this field, on which this book is based. I would also like to thank individuals who have stimulated my interests through technical discussions and those who reviewed parts of or the entire manuscript. These include (in alphabetical order) the following: Atilla Ansal (European Association for Earthquake Engineering), Kuvvet Atakan (University of Bergen), Gunnar Bremer (Aker Solutions), Jacopo Buongiorno (Massachusetts Institute of Technology), Wai-Fah Chen (University of Hawaii), Donald W. Davies (Magnusson Klemencic Associates), Odd Magnus Faltinsen (Norwegian University of Science and Technology), Ove Tobias Gudmestad (University of Stavanger), Muneo Hori (University of Tokyo), Amir M. Kaynia (Norwegian Geotechnical Institute), Steven L. Kramer (University of Washington), Conrad Lindholm (NORSAR), Lance Manuel (University of Texas At Austin), Preben Terndrup Pedersen (Technical University of Denmark), John Michael Rotter (University of Edinburgh and Imperial College), Valentin Shustov (California State University), Richard Snell (Oxford University), Didier Sornette (Swiss Federal Institute of Technology, Zurich), Douglas Stock (Digital Structures, Inc. Berkeley), Christopher Stubbs (Colebrand International Limited, London), and Armin Winkler (GERB Schwingungsisolierungen GmbH & Co.KG). Furthermore, I would like to thank Statoil, BP and Norwegian Geotechnical Institute for their close cooperation on relevant engineering projects. Moreover, there are numerous others not named to whom I extend my sincere thanks.

This book has an extensive list of references reflecting both the historical and recent developments of the subject. I would like to thank all the authors referenced for their contribution to the area. However, the literatures listed at the end of each chapter can only be indicative. It is impossible for me to acknowledge all the individual contributions.

Finally, I dedicate this book to Jing and Danning, for their support and patience. I conclude this preface with an expression of deep gratitude to them.

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