GEOTECHNICAL EARTHQUAKE ENGINEERING

STEVEN L. KRAMER

Geotechnical Earthquake Engineering

Steven L. Kramer
University of Washington

Prentice-Hall International Series
in Civil Engineering and Engineering Mechanics

Prentice Hall

Prentice Hall
Upper Saddle River, New Jersey 07458

Library of Congress Cataloging-in-Publication Data

Kramer, Steven Lawrence.
Geotechnical earthquake engineering / Steven L. Kramer.
p. cm. -- (Prentice-Hall civil engineering and engineering mechanics series)
Includes bibliographical references and index.
ISBN 0-13-374943-6
1. Earthquake engineering. 2. Engineering geology. I. Title. II. Series.
TA654.6.K72 1996
624.1'762--dc20 95-33020
CIP

Acquisitions editor: **BILL STENQUIST**
Production editor: **IRWIN ZUCKER**
Cover director: **JAYNE CONTE**
Buyer: **JULIA MEEHAN**
Editorial assistant: **MEG WEIST**

Prentice Hall

Upper Saddle River, NJ 07458

Printed in the United States of America

10 9 8 7

ISBN 0-13-374943-6

Prentice-Hall International (UK) Limited, London
Prentice-Hall of Australia Pty. Limited, Sydney
Prentice-Hall Canada Inc., Toronto
Prentice-Hall Hispanoamericana, S.A., Mexico
Prentice-Hall of India Private Limited, New Delhi
Prentice-Hall of Japan, Inc., Tokyo
Editora Prentice-Hall do Brasil, Ltda., Rio de Janeiro

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To my parents

Preface

Compared to most disciplines of civil engineering, geotechnical earthquake engineering is quite young. While the damaging effects of earthquakes have been known for centuries, the strong contribution of soils to the magnitude and pattern of earthquake damage was not widely appreciated until relatively recently. Following damaging earthquakes in 1964 in Niigata, Japan and Alaska, and spurred by the growth of the nuclear power industry in the 1960s and 1970s, the field of geotechnical earthquake engineering has grown rapidly. Although much remains to be learned, the field has matured to the point where generally accepted theories and analytical procedures now exist for many important problems.

The purpose of this book is to introduce the reader to the concepts, theories, and procedures of geotechnical earthquake engineering. It is intended for use as a text in graduate courses on geotechnical earthquake engineering and as a reference book for practicing engineers. Recognizing that geotechnical earthquake engineering is a broad, multidisciplinary field, the book draws from seismology, geology, structural engineering, risk analysis, and other technical disciplines.

The book is written at a level suitable for students with knowledge equivalent to that of a senior (fourth-year) civil engineering student. The student should have had basic courses in soil mechanics, structural engineering, and hydraulics; introductory courses in geology and probability/statistics would also be helpful. Many graduate students will have had courses in structural dynamics or soil dynamics by the time they begin study of geotechnical earthquake engineering. For those readers without prior exposure, introductions to the nomenclature and mathematics of dynamic systems, structural dynamics, and probability are presented in three appendices.

ORGANIZATION

The subject matter falls into two main categories. The appendices and the first six chapters present fundamental principles of seismology, ground motion, dynamics, and soil behavior. Applications of these principles to the practical problems most commonly encountered in geotechnical earthquake engineering practice are presented in the last six chapters.

Chapter 1 introduces the reader to the types of damage that can occur during earthquakes and to the problems they present to geotechnical earthquake engineers. Basic concepts of earthquake seismology and the terminology used to describe earthquakes and their effects are described in Chapter 2. Chapter 3 describes ground motion measurement, the parameters used to characterize strong ground motion, and methods for prediction of those parameters. Deterministic and probabilistic seismic hazard analyses are presented in Chapter 4. Chapter 5 introduces the reader to wave propagation, beginning with simple one-dimensional body waves in homogeneous materials and extending to surface waves and multidimensional, layered systems. The properties of soil that control their wave propagation behavior are described in Chapter 6. Field and laboratory techniques for measurement of these properties are also described.

Chapter 7 presents methods for analysis of ground response during earthquakes, beginning with one-dimensional ground response analysis and moving through two- and three-dimensional dynamic response analyses. Both frequency- and time-domain approaches are described. Chapter 7 concludes with an introduction to the basic concepts and effects of soil-structure interaction. The effects of local soil conditions on ground motions and earthquake damage are described in Chapter 8. Chapter 8 also introduces the concept of design ground motions, and how they are obtained from site-specific analyses and from building codes. Chapter 9 deals with liquefaction—it begins with a conceptual framework for understanding various liquefaction-related phenomena and then presents practical procedures for evaluation of liquefaction hazards. Seismic stability of slopes is covered in Chapter 10, and seismic design of retaining structures in Chapter 11. Chapters 10 and 11 address their respective topics initially from pseudo-static and then from permanent displacement standpoints. Chapter 12 introduces commonly used soil improvement techniques for mitigation of seismic hazards.

PEDAGOGY

This book is the first to deal explicitly with the topic of geotechnical earthquake engineering. During its preparation, a great deal of time and effort was devoted to decisions regarding content and organization. The final form naturally reflects my own preference, but the text has been reviewed by many engineers from both academia and professional practice. Preparation of the text also involved a great deal of interpretation of information from a wide variety of sources. While the text reflects my own interpretation of this information, it is heavily referenced to allow readers to explore background or more detailed information on various geotechnical earthquake engineering topics.

A couple features are noteworthy. Two ground motions from the Loma Prieta earthquake, one from a rock outcrop and one from the surface of a nearby deep soil deposit, are used to illustrate a number of concepts throughout the book. Differences in the amplitudes, frequency contents, and durations of the motions are emphasized in Chapter 3. The reasons for these differences later become apparent in Chapters 7 and 8. The book also emphasizes the use of transfer functions, particularly in the solution of ground response problems. The transfer function approach helps students form a more complete understanding of ground response—in the frequency domain as well as the time domain. With the advent of computer programs such as MATLAB, MathCad, and Mathematica, the Fourier analyses required in the transfer function approach are quite simple; students use MATLAB extensively in my soil dynamics and geotechnical earthquake engineering courses.

The book contains worked examples and homework problems. The example problems are intended to illustrate the basic concepts of the problems they address; to allow the results to be checked, a number involve calculations carried out to more significant figures than the accuracy of the procedures (and typical input data) would justify. Many of the important problems of geotechnical earthquake engineering, however, do not lend themselves to the type of short, well-defined homework problem that is readily placed in a book. My preference is to assign longer, project-oriented assignments based on actual case histories, and I recommend that the homework problems in this book be supplemented by such assignments.

UNITS

As in many other fields, the use of units in geotechnical earthquake engineering is neither uniform nor consistent. The current state of knowledge in geotechnical earthquake engineering has resulted from advances in a variety of technical fields and a variety of countries, many of which customarily use different units. Fortunately, most conform to relatively standard metric or British systems. Rather than attempt to force the use of one system or the other, this book uses dual units. In recognition of their origins, the most common units for each quantity is listed first with the alternative following in parentheses. The approach is intended to allow all readers to proceed through the material without stopping to convert (mentally or otherwise) from one set of units to another. To encourage familiarity with both sets of units, some example and homework problems are specified in metric units and some in British units.

ACKNOWLEDGMENTS

A number of people have helped directly and indirectly in the preparation of this book. The professional and academic portions of my career have benefited greatly from a number of people that I have worked closely with, particularly (in chronological order) Bill Houston, Tom Tejima, H.B. Seed, Joe Mahoney, and Bob Holtz. Their assistance, advice, and encouragement has taken many forms, and I am grateful to each.

As this book evolved from a collection of lecture notes and handouts, it was continually improved by comments and suggestions from many students in my soil dynamics and geotechnical earthquake engineering courses. Their assistance is greatly appreciated. I am also grateful to many colleagues who provided constructive critical reviews of different parts of the book, including Dr. Donald G. Anderson, Dr. Juan Baez, Mr. David Baska, Dr. Gopal Biswas, Prof. Ross W. Boulanger, Dr. C.B. Crouse, Prof. Emeritus William J. Hall, Ms. Karen Henry, Prof. Carlton L. Ho, Prof. William D. Kovacs, Prof. Roberto T. Leon, Prof. Gregory R. MacRae, Dr. Lelio H. Mejia, Dr. Robert Pyke, Prof. Peter K. Robertson, Prof. Raj Siddharthan, Prof. Stewart Smith, Prof. Timothy D. Stark, and Prof. George M. Turkiyyah. Each made suggestions that improved the quality of the book. Prof. Geoffrey R. Martin and Prof. T. Leslie Youd reviewed substantial portions of the book; their efforts are particularly appreciated.

Finally, I am most grateful to my wife, Diane, and to my daughters, Katie and Megan. Preparation of this book involved several years of long working hours; I could not have done it without their cheerful understanding and encouragement.

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