Jack Moehle

Seismic Design of Reinforced Concrete Buildings

Mc Graw Hill Education

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To Melissa,
For time, encouragement, diversions.

Preface

This book emphasizes the behavior and design requirements for earthquake-resistant reinforced concrete buildings. Design of a building for earthquake effects requires a different perspective than is required for other load effects. Earthquake loads are mainly absent during the life of a building, but suddenly may be applied with an intensity that drives the structure beyond the linear range of response in multiple loading cycles. Earthquake response of a structure is dynamic, with distributed inertial forces that act in all directions simultaneously. To meet established performance objectives under earthquake loading, a building requires a structural system that is appropriately configured, proportioned, and detailed. These complicated design conditions are beyond the scope of traditional reinforced concrete or earthquake engineering textbooks. This book aims to provide the focused and in-depth treatment necessary to fully understand the design requirements for earthquake-resistant concrete buildings.

The content emphasizes the mechanics of reinforced concrete behavior and the design requirements applicable to buildings located in "highly seismic" regions. The content will also be of value to engineers interested in the seismic evaluation of existing structures, design in regions of lower seismicity, and the general design of concrete structures for routine and extreme loading conditions.

Although the mechanics of reinforced concrete is universal, the performance expectations and associated design requirements may vary by region. This book mainly follows the requirements of the 2014 edition of the American Concrete Institute's *Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary*. Those requirements are augmented by additional recommendations derived from other codes, guidelines, and the general literature, as deemed appropriate by the author. Dual units [U.S. customary units and International System of Units (SI)] are used throughout.

The target audience is twofold: (1) graduate students with structural engineering emphasis and (2) practicing structural engineers. For graduate students, this book provides a logical progression of content that builds knowledge of reinforced concrete construction, including design methods, behavior of structural materials and members, and the assembly of structural members into complete buildings capable of resisting strong earthquake shaking. This content has been developed and honed through years of graduate student instruction. For the practitioner, this book can build knowledge and serve as a reference resource to help solve challenging design problems. The book draws extensively from research literature and the experience of the author working with practicing structural engineers. The presentation emphasizes practical aspects, with numerous illustrations of concepts and requirements.

Topics are organized in four main parts. The first part (Chapter 1) reviews design methods applicable to the earthquake-resistant design of reinforced concrete buildings. The second part (Chapters 2 to 4) discusses material properties of steel, concrete, and confined concrete that are important for seismic performance and design. The third part (Chapters 5 to 10) covers the behavior of structural concrete components, including tension and compression members, beams, columns, walls, beam-column connections, and slab-column and slab-wall framing subjected to axial force, moment, shear, and imposed inelastic deformations. The last part of the book (Chapters 11 to 16) addresses seismic design of moment-resisting frames, structural walls, gravity frames, diaphragms, and foundations. Taken together, these four parts provide comprehensive coverage of the mechanics and design of earthquake-resistant concrete buildings.

The book is suitable for advanced undergraduate or graduate courses in structural engineering. At the University of California, Berkeley, it serves as a resource for a first-semester graduate course on seismic design of reinforced concrete buildings, touching on selected subjects in most of the chapters, but leaving the remaining chapter content for individual study. The book could also be used in a two-semester sequence, the first semester covering design methods, materials, and structural components (Chapters 1 to 10) and the second semester covering the design of earthquake-resistant structural systems (Chapters 11 to 16).

Numerous graduate students have read early drafts of this book in graduate classes, and individual experts have reviewed individual chapters. Readers are encouraged to send further suggestions for improvements, clarifications, and corrections to my attention at moehleRCSeismic@gmail.com.

Jack Moehle
August 2014

Acknowledgments

An early text on seismic design of concrete buildings[1] begins with the line: "Considerable knowledge has been gained in the last three decades about the phenomena of ground motion, the characteristics of structures, and their behavior in earthquakes." In the intervening five decades, knowledge and methods for earthquake-resistant concrete buildings have grown at an increasing rate. The key contributions to this book are acknowledged in an extensive list of references at the end of each chapter.

I am grateful for the contributions of several individuals and organizations as noted below.

Instructors at the University of Illinois at Urbana–Champaign introduced me to reinforced concrete and inspired a lifelong study of the subject. Especially, Professors William Gamble and Mete Sozen emphasized the mechanics of reinforced concrete and instilled an appreciation of the role and the limits of mechanics in engineering practice and the building code. Professor Sozen has continued as a lifelong mentor.

The University of California, Berkeley, has extended to me the privilege of teaching courses and conducting research on the subject of this book over three decades. An extraordinary group of faculty members and graduate students provided me with challenges, ideas, solutions, and a testing ground for much of the content of this book.

Many structural and geotechnical engineers have collaborated with me on research, code and guideline development efforts, and structural/earthquake engineering design and assessment projects. These interactions have revealed engineering problems and solutions that served as the basis for many practical recommendations presented in the book.

Several individuals contributed directly to this book. Nicholas Moehle processed the data in support of the confined concrete models of Chapter 4. Santiago Pujol of Purdue University, while on leave at UC Berkeley in 2014, led developments on panel zone shear that are presented in Chapters 7 and 13.

[1]Blume, J.A., N.M. Newmark, and L.H. Corning (1961). *Design of Multistory Reinforced Concrete Buildings for Earthquake Motions*, Portland Cement Association, Evanston, IL, 318 pp.

Ian McFarlane, Michael Valley, and John Hooper of Magnusson Klemencic Associates; Jay Love and Wayne Low of Degenkolb Engineers; and Dom Campi of Rutherford & Chekene discussed and provided examples of foundation design. Steve Kramer of the University of Washington provided extensive references on geotechnical earthquake engineering and foundation design, and Marshall Lew of AMEC, Los Angeles, provided references on retaining wall design.

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