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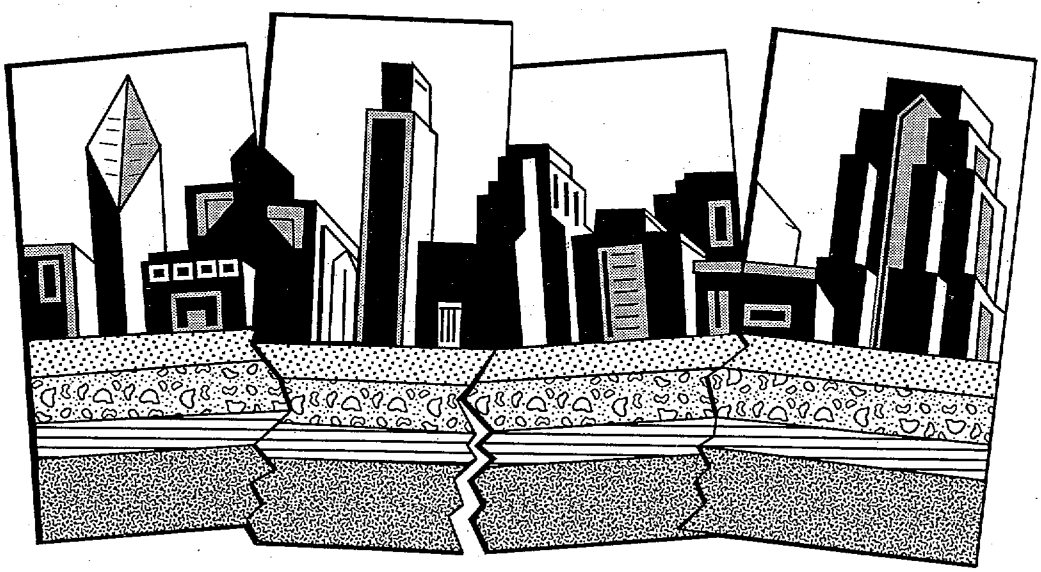
SEISMIC CONSIDERATIONS FOR COMMUNITIES AT RISK



Issued by FEMA in furtherance of the Decade for Natural Disaster Reduction

BUILDING SEISMIC SAFETY COUNCIL

Program on Improved Seismic Safety Provisions

SEISMIC CONSIDERATIONS FOR COMMUNITIES AT RISK

The **Building Seismic Safety Council** (BSSC) was established in 1979 under the auspices of the National Institute of Building Sciences as an entirely new type of instrument for dealing with the complex regulatory, technical, social, and economic issues involved in developing and promulgating building earthquake hazard mitigation regulatory provisions that are national in scope. By bringing together in the BSSC all of the needed expertise and all relevant public and private interests, it was believed that issues related to the seismic safety of the built environment could be resolved and jurisdictional problems overcome through authoritative guidance and assistance backed by a broad consensus.

The BSSC is an independent, voluntary membership body representing a wide variety of building community interests. Its fundamental purpose is to enhance public safety by providing a national forum that fosters improved seismic safety provisions for use by the building community in the planning, design, construction, regulation, and utilization of buildings.

To fulfill its purpose, the BSSC: (1) promotes the development of seismic safety provisions suitable for use throughout the United States; (2) recommends, encourages, and promotes the adoption of appropriate seismic safety provisions in voluntary standards and model codes; (3) assesses progress in the implementation of such provisions by federal, state, and local regulatory and construction agencies; (4) identifies opportunities for improving seismic safety regulations and practices and encourages public and private organizations to effect such improvements; (5) promotes the development of training and educational courses and materials for use by design professionals, builders, building regulatory officials, elected officials, industry representatives, other members of the building community, and the public; (6) advises government bodies on their programs of research, development, and implementation; and (7) periodically reviews and evaluates research findings, practices, and experience and makes recommendations for incorporation into seismic design practices.

BSSC Program on Improved Seismic Safety Provisions

SEISMIC CONSIDERATIONS FOR COMMUNITIES AT RISK

Developed by the
Building Seismic Safety Council
for the
Federal Emergency Management Agency

BUILDING SEISMIC SAFETY COUNCIL
Washington, D.C.
1995

This report was prepared under Contract EMW-90-C-3309 between the Federal Emergency Management Agency and the National Institute of Building Sciences.

Building Seismic Safety Council reports include the documents listed below; unless otherwise noted, single copies are available at no charge from the Council:

The NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for Seismic Regulations for New Buildings, 1994 Edition, 2 volumes and maps (FEMA Publications 222A and 223A).

The NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for the Development of Seismic Regulations for New Buildings, 1991 Edition, 2 volumes and maps (FEMA Publications 222 and 223).

Guide to Application of the 1991 Edition of the NEHRP Recommended Provisions in Earthquake Resistant Building Design, Revised Edition, 1995 (FEMA Publication 140).

A Nontechnical Explanation of the 1994 NEHRP Recommended Provisions, Revised Edition, 1995 (FEMA Publication 99) .

Seismic Considerations for Communities at Risk, Revised Edition, 1995 (FEMA Publication 83).

Seismic Considerations: Apartment Buildings, Revised Edition, 1995 (FEMA Publication 152).

Seismic Considerations: Elementary and Secondary Schools, Revised Edition, 1990 (FEMA Publication 149).

Seismic Considerations: Health Care Facilities, Revised Edition, 1990 (FEMA Publication 150).

Seismic Considerations: Hotels and Motels, Revised Edition, 1990 (FEMA Publication 151).

Seismic Considerations: Office Buildings, Revised Edition, 1995 (FEMA Publication 153).

Societal Implications: Selected Readings, 1985 (FEMA Publication 84).

NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings, 1992 (FEMA Publication 172).

NEHRP Handbook for the Seismic Evaluation of Existing Buildings, 1992 (FEMA Publication 178).

An Action Plan for Reducing Earthquake Hazards of Existing Buildings, 1985 (FEMA Publication 90).

Abatement of Seismic Hazards to Lifelines: An Action Plan, 1987 (FEMA Publication 142).

Abatement of Seismic Hazards to Lifelines: Proceedings of a Workshop on Development of An Action Plan, 6 volumes, 1987.

Strategies and Approaches for Implementing a Comprehensive Program to Mitigate the Risk to Lifelines from Earthquakes and Other Natural Hazards, 1989 (available from the National Institute of Building Sciences for $11).

An Integrated Approach to Natural Hazard Risk Mitigation, 1995 (FEMA Publication 261).

For further information concerning any of these documents or the activities of the BSSC, contact the Executive Director, Building Seismic Safety Council, 1201 L St., N.W., Suite 400, Washington, D.C. 20005.

FOREWORD

The Federal Emergency Management Agency (FEMA) is pleased to have the opportunity to sponsor the Program on Improved Seismic Safety Provisions being conducted by the Building Seismic Safety Council (BSSC). The materials produced by this program represent the tangible results of a significant effort, under way for more than a decade, to lessen adverse seismic effects on buildings throughout the United States.

This community handbook is a companion publication to the 1994 Edition of the *NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for Seismic Regulations for New Buildings*, and it is one of a series of reports produced to increase awareness of seismic risk and to disseminate information on up-to-date seismic design and construction practices. It is designed to provide interested individuals across the nation with information that will assist them in assessing the seismic risk to their buildings and their community and in determining what might be done to mitigate that risk – whether on an individual basis or through community building regulatory action.

This community handbook reflects very generous contributions of time and expertise on the part of many individuals. FEMA compliments the participants in the BSSC program and gratefully acknowledges their efforts.

Federal Emergency Management Agency

ACKNOWLEDGMENTS

This publication was made possible through very generous contributions of time and expertise on the part of many individuals. The Building Seismic Safety Council is particularly grateful to Christopher Arnold of Building Systems Development, Inc., who reviewed this document and provided many of the photographs and illustrations used, and to Michael Mahoney, the FEMA Project Officer whose continuing interest and support have been essential to the success of many of the Council's activities involving the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings*.

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1 INTRODUCTION

". . . without a moment's warning, a subterranean roar was heard, buildings shook from garret to cellar, the fearful noises growing louder and louder, building's swaying to and fro like trees in a storm, and then came the crash of tumbling houses, and simultaneously mingling with those notes of horror, came the shrieks and wailings of frightened women and children."

– newspaper report, Charleston, South Carolina, September 1, 1886

THE SCIENCE OF EARTHQUAKES

Earthquakes have long been feared as one of nature's most terrifying phenomena. Early in human history, the sudden shaking of the earth and the death and destruction that resulted were seen as mysterious and uncontrollable. Often, the upheaval of the ground was seen as an act of retribution by a supernatural power. The Japanese, for example, believed that earthquakes were caused by the stirring of a huge catfish – *Namazu* – who lived in the ocean depths. Nineteenth century Japanese prints show *Namazu* alternatively being attacked by irate citizens whose homes he had destroyed or being wined and dined by building contractors whom he had enriched.

NAMAZU, THE GIANT CATFISH

The theory of plate tectonics proposed in 1969 has removed the mystery by explaining the origin of earthquakes and showing that they must be accepted as a natural environmental process, one of the periodic adjustments that the earth makes in its evolution. This scientific explanation, however, has not lessened the terrifying nature of the earthquake experience. Indeed, in some respects, it has increased it for now, when we tend to expect to control nature's forces to a degree inconceivable only a century or so ago, earthquakes continue to remind us that nature still can strike without warning and, after only a few seconds, leave damage and casualties in its wake. This uncertainty, lack of warning, and instant threat to life contributes to our fundamental fear of earthquakes. Beyond the threat to life is the threat of the destruction of public and private property. Jobs, services, and business revenues can disappear instantly and, for many, homelessness can suddenly be very real.

The aftermath of a great earthquake endures for years or even decades: six years after the Loma Prieta earthquake centered in Santa Cruz County, California, the central retail area of Santa Cruz is still only partially reconstructed and San Francisco traffic remains hampered by freeways still being replaced and repaired.

Although earthquakes cannot be prevented, modern science and engineering provide tools that can be used to reduce their effects. Science can now identify, with considerable accuracy, where earthquakes are likely to occur and what forces they will generate while engineering permits the design and construction of structures that will survive these forces.

Seismic safety, however, is a complex issue that involves life safety, community values, and a relatively uncommon hazard. Since scientific seismic hazard information understandable to those who are not scientists often is not available, a community's public officials, building professionals, and citizenry may not even realize that a seismic hazard exists, let alone understand the risk that it poses.

Several misconceptions contribute to this lack of appreciation for seismic risk in many U.S. communities. Consider the following true or false questions to determine your level of earthquake awareness:

- **Since most Americans have not experienced a large, damaging earthquake, it is unlikely that they will during their lifetime.**

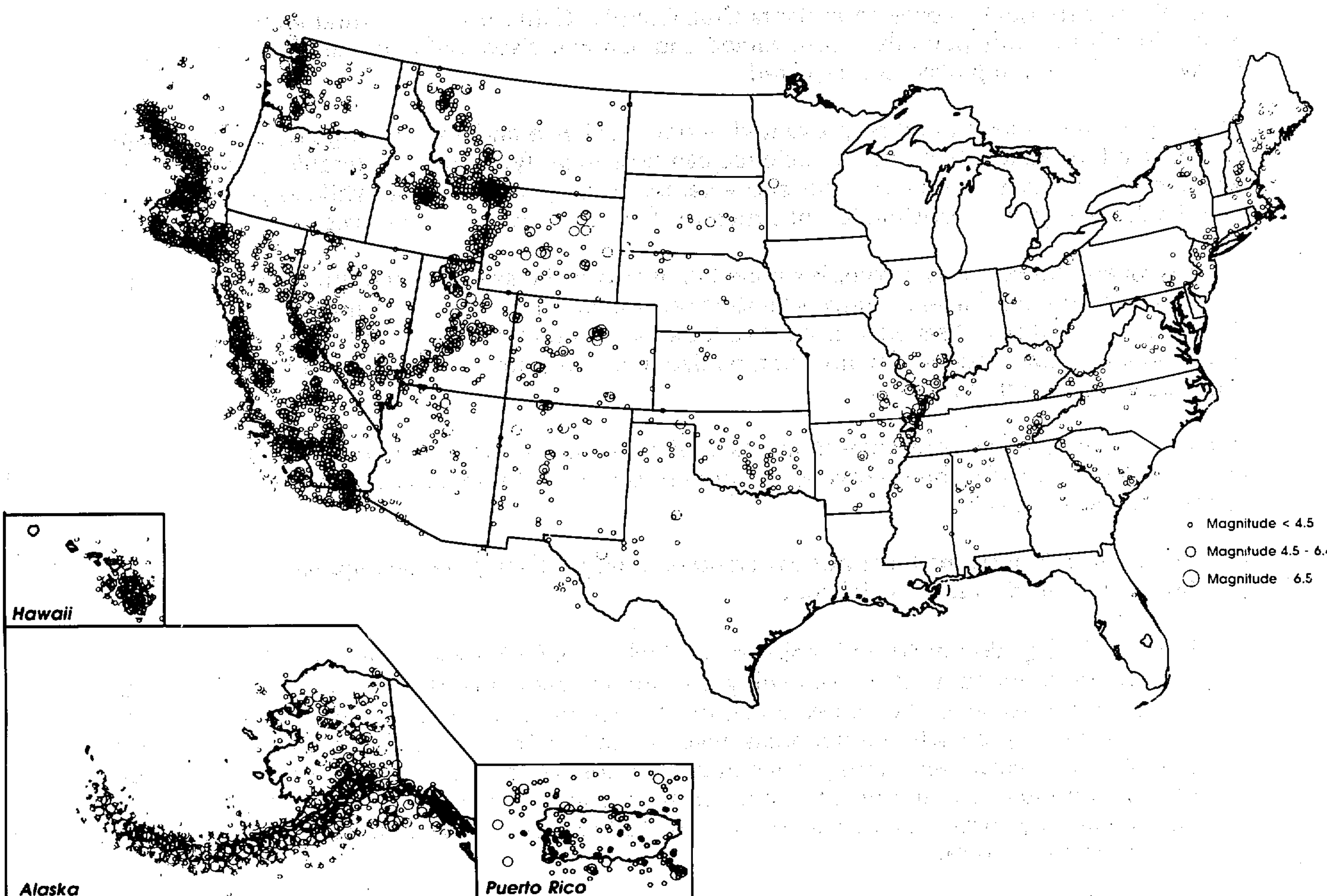
  FALSE! Earthquakes occur in "geologic time" which is far "slower" than that which we usually use to judge whether something is of immediate concern to us. Records show that some seismic zones in the United States experience moderate to major earthquakes about every 50 to 70 years while other areas have "repeat" or "recurrence" intervals of about 200 to 400 years. However, these probabilities or "odds" are simply best estimates, and one or several earthquakes could occur in a much shorter-than-average period. The rule of thumb cited by some seismic experts is: "The further you are from the last one, the closer you are to the next one."

- **Earthquakes occur only in a few places in the United States, primarily California and Alaska.**

  FALSE! As indicated in the map on the next page, more than 40 of the 50 states as well as many U.S. territories and possessions are at some risk from earthquakes. In fact, the greatest U.S. earthquakes occurred not on the West Coast, but in the East and Midwest.

- **Local building codes and regulations in areas of seismic risk generally include seismic safety provisions.**

  FALSE! The building codes in many communities at risk from earthquakes include no seismic provisions.



Seismicity of the United States: 1899 - 1990 (from the U.S. Geological Survey National Earthquake Information Center, prepared by Susan K. Goter).

- **If a community's building regulations include seismic provisions, there will be no damage to the buildings designed under those regulations.**

  FALSE! As with building codes in general, the principal purpose of seismic code provisions is to put forth minimum standards to ensure public safety, health, and welfare insofar as they are affected by building design and construction. Because of the many variables concerning the nature, extent and frequency of earthquake forces, measures essential to ensure total safety from earthquakes would be prohibitively expensive. Thus, seismic code provisions usually reflect some degree of compromise. Seismic code provisions generally are formulated to ensure that structures resist minor earthquakes without damage, resist moderate earthquakes without structural damage but suffer some nonstructural damage, and resist major earthquakes without collapse but with some structural as well as nonstructural damage. This approach is based on the study of many earthquakes where it has been shown that structural collapse is the overwhelming cause of life loss and serious injury. It is important to understand, however, that damage may occur in even a very well designed building if it is subjected to the effects of a violent or severe earthquake.

- **Requiring seismic design and construction for new buildings will not really lessen a community's risk because of all the existing buildings that were not built to resist earthquakes.**

  FALSE! With respect to the seismic hazard, there is no doubt that those buildings not designed to resist earthquakes are at some risk. In areas where earthquakes occur often and seismic design for new buildings has been required for many years (for example, in California), efforts to rehabilitate existing buildings to resist earthquakes are being given considerable attention even though they are expensive. In the eastern and central states, however, where seismic requirements for new buildings have been the exception rather than the rule, it is most reasonable to start by protecting new construction. After addressing new construction, a community should at least evaluate its existing building inventory to determine whether certain important facilities that are expected to remain in service for a long period of time (for example, schools and hospitals) should be rehabilitated to resist earthquakes.

No matter how well or how poorly you scored on this quiz, once you and other concerned individuals in your community seriously consider the social, economic, and legal implications of the earthquake risk to buildings and to those who occupy them, you will actively support efforts to improve the seismic resistance of these facilities.

NEED FOR LOCAL SEISMIC HAZARD ASSESSMENT

Those responsible for or concerned about a community's buildings first need to research the local seismic situation to determine the community's seismic hazard. Once this is done, an individual or a community as a whole will have a rational basis for deciding how much seismic risk to accept and the degree to which the risk should be lessened. The adoption of building code regulations based on up-to-date seismic safety design provisions like the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings* is generally considered to be one significant way of lessening the risk to life by requiring that new buildings be designed and constructed in a manner that will prevent their structural collapse during an earthquake.

IMPLICATIONS OF SEISMIC DESIGN

The use of seismic design provisions can affect a building owner or a community in various ways and to varying degrees. Among the major factors to be considered are the following:

- Buildings designed and constructed in accordance with up-to-date seismic provisions can be expected to reduce life loss, injuries, and property damage when an earthquake occurs. For an individual building owner, this should reduce the cost of repairs and minimize the amount of time that the building cannot be used. For a community, this should reduce the costs of emergency response and recovery, keep essential facilities operational, and lower the cost of replacing public buildings.

- The possibility of costly litigation concerning liability for earthquake effects most likely would be reduced for all those involved in the building process.

- Requiring seismic design and construction of new buildings may increase costs but far less than many people think. From a community's perspective, these increased costs could result in a reduced supply of housing and of industrial and commercial facilities, reduced availability of housing or other facilities to a particular income segment of the market, and/or a loss of business development (and the accompanying jobs and tax revenues) to neighboring jurisdictions that do not enforce seismic regulations.

The degree to which these effects will be felt depends on several factors including the nature of the seismic hazard, the degree of seismic risk that a building owner or a community deems to be acceptable, and the extent to which something has already been done to mitigate the risk. A variety of community members with different roles and varying interests will play a part in assessing the significance of these effects and the decision each makes will reflect his or her view of what is important.

CONTENTS OF THIS BOOK

The remainder of this book is structured to provide both concerned individuals and community decision-makers with information they can use in assessing their situation and in making more informed and reasoned decisions. It is intended for a broad audience composed of both those who have little specific knowledge about building regulation, seismic phenomena, design, and engineering and for those who are somewhat familiar with these concepts. Specifically, the remainder of this book provides information on:

- Who and what is at risk in Chapter 2,
- What earthquakes do to buildings in Chapter 3,
- Seismic codes and the importance of the *NEHRP Recommended Provisions* in Chapter 4,
- How to stimulate community action in Chapter 5, and
- Some factors to be considered in deciding whether and how to take action to mitigate the risk from earthquakes in Chapter 6.

Appendices provide readers with additional helpful information:

- Appendix A defines terms and concepts frequently used in discussions of seismicity and seismic design and construction;
- Appendix B explains the U.S. building regulatory system;
- Appendix C explains the nature of earthquake ground motion and how buildings can be designed and constructed to resist earthquakes;
- Appendix D presents an overview of U.S. seismicity; and
- Appendix E lists organizations, publications, and electronic resources that offer more specific information and assistance.

Readers not deeply involved with the building process are encouraged to read Chapters 2 through 6 and then to pursue those topics covered in the appendices that are of special interest to them. Although Appendix C presents information that is relatively technical, the nontechnical reader is urged to at least scan this appendix since it features a number of illustrations that may help to clarify important aspects of earthquake effects on buildings and the importance of seismic design.

2 IS MY COMMUNITY AT RISK?

"Recent major earthquakes . . . attest to the need for considering such natural hazards, their possibility of occurrence and their consequences. Because our expanding population is concentrated in large metropolitan centers with a proliferation of man-made structures and facilities, the number of incidents and extent of the consequences . . . from such disasters can be expected to increase in the years ahead. Even in geographical areas where seismic risk is assumed to be low, as in the eastern United States, consequences of a possible large earthquake are serious and require careful consideration."

– N. M. Newmark and W. J. Hall, University of Illinois

WHO IS AT RISK?

A severe earthquake is one of nature's most terrifying and devastating events, and collapsing structures and falling debris do most of the killing. The Loma Prieta and Northridge earthquakes in California in 1989 and 1994, respectively, and the Kobe earthquake in Japan in 1995 showed the nation just how horrifying an earthquake is while also illustrating that modern buildings, designed and constructed under up-to-date seismic regulations, will perform well. Such regulations, however, have not been adopted in many areas of high to moderate seismic risk in the United States.

Many people assume that earthquakes are primarily confined to the West Coast when, in fact, more than 70 million Americans in 44 states are at some risk from earthquakes (see Appendix D for an overview of U.S. seismicity). Indeed, three of the most severe U.S. earthquakes occurred, not on the West Coast, but in the East and Midwest: in Charleston, South Carolina, in 1886; at Cape Anne, Massachusetts, in 1755; and in New Madrid, Missouri, in 1811-12. The New Madrid event involved a series of three major shocks that affected a 2 million square mile area, which is equal to about two thirds of the total area of the continental United States excluding Alaska. The Charleston earthquake also had a "felt" area of 2 million square miles.

Unfortunately, scientists cannot now predict precisely when and where a damaging earthquake will occur or anticipate accurately the range of damaging effects. This lack of detailed knowledge leads some people to believe the risk is minimal. This is especially true in areas east of the Sierra Mountains. Nevertheless, the forces that caused major shakes in the past in the eastern and central states have not dissipated, and seismic specialists expect damaging earthquakes to occur again in these areas even though they cannot predict exactly when or precisely where they will happen. In this respect, it should be noted that an earthquake of a given size or magnitude will affect a much larger area in the eastern and central states than it will on the West Coast because the ground in the eastern and central portions of the country transmits certain earthquake waves much farther.

WHAT IS AT RISK?

Of most serious concern is the high concentration of population and structures in areas that were only sparsely populated at the time of the last major quake. If the earthquakes that occurred in the New Madrid area in 1811-12 were to occur again today, they would affect 2,400,000 people and 24 sizeable cities located in 7 states (Missouri, Arkansas, Mississippi, Tennessee, Kentucky, Indiana, and Illinois) and would fall within the responsibilities of 4 separate federal regions. Such an earthquake event would significantly disrupt major commercial distribution networks, oil and gas pipelines, and interstate commerce and would cause thousands of casualties and leave many more homeless. Further, the several major tremors that occurred in the 1811-12 event were followed by two years of aftershocks that were sizeable tremors in their own right. Even moderate earthquakes can do significant damage, and Chapter 3 presents photographs of typical damage from a number of such earthquakes.

Between 1900 and 1986, about 3,500 lives were lost as a result of earthquakes in the United States and property damage amounted to approximately $5 billion (in 1979 dollars). Since 1987, however, earthquake-related property damage has more than exceeded that amount. The 1987 Whittier Narrows earthquake in the Los Angeles area caused three deaths and over $350 million in property damage, the 1989 Loma Prieta earthquake in the San Francisco Bay area caused 62 deaths and over $5 billion in property damage, and the 1994 Northridge earthquake in the Los Angeles/San Fernando area caused 57 deaths and over $20 billion in losses (if the Northridge earthquake had occurred a few hours later on a normal workday instead of a public holiday, the death toll could easily have run into the thousands).

WHAT SHOULD BE DONE?

Many variables contribute to seismic activity. The nature of the hazard varies considerably throughout the United States and so do the risk and the vulnerability of different communities. Thus, it is very important that the nature of the hazard in a specific community be understood. One cannot simply adopt the ordinance, program, or approach of a community in one seismic area and expect that it will be technically appropriate or useful in a different community in another seismic area. What works in a medium-size community in California, for example, is unlikely to work in a small town in Missouri.

Communities throughout the United States therefore need to assess their seismic situation and take into account the amount of development that has occurred and the highly populated areas that now exist in areas at risk from moderate and major earthquakes. It is especially important that cities east of the Sierra Mountains give more attention to these issues so that they can adequately assess the need for seismic-resistant construction techniques for their buildings and other essential structures.

INFORMATION SOURCES

To obtain the information needed to define your community's seismic situation, contact:

- Geologists, geophysicists, and seismologists at your local academic institutions;
- Your state's geologist;
- Regional offices of the Federal Emergency Management Agency (FEMA) and U.S. Geological Survey (USGS) and the Internet resources offered by these agencies; and
- National and regional earthquake information organizations.

The names and addresses of many sources of information are listed in Appendix E as are publications that will provide additional information. Information from FEMA is available on the Internet at http://www.fema.gov. For the USGS, go to http://geology.usgs.gov. Other electronic resources on earthquakes also are available on the Internet and many are listed in Appendix E.

A general discussion of seismic phenomena is included in Appendix C of this handbook and an overview of U.S. seismicity appears as Appendix D.

3 WHAT HAPPENS TO STRUCTURES WHEN THE GROUND MOVES?

". . . the road was swaying from side to side. . . . there was great, dramatic side to side movement. There was also up and down movement. The car felt like it was bouncing up and down, but the side to side movement was greater than the up and down movement. . . ."
– report by survivor of the Cypress Freeway collapse, Loma Prieta earthquake, 1989.

This book focuses on the risk posed by and to buildings in earthquakes and the steps that can be taken through building regulation and voluntary design education to reduce this risk. First and foremost is the risk to human life in houses, at offices, in schools, in shops and malls, at places of recreation where thousands of people may gather to watch a sporting event or concert, and elsewhere. Beyond the risk to life is the economic and social disruption caused by an earthquake; even moderate earthquakes can result in the loss of many homes, jobs, investments, and community resources.

While earthquakes cause damage and disruption to utilities such as water and power services, these problems are relatively short-lived because utility companies encounter outages and disruption on a normal basis and are equipped to deal with them. Earthquakes may cause severe damage to transportation systems such as railroads and freeways, and collapsing bridges and overpasses may cause injury and death – like that which occurred in the 1989 Loma Prieta earthquake and the 1985 Northridge earthquake in California. These are special problems, however, and need to be dealt with primarily by state transportation agencies. In essence, improving the seismic resistance of buildings is seen as the key to reducing the earthquake threat to the public at large and to the community.

Issues of health and safety in buildings typically are regulated by building codes written to ensure that some minimal standards of design and construction are adhered to for potentially dangerous aspects of buildings. These codes generally establish such things as maximum loads so that floors of a building will not collapse because they are overloaded with people and equipment and the minimum height of a balcony railing so people will not fall over it. These regulations ensure a common minimum standard of safety and mean that building designers work to meet common criteria and do not have to try and solve all the problems of building design on their own every time a new building is planned.

In regions of the United States such as California and Alaska where earthquakes are frequent, seismic codes have been developed and enforced by local communities for many decades, and most existing buildings have been designed with earthquakes in mind. However, since the "science" of earthquake-resistant building design is a relatively new field (the first seismic codes were enforced in California only in 1927), buildings designed to earlier codes are not now necessarily assumed to be safe, and work continues in these regions to, in some instances, strengthen and improve buildings designed to meet the provisions of the earlier codes and to improve the codes.

In regions of the country where the seismic threat has not been accompanied by the continual occurrence of earthquakes the story of different. There may be large inventories of buildings at risk that were designed with no consideration of the seismic problem, and new buildings may still be constructed every year that add to this inventory. When the inevitable large or even moderate earthquake occurs , these buildings may suffer devastating losses. For example, earthquake experts cite the terrible damage to the city of Kobe in Japan where over 5,000 people lost their lives in the January 1995 earthquake. This region had been clearly earmarked as an earthquake hazard area by the seismologists and earth scientists, but because a severe earthquake had not affected the city for several hundred years, its buildings (although designed to a seismic code) were vulnerable and its population and government emergency response services were largely unprepared.

For communities where a significant earthquake has not occurred in the lifetime of its citizens, the experience of an earthquake is hard to imagine and it is difficult to visualize what an earthquake would do to familiar buildings and other structures. This chapter of *Seismic Considerations for Communities at Risk* is intended to give readers some idea of the sort of damage that earthquakes do to buildings. The photographs generally show the results of California and Alaska earthquakes and, for the most part, show older buildings designed to lower-than-present-day standards or, in the case of unreinforced masonry buildings, designed prior to the adoption of seismic codes.

As noted earlier, in the less active seismic regions of the country, limited resources may permit the seismic strengthening of only a few critical or valuable existing buildings, but such regions quite likely have the advantage of time – that is, a crippling earthquake is less likely to occur in the near future, thus giving communities in these regions the opportunity to at least ensure that new buildings are designed to meet up-to-date seismic standards while ridding themselves of the most hazardous existing buildings through the normal cycle of building decay, removal, and replacement.

UNREINFORCED MASONRY BUILDINGS

Unreinforced masonry buildings have long been identified as performing very poorly in earthquakes. Unreinforced masonry buildings typically have brick or block bearing walls and wood-framed floors and roofs. The floors and roofs tend to pull away from the walls and collapse; the upper portions of walls, particularly parapets, tend to fall and, depending on the quality and age of the mortar, walls tend to disintegrate.

In California, the state requires that all cities develop an inventory of their unreinforced masonry buildings and devise a plan for their demolition or improvement. In Los Angeles, an ordinance was enforced in 1981 that required all owners of unreinforced masonry buildings to demolish or strengthen them. By 1995, essentially all 8,000 buildings of this type had either been demolished or strengthened. The 1994 Northridge earthquake showed a notable improvement in the performance of these types of buildings compared to earlier earthquakes – no one was killed and injuries were minimal. San Francisco and a number of other California cities now have similar ordinances in effect.

Typical damage to unreinforced masonry buildings on the main street of Coalinga, California, after the 1983 earthquake (Chris Arnold, Building Systems Development, Inc.).

Typical upper wall failures after the 1987 earthquake in Whittier, California (Chris Arnold, Building Systems Development, Inc.).

Upper wall failure in San Francisco, California, after the 1989 Loma Prieta earthquake; this collapse killed six people in cars parked beneath the wall (Chris Arnold, Building Systems Development, Inc.).

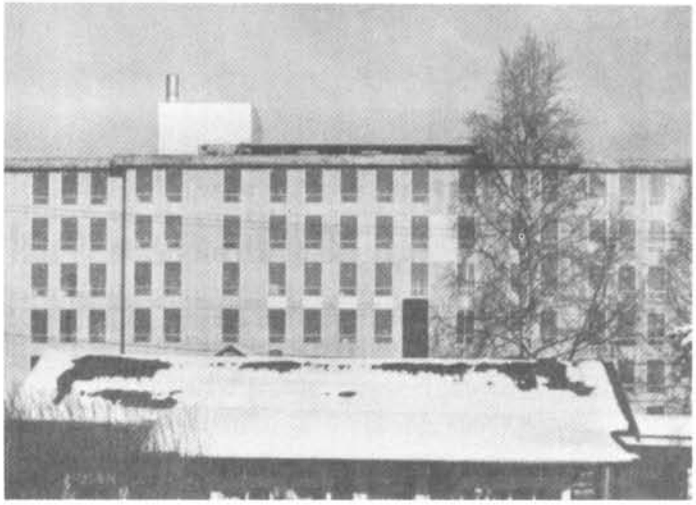
REINFORCED CONCRETE BUILDINGS

Older reinforced concrete structures designed before the characteristics of the material were fully understood have suffered severe damage in earthquakes. Unless heavily reinforced with steel, concrete is a brittle material that tends to fail without warning. In foreign countries, earthquakes have caused many total collapses but, in California and Alaska, total collapses have been few. Irreparable damage, however, has been significant. Frame structures with few structural walls suffer the most damage, and the problem is less acute for structures with many concrete walls. Seismic codes in force since the 1970s require special reinforcing that greatly reduces the possibility of these brittle failures.

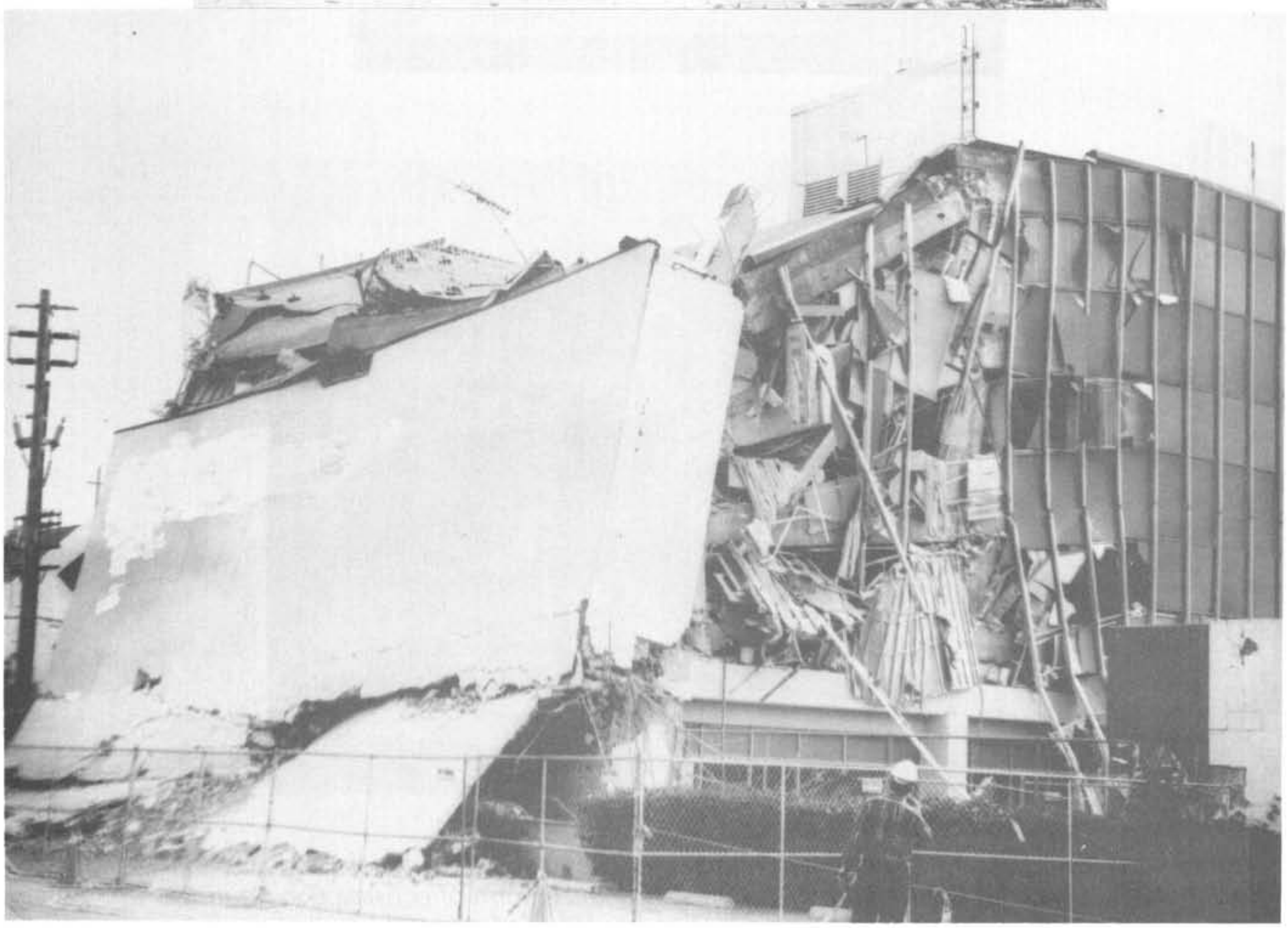
Precast concrete structures and the "tilt-up" type of reinforced concrete construction often used for industrial and commercial buildings also have suffered badly in earthquakes. In these types of structures, the damage has been due primarily to inadequate connections between the precast members or between the walls and roof.

Olive View hospital was badly damaged in the 1971 earthquake in San Fernando, California, primarily because of a "soft story" condition – that is, its lower two floors were much more flexible than the upper floors causing failure where the structure changed from flexible columns to stiff walls.

Staircase towers at Olive View hospital collapsed, rendering evacuation of patients much more difficult; two patients were killed at this hospital because their life-support system failed, and one maintenance worker was killed by a falling canopy.



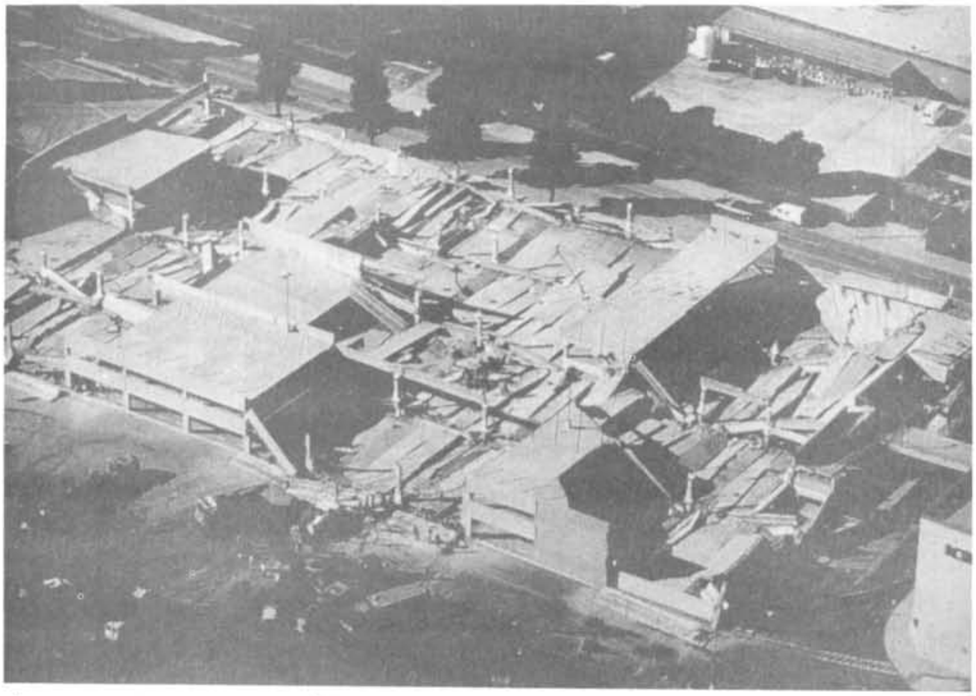
The six-story Four Seasons apartment building in Anchorage, Alaska, before and after the 1994 earthquake. It was designed with pre-cast lift-slab floors (a form of construction no longer in use). The earthquake forces were resisted by two poured-in-place reinforced concrete towers. However, in the 1964 Anchorage earthquake, both towers proved to have inadequate strength to resist the lateral forces; they fractured at the first floor and toppled over; when the slabs tore loose from the towers, the whole building collapsed. Fortunately the building was still under construction (though structurally complete) and was unoccupied.



This older medical office building suffered partial collapse at each end and the entire second floor collapsed as a result of the 1994 earthquake in Northridge, California. The building was unoccupied due to the early morning hour at which the quake occurred (Chris Arnold, Building Systems Development, Inc.).

This office building lost its end wall in the 1994 Northridge earthquake; the end wall was nonstructural and inadequately attached to the building. The comparable wall at the other end of the building was damaged but did not detach (Chris Arnold, Building Systems Development, Inc.).

This large commercial building, which had tilt-up concrete walls and a wood roof, lost its end wall in the 1994 Northridge earthquake. The wall was inadequately attached to the roof and movement of the heavy storage racks that now appear to support the roof may have helped to push the wall down (Chris Arnold, Building Systems Development, Inc.).



Failure of a precast concrete parking structure in the Northridge earthquake; the joints were unable to resist the earthquake forces (Earthquake Engineering Research Institute).

COMMERCIAL AND RESIDENTIAL BUILDINGS

This steel frame and reinforced masonry commercial building suffered a partial collapse in the 1994 Northridge earthquake; it had to be demolished (Chris Arnold, Building Systems Development, Inc.).

This older San Francisco apartment house has a soft story because the garage floor is much weaker than the upper floors. It almost collapsed in the 1989 Loma Prieta earthquake (Chris Arnold, Building Systems Development, Inc.).

This apartment house had a soft first story that completely disappeared during the 1994 Northridge earthquake crushing a number of parked cars. This was a fairly new building, but the earthquake found the weak points of the seismic design (Chris Arnold, Building Systems Development, Inc.).

Northridge earthquake damage to another new apartment house with a soft first story created by ground floor parking (Chris Arnold, Building Systems Development, Inc.).

The Northridge Meadows apartment house with a soft first story. It collapsed in the Northridge earthquake and 16 people were killed (Earthquake Engineering Research Institute).

A common example of damage to an older single-family residence as a result of the 1983 earthquake in Coalinga, California. The wood frame was too weak to support the heavy roof (Chris Arnold, Building Systems Development, Inc.).

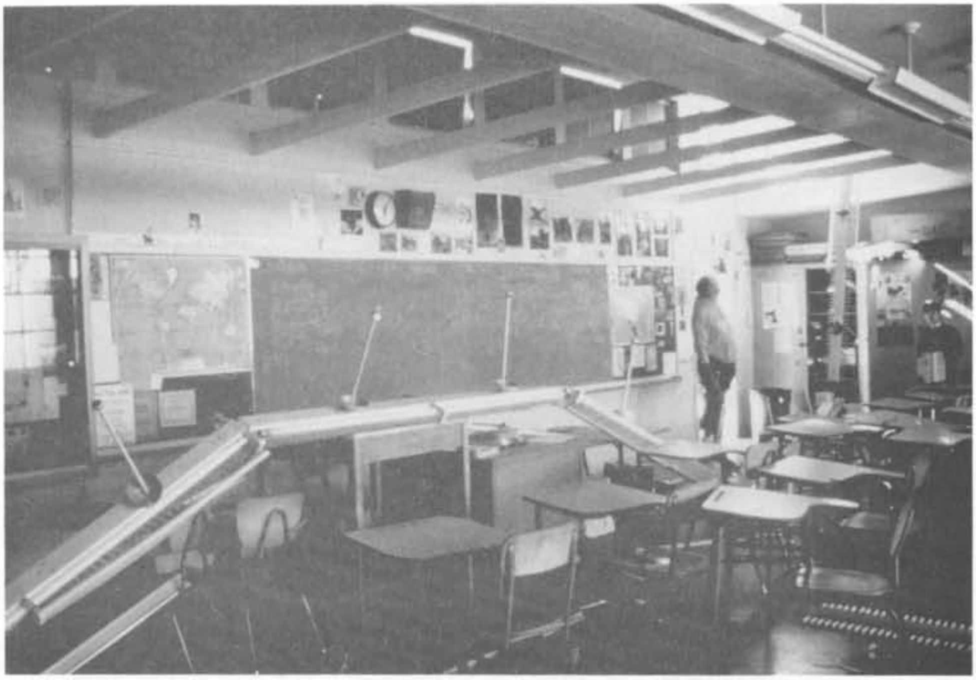
Typical damage to a single-family residence caused by inadequate bracing of the "cripple wall" – the short stud wall between the foundation and the first floor. This type of failure causes costly damage but the problem can be solved easily by bracing the walls with plywood (Chris Arnold, Building Systems Development, Inc.).

NONSTRUCTURAL DAMAGE

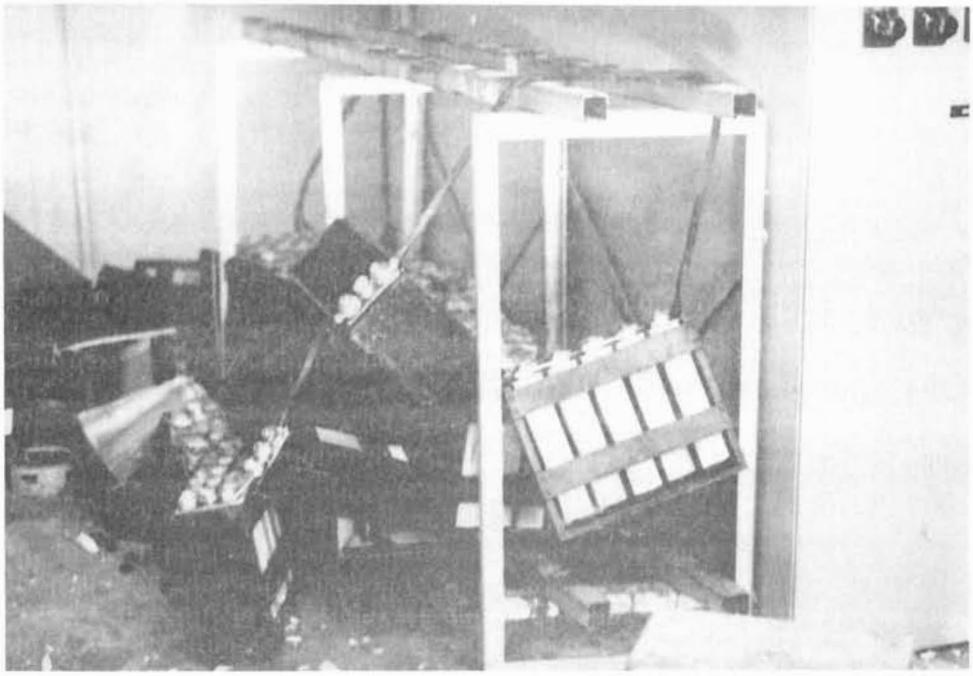
In a typical building the structural components (floor and roof structure, bearing walls, columns, beams, and foundations) account for only about 15 to 20 of the construction cost: the nonstructural architectural, mechanical and electrical components make up between 70 and 85 percent of the building's replacement value.

All these nonstructural components are subject to damage, either directly due to shaking or because of distortion due to movement of the structure. Building occupants are particularly vulnerable to nonstructural damage, and people outside have been injured and even killed by falling parapets and glass. Fires and explosions have been caused by damaged mechanical and electrical equipment. Moreover, nonstructural damage is very costly to repair, and can occur when there is little or no structural damage. It has been estimated that, in recent earthquakes, many buildings with no serious structural damage have suffered considerable nonstructural damage, sometimes totaling as much as 50 per cent of the building's replacement value.

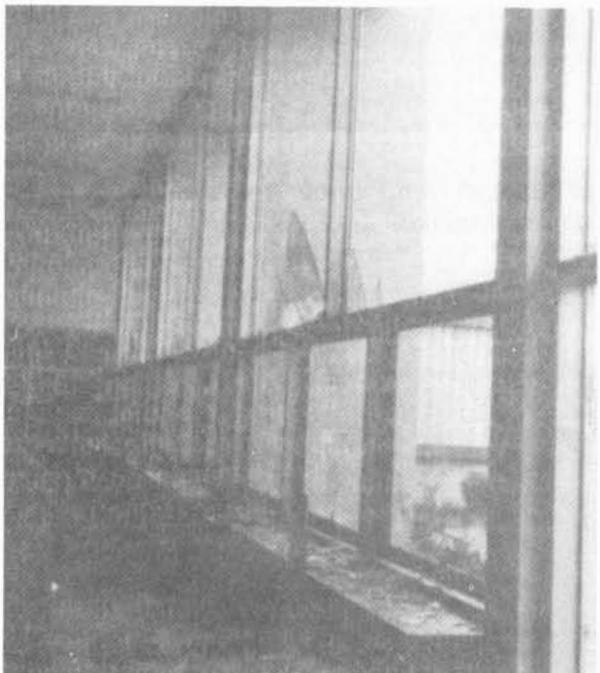
In addition, nonstructural damage causes operational disruption, and a building may be unusable for months while nonstructural damage is repaired. This may represent a crippling financial loss to the owners and employees.



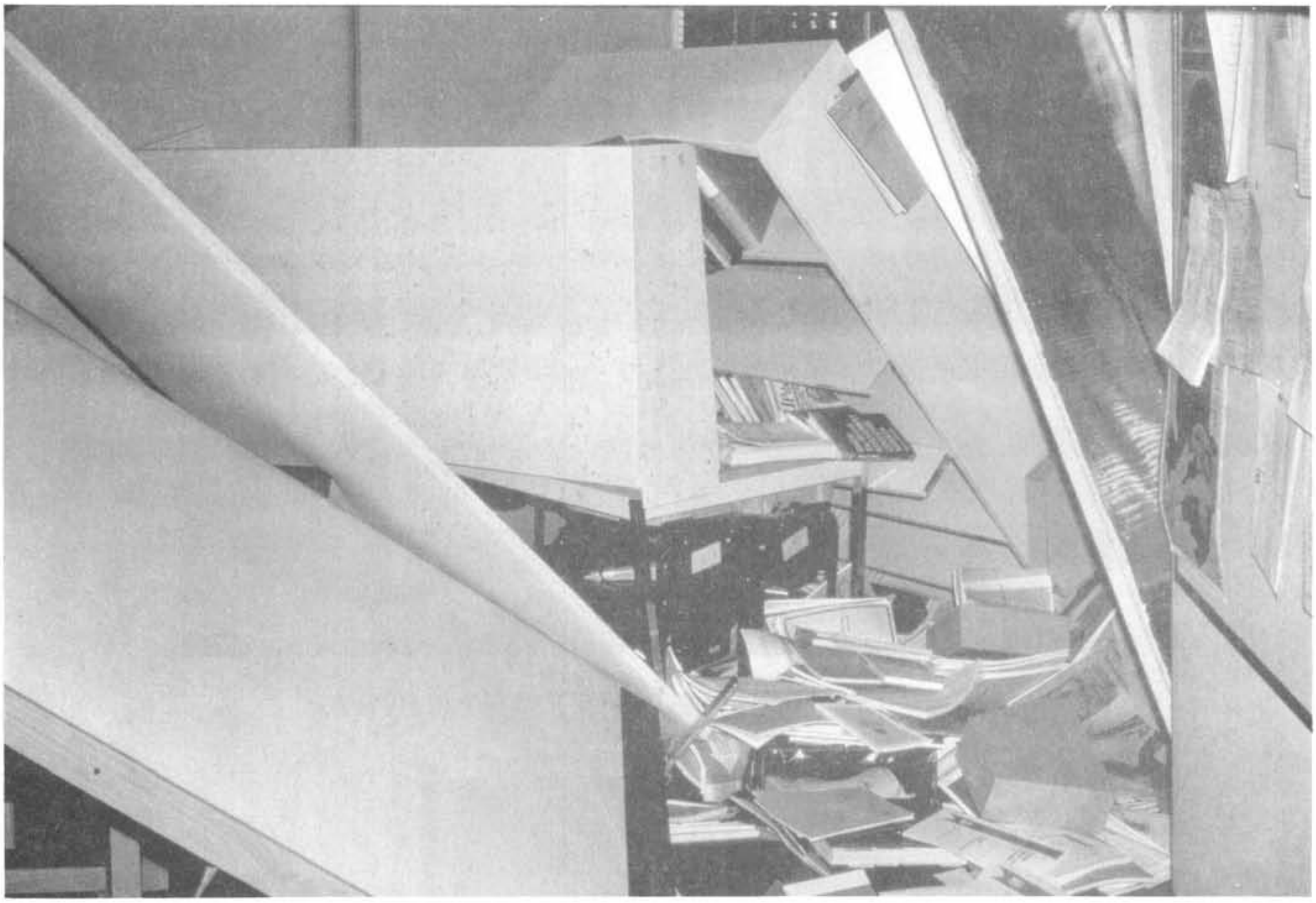
Fallen light fixtures in a school after the 1994 Northridge earthquake (Gary McGavin).



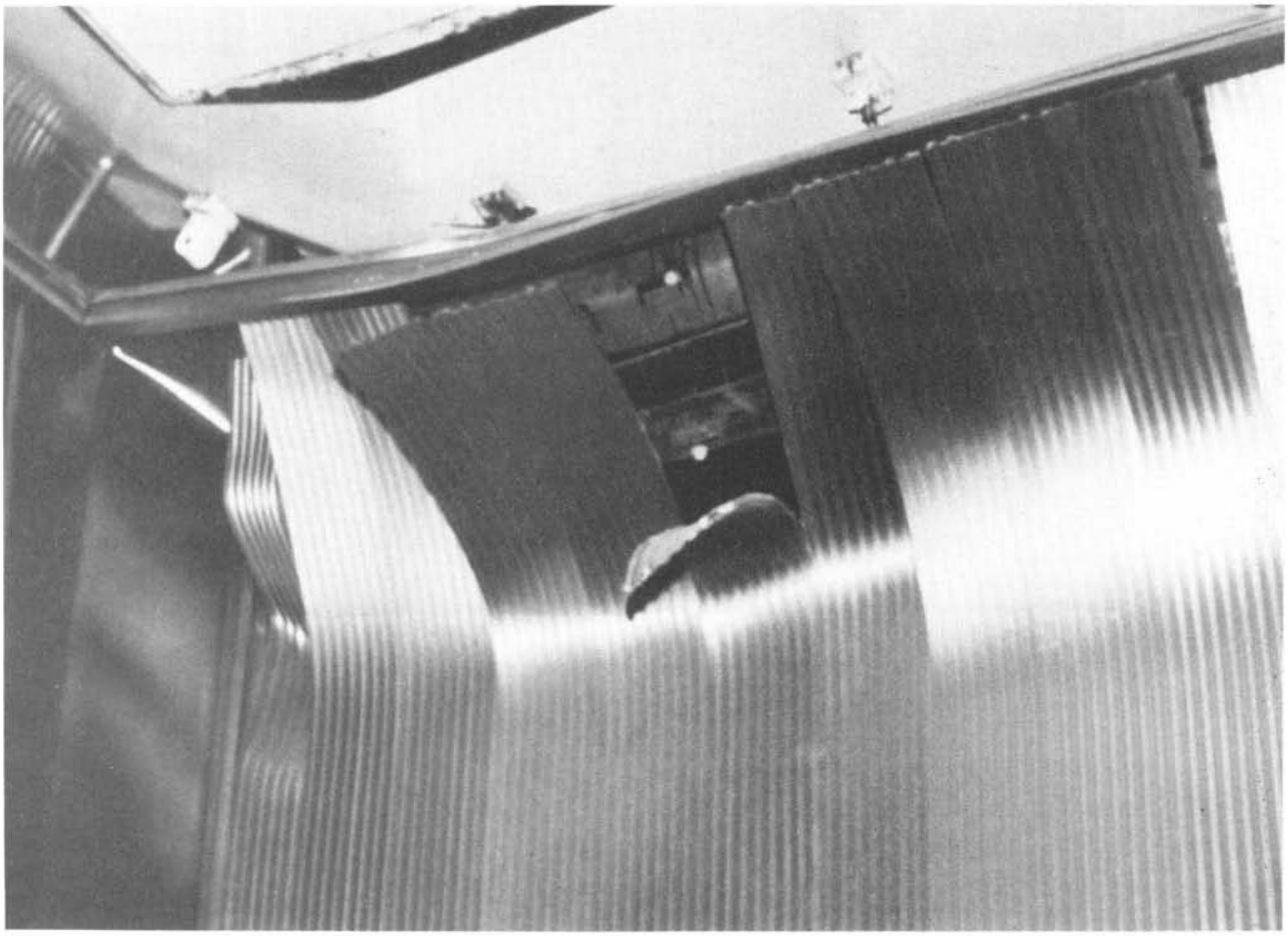
Collapsed battery racks for emergency electrical supply.



Damage to junior high school classroom in 1983 Coalinga earthquake. If the students had been in the room, serious injuries might have occurred.



Damage to the furniture and contents in the upper floors of an open planned office after the 1984 Morgan Hill, California, earthquake. There was no structural damage to this building.

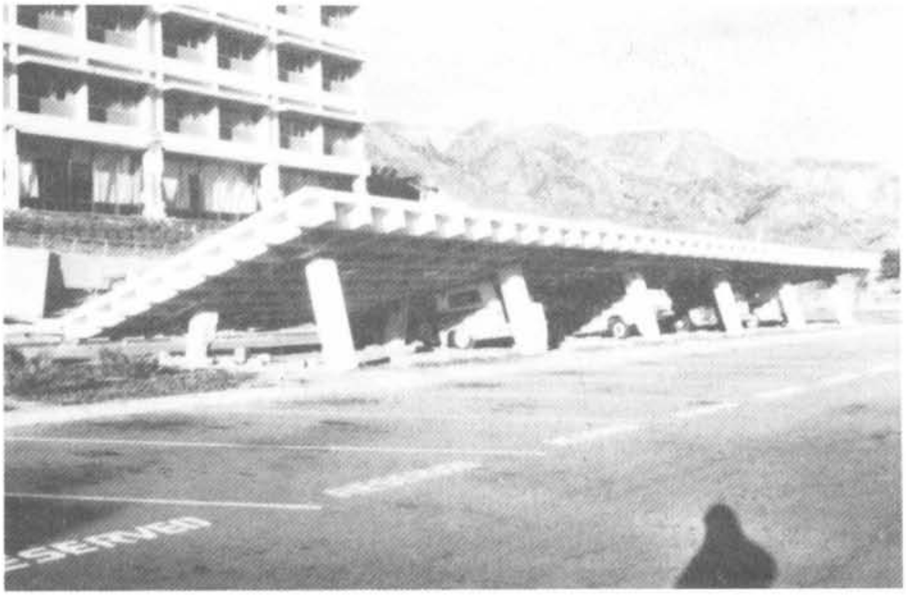


Earthquake damage to an elevator.

Exit corridor in Olive View Hospital after the 1971 San Fernando earthquake.

Stairway blocked by falling wall and ceiling materials.

Hallway blocked by fallen ceiling materials.



Parking canopy collapsed on ambulances at Olive View Hospital as a result of the 1971 San Fernando earthquake.

4 CODES, STANDARDS, AND THE *NEHRP RECOMMENDED PROVISIONS*

"To many members of the design and construction industry, codes and standards can be intimidating, complicated, and vastly confusing with variations both among and within jurisdictions."
—An Architect's Guide to Building Codes and Standards, AIA 1991.

"In reality, the quality of a building depends much more upon the talent of the engineer, the architect, and the builder than it does upon the code.
—James Gere and Haresh Shah, Terra non Firma, 1984

CODES, PROVISIONS, AND STANDARDS

A building code is a set of legal requirements intended to ensure that a building is so located, designed, and constructed that, if it is subjected to natural or man-made destructive forces, it will present no significant threat to the life, health, or welfare of its occupants or the general public. In addition, a code is intended to ensure *uniform minimum standards of health and safety* with reasonable economy and to obviate the need for expensive and difficult studies for every building project, large or small.

In the absence of a code that covers earthquake resistance, seismic design would require lengthy consultations with geologists, seismologists, and engineers every time a new building was planned. As a result, buildings in the same general location probably would be designed using different assumptions concerning earthquake forces and engineering design depending on the opinions and knowledge of the people involved.

Seismic codes are based on knowledge derived from experience, laboratory testing, and theoretical analysis. The *NEHRP Recommended Provisions* is a source document providing a knowledge base that represents a consensus, both of seismic experts and affected members of the building community, on the most up-to-date criteria for designing buildings against earthquake effects. The full title of the current edition of the document is *NEHRP Recommended Provisions for Seismic Regulations for New Buildings, 1994 Edition: Part 1, Provisions, and Part 2, Commentary*; maps also are included (FEMA Publications 222A and 223A. (The two-part document and maps is referred to in this publication as the *Provisions*.)

Thus, the *Provisions* is not a code but can serve as the basis for a code or be incorporated into an existing code. (How building codes are used to regulate design and construction in the United States is explained in Appendix A.)

Both codes and the *Provisions* may refer to *standards*. Standards present acceptable design and construction criteria developed by those with expert knowledge, but they are not law unless incorporated by reference within a code. Standards provide for levels of design, manufacturing, and construction that often are embodied in codes. In addition, standards often are voluntarily used by designers to specify the quality of materials and components of construction.

Building codes do not explain how to design a building. Rather, they provide the minimum criteria and standards to which a building must be designed and assume that the designer is a professional who is knowledgeable about the nature of the seismic hazard in general and is experienced in earthquake-resistant building design.

THE IMPORTANCE OF THE *PROVISIONS*

The goal of the *Provisions* is:

> ". . . to present criteria for the design and construction of new buildings subject to earthquake ground motions in order to minimize the hazard to life for all buildings, to increase the expected performance of higher occupancy structures as compared to ordinary structures, and to improve the capability of essential facilities to function after an earthquake. To this end, the *Provisions* provides the *minimum criteria considered prudent and economically justified* for the protection of life safety in buildings subject to earthquakes at any location in the United States. The *Provisions* document has been reviewed extensively and balloted by the building community and, therefore, it is a proper source for the development of building codes in areas of seismic exposure."

Even if it were technically possible to design for "zero risk," economic considerations would prevent any such attempt as would requirements concerning building function and appearance. Thus, the *Provisions* and seismic codes and standards reflect some degree of compromise.

The objective of the *Provisions* therefore is to present the *minimum requirements* to provide reasonable and prudent life safety for building occupants. For most structures designed and constructed according to the *Provisions*, it is expected that structural damage from even a major earthquake would likely be repairable; however, this would depend upon a number of factors including the type, materials, and details of construction used. For ground motions larger than the design levels, the *Provisions* intend to reduce the likelihood of building collapse; however, it is possible that a building would be damaged beyond repair.

Prediction of building performance in earthquakes is uncertain, and building owners and the public are increasingly concerned about possible damage, particularly since it is now generally acknowledged that adherence to seismic building codes cannot *guarantee* a damage-free structure.

A building code, or set of guidelines such as the *Provisions*, cannot solve the whole problem of building safety. The 1994 *Provisions* discusses the uncertainty in a number of the quantities that are used to determine the forces on the building and how the building will resist them. For example, the estimate of the seismic hazard – the size of the earthquake – may be overestimated or underestimated by as much as 100 percent, and the properties of the soil may be off by as much as 40 percent up or down. In estimating the seismic forces, the properties of materials may vary by 20 percent, the estimate of building weight may vary by 15 percent, and the selected structural system's ability to resist seismic forces may vary by as much as 40 percent. (These numbers represent the considered opinions of a number of experts in the field). Given these uncertainties with respect to estimation of earthquake forces that may be imposed on a building and the building's ability to resist them, the *Provisions* embodies some "conservatism" – that is, a "factor of safety" is built into the equations and coefficients that are used to establish the design criteria.

Beyond the estimation of forces and capacities in the *Provisions*, other factors affect the actual performance of the building. The *Provisions* requirements must be correctly interpreted by the building engineer, the materials must meet specifications, and materials and components – particularly structural connections – must be correctly installed on the site. Inspection procedures, whether by a community's regulatory agency or the owner's representatives, must be properly implemented to ensure that the building is constructed strictly according the plans and specifications.

An objective – although not a guarantee – for buildings designed according to the *Provisions* is that if the design ground motion (i.e., the level of shaking determined by procedures in the *Provisions* against which the building is required to be designed) were to occur, structural collapse of all or part of the building should not be expected. However, life-threatening damage may be expected in 1 to 2 percent of the buildings with 1 percent of the occupants of these damaged buildings possibly becoming casualties. If ground motion *twice as strong* as the design motion were to occur, one might expect from 1 to 2 percent of the buildings to collapse and, at three times the design motion, from 5 to 10 percent. The percentage of buildings with life-threatening damage might rise to 10 and 50 percent, respectively.

These objectives reinforce the point that seismic codes are aimed at reducing the possibility of life-threatening collapse but that some building damage may occur even in a well designed building that is subjected to a severe earthquake.

5 DECISIONS, DECISIONS!!!

TO REGULATE OR NOT TO REGULATE

It is not easy for a community to evaluate the probable effects of introducing into its building regulatory process new or more stringent seismic design and construction requirements.

- Communities like some in California that are used to experiencing small to moderate seismic events are continually aware of the threat and already have taken some protective measures. To those communities, any changes in their current regulations likely would have to be justified by a soundly based cost-benefit analysis.

- Communities in seismic risk areas with no memorable seismic experience often have little, if any, concern for regulating the seismic resistance of their buildings. Some probably could never be convinced, short of an actual damaging earthquake, that any change in the *status quo*, regardless of its potential advantages, would be worth the effort.

- The conscientious community that falls somewhere between these two types will have to keep in mind that bringing about change in local practices undoubtedly will have differing effects on various segments of the community, some of which will generate interest, and others, concern.

As noted in Chapter 4, a building code is intended to ensure that a building or facility is so located, designed, and constructed that, if it is subjected to natural or man-made destructive forces, it will present no particular threat to the life, health, and welfare of its occupants or the general public. In addition, a building code is intended to ensure uniform minimum standards of health and safety with reasonable economy and to obviate the need for expensive and difficult studies based on first principles for every building project, large or small.

The concerns about seismic code provisions most often voiced are described below.

DO SEISMIC DESIGN REQUIREMENTS REALLY WORK?

Although no specific quantitative information is available to determine the effectiveness of seismic codes (for example, the number of lives actually saved and injuries prevented), experience in recent earthquakes gives convincing proof that properly designing buildings to meet a modern seismic code will dramatically reduce the impact of an earthquake. Although the magnitude of the earthquake that occurred in 1933 in Long Beach, California, was moderate (Richter magnitude 6.3), the damage to buildings was widespread. One of the occupancies to suffer the worst were the public schools (see the photos on the following page). Within seconds, an estimated 75 percent of the public school buildings were heavily damaged and many collapsed. It was readily apparent to responsible public officials that a horrifying number of students and teachers would have been killed and injured if the earthquake had occurred during regular school hours.

This experience resulted in a prompt legislative response to ensure that future public school buildings would be designed and constructed with sufficient earthquake resistance to protect occupants from death or injury. The history of this legislation, and its effect on building performance in subsequent earthquakes, provides some useful lessons for other areas that now find themselves confronted by the realization of an earthquake threat.

The California legislation stimulated by the Long Beach earthquake, the *Field Act*, became effective as an emergency measure one month after the earthquake. It applied only to the design and construction of public school buildings used for elementary, secondary, or community college purposes; private schools, the state college system, and the University of California campuses were not involved. Thus, the act related to facilities at which attendance was compulsory (with the exception of community colleges). The act's principal provisions require that all construction plans be prepared by qualified persons (architects or structural engineers) and that the designs be checked by an independent state agency, which was identified as the Structural Safety Section of the Office of the State Architect. The plan checking is financed by fees, based on the cost of construction, charged against school districts submitting plans for approval.

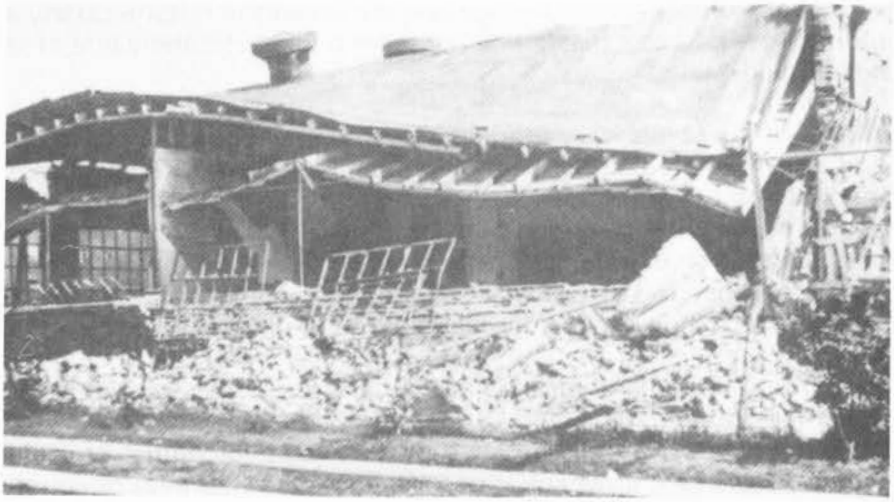
The independent review generally is considered to be one of the most important parts of the *Field Act*. The review has always been rigorously administered by experienced designers. It is aimed at enforcing the state building code and identifying design errors and omissions and conceptual errors of judgment that might result in inadequate earthquake resistance.

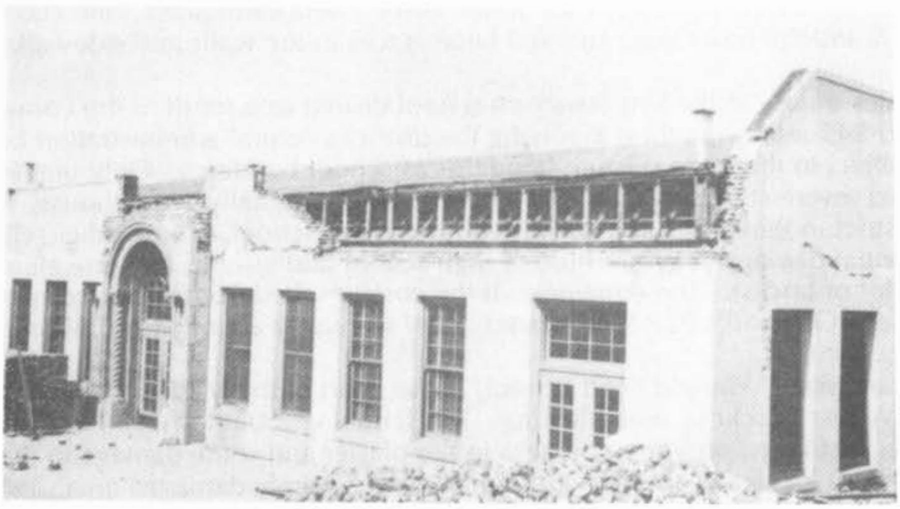
Another very important part of the *Field Act* requires construction to be continually inspected by a qualified person approved by the designers and retained by the school board to see that all of the design requirements are carried out. This inspector is independent of the contractor or architect. All parties with assigned responsibilities, including the architect, consulting engineer, inspector and contractor, must submit verified reports stating that the construction complies with all requirements of the approved plans and specifications. The state also is authorized and required to make any inspections of the buildings and construction judged necessary to enforce the law.

The *Field Act* generally is regarded in California as having been immensely successful in assuring reasonable compliance with acceptable levels of earthquake resistance. It should be noted that the act was in effect during the enormous post-war expansion of population in California and correspondingly massive public school building programs. Although the seismic design review process resulted in an increase of some 2 to 3 months in plan processing and undoubtedly increased the costs of both design and construction, no substantive criticism or limitation has ever been directed at the program.

Since the *Field Act* was implemented, school buildings in California have been tested in a number of earthquakes, and, to date, no students or teachers have been killed or injured in a post-*Field Act* school building during an earthquake. The damaging Kern County earthquakes of 1952 involved one earthquake of Richter magnitude 7.6 followed a month later by one of magnitude 5.8. Of 40 schools constructed prior to the *Field Act*, 40 percent suffered severe damage, 33 percent suffered moderate damage, 25 percent suffered slight damage, and 2 percent had no damage. Of the 18 schools constructed in accord with the *Field Act*, 61 percent had no damage, 33 percent suffered slight damage, and only 6 percent had moderate damage. The fact that some non-life-threatening damage was suffered by *Field Act* schools is an indication that the requirements are not too restrictive.

School damage after the 1933 earthquake in Long Beach.





In December 1954, an earthquake of magnitude 6.6 occurred in the Eureka area north of San Francisco. It caused considerable minor damage to non-*Field Act* schools and no damage to post-*Field Act* schools. The San Fernando earthquake of 1971 (magnitude 6.6) caused shaking over a wide area. No *Field Act* schools received any significant structural damage although the shaking did cause some hazardous nonstructural damage to ceilings, ventilation diffusers, and light fixtures; since the earthquake occurred at 6 a.m., there were no casualties as a result of this damage. Pre-*Field Act* schools received extensive damage; many were closed and subsequently demolished. Several other pre-*Field Act* schools had been strengthened prior to the earthquake, and these performed well.

On May 2, 1983, an earthquake of magnitude 6.7 occurred in the area of Coalinga, California. Public school buildings constructed under the provisions of the *Field Act* performed quite well while some schools that were not constructed under the provisions of the act partially collapsed or were heavily damaged.

The Coalinga junior high school includes several buildings that had been constructed prior to the enactment of the *Field Act*. Both end spans of the roof framing of a gymnasium, which had been constructed in 1928 and converted to maintenance use after an examination declared it to be unsafe, collapsed to the floor. The building subsequently was demolished. In contrast, at West Hills College in Coalinga, the gymnasium with a 96 feet span designed under *Field Act* provisions suffered only minor damage and remained safe. Immediately after the earthquake, the building was used as a disaster center, which illustrates the value of safe school buildings to post-earthquake relief efforts.

In the 1987 Whittier Narrows earthquake, damage to schools in Los Angeles was minimal and limited to nonstructural components and contents. A recent serious test of school buildings was the 1989 Loma Prieta earthquake, a magnitude 7.1 event that affected the entire San Francisco Bay area. A survey of 1,544 public schools in the impacted area showed an estimated $81 million in damage. Only three schools--one in San Francisco, one in Watsonville, and one in Los Gatos--sustained severe damage. Many public school buildings were used as evacuation shelters for the earthquake victims.

The Loma Prieta school buildings in Los Gatos, close to the epicenter of the 1989 earthquake, were constructed in the 1950s and 1960s over hidden branches of the San Andreas fault system. At that time, there was no legislative mandate for studies of geologic hazards at school sites. Several years ago, however, it became apparent that these buildings were sited over potentially active fault traces and, since then, the school system and the state have attempted to purchase a new and safer site. In the Loma Prieta earthquake, one classroom wing heaved upward and the other wing suffered large cracks in the walls and sidewalks.

Estimates of loss to the San Francisco school district as a result of the Loma Prieta earthquake exceed $45 million, a third involving the district's central administration buildings, which are not subject to the same seismic standards as school buildings. Only one San Francisco school suffered severe structural damage. This building, originally a warehouse, was purchased by the district in the 1950s and converted into a high school. Three other schools reported substantial damage (a gymnasium, a high school auditorium, and one elementary school that lost a lot of bricks). The remainder of the costs resulted from minor cosmetic damage at many facilities. Oakland's 92 schools fared better with only about $1.5 million in damage.

San Francisco's Winfield Scott School, in the heart of the Marina area, showed the effectiveness of school strengthening. The school was built in 1930 and strengthened in the 1970s. It suffered only minor cracks in the plaster and some damage to the playground even though it is located in the center of what was a severely damaged area. Its losses were estimated at less than $100,000 and it played an important role in sheltering Marina residents displaced from their dwellings.

In the 1994 earthquake in Northridge, California, no public school building suffered even partial collapse. Further, no structural elements such as beams or columns failed and fell to the floor. Spalling and cracking of concrete occurred in a number of places in several structures; however, all structural damage of this sort could be repaired and the buildings restored to their previous earthquake-resistant capacity. The Superintendent of Schools for the Los Angeles School District stated in testimony to the state Seismic Safety Commission: "I believe in the *Field Act*. I think that if we had not had the *Field Act*, it would have been a complete catastrophe."

Thus, the structural performance of schools in the Northridge earthquake was good; however, considerable nonstructural damage resulted and, had the earthquake not occurred in the early morning hours when school was not in session, many casualties could have resulted. The extent to which students followed their "duck, cover, and hold" training would have had a great bearing on the incidence of injuries. Because the area affected by the Northridge earthquake contains only a few schools constructed since the mid-1970s when nonstructural components began to be increasingly covered by the state's regulations, this earthquake did not provide a comprehensive test of the adequacy of current procedures.

To date, the intention of the *Field Act* appears to have been met. However, the ultimate test – a great earthquake comparable to the 1906 San Francisco earthquake of magnitude 8.3 occurring while schools are in session – has not yet been encountered. Officials in California are confident that decades of application of the *Field Act* should greatly reduce the damage and casualties resulting from such an event.

DOES SEISMIC DESIGN AND CONSTRUCTION COST A LOT?

Although the main purpose of seismic design is to save lives and prevent injuries, the decision to design against earthquakes and to establish seismic design standards often is based on economic considerations: By how much can we afford to reduce the risk of damage to our building? Because modern facilities are very expensive to build and operate, the economics of seismic design are particularly critical.

It is widely believed that seismic resistant design and construction are extremely costly. Although it is generally true that some increase in design and construction costs is involved, available data indicate that it is not nearly so great as is sometimes argued. In fact, earthquake resistance need not be expensive, and seismic safety provisions, when incorporated in a sound design from the very beginning of the planning effort by a competent team, actually usually amount to only about 1.5 percent of the cost of construction.

An analysis of the information supplied by those conducting trial designs as a part of the BSSC program resulting in the first edition (1985) *NEHRP Recommended Provisions* indicates that the design and construction costs associated with the seismic upgrade of the structural components of a building will increase the total cost of a building an average of less than 2 percent. Although the data used in this analysis were somewhat limited because only some of the trial designers were required to include the costs associated with nonstructural building components, which in many cases could add considerably to the total cost of a building when designed and constructed in accordance with the *NEHRP Recommended Provisions*, the analysis itself is one of a kind and, hence, tentative though conclusions based on it may be, they are at least based on real data and statistical analysis rather than on "intuition."

In general, the added cost of seismic design will be in increased design and analysis fees, additional materials (steel reinforcement, anchorages, seismic joints, etc.), and additional elements (bracing, columns, beams, etc.). The major factors influencing the increased costs of seismic design to comply with a code reflecting the *NEHRP Recommended Provisions* are:

- The complexity of the building form and structural framing system – It is much more economical to provide seismic resistance in a building with a simple form and framing.

- The overall cost of the structural system in relation to the total cost of the building – For a typical building, the structural system usually represents between 10 and 15 percent of the building cost.

- The stage of design at which increased seismic resistance is considered – The cost of seismic design can be greatly inflated if no attention is given to it until after the configuration of the building, the structural framing plan, and the materials of construction have been selected.

In the best case (a simple building with short spans where earthquake requirements are introduced at a very early stage of project planning), the increased cost for seismic design should be in the range of 1 to 4 percent of the structural system or between 1.5 and considerably less than 1 percent of the building cost. In the worst case (a complex, irregular building with long spans where earthquake requirements are considered only after the major design features are frozen), the increase can be considerably more – perhaps as large as 25 percent of the structural cost or up to almost 5 percent of the building cost. In addition, because of the importance of utilities and other nonstructural elements, an additional cost must be estimated for ensuring their protection, but this should not exceed 0.5 percent of construction cost.

Thus, the average increase in cost of buildings conforming to a code reflecting the *NEHRP Recommended Provisions* should be less than I.5 percent of the construction cost of the building, which, of course, is only a part of the total project costs. The actual construction cost of an elementary school, for example, is only about 50 percent of the total project cost, which also includes technical expenses, administrative expenses, land cost, and site development. The cost of equipping a modern building further reduces the impact of a small increase in construction cost. And, because of the high level of wages and salaries, the capital cost of construction represents only a small percentage of yearly operating costs.

These costs also can be considered to be a kind of insurance against the failure of individual elements and pieces of equipment in the building. When looked at in this way, such expenditures take on a new perspective. For instance, the difference between disruption of electricity in a building and severe damage to or destruction of a $50,000 emergency power generator or electrical transformer may lie in an additional $250 for seismic snubbers or restraints. The cost implications of damage to expensive equipment are great in terms of both direct repair or replacement costs and indirect costs resulting from the effect of unusable equipment on building operations.

It is illustrative to examine the increased costs and benefits of seismic design in terms of the rate of return to the building owner (whether an individual or a community) and the public on the increased investment in the building over a 25-year period. This assumes that a damaging earthquake will occur before the end of the 25 years, which is a reasonable probability in many areas.

Consider an elementary school for example. If two alternatives – with and without seismic design – are compared, the rate of return on the extra investment can be determined. This rate of return is the initial rate that the investment would have to be earning if, after 25 years, the community wanted to use the investment to pay for earthquake damage to the school, repairs that would need to be paid for in future inflated dollars.

For the purposes of this example, consider a 50,000 square foot elementary school building with a construction cost of $60.00 per square foot with 25 percent of the cost attributable to the structural and foundation systems, 21 percent to the mechanical and plumbing systems, 13 percent to the electrical system, 33 percent to the architectural systems, and 8 percent to fixed equipment. The cost of seismic design is estimated to be 5 percent of the cost of the structural system or 1 percent of total building construction. (Remember that construction cost represents only a portion of total project cost which also includes design, land acquisition, and site development costs.)

The assumptions for this example are as follows:

- The school costs $3,000,000 to construct without seismic design and $3,037,500 to construct with seismic design.

- At the end of 25 years (with a 4 percent inflation rate), the school without seismic design will be worth $7,998,000 and the school with seismic design will be worth $8,097,975.

- In future dollars, the earthquake damage to the school without seismic design will be $1,199,700 (damage to 15 percent of the structure, 15 percent of mechanical/electrical systems, and 15 percent to the architectural components) and to the school with seismic design will be $267,933 (damage to 5 percent of the mechanical/electrical systems and architectural components).

- The extra finance charges for the $37,500 investment for seismic design will be $125,344 in future dollars (25 year loan at 8 percent).

Thus, the total future extra costs of the school without seismic design would be $906,398 (a negative $99,975 difference in building worth, a negative $931,767 difference in damage repairs, and a positive $125,344 for the principal and finance charges for the seismic investment) and a 13 percent investment would be needed to receive a similar return on the original seismic design investment. In another words, the school board would have had to invest $37,500 (the original cost of seismic design) at 13 percent per year for 25 years to be able to pay for school repairs. In essence, then, seismic design for the school represents both increased life safety of the community's children and a sound investment economically.

If the earthquake damage was severe, the financial loss would affect not only the educational facility and the community as a whole but also the staff and other businesses and professionals who provide goods and services to the school. Earthquake damage therefore will have a very broad effect on community business activities.

Although economic analyses of new construction requirements can be useful in decision-making, their results do not, and should not, necessarily control the decision-making in this area since what is at risk are the people who live, work, and play in a community's buildings. Indeed, the goal of building code requirements is life safety; consequently, trade-offs between construction costs and protection of life must be made concerning seismic resistance just as they are concerning other aspects of design that affect life safety.

WHAT ABOUT RESPONSIBILITY AND LIABILITY?

Questions of responsibility and liability are very real ones even if there are no clear cut answers.

Structural engineers participating in the BSSC program have expressed considerable concern about professional responsibility. Several have voiced strong opinions about their professional responsibility to advise a client about the need for seismic-resistant design even though the local building code does not require it.

Use of the *NEHRP Recommended Provisions* in upgrading a code that includes no seismic considerations will require many design practice changes. During the early phases of the BSSC trial design effort, concern was expressed about the lack of seismic design knowledge and experience of some of the engineers employed by contractors selected to design the hypothetical buildings. This proved to be something of a "red herring," however, in that knowledge and familiarity obviously increase with each design performed. Further, both the BSSC and other technical groups (including the national model code groups whose seismic requirements are based on the *Provisions*) have been and continue to offer courses on application of the *Provisions* requirements.

In addition, although they cannot yet be quantified, liability risks should be considered by all those responsible for buildings. Few data are available that reflect the magnitude of the risks that building decision-makers face in terms of liability for casualties incurred in their buildings during an earthquake, but this will almost certainly be decided by the courts eventually. As soon as the earthquake threat is identified and means of reducing its effect are documented, it can no longer be considered an "act of God" and the owner who makes no reasonable provision for seismic design will be in a very tenuous legal situation when an earthquake occurs. In fact, it was suggested by one municipal code administrator participating in the BSSC program that the best instructional manual regarding responsibility for building safety would be the proceedings from a local court case.

Further, it has been determined in California, for example, that school board members are individually liable for the occupants of a school building if the building has been found to be unsafe and proper steps have not been taken to correct the deficiencies or close the building. Needless to say, when the school boards in California became aware of this liability, they pursued every means necessary to correct unsafe buildings. Many school boards in the West also are exploring more stringent seismic regulations based on the expected liability that they will incur as a result of the earthquake performance of their school buildings.

Liability for earthquake losses also may have a considerable impact on designers. After the 1985 earthquake in Mexico City, for example, a Mexico resident sought justice in the case of the loss of his family in an apartment building that collapsed as a result of the earthquake. His claims were based on an investigation of the design, materials, and construction of the building, and, as a result, the Mexican federal courts issued arrest warrants for the designers of the building. This case is reported to be the first to be brought against individuals as being responsible for deaths and injuries during an earthquake, but it is unrealistic to expect it to be the last.

POTENTIAL JURISDICTIONAL PROBLEMS

An increase in the costs of a new building caused by requiring improved earthquake protection could result in:

- Less new construction and, as a consequence, a reduced supply of housing (especially for the low-income housing market) and commercial and industrial facilities.

- Fewer amenities in what is being built.

- Businesses deciding to locate in adjacent or nearby jurisdictions where they can build or rent more cheaply.

In the last instance, missing out on potential new businesses and the relocation of existing businesses would affect the job market and revenue situation. Questions concerning these matters can be expected to arise in any community surrounded by jurisdictions with less stringent building regulations, and they will be especially troublesome in those communities located in a large seismic zone that includes many other communities and perhaps two or more states. Concern about being the "first" and, for a while, the only community in an area to require seismic-resistant construction is very real and responding to it is not easy.

One way to reduce potential jurisdictional competition and a community's initial isolation as it initiates seismic safety efforts is to attempt to gain intergovernmental cooperation on a regional basis. A number of organizations have been formed to pursue such an approach (see the listing in Appendix E).

The importance of life safety must be emphasized, but in areas where earthquakes have not occurred for a long time and general awareness of the earthquake threat is low, jobs and taxes may well be viewed by many citizens to be of much more "immediate" concern. Nevertheless, when an earthquake occurs, the impacts on all community systems (especially the adverse social and economic impacts) and the duration of response and recovery can be reduced considerably because of seismic-resistant structures. Communities that have not experienced a natural disaster may be unaware of the traumas caused by such an event and of the long-term hardships usually endured afterwards; dissemination of such information may be quite persuasive.

Even though it is difficult to estimate the economic and social impacts of seismic safety, each community must do so for itself as objectively as possible. Decision-makers must make sure they understand the possible consequences of any increase in costs of new construction, especially the impacts that could be felt by those members of the community who fall in the lower income ranges. At the same time, they must bear in mind such things as a loss expectancy study of the Memphis area that indicated that approximately 3,900 lives could be lost if the area today experienced a seismic event similar to that of 1811-12 centered nearby at New Madrid, Missouri.

The liability issue also should stimulate the building community to do what it can to protect itself from litigation. One key way involves the adoption and enforcement of appropriate seismic building codes. It is also apparent that many members of the building community have a strong enough sense of professional responsibility to recognize the need for seismic design and these individuals should be encouraged to communicate their knowledge and views to their peers.

A number of other forces can affect the seismic safety decision-making process. For example, in known seismic-risk areas, lenders are beginning to require seismic design and earthquake insurance as a condition for their financial support. Furthermore, many industrial and service organizations (e.g., Monsanto in the St. Louis area, Federal Express in the Memphis area, and Boeing in the Seattle area) are beginning to require seismic protection in their facilities. It is becoming increasingly important to those businesses and organizations that rely on sophisticated electronic and computer equipment to avoid operational interruptions and shut-downs. To them, ensuring seismic resistance in their structures is a very small price to pay given what they would lose from a major disruption of their operations. Also, some buildings house priceless art or historic treasures that could never be replaced if the building collapsed; indeed, protecting such treasures might stimulate a community to adopt even more stringent seismic safety requirements that cover nonstructural as well as structural components.

Two recent Presidential executive orders imposing new directives on the federal government may also have an effect on communities. With respect to new construction, Executive Order 12699 requires that new federally owned or assisted buildings be designed and constructed to meet the requirements of either the latest edition of the *NEHRP Recommended Provisions* or the immediately preceding edition. Executive Order 12941 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.

In short, there are many reasons for safeguarding a building, and these reasons continue to be acted on whether or not a community has seismic-resistant construction standards and whether or not those standards are enforced.

With respect to other potential effects, all of the possible outcomes are not yet known. Seismic resistant design and construction are obviously already occurring with few, if any, adverse impacts in California where they are mandated by a statewide code as well as in areas without seismic code requirements. Therefore, it is fair to assume that many of the changes resulting from seismic resistant design and construction will be absorbed in time just as are other changes resulting from new technology.

INFORMATION SOURCES

The regional earthquake consortia and national information centers identified in Appendix E are valuable resources. Much can be learned from them concerning what is being done in various areas. The building community professional societies and the various materials organizations also listed in Appendix E can be sources of specific information useful to community decision-makers.