INTRODUCTION 1

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1.1 THE BACKGROUND

Earthquakes have long been feared as one of nature's most terrifying phenomena. Early in human history, the sudden shaking of the earth and the death and destruction that resulted were seen as mysterious and uncontrollable.

We now understand the origin of earthquakes and know that they must be accepted as a natural environmental process, one of the periodic adjustments that the earth makes in its evolution. Arriving without warning, the earthquake can, in a few seconds, create a level of death and destruction that can only be equalled by the most extreme weapons of war. This uncertainty, combined with the terrifying sensation of earth movement, creates our fundamental fear of earthquakes.

The Tangshan, China, earthquake of 1976 is officially reported to have caused 255,000 deaths: foreign observers say the total may be much more. The city of Tangshan was essentially leveled as if struck by an atomic bomb (Figure 1-1).

Figure 1-1

The city of Tangshan, China, after the 1976 earthquake. The city was leveled and over 250,000 of the city's 750,000 inhabitants were killed.

SOURCE: CHINA ACADEMIC PUBLISHERS, THE MAMMOTH TANGSHAN EARTHQUAKE OF 1976, BEIJING, 1986

However, Tangshan was a city of largely nonengineered, unreinforced masonry buildings: this level of destruction is not expected in a city built in accordance with recent seismic codes.

As described in this publication, many characteristics of the site, the earthquake and the structure influence seismic performance. It is common for a group of engineered buildings to demonstrate extremely varied damage patterns within a small area that receives essentially the same ground motion. The effect of poor soils, clearly shown in the San Francisco earthquake of 1906, was demonstrated again in the Loma Prieta earthquake of 1989. The Marina district, which was built partially on fill recovered from the debris of the 1906 earthquake, suffered substantial damage, and some buildings collapsed because of the amplified ground motion at the site (Figure 1-2). The United States does not rate very high in deadly earthquakes compared to other countries. In the entire history of the United States, the estimated number of earthquake-related deaths is only about 3,100, of which some 2,000 are accounted for by the 1906 San Francisco quake.

Figure 1-2

Collapsed apartment house in the Marina District of San Francisco, caused by a combination of amplified ground motion and a soft story.

SOURCE: NIST

The Northridge (Los Angeles) earthquake of 1994 is the most recent large earthquake in the United States. It was responsible for only 57 deaths (of which 19 were heart attacks deemed earthquake-related).

Figure 1-3

Damage in Kobe after the 1995 earthquake. Extensively damaged by air raids in World War II, Kobe was a relatively new city. Major development took place during the boom years of the 1970s and 1980s. Over 5,000 people were killed.

This was the result of the excellence of California design and construction, the time the earthquake occurred (4:31am), and because most of the earthquake's energy was directed north into a sparsely populated mountain area. However, the economic losses were estimated at $46 billion, and the earthquake was the most costly disaster in the nation's history until the recent Gulf area hurricane and floods.

However, the Kobe earthquake of 1995 showed what an earthquake centered on the downtown region of a modern city could do, even though Japan vies with the United States in the excellence of its seismic design and research. Over 5,000 deaths occurred, the majority of which happened in old timber frame buildings that had not been engineered. The earthquake sought out a weakness in the building inventory that had been overlooked. The regional economy, centered on the port of Kobe, was crippled, and large sections of the city's freeways collapsed (Figure 1-3).

At the regional and national levels, economic losses can be very high in industrialized countries for earthquakes that kill relatively few people. Even moderate earthquakes cause huge economic losses, largely due to the fragility of modern buildings' interiors, systems and enclosures.

While the low loss of life in United States earthquakes has been a cause of cautious optimism - now tempered by the experience of Kobe - increasing economic losses as a result of earthquakes are becoming a major concern. For example, in the past 30 years, earthquake losses in California, by far the most earthquake-prone state, have increased dramatically.

TABLE 1-1: Recent California Earthquakes

Earthquake	Date	Richter Magnitude	Total Loss ($ million)
San Fernando (Los Angeles)	2/9/1971	6.7	2,240
Imperial Valley (Mexican border)	10/15/1979	6.5	70
Coalinga (Central California)	5/2/1983	6.4	18
Loma Prieta (San Francisco)	10/17/1989	7.0	8,000
Northridge (Los Angeles)	1/17/1994	6.7	46,000

Table 1-1 shows a tabulation by the Federal Emergency Management Agency of earthquake losses in California between 1964 and 1994 (FEMA 1997).

Although earthquakes cannot be prevented, modern science and engineering provide tools that, if properly used, can greatly reduce their impacts. Science can now identify, with considerable accuracy, where earthquakes are likely to occur and what forces they will generate. Good seismic engineering can provide structures that can survive to a useful degree of predictability.

1.2 THE ARCHITECT'S ROLE IN SEISMIC DESIGN

The key figures in ensuring safe seismic design are the seismologist and the structural engineer. However, the architect initiates the building design and determines a number of issues relating to its configuration that have a major influence on the building's seismic performance. Configuration is defined as the building's size and three-dimensional shape, the form and location of the structural elements, and the nature and location of nonstructural components that may affect seismic performance. Many experienced earthquake engineers say that the architect plays the key role in ensuring the satisfactory seismic performance of a building.

To develop an effective seismic design, the architect and engineer must work together from the inception of the project so that seismic issues and architectural requirements can be considered and matched at every stage of the design process. For this process to be successful, the architect and engineer must have mutual understanding of the basic principles of their disciplines. Hence, the architect should have a basic understanding of the principles of seismic design so that they will influence the initial design concepts, enabling the engineer and architect to work together in a meaningful way, using a language that both understand. In turn, the engineer must understand and respect the functional and aesthetic context within which the architect works. The purpose of this publication is to provide the foundation for these understandings and to make the engineering and seismological language of seismic design clear to the architect and others who form the design team.

It is not intended that the study of this publication can turn the architect into a seismic engineer, capable of performing seismic analysis and creating the engineering design for the building. The intent is to help architects and engineers become better partners, not to further their separation, and to encourage a new level of architect and engineer collaboration.

Inspection and analysis of earthquake-damaged buildings play important roles in understanding the effectiveness of seismic design and construction. Although earthquake damage often appears random (one building may survive while its immediate neighbor will collapse), there are, in fact, patterns of damage that relate to the characteristics of the site discussed in Chapter 2 and Chapter 3 and to the building characteristics discussed on Chapters 4, 5, and 7.

1.3 THE CONTENTS OF THIS PUBLICATION

Chapter 1 provides an introduction to some of the key issues involved in seismic design, including a summary of the effects of earthquakes worldwide and in the United States.

The nature of earthquake damage is shown graphically, to provide a context for the chapters that follow.

Chapter 2 outlines the characteristics of earthquakes that are important for building design and discusses the nature of seismic hazard and how it is expressed. The chapter includes up-to-date information on new topics such as near-field activity and directivity.

Chapter 3 discusses the selection and assessment of sites in earthquake hazard areas. Important collateral issues such as earthquake-induced landslide and liquefaction are covered with special attention to tsunamis.

Chapter 4 explains the basic ways in which earthquake-induced ground motion affects buildings. This includes the ways in which buildings respond to ground motion and the characteristics of buildings that may amplify or reduce the ground motion that they experience.

Chapter 5 explains the ways in which fundamental architectural design decisions influence building seismic performance, and shows how the building becomes more prone to failure and less predictable as the building becomes more complex in its overall configuration and detailed execution. A discussion of the ways in which architectural configurations are created leads to some speculation on the future of architectural design in relation to the seismic problem.

Chapter 6 provides a sketch of the recent history of seismic codes as a means of ensuring a minimum level of building safety against earthquakes, and discusses some of the key concepts in seismic codes, using the *International Building Code* as a basis. The concept of performancbased design is outlined as a means of redressing some of the flaws of current prescriptive methods of building that have been revealed in recent earthquakes.

> The principles behind failures caused by architectural decisions are discussed in Chapter 4, and specific types of failure are categorized in Chapter 5. These two chapters present the core concepts with which the architect should be familiar, and make the central argument for the importance of architectural design decisions in determining a building's seismic performance.

Chapter 7 uses a largely historical approach to show the development of earthquake resistant-design in the twentieth century. By tracing the evolution of design in the San Francisco Bay region the chapter shows the great inventiveness of earthquake engineers throughout the first half of the century, the gradual introduction of advanced methods during the latter half of the century, and the application of advanced research in base isolation methods and energy dissipation devices that has marked the last two decades.

Chapter 8 tackles perhaps the most difficult problem facing the seismic design community, that of improving the safety of our existing seismically hazardous buildings. The chapter sketches the main issues of the existing building problem and outlines current methods of dealing with them. A common typography of building types is illustrated together with their seismic deficiencies and common retrofit techniques.

> This chapter stresses that the structural systems that are in common use have different performance characteristics, and the system selection must be properly matched to the site conditions, the architectural configuration, and the nature of the nonstructural components and systems in order to achieve the desired performance. The performance characteristics of commonly used structural systems, both those that are obsolete but still present in older buildings and those currently defined in the seismic codes, are outlined in Chapter 7, Figures 7.11A and 7.11b, and also in Chapter 8, Table 8.3.

Chapter 9 outlines the scope of the nonstructural design problem: the protection of the components and systems that transform a bare structure into a functioning building. The chapter suggests that the nonstructural problem demands a systems approach to its solution in which the critical linkages between systems are protected in addition to the components and systems themselves.

Chapter 10 recognizes that seismic design does not exist in a vacuum but the building must also be protected against other hazards, natural and man-made. In this regard, one issue is the extent to which protection from one hazard reinforces or conflicts with protection from another. This chapter uses a matrix to compare seismic protection methods to those of the key natural hazards: flood and high winds, the traditional hazard of fire, and the new hazard of physical attack.

1.4 THE BOTTOM LINE

This publication is an introduction to its subject, and deals more with principles than with the many detailed tasks that go into ensuring the seismic safety of a building. These tasks require a team approach in which all the participants in the building design and construction process must participate in a timely manner. Understanding the principles discussed in this publication will assist the design team as they search for affordable solutions that will provide building safety without compromising building function, amenity and delight.

In the confines of a document that contains a huge scope, the authors must necessarily be very selective. Seismic hazard is now clearly recognized as a national problem, and analytical and experimental research is being pursued in a number of regional centers and universities. However, there are great regional variations in seismic hazard levels. California, in particular, has had extensive experience with damaging earthquakes that have significantly influenced building design. Seismic codes, design practices and related land use and rehabilitation provisions originated in California and have been refined there for decades. Most of the material in this publication, developed by authors with first-hand experience, draws on that readily available wealth of knowledge and lessons learned.

Each chapter includes references to other readily available publications and other sources that will enable the interested reader to dig deeper into the subject matter.