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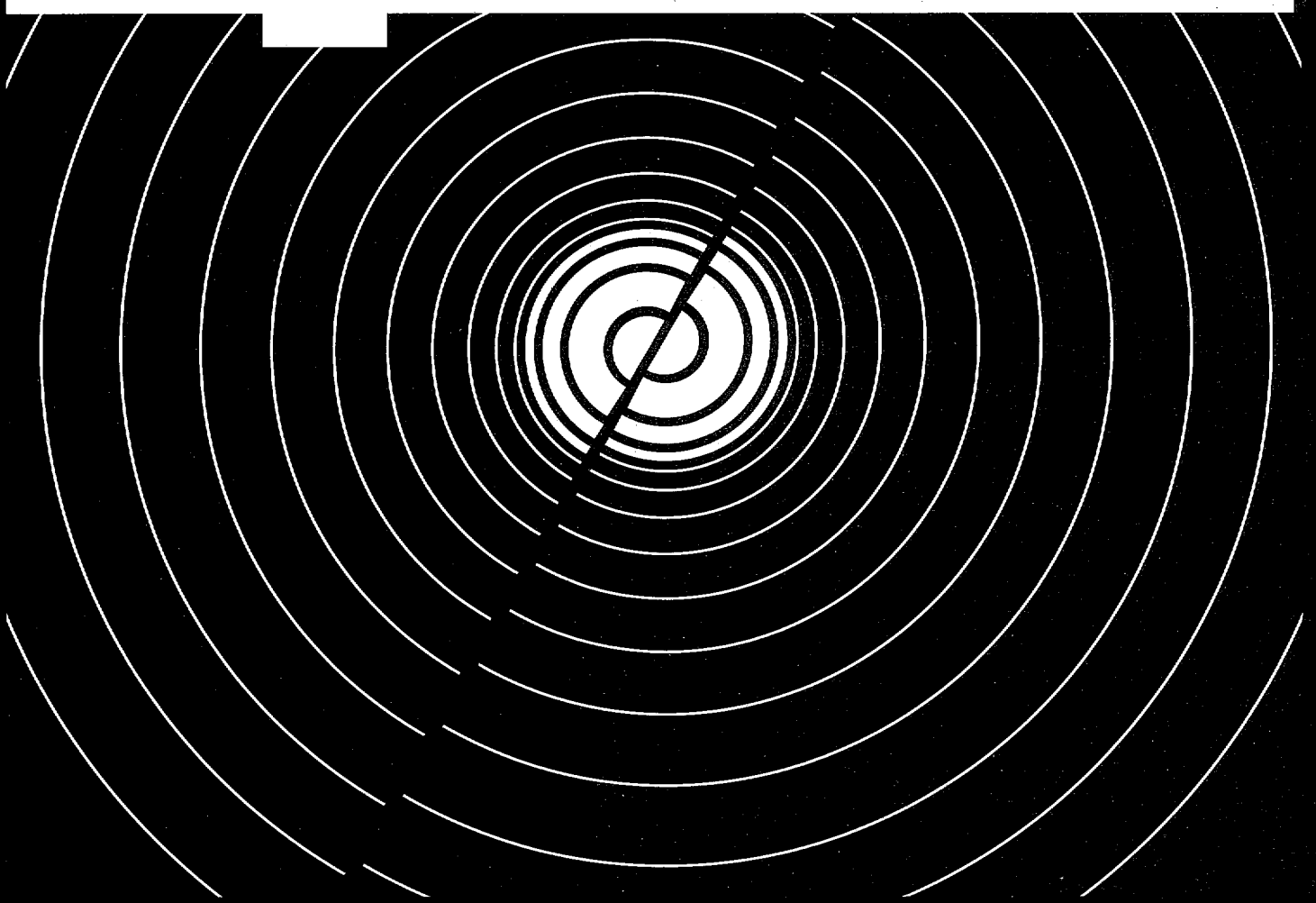
Promoting the Adoption and Enforcement of Seismic Building Codes:

A Guidebook for State Earthquake and Mitigation Managers



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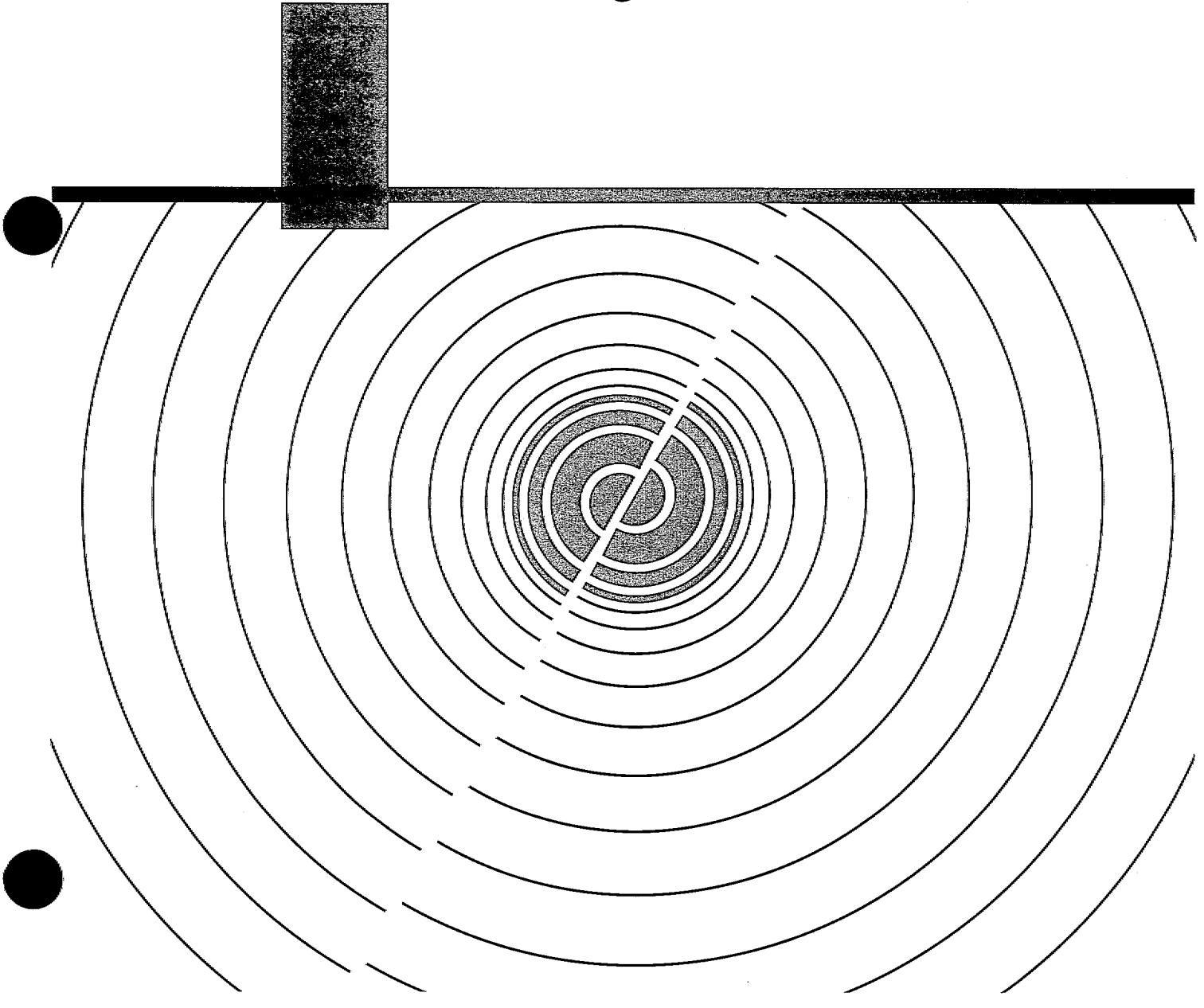

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A Guidebook for State Earthquake and Mitigation Managers

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Chapter 1
How To Use This Book

Purpose

This book provides background information and educational materials to help state officials promote the adoption and enforcement of state and local model building codes that contain the latest seismic provisions. These codes can reduce the damage that will inevitably occur when future earthquakes strike at-risk parts of the country.

Audience

This book is intended for state officials, especially for earthquake program managers and hazard mitigation officers in the emergency management agencies of the states and territories prone to earthquakes. It is designed to help you convince your state and local governments that codes are effective, inexpensive, and a good investment for the future of our communities.

Additionally, this book is designed to be of use to local officials, state legislators, professional organizations, and concerned citizens. Portions of this book are meant to be copied and distributed to these various groups.

Content

Chapters 2 and 3 of this book contain background material on the purpose, function, and effectiveness of building codes in general and seismic codes in particular. Chapters 3, 4, and 5 describe step-by-step processes for adopting state or local codes and for administering codes. Several appendices contain:

- the history and principles of seismic design
- current seismic design practices in the United States
- examples of state building code requirements
- examples of state legislation
- examples of local code administration
- the services of the three model code organizations in the United States
- sources of further information and addresses
- recommended readings
- educational material for making local presentations
- sample press releases for the media
- sample brochures aimed at local audiences
- a glossary of relevant terms

Chapter 2
Why Adopt A Building Code?

Building Codes Protect Public Safety

Building codes regulate building construction and use in order to protect the safety and health of occupants. Codes address structural integrity, fire resistance, safe exits, lighting, and ventilation. Codes also regulate construction materials.

Building codes classify structures by use and apply different standards to each classification. For example, office buildings and residential multi-unit buildings are in separate categories with different performance requirements.

FIGURE 2.1 The first building codes were designed to improve substandard housing. (Photo: Presidents Commission on Urban Housing, 1968)

The validity of building codes is based on state police powers, which allow regulation of activities and property to preserve or promote the public health, safety, and general welfare. Zoning ordinances and environmental protection regulations are also founded in police powers.

Building Codes Have a Long History in the U.S.

Building codes to reduce the loss of life, limb, and property have existed in North America since the seventeenth century. The earliest building regulations addressed problems resulting from dense urban construction, such as rapid spread of fire. New York City, then called New Amsterdam, first regulated chimneys and roofing material in 1648. These regulations were aimed at controlling the destructive force of fire in urban areas, as evidenced by London's 1666 fire, New York's 1835 and 1845 fires, and the great Chicago fire of 1871.

Comprehensive building regulations were introduced in the mid-1800s.[1] Building regulations were of two types: housing codes and building codes. Housing codes were intended to reduce the ill effects of residential overcrowding, and their introduction paralleled Europe's housing and sanitation reform. New York City in the late 1850s adopted a citywide housing code in order to provide air and light into dwellings and reduce the risk of fatal hazards. Chicago followed by passing its initial tenement housing ordinance in 1874. Building codes were later enacted to comprehensively specify construction methods and materials.

In 1905 the National Board of Fire Underwriters published a model

building law aimed at reducing fire risks.[2] The three model building codes used today were initiated between 1927 and 1950. The use of codes spread with the growth of new building across the country, particularly after World War II. By 1960 more than 60 percent of American municipalities had adopted building codes.

Model Building Codes

A model building code is a document containing standardized building requirements applicable throughout the United States. Model building codes are standards specifying the required performance of all structures. They are published by private organizations, whose voting members are government jurisdictions.

It is the policy of the federal government to rely on voluntary standards whenever feasible and to encourage employees to participate in voluntary standards-developing activities (OMB Circ. A-119).

The United States has three prominent model building code organizations: the International Conference of Building Officials (ICBO), which publishes the Uniform Building Code (UBC); the Building Officials and Code Administrators International, Inc. (BOCA), which publishes the BOCA National Building Code (BNBC); and the Southern Building Code Congress International, Inc. (SBCCI), which publishes the Standard Building Code (SBC). Each organization also publishes companion documents covering mechanical work, plumbing, fire protection, electrical work, energy, accessibility, and life safety codes.

Simple one- and two-unit residential structures also are covered by another model building code: the *One- and Two-Family Dwelling Code,* by the Council of American Building Officials (CABO). CABO is composed of the three model building code organizations: ICBO, BOCA, and SBCCI.

In addition to writing and updating the codes, the organizations offer a variety of support services, including such technical services as training seminars, code interpretation, technical and administrative publications, customized consulting, plan-checking services, videos, and software (see Appendix D). Each organization offers certification programs to allow skilled inspectors and plan reviewers to be recognized for their levels of knowledge and experience. For example, BOCA offers certification by examination in twenty-two categories and ICBO in nineteen categories. SBCCI offers four levels of certification in various categories to encourage professional growth through progressive levels of certification.

Membership in model building code organizations is open to governmental officials, private sector building and construction professionals, and students. Each member participates in varying degrees depending on membership classification. For all three organizations only active governmental members may vote. Typically, these are local and state officials responsible for enforcing the building codes.

The model building codes are revised periodically by a democratic process. Each organization allows the public to propose code amendments and hear testimony in meetings organized by the organization, so members and nonmembers are equal participants. Active members of each organization vote on revisions after final testimony is heard during their annual meeting. The content of the codes has become more similar over time, although they still address regional conditions and practices. The newest versions reflect a common code format so that similar topics can be found in consistently numbered chapters among the codes.

Although the code organizations have widespread membership, each organization's model building code

Building Code Timeline

1648	Chimneys and roofing materials regulated to prevent fire in New Amsterdam (now New York City)
1850s	(late) Comprehensive housing regulations introduced in NYC
1874	Tenement housing ordinance passed in Chicago
1905	Model building law published by NBFU
1906	San Francisco earthquake kills 3,000
1927	Uniform Building Code (UBC), with seismic provisions, first published by ICBO
1933	Long Beach earthquake kills 115
1935	Charles Richter devises magnitude scale for earthquakes
1940	Standard Building Code (SBS) published by SBCCI
1949	UBC contains first national seismic hazard map
1950	Basic Building Code (now the BOCA National Building Code) published by BOCA
1960	60% of American municipalities had adopted one of the model codes
1970s	Study of earthquake-resistant design provisions funded by NSF
1971	San Fernando earthquake kills 65
1972	CABO formed
1973	UBC revised because of San Fernando quake
1976	UBC includes new seismic provisions
1978	ATC releases ATC3-06 report
1979	BSSC formed
1985	FEMA releases NEHRP provisions for new buildings
1989	95% of American municipalities covered by codes; Loma Prieta earthquake kills 63
1990	EO 12699 requires all federal agencies to incorporate seismic resistant design in new buildings
1992	All three model codes require seismic designs consistent with NEHRP provisions; Northridge earthquake kills 57
1993	EO12699 provisions take effect
1994	EO 12941 establishes seismic standards for federally owned or leased buildings; ICC formed
2000	ICC codes to be finished

The ABCs of Model Building Codes

Building Officials and Code Administrators International, Inc. (BOCA). BOCA, headquartered in Country Club Hills, Illinois, was formed in 1915. Its first code, the BOCA Basic Building Code now titled the *BOCA National Building Code* (BNBC), was published in 1950 in an attempt to standardize existing codes. The BNBC is revised every three years, most recently in 1996, with a new edition due out in 1999.

International Conference of Building Officials (ICBO). ICBO was formed in 1922 to integrate various design requirements into one code. ICBO published its first model code, the *Uniform Building Code* (UBC), in 1927. ICBO, headquartered in Whittier, California, updates the UBC every three years. The latest edition was published in 1994.

Southern Building Code Congress International, Inc. (SBCCI). The third model building code organization, SBCCI was founded in 1940. Located in Birmingham, Alabama, it publishes the *Standard Building Code* (SBC). The SBC is updated every three years, most recently in 1994.

Council of American Building Officials (CABO). CABO was founded in 1972 by BOCA, ICBO, and SBCCI. The *One- and Two-Family Dwelling Code* applies to the construction, prefabrication, alteration, repair, use, occupancy, and maintenance of detached one- or two-family dwellings and one-family town houses not more than three stories in height.

Further information on these organizations and their services is included in Appendix D.

is predominantly adopted in one portion of the United States (Fig. 2.2). The BNBC is predominantly adopted in the northeast and north central states, the SBC predominates in the southern states east of the Mississippi, and the UBC is predominant in the western states, including Guam (see Figure 2.2).[3]

In addition, BOCA, ICBO, and SBCCI have moved forward on the development of a single model code, the International Building Code. On December 9, 1994, the International Code Council (ICC) was formed to develop a single set of comprehensive and coordinated national codes. The advantages of a single code are numerous. Code enforcement officials, architects, engineers, designers, and contractors can have consistent requirements that can be used across the country and around the world. Manufacturers can put their efforts into innovative products, instead of designing for all three regional codes. To date, the ICC has produced codes that address plumbing, mechanical systems, and private sewage disposal. The goal is for the complete family of international codes to be developed by the year 2000.

Compared to the Benefits, the Costs of Codes Are Small—and Uniform Codes Reduce Costs

There are two costs associated with building codes. One is the cost of additional material and quality of workmanship, and the other is the cost of administration and enforcement. In the studies cited below, research has shown that building codes do not significantly increase building cost, and adoption of statewide codes can help reduce the costs.

Criticism of the cost of building codes in the 1950s and 1960s centered around the inefficiencies of having numerous codes, inconsistently applied. Builders often were required to alter their construction methods and materials from one community to the next, which meant spending more time and money. A survey of Detroit area construction companies in 1966 found that use of nonuniform building codes throughout the metropolitan region increased housing costs approximately 4 to 11 percent.[4] In contrast, a 1953 study in the San Francisco Bay Area found that the restrictive effect of codes had been greatly overemphasized, and that only 1 percent of housebuilding costs could be attributed to code inefficiencies.[5]

University studies[6] based on 1967 and 1970 housing costs found that building codes increased the cost of housing by less than 2 percent, and up to as much as 5 percent for particularly restrictive codes.

To address these issues, the National Commission on Urban Problems in 1968 recommended more uniformity in building codes, including adoption of state building codes.[7] According to a 1989 Federal Trade Commission study, because of the widespread adoption of model codes, differences among codes no longer contribute to higher housing costs.[8] Thus, the impact of codes on housing costs has always been relatively small, and is decreasing as more localities adopt model codes.

Most States and Municipalities Have Building Codes

Constitutionally, states have jurisdiction over regulation of construction. As of 1996, the Institute for Business and Home Safety (formerly IIPLR) reported that 23 states mandate a model code or state code to cover all buildings,[9] relying mostly on local municipal enforcement and administration (Fig. 2.3). An additional 18 states and Washington, D.C., mandate the code for all buildings except one-family dwellings. Ten states do not have state-mandated codes.

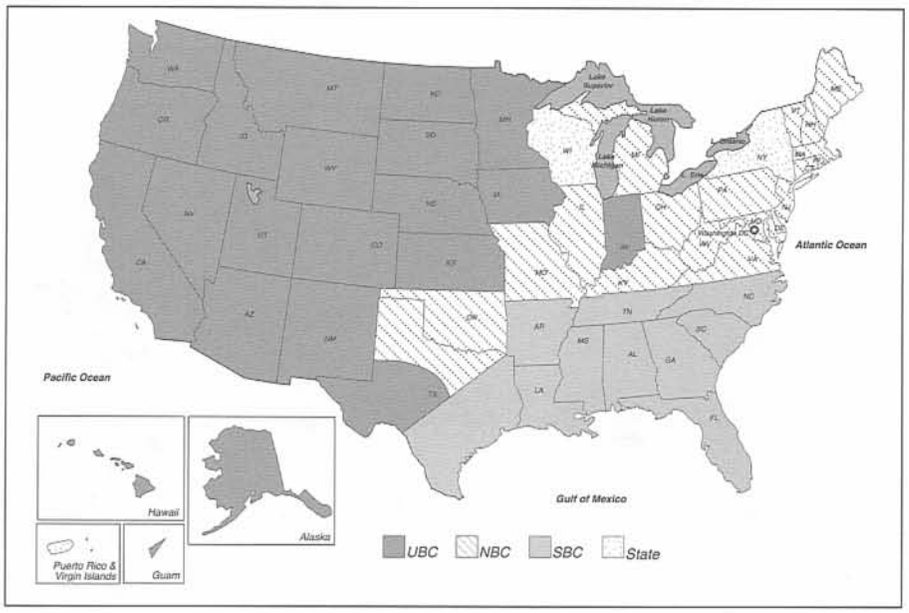
Currently two states, New York and Wisconsin, and one territory, Puerto Rico, have written their own building codes. Other states and territories that enforce statewide codes use one of the model building

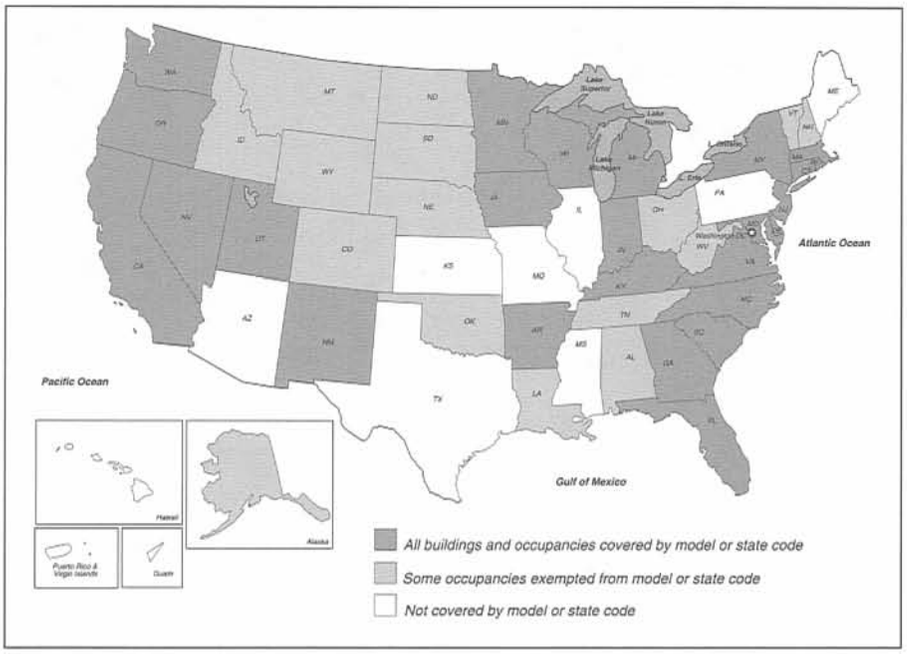
codes described previously. (See Appendix A for a list of current state and territory codes.)

Usually county and local governments adopt a model building code by ordinance. As of 1992, 44,000 local governmental units enforced building codes.[10] The Federal Trade Commission in 1989 estimated that 95 percent of all cities and towns are covered by building codes.[11] These local governments have either adopted a model building code or are covered by a statewide building code.

Codes Are Easy to Adopt

State and local governments usually adopt an entire model building code, though sometimes with minor revisions or deletions. Model building codes save governments the time and cost required to write an original code. They include sections detailing the administrative procedures for plan review, building inspection, plan and building approval, and code enforcement.





Top, FIGURE 2.2 General areas of building construction code influence. (Source: National Conference of States on Building Codes and Standards)

Above, FIGURE 2.3 States with mandatory statewide building codes. (Source: Copyright 1996, Insurance Institute for Property Loss Reduction [now IBHS])

NOTES

1 National Conference of States on Building Codes and Standards Inc., *Directory of Building Codes and Regulations*, Vol. 1, Code Primer, NCSBCS (Herndon, VA), 1989.

2 Ibid.

3 Ibid.

4 Metropolitan Fund, Inc., *A Study of Local Building Codes and Their Administration in the Southeast Michigan Six-County Region*, Public Administration Service (Chicago), August 1966.

5 Maisel, Sherman J., *Housebuilding in Transition*, University of California Press, 1953.

6 For 1967 costs, see Muth, Richard F., and Wetzler, Elliot, "The Effect of Constraints on House Costs," *Journal of Urban Economics*, Vol. 3, 1976, 57-67; for 1970 costs, see Noam, Eli M., "The Interaction of Building Codes and Housing Prices," *AREUEA Journal*, Vol. 10, 1983, 394-404.

7 U.S. National Commission on Urban Problems, *Building the American City*, report to the Congress and the President, House Document No. 91-34, December 1968.

8 Reported by Korman, Richard, "A Much Misunderstood Contraption," *Engineering News-Record*, June 22, 1989, 30-36.

9 Insurance Institute for Property Loss Reduction (now IBHS), *Summary of State-Mandated Codes*, IIPLR (Boston), April 1996.

10 National Conference on States on Building Codes and Standards, *Seismic Provisions of State and Local Building Codes and their Enforcement*, NIST GCR 91599, April 1992.

11 Korman, Richard; see note 8.

Chapter 3
Why Adopt a Seismic Code?

FIGURE 3.1 Most of the building damage in the 1989 Loma Prieta earthquake was to older unreinforced masonry buildings built before the adoption of seismic codes. (Photo: Rob Olshansky)

The term *seismic code* refers to the seismic design requirements included within building codes. In the past, local governments sometimes viewed the seismic sections of the model codes as optional, adopted at local discretion. Now seismic provisions are fully integrated into all three model codes. Local governments should adopt the latest version of a model code in its entirety, including the seismic sections, in order to be operating at the current standard. This point is very important and is emphasized throughout this book.

Seismic Codes Are Effective

Experience with recent earthquakes in the United States and throughout the world shows that seismic codes work. Cities with seismic codes suffer much less damage than those without such codes.

The Loma Prieta earthquake clearly illustrates the effectiveness of seismic codes. Occurring on October 17, 1989, this earthquake measured 7.1 on the Richter scale and was the strongest to affect a U.S. city since the 1964 Alaskan earthquake.[1] It shook the San Francisco Bay Area and killed sixty-three people. Two-thirds of the deaths were a result of the Cypress viaduct collapse. Although the ground-shaking was intense within the metropolitan area, few buildings collapsed. Most of the damage occurred to unreinforced masonry buildings built before the adoption of seismic codes. Nearly all major reinforced concrete structures built after World War II survived without collapse. Even at the quake's epicenter new buildings and buildings located on firm ground suffered little damage. Informed observers attribute the success to the required UBC seismic codes.[2] This example illustrates that code requirements reduced the damage and loss of life during this moderate earthquake.

The 1994 Northridge, California, earthquake shows similar evidence. Almost all the buildings in the affected area were built during the past fifty years under one of the UBC seismic codes. Virtually all buildings, even in the areas of strongest shaking, remained standing and allowed for safe evacuation of occupants. Regrettably, one apartment building collapsed on its residents, and two high-occupancy concrete-frame buildings collapsed, fortunately with no occupants at the time.[3] Still, these three buildings were built under an older version of the UBC code, and damage and life loss would have been immeasurably greater without the seismic-resistant construction prevalent in the San Fernando Valley.

A Kyoto University study of the 1995 earthquake in Kobe, Japan, Richter magnitude 6.9, found that damage to reinforced concrete buildings closely paralleled improve-

ments to seismic provisions in the Japanese building code. More than 55 percent of pre-1970 buildings (old version of code) were severely damaged, compared with no post-1980 buildings (newest version of code). Similarly, steel buildings built before 1970 sustained severe damage, compared with little damage in post-1981 buildings.[4] Ohbayashi Corporation studied buildings it had constructed in Kobe and found that 58 percent of pre-1971 buildings were damaged, compared with 28 percent of 1972-80 buildings and only 16 percent of post-1981 buildings.[5]

In contrast, a Richter magnitude 6.9 earthquake in Armenia in 1988 destroyed entire communities and killed 25,000 people. This disaster has been attributed to several factors: design deficiencies; poor quality of construction; and the earthquake's intensity exceeding that anticipated by the code.[6] Similar problems exist in much of the United States.

Even smaller earthquakes can cause extensive damage where buildings are not designed for seismic shaking. A Magnitude 5.6 earthquake in 1993 at Scotts Mills, Oregon, caused significant structural damage to a number of unreinforced masonry (brick) buildings in the area.[7] A high school building was significantly damaged and vacated, 16 residences and 54 businesses sustained major damage, and the Oregon State Capitol, in Salem, suffered cracking in the rotunda. The estimated damage cost to public facilities alone was nearly $13 million. This earthquake confirmed the susceptibility of unreinforced buildings to severe damage, even in a minor earthquake.

New lessons are learned from every earthquake and incorporated into U.S. seismic codes. For example, the 1985 Mexico City earthquake confirmed that the local soil conditions are as important to building stability as the epicenter location.[8] In response to this new information, ICBO in the 1988 and 1991 UBC editions has emphasized soil conditions by increasing the force requirements according to the type of underlying soil. *The National Earthquake Hazard Reduction Program (NEHRP) Recommended Provisions* (described on page 8) have also taken into account soil conditions in the latest edition.

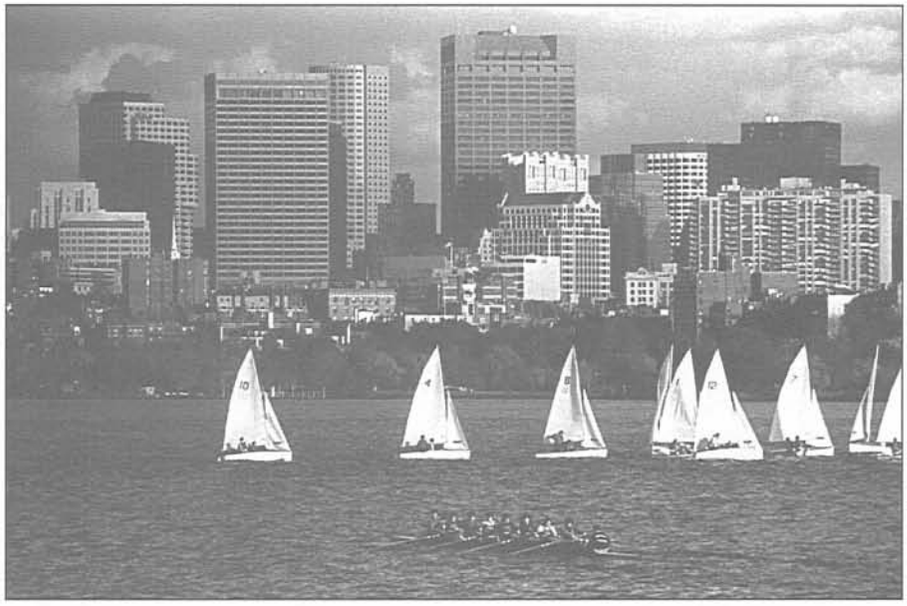


FIGURE 3.2 Lessons about underlying soil conditions learned in the 1985 Mexico City quake can help areas built on fill, such as the Back Bay area of Boston shown above, minimize damage. (Photo: Greater Boston Convention & Visitors Bureau)

Today's Seismic Codes Are Based on More Than Sixty Years of Earthquake Experience

Seismic codes in use now reflect a long history of learning from earthquakes and represent the collective knowledge of hundreds of design and construction professionals. The following is a brief account of that history. See Appendix A for a more detailed account.

The earliest seismic design provisions in the U.S. were introduced in the appendix to the 1927 *Uniform Building Code*, the first edition of the UBC. By the 1950s, some California municipalities had adopted additional seismic-resistant design and material specifications. The 1949 edition of the UBC contained the first national seismic hazard map. After the 1971 San

Earthquake Magnitude and Intensity

Earthquake *magnitude* is a measure of the absolute size of an earthquake so that we may compare earthquakes with one another. Generally speaking, earthquakes that release more energy

- shake for a longer amount of time,
- affect a wider area, and
- produce more violent shaking near the source.

Because we cannot measure the energy released by an earthquake, Charles Richter in 1935 devised a substitute measure—the Richter magnitude scale. The scale is based on what a seismograph would measure; it has no inherent meaning of its own. The Richter scale is logarithmic, and each whole number increase in the scale represents approximately a 31.5-fold increase in energy release: that is, a magnitude 7 earthquake releases about 31.5 times more energy than does a magnitude 6 earthquake. Several different magnitude scales are now in common use, and they all share basic characteristics with the Richter Scale.

Shortly after an earthquake occurs, the *surface wave magnitude or body wave magnitude* is often reported. The scale that most accurately represents the energy of an earthquake is the *moment magnitude scale*. For smaller earthquakes (less than magnitude 6), the scales are nearly identical, but only the moment magnitude scale can distinguish differences among very large earthquakes.

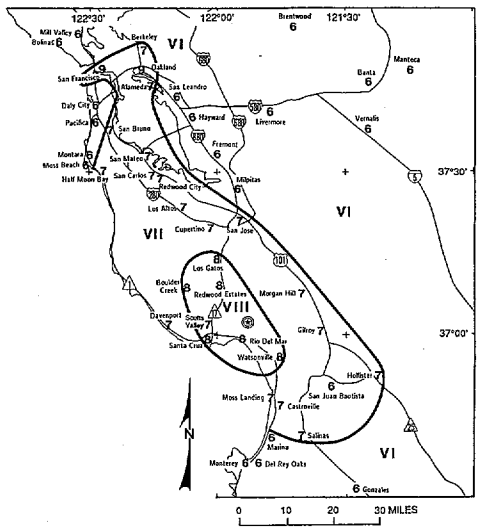


FIGURE 3.3 The Loma Prieta, California, earthquake of 1989 had a magnitude of 7.1, but intensities in the affected area ranged from MMI VII to IX. (Source: USGS Circular 1045, 1989)

Earthquake *intensity* is a measure of the actual shaking experienced at a location. The United States uses the Modified Mercalli Intensity Scale, a twelve-point qualitative scale that describes observable effects of earthquakes. For example, Intensity VIII is described, in part, as "damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures . . . fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned." Whereas magnitude is an inherent quality of an earthquake, intensity generally decreases with greater distance from the earthquake's center. Intensity is a very useful measure because it describes what is most important to society—the degree of damage to structures built by humans.

Fernando earthquake, revisions were made to the 1973 UBC, and new requirements were introduced in the 1976 edition.[9]

Early in the 1970s the National Science Foundation (NSF) funded a project, under the guidance of the National Bureau of Standards (NBS, now the National Institute of Standards and Technology), to evaluate existing earthquake-resistant design provisions. This extensive multi-year project relied on the input of a large number of seismic design experts and resulted in a 1978 report by the Applied Technology Council titled *Tentative Provisions for the Development of Seismic Regulations for Buildings (ATC 3-06).*

Under a contract with the Federal Emergency Management Agency (FEMA), the Building Seismic Safety Council (BSSC, formed in 1979 within the National Institute for Building Sciences, NIBS) revised ATC 3-06 by a consensus of its members. In 1985 FEMA released the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*, commonly called the *NEHRP Provisions*. Although not a code, the *NEHRP Provisions* are designed to provide guidance to the writers of building codes. FEMA and BSSC continue to update the *NEHRP Provisions* every three years, with the latest edition being published in 1994. The 1997 edition is due out in December 1997.

All Three Model Codes Contain State-of-the-Art Seismic Requirements

The past two decades have seen great strides in the knowledge of building responses to earthquakes. Based on the collective efforts of engineers, scientists, and tradespeople, the *NEHRP Provisions* contain seismic design provisions that are technically advanced and widely accepted.

Since 1992 all three model codes require seismic design standards consistent with the *NEHRP*

Modified Mercalli Intensity Scale

Figure 3.4 Percentage of Buildings Expected in Each Damage State for Various Shaking Intensities: Buildings Designed for Seismic Zone 4 under the 1991 UBC

Size of Earthquake (Magnitude)		Expected MMI	Standardized Damage States A	B	C	D	E
6.0-6.5	7.5-8.0		None	Slight	Moderate	Extensive	Complete
Distance to Fault							
30 mi.	50 mi.	VII	60-90%	10-40%	1-5%	<1%	0
5 mi.	40 mi.	VIII	35-60%	35-45%	10-30%	<5%	<1%
1 mi.	30 mi.	IX	25-40%	25-40%	20-40%	3-10%	<2%
—	3 mi.	X	5-25%	5-25%	40-70%	10-30%	<5%

Source: EERI Ad Hoc Committee (see note 12).

MMI VI: Ground-shaking felt by all; some cracked plaster; broken dishes and glassware. (Photo: Caltech EERL)

MMI VII: Disturbance frightens all; cracked chimneys; cracking in unreinforced masonry structures. (Photo: Rob Olshansky)

MMI VIII: Causes near panic; partial collapse of unreinforced masonry structures. (Photo: Rob Olshansky)

MMI IX: General panic; ground-cracking; considerable damage in buildings designed to seismic code. (Photo: J. David Rogers)

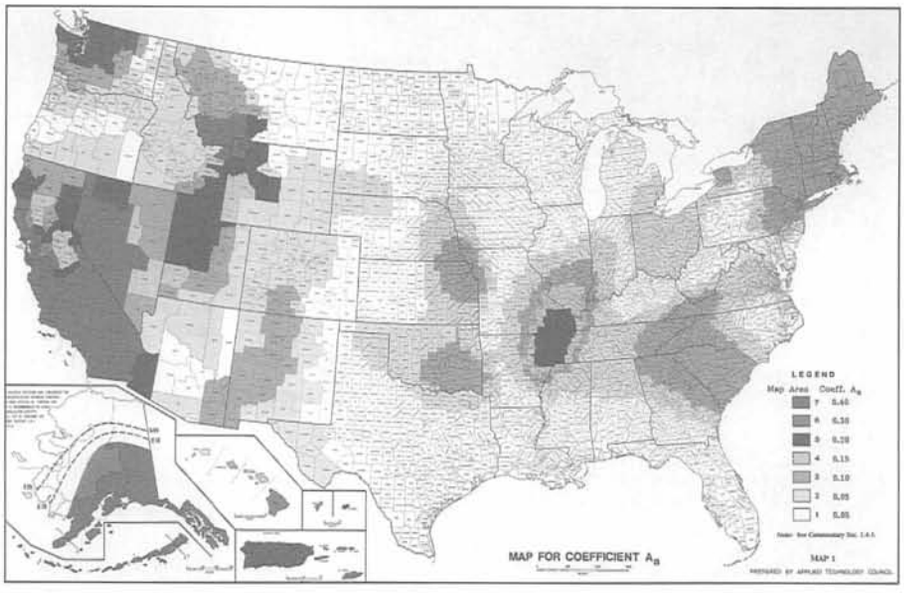


FIGURE 3.5 U.S. seismic hazard map based on effective peak acceleration.

This seismic hazard map, published by the Applied Technology Council in 1978, shows 7 zones of effective peak acceleration with a 10 percent probability of occurring in a 50-year period. Each county is assigned a value. This map became the basis for the first NEHRP Provisions in 1985. (Source: Applied Technology Council, 1978)

Provisions.[10] ICBO has long been a leader in seismic code development; BOCA incorporated the 1988 *NEHRP Provisions* into the 1992 BOCA *Supplement*; and SBCCI incorporated the 1988 *NEHRP Provisions* in the 1992 amendments to the SBC. Thus, all communities **that adopt the most recent editions of these codes** have the most advanced seismic codes available.

The Federal Government Requires Seismic Design for All Its Buildings

Signed in January 1990, presidential Executive Order 12699 required all federal agencies by February 1993 to issue regulations or procedures that incorporate cost-effective seismic safety measures for all *new* federal buildings and buildings that are leased, assisted, or regulated by the federal government. All of the affected federal agencies have adapted one or more minimum standards for seismic safety and have issued the required regulations or procedures.

Because of EO 12699, it is in the best interests of local governments to adopt seismic codes. To best facilitate the possibility of federal financial assistance for new buildings, local governments would be well advised to adopt one of the model codes that have been found to be seismically adequate. For example, the federal agencies providing financial assistance for housing construction (VA, FHA, HUD) all now require adequate seismic design and construction.

In conjunction with EO 12699, Executive Order 12941 (December 1, 1994) directs federal agencies to evaluate *existing* federally owned and leased buildings to identify buildings that are potentially hazardous and to plan for the seismic rehabilitation of those so identified.[11]

Both executive orders are significant in that the federal example encourages state and local governments to make seismic design more prevalent throughout the nation. They also increase the number of experienced seismic designers and contractors.

Seismic Codes Account for Variations in Earthquake Hazard across the U.S.

All the model codes include a seismic hazard map that indicates likely levels of earthquake groundshaking in every part of the United States. The latest adopted maps depict the peak ground acceleration that has a 10 percent probability of being exceeded every fifty years. New maps based on spectral accelerations have recently been issued by the U.S. Geological Survey and are currently under consideration for use in future code editions (see Appendix A).

The code requirements reflect the fact that some places are more prone to earthquakes than others. Sometimes local officials question whether their jurisdiction warrants seismic design. Because of the seismic hazard map in the code, this decision need not be made by individual local officials—the codes themselves require the appropriate level of seismic design (which in some cases is *no* seismic design) for every county in the United States. The zone boundaries are based on probability: a structure on one side of a zone line

is not markedly safer than a structure immediately on the other side. But these maps do represent a consensus of informed scientific opinion on the likelihood of earthquake ground-shaking and its effects. By using these maps as guides to design, we reduce the overall chances of damage to buildings in a region.

Seismic Codes Are Designed to Help Buildings Resist Earthquake Shaking

It is important to understand that seismic codes result in earthquake-*resistant* buildings rather than earthquake-*proof* buildings. Their purpose is to protect life safety by preventing building collapse and allowing for safe evacuation. The contents and interiors of buildings, even those of well-designed buildings, may receive extensive damage, and critical functions of a building may cease. And structural damage may occur from major earthquake ground-shaking. According to the Structural Engineers Association of California, structures built according to a seismic code should:

- resist minor earthquakes undamaged,
- resist moderate earthquakes without significant structural damage even though incurring nonstructural damage, and
- resist severe earthquakes without collapse.[12]

Occasionally even a code-designed building may collapse due to unique site conditions or other factors. A report completed by the Earthquake Engineering Research Institute (EERI) just prior to the Northridge, California, earthquake summarized expected earthquake damage to buildings designed according to the 1991 UBC. It stated, for example, that shaking of Intensity VIII could cause moderate damage (easily repairable) to 10 to 30 percent of code-designed buildings, and extensive damage (long-term closure, difficult to repair) to 0 to 5 percent of code-designed buildings.[13] This was the intensity level experienced by much of the San Fernando Valley in January 1994, and buildings performed generally as expected.

Seismic Codes Reflect Social Judgments Regarding Acceptable Risk and Cost

Seismic design standards reflect society's balancing of the risks versus the costs of designing to withstand that risk. They do this in two ways: by designing for (a) an appropriate-sized event and (b) an appropriate performance goal. Society cannot justify the expense of designing for large but highly improbable events. So we select a ground motion event—called the *design event*—that although large and rare has a reasonable chance (10 percent) of being exceeded during a building's lifetime (50 years). The probability selected reflects society's attitude toward risk.[14] This is similar to the philosophy long used for flood protection: Society is willing to absorb the cost of designing for a 100-year flood, but with the exception of critical facilities it would not make economic sense to design for the 500-year or 1,000-year flood.

The goal of seismic codes is to ensure that buildings will not collapse, thereby killing those inside, if shaken by the design event. Seismic codes are for "life safety" and are not aimed at completely preventing damage to existing buildings (see Fig. 3.4). Additionally, it is important to realize that there is a 10 percent chance of an earthquake occurring that exceeds the design event.

Seismic Codes Are Inexpensive

Seismic codes add relatively little to the costs of a structure. To assess the costs of the *NEHRP Provisions* (seismic provisions), the BSSC in 1985 contracted seventeen design firms from nine U.S. cities to per-

Increase in Cost by Building Type Resulting from Seismic Design

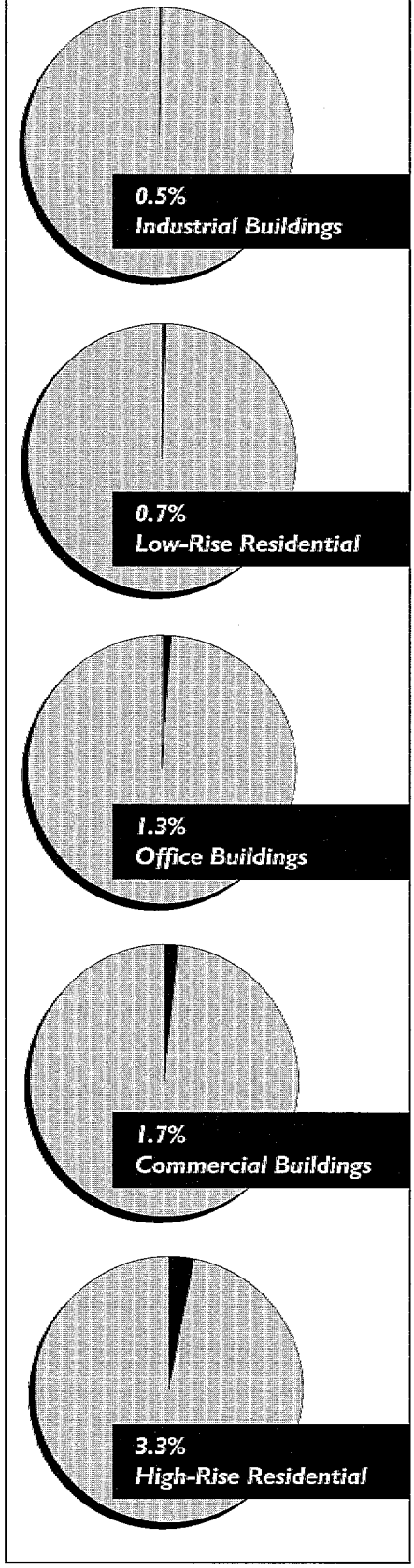


FIGURE 3.6 The extensive damage in Armenia in 1988 can be attributed to the lack of seismic-resistant design and construction. The same limitations are true of existing building stock throughout the United States. (Photo: NOAA)

Damage costs from earthquakes are estimated to be reduced substantially by seismic codes. For a magnitude 8 earthquake affecting Memphis, damage estimates are $10.4 billion without codes and $5.81 billion with codes—a savings of about 50 percent. For a magnitude 6 earthquake, damage estimates are $1.49 billion and $.49 billion, respectively—an even larger savings of about 66 percent.

form two designs for each of several typical building types, first using the existing local code and then using the seismic provisions. They found the average increase in total costs to be 0.7 percent for low-rise residential buildings, 3.3 percent for high-rise residential buildings, 1.3 percent for office buildings, 0.5 percent for industrial buildings, and 1.7 percent for commercial buildings. Cities with previous seismic design provisions in their codes averaged much smaller cost increases (0.9 percent) than did cities with no seismic codes at all.[15]

A 1992 study by the National Association of Home Builders (NAHB) for the Insurance Research Council examined the incremental costs of building single-family residences to 1991 *NEHRP Provisions*. They found that "builders can construct houses providing for life safety in earthquakes at a very reasonable added cost—less than 1 percent of the purchase price of a new home in most instances."[16]

Costs of seismic design can vary. It is easier to provide seismic design for simple-shaped structures, with basic geometric shapes such as a square, and cheaper to do if seismic considerations are integrated into the earliest stages of building design. In certain situations, the costs for the structure are relatively small in proportion to the total project costs. This occurs if the project has expensive contents or high land values. If this is the case, the cost of seismic-resistant design becomes a smaller proportion of the total project cost.

Studies Indicate That the Benefits Outweigh the Costs

A few studies have attempted to look at the costs and benefits of seismic design provisions. The studies generally indicate that the costs of seismic-resistant construction are justified. Such studies, however, cannot easily provide definitive answers. Although the direct costs of codes are relatively easy to estimate, the benefits of codes (future damages and injuries that will not occur) are more problematic. These studies are limited by the number of assumptions that must go into such models and by the difficulty of quantifying life loss, injury, and indirect effects on the economy resulting from an earthquake. Nevertheless, benefit/cost models can provide useful guidance to decision-makers and are being used with increased frequency.

In a 1987 study led by William Schulze of the University of Colorado, the costs of seismic codes in southern California were compared to the benefits of protection from an earthquake on the San Andreas fault. They found costs and benefits roughly equal within the accuracy limits of their model. However, this model was very limited in that it ignored all other southern California earthquake sources and did not consider benefits of reduced emergency services, injuries, and uninterrupted economic activity.[17] A more comprehensive model that would account for these factors would likely find seismic codes in southern California to be worth the cost.

A 1992 study, *Physical Damage and Human Loss: The Economic Impact of Earthquake Mitigation Measures*, funded by the National Committee on Property Insurance (now IBHS),

analyzed the estimated costs and benefits of seismic building codes for Memphis, Tennessee, assuming damage from magnitude 6 and 8 earthquakes in the southern New Madrid fault zone. It found that benefits exceed costs by a factor of 1.8 for the magnitude 6 event and 10.3 for the magnitude 8 event. Moreover, the benefit-cost ratio averaged over a forty-year time horizon, accounting for the expected probability of earthquakes in that time period, was estimated at 3.3. Thus, the expected damage over forty years is more than three times greater than the costs of building to code. Furthermore, the benefits are underestimated because they do not account for the benefits of reducing fatalities, injuries, fire potential, or economic losses. This recent study provides valuable analytic support to the claim that seismic building codes are cost-effective, even in the central United States.[18]

NOTES

1 Bruce A. Bolt, *Earthquakes*, W.H. Freeman and Company (NY), 1993.

2 E.g., Fratessa, Paul F., "Buildings" (chap. 3), in *Practical Lessons from the Loma Prieta Earthquake*, National Academy Press, 1994.

3 Earthquake Engineering Research Institute, "Northridge Earthquake of January 17, 1994," *Earthquake Spectra*, Supplement to Vol. 11, April 1995.

4 Cited in Chung, Riley, ed., *The January 17, 1995 Hyogoken-Nanbu (Kobe) Earthquake: Performance of Structures, Lifelines and Fire Protection Systems*, National Institute of Standards and Technology, NIST Special Publication 901, July 1996.

5 Cited in Shinozuka, Masanobu, "Summary of the Earthquake," in *NCEER Response: Preliminary Reports from the Hyogo-ken Nanbu Earthquake of January 17, 1995*, National Center for Earthquake Engineering Research, State University of New York at Buffalo, January 1995.

6 Wyllie, Loring A., Jr., and John R. Filson, eds., *Armenia Earthquake Reconnaissance Report, Special Supplement to Earthquake Spectra*, Earthquake Engineering Research Institute (Oakland, CA), August 1989.

7 "The March 25, 1993, Scotts Mills Earthquake—Western Oregon's Wake-Up Call," *EERI Newsletter*, Vol. 27, No. 5, May 1993.

8 Esteva, Luis, "Seismic Zoning, Design Spectra and Building Codes in Mexico," in *Proceedings of the Fourth International Conference on Seismic Zonation*, Vol. 1, Earthquake Engineering Research Institute, August 1991.

9 This history of seismic codes comes from a number of sources, most notably: Beavers, James E., "Perspectives on Seismic Risk Maps and the Building Code Process," in *A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977–1987*, Walter Hays, ed., U.S. Geological Survey Open-File Report 88-13-A, 1988, 407-432; Whitman, R.V., and Algermissen, S.T., "Seismic Zonation in Eastern United States," *Proceedings, Fourth International Conference on Seismic Zonation*, Vol. I, Earthquake Engineering Research Institute, 1991, 845-869; Martin, H.W., "Recent Changes to Seismic Codes and Standards: Are They Coordinated or Random Events?" *Proceedings, 1993 National Earthquake Conference*, Vol. II, Central U.S. Earthquake Consortium, 1993, 367-376.

10 As part of implementing EO 12699, the Federal Government reviewed all three model codes to see if they were consistent with the 1988 *NEHRP Provisions*. In 1992 they declared that the following codes meet those provisions: 1991 UBC, 1992 BOCA supplement, and the 1992 SBC amendments. See *Guidelines and Procedures for Implementation of the Executive Order on Seismic Safety of New Building Construction*, ICSSC RP2.1A, NISTIR 4852, June 1992. In a May 17, 1995, Recommendation, the Interagency Committee on Seismic Safety and Construction updated this finding. They found that the 1994 UBC, 1993 BNBC, and 1994 SBC provide a level of seismic safety substantially equivalent to that of the 1991 *NEHRP Provisions*.

11 EO 12941, by adopting the *Standards of Seismic Safety for Existing Federally Owned or Leased Buildings*, by the Interagency Committee on Seismic Safety and Construction (ICSSC), promulgates a set of seismic standards for federally owned or leased buildings. It also establishes five triggers for evaluation and possible mitigation of risks in a building. For example, when there is a change of building function, a building must be evaluated according to the ICSSC standards. See Todd, Diana, ed., *Standards of Seismic Safety for Existing Federally Owned or Leased Buildings, National Institute of Standards and Technology Report NISTIR 5382*, Interagency Committee of Seismic Safety and Construction Recommended Practice 4 (ICSSC RP 4), February 1994.

12 From the 1990 SEAOC Blue Book, cited in EERI Ad Hoc Committee on Seismic Performance, *Expected Seismic Performance of Buildings*, Earthquake Engineering Research Institute, February 1994.

13 EERI Ad Hoc Committee; see note 9.

14 The 10-percent-in-50-year standard is actually an artifact from the initial development of the ATC 3-06 maps. The profession has been moving toward a 2-percent-in-50-year standard as being more reflective of public attitudes toward life safety, and this will be reflected in the 1997 *NEHRP Provisions* (Christopher Rojahn, Executive Director of ATC, March 1997).

15 Building Seismic Safety Council, *Societal Implications: Selected Readings*, FEMA #84, June 1985.

16 National Association of Home Builders, *Estimated Cost of Compliance with 1991 Building Code Requirements*, Insurance Research Council, August 1992.

17 Schulze, William D., et al., "Benefits and Costs of Earthquake Resistant Buildings," *Southern Economic Journal*, Vol. 53, April 1987.

18 Litan, Robert, et al., *Physical Damage and Human Loss: The Economic Impact of Earthquake Mitigation Measures*, The National Committee on Property Insurance (now IBHS), February 1992.