

Ductile Design of Steel Structures

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Second Edition

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Ductile Design of Steel Structures

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Preface

The first edition of *Ductile Design of Steel Structures*, published in 1998, arrived at a time when the structural design practice was undergoing important changes. Most significantly, the impact of the Northridge and Kobe earthquakes was still being felt in the engineering community, and substantial shifts in philosophy for the seismic design of steel structures were underway. This led to numerous and frequent changes to the relevant seismic design and detailing provisions for steel structures in many codes and design standards—all while the United States completed the process of unifying its three major regional model design codes into the International Building Code (first published in 2000, and eventually adopted by all states and most municipalities in the country), and while the American Institute of Steel Construction (AISC) unified its Load and Resistance Factor Design (LRFD) and Allowable Stress Design (ASD) requirements into a single specifications.

Although these whirlwind changes made the first edition a timely document in 1998, they also progressively left it in need of an update sooner than expected. Even though the fundamental principles and structural behaviors emphasized throughout the first edition of this book remained valid, design principles and examples were anchored in specifications that had changed in a number of subtle ways over time (more so than is typically the case from one code cycle to another). With publication of the AISC 2010 Seismic Provisions and of the 2009 CSA S16 Standard for the Design of Steel Structures, crystallizing the knowledge developed in the prior 15 years on this topic (and becoming more similar to each other in content and design philosophy), and with the evolution of code changes foreseen to return to a more regular pace—barring another major earthquake that would challenge design wisdom—publication of a revised second edition of *Ductile Design of Steel Structures* is again timely.

Two audiences were kept in mind when writing this book: practicing engineers and graduate students. With respect to the first audience, engineers are nowadays exposed to a wide range of professional development opportunities, and day courses on seismic design of steel structures are common. Similar information is also scattered

over the World Wide Web (albeit covering the same topic with various degrees of technical rigor, depending on the source). This widely available and accessible information has been helpful to dispel the erroneous belief that the ductile nature of structural steel directly translates into inherently ductile structures, but a first introduction to the topic of ductile design usually leaves the engineer with many questions on the origin of many design requirements and strategies to achieve ductile structural behavior. With respect to the second group, although seismic design is not part of most undergraduate civil engineering curricula, substantial opportunities exist for graduate learning on this topic. Nowadays, most graduate structural engineering programs in North America offer a general seismic design course, often complemented by specialized courses on the design of ductile concrete and ductile steel structures, and textbooks that comprehensively cover design aspects related to this topic are needed.

In that perspective, the second edition of *Ductile Design of Steel Structures* is intended to serve both as a reference textbook on this topic and as a resource document providing breadth and depth in support of graduate and professional education opportunities. It aims to help senior undergraduate and graduate students, as well as professionals, design ductile steel structures in an informed manner. It summarizes the relevant existing information on this topic (often scattered in research reports, journal articles, and conference proceedings) into chapters on material, cross-section, component, and system response, providing useful guidance and design examples while presenting the concepts and key research results supporting the rationale underlying many of the current design principles. It is written starting from the assumption that the reader has background knowledge of conventional (nonseismic) steel design.

The emphasis of this book is on earthquake-resistant design because providing ductile structures is crucial to ensure seismic survival. However, there exist many other important applications of the principles and design approaches outlined in this textbook. For example, knowledge of how to design and detail steel structures to achieve ductile behavior is vital to ensure the satisfactory performance of structures exposed to other extreme events, such as blast forces, and to prevent their progressive collapse—two topics pushed to the forefront by the September 11, 2001 events. Other possible applications of ductile steel design include offshore structures subjected to extreme wave and ice loads, as well as bridges that can now be designed to carry normal traffic using an alternative bridge design procedure (the Autostress method) that relies heavily on ductile response and requires a good understanding of the shakedown theory. Likewise, for existing construction, plastic analysis can provide a much better estimate of a structure's actual strength than procedures based on elastic analysis, which in turn can be used advantageously to minimize the extent of needed rehabilitations—an important

advantage given that the rehabilitation of existing buildings is a growing market in North America, as part of the revitalization activities taking place in many city centers of seismic and nonseismic regions (as a consequence of either commuters' frustrations, the aging North American infrastructure, the projected North American population growth patterns, the goals of historical or heritage building preservation, and/or other societal trends). Thus, although the focus of this text is earthquake engineering, the information presented herein is broadly applicable to the ductile design of steel structures.

For its second edition, this book has been substantially expanded as follows:

- Three entirely new chapters have been added, to respectively address the design of buckling-restrained braced frames (Chapter 11) and steel plate shear walls (Chapter 12), and to review some hysteretic energy dissipating systems and design strategies that have been the subject of growing interest and proposed to achieve the objective of ductile design (Chapter 13). The latter chapter addresses structural fuses, hysteretic energy dissipating devices, bimetallic friction, rocking, and self-centering systems; it replaces the former Chapter 11 that only provided a cursory overview of passive energy dissipation.
- The previous chapter on braced frames has been completely rewritten, to eliminate obsolete and/or ambiguous information and, more importantly, to reflect the substantial changes and new developments that have taken place and have been implemented in the AISC and CSA design requirements since the last edition of this book. Concentrically braced frames and eccentrically braced frames are now each covered in separate chapters. Each chapter provides thorough insights into the knowledge on those topics that has led to the current design provisions and corresponding capacity design procedures.
- The chapter on moment-resisting frames has been substantially expanded, to reflect the major changes and developments in design requirements that have taken place since 1997.
- Chapter 2 has been expanded to include additional information and new knowledge on steel's high-temperature properties, strain rate effects, k -area fractures, strain aging, and stress corrosion, as well as information on fatigue and ductility of corroded shapes, yielding mechanism, new steel grades, and low-cycle fatigue modeling. It also includes a new section on hysteretic models, which provides much needed information for the nonlinear

inelastic analyses more frequently required by specific engineering projects nowadays.

- Chapter 3 (on cross-section properties) has been revised to address biaxial bending, introduce layer models (required for some nonlinear analyses), and add information on plastic strength of concrete-filled steel tube cross-sections.
- Chapter 4 (on plastic analysis) has been expanded to introduce yield line analysis, which is important for calculation of connections' ultimate strength and resistance to out-of-plane loads (such as blast loads).
- Chapter 6 (on applications of plastic analysis) has been expanded to address global versus local ductility demand and some other important code-related issues.
- To better link with Chapters 8 to 13, focused on earthquake engineering applications, Chapter 7 (formerly Chapter 9) has been entirely rewritten, focusing on the basic principles to relate seismic design forces and corresponding ductile demands in structures.
- New design examples in Chapters 8 to 12 have been developed in compliance with the AISC Seismic Provisions (ANSI/AISC 341-10) and Load and Resistance Factor Design, and from a practicing engineering perspective. Note that the examples in the first edition of this book approached seismic design as a secondary design step called "ductile design" (coupled with "drift-control design" in the special case of moment-resisting frames), which consisted of a design iteration starting with the results from a first design step accomplished using conventional steel design principles in nonseismic applications (called "strength design"). That two-step approach is still valid and the examples contained in the first edition remain instructive in many ways. However, the publication by the American Institute of Design Construction of design aids for seismic design has made seismic design more expeditious, eliminating the benefits of the two-step approach. Therefore, this second edition contains only new design examples consistent with this new context.
- Self-study problems have been provided for most chapters; these could be assigned to students by instructors using this book as a textbook—note that all of the problems are former assignment or exam questions I gave to students at the University at Buffalo or the University of Ottawa. Partial solutions to the problems will eventually be accessible to instructors via a password-protected link posted on the website www.michelbruneau.com.

- Chapter 14 is the only chapter that remains unmodified since the first edition. While interesting research has been conducted since the mid-1990s on the topics covered in this chapter, it has not resulted in changes to the seismic design provisions at the time of this writing.

The authorship of this second edition reflects these numerous changes in scope, breath, and structure. I sincerely thank my coauthors for helping to bring this project to fruition, namely Chia-Ming Uang (Professor, University of California, San Diego) for writing most of Chapters 7, 10, 11, and 14, and Rafael Sabelli (Structural Engineer, Walter P. Moore, Oakland, CA) for developing the design examples at the end of Chapters 8 to 12 and contributing parts of Chapter 11. The challenges of bringing to life a second edition that is twice the length of the first can be overwhelming, and their commitment and contributions are gratefully acknowledged.

From a graduate curriculum perspective, the resulting expanded textbook provides enough material to support two graduate courses: a first course on plastic analysis and design, using the material in Chapters 2 to 6, and a second course on the seismic design of steel structures based on Chapters 7 to 13. However, another effective approach is to use some aspects of all chapters as part of a single graduate course, covering only the essential aspects of Chapters 2 to 6 needed to understand the capacity design in support of the material presented in Chapters 7 to 12 (or 7 to 10 for shorter academic terms), leaving the rest of the material for future self-study in answer to project needs or for professional development purposes. Other combinations also are anticipated, reflecting the preferences and teaching styles of various instructors.

Finally, suggestions and general feedback on this book are always welcome (including e-mails confirming that there are people in this world reading book prefaces). A list of errors brought to the authors' attention will be compiled into an errata list eventually posted on the website www.michelbruneau.com, until fixed by the publisher in subsequent printings.

Michel Bruneau, Ph.D., P.Eng.

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