Building for the Earthquakes of Tomorrow

Complying with Executive Order 12699

IS-8.A / February 2006

U.S. DEPARTMENT OF HOMELAND SECURITY
FEMA

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Background

Since the Earthquake Hazards Reduction Act was passed in 1977, many actions have been taken to improve seismic safety. Executive Order 12699, "Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction," signed by President Bush in January 1990 is a significant Federal seismic risk reduction action. This Executive Order requires all new Federal, federally assisted, and federally regulated buildings to be appropriately seismic resistant. Among new construction affected are all buildings financed, either partially or fully, with Federal grants or federally guaranteed loans.

Because this Executive Order is so wide reaching, covering everything from single-family dwellings to large Federal complexes across the nation, a training course was needed to provide the tools, information, and planning guidance for those people affected by the Executive Order. The purpose of this course is to provide individuals in State and local governments, and the building and financial industries, with information about the requirements of the Executive Order and how they will be implemented. The course is also intended to provide the student with basic knowledge about earthquakes and how buildings can be built to be safe during an earthquake.

Course Goals and Objectives

The goal of this training course is to provide the students with the tools, information, and planning guidance they need to effectively deal with and prepare for the implementation of the Executive Order and its consequences.

At the conclusion of this course, the student will be able to:

- Describe the intent and implications of the Executive Order and the consequences of noncompliance;
- Describe how the Executive Order will affect the built environment;
- Describe the theory and practice of the Executive Order, hazard mitigation, and the need/rationale for including seismic provisions in the building codes;
- Compare Executive Order standards and local codes to determine substantive differences and deficiencies; and
- Develop a plan of action to achieve compliance if local codes do not comply with the Executive Order.

Unit 1

Course Introduction

INTRODUCTION

On the morning of September 2, 1886, the people of Charleston, South Carolina, awoke to a devastating scene. For a day and a half, their city had been racked by a series of disastrous earthquakes. Most inhabitants of the city were camped out in tents in parks and open places, afraid to return to what remained of their homes. The streets were cluttered with rubble from the 102 buildings destroyed. Ninety percent of the city lay in ruins. Seventy people were dead, and doctors had been working around the clock to tend to the thousands of injured. People as far away as New York, Chicago, Boston, and St. Louis also had felt the tremors and wondered if they might be next.

If President Grover Cleveland had signed Executive Order 12699, "Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction," at that time, there would be very little need for this course. People throughout the United States would only have to look at the pictures in their newspapers and remember the tremors. They would have been clamoring to know, "How do I protect my family, my home, and my business?"

Unfortunately, Executive Order 12699 was not signed by President Cleveland in 1886. It was signed by President George Bush in 1990 and became effective only in February 1993. More than 100 years have gone by since the Charlestonians witnessed the devastation of their city. No one remembers the earthquakes, and no one remembers the tremors experienced in cities throughout the eastern part of the country. However, the hazard has not gone away. The geologic stresses and strains in this region continue to build, waiting for their release—an earthquake. Scientists have not had much success with predicting earthquakes, but they are fond of saying, "The farther away you are from the last earthquake, the closer you are to the next." Even though 100 years have gone by without a repeat of the 1886 disaster, it does not mean that we are out of the woods; it means we are just that much closer to the next damaging earthquake.

We cannot escape the threat of an earthquake, but we can mitigate the damage caused by earthquakes. That is the purpose of Executive Order 12699: to prepare our communities by using building codes that ensure structures that are built to withstand an earthquake with reduced risk of injury or loss of life and devastation to the built environment.

Concern over the potential for earthquakes, the safety of people, and the security of infrastructure and property gave rise to Executive Order 12699. This course presents the intent of the Executive Order in detail and discuss how your community can protect itself. Topics covered in each unit are summarized later in this unit. Unit 1 answers the following questions:

- What is the history of earthquakes in the United States?
- How can your community be protected?
- What is the purpose of this course?
- For whom is this course designed?
- How should I proceed through the course?
- What will be covered in this course?

WHAT IS THE HISTORY OF EARTHQUAKES IN THE UNITED STATES?

Although we associate earthquakes with the western United States—especially California—the fact is that all 50 States are vulnerable. Take a look at the map in Figure 1-1. It shows the earthquake hazard across the country. What is the highest hazard in your State?

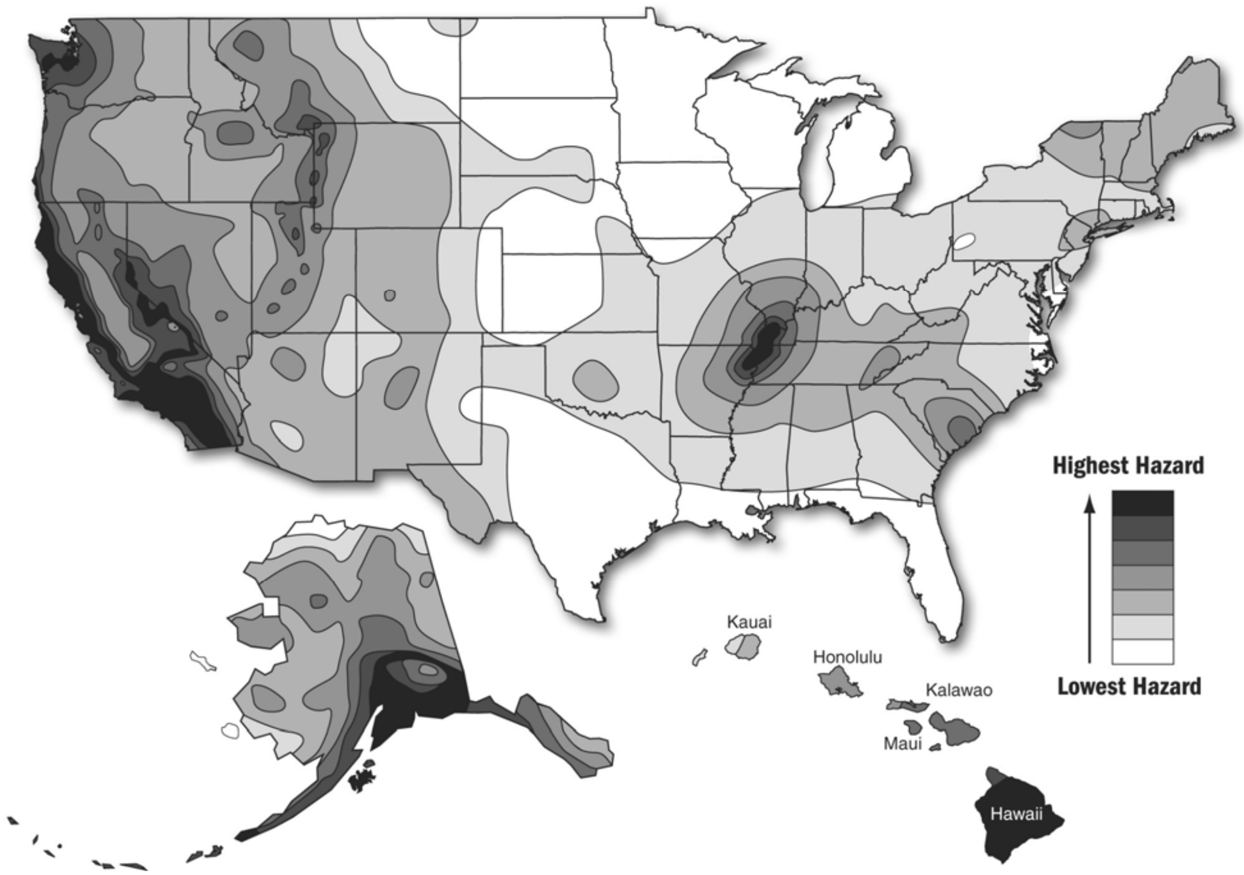


Figure 1-1 *Source: U.S. Geological Survey.*

Was the hazard in your State higher or lower than you thought? Did you realize that there is a high potential for earthquake activity in Illinois, Kentucky, Tennessee, Missouri, and Arkansas? Everyone has heard about the great earthquake that struck San Francisco in 1906. Few people realize that earthquakes of equal magnitude occurred near the New Madrid seismic zone of the central United States in 1811 and 1812. (New Madrid is a town in southern Missouri.) The damage done by these earthquakes resulted in fewer deaths and less damage to the built environment (buildings, transportation lines and structures, communications lines, and utilities) than the San Francisco earthquake. This is because there were fewer people and buildings there in 1811 and 1812, but imagine what a similar earthquake might do today. Cities like Memphis and, to a lesser extent, Little Rock and St.

Louis, most likely would experience significant damage. Traffic on the Mississippi River would be disrupted. Bridges, highways, railroads, and communications networks that did not exist in 1811 and 1812 could be badly damaged or destroyed.

The earthquakes around the New Madrid area happened a long time ago. Many of the areas where the earthquakes occurred do not appear to be seismically active today. The lack of recent earthquake, or seismic, activity does not mean that an area is safe from earthquakes. In fact, some scientists believe that a lack of recent seismic activity—especially in a region that once was seismically active—could indicate a higher likelihood of an earthquake occurrence. The earthquake hazard for the central United States has probably not changed since 1812. What has changed is the risk to the communities in this area. These terms, hazard and risk, are sometimes used interchangeably. In fact, they have very different meanings. There are many types of hazards—earthquakes, floods, volcanoes, and many others. Hazards exist because of some natural phenomena. For earthquakes, a hazard exists because of the structure of the rocks below the surface of the earth. A hazard has the potential to cause the loss of life, personal injury, and damage. So when we say the earthquake hazard for an area has not changed, it means that the potential for an earthquake to occur has not changed.

Risk, on the other hand, refers to the potential exposure of persons and the built environment (buildings, transportation lines and structures, communications lines, and utilities) to loss of life, personal injury, and damage as a result of an earthquake. Seismic hazard is high in some areas of the West, such as in Montana, but the seismic risk is much lower than in the central United States because the population and built environment is much smaller. The risk in the central United States has increased dramatically since 1812 with the growth of major cities, highways, and utilities while the hazard has stayed the same. When almost 200 years go by without any substantial earthquake activity, it is easy for a community to put the hazard out of their minds. Unfortunately, this also makes it easy to ignore the need to reduce seismic risk in local communities.

This course will help you evaluate and take steps to reduce the risk, or mitigate, earthquake damage occurring in your community. You will need to look at both the seismic hazard and risk for your community. You can’t change your community’s seismic hazard, but you can change its seismic risk. The time to act is now, before a major seismic event causes a devastating loss of life and structural damage. Making sure that new construction in your community is seismically resistant will help reduce the risk to your community in the future.

Figure 1-2 (page 1-6) lists some of the major earthquakes that have occurred in the central and eastern United States, Mexico, and Canada since 1700 and their magnitudes. (For a complete list of major earthquakes that have occurred in the United States, Mexico, and Canada between 1700 and 2004, see Appendix A.) We have grown accustomed to earthquakes occurring in California and some western states, but it is rare to see a list that features other areas of the United States.

Year	Date	Time[1]	Place	Magnitude[2]
1700	January 26	NA[3]	Cascadia subduction zone	~9
1811	December 16	08:00	New Madrid, MO	~8.1
1812	January 23	15:00	New Madrid, MO	~7.8
1812	February 7	09:45	New Madrid, MO	~8
1857	January 9	16:24	Fort Tejon, CA	~7.9
1868	April 3	02:25	Hilea, southeast Hawaii, HI	~7.9
1886	August 31	02:51	Charleston, SC	~7.3
1895	October 31	11:08	Charleston, MO	~6.6
1906	April 18	13:12	San Francisco, CA	7.8
1918	October 11	14:14	Puerto Rico	7.5
1929	November 18	20:32	Grand Banks, Nova Scotia, Canada	7.3
1938	November 10	20:18	Shumagin Islands, AK	8.2
1940	May 19	04:36	Imperial Valley, CA	7.1
1946	April 1	12:28	Unimak Island, AK	8.1
1949	August 22	04:01	Queen Charlotte Island, British Columbia, Canada	8.1
1952	July 21	11:52	Kern County, CA	7.3
1954	December 16	11:07	Fairview Peak, NV	7.1
1959	August 18	06:37	Hebgen Lake, MT	7.3
1964	March 28	03:36	Prince William Sound, AK	9.2
1965	February 4	05:01	Rat Island, AK	8.7
1975	November 29	14:47	South flank of Kilauea, HI	7.2
1983	May 2	23:42	Coalinga, CA	6.4
1985	September 19	13:17	Michoacan, Mexico	8.0
1994	January 17	12:30	Northridge, CA	6.7
2001	February 28	18:54	Olympia, WA	6.8
2002	April 20	10:50	Au Sable Forks, NY	5.2
2003	December 22	19:15	San Simeon, CA	6.6

[1]Greenwich Mean Time (GMT) *Source: U.S. Geological Survey.*
[2]Earthquake magnitude as measured on the Richter Scale, which quantifies the ground motion and energy released at the source of the earthquake. Information about measuring earthquakes with the Richter Scale and the Modified Mercalli Intensity Scale is found in Unit 3.
[3]Not Available

Figure 1-2

What do you think the effects of these earthquakes in terms of loss of life and property damage might be today?

HOW CAN YOUR COMMUNITY BE PROTECTED?

From looking at the seismic hazard map and the historical information on earthquakes in Figures 1-1 and 1-3, we have learned about the general earthquake hazard in various geographic areas. What can be done to protect a community from earthquake damage? However inevitable or unpredictable earthquakes may seem, there are numerous things that can be done to prepare for an earthquake and reduce loss of life and damage to the built environment, which includes buildings, transportation lines and structures, communications lines, and utilities. Design and construction of seismically resistant buildings can reduce risk to communities. One of the key purposes behind Executive Order 12699 is to get the Federal Government and State and local communities to respond to the earthquake hazard by taking steps that will save lives and reduce property damage in the event of a major earthquake.

Post-disaster studies (studies done on the effects of a disaster) have shown that community investment in mitigation pays direct dividends. What do we mean by mitigation? Mitigation is a set of actions, resulting in permanent improvements, taken to reduce risk of injury and loss of life due to damage to structures during a natural disaster. Mitigation is generally achieved through the effective use of building codes, land-use planning, and public awareness.

An analysis published in May 1994, by the National Institutes of Standards and Technology (NIST), showed that seismic engineering techniques do reduce damage to buildings. It said that after the San Fernando, California, earthquake in 1971, during which several hospitals and other structures collapsed or were irreparably damaged, the Uniform Building Code (UBC) section on seismic engineering was made more stringent. The report further stated that no hospitals built to the post 1971 UBC standard were seriously damaged during the Northridge earthquake in 1994. In fact, the report stated that damage to hospitals built after 1971 was almost non-existent. The report found similarly improved performance among other structures, including single-family homes that were built to the post-1971 UBC standard.

Reducing damage to a community's buildings not only saves lives, it can save the community. Reconstruction or replacement of damaged or destroyed buildings is very expensive. Federal assistance programs to repair or replace public buildings often are eligible for reimbursement of a significant portion of expenditures. This program does not pay for the costs which are, or could have been, covered by private insurance. Even with maximum reimbursement allowed, affected communities bear large financial responsibilities to repair or replace public buildings.

The additional cost of seismic resistant construction for a new building is considerably less than the cost for retrofitting an existing building. A 1985 Building Seismic Safety Commission study found that the average increase in total costs to be 0.7% for low-rise residential, 3.3% for high-rise residential, 1.3% for office, 0.5% for industrial, and 1.7% for commercial. (Reducing Earthquake Hazards in the Central United States, Seismic Building Codes; University of Illinois) Many communities that have suffered serious damage from disasters have found that, even with insurance and Federal assistance, the costs of repairing and rebuilding all damaged buildings may be prohibitive. Five years after the 1989 Loma Prieta earthquake, small cities such as Watsonville and Santa Cruz, California, are still struggling with the costs of financing their reconstruction efforts.

How can communities get started? We know that mitigation measures such as adoption of building codes, zoning ordinances, and land-use practices are needed to prevent or reduce actual damage from earthquakes. We also know that awareness and education are key factors in effective mitigation as well. This course and your compliance with Executive Order 12699 are vital steps toward adopting and implementing effective mitigation practices in your community.

WHAT IS THE PURPOSE OF THIS COURSE?

Purpose

Since the Earthquake Hazards Reduction Act was passed in 1977 to establish a program to help communities reduce losses from earthquakes, many actions have been taken to improve seismic safety in the United States. A strong federally mandated effort is Executive Order 12699, “Seismic Safety of Federally Assisted or Regulated New Building Construction,” signed by President George Bush in January 1990. This Order requires all *new* Federal, federally assisted, and federally regulated buildings to be appropriately “seismic resistant.”

Because the scope of Executive Order 12699 is so far-reaching—covering everything from single-family dwellings, public buildings, schools, and hospitals to large Federal complexes across the nation—a course is needed to provide the tools, information, and planning guidance for the people whom the Executive Order affects. This course provides individuals with the information they need to comply with Executive Order 12699.

Goals and Objectives

At the conclusion of this course, you will be able to:

- Describe the intent and implications of Executive Order 12699, the advantages of compliance, and the consequences of noncompliance;
- Describe how it will affect the built environment;
- Describe the theory and practice of Executive Order 12699, hazard mitigation, and the rationale for including seismic provisions in building codes;
- Compare the Executive Order's standards and local codes to determine substantive differences and deficiencies in local codes; and
- Develop a plan of action for achieving compliance if local codes do not comply with Executive Order 12699.

FOR WHOM IS THIS COURSE DESIGNED?

This course is designed for individuals who may be involved in the implementation of Executive Order 12699. The following list shows many, but not all, of those who could benefit from this course:

- Government personnel
    - State and local decisionmakers,
    - Elected and appointed officials,
    - Building code officials,
    - Zoning and land-use officials,
    - Planning and building commission officials,
    - Public works officials,
    - Construction permitting officials,
    - Building inspectors, and
    - Federal officials.
- Others

- Engineers, architects, and construction industry representatives,
- Students in construction technology, engineering, and related fields,
- Lenders, and
- Private industry representatives.

HOW SHOULD I PROCEED THROUGH THE COURSE?

Read and study each section, then complete the Unit Review. You don't have to go through the course sequentially, but each unit assumes that you have covered all the information in previous units. If a term has been defined in a previous section, it will not be defined again. However, if you feel you are already knowledgeable about certain topics, you can jump around.

Each unit ends with a Unit Review. These reviews are designed to help you check your comprehension of the information presented in the units. Questions have been designed to review the information and to give you a chance to explore certain concepts further. You may find it useful to start a section by going through the Unit Review. This will help you focus on unfamiliar information. If you are already familiar with the information in any of the units, use the Unit Reviews to check your knowledge before you move on. The Unit Reviews also will prepare you for the final exam you must pass to receive credit for this course.

WHAT WILL BE COVERED IN THE COURSE?

This course is made up of seven units, each of which is described briefly below:

Unit 1: Course Introduction

This unit introduces you to the course, its objectives and goals, and the history of earthquakes in the United States.

Unit 2: Executive Order 12699

This unit introduces and explains the intent of Executive Order 12699.

Unit 3: Earthquake Causes and Characteristics

This unit presents the current theories on causes of earthquakes and discusses earthquake characteristics.

Unit 4: Earthquake Effects

This unit examines an earthquake's primary effects on the natural and built environments. Secondary consequences to communities also will be explored.

Unit 5: Protecting Your Community

This unit discusses the importance of mitigation practices and helps you to establish a seismic safety program tailored to your community's needs.

Unit 6: Evaluating Your Community's Safety

This unit will help you evaluate your community's susceptibility to loss of life and property damage due to earthquakes.

Unit 7: Conclusions

This unit reviews and summarizes key points made throughout the course.

UNIT 1 - SUMMARY

Unit 1 introduced us to the history of earthquakes in the United States, the purpose of this course, and the topics to be covered. In this unit, we answered the following questions:

- What is the history of earthquakes in the United States?
- How can your community be protected?
- What is the purpose of this course?
- For whom is this course designed?
- How should I proceed through the course?
- What will be covered in the course?

Unit 1

Course Introduction

Unit Review

Directions: For each question, circle the letter of the correct response and check your answers with the Answer Guide at the end of the unit.

1. The set of actions, resulting in permanent improvements, taken to reduce risk of injury and loss of life due to damage to structures during a natural disaster is referred to as:

    a. mitigation
    b. determent
    c. zoning
    d. land-use practices

2. To provide responsible individuals with the information they need to comply with Executive Order 12699 is:

    a. the purpose of the Earthquake Hazard Reduction Act.
    b. the purpose of this course.
    c. the responsibility of all Federal officials.
    d. the responsibility of lenders.

3. Which statement below is ***not*** an objective of this course?

    a. To describe the intent and implications of Executive Order 12699, the advantages of compliance, and the consequences of noncompliance.
    b. To evaluate national model building codes.
    c. To develop a plan of action to achieve compliance if local codes do not comply with the order.
    d. To describe how the order will affect the built environment.

4. Which activity cannot be defined as mitigation?

   a. Earthquake prediction
   b. Seismic education and awareness
   c. Adoption of building codes
   d. Land-use planning

5. This course has been designed for:

   a. only selected Federal officials.
   b. only Federal and State officials.
   c. only State and local decisionmakers.
   d. a variety of State, local, and Federal Government officials, as well as lenders and other private industry representatives.

6. What is the seismic hazard level of New York?

   a. Very low
   b. Very high
   c. Moderate
   d. High

7. The potential damage to the built environment (buildings, transportation lines and structures, communications lines, and utilities) due to an earthquake is referred to as seismic ________.

   a. hazard
   b. risk
   c. load
   d. affect

8. The earthquake hazards for Yellowstone National Park and Los Angeles are about the same. Which area has a higher risk?

   a. Yellowstone National Park
   b. Los Angeles

Unit 1

Course Introduction

Unit Review - Answer Guide

1. The set of actions, resulting in permanent improvements, taken to reduce risk of injury and loss of life due to damage to structures during a natural disaster is referred to as:

    a. mitigation
    Reference: p. 1-7

2. To provide responsible individuals with the information they need to comply with Executive Order 12699 is __________.

    b. the purpose of this course
    Reference: p. 1-9

3. Which statement below is ***not*** an objective of this course?

    b. To evaluate national model building codes.
    Reference: p. 1-9

4. Which activity cannot be defined as mitigation?

    a. Earthquake prediction.
    Reference: p. 1-7

5. This course has been designed for:

    d. a variety of State, local, and Federal Government officials, as well as lenders and other private industry representatives.
    Reference: p. 1-9

6. What is the seismic hazard level of New York?

   c. Moderate
   Reference: p. 1-3

7. The potential damage to the built environment (buildings, transportation lines and structures, communications lines, and utilities) due to an earthquake is referred to as seismic ________.

   b. risk
   Reference: p. 1-4

8. The earthquake hazards for Yellowstone National Park and Los Angeles are about the same. Which area has a higher risk?

   b. Los Angeles
   Reference: p. 1-3

Unit 2

Executive Order 12699

INTRODUCTION

In the last unit, we looked at some of the earthquakes that have occurred in our nation's history. In this unit, we will take a detailed look at the history and intent of Executive Order 12699.

Unit 2 answers the following questions:

- What is the history of Seismic Safety Legislation?
- What is the purpose of Executive Order 12699?
- What does Executive Order 12699 require?
- How are Federal agencies affected by Executive Order 12699?
- If you are not a part of the Federal community, how does Executive Order 12699 affect you?

WHAT IS THE HISTORY OF SEISMIC SAFETY LEGISLATION?

This section will discuss some of the historical events that led to Executive Order 12699.

Legislative History

Very few earth scientists were monitoring earthquake activity before the 1960s. During that decade, the Nuclear Regulatory Commission's seismology projects increased the number of earth scientists and earthquake engineers operating in the United States. By the time of the 1964 Alaskan earthquake, a substantial number of trained specialists were available to take measurements and record this event. The Alaskan earthquake has been called one of the most violent earthquakes of all time. It registered XI (11) on the Modified Mercalli Intensity Scale (maximum 12) and, although Alaska is a largely rural state, the quake caused 114 deaths and more than $311 million in property damage.

After the Alaskan earthquake, President Lyndon Johnson asked the National Academy of Sciences to conduct a comprehensive study of earthquakes and their effects on the natural and built environments. This project mobilized many researchers from various disciplines. Because of this study, the Alaskan earthquake is one of the best-documented in United States history. Research into the quake led to a series of efforts to develop risk reduction measures and identify future research needs. Also after the earthquake, scientists conducted notable work on earthquake prediction, but, even today, earthquake prediction is an inexact science.

Although the Alaskan earthquake spurred significant research, no national legislation was passed to protect the built environment. In February 1971, however, Congress took action. A moderate earthquake measuring VIII-XI on the Modified Mercalli Intensity Scale struck near San Fernando, California, and caused more than $500 million in property damage in the Los Angeles area. The significant damage in a large metropolitan area caused by this earthquake spurred a series of congressional hearings, the introduction of bills to expand the nation's support of earthquake research, and extensive post-earthquake studies. Many began to realize that even *infrequent* moderate seismic events could have devastating effects on an area's schools, hospitals, businesses, homes, and economy.

Many of the bills introduced in response to the 1971 earthquake focused on prediction, but, as they were continually defeated, the scope of the bills was expanded to include education, development of emergency services and seismically resistant construction methods, and creation of reconstruction plans. Effective legislation was impeded by the belief that earthquakes troubled only California and other Western States. Opponents of the legislation believed that only those States affected by earthquakes should conduct earthquake research and pass legislation.

For several years, States passed their own legislation. In 1975 and 1976, however, several critical events occurred that sped up passage of the first earthquake bill to apply to all States. These events were:

- Release of new research indicating that all 50 States have *some* potential for seismic activity,
- Occurrence of several devastating earthquakes around the world, and
- Successful prediction of an earthquake in China.

Earthquake Hazards Reduction Act of 1977

These events and the support of the administration and legislative leaders eventually led to the passage of the Earthquake Hazards Reduction Act of 1977. The act mandated the establishment and maintenance of the National Earthquake Hazards Reduction Program (NEHRP) to effectively reduce the risks to life and property from future earthquakes.

The objectives of NEHRP are:

1. To develop technologically and economically feasible design and construction methods and procedures to make new and existing structures in areas of seismic risk earthquake resistant, giving priority to the development of methods and procedures for power generating plants, dams, hospitals, schools, public utilities, public safety structures, high occupancy buildings, and other structures that are especially needed in time of disaster;

2. To implement, to the greatest extent practicable, in all areas of very high to moderate seismic risk, a system using personnel, technology, and procedures to predict earthquakes and identify, evaluate, and accurately characterize seismic hazards;

3. To develop, publish, and promote, in conjunction with State and local officials and professional organizations, model building codes and to develop means to assess seismic risk and encourage the use of risk information in making land-use policy decisions and building construction activity;

4. To develop improved understanding of and capability with respect to earthquake-related issues, including methods of damage control and prevention, dissemination of earthquake alerts, organization of emergency services, and planning for reconstruction and redevelopment after an earthquake;

5. To educate the public, State and local officials, and members of private industry about earthquakes, to identify locations and structures that are especially susceptible to earthquake damage, to develop methods for reducing the adverse consequences of an earthquake, and related matters;

6. To develop research on:

   - Ways to increase the use of existing scientific and engineering knowledge to mitigate earthquake hazards; and

- Ways to assure the availability of earthquake insurance or some functional substitute.

Early activities under NEHRP addressed more effective building construction techniques. In the 1980s, NEHRP began producing a report titled *Recommended Provisions for the Development of Seismic Regulations for New Buildings* (commonly referred to as the NEHRP *Provisions*), which synthesized all the lessons learned from past seismic events and the most recent research and developed a national approach to seismic design. Previously, there had been a large body of information available for high-risk areas, but not much for moderate- or moderately high-risk areas. The NEHRP *Provisions* gave rational guidance for areas of moderate seismic risk.*

In 1980, the Interagency Committee on Seismic Safety in Construction (ICSSC) was formed as an interagency group for discussion of construction and seismic safety issues. Soon after the ICSSC was formed, its members began to focus on encouraging Federal agencies to adopt the provisions set forth by NEHRP. Toward this end, the ICSSC drafted Executive Order 12699.

History of Executive Order 12699

Executive Order 12699 was drafted to cover all Federal agencies and Federal programs and to include consideration of existing buildings and lifelines, as well as new construction. To gain approval from the Office of Management and Budget (OMB), the ICSSC had to show that the costs of the Executive Order would not be burdensome. The ICSSC showed that there would be only a 1-to-2-percent increase in Federal costs if seismic provisions for *new* building construction were mandated. Estimating the financial impact on the Federal Government for application of the provisions to existing buildings and lifelines, however, was much more difficult. Because no estimate could be made, the mandate for seismic requirements was revised to cover only new building construction. President George Bush signed the Executive Order on January 5, 1990.

*This document continues to be updated triennially, and the latest version is the 2003 edition (FEMA 450). The NEHRP *Provisions* serve as the basis for the seismic requirements of the nation's model building codes (such as the International Building Code [IBC]) and construction standards (such as ASCE 7).

WHAT IS THE PURPOSE OF EXECUTIVE ORDER 12699?

The full text of Executive Order 12699 is included in Appendix B. The following discussion highlights some of its key points:

The President issues an executive order to impose regulations on the Federal community. An executive order may also influence the adoption of certain requirements by State and local governments and private-sector organizations. Even if an executive order directly affects only the Federal community, State and local governments and the private sector should be familiar with it because they often are involved in fulfilling executive orders. Because Executive Order 12699 affects federally financed construction and federally insured loans, it is of concern to the commercial and residential construction industry.

The purpose of Executive Order 12699 is presented in two sections that separately address federally owned and federally leased, assisted, and regulated buildings. Section 1 addresses federally *owned* buildings—buildings purchased by the Federal Government. It says:

> The purposes of these requirements are to reduce risks to the lives of occupants of buildings owned by the Federal Government and to persons who would be affected by the failures of Federal buildings in earthquakes, to improve the capability of essential Federal buildings to function during or after an earthquake, and to reduce earthquake losses of public buildings, all in a cost-effective manner.
>
> *Executive Order 12699, Section 1*

Section 2 addresses the purpose of the order for federally *leased, assisted, and regulated* buildings:

> The purposes of these requirements are to reduce risks to the lives of occupants of buildings leased for Federal uses or purchased or constructed with Federal assistance, to reduce risks to the lives of persons who would be affected by earthquake failures of Federally assisted or regulated buildings, and to protect public investments, all in a cost-effective manner.
>
> *Executive Order 12699, Section 2*

WHAT DOES EXECUTIVE ORDER 12699 REQUIRE?

The very nature of an executive order makes it clear that the Federal community must prepare procedures and regulations necessary for compliance with the Order. It may not be as clear how much the order affects others. It is not our intention here to review the steps that are being taken by each Federal agency to comply with Executive Order 12699, but rather to focus on how this Order might affect those outside of the Federal community. Generally, this involves State and local governments and private organizations that may be involved with buildings *assisted, leased, or regulated* by the Federal Government.

What do we mean by assisted, leased, and regulated?

Assisted

This refers to direct Federal financing such as grants and loans and federally insured financing such as Federal Housing Administration (FHA) or Department of Veterans Affairs (VA) loans. The Executive Order applies to federally assisted construction of new buildings and additions to existing buildings. Federally assisted new construction will have the biggest effect on the State and local community. Many people in the State and local community must be aware of the seismic provisions specified in the Executive Order to ensure receipt of Federal funds. For example, all new construction projects using VA or FHA loans or Federal grant funds must meet the seismic provisions specified in Executive Order 12699.

Builders aren’t the only ones affected by these provisions. Let’s say a group of investors decides to build a moderately-priced housing development in their community. They want to attract as many buyers as possible, so they need to ensure that every financing option is available to their potential buyers. If the homes that buyers hope to purchase have not been built according to appropriate seismic provisions, the buyers will not be able to acquire FHA or VA loans. Community centers, schools, libraries, nursing homes, fire stations, and many others often receive funds from various Federal agencies, including the U.S. Department of Housing and Urban Development (HUD), Department of Education, and U.S. Department of Health and Human Services (HHS). State and local officials must make sure that all seismic provisions have been adhered to—from design to completion.

Leased

This term refers to any new building or addition in which the Federal Government leases at least 15 percent of the space available. This means that if a builder in your community plans to construct a building that will be rented in part by a Federal agency, the building must be constructed to reduce the risk of loss of life and to prevent property damage in an earthquake. The requirement covers all leased buildings for which plans were developed after February 1, 1993. The Federal agency leasing the building will require that the owner provide verification of the building’s seismic safety.

Regulated

This term refers to any new construction that will be regulated for structural safety by the Federal Government. For example, HUD regulates safety issues concerning manufactured (mobile) homes.

What Does "Cost-Effective" Mean?

Making a building completely seismically safe or designing a building that will not be damaged in an earthquake is technically difficult and economically prohibitive. The ICSSC recognized this fact in drafting Executive Order 12699 and included a “cost-effective” clause. This clause says that a building should be designed to prevent *collapse*, not damage. Designing a building to prevent collapse will reduce the loss of life in an earthquake, but does not necessarily eliminate damage to the building. In a severe earthquake, a seismically safe building built under the “cost-effective” clause may not collapse and kill or injure its inhabitants, but it may be so badly damaged that it must be demolished.

What Other Federal Requirements Need To Be Considered?

Section 3 of Executive Order 12699 addresses other Federal requirements that relate to the issues addressed here. Two of these requirements are discussed below:

First, Section 3 refers to the Robert T. Stafford Disaster Relief and Emergency Assistance Act, which provides programs for Federal disaster response and recovery assistance. Executive Order 12699 requires that any *permanent structures* rebuilt after a disaster and using Federal funds through the Stafford Act abide by the Executive Order’s provisions. This means that, following a Presidential disaster declaration, all reconstructed buildings using Stafford Act funds must meet the seismic safety standards of one of the three model building codes, which will be discussed later. (However, the Executive Order does not require *temporary* emergency work to abide by its provisions.)

In the Federal Emergency Management Agency (FEMA) Public Assistance Program, the Executive Order also applies to new construction for an alternate project or an improved project, as well as for replacement of a damaged or destroyed facility. New construction funded by FEMA or any Federal grant programs also must be built to meet the seismic safety requirements of Executive Order 12699.

Second, OMB Circular A-119, “Federal Participation in the Development and Use of Voluntary Standards”, requires that Federal agencies adopt nationally recognized standards where they are available. To accommodate Circular A-119, Executive Order 12699 allows Federal agencies to use local standards where adequate building codes exist. Therefore, federally assisted new building construction, in communities whose local codes have adequate seismic provisions, will satisfy Executive Order regulations by adhering to those local codes. Later in this course, we will explore evaluation of local building codes to meet Executive Order 12699 requirements in greater detail.

Executive Order 12699 further states that Federal agencies that already have adopted safety levels higher than those imposed by this Order may maintain current regulations. Furthermore, an agency may adopt more stringent regulations if it chooses.

When Did Executive Order 12699 Go Into Effect?

Section 4 of Executive Order 12699 specifies that agencies have 3 years from the time the Executive Order was issued to comply. Since the Order was signed on January 5, 1990, all agencies were to have had all regulations and procedures in place by February 1, 1993.

HOW ARE FEDERAL AGENCIES AFFECTED BY EXECUTIVE ORDER 12699?

The Executive Order applies to all Federal agencies that:

- Assist in the financing of newly constructed buildings through grants or loans;
- Guarantee the financing of newly constructed buildings through loan or mortgage insurance programs;
- Construct and lease new buildings for Federal use;

- Design and construct new federally owned buildings;
- Regulate structural safety of new buildings; and
- Lease space in privately owned buildings.

Because agencies establish their own compliance procedures, each agency's approach will be a little different. This means that, if a builder in your community is constructing a building with assistance from a Federal agency, the building must be built to the particular agency's specifications, even if the building codes used in your community are different. Again, Executive Order 12699 allows Federal agencies to use local private-sector standards and practices, unless the agency finds that none are available to meet Executive Order requirements. The agency must evaluate the adequacy of these standards and practices before adopting them for a project.

The ICSSC developed NEHRP's *Recommended Provisions for the Development of Seismic Regulations for New Buildings* as a set of nationally applicable seismic safety guidelines to be used by model code institutions and legislative bodies to establish seismic standards. The minimum standards adopted by Federal agencies must be equivalent or superior to the standards and practices outlined in the NEHRP *Provisions*. The ICSSC periodically evaluates up-to-date national model building codes to determine whether they are substantially equivalent to the most recent or immediately preceding edition of the NEHRP *Provisions*. The ICSSC's latest evaluations are available on the National Institute of Standards and Technology (NIST) website at www.nist.gov.

IF YOU ARE NOT A PART OF THE FEDERAL COMMUNITY, HOW DOES EXECUTIVE ORDER 12699 AFFECT YOU?

Many groups in State and local governments must know and be able to institute the seismic safety standards required by Executive Order 12699. Any time someone from your community is involved in new construction that will be financed or financially assisted, owned, or leased by the Federal Government, seismic provisions must be taken into account. If your community has adopted one of the building codes recommended by the ICSSC, an important requirement of the Executive Order will be met. If the community has its own local building code, the officials cannot assume that existing codes are substantially equivalent to the NEHRP *Provisions*.

In addition, your community also must be aware of the seismic provisions required by specific Federal agencies. For example, the Department of Transportation (DOT) has chosen to adopt the seismic provisions outlined in substantially equivalent national model codes. DOT's requirements specifically state that certificates of compliance with the NEHRP *Provisions* for seismic design and construction must be received before acceptance of a new building. To verify compliance, DOT must receive verification from the architect or engineer, construction observation reports, State or local building department plan review documentation, or other documents. Other agencies, like the Nuclear Regulatory Commission, may decide they require much more stringent seismic standards for any new construction they may own, assist, or lease. Because agencies can choose the seismic provisions they will follow, anyone involved in construction in your community must be familiar with the relevant agency's documentation and compliance requirements procedures.

Those responsible for obtaining federally assisted financing for new construction must make sure that they have met the requirements of the specific Federal agency responsible for financing the new construction. For example, a community that needs a new school can apply to the Department of Education for financial assistance. Receiving this assistance means that the new construction must comply with the Department of Education's regulations for fulfilling the Executive Order. This means that the school board, city manager, or whoever is involved in the initial decision to build the new school must be aware of the Executive Order's requirements and the procedures required by the Department of Education to document compliance. Complying with the Executive Order and agency requirements might involve a signed statement attesting to the use of a specific building code, or the planners may choose to hire a consultant knowledgeable in seismic design to examine the work done. To make sure that all requirements are met, community leaders must know what needs to be done at the very beginning of the project and be familiar with the particular Federal agency requirements.

Communities that have adopted and are enforcing national model building codes that are substantively equivalent to the most current or immediately preceding NEHRP *Provisions* will be in a better position to comply with the requirements for obtaining Federal grants and loans. This could save local governments time and money. If your community already has a mechanism for inspecting building plans and new construction, according to a model building code, complying with the Executive Order and a specific agency's requirements may mean little additional work. If, on the other hand, your community must make special arrangements to comply with the Executive Order's requirements, that could mean a delay in application for the loan or an increase in project costs.

State and local officials involved in securing Federal funds for community projects, such as schools, libraries, or recreational facilities, must be aware of the seismic provisions that must be followed to receive these funds. The earlier seismic design is factored into a new construction plan, the more cost-effective the design will be. It is much easier to plan for seismic safety during the design phase than to try to retrofit an existing plan with a seismically safe design.

Lenders also must know the regulations in Executive Order 12699. They must be aware that FHA and VA insured loans can be used only to purchase new buildings that are seismically resistant for the areas in which they are built. The lenders may be required to inform the construction industry and investors of their need to comply with the Executive Order in order to receive Federal funds.

Architects and engineers must be aware of the seismic provisions to which they must adhere during the planning and design phases of new construction projects. Designing a seismically safe building usually increases the cost of the building very little. Trying to modify a design after it is completed to incorporate seismic provisions can increase the cost of a project dramatically.

Zoning and land-use officials should be aware of how a particular site may be affected by an earthquake. When involved in planning new construction sites or changing zoning regulations, they must take into account an earthquake's potential effects on the natural environment. For example, these officials must approve or reject plans to build on a particular site based upon its response to potential earthquake-related natural disasters, such as landslides, liquefaction, amplification of ground movement, tsunamis, and seiches. (These effects of earthquakes on the natural environment are covered in greater detail in Unit 4.)

Local building code officials also should be familiar with Executive Order 12699. They may be required to enforce compliance with the Executive Order even though their community has not yet adopted seismic provisions in its local building codes. If local building codes do not have up-to-date provisions for seismic safety for new structures built with Federal funds, building codes specified by the funding agency must be used. (Most agencies use the model building codes recommended by the ICSSC.) Local building code officials also are responsible for inspecting new buildings constructed with Federal funds, so they must understand the seismic provisions in Executive Order 12699.

Government and nongovernment organizations receiving Federal grant funds for new construction or addition projects must be able to verify that their new buildings will be constructed according to appropriate seismic provisions.

All new construction projects involve a long line of people that help turn building plans into a reality. If Federal funds are used for *any* part of a project, several people may have responsibility to make sure that all of the Executive Order's requirements and appropriate seismic provisions are satisfied. A project will be completed successfully if:

- Decisionmakers and developers plan the project with seismic provisions in mind,
- Architects and engineers design the structure taking seismic factors into account,
- The lender is assured that all seismic provisions have been incorporated,
- Land-use officials review site selection to ensure conformity with seismic requirements,
- Engineers and construction personnel adhere to seismic construction techniques, and
- Building code officials inspect to ensure seismic provisions have been incorporated.

As with many other Federal guidelines and regulations, it is the Federal Government that specifies the steps to be taken to comply, but it is the responsibility of the officials in every community to see to it that buildings meet Executive Order 12699's requirements for seismic safety. The more that people in local government, on planning committees, and in the construction industry (including inspection) are aware of these requirements to incorporate seismic design and construction features into new buildings and additions, the more likely the goals of Executive Order 12699 will be achieved.

Before you go onto the next unit, take some time to complete the chart in Figure 2-1, titled "Action Plan: People Who Need To Be Aware of Executive Order 12699 and Its Effects on Our Community." To complete the chart:

- List the names and positions of all the people in your community who plan for the use of Federal funds. This list might include the school board, chamber of commerce, property developers, or community leaders.
- Next, add other people in the community who would be involved in completing a project funded with Federal monies. These individuals might include architects, lenders, and land-use officials.
- Finally, list any ideas you have on how to make sure all of these people will become aware of how Executive Order 12699 will affect your community. If you are not in a position to influence these people, who is? How can you be sure that the right people have the information needed to make wise decisions about your community's future?

This list will help you identify the people that need information about Executive Order 12699 and brainstorm ideas for providing this information to them. After you have completed this course, come back to this list again. You may have some new names or ideas to add to the list.

Action Plan: People Who Need To Be Aware of Executive Order 12699 and Its Effects on Our Community		
NAMES	**POSITIONS**	**IDEAS**

Figure 2-1

Action Plan: People Who Need To Be Aware of Executive Order 12699 and Its Effects on Our Community		
NAMES	**POSITIONS**	**IDEAS**

Figure 2-1 continued

UNIT 2 - SUMMARY

The purpose of this unit was to examine the history of Executive Order 12699 and its intent. In this unit, we covered:

- What is the history of Seismic Safety Legislation?
  - Legislative History
  - Earthquake Hazards Reduction Act of 1977
  - History of Executive Order 12699
- What is the purpose of Executive Order 12699?
- What does Executive Order 12699 require?
  - What do we mean by assisted, leased, and regulated?
  - What does "cost-effective" mean?
  - What other Federal requirements need to be considered?
  - When did Executive Order 12699 go into effect?
- How are Federal agencies affected by Executive Order 12699?
- If you are not a part of the Federal community, how does Executive Order 12699 affect you?
  - Action Plan: People Who Need To Be Aware of Executive Order 12699 and Its Effects on Our Community

Unit 2

Executive Order 12699

Unit Review

Directions: For each question, circle the letter of the correct response and check your answers with the Answer Guide at the end of the unit.

1. Which earthquake has been called one of the most violent earthquakes of all time and became one of the best-documented earthquakes in the United States?

   a. 1971 San Fernando
   b. 1811 New Madrid
   c. 1964 Alaska
   d. 1979 Southeastern Alaska

2. What agency contributed to the increase in the number of earth scientists and earthquake engineers available in the 1960s?

   a. Nuclear Regulatory Commission
   b. Federal Emergency Management Agency
   c. Environmental Protection Agency
   d. Department of the Interior

3. Scientists no longer consider earthquake prediction a worthwhile line of research. True or false?

   a. True
   b. False

4. Why did a moderate earthquake like the 1971 San Fernando earthquake have such a big effect on the U.S. Congress?

   a. It occurred outside of the area typically identified with seismic activity.
   b. It was successfully predicted.
   c. Much of the destruction was due to tsunamis.

d. It showed the devastating effects a moderate earthquake could have on a metropolitan area.

5. Which factor contributed to the passage of the Earthquake Hazards Reduction Act?

   a. New research indicating all 50 States have some potential for seismic activity.
   b. The occurrence of devastating earthquakes in 1971, 1975, and 1976.
   c. Strong legislative leaders and a receptive administration.
   d. All of the above.

6. Reduction of risk to life and property from future earthquakes in the United States through the establishment and maintenance of an effective earthquake reduction program was the:

   a. purpose of the Earthquake Hazards Reduction Act.
   b. reason earthquakes were monitored before the 1960s.
   c. the reason President Johnson asked the National Academy of Sciences to perform a comprehensive study.
   d. reason postearthquake studies are done.

7. The Earthquake Hazards Reduction Act created:

   a. NEHRP.
   b. the NEHRP *Provisions*.
   c. FEMA.
   d. ICSSC.

8. Which of the following is ***not*** one of NEHRP's objectives?

   a. Developing model building codes
   b. Developing seismically safe building designs and construction methods
   c. Preventing possible earthquakes
   d. Increasing the use of existing scientific and engineering knowledge to mitigate earthquake hazards

9. Seismic safety provisions for existing buildings and lifelines were removed from the original draft of Executive Order 12699 because:

   a. legislators decided they were not necessary.
   b. State and local governments automatically take care of these issues.
   c. solid financial estimates of the cost to meet the seismic provisions could not be prepared.
   d. it was shown that these provisions would add only a 1-to-2-percent increase in cost to meet the seismic provisions.

10. Executive Order 12699 covers new construction in federally:

    a. owned, leased (15 percent or more), assisted, and regulated buildings.
    b. owned, leased (15 percent or more), and assisted buildings.
    c. owned, leased (80 percent or more), and regulated buildings.
    d. owned, leased (100 percent or more), assisted, and regulated buildings.

11. The purpose of Executive Order 12699 is to:

    a. make a building completely seismically safe.
    b. reduce the risk to the lives of occupants and prevent any damage to a building.
    c. evacuate buildings before they collapse.
    d. reduce the risk to the lives of occupants and prevent building collapse.

12. The Robert T. Stafford Disaster Relief and Emergency Assistance Act is mentioned in Executive Order 12699 as an additional requirement. What does it say?

    a. Temporary emergency paid for with Federal funds need not adhere to the Executive Order's requirements.
    b. Any rebuilding done after a disaster must meet the Executive Order's requirements.
    c. Any additions constructed for existing buildings after a disaster must meet the Executive Order's requirements.
    d. All of the above.

13. Executive Order 12699 states that:

    a. local building codes will be used by Federal agencies unless they are determined to be insufficient.
    b. local building codes may not be used by Federal agencies.
    c. Federal agencies must develop their own standards.
    d. Federal agencies can use only national standards.

14. Individuals who are not part of the Federal community are:

    a. not affected by Executive Order 12699.
    b. affected only if they are *directly involved* in building new construction.
    c. affected by the Executive Order in many different ways.
    d. affected only if they lease 50 percent or more of a building to a Federal tenant.

15. As a building code official, I would be responsible for confirming that a building was constructed according to my local building code only. True or false?

    a. This would always be true.
    b. False. I may need to confirm that a building code specified by a Federal agency was satisfied.

16. It is not necessary for the decisionmakers and investors to be aware of Executive Order 12699's requirements because the architects will include all necessary seismic provisions in designs for new buildings. True or false?

    a. True
    b. False

17. A lender must be concerned only with the Executive Order's requirements if he or she is lending money for new construction of a federally owned building. True or false?

    a. True
    b. False

18. A building constructed according to the NEHRP *Provisions* will not be damaged by an earthquake to the point that it has to be demolished. True or false?

    a. True
    b. False

19. Some Federal agencies may choose to adopt seismic requirements that are more stringent than those in the NEHRP *Provisions*. True or false?

    a. True
    b. False

20. For purposes of complying with the Executive Order, it is in a community's best interest to make sure its local building codes are substantially equivalent to the NEHRP *Provisions*. True or false?

    a. True
    b. False

Unit 2

Executive Order 12699

Unit Review - Answer Guide

1. Which earthquake has been called one of the most violent earthquakes of all time and became one of the best-documented earthquakes in the United States?

   c. 1964 Alaska
   Reference: p. 2-1

2. What agency contributed to the increase in the number of earth scientists and earthquake engineers available in the 1960s?

   a. Nuclear Regulatory Commission
   Reference: p. 2-2

3. Scientists no longer consider earthquake prediction a worthwhile line of research. True or false?

   b. False
   Reference: p. 2-2

4. Why did a moderate earthquake like the 1971 San Fernando earthquake have such a big effect on the U.S. Congress?

   d. It showed the devastating effects a moderate earthquake could have on a metropolitan area.
   Reference: p. 2-2

5. Which factor contributed to the passage of the Earthquake Hazards Reduction Act?

   d. All of the above.
   Reference: p. 2-2

6. Reduction of risk to life and property from future earthquakes in the United States through the establishment and maintenance of an effective earthquake reduction program was the:

   a. purpose of the Earthquake Hazards Reduction Act.
   Reference: p. 2-3

7. The Earthquake Hazards Reduction Act created:

   a. NEHRP.
   Reference: p. 2-3

8. Which of the following is not one of NEHRP's objectives?

   c. Preventing possible earthquakes
   Reference: p. 2-3

9. Seismic safety provisions for existing buildings and lifelines were removed from the original draft of Executive Order 12699 because:

   c. solid financial estimates of the cost to meet the seismic provisions could not be prepared.
   Reference: p. 2-4

10. Executive Order 12699 covers new construction in federally:

    a. owned, leased (15 percent or more), assisted, and regulated buildings.
    Reference: pp. 2-5 and 2-7

11. The purpose of Executive Order 12699 is to:

    d. reduce the risk to the lives of occupants and prevent building collapse.
    Reference: p. 2-5

12. The Robert T. Stafford Disaster Relief and Emergency Assistance Act is mentioned in Executive Order 12699 as an additional requirement. What does it say?

    d. All of the above.
    Reference: pp. 2-7 and 2-8

13. Executive Order 12699 states that:

    a. local building codes will be used by Federal agencies unless they are determined to be insufficient.
    Reference: p. 2-9

14. Individuals who are not part of the Federal community are:

    c. affected by the Executive Order in many different ways.
    Reference: pp. 2-10 to 2-14

15. As a building code official, I would be responsible for confirming that a building was constructed according to my local building code only. True or false?

    b. False. I may need to confirm that a building code specified by a Federal agency was satisfied.
    Reference: p. 2-12

16. It is not necessary for the decisionmakers and investors to be aware of Executive Order 12699's requirements because the architects will include all necessary seismic provisions in design for new buildings. True or false?

    b. False
    Reference: p. 2-12

17. A lender must be concerned only with the Executive Order's requirements if he or she is lending money for new construction of a federally owned building. True or false?

    b. False
    Reference: p. 2-12

18. A building constructed according to the NEHRP *Provisions* will not be damaged by an earthquake to the point that it has to be demolished. True or false?

    b. False
    Reference: p. 2-8

19. Some Federal agencies may choose to adopt seismic provisions that are more stringent than those in the NEHRP *Provisions*. True or false?

    a. True
    Reference: p. 2-9

20. For purposes of complying with the Executive Order, it is in a community's best interest to make sure its local building codes are substantially equivalent to the NEHRP *Provisions*. True or false?

    a. True
    Reference: pp. 2-10 to 2-12

Unit 3

Earthquake Causes and Characteristics

INTRODUCTION

In the last unit, we explored the historical importance and intent of Executive Order 12699. In later sections of this course, we will take a closer look at evaluating a community's safety. First we need some basic information about earthquakes and their effects on the built environment. The built environment includes all buildings, transportation lines and structures (e.g., bridges), communications lines, and utilities. This unit and Unit 4 will give us background on earthquake causes, characteristics, and effects. These units will provide us with the terminology and concepts we need to evaluate mitigation practices in our communities.

Unit 3 answers the following questions:

- What causes an earthquake?
- What are an earthquake's characteristics?
- How do we measure earthquakes?

WHAT CAUSES AN EARTHQUAKE?

Scientists have formulated several theories to explain the causes of earthquakes. The theory of plate tectonics seems to explain much of the earthquake activity the world experiences, but there is also intra-late activity that is well away from the plate boundaries. Intra-plate activity is less understood.

Plate Tectonics

First presented in 1967, the theory of plate tectonics postulates that the earth once was covered by a single crust, or plate, with no oceans. We could think of the earth at this time like a hard-boiled egg, with a thin hard shell extending over the entire surface of the earth. Over time, this single shell, or plate, started to split and drift into separate plates of land or ocean crusts. Now the earth's surface looks much like a spherical jigsaw puzzle; all the plates fit together. Figure 3-1 shows the largest plates as they are today.

The plates over the earth are in constant slow motion. The plates generally move in one of three ways—colliding, spreading, or sliding. Plates experience convergent plate movement when they collide or bump into one another. When they spread or move away from one another, they experience divergent plate movement. Plates also can slide by one another with lateral plate movement. Any one of these plate movements can cause an earthquake. Constant movement of the plates puts a tremendous stress on the earth's rock. Figure 3-2 illustrates these movements.

Earthquakes tend to occur at the boundaries of plates. Convergent, divergent, and lateral movement all can cause earthquake activity. Where plates diverge (move away from each other), molten rock from beneath the earth's crust rushes up to fill in the resulting rift and forms a ridge. These ridges add even more pressure on the divergent plates as they continue to push adjacent plates away from one another. The Mid-Atlantic Ridge, located in the middle of the Atlantic Ocean, is a good example of a ridge formed by the divergent movement of plates.

Convergent plates experience the movement of one plate below the edge of another. As plates collide, the edge of the heavier ocean plate is pushed down into the earth's interior by the lighter continental plate, and a trench forms between the plates. As this occurs, material from the lower plate is "recycled" by melting into the earth's interior. This whole process is called subduction. Major earthquakes, such as the 1964 Alaskan earthquake, can occur in areas where subduction has occurred. Figure 3-3 illustrates the formation of an ocean ridge caused by divergent plates and a subduction trench caused by convergent plates. Plates also can grind past each other laterally, causing the edges to lock and release. This is happening along the San Andreas fault, which runs most of the length of California.

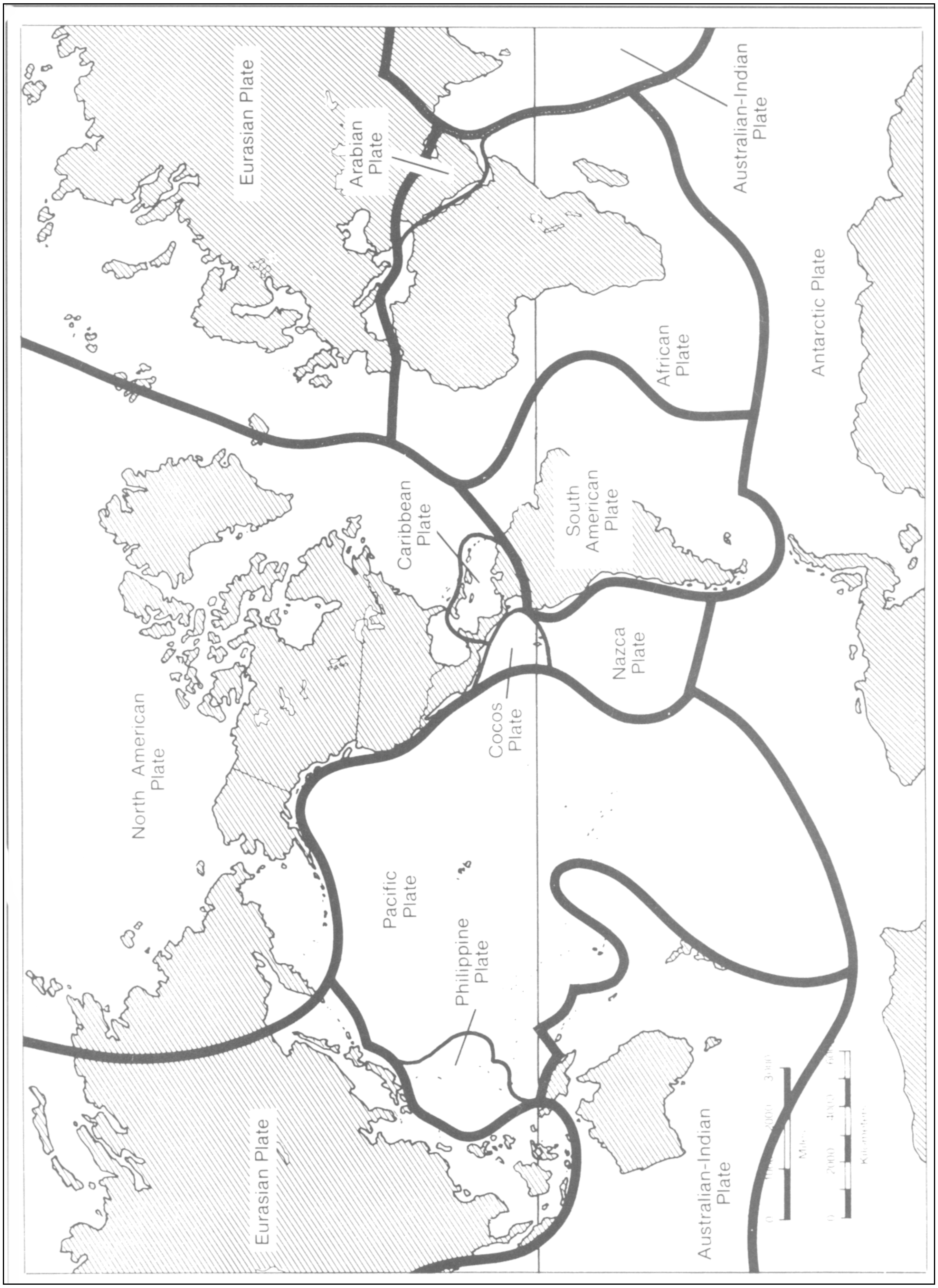


Figure 3-1 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

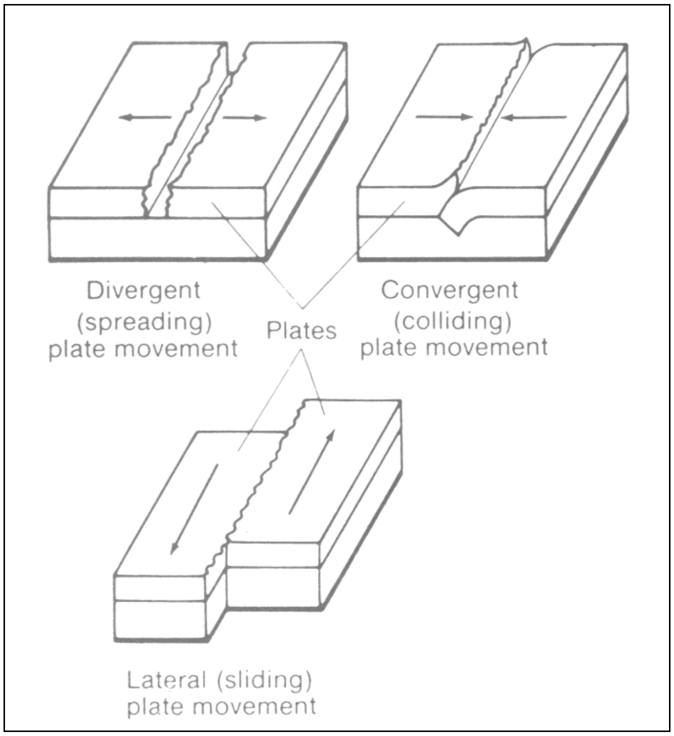


Figure 3-2 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

Maps of earthquake activity throughout the world show that earthquakes most frequently occur at the boundaries of plates. Figure 3-4 graphically displays where the major earthquake zones lie. Compare this map of world earthquake activity to the map of the earth's plates in Figure 3-1. Do you see that earthquake activity mirrors plate boundaries? The "Ring of Fire," well known for its high level of earthquake and volcano activity, lies on the Pacific Plate edge.

Intraplate Activity

Plate tectonics involves interplate, or "between-plate," activity. Although this theory explains plate boundary earthquakes, it does not explain *all* seismic activity. Many large, devastating earthquakes occur *within* continents, away from plate edges. These earthquakes are caused by intraplate activity. The 1811 and 1812 New Madrid fault earthquakes in the central United States are a good example of earthquakes caused by intraplate activity.

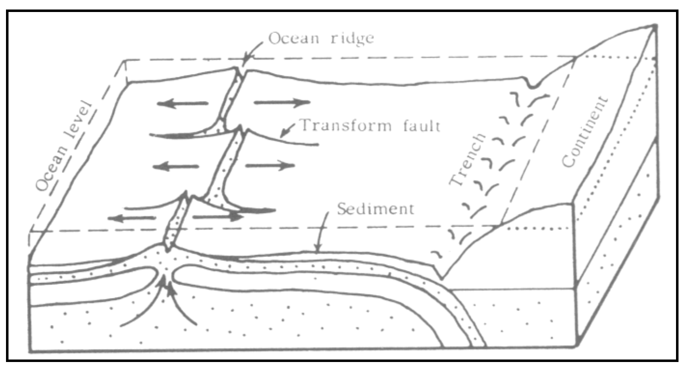


Figure 3-3 *Source: Steinbrugge, K. Earthquakes, Volcanoes, and Tsunamis: An Anatomy of Hazards, 1982.*

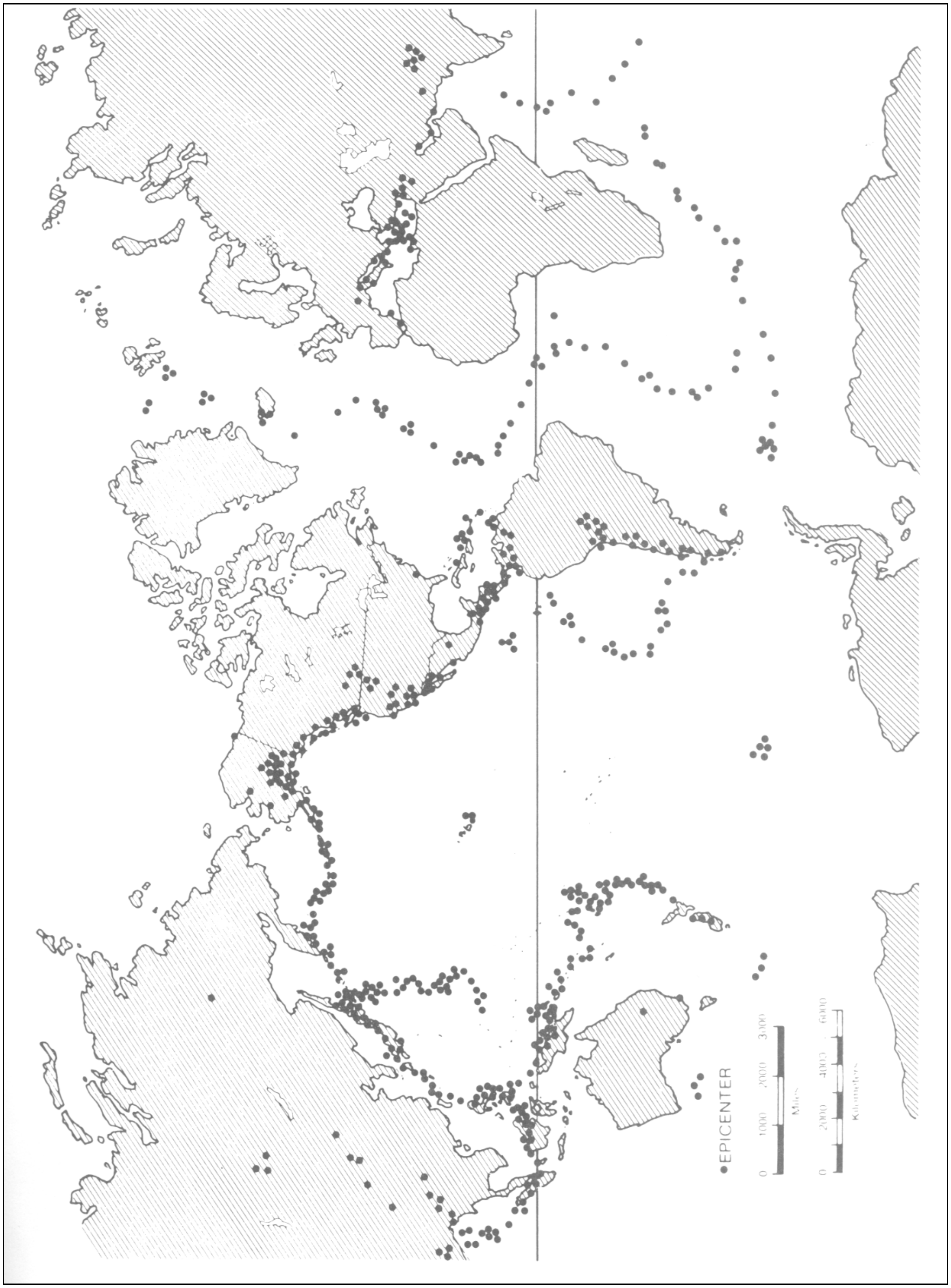


Figure 3-4 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

Earthquakes of this type probably result from more localized geological forces such as mid-plate compression (often themselves being the indirect result of plate tectonics); however, they are harder to predict.

Faults

Plate movement or other forces can cause tremendous stress on the rocks that make up the earth's outer shell. When rock is strained beyond its limit, it will fracture, and the rock mass on either side will move. This fracture is called a fault. Faults often are classified according to whether the direction of movement is predominantly horizontal or vertical. Figure 3-5 shows examples of horizontal and vertical fault movement. A fault can cut at any angle into the earth and does not always cut to the surface. A fault is accompanied by displacement of one side of the fracture with respect to the other. Scientists use certain terms to describe the direction of one fault block in relation to the other block.

Sudden Rupture

Not all faults will cause earthquakes. But, if there is a sudden rupture and movement of rock along a fault line, the vibrations we call an earthquake will result. We think of the earth's rocky surface as hard and impregnable. However, rock under extreme pressure can have elastic properties. Try simulating an earthquake with a shallow plastic mould filled with gelatin. If you gently stretch the surface by pulling on the sides of the mould, you begin to stress the gelatin, just like rock can be stressed by geological forces. What do you think will happen when the gelatin is stretched as tight as possible and a small slit is made in the surface? The rupture rips through the gelatin, and the gelatin quivers as it snaps back into a relaxed state. The same thing happens during an earthquake when a sudden rupture occurs along a fault. As the rupture travels through the rock, energy is released that creates the motions associated with an earthquake. If a fault rupture is shallow enough, the fault line may appear on the earth's surface. Figure 3-6 shows a fault rupture.

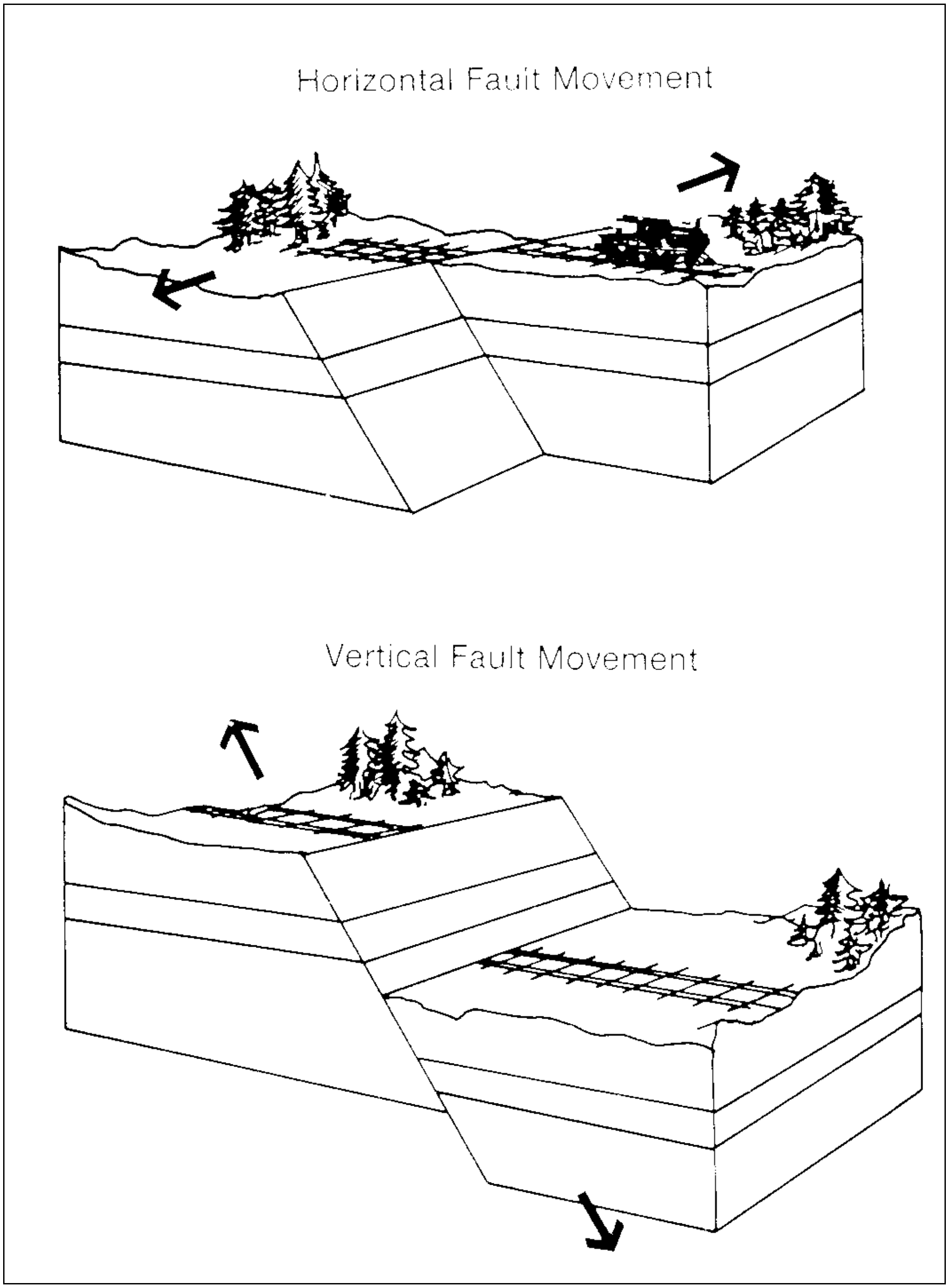


Figure 3-5 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

WHAT ARE AN EARTHQUAKE'S CHARACTERISTICS?

Figure 3-6 *Source: Federal Emergency Management Agency*.

Once the sudden rupture occurs, the earth begins to shake. This shaking is caused by a series of waves known as seismic waves moving from the center of the earthquake out to other parts of the earth. The type of waves involved in an earthquake is a key characteristic of the phenomenon. Next we discuss the types of waves and various soil compositions that affect how far a seismic wave will travel.

Seismic Waves

The four types of seismic waves are grouped into two main categories according to the way they travel from the source, or focus, of an earthquake. P waves and S waves are "body" waves. Love waves and Rayleigh waves are "surface" waves.

Body Waves

Body waves travel through the earth *below* and *on* the surface. Scientists use body waves to determine an earthquake's epicenter, the point on the earth's surface above an earthquake's focus. There are two types of body waves: P waves and S waves.

P waves. The primary wave, or P wave, is the fastest wave to move outward from the earthquake's focus, and it can move through both rock and liquid. The P wave motion is more like a sound wave than an ocean wave. In fact, some P waves actually can be heard as they emerge from the earth and are transmitted as sound waves into the atmosphere. The motion is pushed and pulled along the wave front in a series of compressions and expansions.

The effect of a P wave on a building is like a sharp punch. A child's slinky toy can be used to illustrate P wave motion. If you stretched a slinky across a table as shown in Figure 3-7 and push one end, the force of the push would carry through the slinky to the person on the other end. A P wave repeats this motion over and over in a series of compressions and expansions.

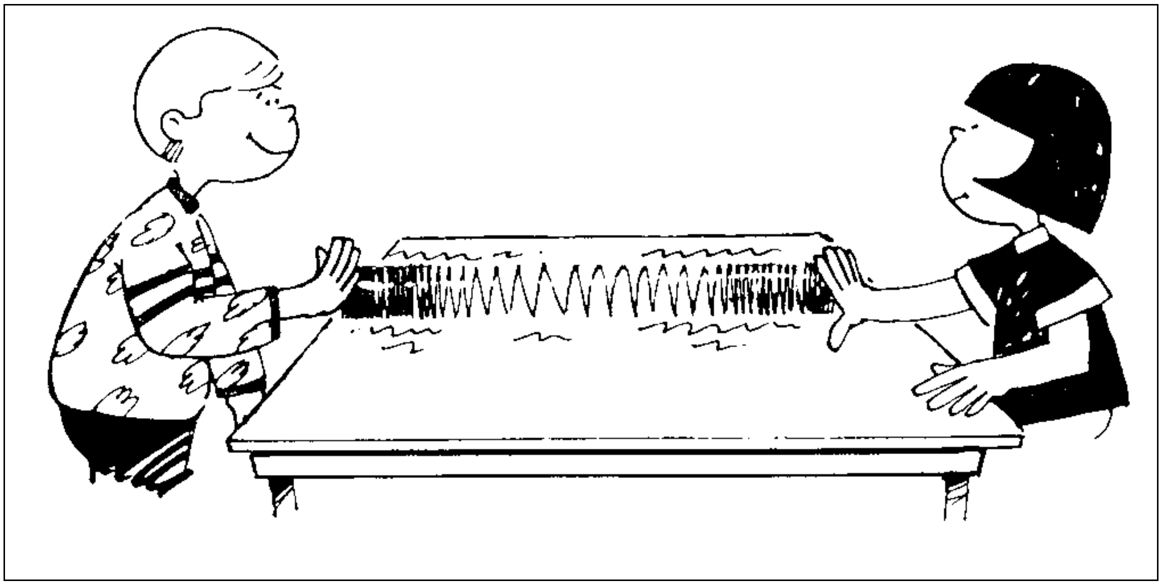


Figure 3-7 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

S waves. Secondary waves, or S waves, move more slowly through the earth. Unlike a P wave, an S wave cannot travel through liquid. At the surface, an S wave produces an up-and-down motion much like rolling waves and a side-to-side motion like a slithering snake. The motion of S waves can be illustrated using the same slinky toy. In Figure 3-8, one child shakes the toy up and down, while the other moves it from side to side. You can imagine that this wave motion is particularly damaging to buildings.

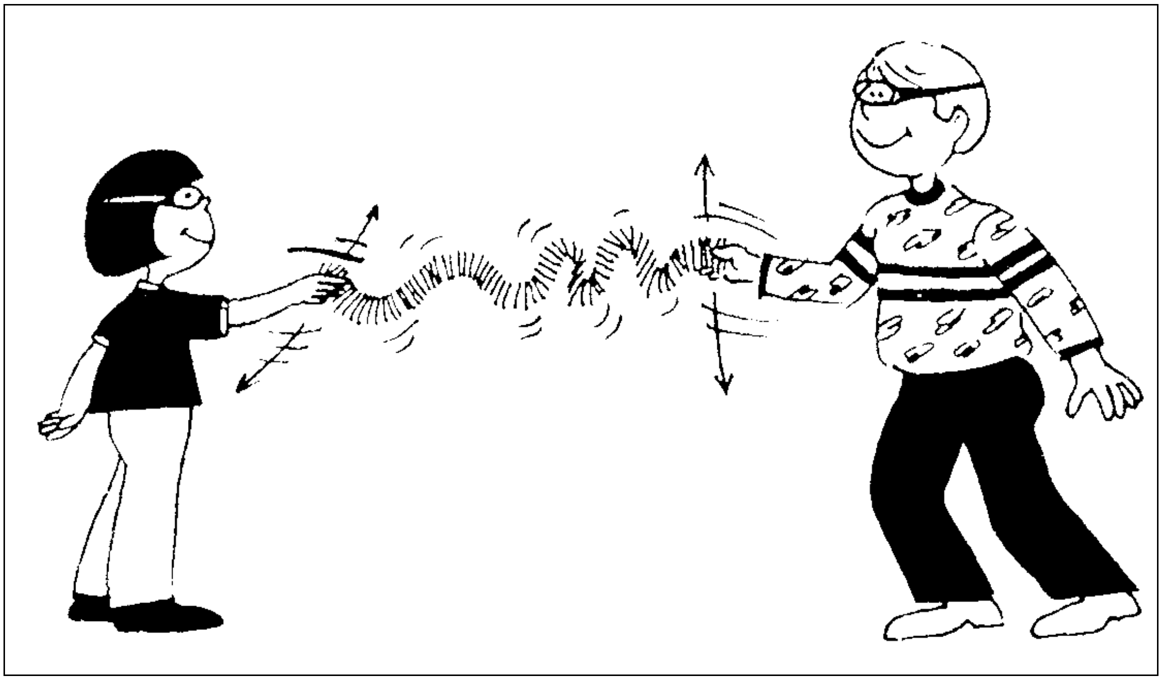


Figure 3-8 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

Surface Waves

Unlike body waves, surface waves travel only near or at the surface of the earth. They are responsible for the strongest ground shaking and most of the damage to the built environment that occurs in large earthquakes. Love and Rayleigh waves are the two main types of surface waves.

Love waves. A Love wave moves sideways along the surface of the earth in a snake-like motion. Like S waves, Love waves do not move through liquid. Figure 3-9 illustrates the way Love waves make the ground move.

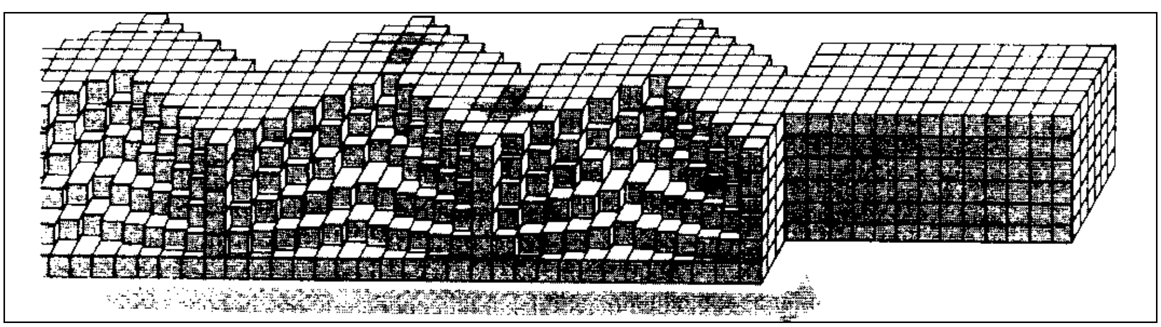


Figure 3-9 *Source: Bolt. Earthquakes, 1993.*

Rayleigh waves. As a Rayleigh wave moves across the earth's surface, the earth moves up and down like an ocean wave. Rayleigh waves can move through the surface of both earth and water. Figure 3-10 illustrates ground motion caused by Rayleigh waves.

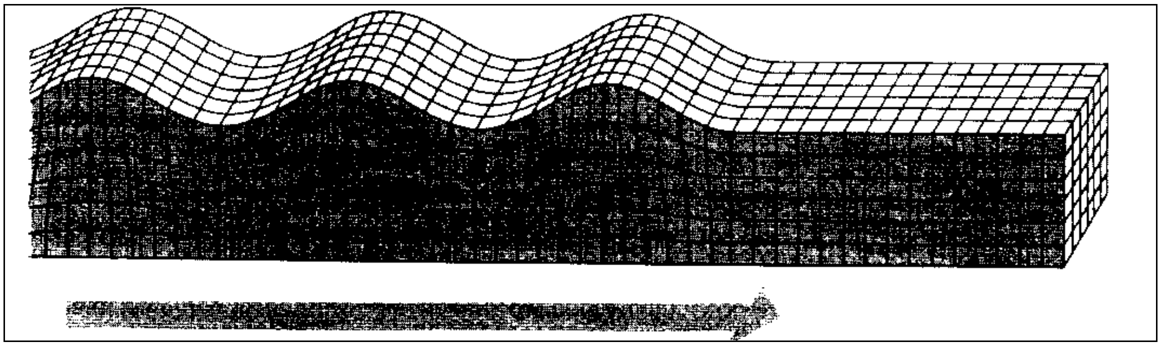


Figure 3-10 *Source: Bolt. Earthquakes, 1993.*

Effect of Soil Composition

The composition of the earth's crust and the physical features of an area will affect the intensity of seismic waves as they move through the ground or along the earth's surface. One concern that seismologists (researchers who study earthquakes) have had about earthquakes east of the Rocky Mountains is that seismic waves remain strong over great distances due to the composition of the crust in the region. For example, a strong earthquake in the New Madrid fault zone near Memphis, Tennessee would be felt, and could cause damage, throughout a much greater area than an earthquake of equal intensity in California. Figure 3-11 shows a map of the intensity lines associated with the 1811 New Madrid earthquake. The curved lines extending out from the center of the earthquake indicate the earthquake's decreasing intensity. The decreasing values of the isoseismal (curved) lines are shown in roman numerals. Intensity values at specific points are given in Arabic numerals. Records show that seismic waves were strong enough to be felt as far away as Washington, D.C., Boston, Canada, and New Orleans. (At the time very few people lived west of New Madrid region, so there is no record of how strong the waves were to the west of the epicenter.) The soil composition east of the Rocky Mountains allows seismic waves to retain strength much further than waves originating on the West Coast and traveling to the Rocky Mountains.

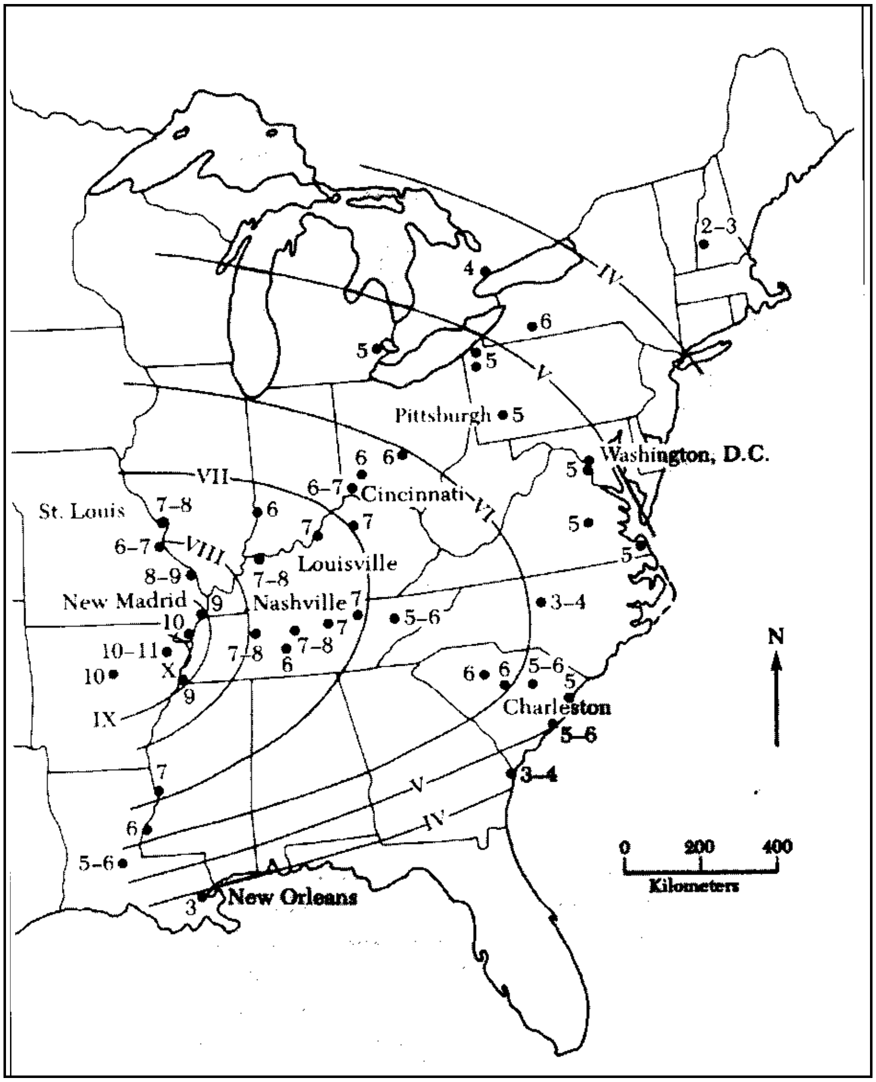


Figure 3-11 *Source: Nuttli, "The Mississippi Valley Earthquakes of 1811 and 1812: intensities, ground motion, and magnitudes," Bulletin of the Seismological Society of America.*

Figure 3-12 compares the areas affected by the 1906 San Francisco and the 1811 New Madrid earthquakes. The magnitudes of these earthquakes were similar, but the San Francisco earthquake affected a much smaller area because the earth's crust in the western United States does not allow seismic waves to travel as far as they do in the east. This is typical, though we have more earthquakes on the West Coast, seismic waves there are not felt at distances as great as those caused by earthquakes on the East Coast or in Canada or Mexico.

The soil composition in your community has a powerful effect on how intense an earthquake will be in your area. Generally speaking, unconsolidated soil or fill amplifies shaking and can make the earthquake feel even stronger than its magnitude might indicate. Topography (the earth's physical features) can focus energy and, again, make the earthquake feel stronger and cause more damage than what might be expected from an earthquake of its size. Therefore, a structure not designed according to mitigation standards will suffer more damage.

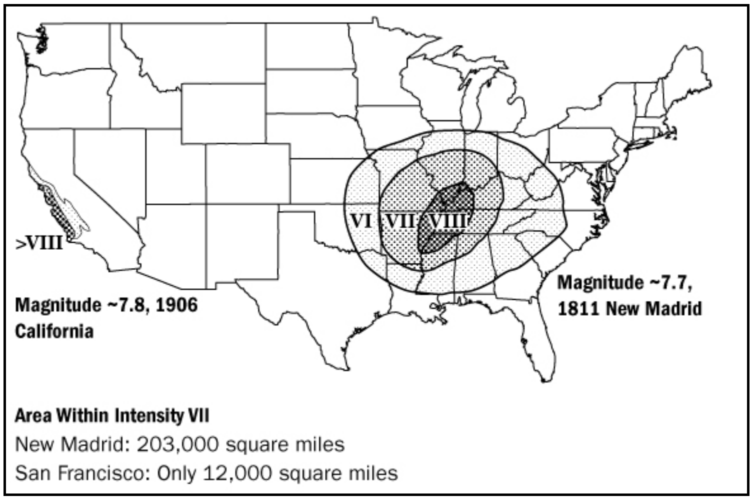


Figure 3-12 *Source: Arch Johnson, Center for Earthquake Research and Information, University of Memphis.*

HOW DO WE MEASURE EARTHQUAKES?

Once an earthquake occurs, it is important to know where the seismic event took place, how intense it was, and what its impact was on the built environment. The more we know about earthquakes and about how and when they occur, the more we can do to lessen their effects on our communities. Two scales are frequently used to measure earthquakes: The Modified Mercalli Intensity Scale measures the intensity or impact of an earthquake on people and the built environment, and the Richter Scale measures the amount of energy released by an earthquake, or its magnitude. In general, magnitude measures the size of an earthquake, while intensity measures the effects, which vary according to how far you are from the earthquake and the soils you are on.

Modified Mercalli Intensity Scale

Early forms of the Modified Mercalli Intensity Scale were developed in 1857. It measures the impact of an earthquake by sending out trained observers to look at the damage done to the built environment and the earth (landslides, etc.) and at the reaction of people to the event. The published intensities of the 1906 San Francisco earthquake were based on this scale. The intensities are given values from I to XII, shown in roman numerals. Figure 3-13 contains the descriptions used to assign earthquake intensity values on a Modified Mercalli Intensity Scale.

One advantage to using the Mercalli Scale is that it relies on the observations of people experiencing an earthquake instead of scientific instruments. This allows seismologists to assign earthquake intensities to historical seismic records, an activity that helps them to estimate seismic risk for earthquake sites today.

LEVEL	DESCRIPTION
I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all, many frightened and run indoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rail bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen of ground surface. Lines of sight and level are distorted. Objects are thrown into the air.

Figure 3-13 *Source: Naeim. The Seismic Design Handbook, 1989.*

The fact that the Mercalli Scale relies on people's observations is also a disadvantage because this makes evaluation subjective and dependent upon the social and infrastructure conditions of a country. For example, look at the description of intensity value VII on the Mercalli Scale in Figure 3-13. This description would have to be rewritten for a country without chimneys and automobiles. This scale also is not very helpful in an area with little human habitation, since no one would be around to experience the earthquake.

Richter Scale

The Richter Scale was developed in 1935 by Charles Richter of the California Institute of Technology in Pasadena. It is widely used today. The Richter Scale value is calculated by measuring the maximum recorded amplitude of a wave. This measurement quantifies the ground motion and the energy released at the source of an earthquake, which is referred to as its magnitude. For example, an earthquake that measures 4.0 on the Richter Scale would release energy equivalent to 6 tons of TNT, or about as much energy as a small atomic bomb. Richter magnitude is expressed as an Arabic number, which helps to distinguish it from the Mercalli Scale.

The Richter Scale is open ended and logarithmic. This means that there are no upper and lower limits to the scale and that every time the magnitude goes up by one unit, the amount of energy this represents increase thirty times. Look at Figure 3-14. We mentioned previously that a Richter magnitude of 4.0 is equivalent to the energy released by 6 tons of TNT. A magnitude of 3.0 is equivalent to only 397 pounds of TNT; 397 pounds is 30 times smaller than 6 tons.

Both the Mercalli Intensity Scale and Richter Scale often are used to describe earthquakes since they refer to different kinds of information. The Richter Scale describes the amount of energy associated with an earthquake, while the Mercalli Scale describe the effect of the energy. As an example, let's consider the effects of two different earthquakes: the 1989 Loma Prieta and the 1988 Armenian earthquakes. The 1989 Loma Prieta earthquake measured 7.1 on the Richter Scale and about VII on the Mercalli Scale. There was a moderate loss of life (67 people died), and the built environment suffered relatively little damage. Most of the buildings affected in the Loma Prieta earthquake had been built with seismic provisions to reduce damage.

RICHTER	TNT ENERGY	EXAMPLE
1.0	6 ounces	Small blast at a construction site
1.5	2 pounds	
2.0	13 pounds	
2.5	63 pounds	
3.0	397 pounds	
3.5	1,000 pounds	
4.0	6 tons	Small atomic bomb
4.5	32 tons	Average tornado
5.0	199 tons	
5.5	500 tons	Massena, NY, quake, 1944
6.0	6,270 tons	
6.5	31,550 tons	Coalinga, CA, quake, 1983
7.0	199,000 tons	Hebgen Lake, MT, quake, 1959
7.5	1,000,000 tons	
8.0	6,270,000 tons	San Francisco, CA, quake, 1906
8.5	31,550,000 tons	
9.0	199,999,000 tons	Prince William Sound, AK, quake, 1964

Figure 3-14

Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.

In contrast, the 1988 Armenian earthquake measured almost the same magnitude (6.9) on the Richter Scale, but its Mercalli-measured intensity was XI. More than 50,000 people lost their lives, and the built environment was almost totally destroyed. The damage done by the Armenian earthquake was much greater than that done by the 1989 Loma Prieta earthquake, although the magnitudes were almost the same.

This illustrates two important points: one, the magnitude of an earthquake does not always correlate with the intensity or impact, and, two, the quality of the built environment is a big factor in the number of lives lost and the amount of damage done in an earthquake. The building codes used in your community will greatly affect the impact of an earthquake in your area, regardless of the magnitude.

Ground Motion

Measures in addition to intensity and magnitude are needed to predict how an earthquake might affect the structures in a specific community. Knowing how fast, for how long, and how much the ground moves during an earthquake is important for estimating how ground motion will affect the built environment. Seismologists use several concepts to express these measurements: acceleration, duration, velocity, and displacement.

Acceleration

As seismic waves move through the ground, they create a series of vibrations. These movements are translated into dynamic loads or inertial forces that cause the ground and anything attached to it (i.e., the built environment) to vibrate in a complex manner. These inertial forces cause damage to buildings and other structures. Inertial forces are created when an outside force tries to make an object move or change its rate of travel. For example, when you get into your car, you are initially at rest, sitting in the seat. Once you turn the key and step on the gas, the force created moves your body, and you feel a gentle push back into the seat. This inertial force is created by your body, which wants to stay at rest as the car accelerates and pushes you forward. Once you are traveling at a steady 40 miles per hour you do not feel any sensation of motion. As you come to a stop, again you feel a push forward as you decelerate. If you stop suddenly, your body is forcefully thrown forward as it attempts to continue to travel at 40 miles per hour while the car is at rest.

Acceleration is the rate of change of motion. We don’t normally associate acceleration with buildings since we don’t expect buildings to move. During an earthquake, however, inertial forces may cause the upper part of a building to sway while the foundation remains stationary, or they may cause the whole building to “move.” Structures built in seismically active areas must be built to withstand predicted acceleration levels.

Duration

Another important measurement of ground motion is duration. Damage will occur the whole time the ground is moving, so more damage is likely to occur the longer an earthquake lasts. Predictions of the amount of potential damage that could occur in a specific area must include the duration of the ground motion.

Velocity and Displacement

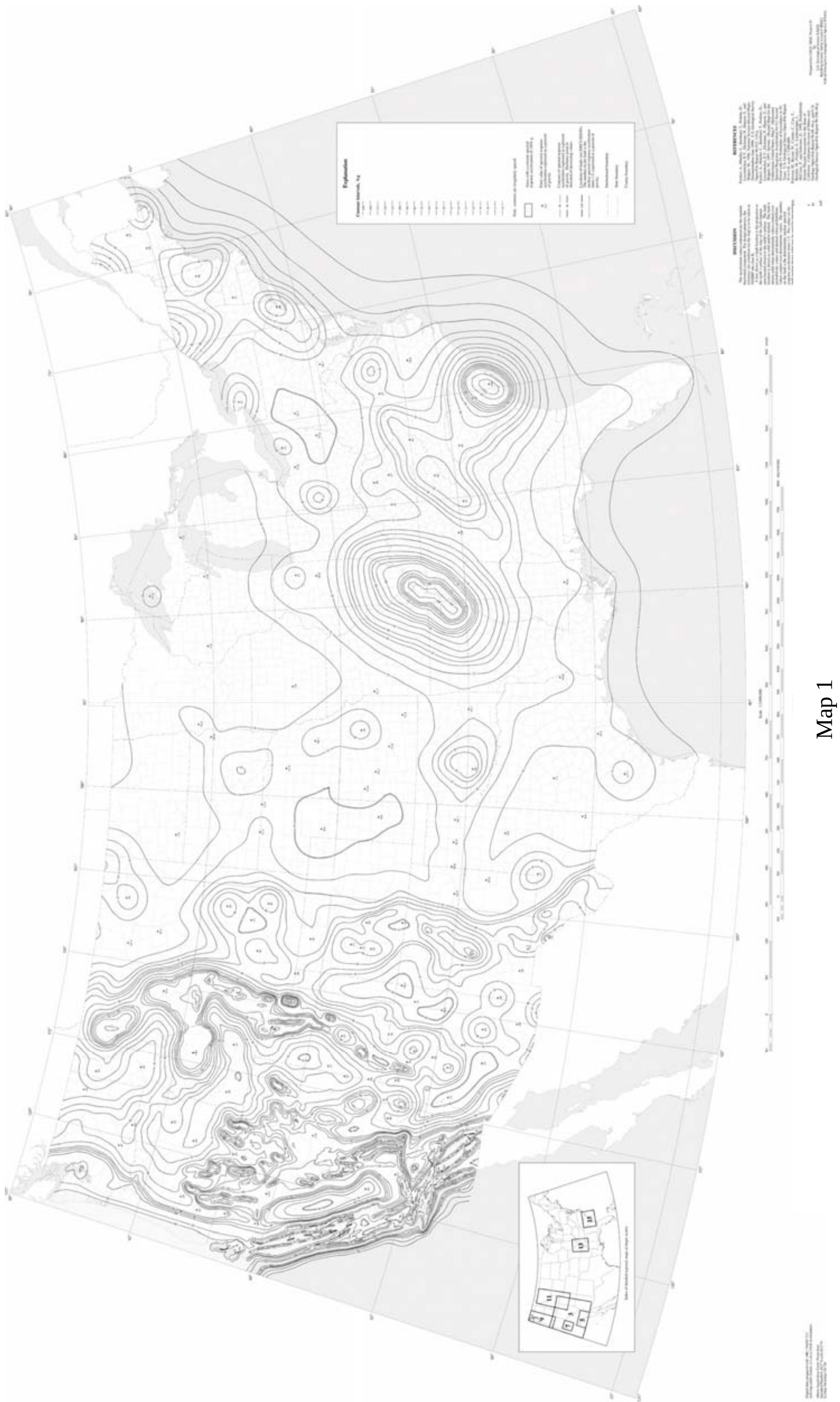
Velocity and displacement are mathematically related to acceleration. Velocity is the speed of an object at an instant in time. Displacement is the distance an object is moved from a resting position, such as how far a building is moved or displaced from its foundation. Seismologists use measurements of displacement to judge the impact of an earthquake on a community.

Velocity is quickly becoming as important as acceleration in determining building damage. Consider the driving example again. If your car decelerates suddenly, the inertial force may cause your head to hit the windshield. The velocity at which your body is traveling at the instant your head hits the windshield determines whether you get a little bump or a fractured skull. For a building, this could mean the difference between superficial damage and building collapse.

None of these measurements alone provides the detailed picture of an earthquake that is needed for further scientific study or for developing present-day design practices. For example, the Richter Scale does not give ground motion information that is important for designers. The Mercalli Scale is subjective and does not cover many new kinds of construction used today. Together they give scientists a good idea of where a seismic event took place, how large it was, and what its impact was on the built environment.

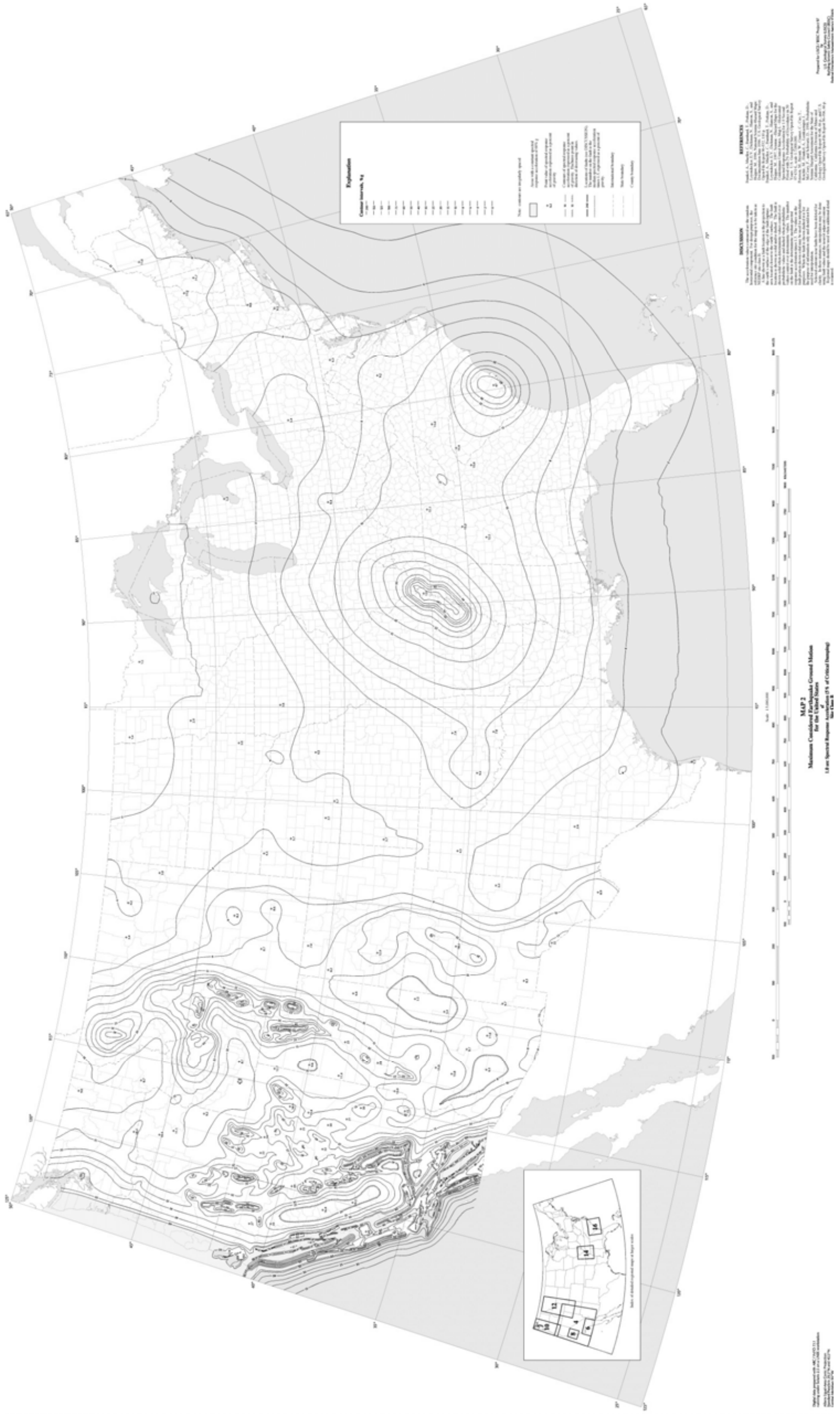
Seismic Hazard Maps

Seismic hazard maps have been developed to give design professionals and emergency response planners an idea of the relative seismic activity of a region. These maps are prepared by the U.S. Geological Survey and are based on the size and location of past earthquakes, their probabilities of recurrence, and the frequency of seismic events in the region. Seismic hazard maps are an important part of the NEHRP *Provisions* and have been adopted by the nation’s model building codes. Hazard maps are an important tool for evaluating and planning a community’s seismic safety. Examples of these maps appear in Figures 3-15 and 3-16. The values on the maps show potential earthquake ground motions, presented in percent of gravity. Figure 3-15 shows short-period ground motions, which affect shorter, stiffer buildings, and Figure 3-16 shows long-period ground motions, which affect taller, more flexible buildings.



Map 1
Maximum Considered Earthquake Ground Motion
for the United States
0.2 Sec Spectral Response Acceleration (5% of Critical Damping)
Site Class B

Figure 3-15 *Source: U S. Geological Survey.*



Map 2
Maximum Considered Earthquake Ground Motion
for the United States
1.0 Sec Spectral Response Acceleration (5% of Critical Damping)
Site Class B

Figure 3-16

Source: U.S. Geological Survey.

UNIT 3 - SUMMARY

This unit presented information on the characteristics and causes of earthquakes. In this unit, we explored the following questions:

- What causes an earthquake?
    - Plate tectonics
    - Faults
    - Sudden rupture
- What are an earthquake's characteristics?
    - Seismic waves
    - Effect of soil composition
- How do we measure earthquakes?
    - Modified Mercalli Intensity Scale
    - Richter Scale
    - Ground motion
    - Seismic risk maps

The knowledge you have gained in this unit will help you understand the effect an earthquake can have on the built environment, which we will cover in more depth in the next chapter. To check your understanding of this section, complete the Unit Review and check your answers before moving on to the next section.

Unit 3

Earthquake Causes and Characteristics

Unit Review

Directions: For each question, circle the letter of the correct response and check your answers with the Answer Guide at the end of the unit.

1. The 1811 and 1812 New Madrid earthquakes are examples of earthquakes caused by:

   a. plate tectonics.
   b. intraplate activity.
   c. liquefaction.
   d. subduction.

2. Because of the soil composition of the eastern and central parts of the United States, seismic waves tend to travel:

   a. short distances.
   b. only on the surface.
   c. farther than they do west of the Rocky Mountains.
   d. only as P waves.

3. The land masses around the Pacific Plate show a large degree of earthquake and volcano activity. This area is commonly called _______________.

   a. intraplate activity
   b. the Ring of Fire
   c. Mid-Atlantic Ridge
   d. subduction area

4. The Mid-Atlantic Ridge is a good example of __________ plate movement.

   a. divergent
   b. convergent
   c. fishbowl
   d. torsional

5. When one plate slides over another, a trench is formed and material from the lower plate is forced into the earth's interior. This process is called:

   a. convergent plates.
   b. divergent plates.
   c. subduction.
   d. a fault.

6. When rock is suddenly displaced along a fault line, _________ results.

   a. subduction
   b. convergent plate
   c. intraplate activity
   d. an earthquake

7. What common substance could you use to demonstrate sudden rupture along a fault line and the resulting violent shaking associated with an earthquake?

   a. Gelatin
   b. Paper
   c. Sand
   d. Fabric

8. Which one of the following attributes is **not** associated with a P wave?

   a. It is a body wave.
   b. It is more like an ocean wave than a sound wave.
   c. It is the fastest wave.
   d. It travels through rock and liquid.

9. The 1989 Loma Prieta, California, earthquake measured 7.1 on the Richter Scale and VII on the Modified Mercalli Scale. The 1988 Armenian earthquake measured 6.9 on the Richter Scale and XI on the Modified Mercalli Scale. If the magnitude measurements were similar, why were the intensity measurements for these two earthquakes so different?

   a. An error was made when the values were calculated.
   b. There is never a correlation between these two measurements because they measure different things.
   c. The buildings were taller in Armenia.
   d. Fewer buildings collapsed and less people died in Loma Prieta because the buildings were better constructed to withstand earthquakes.

10. Which one of the following attributes is ***not*** associated with a Love wave?

    a. At the surface it produces both up-and-down and side-to-side motions.
    b. It is a surface wave.
    c. It has no vertical motion.
    d. It cannot travel through liquid.

11. When an outside force (like an earthquake) tries to move an object or changes its rate of travel, what kind of forces are created?

    a. Seismic
    b. Mercalli
    c. Velocity
    d. Inertial

12. The Modified Mercalli Intensity Scale measures an earthquake's:

    a. magnitude.
    b. intensity.
    c. P waves.
    d. response spectrum.

13. The Richter Scale measures an earthquake's:

    a. magnitude.
    b. intensity.
    c. P waves.
    d. response spectrum.

14. A trained observer described the damage by an earthquake as, "Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop." He would rate the earthquake on the Modified Mercalli Intensity Scale as:

    a. IX.
    b. V.

15. "The rate of change of motion" is the definition of:

    a. acceleration.
    b. duration.
    c. velocity.
    d. period.

16. Study the figures below. Figure 3-17 shows the intensity values, based on the Modified Mercalli Intensity Scale, for various areas on the San Francisco peninsula after the 1906 earthquake. Figure 3-18 is a generalized geological map of the San Francisco peninsula. What do the two maps illustrate about the soil composition and earthquake intensity?

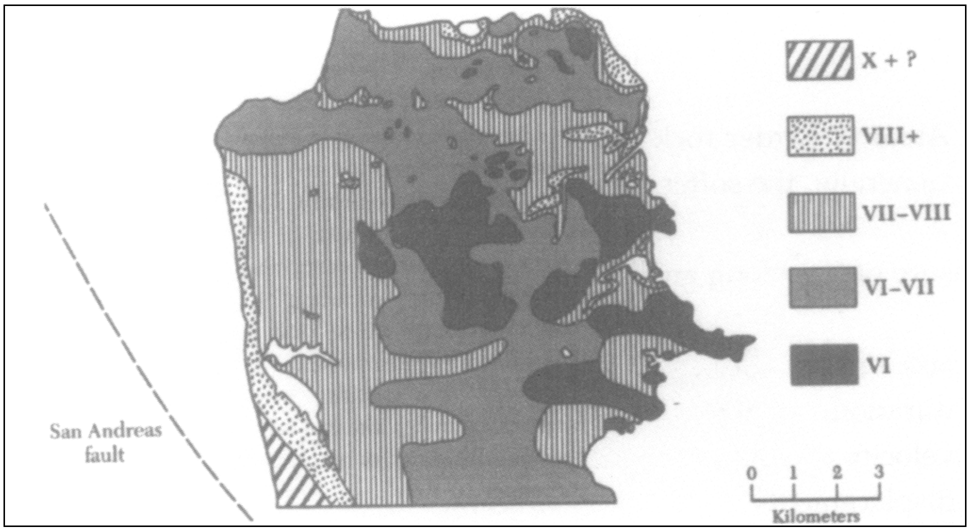


Figure 3-17 *Source: Bolt. Earthquakes, 1988.*

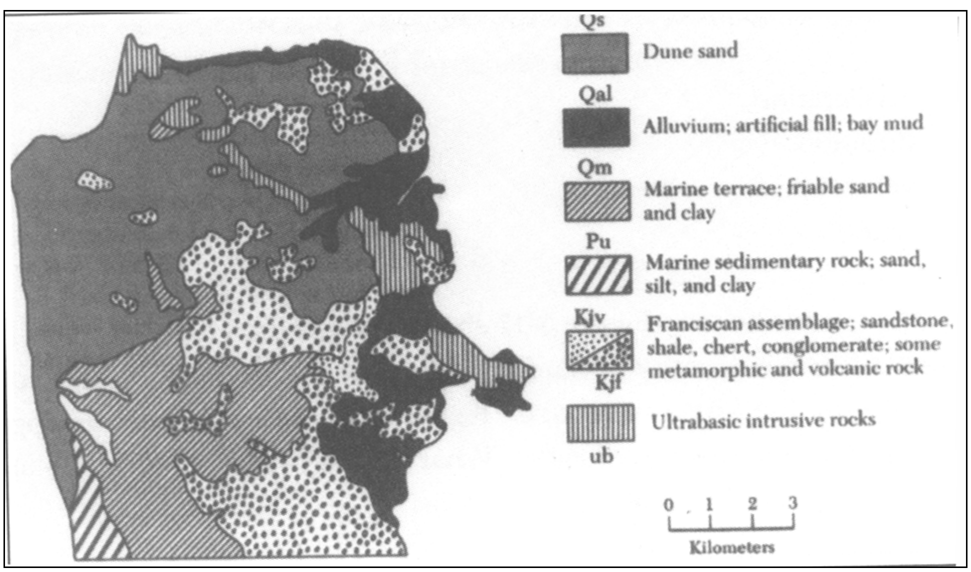


Figure 3-18 *Source: Bolt. Earthquakes, 1988.*

a. Areas of harder rock suffered more damage.
b. Generally, the softer the soil, the more intense the earthquake impact.

17. A measure of how long an earthquake lasts is called

    a. acceleration.
    b. duration
    c. velocity
    d. displacement

18. The speed at which an object is traveling at an instant in time is called:

    a. acceleration.
    b. duration.
    c. velocity.
    d. displacement.

19. The distance an object is moved from a resting position is called:

    a. acceleration.
    b. duration.
    c. velocity.
    d. displacement.

20. Why is it important to measure the magnitude, intensity, and ground motion of an earthquake?

    a. It helps communities decide on appropriate mitigation steps to take in the event of future earthquakes.
    b. It helps communities prepare accurate seismic risk maps.
    c. It helps communities design seismically safe buildings by predicting what forces a structure may have to endure in an earthquake in a specific area.
    d. All of the above.

Unit 3

Earthquake Causes and Characteristics

Unit Review - Answer Guide

1. The 1811 and 1812 New Madrid earthquakes are examples of earthquakes caused by:

   b. intraplate activity.
   Reference: p. 3-4

2. Because of the soil composition of the eastern and central parts of the United States, seismic waves tend to travel:

   c. farther than they do west of the Rocky Mountains.
   Reference: pp. 3-11 and 3-12

3. The land masses around the Pacific Plate show a large degree of earthquake and volcano activity. This area is commonly called ________________.

   b. the Ring of Fire
   Reference: p. 3-4

4. The Mid-Atlantic Ridge is a good example of __________ plate movement.

   a. divergent
   Reference: p. 3-2

5. When one plate slides over another, a trench is formed and material from the lower plate is forced into the earth's interior. This process is called:

   c. subduction.
   Reference: p. 3-2

6. When rock is suddenly displaced along a fault line, _____ results.

   d. an earthquake
   Reference: p. 3-6

7. What common substance could you use to demonstrate the sudden rupture along a fault line and the resulting violent shaking associated with an earthquake?

   a. Gelatin
   Reference: p. 3-6

8. Which one of the following attributes is ***not*** associated with a P wave?

   b. It is more like an ocean wave than a sound wave.
   Reference: p. 3-8

9. The 1989 Loma Prieta, California, earthquake measured 7.1 on the Richter Scale and VII on the Modified Mercalli Scale. The 1988 Armenian earthquake measured 6.9 on the Richter Scale and XI on the Modified Mercalli Scale. If the magnitude measurements were similar, why were the intensity measurements for these two earthquakes so different?

   d. Fewer buildings collapsed and less people died in Loma Prieta because the buildings were better constructed to withstand earthquakes.
   Reference: pp. 3-15 and 3-16

10. Which one of the following attributes is ***not*** associated with a Love wave?

    a. At the surface it produces both up-and-down and side-to-side motions.
    Reference: p. 3-10

11. When an outside force (like an earthquake) tries to move an object or change its rate of travel, what kind of forces are created?

    d. Inertial
    Reference: p. 3-17

12. The Modified Mercalli Intensity Scale measures an earthquake's:

    b. intensity.
    Reference: pp. 3-13 to 3-15

13. The Richter Scale measures an earthquake's:

    a. magnitude.
    Reference: p. 3-15

14. A trained observer described the damage by an earthquake as, "Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop." He would rate the earthquake on the Modified Mercalli Intensity Scale as:

    b. V.
    Reference: p. 3-14

15. "The rate of change of motion" is the definition of:

    a. acceleration.
    Reference: pp. 3-17 and 3-18

16. Study the figures below. Figure 3-17 shows the intensity values, based on the Modified Mercalli Intensity Scale, for various areas on the San Francisco peninsula after the 1906 earthquake. Figure 3-18 is a generalized geological map of the San Francisco peninsula. What do the two maps illustrate about the soil composition and earthquake impact?

    b. Generally, the softer the soil, the more intense the earthquake impact.
    Reference: pp. 3-11 and 3-12

17. A measure of how long an earthquake lasts is called:

    b. duration.
    Reference: p. 3-17

18. The speed at which an object is traveling at an instant in time is called:

    c. velocity.
    Reference: p. 3-18

19. The distance an object is moved from a resting position is called:

    d. displacement.
    Reference: p. 3-18

20. Why is it important to measure the magnitude, intensity, and ground motion of an earthquake?

    d. All of the above.
    Reference: this unit.

Unit 4

Earthquake Effects

INTRODUCTION

In the last unit, we looked at the causes and characteristics of earthquakes. Now let's take a look at an earthquake's effects on the natural and built environments. Knowing more about the effects of earthquakes helps us understand the mitigation steps that must be taken to protect a community from a seismic event.

Unit 4 covers the following topics:

- What are some effects of earthquakes on the natural and built environments?
- What building characteristics are significant to seismic design?
- How do buildings resist earthquake forces?
- What secondary consequences of earthquakes must we be concerned with?

WHAT ARE SOME EFFECTS OF EARTHQUAKES ON THE NATURAL ENVIRONMENT?

In the last unit, we reviewed the different types of seismic waves that produce the violent ground shaking, or motion, associated with earthquakes. These wave vibrations produce several different effects on the natural environment that also can cause tremendous damage to the built environment (buildings, transportation lines and structures, communications lines, and utilities). Researching potential problems, known as site investigation, is a good first step in reducing damage to the built environment due to earthquakes.

Liquefaction

Strong ground motion during an earthquake can cause water-saturated, unconsolidated soil to act more like a dense fluid than a solid; this process is called liquefaction. Liquefaction occurs when a material of solid consistency is transformed, with increased water pressure, in to a liquefied state. Water saturated, granular sediments such as silts, sands, and gravel that are free of clay particles are susceptible to liquefaction. Imagine what would happen to a building if the soil beneath it suddenly behaved like a liquid. This potential for liquefaction to occur is present in many parts of the United States and in other parts of the world. Liquefaction occurred during the 1811-1812 New Madrid, Missouri, the 1989 Loma Prieta, California, the 1964 Niigata, Japan, and the 1967 Caracas, Venezuela, earthquakes. Figures 4-1 and 4-2 show how buildings can topple when soil assumes the properties of a liquid and loses its bearing capacity.

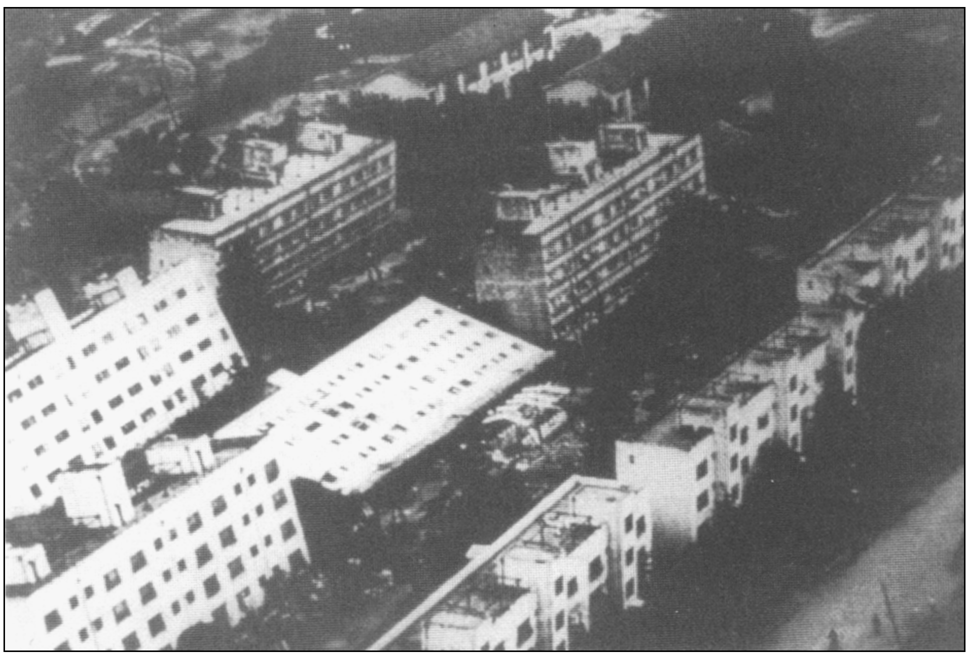


Figure 4-1 *Source: Federal Emergency Management Agency.*

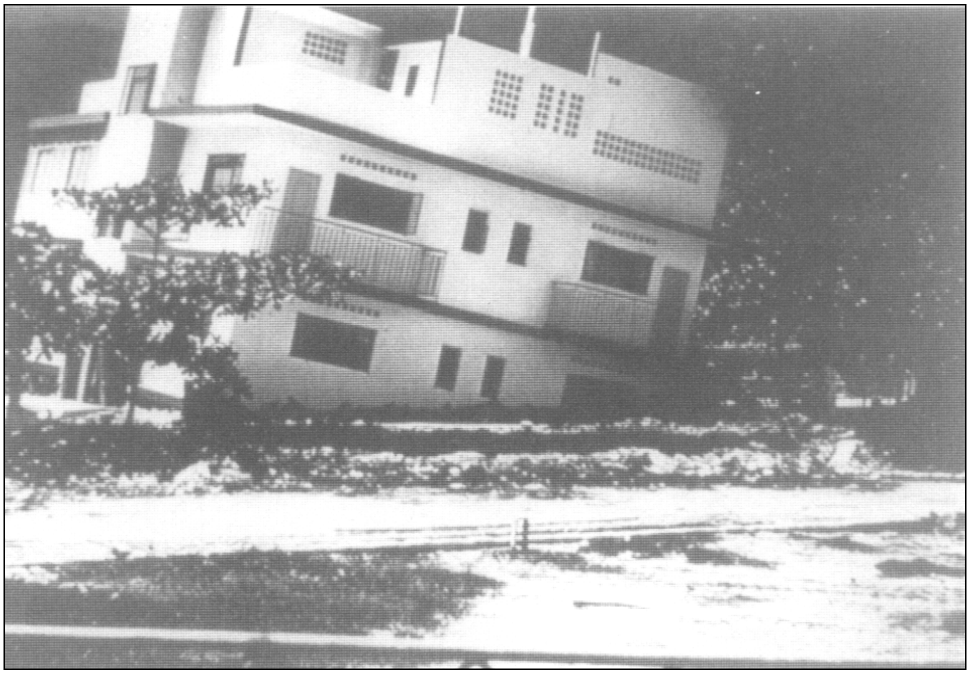


Figure 4-2 *Source: Federal Emergency Management Agency.*

Landslides

Ground motion also can trigger landslides. Careful consideration should be made before developers place a building in a location that could be affected by a landslide. A fire department in California found that out the hard way. During an earthquake in their community, a landslide blocked the exits to the firehouse, and, while the fire equipment was blocked inside, the town suffered millions of dollars in damage from fires caused by the earthquake. Figure 4-3 shows a railroad track that was left hanging on the side of a mountain after the land beneath it slid away.

Tsunamis and Seiche

Tsunami ("Soo na me") is Japanese for tidal wave. A tsunami is caused by an earthquake, landslide, or volcanic eruption on the sea floor. During an earthquake, seismic waves can produce powerful ocean waves. These waves tend to be very deep, with long distance between the peaks. In deep water there may be no noticeable evidence of the tsunami at the surface. However, when the wave enters shallow waters, the energy is forced to the surface and produces a tall wave that travels at high speed and moves far inland. Seaside communities are usually ravaged twice—first, when the water crashes in from the sea and, second, when the water recedes and carries loose objects out to sea. Though tsunamis are not as common as earthquakes, they can cause much more damage. Here in the United States, we can experience tsunamis on the West Coast, Alaska, and Hawaii.

"Seiche" refers to the oscillation (sloshing back and forth) of water in a closed space, such as a lake, reservoir, or swimming pool. This oscillation can cause overtopping of dams and damage to structures near water.

Faults

We saw in the previous unit that ruptures along fault planes or zones sometimes reach the surface. If a building stands on a fault line, little can be done to protect it during an earthquake. It is extremely important to select sites for new buildings that are away from known fault surface traces. Figures 4-4, 4-5, and 4-6 show faults that have risen to the surface.

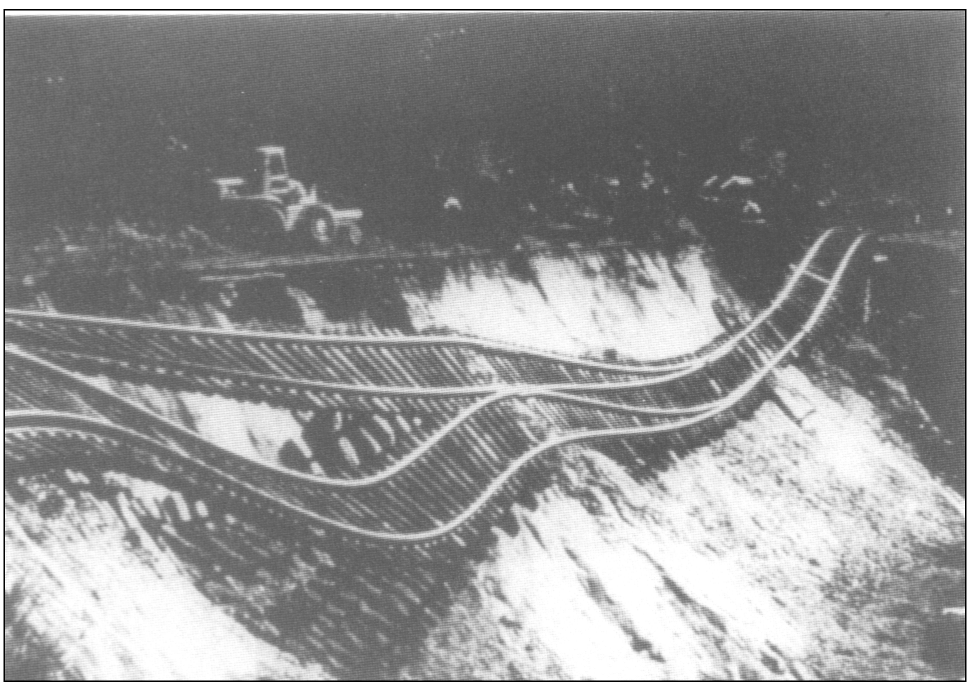


Figure 4-3 *Source: Federal Emergency Management Agency.*

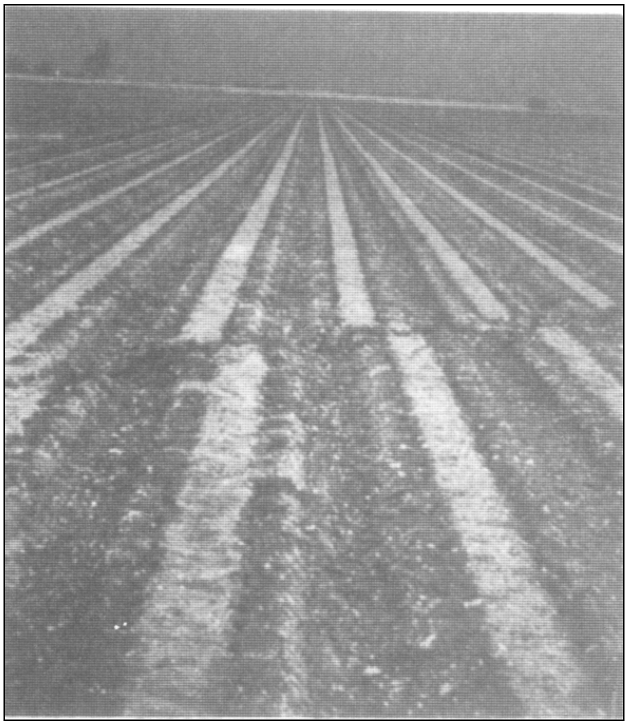


Figure 4-4 *Source: Federal Emergency Management Agency.*

Figure 4-5 *Source: Federal Emergency Management Agency.*

Figure 4-6 *Source: Federal Emergency Management Agency.*

WHAT BUILDING CHARACTERISTICS ARE SIGNIFICANT TO SEISMIC DESIGN?

Several important characteristics of buildings affect performance during an earthquake. Buildings of different construction materials or configurations will respond in different ways to the same ground motion; some may collapse while others survive. Knowing how buildings respond in an earthquake helps architects, engineers, and builders design and construct buildings to withstand ground motion without collapsing. Let's consider some of the structural characteristics of buildings that influence how they behave during an earthquake. These characteristics are natural period, damping, ductility, stiffness, drift, and building configuration.

Natural Period

All objects (including buildings and the ground) have a "natural period," or the time it takes to swing back and forth, from point A to point B and back again. If you pushed the flag pole shown in Figure 4-7, it would sway at its natural period.

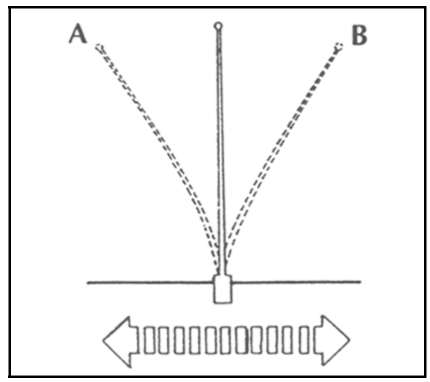


Figure 4-7 *Source: Lagorio. Earthquakes: An Architect's Guide to Nonstructural Seismic Hazards, 1990.*

As seismic waves move through the ground, the ground also moves at its natural period. This can become a problem if the period of the ground is the same as that of a building on the ground. When a building and the ground sway or vibrate at the same rate, they are said to resonate. When a building and the ground resonate it can mean disaster. This is because, as the building and ground resonate, their vibrations are amplified or increased, and greater stress is placed on the building. Think of a building vibrating rapidly; at some point the building will begin to shake apart.

One of the most important factors affecting the period is height. A taller building will swing back and forth more slowly (or for a longer period) than a shorter one. For example, a 4-story building might have a natural period of 0.5 seconds, while a 60-story building may have a period of as much as 7 seconds. Building height can have dramatic effects on a structure's performance in an earthquake. A taller building often suffers more damage than a shorter one because the natural period of the ground tends to match that of buildings nine stories or taller. This explains why some buildings are severely damaged and others are not. During the 1964 earthquake in Anchorage, Alaska, shorter buildings closer to the earthquake's focus suffered less damage than taller buildings up to 75 miles away because the taller, multistory buildings resonated with the long-period ground motions. Buildings resonate only when their natural periods coincide with the period of the ground motions during an earthquake. In the 1985 Mexico City, Mexico, earthquake long-period ground motions were the same as the period of some 9- to 14-story buildings. The results were disastrous for buildings of this size. Buildings taller than 14 stories did not experience resonance and had fewer disastrous effects. Some seismically active areas impose height restrictions on buildings to decrease the possibility of building failure during an earthquake.

Although the phenomenon of resonance can be extremely damaging, its effects can be reduced. In designing seismically safe buildings, an architect or engineer must be concerned with "tuning" a building so that the tendency for its own vibration to be amplified by resonance is reduced or eliminated.

Damping

One way an architect or engineer may decrease the effects of resonance is by constructing buildings so that the vibration of a building is quickly reduced as an earthquake sets it in motion. This is called damping, the termination or retardation of the motion or vibration of a structure. Connections of nonstructural elements such as partitions, ceilings, and exterior walls can dampen a building's vibration. Modern office buildings with open flooring and few partitions tend to be deficient in damping and therefore suffer more damage in an earthquake. It is most advantageous for a building to have a high level of damping characteristics—in effect to be an inefficient vibrator. With damping design, a building is less likely to resonate in tune with the ground.

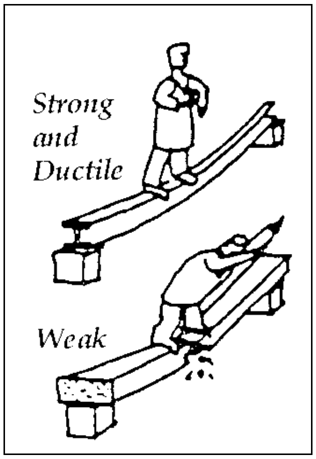


Figure 4-8

Source: Building Seismic Safety Council. Nontechnical Explanation of the NEHRP Recommended Provisions.

Ductility and Strength

Ductility is another factor that can affect the performance of a building during an earthquake. Ductility is the property of certain materials to fail only after large stresses and strains have occurred. Figure 4-8 illustrates what we mean by ductility. Brittle materials, such as non-reinforced concrete, fail suddenly with minimum tensile stresses, so plain concrete beams are no longer used. Other materials, primarily steel, bend or deform before they fail. We can rely on ductile materials to absorb energy and prevent collapse when earthquake forces overwhelm a building. In fact, adding steel rods to concrete can reinforce it and give the concrete considerable ductility and strength. Concrete reinforced with steel will help prevent it from failing during an earthquake.

Stiffness

A building is made up of both rigid and flexible elements. For example, beams and columns may be more flexible than stiff concrete walls or panels. Less rigid building elements have a greater capacity to absorb several cycles of ground motion before failure, in contrast to stiff elements, which may fail abruptly and shatter suddenly during an earthquake. Earthquake forces automatically focus on the stiffer, rigid elements of a building. For this reason, buildings must be constructed of parts that have the same level of flexibility, so that one element does not bend too much and transfer the energy of the earthquake to less ductile elements of the building.

The 1987 failure of a parking structure in Whittier-Narrows, California, was a dramatic illustration of this phenomenon. To accommodate the natural slope of the land on which it was built, the structure was designed with long vertical supports at the front of the building and short columns at the other end, and the roof level was designed as a flat horizontal plane. Figure 4-9 shows a drawing of this structure.

When the earthquake struck, the longer, more flexible columns at the front of the building passed the earthquake forces on to the short, stiffer columns in the back instead of distributing the forces equally among all of the columns. Deflection, the extent to which a structural element moves or bends under pressure, played a major role. The longer columns simply deflected or bent without cracking. The short columns, therefore, were overwhelmed and cracked. The rate of deflection is used as a measure of the stiffness of a structure.

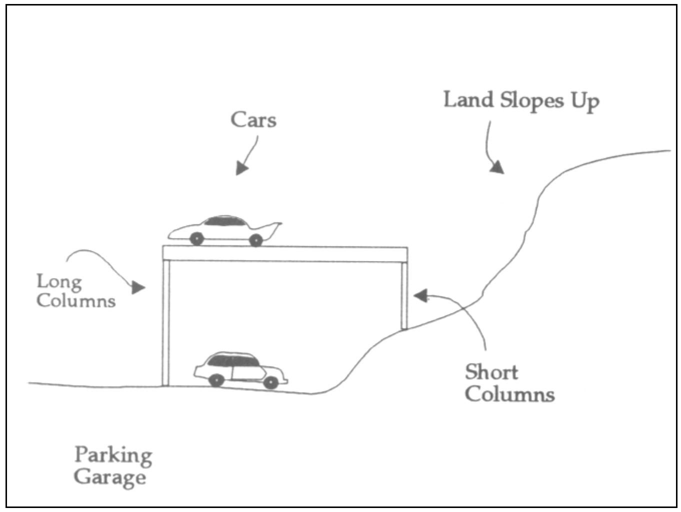


Figure 4-9

Drift

Drift is the extent to which a building bends or sways. Limits are often imposed on drift so a building is not designed to be *so* flexible that the resulting drift or swaying during an earthquake causes excessive damage. Figure 4-10 shows how a building can be affected by drift in an earthquake. If the level of drift is too high, a building may pound into the one next to it. Or the building may be structurally safe but nonstructural components, such as ceilings and walls, could be damaged as the building bends and the ceilings and walls are ripped away from their attachments. Of course, people in the building could be killed or injured from falling debris.

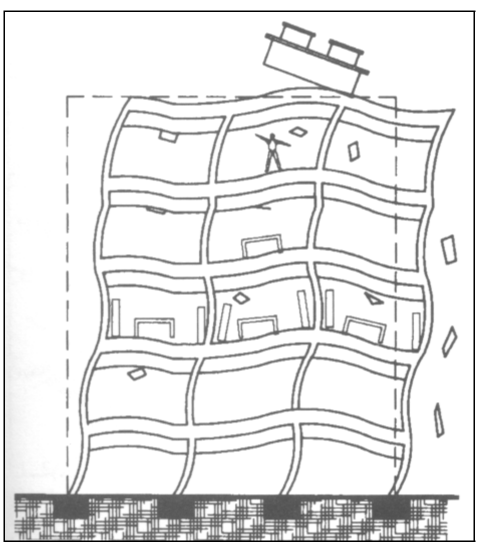


Figure 4-10
Source: Naeim. The Seismic Design Handbook, 1989.

Building Configuration

Configuration of a building determines the ways in which seismic forces are distributed throughout the building. Earthquakes have earned a reputation for their ability to find and exploit the weak link in buildings.

Generally speaking, a building with a symmetrical design and balanced resistance will hold up best. Let's look at several types of buildings that illustrate this point.

L-shaped Buildings

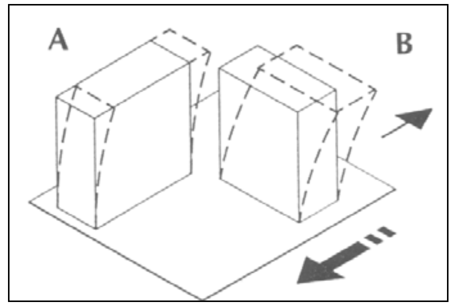


Figure 4-11 *Source: Naeim. The Seismic Design Handbook, 1989.*

During an earthquake, an L-shaped building will experience increased stress at the point where the wings of the building meet. The difference in stiffness between the two wings causes this stress. To illustrate this point, let's think for a moment about the two wings of our L-shaped building as separate buildings, as shown in Figure 4-11.

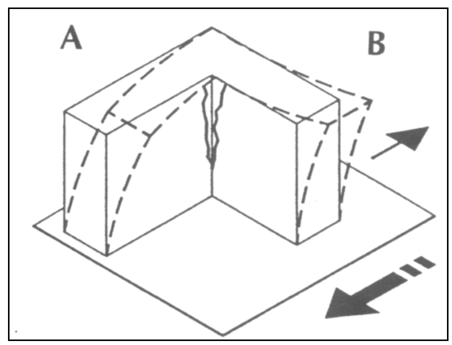


Figure 4-12 *Source: Naeim. The Seismic Design Handbook, 1989.*

Let's say the force of an earthquake travels parallel to building A. The orientation of building A to the earthquake results in it swaying less than building B. This means that the perpendicular building, building B, will sway more than the parallel building, building A. Now let's put the buildings back together into an L shape, as shown in Figure 4-12.

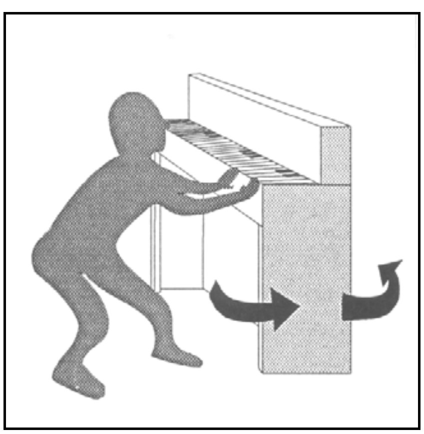


Figure 4-13

In an L-shaped building, the two wings are forced to move together. As the two wings pull and push on each other, high stresses occur at the point where the two wings are joined. This problem also occurs in buildings with a T, H, or + shape.

Torsional forces also affect the way an L-shaped building reacts during an earthquake. Torsional forces are forces that make an object rotate. They are created in a building by a lack of balance in forces. These forces build up as the B wing (perpendicular) attempts to rotate around the stiffer A wing (parallel). Another way to illustrate torsional forces is to think about moving a piano. To move the piano you would be careful to push it from the center. If you pushed at only one end, the piano would rotate around its center of mass, as shown in Figure 4-13. Torsional forces create this rotating effect. The same thing happens to L-, T-, H-, or +-shaped buildings. Torsional forces on these buildings can cause one wing to rotate around the other. If buildings are not designed to resist torsional forces, considerable damage or collapse could occur.

Symmetrical Buildings with Nonsymmetrical Elements

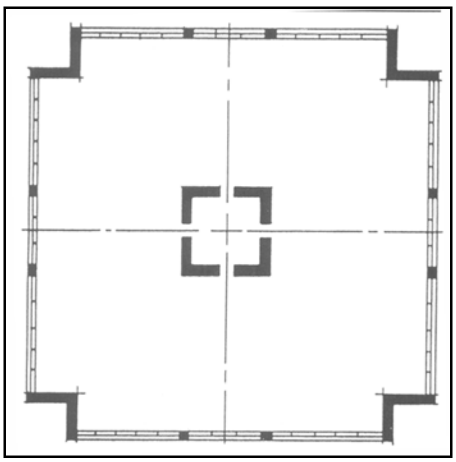


Figure 4-14 *Source: Lagorio. Earthquakes: An Architect's Guide to Non-structural Seismic Hazards, 1990.*

Torsional forces also can be a factor of performance in a symmetrically designed building in which isolated or single structural elements (elevators, etc.) have not been symmetrically distributed. Let's compare damage done to two bank buildings in the 1972 Managua, Nicaragua, earthquake. One bank was symmetrically designed with a stiff elevator core in the center of the building. Figure 4-14 shows the floor plan of this building.

The second bank also was a symmetrically shaped building with its stiff elevator core at one end. Figure 4-15 shows the floor plan of this bank.

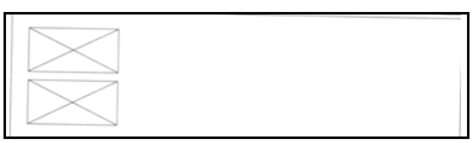


Figure 4-15

The first building (Figure 4-14) suffered little damage during the earthquake. The second building (Figure 4-15) developed unrestrained torsional forces as the free end attempted to rotate around the stiff, off-center elevator core. This building incurred major damage and was demolished.

Soft-story

A soft-story building is a structure with stiffer, more rigid upper stories and an open, flexible first story. This design is found in buildings where the first story contains a parking garage or an open commercial area for stores and the upper floors house offices or apartments. Figure 4-16 illustrates a soft-story building.

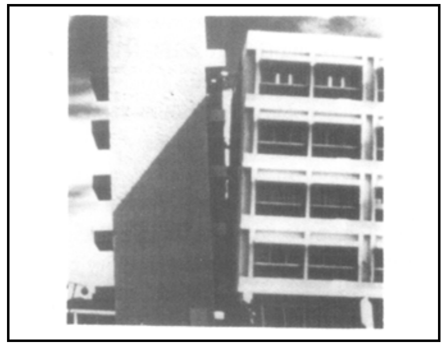


Figure 4-16 *Source: Federal Emergency Management Agency.*

This design creates a discontinuity of strength and stiffness. If all stories are approximately equal in strength, the entire building would bend in an earthquake. If the first story is softer, or more flexible, than the other stories, the bending would concentrate there. Because the first floor is also the most highly loaded, the problem is compounded, thus possibly causing column failure.

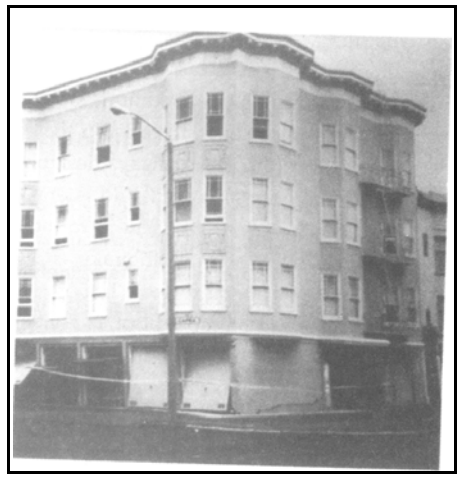


Figure 4-17 *Source: Federal Emergency Management Agency.*

This also will put additional stress on the connection between the first and second stories and can cause the building to collapse. You can see what the stress between the first and second floors did to these soft-story buildings (Figures 4-17 and 4-18) during the 1972 San Fernando and the 1989 Loma Prieta earthquakes. Building configuration can have significant effect on how a building performs in an earthquake.

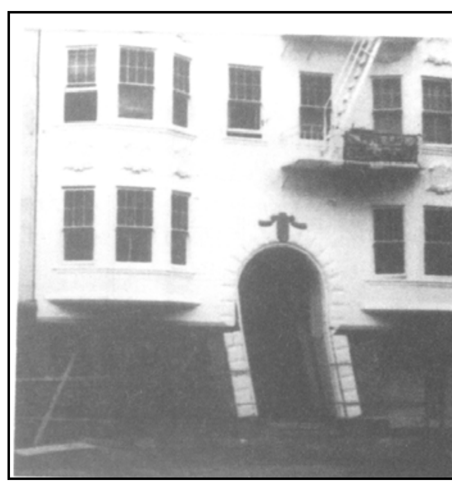


Figure 4-18 *Source: Federal Emergency Management Agency.*

Generally, the simpler the design and the more balanced the building and its structural and nonstructural components, the better the building will perform during an earthquake.

HOW DO BUILDINGS RESIST EARTHQUAKE FORCES?

Now that we have discussed some of the forces that can affect a building and elements of building design that make buildings more or less susceptible to damage by seismic forces, let's look at systems that can be built into a structure to help it resist these forces.

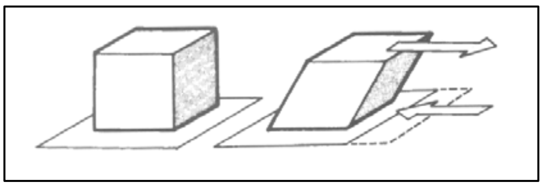


Figure 4-19 *Source: Botsai, et al., Architects and Earthquakes, 1976.*

As a building responds to ground motions produced by an earthquake, the bottom of the structure moves immediately, but the upper portions do not because of their mass and inertia. Figure 4-19 shows the base of a building moving while the upper part lags behind.

The horizontal force, or base shear, created by ground motion resulting from an earthquake must be resisted by the building. The more the ground moves, or the greater the weight of the building, the more force must be resisted by the building. When an architect or engineer designs a building, he or she must determine the maximum force a building might have to resist in the future. Buildings are always designed to handle normal vertical and lateral forces. However, once you introduce the possibility of an earthquake, a building must be designed for extraordinary horizontal or lateral forces. The horizontal (lateral) forces associated with an earthquake can be thought of as a lateral force applied to each floor and to the roof of a building. Figure 4-20 shows the vertical and horizontal forces on a building during an earthquake. Panel (a) shows the direction of gravitational forces on a building, panel (b) shows the horizontal force of seismic waves, and panel (c) shows the combined forces of gravity and an earthquake applied to the floors and roof of a building.

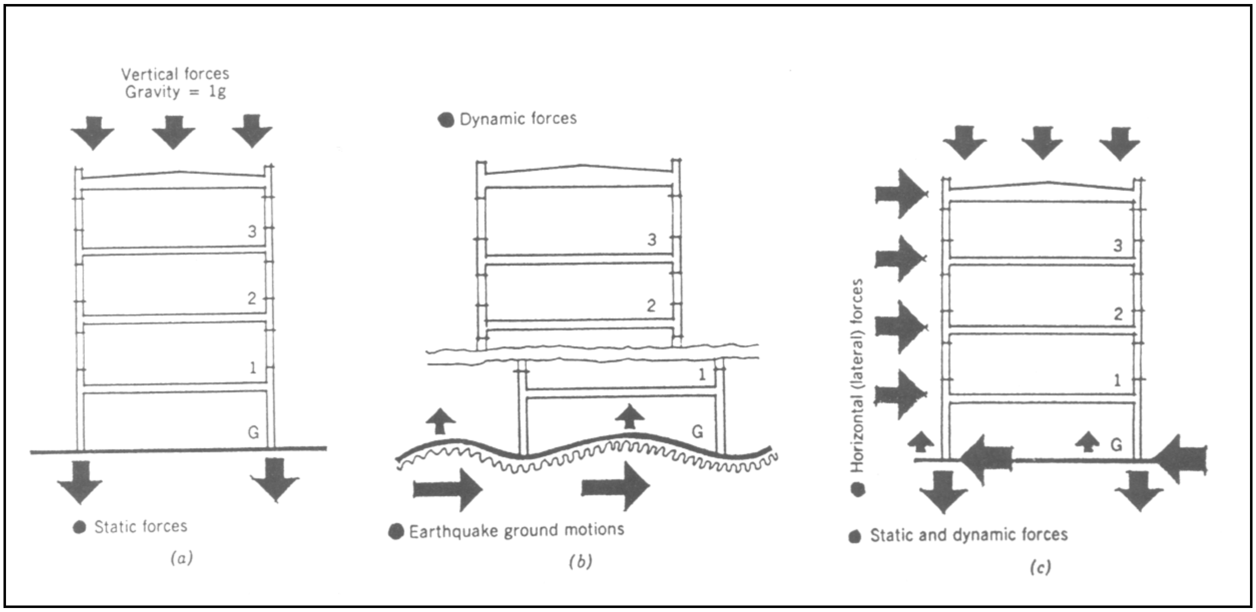


Figure 4-20 *Source: Lagorio. Earthquakes: An Architect's Guide to Nonstructural Seismic Hazards, 1990.*

Horizontal forces accumulate along the floors and roof and then are distributed through the vertical supports into the foundation. A structural engineer must design a building so that lateral forces are distributed throughout the building without a break. Several structural systems, such as floors, walls, and columns, may be used in new buildings to reduce the effects of earthquakes and associated natural disasters.

Diaphragms

The floor and roof systems that distribute an earthquake's lateral forces are referred to as diaphragms. Diaphragms support the gravitational and lateral forces on a building and transfer them to vertical structural elements like shear walls, braced frames, and moment-resistant frames. These vertical elements help resist lateral forces and are therefore called horizontal (or lateral) bracing systems.

Horizontal Bracing Systems

Three horizontal bracing systems can be used to resist earthquake forces. These are:

- Shear wall systems,

- Braced frame systems, and
- Moment-resistant systems.

Shear Wall System

Walls within a building that are designed to receive horizontal forces parallel to the wall are called shear walls. Houses with many rooms separated by structural walls with minimal openings are good examples of shear wall buildings. Figure 4-21 illustrates shear walls.

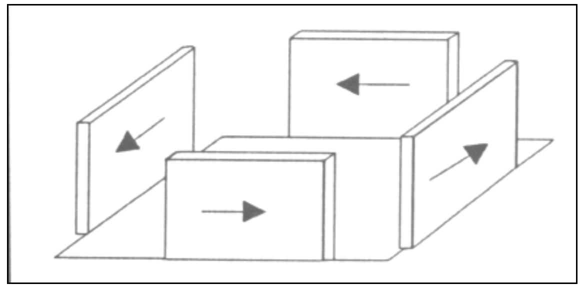


Figure 4-21 *Source: Building Seismic Safety Council. Nontechnical Explanation of the NEHRP Recommended Provisions.*

Braced Frame System

Braced frames act like shear walls but they are somewhat more flexible. In Figure 4-22, the dotted lines show the normal position of a shear wall and a braced frame. The braced frame is more flexible and bends farther from its normal position than the shear wall.

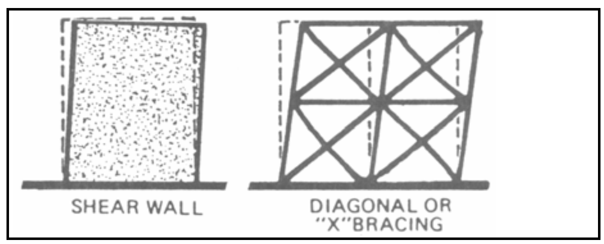


Figure 4-22 *Source: Lagorio. Earthquakes: An Architect's Guide to Nonstructural Seismic Hazards, 1990.*

Moment-Resistant System

This system helps a building resist horizontal (lateral) forces at the joints between the columns and the beams. These joints become highly stressed, so they must be constructed of a strong, ductile material like steel. Figure 4-23 illustrates the moment-resistant system.

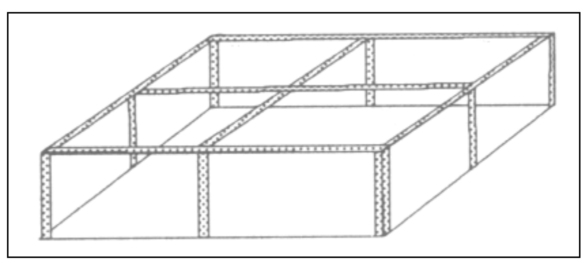


Figure 4-23 *Source: Building Seismic Safety Council. Nontechnical Explanation of the NEHRP Recommended Provisions.*

Dual Systems

Sometimes it is advantageous to use a combination of a moment-resistant frame and a shear wall or braced frame. This combination is called a dual system.

The resisting systems (floors and walls) we have just covered are basic architectural components used in many buildings. In designing a seismically resistant building, the designer must choose some combination of these elements that will provide proper horizontal support. The choices the designer makes will have a major impact on the seismic safety, cost, and architecture of a building.

WHAT SECONDARY CONSEQUENCES OF EARTHQUAKES MUST WE BE CONCERNED WITH?

So far we have talked about the effects of earthquakes on the natural and built environments. These are generally referred to as an earthquake’s “primary effects.” In this section, we will examine an earthquake’s “secondary effects.” Secondary effects, such as fire, hazardous material spills, and water main breaks, can cause extensive damage and loss of life.

FIRES AND HAZARDOUS MATERIAL SPILLS

The San Francisco earthquake of 1906 is one of the best illustrations of the problems generated by secondary effects:

> The state-of-the-art city-wide fire alarm system was knocked out of action by the first shock wave. The writhing of the San Andreas fault not only broke telegraph lines and twisted streetcar tracks to stop all transit, it ruptured gas lines and water pipes. The gas fed flames from damaged fireplaces, flues and stove pipes, while the broken water mains rendered fire hydrants pressureless and firemen helpless.

The Day the Earth Shook, Dillon, 1985

Fires burned for 3 days, consuming 508 city blocks. Ground motion caused an estimated 20 percent of all damage to the city, but fire caused the rest.

Certainly California is better prepared for the primary effects of earthquakes today. However, an earthquake can initiate a secondary chain of events involving damage to such lifelines as water supply, gas, and electricity that can turn a moderate seismic event into a catastrophic one. We have only to look at a more recent example to bring this point home:

> In Managua, Nicaragua, an earthquake in 1972 collapsed the second floor of the central fire station, crushing fire apparatus, killing two firemen and injuring others. The communication radio was destroyed and no emergency electric power was available. Fires soon began to break out in the city, where temporary hose lines were laid from the lake and pumps put into place because the local water system failed.
>
> *Bolt, et al., 1977*

Earthquakes also can cause hazardous material incidents that can be dangerous or deadly to a community. These incidents can involve materials such as:

- Poisonous gas,
- Medical materials at clinics and laboratories,
- Sewage,
- Radioactive materials, and
- Carcinogens.

After the 1989 Loma Prieta earthquake, for example, the town of Watsonville, California, was left without running water for weeks after the earthquake broke water and sewer distribution lines, mixing the two together in the trenches where the pipes were located side by side. The cost in time and money to clean and repair the water and sewage lines was tremendous.

LIFELINES

Our previous examples have illustrated the damaging effects a breakdown in lifelines can have following an earthquake. Mitigation plans should consider such lifelines as:

- Water and sewage systems,
- Electric power systems,
- Oil and natural gas systems,
- Communications systems, and
- Transportation systems.

UNIT 4 - SUMMARY

This unit explored some of the effects an earthquake can have on the natural and built environments in a community. In this unit, we have answered the following questions:

- What are some effects of earthquakes on the natural environment?
    - Liquefaction
    - Landslides
    - Faults
    - Tsunamis, flooding, and seiche

- What building characteristics are significant to seismic design?
  - Period and resonance
  - Damping
  - Ductility
  - Stiffness
  - Drift
  - Building configuration
- How do buildings resist earthquake forces?
  - Diaphragms
  - Horizontal bracing systems
  - Moment-resistant systems
- What secondary consequences of earthquakes must we be concerned with?
  - Fires and hazardous material spills
  - Utility lifelines

To check your understanding of this section, complete the Unit Review and check your answers before moving on to the next section.

Unit 4

Earthquake Effects

Unit Review

Directions: For each question, circle the letter of the correct response and check your answers with the Answer Guide at the end of the unit.

1. __________ occurs when loose, sandy soil acts more like a fluid than a solid.

   a. Tsunami
   b. Liquefaction
   c. Resonance
   d. Subduction

2. Three effects an earthquake can have on the natural environment that can cause tremendous damage are:

   a. faults, landslides, and damping.
   b. liquefaction, drift, and tsunamis.
   c. liquefaction, landslides, and tsunamis.
   d. faults, seiche, and damping.

3. The term that refers to the oscillation of water in a closed space is:

   a. tsunami.
   b. liquefaction.
   c. seiche.
   d. subduction.

4. The pendulum of a clock demonstrates the tendency of an object to swing back and forth in its natural _________ .

   a. resonance
   b. ductility
   c. period
   d. torsion

5. If the period of the ground movement and a building are the same, what results?

   a. Resonance
   b. Ductility
   c. Period
   d. Torsion

6. During the 1964 Anchorage, Alaska, earthquake, buildings 75 miles away from the epicenter incurred greater damage than buildings much closer. How did authorities account for this?

   a. The buildings 75 miles away were older.
   b. The buildings 75 miles away had been poorly constructed.
   c. The buildings 75 miles away were taller and resonated with the ground motion.
   d. The buildings 75 miles away were shorter and resonated with the ground motion.

7. The quality of partitions, ceilings, and other nonstructural elements of a building that make it a less efficient vibrator is called:

   a. stiffness.
   b. ductility.
   c. damping.
   d. torsion.

8. Steel has the ability to absorb energy and distort, rather than suddenly break like a more brittle material. This quality is called:

   a. stiffness.
   b. ductility.
   c. damping.
   d. torsion.

9. What could happen to the building pictured below during an earthquake?

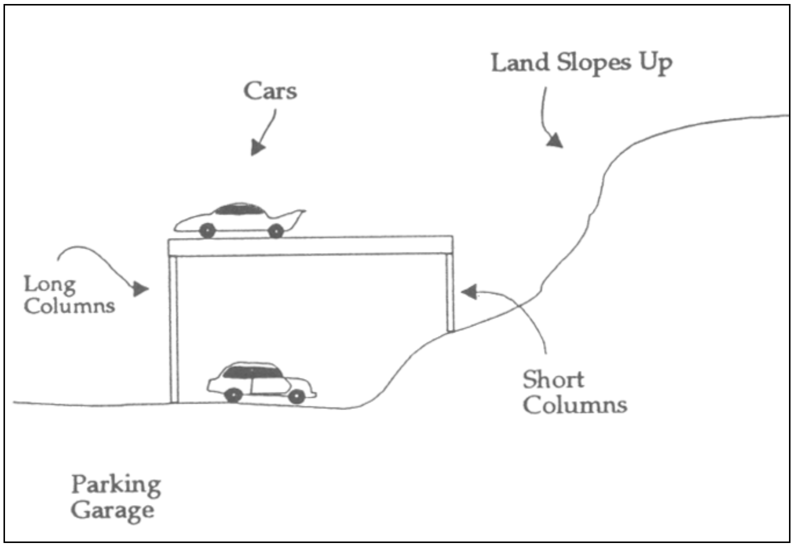


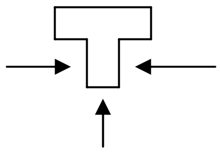
Figure 4-24

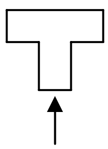
a. Nothing. This is a very strong structure that could withstand a high degree of ground shaking.
b. The longer columns in the front of the structure would receive more of the lateral load and if not properly designed would crack and collapse.
c. The shorter columns in the back of the structure would receive more of the lateral load and if not properly designed would crack and collapse.
d. It is hard to say without knowing the composition of the soil.

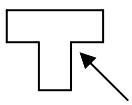
10. Horizontal swaying of a building is called:

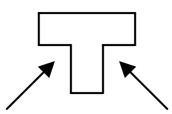
a. torsion.
b. drift.
c. ductility.
d. tectonics.

11. Select the location on a T-shaped building that would suffer the greatest stress during an earthquake.

a. 

b. 

c. 

d. 

12. This illustration shows a building with a stiff elevator core placed at one end. During an earthquake, the free end of the building attempted to rotate around the stiff off-center elevator core. This is an example of what type of force?

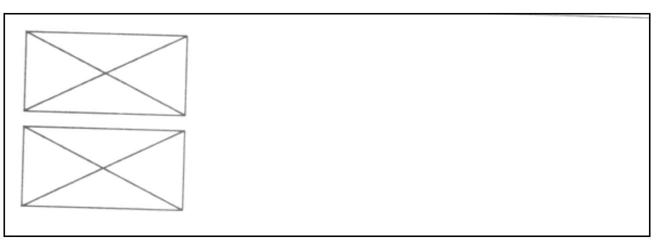


Figure 4-25

a. Velocity
b. Acceleration
c. Torsional
d. Symmetrical

13. This building illustrates what type of structural design problem?

    a. Soft-story
    b. Irregular configuration
    c. Nonuniform mass distribution
    d. Interruption of vertical elements

14. The horizontal force at the base of a building created by an earthquake is often referred to as:

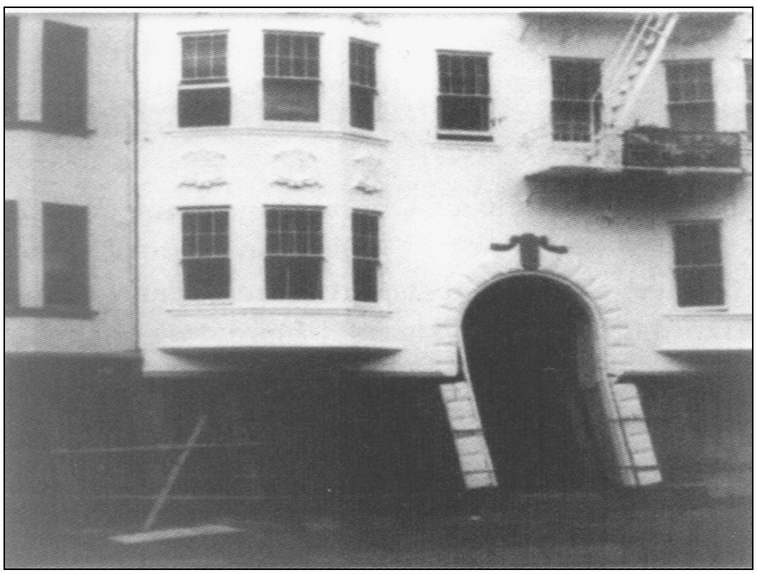


Figure 4-26 *Source: Federal Emergency Management Agency.*

    a. torsional force.
    b. acceleration rate.
    c. base shear.
    d. force of gravity.

15. Diaphragms are the _________ of a building.

    a. shear wall system
    b. lateral bracing systems
    c. floor and roof systems
    d. dual system

16. Buildings resist earthquake forces with basic structural systems, such as:

    a. diaphragms.
    b. horizontal bracing systems (shear walls, braced frames, and moment-resistant systems).
    c. floors and walls.
    d. all of the above.

17. This illustration is an example of what type of horizontal bracing system?

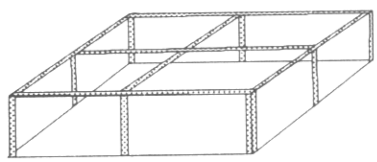


Figure 4-27 *Source: Building Seismic Safety Council. Nontechnical Explanation of the NEHRP Recommended Provisions.*

    a. Shear wall
    b. Braced frame
    c. Moment-resistant system
    d. Dual

18. Houses with many interior walls are a good example of what type of horizontal bracing system?

    a. Shear wall
    b. Braced frame
    c. Moment-resistant system
    d. Dual

19. What makes up the built environment?

    a. Buildings only
    b. Buildings and bridges
    c. Buildings, bridges, and water lines
    d. Buildings, transportation lines and structures, communications lines, and utilities

20. Secondary effects caused by an earthquake do more damage than the damage done by ground motion.

    a. This statement is never true.
    b. This statement is always true.

c. This statement is sometimes true.
d. This statement was true 100 years ago.

Unit 4

Earthquake Effects

Unit Review - Answer Guide

1. _________ occurs when loose, sandy soil acts more like a fluid than a solid.

   b. Liquefaction
   Reference: p. 4-2

2. Three effects an earthquake can have on the natural environment that can cause tremendous damage are:

   c. liquefaction, landslides, and tsunamis.
   Reference: pp. 4-2 and 4-3

3. The term that refers to the oscillation of water in a closed space is:

   c. seiche.
   Reference: p. 4-4

4. The pendulum of a clock demonstrates the tendency of an object to swing back and forth in its natural _________ .

   c. period
   Reference: p. 4-6

5. If the period of the ground movement and a building are the same, what results?

   a. Resonance
   Reference: p. 4-7

6. During the 1964 Anchorage, Alaska, earthquake, buildings 75 miles away from the epicenter incurred greater damage than buildings much closer. How did authorities account for this?

   c. The buildings 75 miles away were taller and resonated with the ground motion.

   Reference: p. 4-7

7. The quality of partitions, ceilings, and other nonstructural elements of a building that make it a less efficient vibrator is called:

   c. damping.

   Reference: pp. 4-7

8. Steel has the ability to absorb energy and distort, rather than suddenly break like a more brittle material. This quality is called:

   b. ductility.

   Reference: p. 4-8

9. What could happen to the building pictured, during an earthquake?

   c. The shorter columns in the back of the structure would receive more of the lateral load and if not properly designed would crack and collapse.

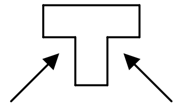
   Reference: pp. 4-8 and 4-9

10. Horizontal swaying of a building is called:

    b. drift.

    Reference: p. 4-9

11. Select the location on a T-shaped building that would suffer the greatest stress during an earthquake.

    d. 

    Reference: pp. 4-10 and 4-11

12. The illustration shows a building with a stiff elevator core placed at one end. During an earthquake, the free end of the building attempted to rotate around the stiff off-center elevator core. This is an example of what type of force?

c. Torsional
Reference: p. 4-11

13. The building illustrates what type of structural design problem?

a. Soft-story
Reference: p. 4-12

14. The horizontal force at the base of a building created by an earthquake is often referred to as:

c. base shear.
Reference: p. 4-13

15. Diaphragms are the _______ of a building.

c. floor and roof systems
Reference: p. 4-14

16. Buildings resist earthquake forces with basic structural systems, such as:

d. all of the above
Reference: pp. 4-13 to 4-16

17. The illustration is an example of what type of horizontal bracing system?

c. Moment-resistant system
Reference: p. 4-15

18. Houses with many interior walls are a good example of what type of horizontal bracing system?

a. Shear wall
Reference: p. 4-15

19. What makes up the built environment?

d. Buildings, transportation lines and structures, communications lines, and utilities.
Reference: p. 4-1

20. Secondary effects caused by an earthquake do more damage than the damage done by ground motion.

c. This statement is sometimes true.

Reference: p. 4-16

Unit 5

Protecting Your Community

INTRODUCTION

In previous units, we learned the causes of earthquakes and their effects on the natural and built environment and that earthquakes can occur *anywhere* in the United States. How can your community protect itself from the potentially devastating effects of an earthquake? In this unit, we will begin to explore some steps your community can take.

Unit 5 answers the following questions:

- What is mitigation?
- Why use building codes?
- What are the NEHRP *Provisions*?
- What do building codes have to do with Executive Order 12699?

WHAT IS MITIGATION?

In Unit 1, at the beginning of this course, you read about the devastating effects of the Charleston, South Carolina, earthquake in 1886. That community was totally unprepared for an earthquake striking it. The result was the loss of more than 70 lives, the destruction of 90 percent of the community (buildings, equipment, supplies, personal belongings, etc.) and loss of an unknown amount of income to the community. Unfortunately we have seen many more earthquake disasters since 1886 in the United States and abroad. After each disaster, we have learned a great deal about how to design buildings to resist earthquake forces, how to evaluate the land a building might be built upon and how to plan and build essential buildings so they will remain functional during an earthquake. All of these steps are what we call mitigation.

Mitigation is the set of actions taken to prevent or reduce the risk to life, property, social, and economic activities from natural hazards as earthquakes, floods, and hurricanes. An effective mitigation plan anticipates actions a community must take before a disaster strikes. Planning is one of the most important parts of any mitigation effort. Taking the time up front to make people aware of earthquake risk to their community, making a plan of how to reduce that risk over time and what to do in the event of an earthquake can make a tremendous difference in postdisaster recovery efforts.

There are many different mitigation measures a community can take; we already have mentioned education and planning. A community also can adopt zoning regulations and guidelines on land-use practices. In Unit 4 we explored some of the effects the natural environment can have on the built environment. Making sure that new buildings are not constructed on or near land that is subject to liquefaction, landslides, faults, and tsunamis can be an important mitigation step to prevent or reduce loss of life and property. Building codes are one of the most powerful mitigation tools that can be adopted by a community in anticipation of a seismic event. Over and over again, we have seen that the enforcement of effective building codes will save lives and property.

In the next section, we will talk more about the history of building codes and their use today. A community that is concerned about potential loss of life and property damage due to seismic activity should ensure that seismic considerations have been included in their building codes. What do you think the people of Charleston would have said in 1886 if they knew they could rebuild their city to resist earthquake forces and prevent the devastating effects they had just encountered? Would they have used the seismic factors provided for in today's building codes? What about your community? Are you taking advantage of what we have learned since 1886, or are you still waiting to see what might happen tomorrow?

WHY USE BUILDING CODES?

Building codes have been used in the United States for many years, but they were not used specifically to protect communities from potential earthquake damage until the 1930s. During the Long Beach, California, earthquake of 1933, California Congressman C. Don Field witnessed the collapse of buildings, some of which were public school buildings. Because the State required students to attend school until they were 16 years old, Congressman Field believed the State was responsible for their safety. Soon after the earthquake, Field sponsored a State bill requiring all new public schools in California to be designed and constructed to withstand earthquake-generated forces; the new law also mandated that the State Architect check and approve all new school building plans. The Field Act protected public schools so effectively that California passed earthquake legislation for hospitals following the 1971 San Fernando earthquake. The California Hospital Act of 1972 set up standards and regulations similar to those the Field Act mandated for public school buildings.

It was these early efforts that helped show the nation that building codes made a difference in reducing the loss of life and property in the event of an earthquake. The strong effect that building codes can have on reducing a community's seismic risk is the main reason the use of building codes is stressed as a way of meeting the seismic considerations in the NEHRP *Provisions*. The enactment of Executive Order 12699 is a significant Federal Government effort to recognize and encourage the use of building codes to reduce the loss of life and property as a result of seismic activity.

National Model Building Codes

Building codes are established to ensure uniform minimum standards of health and safety across the United States. A building code requires that a building or facility be located, designed, and constructed so that any threat to the life, health, and welfare of its occupants and the public is minimized or prevented.

Builders that use building codes in the United States generally use one of the prominent national model building codes, which have been published by separate private organizations.

Model codes have effectively reduced loss of life and property damage in many communities. However, seismic provisions were not always included in model codes. Seismic provisions established standards for how buildings should be located, designed, and constructed to resist ground motion. The NEHRP *Recommended Provisions for the Development of Seismic Regulations for New Buildings* changed that.

WHAT ARE THE NEHRP *PROVISIONS*?

The Earthquake Hazards Reduction Act of 1970 established NEHRP, a Federal multiagency program that funds research focusing on preventing or reducing loss of life and property damage caused by earthquakes. Based on the collective efforts of engineers, scientists, and tradespeople, the NEHRP *Provisions* encompass all that has been learned over the past 20 years about the responses of buildings to seismic forces and contain seismic design specifications that are technically advanced and widely accepted.

Although the *Provisions* are recommendations for establishing seismic standards and not regulations, the nation's model building codes are based on them. The seismic provisions in the International Building Code (IBC), NFPA 5000 Building Code, and ASCE 7 Design Loads Standard are substantially equivalent to the NEHRP *Provisions*. All communities that adopt the most recent editions of these model codes utilize the most advanced seismic provisions available.

The NEHRP *Provisions* include a number of factors that help engineers, architects, and construction personnel decide what seismic design factors need to be included in a specific building at a specific site. Some of these factors include:

- Seismic forces,
- Seismic hazard maps,
- Seismic Use Groups, and
- Seismic Design Categories.

The following discussions explain each of these factors.

Determining Seismic Forces

For a given location, the nature of ground motion that occurs during an earthquake will depend on several factors, including:

- Magnitude of the earthquake,
- Duration of ground shaking,
- Distance from the epicenter,
- Type of soil (whether the ground is dense or loose), and
- Depth below the surface where the earthquake begins.

The design and construction of a building also affect the forces that are created within it during an earthquake. The following influence a building most:

- Weight or size,
- Shape and proportion,
- Construction materials, and
- Construction quality.

A seismic code must provide a uniform method by which the nature of ground motion at any location may be assessed and a safe, economical building be designed.

Seismic Hazard Maps

As we have discovered in previous units, different States have different levels of hazard and risk from earthquakes. The NEHRP *Provisions* were created with this in mind. They reflect the relative earthquake hazard of regions across the nation and suggest risk-reduction measures tailored to each region's unique level of hazard. The *Provisions* acknowledge that it makes little economical sense to design a building in New York to resist the same earthquake forces as those a building must resist in California. The NEHRP *Provisions* provide two United States maps (shown in Figures 5-1 and 5-2) that contain quantitative measures from which seismic forces on buildings may be determined. These maps were developed from information for each location on:

- Historical seismicity,
- A location's proximity to known faults, and
- Geological investigations that indicate earthquake ground motion is more or less likely than historical seismicity might indicate.

The two maps give, in slightly different form, estimates of horizontal accelerations for any location in the United States. The accelerations for any location are illustrated in the form of contour lines indicating areas of equal acceleration.

The map in Figure 5-1 shows short-period spectral response accelerations for locations throughout the United States, and the other (Figure 5-2) shows long-period spectral response accelerations. Both maps are needed to give the design engineer information on possible ground shaking and intensity characteristics in a particular area. The first map works well for earthquakes of shorter duration, while the second is better for longer duration earthquakes. Both values are important for the design engineer to consider when designing a building.

Seismic Use Groups

Just as they recognize that different regions require different sets of seismic provisions, the NEHRP *Provisions* acknowledge that buildings require various types of protection as well. The NEHRP *Provisions* take into account the relative importance of some buildings over others within a single community. NEHRP developed a system by which buildings are grouped into categories according to the whole community's use of and need for them. For instance, an entire community would need a hospital during a seismic event, and the collapse of a sports arena would affect many more people than a single dwelling.

Seismic Use Groups reflect this relative importance and place buildings in one of three groups—III being the most critical, I the least. This system is intended to ensure that important buildings such as hospitals, fire stations, and police stations and high-occupancy buildings such as schools, auditoriums, hotels, and office buildings are built using higher standards for seismic protection than other buildings.

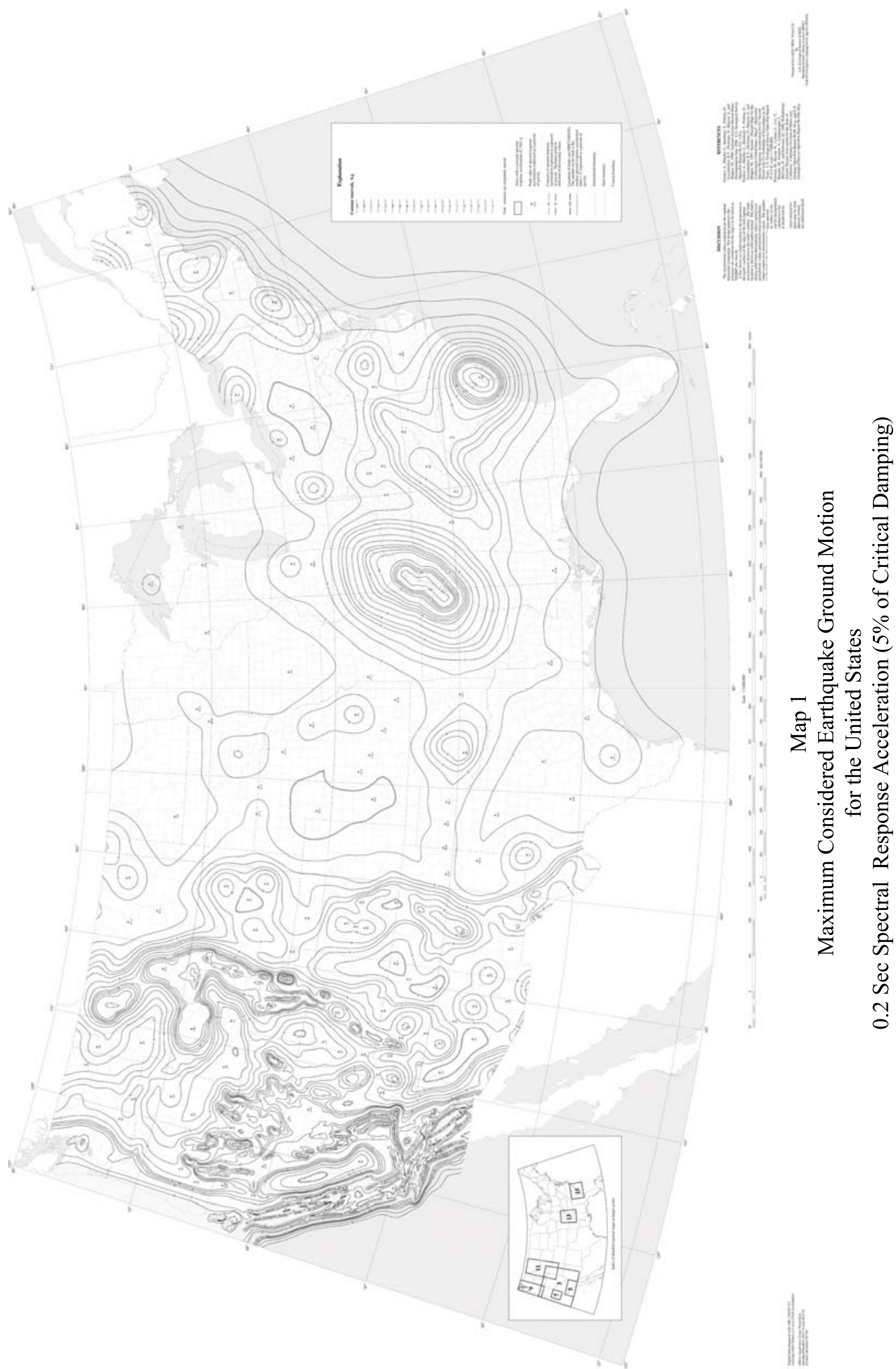


Figure 5-1 *Source: U.S. Geological Survey.*

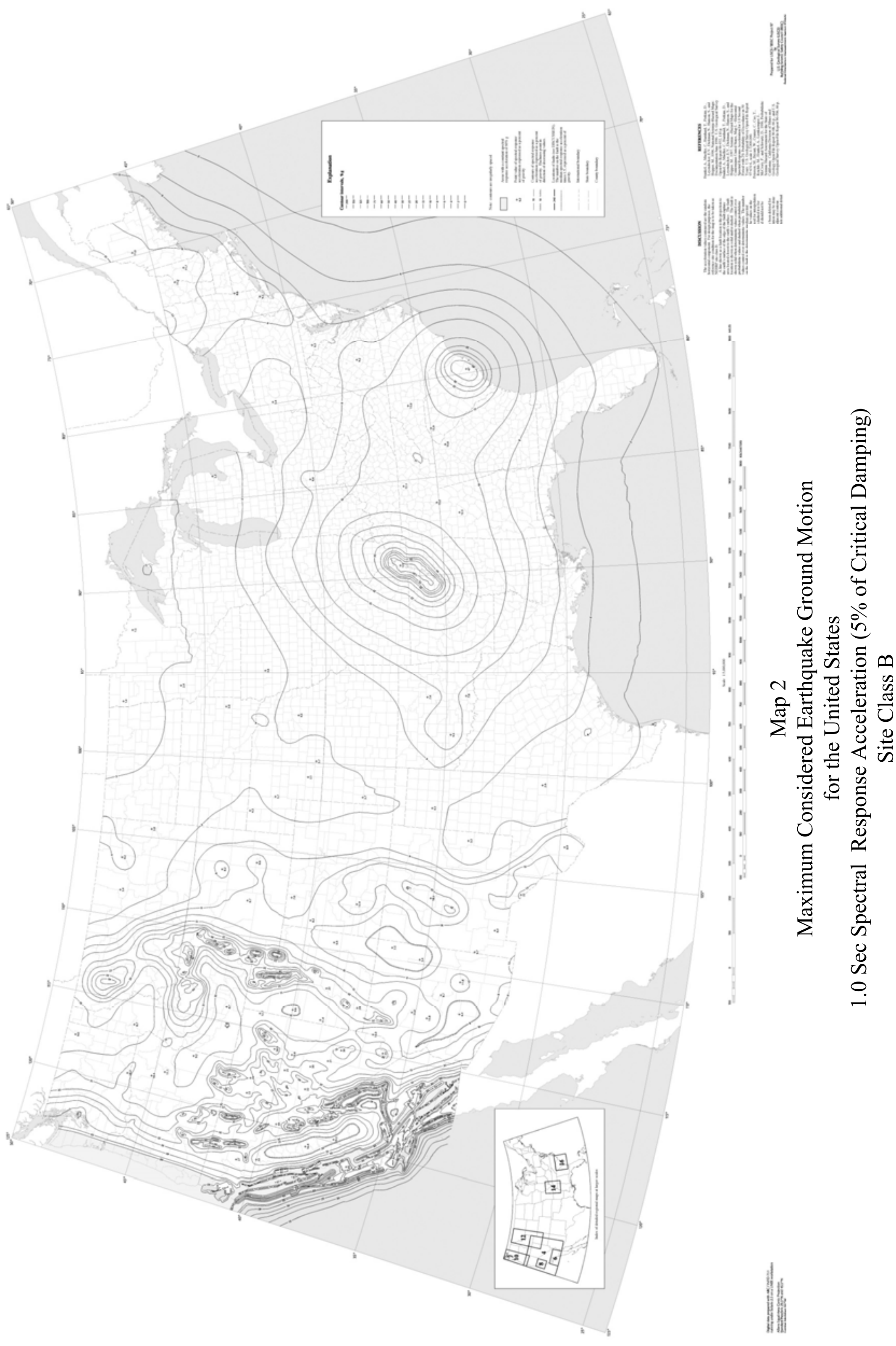


Figure 5-2 *Source: 1991 Edition NEHRP Provisions, Part 2 – Commentary.*

Figure 5-3 shows examples of buildings in each Seismic Use Group:

Which buildings in your community would you add to these Seismic Use Groups?

Seismic Use Group	Sample Buildings
I	One- or two-family dwellings
II	Schools
III	Hospitals, Police Facilities

Figure 5-3

Seismic Design Categories

The *Provisions* also utilize Seismic Design Categories. The Seismic Design Categories consider both a building's hazard and importance in order to determine the category of seismic performance to which it must be designed. A specific building's design category is determined using a table that relates design acceleration (from the Seismic Hazard Map) to a building's Seismic Use Group rating. There are six Seismic Design Categories:

- *Seismic Design Category A* represents structures in regions where anticipated ground motions are minor, even for very long return periods. For such structures, the NEHRP *Provisions* require only that a complete seismic-force-resisting system be provided and that all elements of the structure be tied together. A nominal design force equal to 1 percent of the weight of the structure is used to proportion the lateral system.

- *Seismic Design Category B* includes Seismic Use Group I and II structures in regions of seismicity where only moderately destructive ground shaking is anticipated. In addition to the requirements for Seismic Design Category A, structures in Seismic Design

Category B must be designed for forces determined using NEHRP *Provisions* Maps 1 through 24.

- *Seismic Design Category C* includes Seismic Use Group III structures in regions where moderately destructive ground shaking may occur as well as Seismic Use Group I and II structures in regions with somewhat more severe ground shaking potential. In Seismic Design Category C, the use of some structural systems is limited and some nonstructural components must be specifically designed for seismic resistance.

- *Seismic Design Category D* includes structures of Seismic Use Group I, II, and III located in regions expected to experience destructive ground shaking, but not located very near major active faults. In Seismic Design Category D, severe limits are placed on the use of some structural systems and irregular structures must be subjected to dynamic analysis techniques as part of the design process.

- *Seismic Design Category E* includes Seismic Use Group I and II structures in regions located very close to major active faults and *Seismic Design Category F* includes Seismic Use Group III structures in these locations. Very severe limitations on systems, irregularities, and design methods are specified for Seismic Design Categories E and F. For the purpose of determining whether a structure is located in a region that is very close to a major active fault, the *Provisions* use a trigger of a mapped maximum considered earthquake spectral response acceleration parameter at 1-second period, S_1, of 0.75 or more regardless of the structure's fundamental period. The mapped short-period acceleration, S_S, was not used for this purpose because short-period response accelerations do not tend to be affected by near-source conditions as strongly as do response accelerations at longer periods.

Figures 5-4 and 5-5 express the relationship of an area's seismicity to its Seismic Use Group and Seismic Design Category.

Seismic Design Category Based on S_{DS}

Value of S_{DS}	Seismic Use Group I	Seismic Use Group II	Seismic Use Group III
$S_{DS} < 0.167$	A	A	A
$0.167 \le S_{DS} < 0.33$	B	B	C
$0.33 \le S_{DS} < 0.50$	C	C	D
$0.50 \le S_{DS}$	D[a]	D[a]	D[a]
[a] See footnote to Figure 5-5.			

Figure 5-4 *Source: 2003 NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Table 1.4.1.*

Seismic Design Category Based on S_{DI}

Value of S_{DI}	Seismic Use Group I	Seismic Use Group II	Seismic Use Group III
$S_{DI} < 0.067$	A	A	A
$0.067 \le S_{DI} < 0.133$	B	B	C
$0.133 \le S_{DI} < 0.20$	C	C	D
$0.20 \le S_{DI}$	D[a]	D[a]	D[a]
[a] Seismic Use Group I and II structures located on sites with S_I greater than or equal to 0.75 shall be assigned to Seismic Design Category E, and Seismic Use Group III structures located on such sites shall be assigned to Seismic Design Category F.			

Figure 5-5 *Source: 2003 NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Table 1.4.2.*

Using this information, an essential building, like a hospital, located in an area experiencing severe seismic accelerations would be assigned to Seismic Design Category E or F and, thus, would be subjected to more stringent seismic regulations. Which Design Category would you assign to a low-occupancy building in an area of high seismicity? Answer: Design Category C or D.

The NEHRP *Provisions* have provided builders with the seismic guidance needed to build seismically safe, economical buildings. These provisions have been adopted by the model building codes—so that the most recent edition of each model building code now contains seismic provisions that can be applied to all construction done in the United States.

WHAT DO BUILDING CODES HAVE TO DO WITH EXECUTIVE ORDER 12699?

Since 1977, the Federal Government actively has sought ways to decrease the seismic risk to communities throughout our nation. As research on seismic risk reduction has developed, it has become clear that one of the most important factors affecting a community is the quality of the built environment. Time and time again, post-disaster studies have shown that new construction incorporating seismic design features decreases the structural damage done to a community and saves lives.

Saving lives and property is the main purpose of Executive Order 12699. The Executive Order was drafted to "reduce the risks to the lives of occupants of buildings owned, leased, assisted, and regulated by the Federal Government and to reduce risks to the lives of persons who would be affected by earthquake failures of Federal buildings and to protect public investments, all in a cost-effective manner."

Executive Order 12699 is a wide-reaching order that affects any State and local government and any private institution that is involved with buildings assisted, leased, or regulated by the Federal Government. It requires that all new construction be built according to the seismic standards outlined in the NEHRP *Provisions*. As we noted earlier in this unit, the NEHRP *Provisions* have been incorporated into national model building codes used in the United States. That means that any community that adopts an up-to-date model building code that includes all NEHRP seismic provisions will meet the Executive Order requirements. Any community that hopes to continue receiving Federal funds for new construction that is assisted, leased, or regulated by the Federal Government must be concerned with complying with Executive Order 12699.

In Unit 2, we discussed many of the ways a community can be affected by this order. Your community's local government officials, architects, lenders, land-use officials, engineers, construction personnel, building-code officials, and many others all will be responsible for making sure they comply with the Executive Order. Though this sounds like a big task, it can be as easy as making sure your community consistently uses one of the most recent model building codes with all its seismic provisions. In the next unit, we will explore what your community can do to comply with Executive Order 12699.

UNIT 5 - SUMMARY

This unit explored some of the steps a community can take to protect itself from earthquakes. The following questions were discussed:

- What is mitigation?
- Why use building codes?
  - Model building codes
- What are the NEHRP *Provisions*?
  - Determining seismic forces
  - Seismic hazard maps
  - Seismic Use Groups
  - Seismic Design Categories
- What do building codes have to do with Executive Order 12699?

Unit 5

Protecting Your Community

Unit Review

Directions: For each question, circle the letter of the correct response and check your answers with the Answer Guide at the end of the unit.

1. Which of the following is **not** part of effective mitigation planning?

   a. Earthquake prediction
   b. Adopting zoning regulations
   c. Developing land-use guidelines
   d. Adopting building codes

2. In 1933, Congressman C. Don Field set a precedent for building codes by sponsoring a State bill that required all new _____________ in California to be designed and constructed to withstand earthquake-generated forces.

   a. hospitals
   b. State office buildings
   c. public schools
   d. all public buildings

3. The NEHRP *Provisions* assign every building to one of three Seismic Use Groups based on:

   a. location, design, and construction of the building.
   b. importance of the building and how heavily occupied it is.
   c. age of the building.
   d. history of earthquake damage to the building.

4. A building's Seismic Design Category is based on a combination of its Seismic Use Group and an area's:

   a. climate.
   b. geological formations and vegetation.

c. importance.
d. seismicity.

Unit 5

Protecting Your Community

Unit Review - Answer Guide

1. Which of the following is **not** part of effective mitigation planning?

   a. Earthquake prediction
   Reference: p. 5-2

2. In 1933, Congressman C. Don Field set a precedent for building codes by sponsoring a State bill that required all new _____________ in California to be designed and constructed to withstand earthquake-generated forces.

   c. public schools
   Reference: p. 5-3

3. The NEHRP *Provisions* assign every building to one of three Seismic Use Groups based on:

   b. importance of the building and how heavily occupied it is.
   Reference: p. 5-6

4. A building's Seismic Design Category is based on a combination of its Seismic Use Group and an area's:

   d. seismicity.
   Reference: pp. 5-9 to 5-11

Unit 6

Evaluating Your Community's Safety

INTRODUCTION

Knowledge of earthquakes, earthquake forces, and improved building techniques has expanded rapidly over the past 20 years. In this course we have learned many techniques that can be used by communities to help protect themselves from the loss of life and damage due to seismic forces. The latest editions of the national model building codes incorporate all of this information and knowledge, and are substantially equivalent to the NEHRP *Provisions*. We know that a community can reduce its seismic risks if it adopts and enforces model building codes that include seismic provisions. Is your community doing all that it can to reduce its seismic risk?

Unit 6 answers the following questions:

- Do your community's local building codes comply with Executive Order 12699?
- How should your community go about adopting a model code?

DO YOUR COMMUNITY'S LOCAL BUILDING CODES COMPLY WITH EXECUTIVE ORDER 12699?

Federal agencies offering home loan guarantees, loans, and grants to States and counties for public buildings and construction of federally owned buildings are instructed by Executive Order 12699 to use local standards (or building codes) where appropriate codes are available. Besides increasing the safety of people and property, complying with Executive Order 12699 will allow your community to obtain Federal money for new construction. If your community uses the seismic provisions in the latest edition of a national model building code, you probably are already in compliance with the Executive Order.

Adopted in its entirety, a national model building code will include seismic provisions that cover all the requirements specified by the Order.

One of the keys to compliance is the use of a national model building code along with its seismic provisions. Adopting and enforcing a model building code makes it very easy for your community to show that it is in compliance with Executive Order 12699. Everyone who receives

Federal grants, or federally assisted or guaranteed financing for new building construction, must be in compliance with the Executive Order. To find out if your community is in compliance with Executive Order 12699, you will need to know the answers to the questions listed in Figure 6-1 below.

ARE YOU IN COMPLIANCE?

- Which model code does your community use?
- Which edition currently is adopted?
- Does it have seismic provisions?
- Have the seismic provisions been modified?

Figure 6-1

Which Building Code Is Your Community Using?

As we have noted already, if your community is presently using a current version of a national model code that includes all the current seismic provisions, your community's building standards meet the requirements of Executive Order 12699.

But if your community's building code is:

- Not based on one of the national model codes, or
- Not current, or
- Adopted without seismic provisions . . .

members of your community may encounter delays or extra costs when applying for Federal grants or assistance. Each agency will set up its own criteria, standards, and procedures for determining if a building code satisfies its program requirements. Or they could require the applicant (your community) to certify that the code is equivalent. Whatever the case, this can be a long and tiresome process. If a Federal agency is looking for a site for new construction, this additional step in the process might cause the agency to look for a new community that already has a model building code in place. Loan and grant-giving agencies simply may not process applications until compliance can be verified. Can your community afford to wait for these loans?

What Should You Do If Your Community Doesn't Have Adequate Seismic Provisions?

If your community does not have adequate seismic provisions, then to continue receiving Federal monies for new construction you will need to put in place:

- One of the national model building codes, with seismic provisions substantially equivalent to the NEHRP *Provisions*, or
- A building code with seismic provisions substantially equivalent to the NEHRP *Provisions*.

Preparing a building code to meet the Executive Order's requirements can be a long and technically difficult task involving a lot of people and money. Chances are that your community would not have the money, time, or expertise needed to develop an original building code.

Therefore, the easiest route for your community to take is to adopt a national model code with all seismic provisions.

National model codes already have been determined to meet the Executive Order's requirements. In fact, public debate over technical details already has been conducted at a national level. Adopting a model code also means there is no need for drafting an ordinance or conducting a legal review. Furthermore, the model code groups have worked very hard to prepare materials and support services for communities wishing to adopt their model code. These organizations can lead your community through the steps required to adopt their code and comply with Executive Order 12699.

The flow chart in Figure 6-2 on the following page shows a summary of the questions and action steps your community will need to take to ensure compliance with Executive Order 12699.

HOW SHOULD YOUR COMMUNITY GO ABOUT ADOPTING A MODEL CODE?

The national model code organizations make it very easy for a community to adopt their codes. Each organization can give a community a sample ordinance that they can adopt or revise to fit local building conditions. They also can provide community officials with assistance during the adoption process.

Though a model building code can be modified to fit local conditions, any modifications must be done very carefully to ensure that a revision in one section does not interfere with another section's requirements. To meet Executive Order 12699's requirements, the seismic component of the model code must be substantially equivalent to the most recent, or immediately preceding, version of the NEHRP *Provisions*.

It also is essential to establish a process for *updating* your community's code on a regular basis. That way, when the model code organization issues a provision, there is a clear cut process for updating your building code. Some communities include a provision in the ordinance that automatically updates the building code to the newest version when it is released.

The NEHRP *Provisions* and the national model building codes are periodically updated to ensure that the lessons learned from earthquakes are incorporated so that seismic risk reduction techniques can improve over time.

If your community already has adopted a model building code that is not up-to-date, you may need only to update your code by adopting the most recent version and the seismic provisions.

What Is Your Community’s Adoption Process?

Each community will vary in its specific adoption procedures. However, most communities follow a similar process. Once an ordinance calling for adoption of a building code is introduced, it usually is assigned to a committee that conducts a public hearing. Supporters of the ordinance must present clear and concise arguments showing why the ordinance is necessary. If the committee recommends the ordinance be passed, the ordinance is brought before the governing body for debate. Once adopted, an ordinance becomes effective after publication of an official notice. Finally, it is assigned to a department for implementation and enforcement.

You can see from this brief description of the adoption process how important public support can be to the success of the adoption efforts. Many people must be convinced that adopting a new building code will benefit the community. In Unit 2 you made a list of community leaders that need to know about Executive Order 12699. These same leaders must be strong supporters of adopting a model code and be able to convince others of its necessity.

Figure 6-3 contains some common arguments you may encounter and responses you can use to support adoption of seismic provisions.

Building Code Enforcement

Building code adoption is a community’s essential first step toward seismic safety and compliance with Executive Order 12699. However, enforcement of building codes is also essential if the community is to benefit from their adoption. The enforcement process varies from

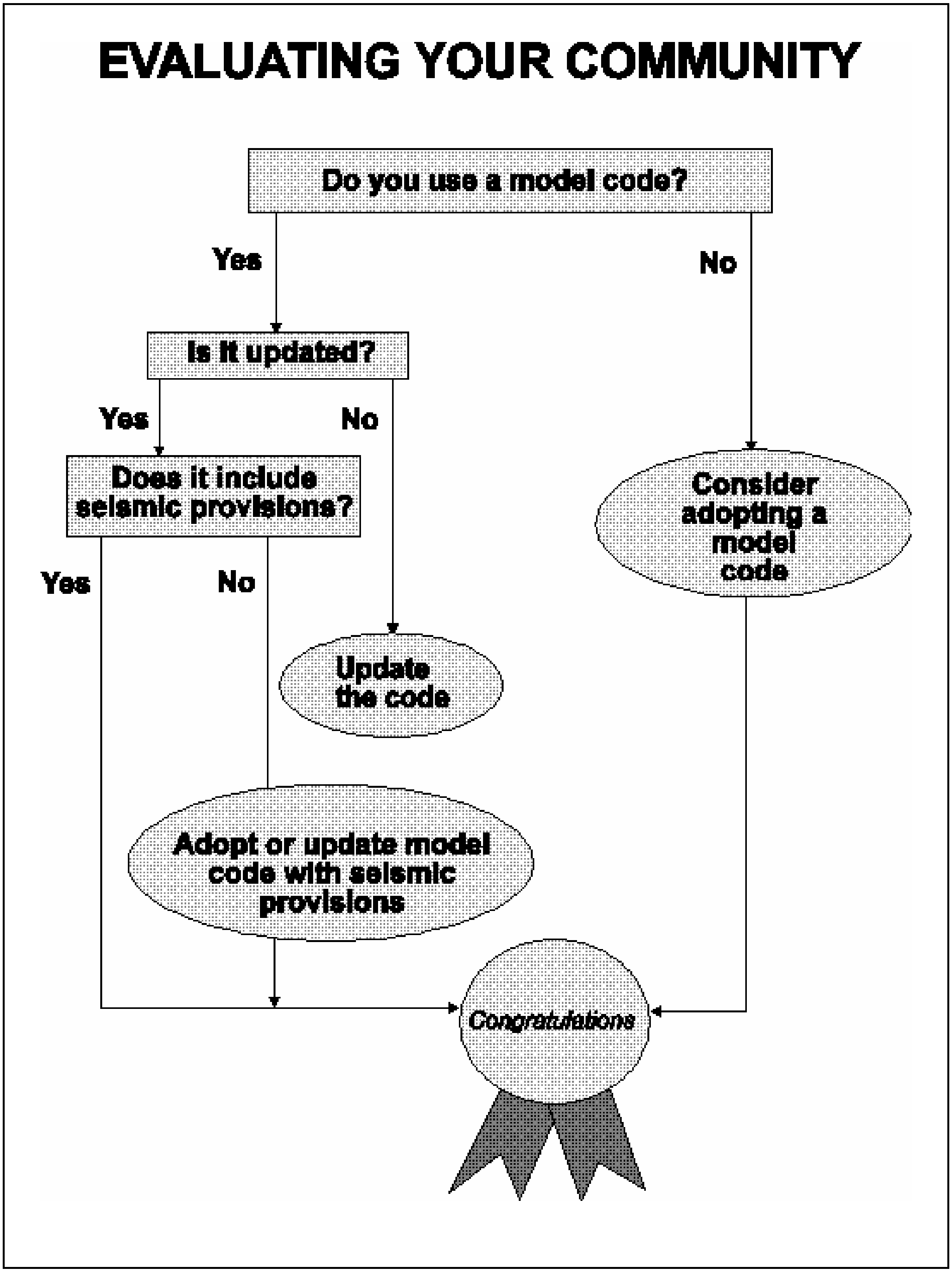

EVALUATING YOUR COMMUNITY
Do you use a model code?
Yes
No
Is it updated?
Yes
No
Does it include seismic provisions?
Yes
No
Consider adopting a model code
Update the code
Adopt or update model code with seismic provisions
Congratulations

Figure 6-2

State to State. Either the State government or local government is the enforcement authority, but the process is generally the same. There are usually two steps: (a) plan review and (b) construction inspection.

Plan review involves requiring the builder to submit building plans to the local or State building department for review and approval. The building department can approve, require revisions, or reject the plans based on the plan's conformance with the building code. The building department does not issue a permit to begin construction until the plans conform to the building code.

The building department also periodically inspects the construction in progress. The inspections coincide with prescribed stages in the construction. If the inspector discovers a code violation, a stop work order is issued and construction is halted. The order remains in effect until the violation is corrected and a reinspection verifies the correction. Upon successful completion of the final inspection for habitability, an occupancy certificate is issued to the builder.

The construction permit, the stop work order, and the occupancy certificate are the principal enforcement tools of the building department. Code violations occur for a variety of reasons, such as lack of knowledge about applying the codes or poor construction practices. The three model code groups can provide information and training in applying building codes.

UNIT 6 - SUMMARY

This unit explored ways your community can ensure its compliance with Executive Order 12699. In this unit we examined the following questions:

- Do your community's local building codes comply with Executive Order 12699?
    - Which building code is your community using?
    - What should you do if your community doesn't have adequate seismic provisions?
- How should your community go about adopting a model code?

- What is your community’s adoption process?

ARGUMENTS AND RESPONSES

Argument: "Seismic codes will burden our business."

Response: Codes won't hurt business—most States and almost 95 percent of all cities and towns in the United States already use building codes. There is no evidence that businesses have suffered in these States and cities, and there is little reason to believe that others will.

Argument: "What will seismic provisions really do for us, anyway?"

Response: A seismic code will save lives. Buildings designed and constructed in accordance with up-to-date seismic provisions are less likely to collapse and kill or injure people during an earthquake. Building codes work. Compare the result of the earthquake in Armenia in 1988 with the earthquake in California in 1989.

Argument: "We shouldn't spend any extra money if we are not going to profit from it."

Response: There are economic benefits to adopting a seismic code. Adopting the most recent version of a national model building code will make it easier for local governments to qualify for Federal loans and grants, for citizens to qualify for federally insured new home loans, and for small business loans for new construction. Executive Order 12699 requires that new building construction even partially financed with Federal grants or federally insured loans must meet existing seismic safety standards. It is easiest to comply with the Executive Order if local building codes already are equivalent to existing seismic standards, as defined by NEHRP *Recommended Provisions for Seismic Safety in New Buildings*. Project developers could incur additional consulting and design costs, as well as project delays, if local codes are insufficient to meet the NEHRP *Provisions*. Individual Federal agencies administering grant and loan programs set the guidelines for compliance with the Executive Order. The Executive Order encourages Federal agencies to use local building codes if they are substantially equivalent to the current NEHRP *Provisions*.

Figure 6-3

Argument: "It is too hard to develop seismic codes; we don't know how."

Response: It's easy. Communities can use the NEHRP *Provisions* and national model building codes to frame their own building codes. Besides, it is much easier to adopt seismic provisions and prepare a community than to endure a long recovery period.

Argument: "We don't have earthquakes; we have floods (or tornadoes, etc.). Why prepare for earthquakes?"

Response: The risk from earthquakes is more widespread and immediate than many people think—more than 40 of the 50 States have a moderate or higher earthquake hazard. The Northeast suffered significant earthquakes in the 17th century; the central United States suffered the worst known series of earthquakes in U.S. history in 1811 and 1812; Charleston, South Carolina suffered a devastating earthquake in 1886 that killed 60 people. Geologically speaking, these are recent events, which will very probably occur again. In the cases of Northeast and Charleston, scientists cannot determine the precise cause of the quakes. Both of these areas, like most of the rest of the United States, continue to experience small earthquakes that confirm these areas to be seismically active. Also, buildings constructed to resist damage from earthquakes will suffer less damage from most other natural hazards.

Argument: "Why should we build for earthquakes and incur the expenses if one is not likely to occur?"

Response: All communities need a seismic code regardless of the level of hazard. The NEHRP *Provisions* acknowledge that different communities have different levels of hazard. Building codes are designed to accommodate the probable ground shaking in any given geographic area of the United States. For example, applying the same model building code, a residence built in California would have greater structural seismic reinforcement requirements than a similar residence built in Florida.

Argument: (An elected official): "I don't think an earthquake will happen while I am in office. Let someone else worry about developing building codes with seismic provisions."

Response: A damaging earthquake can occur anytime, and there is plenty of evidence to support this. Nearly 75 percent of the nation has a history of earthquakes. The Federal Government has set a standard requirement with Executive Order 12699 for an effective Federal safety program. A recommended standard for seismic safety also has been developed by NEHRP. It is up to States and local governments to implement the standard through the adoption of the model building codes. Letting "someone else" worry about earthquakes and delaying the adoption of model building codes perpetuates the construction of unsafe buildings. Allowing buildings to be constructed without seismic provisions while you are in office means that they are more likely to collapse and cause deaths and injuries during a future earthquake. Adopting a model building code, with its seismic provisions, will begin a legacy of building safety that will be a credit to your public service.

Figure 6-3 *continued*

Unit 6

Evaluating Your Community's Safety

Unit Review

Directions: For each question, circle the letter of the correct response and check your answers with the Answer Guide at the end of the unit.

1. What is the clearest indication that your community can meet the requirements of the Executive Order 12699?

   a. An earthquake occurred in recent years causing no injuries and little damage.
   b. Scientists say that your community is at low risk for earthquakes.
   c. The community has adopted a recent version of one of the model building codes, including its seismic provisions.
   d. The community has had building codes in effect for many years, so most buildings have been built to be safe.

2. Besides adopting a model code, what is another way a community might comply with the Executive Order?

   a. They can have their community evaluated for seismic safety.
   b. They may update the model code they are using to a more recent version that includes seismic provisions.
   c. They can forbid any new construction in the community.
   d. There are no other options.

3. If you do not have a building code with seismic provisions, which of the following questions should you consider?

   a. Can we update our existing building code to include seismic provisions?
   b. Can we adopt a recent model building code including its seismic provisions?
   c. Should we develop our own building code and seismic provisions?

d. all of the above.

4. To mount a campaign aimed at getting your community to adopt a new building code with seismic provisions, start by talking with:

a. professional and labor organizations that may be affected.
b. local government officials who would be involved in decisionmaking.
c. individual business owners in the building community.
d. all of the above.

5. What are some common questions or concerns people might have about adopting a model code with seismic provisions?

a. The increased costs associated with seismic codes will burden our business.
b. Providing for earthquake preparedness will increase building costs substantially.
c. We don’t have earthquakes; we have floods. Why prepare for earthquakes?
d. Why should we build for earthquakes and incur the expense if one is not likely to occur?
e. all of the above.

Unit 6

Evaluating Your Community's Safety

Unit Review - Answer Guide

1. What is the clearest indication that your community can meet the requirements of Executive Order 12699?

   c. The community has adopted a recent version of one of the model building codes, including its seismic provisions.
   Reference: p. 6-2

2. Besides adopting a model code, what is another way a community might comply with the Executive Order?

   b. They may update the model code they are using to a more recent version that includes seismic provisions.
   Reference: p. 6-6

3. If you do not have a building code with seismic provisions, which of the following questions should you consider?

   d. all of the above.
   Reference: pp. 6-3 and 6-4

4. To mount a campaign aimed at getting your community to adopt a new building code with seismic provisions, start by talking with:

   d. all of the above.
   Reference: p. 6-5, Unit 2

5. What are some common questions or concerns people might have about adopting a model code with seismic provisions?

   e. all of the above.
   Reference: pp. 6-8 and 6-9

Unit 7

Conclusions

COURSE REVIEW

The purpose of Executive Order 12699 is to prepare the nation to better withstand the force of an earthquake. The Order accomplishes this goal by requiring minimum standards for the seismic safety of federally owned, assisted, or regulated new buildings—standards which, once implemented, can reduce the risk of injury, loss of life, and devastation to buildings and other structures. This requirement is expected to compel jurisdictions to adopt building codes with appropriate seismic components.

HISTORY OF EARTHQUAKES IN THE UNITED STATES

In Unit 1, we learned that major earthquakes have occurred in such disparate locations as New Mexico, South Carolina, Missouri, Utah, and Massachusetts. This means that States well known for earthquake activity are not the only ones experiencing significant levels of seismic hazard. Furthermore, increased population and construction in these and other areas mean that an earthquake of a force similar to that of earthquakes in the past would present much greater risk to human life and property today.

Although the region in which you live may not have experienced seismic activity in the recent past, your community must not ignore the need to take steps to reduce the risk of damage from seismic activity. Post-disaster studies have shown that community investment in mitigation efforts like the adoption of building codes, zoning regulations, and land-use practices pay direct dividends.

Executive Order 12699

Unit 2 presented the history and intent of Executive Order 12699. The first piece of Federal earthquake hazard mitigation legislation enacted by Congress was the Earthquake Hazards Reduction Act of 1977, which established the National Earthquake Hazards Reduction Program (NEHRP). NEHRP was created to focus on:

- Design and construction methods for earthquake resistant structures;
- Earthquake prediction;
- Model building codes;
- Education of the public, State and local officials, and private industry; and
- Research in earthquake hazard mitigation and earthquake insurance.

Recommended Provisions for the Development of Seismic Regulations for New Buildings, a report produced by NEHRP, presents a national approach to seismic design. In 1980, the Interagency Committee on Seismic Safety in Construction (ICSSC) began to encourage Federal agencies to adopt the provisions set forth by NEHRP. Toward this end, ICSSC drafted Executive Order 12699.

In its final form, Executive Order 12699 contains procedures and regulations for ensuring the structural safety of newly constructed buildings and new additions to buildings that are Federally owned, purchased or constructed with Federal assistance, or leased for Federal use. The Order also applies to Federally assisted reconstruction of buildings following disasters. The minimum standards set forth in Executive Order 12699 are the standards and practices of NEHRP.

Anyone involved in new construction that is subject to the Order must know and use the seismic provisions in your community's building code. These individuals include State and local decisionmakers, architects, lenders, zoning and land-use officials, engineers and construction personnel, and building code officials.

Causes of Earthquakes

In Unit 3 of this course, we discussed the causes and characteristics of earthquakes. Widely accepted plate tectonics theory holds that the earth once was covered by a single crust, or plate and that over time this plate split and drifted into separate plates of land masses and oceans. Any movement of these plates—whether toward, away, or past one another—can cause an earthquake. Maps of earthquakes throughout the world show that earthquakes most frequently occur at the boundaries of plates. Plate movement can create tremendous stress on rock, causing it to fracture so that the rock mass on either side of the fracture moves. This fracture is called a fault. If there is a sudden rupture and movement of rock along a fault line, an earthquake will result.

The shaking we experience during an earthquake is caused by seismic waves moving from the center of the earthquake out to other parts of the earth. There are two main categories of seismic waves:

- *Body waves* travel through the earth *below* and *on* the surface. Scientists use body waves to find the epicenter of an earthquake.

- *Surface waves* travel on the surface only and cause the greatest amount of damage.

Within these categories there are subcategories of seismic waves, which cause different types of damage. Because the composition of the soil and topography of an area will affect the intensity of seismic waves, you should consider these when developing your earthquake mitigation plan. Two scales frequently are used to measure earthquakes:

- The *Modified Mercalli Intensity Scale* measures the intensity or impact of an earthquake on people and the built environment.

- The *Richter Scale* measures the amount of energy released by an earthquake, or its magnitude.

Measures in addition to intensity and magnitude are needed to predict how an earthquake might affect structures in a community. Buildings constructed according to estimates of how fast, how long, and how much the ground moves during an earthquake will sustain far less damage.

Seismic risk maps are another important tool for constructing seismically safe buildings. Designers use them to determine an area's relative level of seismic activity. The NEHRP *Provisions* and the three national model building codes include these maps.

Effects of Earthquakes

In Unit 4, we learned about the effects earthquakes can have on the natural and built environments. The vibrations of seismic waves produce several different effects on the natural environment, which in turn can cause tremendous additional damage to the built environment:

- Liquefaction,
- Landslides,
- Faults,
- Tsunamis, and
- Seiche.

Communities should give careful consideration to location before starting to build, particularly avoiding known faults or sites that are subject to or can be affected by a landslide.

Unit 4 also addressed the characteristics of buildings that affect performance during an earthquake and talked about how buildings can be designed to resist earthquake forces. Designers must determine how a building's period, configuration, story design, and propensity to drift and the rigidity or ductility of the materials with which it is built will affect the structure during an earthquake.

Period

The period, or rate at which a building sways back and forth, influences how a building will react to an earthquake. If a seismic wave causes the ground to move with the same period as a building

on the ground, their vibrations are magnified, causing greater stress on the building. Buildings can be designed using partitions, ceilings, and exterior walls to dampen a building's vibration.

Ductility

Buildings made of ductile (flexible) materials such as steel are less likely to collapse during an earthquake than buildings made of concrete. Problems also can occur during an earthquake if a building is made of a combination of rigid and flexible materials. This happens because earthquake forces focus on the stiffer elements of a building and cause them to fail abruptly and shatter. To avoid this, buildings should be constructed of elements having the same level of flexibility.

Drift

Drift is the extent to which a building sways. We normally do not think of a building as swaying, but earthquake forces can cause it to do so. A high level of drift (bending or swaying) can cause a building to bump into the building next to it. Limits often are imposed on ductility so a building will not be *so* flexible that drift resulting from earthquakes does not cause one building to damage another.

Configuration

In general, a building with a symmetrical design and balanced resistance will best resist an earthquake. T-, H-, and L-shaped buildings will experience increased stress at the point where the wings of the building meet and incur damage during an earthquake. Symmetrical buildings with nonsymmetrical elements, such as ceilings and walls, also may incur major damage during an earthquake.

Soft-story

Buildings with stiff upper stories and open, flexible first stories also are likely to be damaged in an earthquake. An example of this type of building is an office building in which the first floor is a parking garage.

Earthquake-Resistant Construction Methods

During an earthquake, a building is subjected to the horizontal forces created by ground motion, as well as the normal vertical forces of gravity. Three horizontal bracing systems can be used to resist earthquake forces:

- Shear wall systems,
- Braced frame systems, and
- Moment-resistant systems.

Sometimes it is advantageous to use a combination of a moment-resistant frame and a shear wall or braced frame, called a dual system. Seismic safety, cost, and architecture all play a part in a designer's choice of methods.

In addition to the risk of direct harm to people and the built environment, several secondary hazards from earthquakes exist. The secondary effects of earthquake-induced fires, hazardous material spills, and breakdowns in utility lifelines can cause extensive damage and loss of life. Taking steps to prepare your community before an earthquake strikes can save lives and prevent or reduce property damage from these effects.

Protecting Your Community

Unit 5 provided information on how you can ensure that earthquake mitigation planning is taking place in your community. Use of one of the major building codes is a tremendous help to a community's mitigation efforts.

A building code requires that a building or facility be located, designed, and constructed so that any threat to the life, health, and welfare of its occupants and the public is minimized or prevented. The seismic provisions in the national model codes are substantially equivalent to the NEHRP *Provisions*. If your community adopts the most recent editions of one of these codes, including its seismic provisions, you will be utilizing the most advanced seismic provisions available.

The seismic forces created within a building during an earthquake depend on the nature of the ground motion, as well as the design and construction of the building. Builders use seismic hazard maps developed using historical seismicity, proximity to known faults, and geological information to determine a likely level of seismic risk for their communities. This information helps them to determine how to design and construct safe buildings economically.

In addition to the seismic hazard level in a particular location, mitigation planners also take into account the relative importance of some buildings and their occupancy rate over others in a specific community. Buildings like hospitals and police departments, which are needed particularly following an earthquake, or high-occupancy buildings like schools, hotels, and office buildings are built using higher standards for seismic protection than others. The NEHRP *Provisions* divide buildings into three Seismic Use Groups that are subject to different provisions.

The *Provisions* go one step further and combine the Seismic Use Group assigned to a building with the seismicity of the location of the building to put it in a Seismic Design Category. The six Seismic Design Categories defined in the *Provisions* provide communities with guidance on enforcing seismic safety standards for various buildings within their community.

Evaluating Your Community's Safety

Unit 6 of this course addressed evaluation of your community’s level of seismic safety.

The best way to protect your community and, at the same time, comply with Executive Order 12699 is to adopt a national model building code with its seismic provisions. Any version of a model building code adopted in its entirety will include seismic provisions that cover all the requirements listed in the Executive Order.

Figure 7-1 shows a summary of action steps your community will need to take to ensure compliance with Executive Order 12699.

The model building code organizations make it easy to adopt a code by providing a sample ordinance and assistance during the adoption process. In those communities that have already adopted a model code, but an earlier version (not the latest version that contain seismic provisions), need only *update* their code to include the provisions. Each community should be sure to provide updating procedures within its building code administration steps.

No matter what the building code adoption process is in your community you will have to convince key decision-makers that adopting a building code with seismic provisions is the best step to take to secure the community's safety and compliance with the Executive Order. Being prepared with answers to likely questions and concerns is an important step in building public support for adopting or updating your community's building code.

COURSE SUMMARY

The purpose of the Executive Order 12699 is to reduce risk to the lives of occupants of buildings owned, leased, assisted, or regulated by the Federal Government and to persons who would be affected by the failures of Federal buildings in earthquakes; to improve the essential Federal buildings so they can function during or after an earthquake; and to reduce earthquake losses of public buildings and investments in a cost-effective manner. While it is clear that the Federal community must prepare procedures and regulations necessary to comply with Executive Order 12699, it is not as clear how this Order affects others.

Several units in this course provided you with background information on earthquakes and their effects. The most important point of this course is that earthquake effects can be lessened with the use of seismic components of building codes. The three model building codes used throughout the United States will protect a community by reducing its seismic risk and, at the same time, allow communities to comply with Executive Order 12699 so they can receive Federal funds and new Federal business.

Finally, a series of questions is provided to help evaluate your community for seismic safety and compliance with Executive Order 12699. The best and easiest way to protect your community, comply with Executive Order 12699, and continue to receive Federal funds, loans, and grants is to adopt and enforce the seismic components of a model building code.

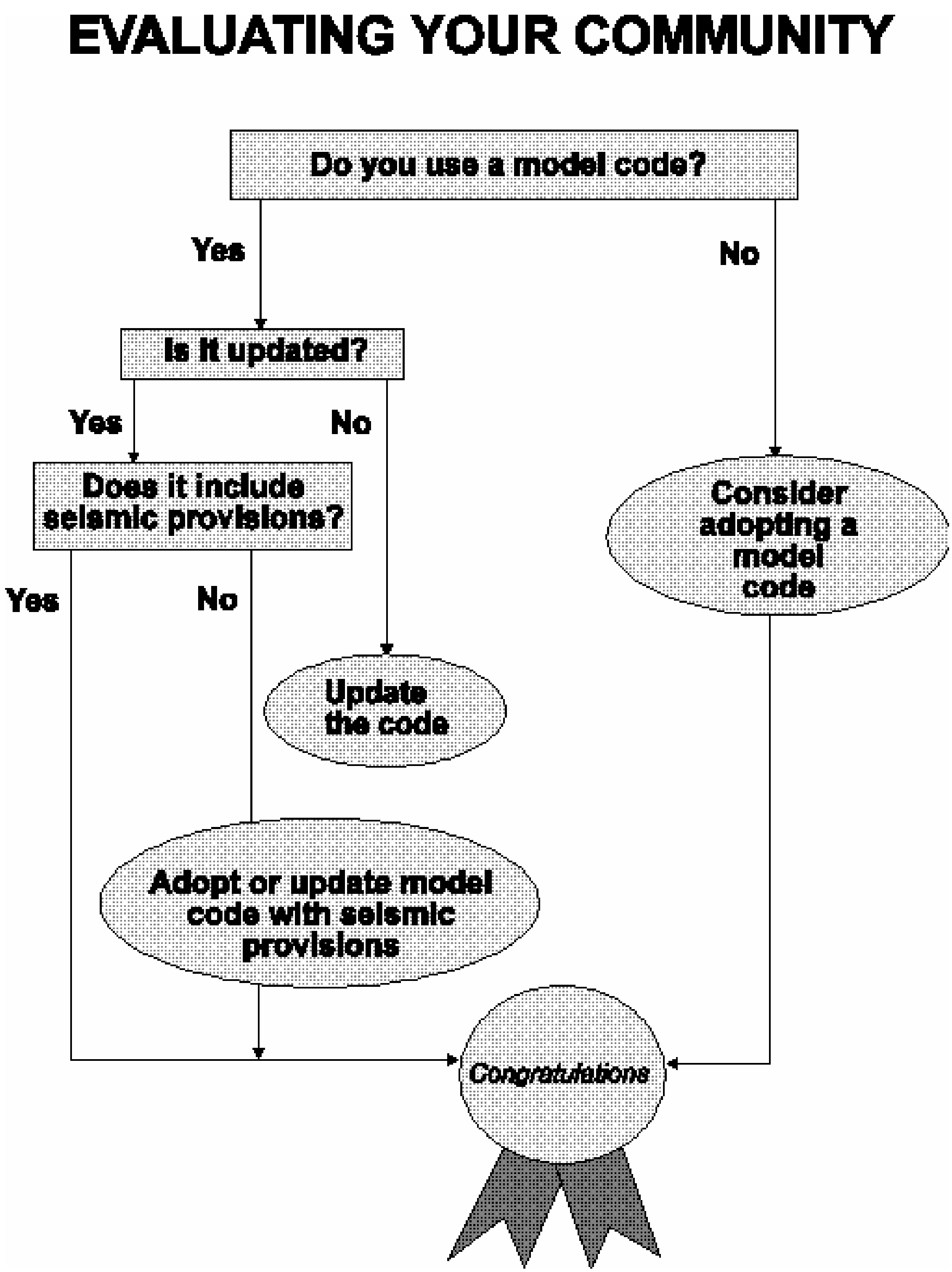

EVALUATING YOUR COMMUNITY
Do you use a model code?
Yes
No
Is it updated?
Yes
No
Does it include seismic provisions?
Yes
No
Consider adopting a model code
Update the code
Adopt or update model code with seismic provisions
Congratulations

Figure 7-1

APPENDIX A

Major Earthquakes in the United States, Mexico, and Canada, 1700-2004

Source: U.S. Geological Survey

Year	Date	Time[1]	Place	Magnitude[2]
1700	January 26	NA[3]	Cascadia subduction zone	~9
1811	December 16	08:00	New Madrid, MO	~8.1
1812	January 23	15:00	New Madrid, MO	~7.8
1812	February 7	09:45	New Madrid, MO	~8
1823	June 2	08:00	South flank of Kilauea, HI	~7
1836	June 10	15:30	South San Francisco Bay region, CA	~6.5
1838	June	NA[3]	San Francisco Peninsula, CA	~6.8
1843	January 5	02:45	Marked Tree, AZ	~6.3
1857	January 9	16:24	Fort Tejon, CA	~7.9
1865	October 8	20:46	San Jose, CA	~6.5
1868	April 3	02:25	Hilea, southeast Hawaii, HI	~7.9
1868	October 21	15:53	Hayward, CA	~6.8
1871	February 20	08:42	Molokai, HI	~6.8
1872	March 26	10:30	Owens Valley, CA	~7.4
1872	December 15	05:40	North Cascades, WA	~7.3
1873	November 23	05:00	California-Oregon coast	~7.3
1886	August 31	02:51	Charleston, SC	~7.3
1890	April 24	11:36	Corralitos, CA	~6.3
1892	April 19	10:50	Vacaville, CA	~6.4
1892	April 21	17:43	Winters, CA	~6.4
1895	October 31	11:08	Charleston, MO	~6.6
1897	June 20	20:14	Calaveras fault, CA	~6.3
1898	March 31	07:43	Mare Island, CA	~6.3
1898	April 15	07:07	Mendocino County, CA	~6.8
1899	September 4	00:22	Cape Yakataga, AK	7.9
1899	September 10	21:41	Yakutat Bay, AK	8.0
1900	October 9	12:28	Kodiak Island, AK	7.7
1901	March 3	7:45	Parkfield, CA	6.4
1904	August 27	21:56	Fairbanks, AK	7.3
1906	April 18	13:12	San Francisco, CA	7.8

[1]Greenwich Mean Time (GMT) *Source: U.S. Geological Survey*

[2]Earthquake magnitude as measured on the Richter Scale, which quantifies the ground motion and energy released at the source of the earthquake. Information about measuring earthquakes with the Richter Scale and the Modified Mercalli Intensity Scale is found in Unit 3.

[3]Not Available

Year	Date	Time[1]	Place	Magnitude[2]
1911	July 1	22:00	Calaveras fault, CA	6.5
1915	October 3	06:52	Pleasant Valley, NV	7.1
1918	October 11	14:14	Puerto Rico	7.5
1918	December 6	08:41	Vancouver Island, B.C., Canada	7.0
1922	January 31	13:17	Offshore Cape Mendocino, CA	7.3
1922	March 10	11:21	Parkfield, CA	6.1
1923	January 22	09:04	Offshore Cape Mendocino, CA	7.2
1925	March 1	02:19	Charlevoix, Quebec, Canada	6.3
1925	June 28	01:21	Clarkston Valley, MT	6.6
1925	June 29	14:42	Santa Barbara, CA	6.8
1926	October 22	12:35	Monterey Bay, CA	6.1
1926	October 22	13:35	Monterey Bay, CA	6.1
1927	November 4	13:51	Offshore Lompoc, CA	7.1
1929	November 18	20:32	Grand Banks, Nova Scotia, Canada	7.3
1932	December 21	06:10	Cedar Mountain, NV	7.2
1933	March 11	01:54	Long Beach, CA	6.4
1933	November 20	23:21	Baffin Bay, Canada	7.4
1934	June 8	04:47	Parkfield, CA	6.1
1935	November 1	06:03	Timiskaming, Quebec, Canada	6.2
1937	July 22	17:09	Salcha, AK	7.3
1938	January 23	08:32	Maui, HI	6.8
1938	November 10	20:18	Shumagin Islands, AK	8.2
1940	May 19	04:36	Imperial Valley, CA	7.1
1946	April 1	12:28	Unimak Island, AK	8.1
1946	June 23	17:13	Vancouver Island, B.C., Canada	7.3
1947	October 16	02:09	Fairbanks, AK	7.2
1949	April 13	19:55	Olympia, WA	7.1
1949	August 22	04:01	Queen Charlotte Island, British Columbia, Canada	8.1
1951	August 21	10:57	Kona, HI	6.9
1952	July 21	11:52	Kern County, CA	7.3
1954	July 6	11:13	Rainbow Mountain, NV	6.6
1954	August 24	05:51	Stillwater, NV	6.8
Year	**Date**	**Time[1]**	**Place**	**Magnitude[2]**

1954	December 16	11:07	Fairview Peak, NV	7.1
1954	December 16	11:11	Dixie Valley, NV	6.8
1955	October 24	04:10	Concord, CA	5.4
1957	March 9	14:22	Andreanof Island, AK	8.6
1958	April 7	15:30	Huslia, AK	7.3
1958	July 10	06:15	Fairweather, AK	7.7
1959	August 18	06:37	Hebgen Lake, MT	7.3
1964	March 28	03:36	Prince William Sound, AK	9.2
1965	February 4	05:01	Rat Island, AK	8.7
1965	April 29	15:28	Seattle-Tacoma, WA	6.5
1966	June 28	04:26	Parkfield, CA	6.1
1966	September 12	16:41	Truckee, CA	5.9
1969	October 2	06:19	Santa Rosa, CA	5.7
1971	February 9	14:00	San Fernando, CA	6.7
1975	August 1	20:20	Oroville, CA	5.8
1975	November 29	14:47	South flank of Kilauea, HI	7.2
1979	August 6	17:05	Coyote Lake, CA	5.7
1979	October 15	23:17	Imperial Valley, CA	6.5
1980	January 24	19:00	Livermore, CA	5.8
1980	May 25	16:33	Mammoth Lakes, CA	6.2
1980	May 25	16:49	Mammoth Lakes, CA	5.9
1980	May 25	19:44	Mammoth Lakes, CA	5.9
1980	May 27	14:50	Mammoth Lakes, CA	6.0
1980	November 8	10:27	Gorda Plate, CA	7.2
1983	May 2	23:42	Coalinga, CA	6.4
1983	October 28	14:06	Borah Peak, ID	7.0
1983	November 16	16:13	Kaoiki, HI	6.7
1984	April 24	21:15	Morgan Hill, CA	6.2
1984	November 23	18:08	Round Valley, CA	5.8
1985	September 19	13:17	Michoacan, Mexico	8.0
1985	December 23	05:16	Nahanni, NW Territory, Canada	6.8
1986	May 7	22:47	Andreanof Island, AK	8.0
1986	July 8	09:20	North Palm Springs, CA	6.1
Year	**Date**	**Time**[1]	**Place**	**Magnitude**[2]
1986	July 21	14:42	Chalfant Valley, CA	6.2

1987	October 1	14:42	Whittier Narrows, CA	5.9
1987	November 30	19:23	Gulf of Alaska	7.9
1988	March 6	22:35	Gulf of Alaska	7.8
1988	November 25	23:46	Saguenay, Quebec, Canada	5.9
1989	October 18	00:04	Loma Prieta, CA	6.9
1989	December 25	14:24	Ungava, Quebec, Canada	6.0
1991	June 28	14:43	Sierra Madre, CA	5.6
1991	August 17	22:17	Honeydew, CA	7.1
1992	April 23	04:50	Joshua Tree, CA	6.2
1992	April 25	18:06	Cape Mendocino, CA	7.2
1992	April 26	07:41	Offshore Cape Mendocino, CA	6.5
1992	April 26	11:18	Offshore Cape Mendocino, CA	6.7
1992	June 28	11:57	Landers, CA	7.3
1992	June 29	10:14	Little Skull Mountain, NV	5.7
1994	January 17	12:30	Northridge, CA	6.7
1994	September 1	15:15	Cape Mendocino, CA	7.1
1999	October 16	09:46	Hector Mine, CA	7.2
2000	September 3	08:36	Napa, CA	5.0
2001	February 28	18:54	Olympia, WA	6.8
2002	April 20	10:50	Au Sable Forks, NY	5.2
2002	November 3	22:12	Denali Park, AK	7.9
2003	November 17	06:43	Rat Island, AK	7.8
2003	December 22	19:15	San Simeon, CA	6.6
2004	September 28	17:15	Parkfield, CA	6.0

APPENDIX B

Executive Order 12699

Source: Federal Register, Vol. 55, No. 8, 1990

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Federal Register
Vol 55. No. 8
Tuesday, January 9, 1990

Presidential Documents

Title 3—

The President

Executive Order 12699 of January 5, 1990

Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction

By the authority vested in me as President by the Constitution and laws of the United States of America, and in furtherance of the Earthquake Hazards Reduction Act of 1977, as amended (42 U.S.C. 7701 *et seq.),* which requires that Federal preparedness and mitigation activities are to include "development and promulgation of specifications, building standards, design criteria, and construction practices to achieve appropriate earthquake resistance for new . . . structures, "and" an examination of alternative provisions and requirements for reducing earthquake hazards through Federal and federally financed construction, loans, loan guarantees, and licenses. . . (42 U.S.C. 7704(1)(3,4)), it is hereby ordered as follows:

Section 1. Requirements for Earthquake Safety of New Federal Buildings.

The purposes of these requirements are to reduce risks to the lives of occupants of buildings owned by the Federal Government and to persons who would be affected by the failures of Federal buildings in earthquakes, to improve the capability of essential Federal buildings to function during or after an earthquake, and to reduce earthquake losses of public buildings, all in a cost-effective manner. A building means any structure, fully or partially enclosed, used or intended for sheltering persons or property.

Each Federal agency responsible for the design and construction of each new Federal building shall ensure that the building is designed and constructed in accord with appropriate seismic design and construction standards. This requirement pertains to all building projects for which development of detailed plans and specifications is initiated subsequent to the issuance of the order. Seismic design and construction standards shall be adopted for agency use in accord with sections 3(a) and 4(a) of this order.

Sec. 2. Federally Leased, Assisted, or Regulated Buildings.

The purposes of these requirements are to reduce risks to the lives of occupants of buildings leased for Federal uses or purchased or constructed with Federal assistance, to reduce risks to the lives of persons who would be affected by earthquake failures of federally assisted or regulated buildings, and to protect public investments, all in a cost-effective manner. The provisions of this order shall apply to all the new construction activities specified in the subsections below.

(a) Space Leased for Federal Occupancy. Each Federal agency responsible for the construction and lease of a new building for Federal use shall ensure that the building is designed and constructed in accord with appropriate seismic design and construction standards. This requirement pertains to all leased building projects for which the agreement covering development of detailed plans and specifications is effected subsequent to the issuance of this order. Local building codes shall be used in design and construction by those concerned with such activities in accord with section 3(a) and 3(c) of this order and augmented when necessary to achieve appropriate seismic design and construction standards.

(b) Federal Domestic Assistance Programs. Each Federal agency assisting in the financing, through Federal grants or loans, or guaranteeing the financing, through loan or mortgage insurance programs, of newly constructed buildings shall plan, and shall initiate no later than 3 years subsequent to the issuance of this order, measures consistent with section 3(a) of this order, to assure appropriate consideration of seismic safety.

(c) Federally Regulated Buildings. Each Federal agency with generic responsibility for regulating the structural safety of buildings shall plan to require use of appropriate seismic design and construction standards for new buildings within the agency's purview. Implementation of the plan shall be initiated no later than 3 years subsequent to the issuance of this order.

Sec. 3. Concurrent Requirements. (a) In accord with Office of Management and Budget Circular A-119 of January 17, 1980, entitled "Federal Participation in the Development and Use of Voluntary Standards," nationally recognized private sector standards and practices shall be used for the purposes identified in sections 1 and 2 above unless the responsible agency finds that none is available that meets its requirements. The actions ordered herein shall consider the seismic hazards in various areas of the country to be as shown in the most recent edition of the American National Standards Institute Standards A58, *Minimum Design Loans for Buildings and Other Structures,* or subsequent maps adopted for Federal use in accord with this order. Local building codes determined by the responsible agency or by the Interagency Committee for Seismic Safety in Construction to provide adequately for seismic safety, or special seismic standards and practices required by unique agency mission needs, may be used.

(b) All orders, regulations, circular, or other directives issued, and all other actions taken prior to the date of this order that meet the requirements of this order, are hereby confirmed and ratified and shall be deemed to have been issued under this order.

(c) Federal agencies that are as of this date requiring seismic safety levels that are higher than those imposed by this order in their assigned new building construction programs shall continue to maintain in force such levels.

(d) Nothing in this order shall apply to assistance provided for emergency work essential to save lives and protect property and public health and safety, performed pursuant to Sections 402, 403, 502, and 503 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act) (42 U.S.C. 5170a, 5170b, 5192, and 5193), or for temporary housing assistance programs and individual and family grants performed pursuant to Sections 408 and 411 of the Stafford Act (42 U.S.C. 5174 and 5178). However, this order shall apply to other provisions of the Stafford Act after a presidentially declared major disaster or emergency when assistance actions involve new construction or total replacement of a building. Grantees and subgrantees shall be encouraged to adopt the standards established in section 3(a) of this order for use when the construction does not involve Federal funding as well as when Federal Emergency Management Agency (FEMA) funding applies.

Sec. 4. Agency Responsibilities. (a) The Director of the Federal Emergency Management Agency shall be responsible for reporting to the President on the execution of this order and providing support for the secretariat of the Interagency Committee on Seismic Safety in Construction (ICSSC). The ICSSC, using consensus procedures, shall be responsible to FEMA for the recommendation for adoption of cost-effective seismic design and construction standards and practices required by sections 1 and 2 of this order.

Participation in ICSSC shall be open to all agencies with programs affected by this order.

(b) To the extent permitted by law, each agency shall issue or amend existing regulations or procedures to comply with this order within 3 years of its issuance and plan for their implementation through the usual budget process. Thereafter, each agency shall review, within a period not to exceed 3 years, its regulations or procedures to assess the need to incorporate new or revised standards and practices.

Sec. 5. Reporting. The Federal Emergency Management Agency shall request from each agency affected by this order, information on the status of its procedures, progress in its implementation plan, and the impact of this order on its operations. The FEMA shall include an assessment of the execution of this order in its annual report to the Congress on the National Earthquake Hazards Reduction Program.

Sec. 6. Judicial Review. Nothing in this order is intended to create any right or benefit, substantive or procedural, enforceable at law by a party against the United States, its agencies, its officers, or any person.

THE WHITE HOUSE,
January 5, 1990.

(FR Doc 90-720)
Filed 1-8-90 12:08pm
Billing code 312501-M

Glossary

Acceleration	The rate of change of motion. The rate of increase in ground velocity as seismic waves travel through the earth. The ground moves backward and forward; acceleration is related to velocity and displacement. (Reference: p. 3-17)
Amplitude	The extent of a vibratory movement. The amount of energy released by an earthquake. (Reference: p. 3-15)
Body waves	A category of seismic wave that travels through the earth *below* and *on* the surface and is used to determine the earthquake's epicenter. There are two types of body waves—P waves and S waves. (Reference: p. 3-8)
Building configuration	A characteristic of buildings that affects their performance in an earthquake. (Reference: p. 4-9)
Built environment	Any manmade structures such as buildings, transportation lines and structures, communications lines, and utilities. (Reference: p. 1-3)
Cost-effective	A clause in Executive Order 12699 that says that a building should be designed to prevent collapse, not damage. (Reference: p. 2-5)
Damping	The termination or retardation of the motion or vibration of a structure. (Reference: p. 4-7)
Deflection	The extent to which a structural element moves or bends under pressure. (Reference: p. 4-9)
Diaphragm	Horizontal structural elements such as floors and roof systems that are designed to transmit lateral or seismic forces to the vertical elements of the seismic resisting system. (Reference: p. 4-14)
Displacement	The distance an object is moved from a resting position. (Reference: p. 3-18)
Drift	Horizontal swaying of a building. (Reference: p. 4-9)

Ductility	The quality of certain materials to absorb energy and distort, rather than to suddenly break. Capability of being drawn out or otherwise distort without breaking or fracture. Flexibility is a very close synonym. (Reference: p. 4-8)
Duration	The time interval between the first and last peaks of strong ground motion above a specified amplitude. (Reference: p. 3-17)
Earthquake	The result of the sudden displacement of rock along a fault line. The vibrations of the earth caused by the passage of seismic waves radiating from some source of elastic energy. (Reference: p. 3-6) The sudden motion or vibration in the earth caused by the abrupt release of energy in the earth's lithosphere. The wave motion may range from violent at some locations to imperceptible at others.
Earthquake Hazards Reduction Act of 1977	An act mandating the establishment and maintenance of the National Earthquake Hazards Reduction Program (NEHRP). (Reference: p. 2-3)
Spectral response acceleration	Coefficients shown on maps in the NEHRP *Provisions* for determining the prescribed seismic forces. (Reference: p. 5-6)
Epicenter	The point on the earth's surface directly above the focus (origination or hypocenter) of an earthquake. (Reference: p. 3-11)
EO	Executive Order (Reference: p. iii)
Executive Order 12699	The most recent and strongest federally mandated effort requiring all new Federal, federally assisted, and federally regulated buildings to be appropriately "seismic resistant." (Reference: p. 1-8)
Fault	A fracture or zone of fractures in rock along which the two sides have been displaced relative to each other parallel to the fracture. The total fault offset may range from centimeters to kilometers. (Reference: p. 3-6)

Federally assisted	Any new construction (or additions to existing buildings) for which any Federal financing (assisted) or the guarantee of any Federal financing is secured. (Reference: p. 2-6)
Federally leased	Any new building or addition in which the Federal Government leases at least 15 percent of the space available. (Reference: p. 2-7)
Federally regulated	Any new construction that will be regulated for structural safety by the Federal Government. (Reference: 2-8)
Hazard (earthquake)	Natural phenomena, such as ground shaking, liquefaction, landslide, surface faulting, tsunami, volcanoes, etc., which occur as a result of tectonic activity and have the potential to cause loss of life, personal injury, and damage to manmade structures. (Reference: p. 1-4)
Horizontal bracing system	Vertical elements such as shear walls, braced frame systems, and moment-resistant systems which help resist lateral forces. (Reference: p. 4-14)
ICSSC	Interagency Committee on Seismic Safety in Construction (Reference: p. 2-4)
Intensity	A measure of ground shaking obtained from the damage done to structures built by humans and changes in the earth's surface. (Reference: p. 3-13)
Isoseismal	Contour lines drawn to separate one level of seismic intensity from another. (Reference: p. 3-11)
Landslide	The dislodging and fall of a mass of earth and rock. (Reference: p. 4-3)
Liquefaction	The conversion (by heat, pressure, or violent motion) of soil and sand into a dense fluid rather than a wet solid mass during an earthquake. (Reference: p. 4-2)

Magnitude — A measure of earthquake size, determined by taking the common logarithm (base 10) of the largest ground motion recorded during the arrival of a seismic wave type and applying a standard correction for distance to the epicenter. Three common types of magnitude are Richter, P body wave, and surface wave. (Reference: p. 3-12)

Mitigation — A set of actions resulting in permanent improvements, taken to reduce risk of injury and loss of life due to damages to structures during a natural disaster. (Reference: p. 1-7)

Model building code — A published document containing standardized building requirements available for adoption by political units in the United States. These are published by private organizations whose members are local governments. (Reference: p. 5-3)

Model code organization — Building Official and Code Administration (BOCA), Southern Building Code Congress International (SBCCI), International Conference of Building Officials (ICBO) (Reference: p. 5-4)

Modified Mercalli Intensity Scale or mm intensity — Named after Giuseppe Mercalli, an Italian priest and geologist, it is an arbitrary scale of earthquake intensity related to damage produced. (Reference: p. 3-13)

NEHRP — National Earthquake Hazards Reduction Program. (Reference: p. 2-3)

NEHRP's *Recommended Provisions for the Development of Seismic Regulations for New Buildings* — A report summarizing lessons learned from past seismic events, the most recent research, and a national approach to seismic design—a set of nationally applicable seismic safety guidelines to be used by model code institutions and legislative bodies to establish seismic standards. (Reference: p. 2-4)

New Madrid Fault — A pattern of geologic faults in the area of the common borders of Arkansas, Missouri, Illinois, Kentucky, Tennessee, and Mississippi. (Reference: p. 1-3).

Nonstructural elements — Building elements such as partitions, ceilings, and exterior walls. (Reference: p. 4-7)

OMB Circular A-119 — Requires that Federal agencies adopt nationally recognized standards where they are available. (Reference: p. 2-8)

Period	The elapsed time of a single cycle of a vibratory motion or oscillation. (Reference: p. 4-6)
Plate tectonics theory	The attempt to explain earthquakes, volcanoes, and mountain building as consequences of large horizontal surface motions. (Reference: p. 3-2)
Resonance	The amplification of a vibratory movement occurring when the rhythm of an impulse or periodic stimulus coincides with the rhythm of the oscillation (period). For example, when a child on a swing is pushed with the natural frequency of a swing. (Reference: p. 4-6)
Retrofit	The correction or addition to a building after the initial construction is completed. (Reference: p. 2-11)
Richter Scale	Named after its creator, the American seismologist Charles R. Richter, a logarithmic scale expressing the magnitude of a seismic (earthquake) disturbance in terms of its dissipated energy. (Reference: p. 3-15)
Ring of Fire	The land masses around the Pacific Plate. (Reference: p. 3-4)
Risk (earthquake)	The exposure of persons and manmade structures, such as buildings, pipelines, bridges, etc., to loss of life, personal injury, and damage in the face of an earthquake hazard. Risk may be reduced by designing structures to eliminate the sources of injury and resist damage from earthquake forces. (Reference: p. 1-4)
Seiche	Oscillation (standing waves) of the water in a bay or lake. (Reference: p. 4-4)
Seismic	Of, subject to, or caused by an earthquake or an earth vibration. (Reference: p. 1-4)
Seismic Use Group	A classification assigned in the NEHRP *Provisions* to a building based on its occupancy and use. (Reference: p. 5-9)

Seismic hazard maps	U.S. maps that contain quantitative measures from which seismic forces on buildings may be determined. (Reference: p. 5-5)
Seismic Design Category	A classification assigned to a building as defined in the NEHRP *Provisions*. (Reference: p. 5-9)
Seismic risk maps	Maps developed to give design professionals and emergency response planners an idea of the relative seismic activity of a region. (Reference: p. 3-19)
Seismically resistant design	Building design that evaluates expected horizontal earthquake forces and strengthens the building to withstand these forces. (Reference: p. 1-7)
Seismic activity	The occurrence of earthquakes in space and time. (Reference: p. 1-4)
Seismology	The study of earthquakes. (Reference: p. 2-2)
Robert T. Stafford Disaster Relief and Emergency Assistance Act	Provides programs for Federal disaster response and recovery assistance. (Reference: p. 2-7)
Stiffness	A characteristic of buildings that affects their performance in an earthquake. Stiff building elements may fail abruptly and shatter suddenly in an earthquake. (Reference: p. 4-8)
Subduction	As the edge of a heavier ocean plate is pushed down into the earth's interior by a lighter continental plate, material from the lower plate is "recycled' by melting into the earth's interior. (Reference: p. 3-2)
Surface waves	Seismic waves that follow the earth's surface only, with a speed less than that of S waves. There are two types of surface waves—Rayleigh waves and Love waves. (Reference: p. 3-10)
Topography	The earth's physical features. (Reference: p. 3-12)
Tremors	A low intensity earthquake. (Reference: p. 1-1)

Tsunami — A long ocean wave, or tidal wave, usually caused by seafloor movements in an earthquake, landslide, or volcanic eruption. (Reference: p. 4-3)

Unconsolidated soil — Fill dirt. (Reference: p. 3-12)

Velocity — The speed of an object at an instant in time. The rate of motion. In earthquakes, it is usually calculated in inches per second or centimeters per second. (Reference: p. 3-18)

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