INTRODUCTION 1

Seismic risk management tools, including new seismic engineering technology and data, are now available to assist with evaluating, predicting, and controlling financial and personal-injury losses from future damaging earthquakes. These tools have evolved as a result of scientific and engineering breakthroughs, including new earth-science knowledge about the occurrence and severity of earthquake shaking, and new engineering techniques for designing building systems and components to withstand the effects of earthquakes. As a result, design and construction professionals can now design and construct new buildings with more predictable seismic performance than ever before.

Seismic risks can be managed effectively in a number of ways, including the design and construction of better performing buildings as well as the employment of strategies that can result in risk reduction over the life of the building. Risk reduction techniques include the use of new technologies, such as seismic isolation and energy dissipation devices for both structural and non-structural systems; site selection to avoid hazards such as ground motion amplification, landslide, and liquefaction; and the use of performance-based design concepts, which enable the engineer to better estimate building capacity and seismic loading demand and to design buildings for enhanced performance (beyond that typically provided by current seismic codes). The implementation of risk reduction strategies by building owners and managers is critically important, not only for reducing the likelihood of life loss and injury, but also for reducing the potential for losses associated with earthquake damage repair and business interruption.

The implementation of risk reduction strategies by building owners and managers is critically important, not only for reducing the likelihood of life loss and injury, but also for reducing the potential for losses associated with earthquake damage repair and business interruption.

The Federal Emergency Management Agency (FEMA) has commissioned and funded the development of this document to facilitate the process of educating building owners and managers about seismic risk management tools that can be effectively and economically employed by them during the building development phase – from site selection through design and construction – as well as the operational phase.

This document also recognizes that seismic design professionals (architects and engineers) throughout the United States have varying levels of technical knowledge and experience pertaining to the seismic design of buildings. In areas of moderate and high seismicity, the knowledge and experience is substantially greater than in areas of low seismicity. In

many cases, design professionals rely extensively, if not exclusively, on local building seismic codes for specifications and instruction for incorporating seismic resistance in buildings that they design. In other cases, design professionals supplement their design experience and knowledge by using technical resource documents on seismic-design related issues prepared by professional structural engineering organizations and institutions,[1] in many cases with funding from state and federal agencies (e.g., FEMA). As a result, many design professionals are likely to have substantial knowledge about concepts and approaches for reducing seismic risk in new buildings, the special focus of this document.

Regardless of their level of knowledge and experience in seismic design, seismic design professionals are likely to have little knowledge regarding non-engineering-related strategies and options that could be employed by building owners and managers to reduce their seismic risk. This document has therefore also been written to educate the seismic design professional on these non-engineering-related risk management approaches, including risk transfer through insurance, risk reduction through earthquake response planning, and risk reduction through other non-engineering-related means.

This document has also been written to educate the seismic design professional on non-engineering-related risk management approaches.

While the methods described are general in nature and apply to most building uses, the document specifically addresses six occupancy types:

- commercial office facilities,
- retail commercial facilities,
- light manufacturing facilities,
- healthcare facilities,
- local schools (kindergarten through grade 12), and
- higher education (university) facilities.

The intended audience for this document consists of those design professionals (architects and engineers) who typically work with building owners and managers in developing new building projects. The document is intended to be used in conjunction with a set of six companion FEMA-funded brochures for building owners and managers, written to encourage the use of seismic risk management tools and strategies in the design and construction of new buildings. A brochure has been pre-

1. Example organizations and institutions include: the American Society of Civil Engineers, the Applied Technology Council, the Building Seismic Safety Council, and the Structural Engineers Association of California.

pared for each of the six facility types identified above, and each is limited in scope and content so that it can be quickly read and easily understood by building owners and managers. The brochures identify a number of issues, many of them posed in the form of questions, that relate to seismic risk and the benefits that seismic risk management, including performance-based design, can provide to building owners and managers. Each brochure is amply illustrated with photographs, charts, and tables that demonstrate important concepts in seismic risk management and seismic design and construction.

This document and set of brochures were preceded approximately fifteen years ago with a series of FEMA documents, known as the *Seismic Considerations Series*, which were written for a broad range of professionals and stakeholders interested in and concerned about building seismic performance issues.

1.1 IMPETUS FOR UPDATING THE PRIOR DOCUMENTS IN THE FEMA *SEISMIC CONSIDERATIONS SERIES*

The initial publications in the FEMA-funded *Seismic Considerations Series*, prepared by the Building Seismic Safety Council and published in the time period, 1988-1990, provided guidance on seismic safety and design-related issues to owners, managers, and designers of selected building types. The series consisted of the following documents:

- *Seismic Considerations, Elementary and Secondary Schools* (FEMA 149 Report)
- *Seismic Considerations, Health Care Facilities* (FEMA 150 Report)
- *Seismic Considerations, Hotels and Motels* (FEMA 151 Report)
- *Seismic Considerations, Apartment Buildings* (FEMA 152 Report)
- *Seismic Considerations, Office Buildings* (FEMA 153 Report)

The documents were written to address seismic performance issues and cost-effective strategies for improving building seismic performance through engineering approaches and procedures laid out in the then state-of-the-art *NEHRP Recommended Provisions for the Development of Seismic Regulation for New Buildings* (BSSC, 1988).

Since 1990, a considerable amount of new knowledge and information has been developed and published under the

National Earthquake Hazards Reduction Program (NEHRP), a broad multidisciplinary and Congressionally-mandated research and development program, administered by four Federal agencies and funded at the level of approximately $100 million per year. The purpose of NEHRP is to improve the capacity of the nation's built environment to resist the effects of earthquake induced ground shaking and the collateral hazards of landslide, liquefaction, ground failure, inundation, and postearthquake fires.

Major new seismic hazard mitigation tools and strategies developed in the 1990s include:

- new seismic hazard maps, published by the U. S. Geological Survey, that incorporate (1) state-of-the-knowledge earthquake occurrence models, (2) state-of-the-knowledge ground motion attenuation relationships, and (3) new probability-of-occurrence levels that better characterize expected ground motions in regions of large, infrequent earthquakes;
- new performance-based seismic design concepts, criteria, and procedures, funded by FEMA and published in the FEMA 273 *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (ATC, 1997a), and its successor document, FEMA 356, *Prestandard and Commentary for Seismic Rehabilitation of Buildings* (ASCE, 2000), that enable the building owner and design engineer to evaluate and upgrade buildings to meet specific performance levels (e.g., collapse prevention, life safety, immediate occupancy, continued operation) for defined levels of earthquake ground shaking; and
- new seismic risk management strategies, developed largely by the private sector, which enable building owners and managers to reduce the financial impacts of earthquakes by diversifying the locations of operations, by obtaining higher levels of earthquake insurance, and by using securitization instruments, such as Catastrophic Bonds.

These new technological developments provide the necessary tools for building owners and managers, with the assistance of design professionals, to make and implement cost-effective decisions regarding seismic safety and seismic hazard mitigation. They also provide the impetus and justification for updating the original *Seismic Considerations Series* documents, which are based on seismic hazard information and engineering knowledge and concepts developed in the 1970s and 1980s.

1.2 OBJECTIVES AND SCOPE OF THIS DOCUMENT

The objectives of this report are fourfold: (1) to summarize, in a qualitative fashion, important new concepts in performance-based seismic design and new knowledge about the seismic hazard facing the United States (in a way that can be easily communicated to building owners and managers); (2) to describe a variety of concepts for reducing seismic risk, including the means to reduce economic losses that are not related to engineering solutions; (3) to provide illustrative examples and graphical tools that can be used by the design community to more effectively "sell" concepts of seismic risk management and building performance improvements; and (4) to establish a means by which seismic engineering and financial risk management can be integrated to form a holistic seismic risk management plan. The overarching goal of the document is to provide a means to facilitate communications between building owners/managers and design professionals on the important issues affecting seismic risk decision making during the design and construction of new facilities, as well as the operational phase.

The overarching goal of the document is to provide a means to facilitate communications between building owners/managers and design professionals on the important issues affecting seismic risk decision making during the design and construction of new facilities, as well as the operational phase.

Stated another way, this report may be considered as a framework for integrating seismic risk management into already well established project planning, design, and construction processes used by most owners and designers. The report is intended to be used in:

- the initial project planning stages to address siting, general building performance considerations, and how the design process can incorporate performance-based design principles;
- the budgeting phase of a project to identify the resources that can be allocated to manage risk;
- the design phase of a project to assist in the layout of structural systems, define performance objectives, and perform benefit-cost analyses of various building options; and
- the construction administration phase of a project to achieve a high level of quality assurance and control, thereby increasing the likelihood that the facility, as constructed, will perform as expected.

In addition, the report provides information that pertains to risk management strategies that are not directly part of the project planning, design, and construction processes, but that owners and managers can use to mitigate earthquakes losses. These strategies, applicable to newly constructed buildings as well as existing facilities, should be considered in conjunction with engineering design and construction strategies

when developing a holistic seismic risk management plan for a new building. Thus the report is intended to also be beneficial in:

- evaluating the benefits of earthquake insurance and quantifying coverage needs;
- developing a postearthquake response and recovery program that may reduce down-time and potential loss of business following a major event;
- calculating the benefits of diversifying operations geographically or among different buildings within a single campus; and
- dealing with the risks associated with other types of hazards, both natural and man-made.

1.3 DOCUMENT CONTENTS AND ORGANIZATION

This document has been written and organized to assist building design professionals (architects and structural engineers) in communicating with building owners on earthquake risk, that is, to advise building owners on methods that could be employed to reduce their seismic risk. It is recognized that many design professionals may not be familiar with emerging concepts in (1) seismic risk management, (2) performance-based seismic design, and (3) seismic design and performance issues related to the specific occupancies discussed in this report—commercial office facilities, retail commercial facilities, light manufacturing facilities, healthcare facilities, local schools (kindergarten through grade 12), and higher education (university) facilities. These topics are therefore discussed in detail, including illustrations and tables designed to be used by the building design professionals when communicating with building owners on the means to reduce their seismic risk.

Seismic risk management is introduced and discussed in Chapter 2, including an overview discussion on seismic risk and discussions on a range of risk reduction strategies. This chapter also describes issues to be considered when developing a risk management plan, addressed in the context of the likelihood of potential losses. The identified risk reduction strategies consist of: (1) first cost or design strategies; (2) operating cost or business strategies, and (3) event response strategies. Also included are discussions on the selection of an optimal combination of risk reduction strategies, example applications of seismic risk management strategies on real buildings, and advocacy of seismic risk management.

The means for identifying and assessing earthquake-related hazards during the site selection process are described in Chapter 3. The chap-

ter begins with a discussion of current approaches for seismic shaking hazard determination and assessment in the United States, followed by discussions on the collateral seismic hazards of surface fault rupture, soil liquefaction, soil differential compaction, landsliding, and inundation. Chapter 3 also discusses other earthquake-related hazards affecting building performance, including vulnerable transportation and utility systems (lifelines), the hazards posed by adjacent structures, the release of hazardous materials, and postearthquake fires. Specific guidance for assessing these earthquake related hazards during the site selection process, including a checklist for use by design professionals, is provided at the end of this chapter.

In Chapter 4, emerging concepts in performance-based seismic design are described. This chapter includes a discussion on (1) expected building performance when designing new buildings to current codes; and (2) state-of-the-art concepts in performance based seismic design, which were developed for the seismic rehabilitation of existing buildings and are beginning to be applied on a volunteer basis in the seismic design of new buildings. The chapter concludes with a description of next-generation performance-based seismic design products and tools for engineers and building owners/managers expected to become available over the next decade or so.

Chapter 5 focuses on ways to reduce seismic risk by improving building performance, a first cost or design risk reduction strategy. This chapter describes and discusses performance attributes of various structural systems and materials, selection of the architectural configuration, and the interaction of nonstructural components and systems with the building structure. Also included is a discussion of the costs and benefits associated with improved performance, as well as actual case studies describing structural system cost and performance considerations.

Building and expanding on the ways to improve seismic performance discussed in Chapter 5, the next six chapters (Chapters 6 through 11) briefly identify specific design issues associated with each of the six occupancy types considered in this document. In addition, each of these chapters provides examples of earthquake performance for that facility type and discusses performance expectations and requirements, and specific vulnerabilities. Chapters 6 and 7, respectively, address commercial office buildings and commercial retail buildings; Chapter 8 addresses light manufacturing facilities; Chapter 9 focuses on healthcare facilities; and Chapters 10 and 11, respectively, address local

schools (kindergarten through grade 12) and higher education facilities (universities).

Chapter 12 addresses the various responsibilities of members of the design team, including the building owner, architect, structural engineer, and mechanical/electrical/plumbing engineers. This chapter also includes discussions on the added value of risk management and design and construction quality assurance.

Following Chapter 12 are a list of references and a list of individuals who participated in the development of this report.

1.4 DOCUMENT FORMATTING AND ICONS

Several icons, shown below, are used in highlighted portions of this document to emphasize pertinent information.

The **Definition** icon defines key terms and acronyms.

The **Case Study** icon provides practical and relevant information based on past experience.

The **Resources** icon provides supplemental information from FEMA and other organizations that may impact design considerations and decision-making.

The **Cost Consideration** icon identifies a value or investment cost that needs to be considered in decision-making.

The **Risk Consideration** icon identifies a potential or real risk that needs to be considered in decision-making.

The **Design Consideration** icon identifies a design issue that needs to be considered in decision-making.