CHAPTER 1

Introduction

Earthquake engineering is the science that studies the behavior of structures under earthquake excitation and provides the rules on how to design structures to survive seismic shocks. Earthquakes are wild and violent events that can have dramatic effects on structures. In fact, many structures have collapsed during earthquakes because earthquake-induced forces or displacements exceeded the ultimate capacity of the structures. Therefore, the study of structural behavior at full capacity is a necessary element of earthquake engineering.

Earthquakes are extremely random and oscillatory in nature (as shown in Fig. 1-1). Because earthquakes cause structures to largely deform in opposite directions, earthquake engineering also requires an understanding of structural behavior under cyclic loading. Figure 1-2 shows an example of cyclic loading in the inelastic range. Furthermore, the extreme randomness and uncertain occurrence of earthquakes also require the use of a probability approach in the analysis and design of structures that may experience seismic excitation.

The civil engineering field is basically distinguished by two design philosophies: elastic design and plastic (inelastic) design. In the elastic design philosophy, structures are designed to remain elastic, and no internal force redistribution is permitted during the lifetime of the structure. Elastic design can be characterized by its reversibility: the uniqueness between stress-strain or load-displacement (F-Δ) relationships and whether those relationships are linear or nonlinear, as seen in Fig. 1-3(a) and (b). This behavior implies the recovery of the work done by the external loads after their removal. However, in the plastic design philosophy, the relationship between stress and strain or between load and displacement is not unique. In this philosophy, plastic deformations are defined as those deformations that remain permanent after the removal of forces. Such deformations result in a hysteresis loop as shown in Fig. 1-3(c). This behavior also implies that dissipation of energy has occurred. In addition, because redistribution of internal forces is permitted, the restoring force (resistance of the structure) depends on both material properties and loading history.

Earthquake-resistant structures can be designed to remain elastic under large earthquakes. However, such design requires high strength and, in turn, high cost, which might not be economically feasible. As shown in Fig. 1-4, and as will be described later, the inelastic response of structures under seismic excitation permits them to be designed with strength less than their elastic strength demand. Experience from previous earthquakes and inelastic dynamic analysis shows that elastic and inelastic displacements remain within the same range.

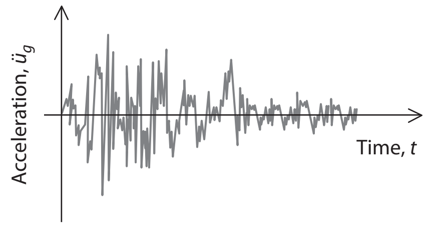

Figure 1-1 Earthquake record.

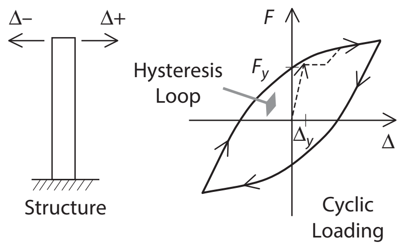

Figure 1-2 Cyclic behavior.

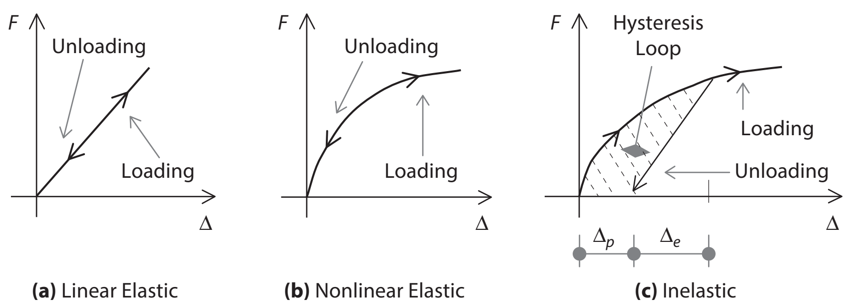

Figure 1-3 Elastic versus inelastic behavior.

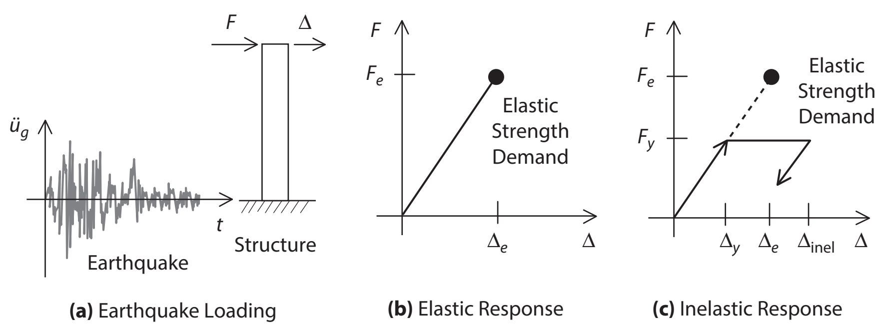

Figure 1-4 Elastic versus inelastic response.

Inelastic dynamic analysis shows that structures with strength less than their elastic strength demand can survive earthquake excitation if they possess enough capacity to deform in the inelastic region. Therefore, we rely on inelastic behavior (yielding and ductility) to design structures with strength less than their elastic strength demand. This implies that designing structures with strength less than their elastic strength demand imposes requirements on the structure other than the traditional requirements in structural design. These requirements include good ductility, good energy dissipation, and good self-centering capacity of the structure.

Therefore, the objective of this book is to provide an understanding of the behavior of structures under earthquake excitation, the characteristics of earthquakes, and the relationship between the force reduction factor and ductility demand. This understanding will provide the knowledge needed to realize the requirements for achieving ductility capacity to meet ductility demand and, eventually, for designing cost-effective structures that can survive earthquake excitation.

Modern seismic codes have set the following objectives as their ultimate goals of earthquake-resistant design:

1. Prevent nonstructural damage caused by minor and frequent earthquakes.
2. Prevent structural damage during moderate and less frequent earthquakes.
3. Prevent collapse of structures during major and rare earthquakes (ultimate goal is to protect human life).
4. Maintain functionality of essential facilities during and after any earthquake (i.e., hospitals, fire departments, and police stations). This would also include lines of transportation (e.g., bridges).

Achieving the first and second objectives in reference to Fig. 1-5 requires that a minimum stiffness, k, and minimum strength, F_y, be provided to keep structural response within acceptable performance limits, usually within the elastic range. Although minimum stiffness requirements limit the elastic deformations needed to achieve objective 1 (prevent nonstructural damage), minimum strength requirements will ensure the achievement of objective 2 (prevent structural damage). Objectives 3 and 4 are

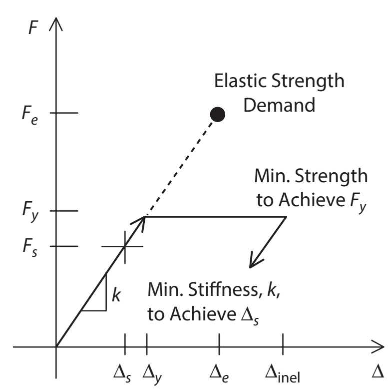

Figure 1-5 Seismic design objectives.

achieved by using the reserved capacity of structures that are due to the inelastic response of structures.

To achieve these objectives, one must understand structural analysis, structural dynamics, inelastic behavior of structures, and earthquake characteristics. This book covers these essential areas through detailed analysis of the characteristics of earthquakes, elastic and inelastic response of structures to dynamic loading (earthquake excitation), behavior of structures under earthquake excitation, and design of earthquake-resistant structures.

In addition to the introduction, the contents of this book may be grouped into four main topics: nature and properties of earthquakes, theory and analysis, practical application and treatment by seismic codes, and special topics. The 12 chapters of the book are organized in a logical sequence of topics, and therefore the reader is advised to start the book with Chap. 1 and proceed chapter by chapter. To receive the maximum benefit of this book, it is highly recommended that the basics (Chaps. 1 through 5) be studied before going to practical applications and special topics. Brief descriptions of the main topics and pertinent chapters is given in the following paragraphs.

A general introduction to the subject is given in Chap. 1. The nature and characteristics of earthquakes are treated in Chap. 2. This chapter does not intend to provide the reader with the geological base of earthquakes; rather, it intends to provide a basic understanding of earthquakes necessary for their direct incorporation in the analysis and design of structures.

The basic theory and analysis of earthquake engineering from a structural viewpoint is treated in Chaps. 3 through 5. Elastic dynamic analysis is treated in Chap. 3; inelastic dynamic analysis in Chap. 4. Dynamic analysis and vibration properties of structures subjected to earthquakes only are treated in these chapters. The behavior of structures under seismic excitation is treated in Chap. 5. The core of modern earthquake engineering is presented in this chapter. The basic seismic parameters and definitions, such as ductility, energy dissipation, and others are also given in this chapter. Ample figures and examples are included in these chapters to further illustrate concepts and ideas.

Practical applications and treatment of seismic codes are covered in Chaps. 6 through 9. Chapter 6 treats seismic provision and design requirements of buildings using the *International Building Code*® (IBC®), and includes the ASCE 7 Standard as the book's reference code for seismic provisions. Force calculations, drift limitations, selection of seismic systems, methods of analysis, and other pertinent issues are presented in this chapter. Comprehensive examples are used to illustrate concepts as deemed necessary.

Chapter 7 treats, in depth, provisions and design of reinforced concrete buildings according to ACI-318. This chapter is used as a model of practical application of seismic design, and hence, comprehensive treatment and design of various systems such as types of frames and types of shear walls are provided. Comprehensive and detailed examples are presented for illustration and practice. Chapter 8 introduces seismic provisions of structural steel buildings according to the American Institute of Steel Construction (AISC) seismic provisions. Basic provisions and identification of systems are illustrated in this chapter without giving examples. This chapter intends to give the reader a flavor of the variation of seismic requirements when the material is changed. Masonry and wood structures are not addressed in this book.

Practical applications and treatment of bridges are covered in Chap. 9, which treats seismic provision and design requirements according to the American Association of State Highway and Transportation Officials (AASHTO) Code. This chapter presents, in detail, the methods used in AASHTO to calculate seismic forces in bridges with comprehensive and illustrative examples. New simplified and efficient methods are also presented in this chapter, which are based on published developments of the author.

The last group of chapters, Chaps. 10 through 12, presents special topics pertinent to earthquake engineering. Concise presentation of geotechnical aspects, such as liquefaction and popular problems in foundations pertinent to earthquake effects are presented in Chap. 10. The basis and development of synthetic earthquake records, which are usually needed in explicit inelastic dynamic analysis, are presented in Chap. 11. The modern technique of seismic isolation is covered in Chap. 12. Seismic isolation is usually used to alleviate harmful effect of earthquakes, and to control and protect structures from damage under seismic excitation.