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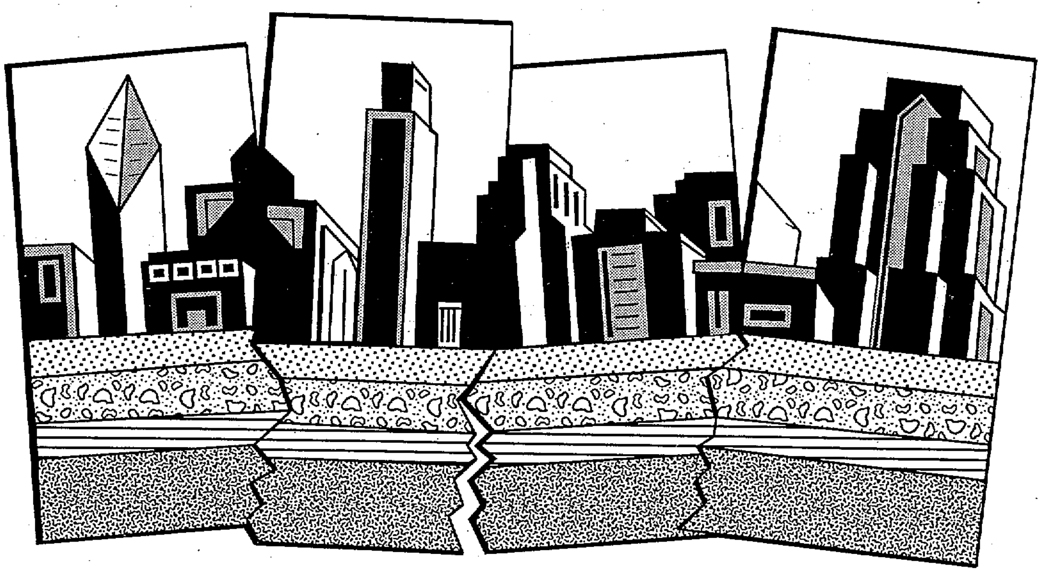
SEISMIC CONSIDERATIONS FOR COMMUNITIES AT RISK



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.

BOARD OF DIRECTION: 1995

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.**

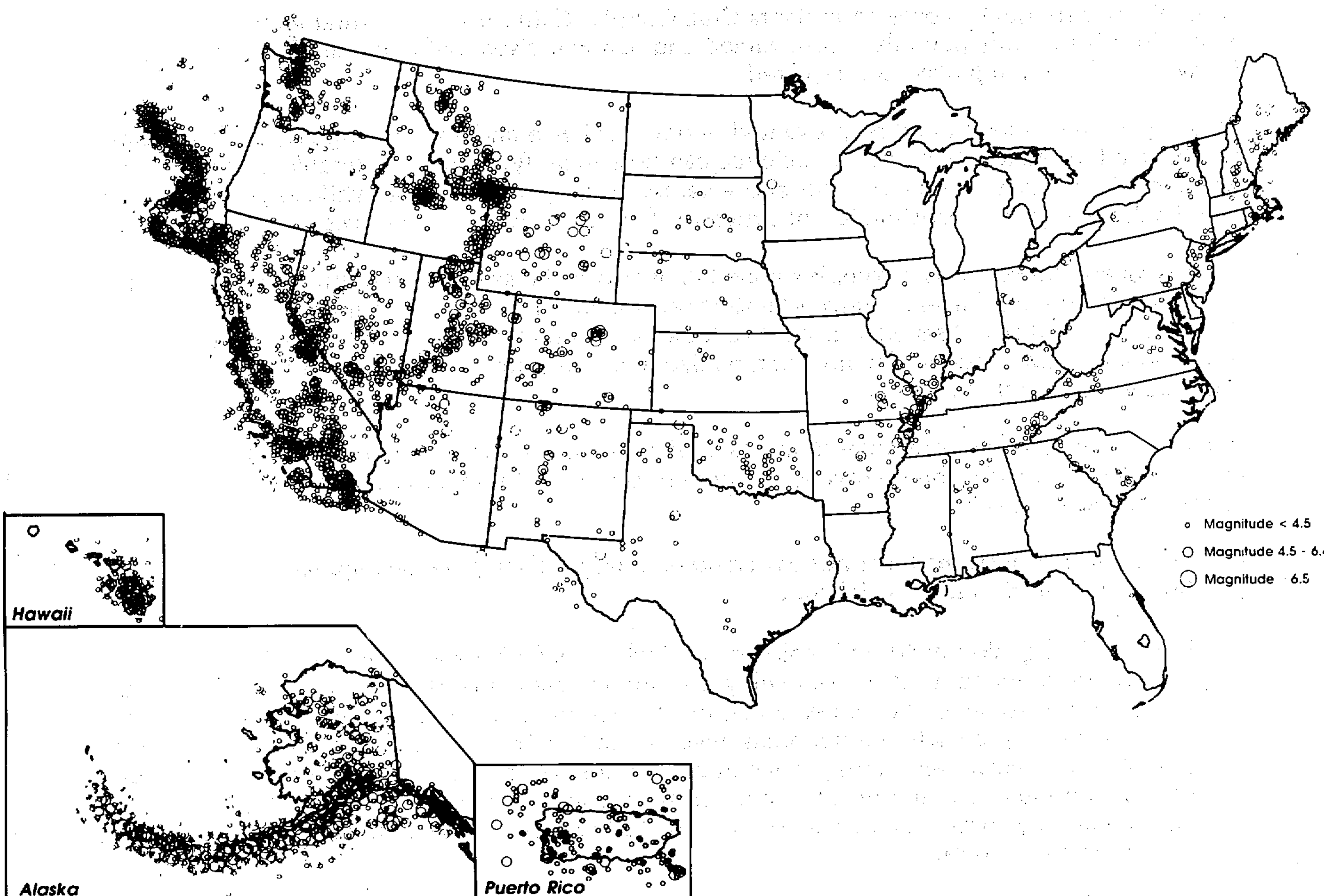
  FALSE! Earthquakes occur in "geologic time" which is far "slower" than that which we usually use to judge whether something is of immediate concern to us. Records show that some seismic zones in the United States experience moderate to major earthquakes about every 50 to 70 years while other areas have "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.).

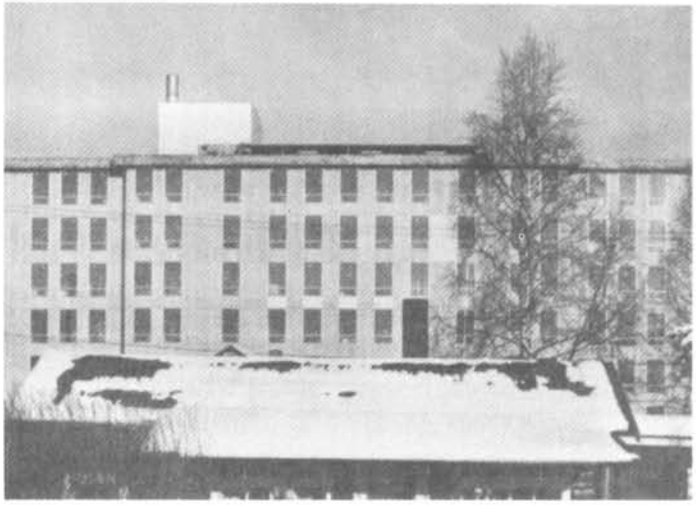
REINFORCED CONCRETE BUILDINGS

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.

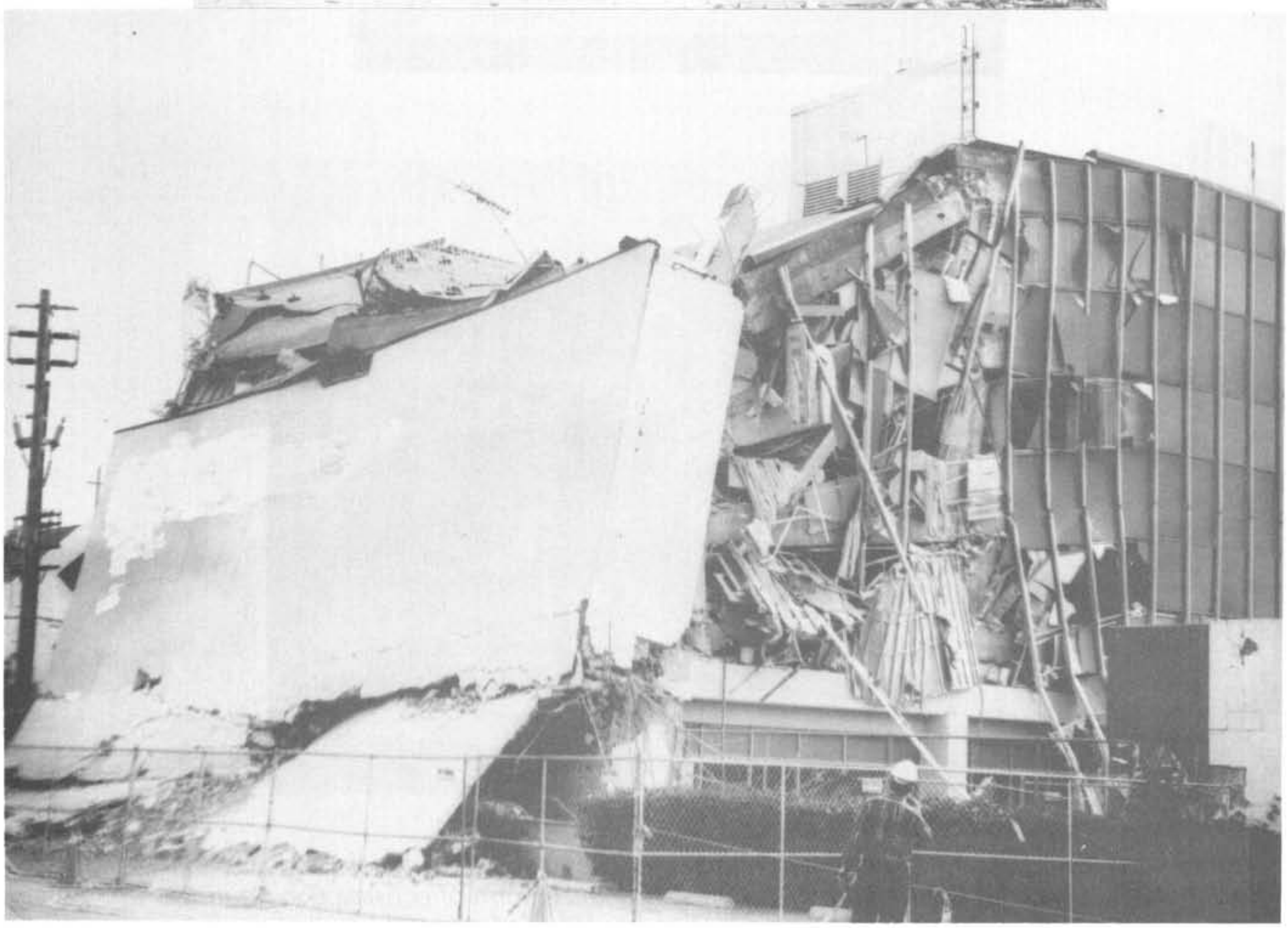
Precast concrete structures and the "tilt-up" type of reinforced concrete construction often used for industrial and commercial buildings also have suffered badly in earthquakes. In these types of structures, the damage has been due primarily to inadequate connections between the precast members or between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



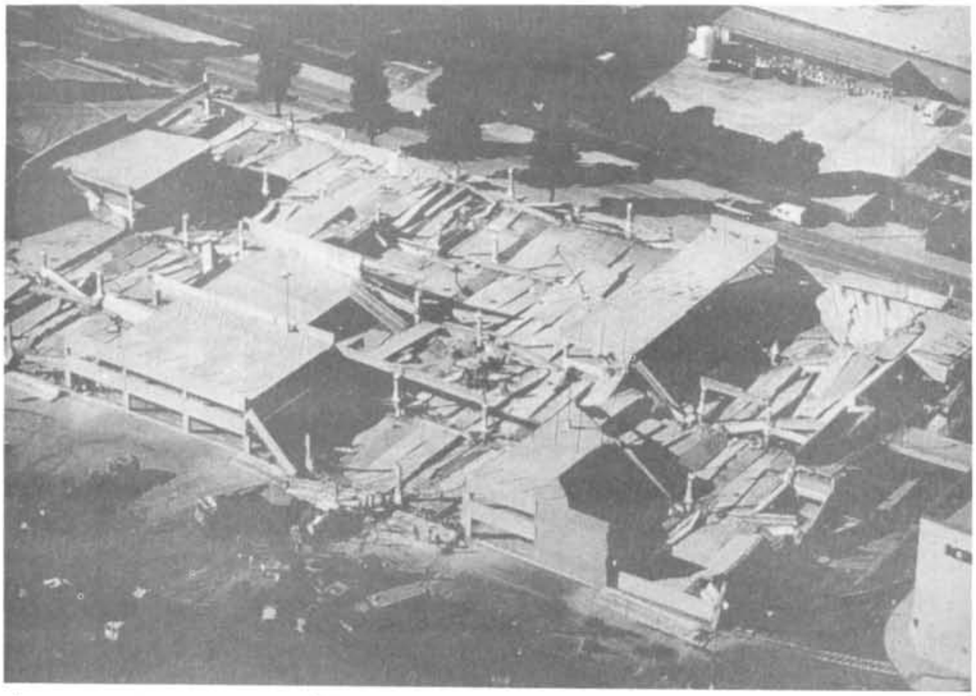
The six-story Four Seasons apartment building in Anchorage, Alaska, before and after the 1994 earthquake. It was designed with pre-cast lift-slab floors (a form of construction no longer in use). The earthquake forces were resisted by two poured-in-place reinforced concrete towers. However, in the 1964 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.).

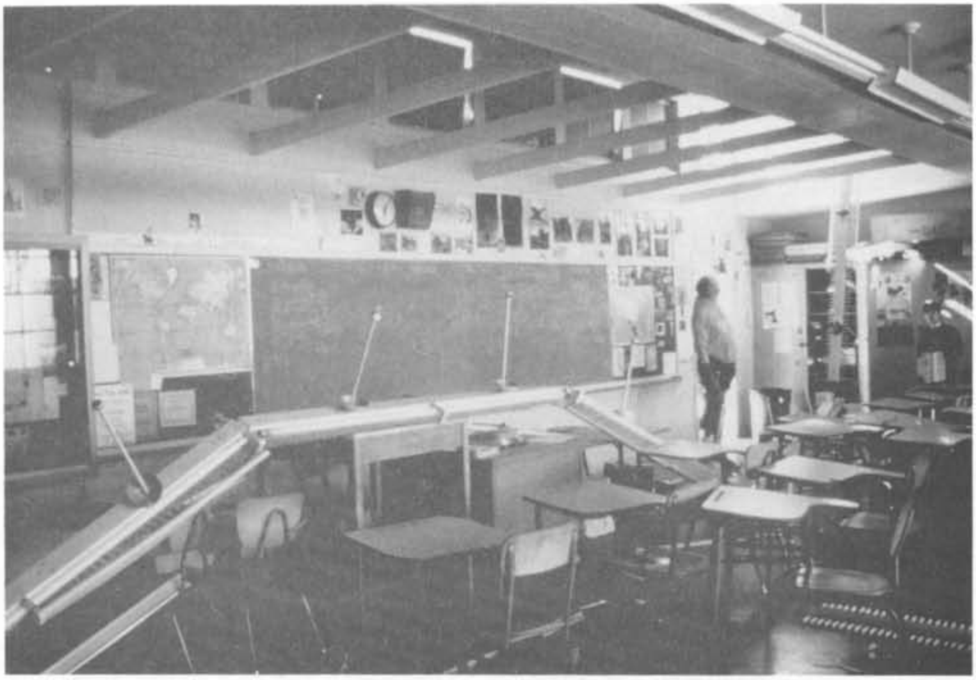
Typical damage to a single-family residence caused by inadequate bracing of the "cripple wall" – the short stud wall between the foundation and the first floor. This type of failure causes costly damage but the problem can be solved easily by bracing the walls with plywood (Chris Arnold, Building Systems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

NONSTRUCTURAL DAMAGE

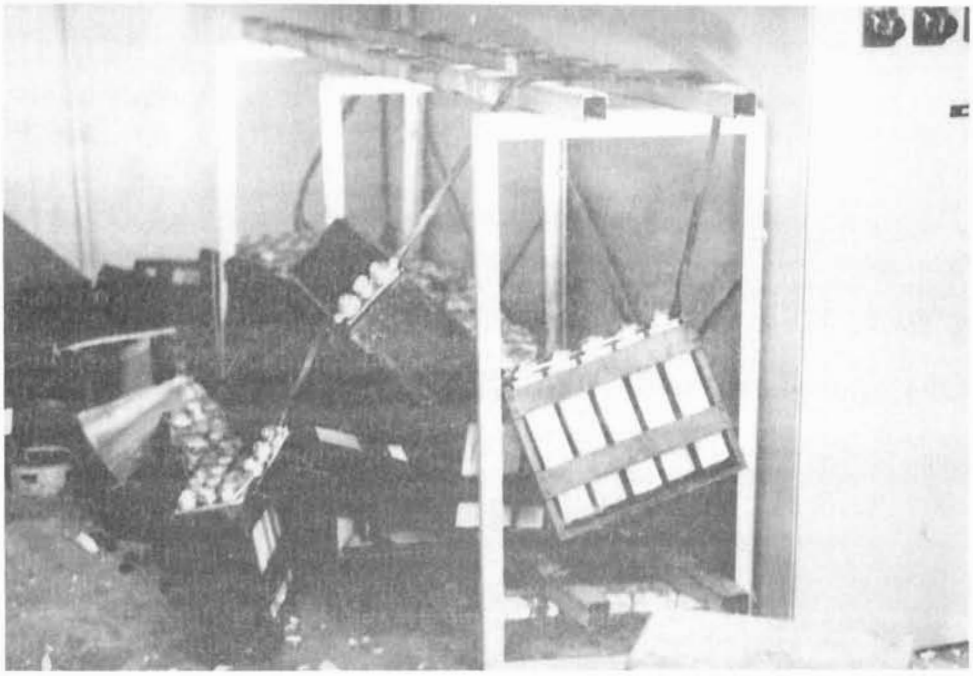
In a typical building the structural components (floor and roof structure, bearing walls, columns, beams, and foundations) account for only about 15 to 20 of the construction cost: the nonstructural architectural, mechanical and electrical components make up between 70 and 85 percent of the building's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

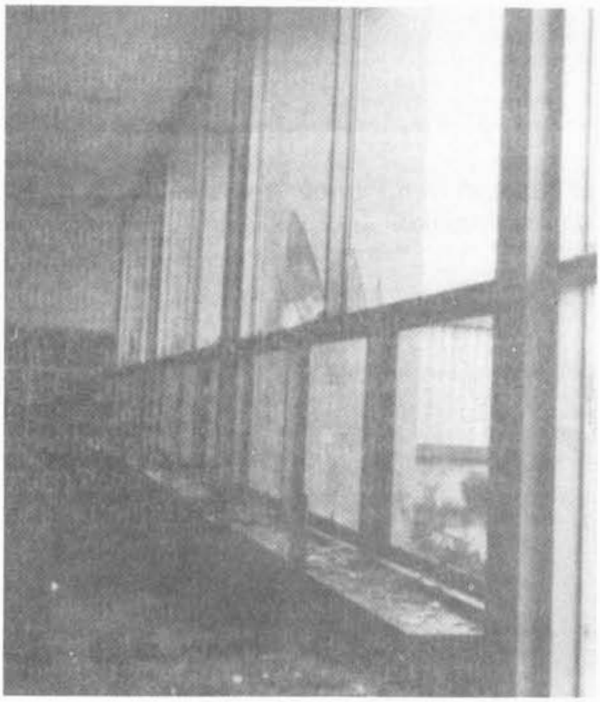
In addition, nonstructural damage causes operational disruption, and a building may be unusable for months while nonstructural damage is repaired. This may represent a crippling financial loss to the owners and employees.



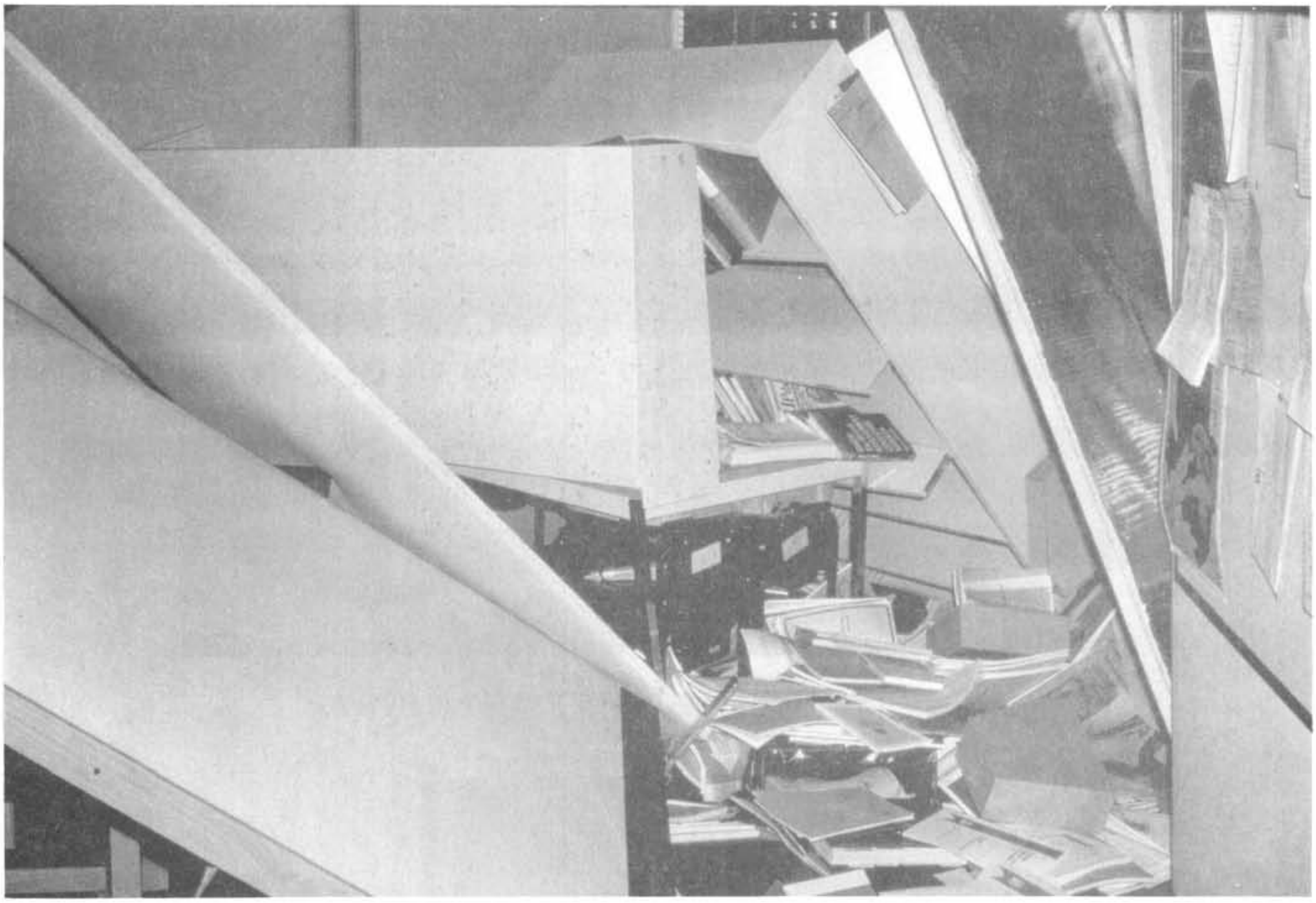
Fallen light fixtures in a school after the 1994 Northridge earthquake (Gary McGavin).



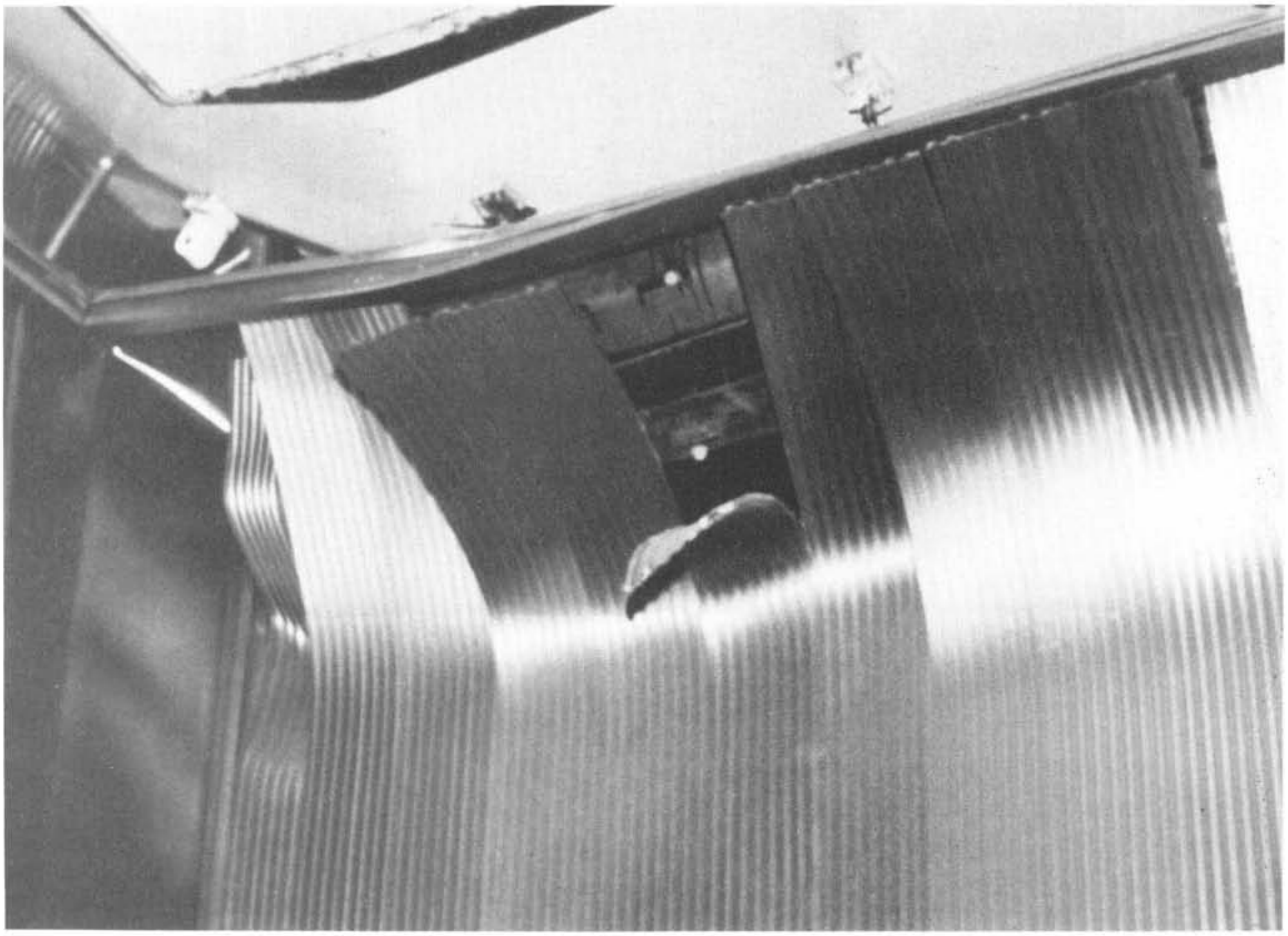
Collapsed battery racks for emergency electrical supply.



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.

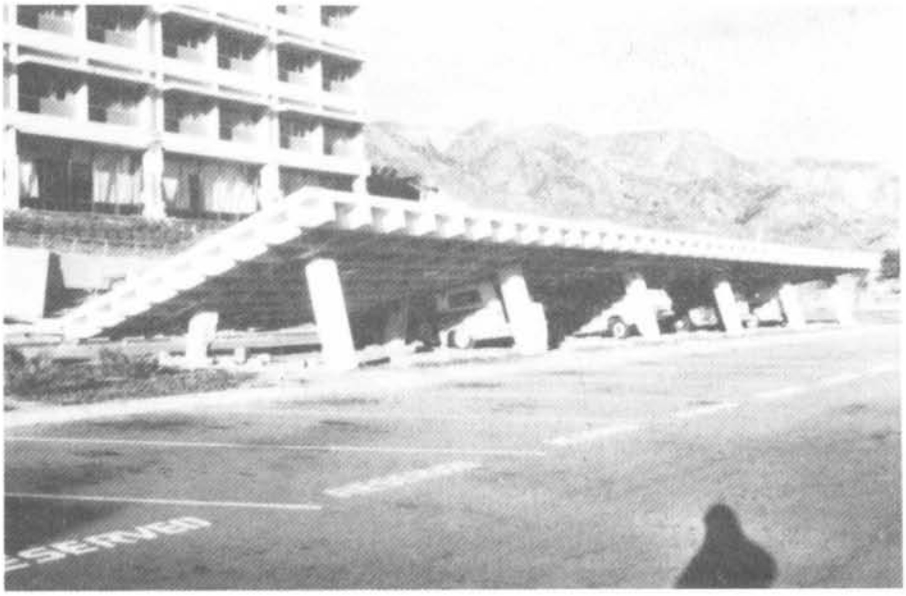


Earthquake damage to an elevator.

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.

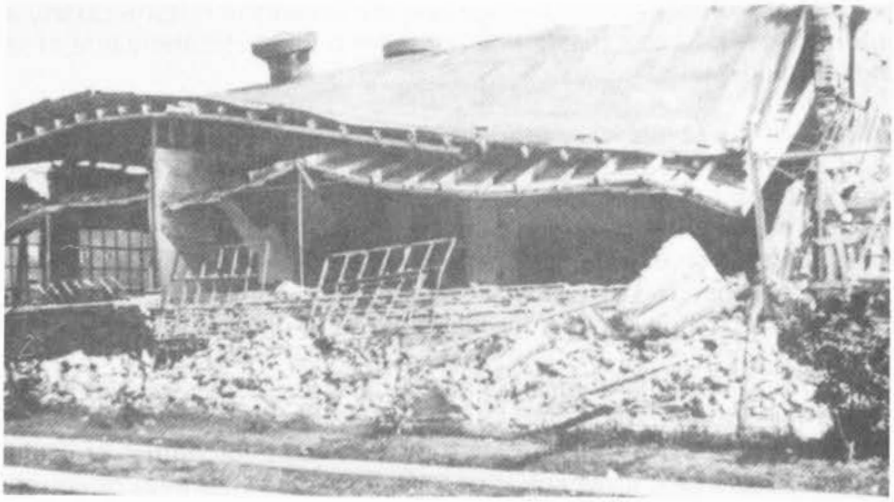
The independent review generally is considered to be one of the most important parts of the *Field Act*. The review has always been rigorously administered by experienced designers. It is aimed at enforcing the state building code and identifying design errors and omissions and conceptual errors of judgment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

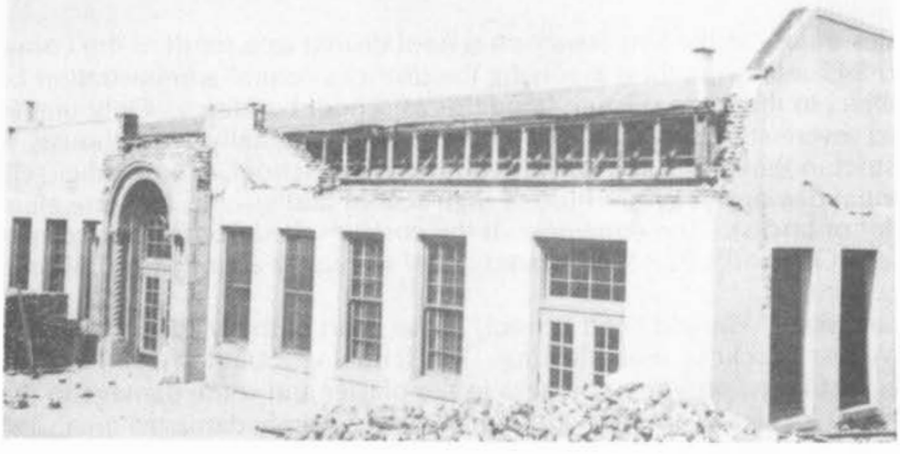
Another very important part of the *Field Act* requires construction to be continually inspected by a qualified person approved by the designers and retained by the school board to see that all of the design requirements are carried out. This inspector is independent of the contractor or architect. All 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 l.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.

6 HOW CAN I MAKE MY COMMUNITY ACT?

Having read in this handbook about the seismic hazards and risks in various parts of the United States, you are probably trying to decide where your community fits in. This chapter is designed to help you determine the risk at your specific location and formulate an action plan that will fill your local needs.

Building on the advice presented in earlier chapters, a series of steps are described here to help you develop a practical and effective approach to reducing your community's exposure to seismic hazards.

KNOW YOUR COMMUNITY'S RISK

To determine your community's seismic risk, you need to take into account:

- The nature of the earthquake hazard as determined by scientists,
- The extent to which your community is aware of and informed about seismic hazards,
- The extent of education and mitigation efforts already made, and
- The degree of risk that your community will be willing to accept.

To help you define your community's seismic situation, consult such groups as:

- Geologists, geophysicists, and seismologists at local academic institutions or in private practice,
- Your state's geologist,
- The regional offices of the Federal Emergency Management Agency and the U.S. Geological Survey,
- The national earthquake information centers, and
- State and regional seismic safety organizations.

Once you determine that your community is at moderate to high risk from earthquakes and related hazards like landslides, go on to the next step.

BECOME FAMILIAR WITH YOUR LOCAL BUILDING REGULATIONS

Find out if your local building regulations provide for seismic protection. If they do, determine what level of protection is provided and how that level was established. If your local building code does not provide for seismic protection or if it does not provide adequately for such protection, discuss your concerns with:

- Your local building officials and
- Knowledgeable individuals from the local chapters of professional societies and organizations and from local academic institutions.

During such discussions, identify the possible impacts on various segments of your community of introducing new or more stringent seismic provisions into the regulations. Establish, insofar as possible, who will benefit and, therefore, most likely favor improved code regulations and who will be adversely affected and opposed. Try to determine if the concerns are real or imaginary.

If by now you believe that your community is at risk but have found that, for one reason or another, the responsible officials have not taken appropriate action, you will have to step up efforts to increase awareness of the seismic risk in your community. Consider the information in Appendix B, which explains how the building regulatory system works and describes how code changes are made.

ORGANIZE, INFORM, EDUCATE

Even in some cities without seismic codes, some individuals, organizations, and companies have already taken steps to increase seismic safety, and they may provide the core of a group of actively interested persons. It also might be wise to link up with adjacent and nearby jurisdictions to develop a network of communities (as well as counties and states if appropriate) in a seismic zone to engage in cooperative, comprehensive seismic safety planning.

In the past few years, a number of state and regional seismic organizations have sprung up to address the geophysical and other conditions that exist in the various seismic zones in the United States. For example, the Central United States Earthquake Consortium (CUSEC) has been organized to promote understanding of the Mississippi Valley seismic zone and to foster seismic safety efforts in the 7 states and 24 major cities that are located in that zone. Other state, regional, and national seismic organizations can provide you with contacts and scientific, educational, and organizational advice.

Building community members and seismic safety proponents who have participated in the BSSC program have emphasized that three groups must be made aware of seismic issues if an effort to change a community's seismic safety policy is to be successful:

- Public officials,
- Building community professionals (engineers, architects, etc.), and
- The general public.

These three groups can be informed and educated through articles and reports, through meetings and conferences, through video tapes and computer software, through direct and indirect technical assistance, and in a variety of other ways. It is most important that you:

- Develop a coordinated approach to informing and educating them and

- Provide information and education in a manner understandable to the specific group being addressed.

- Develop information and education materials that are tailored to fill each group's specific needs.

Public officials can be addressed through such organizations as the U.S. Conference of Mayors, the National League of Cities, the International City Management Association, the National Association of County Officials, and organizations of functional specialists such as city planners, financial officials and community development specialists.

A good way to educate and inform building community professionals is to work through the local chapters of building officials' organizations, the local chapters of professional associations or societies (e.g., the American Institute of Architects, the American Society of Civil Engineers, the Associated General Contractors of America, and the American Consulting Engineers Council), the local structural engineers association, and the various building product organizations.

The general public can be approached through special-purpose seismic organizations, through the local media, and through existing organizations such as public interest groups, voluntary agencies, and other benevolent groups (e.g., PTAs and PTOs, civic clubs, fraternal organizations, the League of Women Voters, and scouting organizations).

If the general public and the various building professionals in your community become fully aware of the seismic situation and conclude that the benefits to be derived from increased protection through building regulation are worth the costs, they can and most likely will be strong advocates when you proceed to the next step.

MOTIVATE LOCAL PUBLIC LEADERS

Local elected and appointed officials play an especially important role in seismic safety efforts. Their attitude with respect to seismic hazard mitigation will be of critical importance in achieving seismic safety objectives. It is therefore essential that the means of educating them about seismic issues be well thought out and that they be approached at the right time.

A BSSC study of societal implications shed some light on the degree of interest in seismic safety of elected and appointed officials. Seismic safety code regulations often are not an issue of high priority for the chief elected and appointed officials and executives of any of the cities and counties visited. The chief building department officials who participated appeared to reflect a full array of positions from pro to con regarding the adoption of new or more stringent seismic safety code requirements.

The general consensus is that a movement to promote improved seismic safety for new buildings will be successful only if it has sufficient "grass roots" support to stimulate public leaders to act. In fact, several seismic safety movements reflect such a "bottom up" approach, and some seismic safety proponents have urged that public officials not even be approached until a united front has been developed by other segments of the community including researchers, academicians, engineers, architects, voluntary agencies, and public interest groups.

INFORMATION SOURCES

In addition to the information sources described above, consult the list of publications in Appendix E.

APPENDICES

Appendix A

WHAT DO THOSE TECHNICAL TERMS MEAN?

MEASURES OF EARTHQUAKE MAGNITUDE AND INTENSITY

Earthquakes commonly are "measured" by use of two different scales – the *Richter magnitude scale* and the *modified Mercalli intensity scale*. As these two names indicate, one scale measures *magnitude* while the other indicates the *intensity* of the earthquake motion at specific places around the earthquake epicenter. Since both scales measure very different things, they cannot really be related to one another or compared. However, since both are used, the concerned individual should have a general understanding of both.

RICHTER MAGNITUDE

The Richter magnitude scale was developed by Charles F. Richter in 1935. It is defined as the logarithm to the base of 10 of the maximum trace amplitude in millimeters as recorded on a standard seismograph located 100 kilometers (or 62 miles) from the earthquake epicenter.

A Richter scale measurement is expressed in whole and decimal numbers and it can be used to identify the magnitude of an earthquake and estimate how much energy was released. In this context, it is important to remember that the Richter scale is logarithmic and, therefore, each unit of increase on the scale reflects a 10 times increase in amplitude. This represents approximately a 32-fold increase in energy released. Thus, an earthquake of Richter magnitude 8.3 would have an amplitude of 10,000 times that of an earthquake of Richter Magnitude 4.3 and would release approximately 1,050,000 times more energy.

As originally developed by Richter, this magnitude scale applied to Southern California shallow earthquakes located less than 375 miles from the recording instrument. Now, however, it is commonly used to compare earthquakes worldwide and at distances much farther from the recording instrument. Other magnitude scales have been developed that more accurately describe the variety of earthquakes that may be encountered, and the Richter magnitude scale is now recommended only for measuring earthquakes between about magnitudes 3 and 7. For the larger earthquakes that are of particular concern for seismic design, the *moment magnitude* (M_w) scale is now used by the U.S. Geological Survey and others. Moment magnitude is a combination of the *rigidity of the rock times the area of faulting times the amount of slippage*; this scale is based on the forces that work at the fault rupture to produce the earthquake rather than the recorded amplitude of seismic waves and is directly related to the energy released by the earthquake.

Moment magnitude, however, can be assigned only after considerable study of the geology and size of the fault rupture, while the Richter magnitude is almost immediately available after the shock. Thus, the Richter magnitude will continue to be a useful comparative index of earthquake size, even though, because of its limitations, it does not give an accurate measure of the earthquake effects in terms of damage.

Note that deep earthquakes more characteristic of the eastern United States are best compared by measuring their *P-waves*, which are not affected by the depth of the source. This measurement is referred to as *body-wave magnitude* (m_b).

MODIFIED MERCALLI INTENSITY SCALE

As noted, use of Richter magnitude gives little indication of earthquake intensity and building damage. The first scale created to do this was developed in the 1880s by the Italian *de Rossi* and the Swiss *Forel*. It was modified in 1902 by the Italian *Mercalli* and later further modified a number of times. A version of the Rossi-Forel scale generally is used in Europe while the modified Mercalli intensity (MMI) scale is used in the United States.

The following excerpt from Bruce A. Bolt's 1978 book, *Earthquakes: A Primer* (W. H. Freeman and Company, San Francisco, California), describes modified Mercalli intensity values (1956 version):

I. Not felt. Marginal and long period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks or sensation of a jolt like a heavy ball striking the walls. Standing cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frames creak.

V. Felt outdoors; directions estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture overturned. Weak plaster, Masonry D cracked. Small bells ring (church and school), Trees, bushes shaken visibly or heard to rustle.

VII. Difficult to stand. Noticed by drivers. Hanging objects quiver. Furniture broken. Damage to Masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, also unbraced parapets, and architectural ornaments. Some cracks in Masonry C. Waves on ponds, water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of cars affected. Damage to masonry C; partial collapse. Some damage to Masonry B; none to Masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; Masonry C heavily damaged, sometimes with complete collapse; Masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted down, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in the ground. In alluviated areas, sand and mud ejected, earthquake fountains and sand craters.

X. Most masonry and frame buildings destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serous damage to dams, dikes, embankments.

Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown in the air.

Note that the masonry definitions used are from C. F. Richter's 1958 book, *Elementary Seismology* (W. H. Freeman and Company, San Francisco, California), and are as follows: Masonry A – good workmanship, mortar, and design; reinforced, especially laterally; bound together by using steel, concrete etc; designed to resist lateral forces. Masonry B – good workmanship and mortar; reinforced but not designed in detail to resist lateral forces. Masonry C – Ordinary workmanship and mortar, no extreme weaknesses like failing to tie in at corners but not reinforced or designed against horizontal forces. Masonry D – weak materials such as adobe, poor mortar, low standards of workmanship; weak horizontally.

Unlike the Richter magnitude scale, whose values are set by instrumented readings, the Mercalli scale is subjective and values are set by observers based on interpretation of the above indicators. A problem with the Mercalli scale is that, due to its age, it has no references to modern structural types of reinforced concrete, steel, etc. On the other hand, since older buildings are most prone to damage, this limitation may not be too serious.

It should be noted that a given earthquake will have one Richter magnitude (once the various seismological stations agree) but will have a number of Mercalli intensities depending on the distance from the epicenter.

TERMINOLOGY

Acceleration – Rate of change of velocity with time.

Amplification – A relative increase in ground motion between one type of soil and another or an increase in building response as a result of resonance.

Amplitude – Maximum deviation from mean of the center line of a wave.

Architectural Components – Components such as exterior cladding, ceilings, partitions, and finishes.

Component (also Element) -- Part of an architectural, structural, electrical, or mechanical system.

Configuration – The size, shape, and geometrical proportions of a building.

Connection – A method by which different materials or components are joined to each other.

Damage – Any physical destruction caused by earthquakes.

Deflection – The state of being turned aside from a straight line, generally used in the horizontal sense; see also "Drift."

Design Earthquake – In the *Provisions*, the earthquake that produces ground motions at the site under consideration that has a 90 percent probability of not being exceeded in 50 years (or a 10 percent probability of being exceeded).

Design Ground Motion – See "Design Earthquake."

Diaphragm – A horizontal or nearly horizontal structural element designed to transmit lateral forces to the vertical elements of the seismic force resisting system.

Drift – Vertical deflection of a building or structure caused by lateral forces; see also "Story Drift."

Ductility – Property of some materials, such as steel, to distort when subjected to forces while still retaining considerable strength.

Earthquake – A sudden motion or vibration in the earth caused by the abrupt release of energy in the earth's lithosphere.

Effective Peak Acceleration and *Effective Peak Velocity-Related Acceleration* – Coefficients shown on maps in the *Provisions* for determining prescribed seismic forces.

Elastic – Capable of recovering size and shape after deformation.

Epicenter – A point on the earth's surface that is directly above the focus of an earthquake.

Exceedance Probability – The probability that a specified level of ground motion or specified social or economic consequences of earthquakes will be exceeded at a site or in a region during a specified exposure time.

Exposure – The potential economic loss to all or certain subsets of the built environment as a result of one or more earthquakes in an area; this term usually refers to the insured value of structures carried by one or more insurers.

Fault – A fracture in the earth's crust accompanied by displacement of one side of the fracture with respect to the other in a direction parallel to the fracture.

Focus – The location of a fault break where an earthquake originates; also termed "hypocenter."

Force – Agency or influence that tries to deform an object or overcome its resistance to motion.

Frame, Braced – Diagonal members connecting together components of a structural frame in such a way as to resist lateral forces.

Frame System, Building – A structural system with an essentially complete space frame providing support for vertical loads; seismic forces are resisted by shear walls or braced frames.

Frame System, Moment – A space frame in which members and joints are capable of resisting lateral forces by bending as well as along the axis of the members; varying levels of resistance are provided by ordinary, intermediate and special moment frames as defined in the *Provisions* with special frames providing the most resistance.

Frame, Space – A structural system composed of interconnected members, other than bearing walls, that is capable of supporting vertical loads and that also may provide resistance to seismic forces.

"g" – The acceleration due to gravity or 32 feet per second per second.

Ground Failure – Physical changes to the ground surface produced by an earthquake such as lateral spreading, landslides, or liquefaction.

Hypocenter – See "Focus."

Intensity – The apparent effect that an earthquake produces at a given location; in the United States, intensity generally is measured by the modified Mercalli intensity (MMI) scale.

Irregular – Deviation of a building configuration from a simple symmetrical shape.

Joint – Location of connections between structural or nonstructural members and components.

Liquefaction – The conversion of a solid into a liquid by heat, pressure, or violent motion; sometimes occurs to the ground in earthquakes.

Load, Dead – The gravity load created by the weight of all permanent structural and nonstructural building components such as walls, floors, roofs, and fixed service equipment.

Load, Live – Moving or movable external loading on a structure; it includes the weight of people, furnishings, equipment, and other items not permanently attached to the structure.

Loss – Any adverse economic or social consequences caused by earthquakes.

Mass – A constant quantity or aggregate of matter; the inertia or sluggishness that an object, when frictionlessly mounted, exhibits in response to any effort made to start it or stop it or to change in any way its state of motion.

Mercalli Scale (or Index) – A measure of earthquake intensity named after Giuseppe Mercalli, an Italian priest and geologist.

Partition – See "Wall, Nonbearing."

Period – The elapsed time (generally in seconds) of a single cycle of a vibratory motion or oscillation; the inverse of frequency.

P-Wave – The primary or fastest waves traveling away from a fault rupture through the earth's crust and consisting of a series of compressions and dilations of the ground material.

Recurrence Interval – See "Return Period."

Resonance – The amplification of a vibratory motion occurring when the period of an impulse or periodic stimulus coincides with the period of the oscillating body.

Return Period – The time period in years in which the probability is 63 percent that an earthquake of a certain magnitude will recur.

Richter Magnitude (or Scale) – A logarithmic scale expressing the magnitude of a seismic (earthquake) disturbance in terms of the maximum amplitude of the seismic waves at a standard distance from their focus named after its creator, the American seismologist Charles R. Richter.

Rigidity – Relative stiffness of a structure or element; in numerical terms, equal to the reciprocal of displacement caused by unit force.

Seismic – Of, subject to, or caused by an earthquake or an earth vibration.

Seismic Event – The abrupt release of energy in the earth's lithosphere causing an earth vibration; an earthquake.

Seismic Forces – The actual forces created by earthquake motion; assumed forces prescribed in the *Provisions* that are used in the seismic design of a building and its components.

Seismic Hazard – any physical phenomenon such as ground shaking or ground failure associated with an earthquake that may produce adverse effects on the built environment and human activities; also the probability of earthquakes of defined magnitude or intensity affecting a given location.

Seismic Hazard Exposure Group – A classification assigned in the *Provisions* to a building based on its occupancy and use.

Seismic Performance Category – A classification assigned in the *Provisions* based on its Seismic Hazard Exposure Group and its seismic hazard.

Seismic Force Resisting System – The part of the structural system that is designed to provide required resistance to prescribed seismic forces.

Seismic Risk – The probability that the social or economic consequences of an earthquake will equal or exceed specified values at a site during a specified exposure time; in general, seismic risk is vulnerability multiplied by the seismic hazard.

Seismic Waves – See "Waves, Seismic."

Seismic Zone – Generally, areas defined on a map within which seismic design requirements are constant; in the *Provisions*, seismic zones are defined both by contour lines and county boundaries.

Shear – A force that acts by attempting to cause the fibers or planes of an object to slide over one another.

Shear Panel – See "Wall, Shear."

Shear Wall – See "Wall, Shear."

Speed – Rate of change of distance traveled with time irrespective of direction.

Stiffness – Resistance to deflection or drift of a structural component or system.

Story Drift – Vertical deflection of a single story of a building caused by lateral forces.

Strain – Deformation of a material per unit of the original dimension.

Strength – The capability of a material or structural member to resist or withstand applied forces.

Stress – Applied load per unit area or internal resistance within a material that opposes a force's attempts to deform it.

S-Wave – Shear or secondary wave produced essentially by the shearing or tearing motions of earthquakes at right angles to the direction of wave propagation.

System – An assembly of components or elements designed to perform a specific function such as a structural system.

Torque – The action of force that tends to produce torsion; the product of a force and lever arm as in the action of using a wrench to tighten a nut.

Torsion – The twisting of a structural member about its longitudinal axis.

Velocity – Rate of change of distance travelled with time in a given direction; in earthquakes, it usually refers to seismic waves and is expressed in inches or centimeters per second.

Vulnerability – The degree of loss to a given element at risk, or set of such elements, resulting from an earthquake of a given intensity or magnitude; expressed in a scale ranging from no damage to total loss; a measure of the probability of damage to a structure or a number of structures.

Wall, Bearing – An interior or exterior wall providing support for vertical loads.

Wall, Nonbearing – An interior or exterior wall that does not provide support for vertical loads other than its own weight as permitted by the building code; see also "Partition."

Wall, Shear – A wall, bearing or nonbearing, designed to resist seismic forces acting in the plane of the wall.

Wall System, Bearing – A structural system with bearing walls providing support for all or major portions of the vertical loads; seismic resistance may be provided by shear walls or braced frames.

Waves, Seismic – Vibrations in the form of waves created in the earth by an earthquake.

Weight – Name given to the mutual gravitational force between the earth and an object under consideration; varies depending on location of the object at the surface of the earth.

GENERAL TERMS

The following excerpt from the National Research Council Report, *Multiple Hazard Mitigation* (Washington, D.C.: National Academy Press, 1983), defines several other terms that sometimes cause confusion in discussions of seismic safety:

> ". . . The level of intensity or severity that is capable of causing damage depends upon the vulnerability of the exposed community; vulnerability is generally a function of the way in which structures are designed, built, and protected, and the vulnerability of a structure or community to a particular natural event is a measure of the damage likely to be sustained

should the event occur. The degree to which a community is prone to a particular natural hazard depends on risk, exposure, and vulnerability. When a natural hazard occurrence significantly exceeds the community's capacity to cope with it, or causes a large number of deaths and injuries or significant economic loss, it is called a disaster.

Hazard management includes the full range of organized actions undertaken by public and private organizations in anticipation of and in response to hazards. Hazard management has two primary (but not completely distinct) components: emergency management, typified by the police, fire, rescue, and welfare work carried on during a disaster; the advance planning and training that are necessary if emergency operations are to be carried out successfully; and the post-disaster recovery period in which damage is repaired; and mitigation, which focuses on planning, engineering, design, economic measures, education, and information dissemination, all carried out for the purpose of reducing the long-term losses associated with a particular hazard or set of hazards in a particular location."

Appendix B

BUILDING REGULATION IN THE UNITED STATES

INTRODUCTION

The regulation of building construction has been a matter of public concern from the beginning of civilization. An early building code provision can be found in the *Old Testament*:

> "When you build a new house you shall make a parapet for your roof that you may not bring the guilt of blood upon your house if anyone fall from it."

This provision has remained relatively intact for 4000 years and is now (in less emotional language) Section 1711 of the *Uniform Building Code*, which reads:

> "All unenclosed floor and roof openings . . . and roof used for other than service of the building shall be protected by a guard rail."

Building regulation reflects the fundamental duty of government to protect people and property from harm within the concept of *police power* – the right of all states to protect the general health, safety and welfare through appropriate legislation. In the United States, building regulations generally are an expression of the police power of government, which the *Constitution* has reserved for the states.

Most states have delegated this function in whole or in part to their political subdivisions (cities, counties, villages, towns, and other special districts). Therefore, the building regulatory system is predominantly an aspect of local *home rule* and has evolved with different traditions and to different degrees in various localities and regions. Even today, building remains unregulated in some parts of the United States in deference to the perceived right of property owners to build as they wish on their own land.

If a community decides that it should have a building code, it can:

- Develop its own code,
- Adopt one of the three available national model codes in its entirety. (The model codes are described later in this appendix), or
- Develop its own code by modifying a model code to reflect specific local concerns.

THE PURPOSE OF BUILDING REGULATION

The specific purposes of building regulations usually are set forth clearly in the code or operative legal document of a jurisdiction. In order to understand building regulations, it is essential to realize that they are *minimum legal criteria for construction that can establish both criminal and civil liability* for noncompliance. The specific goals and objectives of building regulatory systems generally are to:

- Prevent or minimize bodily injury to building users and occupants,
- Prevent or minimize structural failures and collapse with attendant injuries to the public and damage to property,
- Prevent or minimize the incidence of fire damage and spread both for individual structures and the community as a whole,
- Prevent or minimize deterioration and damage to property from the elements,
- Prevent or minimize "overcrowding" and the creation of slum and ghetto community conditions, and
- Protect the public welfare as this concept is further defined in local community and/or state law.

Starting from this basic list, the concept of public welfare in relation to U.S. building regulations has been expanded by the courts significantly during the past 25 years. Building regulations and codes now often include detailed provisions for other than safety objectives (for example, accessibility for the disabled, historic preservation, energy conservation, and noise control). Some broader environmental concerns (for example, air and water pollution), economic development issues, and aesthetic considerations also have found their way into some building regulations under the aegis of the police power protection within an expanded concept of public welfare.

PARTICIPANTS IN THE REGULATORY PROCESS

The principal participants in the U.S. regulatory system are:

- Local government building and safety departments and special districts,
- State agencies (both regulatory and proprietary interests),
- Federal agencies (both regulatory and proprietary interests), and
- Model code organizations, professional societies, and building industry and trade associations.

LOCAL GOVERNMENT BUILDING AND SAFETY DEPARTMENTS AND SPECIAL DISTRICTS

Enforcement of the building regulatory system for some 75 percent of construction activity emanates from local jurisdictions that issue permits and inspect private projects for conformance. The content and detail of these building regulations are developed, however, in a more complex regional and/or national context and process.

Separate from local regulatory jurisdictions are a large number and variety of local special-purpose districts (for example, schools and utilities). The state or regional enabling legislation for these special districts often makes them autonomous authorities and exempts them from local regulatory controls; thus, they may develop their own building regulations for their programs, which may cross local regulatory jurisdictional boundaries.

STATE AGENCIES

Many states, in response to either lack of uniformity in or the absence of local building regulations, have enacted parallel sets of statewide minimum regulations for selected classifications of private buildings (for example, housing or high-rise structures). These statewide regulations reflect a multitude of state organizational formats and legislative backgrounds and often serve as a screening device for state lending, insurance, and other indirect funding programs and mechanisms.

Virtually all states also have agencies that construct, regulate, and maintain state-owned and -operated facilities (for example, schools, correctional facilities, and hospitals). These agencies also often are exempt from local regulations and develop types of internal building regulations for their programs and projects.

Although most state agencies have the authority to write their own building regulations, as a practical matter they usually adopt some form of the model code in current general use in the region, incorporating additions and amendments to reflect specific state concerns.

FEDERAL AGENCIES

Like the states, agencies of the federal government are exempt from the home rule concept of U. S. building regulations. Although the trend is for these agencies to use existing national standards whenever possible, over the years they have developed extensive internal building regulations to address their own proprietary construction interests. In some cases, federal agencies have developed or adopted forms of building regulations as direct qualifying standards for federal funding of private sector construction or for indirect funding through redevelopment and other subsidy programs.

Other federal agencies are directly involved in either developing and writing building regulations and standards or providing technical assistance to and research for those organizations that do write and promulgate them. Many of these agencies participate on the Interagency Committee on Seismic Safety in Construction (ICSSC).

Two recent executive orders impose new directives on the federal government. With respect to new construction, Executive Order 12699 requires that new 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.

MODEL CODE ORGANIZATIONS, PROFESSIONAL SOCIETIES AND INDUSTRY AND TRADE ORGANIZATIONS

Currently the following three model code organizations are active in the United States and produce model sets of basic building regulations:

- The Building Officials and Code Administrators International (BOCA),
- The International Conference of Building Officials (ICBO), and
- The Southern Building Code Congress International (SBCCI).

These model code organizations have regional bases – BOCA produces building and other codes focusing on the Northeast and Midwest, SBCCI produces similar codes for the South and Southeast, and ICBO produces codes for the West and Midwest. In addition, the National Fire Protection Association (NFPA) produces electrical and fire protection codes that are generally used nationwide. All these organizations publish code documents and offer a variety of other educational and support services that assist local jurisdictions.

The model code organizations are structured as nonprofit, membership-owned corporations. Through appropriate bylaws and voting processes, they develop, publish, and modify building regulations in response to changing building technology and experience. A published model code usually is adopted by reference by a local jurisdiction's legislative body.

The building design professions (architects and engineers) have a long-standing tradition of active professional interest in the building regulatory system. Organizations such as the Building Seismic Safety Council (BSSC), the American Society for Testing and Materials (ASTM), the American National Standards Institute (ANSI), the American Institute of Architects (AIA), the American Society of Civil Engineers (ASCE), the Applied Technology Council (ATC), the Earthquake Engineering Research Institute (EERI), and many state and regional structural engineers associations have developed material standards, testing procedures, and design parameters. Beyond this, the major manufacturers of almost every component used in buildings (such as roofs and windows) are members of a trade association that develops standards and design guidelines. This information often is incorporated directly into model codes or serves as background assistance for design and construction professionals.

CODE CHANGE PROCEDURES

A brief outline of some aspects of the code evolution and change process of the model code organizations is presented below as an overview of the general way in which states, counties, and cities develop regulations. Each of the model code groups publishes a new edition every three years and issues amendment supplements each year.

MODEL CODE CHANGE PROCEDURES

Each of the model code groups operates on an annual change cycle so that a code change can be fully processed within a 12-month period.

Each model code group distributes to its membership and all other interested parties a booklet of proposed code changes and a booklet of recommendations by the organization's code revision committee. Each code change proposal is identified with a specific number so that it can be tracked through the code change process. Although anyone may submit a code change proposal to a model code group, those doing so are encouraged to submit adequate substantiating material so that the code revision committees can base their recommendations on factual information.

The model code organizations' code revision committees generally are composed of the organizations' voting members (usually individuals representing a code enforcement entity such as a city, county, or state). Ad hoc committees for each of the model code organization are appointed to study special topics and are composed of all interested parties with appointments limited when required to maintain a balance of interests. All model code hearings are open to the public, and any individual or organization may present testimony on any agenda item. Some entities such as national trade associations, professional associations or committees appointed by the model code group can exert special influence on the code change process and it is up to each code revision committee as a whole to maintain balance.

A committee recommendation is made on each code change proposal. This recommendation may be for approval as submitted, approval as revised at the hearing, or disapproval. In some instances, further study may be recommended.

Committee actions, with reasons for each recommendation, are published and distributed to the model code membership and other interested parties. These actions become the agenda base for a public hearing and membership vote during the model code groups' annual meetings. Final action taken by voting members at an annual meeting (or, in some cases, by letter ballot) are published either in the form of annual supplements and/or as part of the triennial code editions.

STATE CODE ADOPTION PROCEDURES

The adoption of building regulations by states may take a variety of forms. The two most common are total pre-emption, in which the state develops or adopts rules and regulations that must be enforced by the local jurisdiction, or partial pre-emption, in which the state regulations are minimum standards and the local jurisdiction may adopt equal or more restrictive regulations.

In states that have mandatory statewide building regulation (currently approximately 25 states have some form of building regulation), proposed new rules usually are submitted as amendments to existing regulations. When the proposed rules are included in a model code forming the basis of the state code, they may be adopted very simply as a routine update to the model code on an annual basis or upon publication of a new edition of the model code.

In states that do not regulate building, an initiative must be generated by one or more interested persons who arrange for a member of the legislature to introduce a bill containing the proposed rules. Following introduction, the bill is assigned to one or more committees and placed on a calendar that directs its path through the legislative process. If it makes it through the process, the bill is signed by the governor and published in the statute books with responsibility for implementation placed in one of the state agencies.

LOCAL CODE ADOPTION PROCESS

When a city or county uses one of the model codes, new regulations are most readily introduced as part of that code's periodic revision and adoption process. In this situation, local opposition to the proposed rules may be significantly reduced since the public debate over the appropriateness of the rules already has been conducted at the national level; thus, any local opponent must show that the local community's uniqueness warrants noncompliance with the national standards.

When a locally written code is in effect or there is no code at all, new rules must have a local sponsor such as a councilman, building official, fire official, or legal counsel to initiate preparation of an adoption ordinance. Once introduced, a proposed ordinance usually is assigned to a local government standing committee or subcommittee for presentation and discussion at public hearings, the results of which will influence, to a great extent, whether the committee or subcommittee recommends that the ordinance be passed, be referred back for amendment, or be defeated.

Once adopted and after publication in an official paper, an ordinance usually becomes effective on a date specified in the ordinance or set forth by statute and is assigned an agency or department, usually the city or county building department, for implementation and enforcement. The building official then needs to review, and revise as necessary, his rules of procedure to reflect the newly adopted ordinance. Plan review, permit, and inspection procedures must be evaluated for adjustment. Personnel training and qualification in the plan review, permit, and inspection procedures also must be reviewed and updated as necessary.

Appendix C

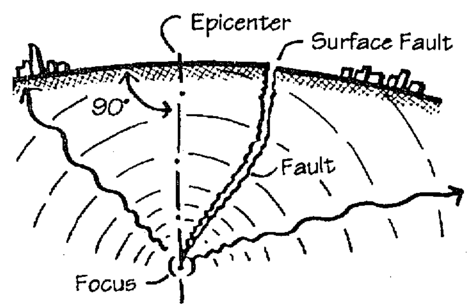
EARTHQUAKES, BUILDINGS, AND THE *NEHRP RECOMMENDED PROVISIONS*

The information that follows in this appendix has been excerpted from another book prepared for FEMA by the BSSC, *A Nontechnical Explanation of the 1994 NEHRP Recommended Provisions* (FEMA Publication 99). Those readers who find this appendix of interest and would like to learn more about how the *Provisions* treats seismic design are encouraged to order this free document from the BSSC.

THE NATURE OF EARTHQUAKE GROUND MOTION

The Origin of Earthquakes

Most earthquakes are the result of abrupt slippage along a fault zone below the surface of the earth. This slippage eventually may result in "*surface faulting*," the cracking or breaking apart on the earth's surface that typifies movie visions of earthquakes.

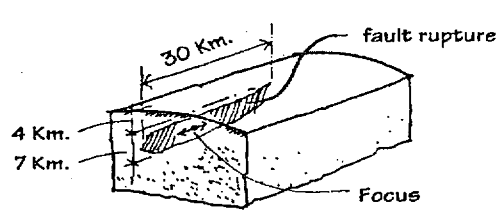


The point where the first slip on the fault occurs is called the "*focus*" or "*hypocenter*." The "*epicenter*" is a theoretical point on the earth's surface that is vertically above the focus. The earthquake starts at the focus, not the epicenter.

Faults and Waves

There are several kinds of faults but, for seismic design purposes, the concern is not what kind of fault slippage generated when the fault slips occurs, but rather what will be the nature of the ground motion to which the building will be subjected.

There is often extensive surface faulting in large earthquakes in the immediate vicinity of the fault. In the 1906 California earthquake, the fault broke the surface over a distance of over 200 miles with lateral movement of as much as 20 feet. In the 1992 Landers earthquake, east of Los Angeles, the fault broke the surface over a distance of 48 miles with lateral movements of up to 18 feet reported.



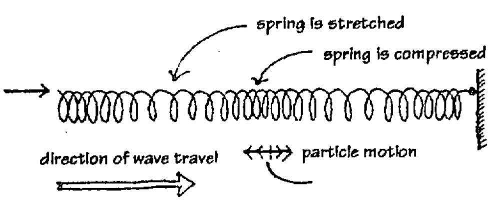
LOMA PRIETA FAULT RUPTURE

When such a large movement occurs, a building straddling the fault would be severely damaged since no building can be designed to deal with such large ruptures. However, this kind of disturbance of the ground is generally quite narrow in width to either side of the fault (in Landers, the maximum width of severely disturbed ground was about 125 feet. Beyond this area, structures are affected only by general ground shaking, and this is what seismic design is intended to deal with. Since almost all building damage is caused by ground motion rather than by fault rupture, this strategy makes sense.

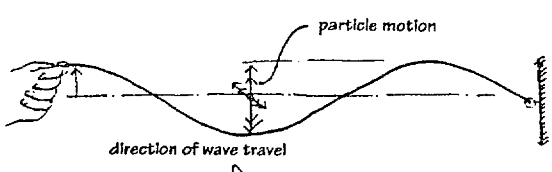
Once the fault slips, the rupture spreads rapidly along the fault. The rupture creates waves of vibration deep in the earth that spread in all directions from the point of inception and along the fault. The seismic waves begin like ripples in a still pond when a pebble is thrown into it, but they rapidly become much more complex.

Because the waves spread not only from the focus but also along the length of the fault rupture as it spreads rapidly along the fault, the intensity of the ground shaking has *directivity* – that is, the waves of vibration are of greater magnitude and last longer in the direction of fault rupture. In addition, the heavy shaking tends to reduce more rapidly in the direction normal to the fault line so that the area of heavy shaking has an elongated shape when viewed from above, instead of being a circle that is centered on the focus.

Studies of recent large earthquakes, such as Landers, Northridge and Kobe, also have shown that a few large pulses of long-period energy often occur towards the beginning of the earthquake close to the fault line. Because of the directivity effect, these large pulses can cause severe and almost instantaneous damage to relatively large, long-period buildings and structures such as bridges that are located close to and along the line of the fault.



P WAVE



S WAVE

There are four main types of seismic waves: two "body" waves within the earth and two "surface" waves confined to the surface layers of the earth. All four are considered in design. First to arrive at the surface is the *P* or *primary* wave. In this wave, the ground is successively pushed and pulled along the wave front. The motion of the ground is analogous to that of a coil spring when one end of the spring is moved. Successive waves can be created that move along the spring from one end to the other, alternately stretching and compressing the coils. A point on a coil – analogous to a spot on the ground – will announce the arrival of the wave by an abrupt movement in the direction of the wave and then will move only back and forth.

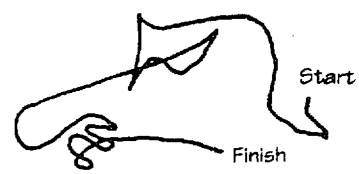
The *P* wave is followed by the *S* or *secondary* or *shear* wave, which is a motion at right angles to the wave front. This can be represented by pulling one end of a horizontal rope rapidly up and down to create waves that travel the length of the rope. A point on the rope will move only perpendicular to the direction of the rope which, for the ground, represents both lateral and vertical motion. When the wave reaches the surface, the motion is mostly horizontal. Just as the *P* wave travels faster than the *S* wave, the back and forth motion of a particle in the *P* wave is faster than the sideways motion of a particle in the *S* wave.

The *P* wave produces a jolt followed soon after by the "rolling" motion of the *S* wave. The two other waves are only at the earth's surface; the *Rayleigh* wave is an elliptical wave in the vertical plane and the *Love* wave is a surface wave that produces sideways motion similar to that of the *S* wave.

These different waves can be identified on records generated by modern strong-motion instruments and an observer some distance from the epicenter often can feel the difference between the "punch" of the primary wave and the "roll" of the secondary wave.

Within a few seconds, all the waves participate and the result is a random wave motion, predominantly in all horizonal directions but also somewhat vertical. The actual ground movement (and consequent building motion) is small, even in a major earthquake, except in the immediate vicinity of a fault rupture. The problem for a building is that the result is hundreds or thousands of tons of steel, concrete, and other materials moving back and forth a few inches in a very violent manner.

Although study of building damage after earthquakes generally shows a clear direction to the shaking (buildings will suffer varying damage depending on the orientation of their long or short sides), this seismic direction cannot be anticipated and therefore does not influence design.



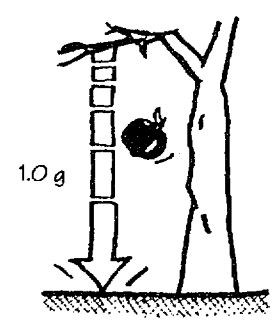
Scratch left on the floor by a kitchen range in the 1933 Long Beach, California earthquake.

Although seismic waves create ground motion that is predominately horizontal, there also often is considerable vertical motion. However, all buildings are designed to withstand vertical loads – the weight of the building and its contents – and large safety factors are used (that is, the calculated loads are multiplied by 2 or 3 to determine the loads for which the building is designed). These large safety factors mean that vertical earthquake forces are generally not a problem, but there are rare cases in which the vertical seismic forces exceed gravity, and buildings and other objects may be tossed into the air. Such was the case in the 1971 San Fernando earthquake when a fireman was tossed out of bed onto the floor and his bed fell on him. Large vertical accelerations in the Northridge earthquake also are believed to be responsible for some of the damage. In spite of these instances, however, seismic design and seismic codes focus on providing resistance to the horizontal forces that try to abruptly push buildings and objects sideways in all directions.

Forces and Gravity

The seismic body and surface waves create inertial forces within the building. These are the forces that may cause damage and are what seismic design tries to cope with. Inertial forces are created within an object when an outside force tries to make it move if it is at rest or change its rate or direction of motion if it is already moving. Inertial force takes us back to high school physics and to *Newton's Second Law of Motion* for when a building shakes it is in motion and must obey this law just as if it were a plane, a ship, or an athlete. Newton's Second Law of Motion states, in essence, that an *inertial force, F, equals mass, M, multiplied by the acceleration, A.*

Mass can be taken as equivalent (at ground level) to the weight of the building and so this part of the law explains why light buildings, such as wood frame houses, tend to perform better in earthquakes than large heavy ones – the forces on the structure are less.

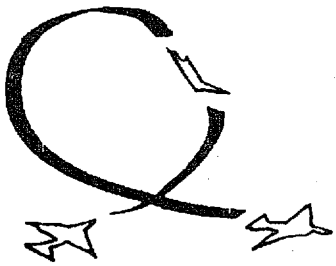


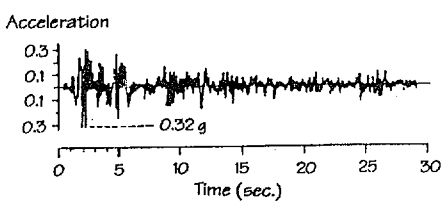
ONE "G" (NEWTON'S APPLE)

The acceleration or the rate of change of the velocity of the waves setting the building in motion determines the percentage of the building mass or weight that must be dealt with as a horizontal force. Acceleration is measured in terms of *the acceleration due to gravity* or "g." One "g" is the rate of change of velocity of a free-falling body in space . This is an additive velocity of 32 feet per second per second. Thus, at the end of the first second, the velocity is 32 feet per second; a second later it is 64 feet per second; and so on. When parachutists or bungee jumpers are in free fall, they are experiencing an acceleration of 1 "g." A building in an earthquake experiences a fraction of a second of "g" forces in one direction before they abruptly change direction.

FORCE = MASS x ACCELERATION

Engineering creations (planes, ships, cars, etc.) that are designed for this dynamic or moving environment can accommodate very large accelerations. Military jet planes, for example, are designed for accelerations of up to 9 "g." At this acceleration, the pilot experiences 9 times his body weight pressing down on his organs and blacks out. A commercial airliner in fairly severe turbulence may experience about 20 percent "g" (or 0.2g) as may a fast moving train on a rough track.


Military Jet - 9 g



ACCELERATION

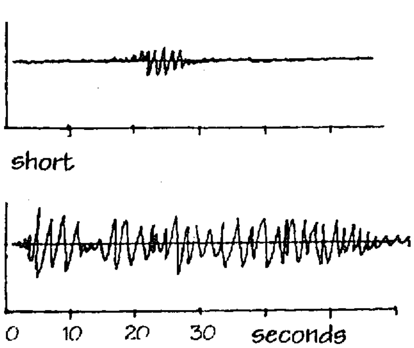
Poorly constructed buildings begin to suffer damage at about 10 percent "g" (or 0.1g). In a moderate earthquake, the waves of vibration may last for a few seconds, and accelerations may be approximately 20 percent "g." For people on the ground or at the bottom of a building, the sensations will be very similar to those of the occupants of a plane in turbulence or passengers in the corridor of a fast moving train over a somewhat uneven track: they feel a little unsteady and may need to grab on to something to help them remain standing. In large earthquakes, the heavy shaking will last for more than a few seconds but, except for rare major events, will not reach one minute. Sustained accelerations may, for a fraction of a second, be as high as 0.6 or 0.7 "g." Acceleration "spikes" – single very short duration accelerations – that reach almost 2 "g" have been recorded by instruments but these are so rapid that they do not damage the building and are not sensed by people.


ACCELERATION "SPIKE"

Duration, Velocity, and Displacement

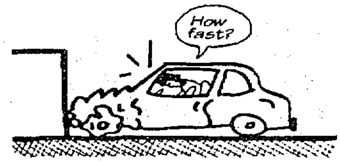
Because of the inertial force formula, acceleration is a key factor in determining the forces on a building, but other characteristics of the earthquake waves also are important.

One of these has already been mentioned. This is *duration* – how long the heavy shaking lasts. Although those who have experienced bad earthquakes believe the shaking lasts a lifetime, in fact almost all significant earthquake shaking can be measured in a few seconds. Duration is important because continued shaking weakens a building structure and reduces its resistance to earthquake damage.



DURATION

Two other measures are directly related to acceleration and can be mathematically derived from it. *Velocity,* which is measured in inches per second or centimeters per second, refers to the rate of motion at any given instant. For example, when a moving car hits an obstacle, it suddenly decelerates and, if the car occupants are not belted in and there are no airbags, they lurch forward toward the windshield. How fast, at that instant, are the occupants moving? The abrupt stop determines the extent of occupant injury and also affects the extent of damage to a structure.



VELOCITY

Displacement, measured in inches or centimeters, refers to the distance a point on the ground is moved from its initial location. Points in a building affected by shaking also will be moved to a comparable, or greater, extent so that this affects the structure (and also the comfort and security of the building occupants).

Acceleration, velocity, and displacement are mathematically and physically related and can be derived from one another.

CRITICAL BUILDING CHARACTERISTICS

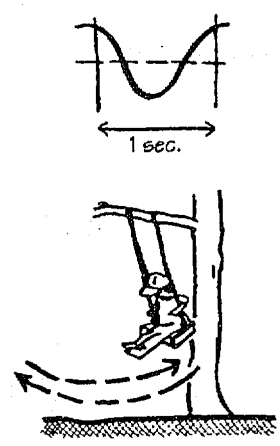
So far, we have been describing the *input motion* – the characteristics of ground motion that affect the building. However, there also are some important things about a building itself that, *in conjunction with* the ground motion, affect its performance and may dictate whether it collapses or survives.

Period and Amplification

Another very important characteristic of earthquake waves is their period or frequency – that is, whether the waves are quick and abrupt or slow and rolling. This phenomenon is particularly important for determining building seismic forces.

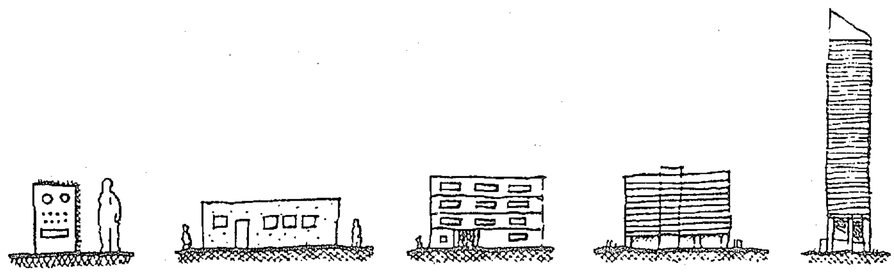
All objects have a *natural or fundamental* period; this is the rate at which they will move back and forth if they are given a horizontal push. In fact, without dragging it back and forth, it is not possible to make an object vibrate at anything other than its natural period. When a child in a swing is started with a push, to be effective this shove must be as close as possible to the natural period of the swing. If correctly gauged, a very small push will set the swing going nicely. Similarly, when earthquake motion starts a building vibrating, it will tend to sway back and forth at its natural period.

When a vibrating structure is given further pushes that are also at its natural period, the structure tends to *resonate*. Its vibrations increase dramatically in response to even rather small pushes and, in fact, its accelerations may increase as much as four or five times.



NATURAL, or FUNDAMENTAL PERIOD

Natural periods vary from about *0.05 seconds* for a piece of equipment such as a filing cabinet to about *0.1 seconds* for a one-story building. Period is the inverse of frequency so the cabinet will

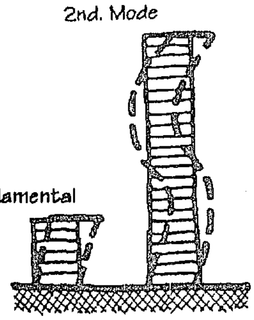


FUNDAMENTAL PERIODS

vibrate at 1/0.05 = 20 cycles a second or 20 Hertz. A four-story building will sway at about a *0.5 second* period and taller buildings between about 10 and 20 stories will swing at periods of about *1 to 2 seconds*. A rule of thumb is that the building period equals the number of stories divided by 10; therefore, period is primarily a function of building height. The 60-story Citicorp building in New York has a period of *7 seconds;* give it a push and it will sway slowly back and forth completing a cycle every 7 seconds. Other factors such as the building's construction materials, which affect the stiffness of the structure, and the building's geometric proportions also affect the period, but height is the most important consideration.

Taller buildings also will undergo several *modes of vibration* so that the building will wiggle back and forth like a snake. For seismic purposes, however, the natural period generally is the most significant.

The ground, of course, also vibrates at its natural period. The natural period of ground in the United States varies from about *0.4 seconds* to *2 seconds* depending generally on the hardness of the ground. Very soft ground may have a period of up to *2 seconds* since it cannot sustain longer period motions except under certain unusual conditions. Since this range is well within the range of common building periods, it is quite possible that the pushes that the ground gives the building will be at the natural period of the building. This may create *resonance*, causing the structure to have to deal with accelerations of perhaps *1 "g"* when the ground is only vibrating with accelerations of *0.2 "g."*

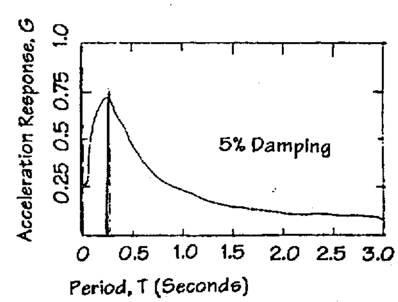


MODES OF VIBRATION

The terrible destruction in Mexico City in the earthquake of 1985 was primarily the result of response amplification caused by coincidence of building and ground motion periods. Mexico City was some 250 miles from the earthquake focus, and the earthquake caused the soft ground under the downtown buildings to vibrate for over 90 seconds at its long natural period of around 2 seconds. This caused tall buildings between about 10 and 20 stories to resonate at a similar period, greatly increasing the accelerations within them. This amplification in building vibration is very undesirable. The possibility of it happening can be reduced by trying to ensure that the building period will not coincide with that of the ground. Thus, on soft (long period) ground, it would be best to design a short stiff (short period) building.

There is also a more general amplification effect related to different types of ground. Earthquake ground shaking tends to be greater on soft ground than on hard ground such as rock. As a result, earthquake damage tends to be more severe in areas of soft ground. This characteristic became very clear when the 1906 San Francisco earthquake was studied and maps were drawn that showed building damage in relation to the ground conditions. Studies after the 1989 Loma Prieta earthquake also showed that shaking in the soft ground around San Francisco Bay was two and a half to three and a half times that of shaking in rock. Extensive damage was caused to buildings in San Francisco's Marina district, which was largely built on filled ground, some of it rubble deposited after the 1906 earthquake.

To assist the engineer in determining whether there may be a problem because the period of a new building is close to that of the site, curves for the site can be drawn (based on information about the nature of the ground) that show estimates of the periods at which *maximum building response* is likely – that is, the building periods for which maximum shaking can be anticipated. Such a curve is termed the *site response spectrum*. This spectrum shows the accelerations (on the vertical ordinate) that may be expected at varying periods (the horizontal ordinate). Thus, the response spectrum illustrated shows a maximum response at a period of about 0.3 seconds – the fundamental period of a mid-rise building. Based on this knowledge, the building design might be adjusted to ensure that the building period does not coincide with the site period of maximum response. For the figure shown, with a maximum response at about 0.3 seconds, it would be appropriate to design a building with a longer period of 1 second or more. Of course, it is not always possible to do this, but the response spectrum shows clearly what the possible accelerations at different periods are likely to be and the building can then be designed accordingly.



TYPICAL SITE RESPONSE SPECTRUM

Damping

The important relationship between the building and ground motion periods was illustrated in above using a the child's swing to show how the swinging motion is amplified by an *input motion*, in this case a judicious push. However, the child's swing is a pendulum that vibrates very efficiently and continue to swing for many minutes after any assistance even though the amplitude will diminish. Buildings and other objects do not swing as efficiently as pendulums because the vibration is *damped* or reduced. The extent of damping in a building depends on the materials of construction, how those materials are connected together, and on its architectural elements such as partitions, ceilings, and exterior walls.

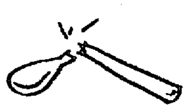
Higher Forces and Uncalculated Resistance

Even if a building is well damped and will not resonate, it may be subjected to forces that are much higher than the computed forces for which it was designed. Why is this the case? Because designing a building for the rare maximum conceivable earthquake forces and then adding a factor of safety of two or three times as is done for vertical loads would result in a very expensive structure whose functional use would be impeded by huge walls and columns.

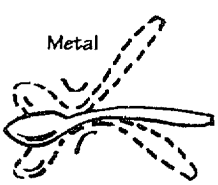
Experience shows, however, that many buildings have encountered forces far higher than they were designed to resist and yet have survived, sometimes with little damage. This phenomenon can be explained by the fact that the analysis of forces is not precise and deliberately errs on the conservative side so that the building can really survive higher forces than is apparent. In addition, the building often gains additional strength from components, such as partitions, that are not considered in an analysis. Some structural members may be sized for adequate stiffness rather than for strength. Finally, materials often are stronger in reality than the engineer assumes in his calculations. Taken together, these factors provide a considerable safety factor or uncalculated additional resistance.

Ductility

An additional property of materials is used to ensure that a building may adequately resist much more than its design ground shaking. This material property is called *ductility*. Ductility is the characteristic of certain materials – steel in particular – to fail only after considerable distortion or deformation has occurred. This is why it is much more difficult to break a metal spoon by bending it than one made of plastic. The metal object will remain intact – though distorted – after successive bending to and fro while the plastic spoon will snap suddenly after a few bends. The metal is far more *ductile* than the plastic.



BRITTLENESS



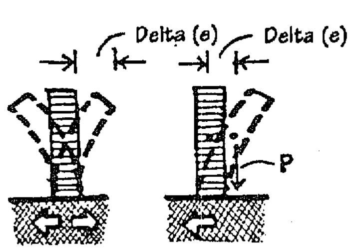
DUCTILITY

The deformation of the metal (even in the spoon) absorbs energy and defers absolute failure of the structure. The material bends but does not break and so continues to resist forces and support loads, although with diminished effectiveness. The effect of earthquake motion on a building is rather like that of bending a spoon rapidly back and forth – the heavy structure is pushed back and forth in a similar way several times a second (depending on its period of vibration).

Brittle materials, such as unreinforced brickwork or unreinforced concrete, fail suddenly with a minimum of distortion. However, the steel contained in a well designed modern reinforced concrete structure can give the combined material the ductility that is needed for earthquake resistance.

Thus, buildings are designed in such a way that in the rare case when they are subjected to forces higher than those required by a code, the materials and connections will distort but not break. In so doing, they will safely absorb the energy of the earthquake vibrations, and the building, although distorted and possibly unusable, is at least still standing.

Overturning



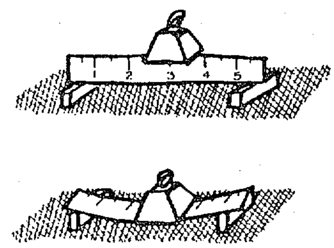
P-DELTA

Although building mass or weight was discussed as part of the *F = MA* equation for determining the horizontal forces, there is another way in which the building's weight may act under earthquake forces to overload the building and cause damage or even collapse.

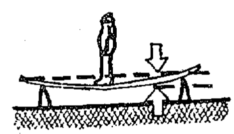
Vertical members such as columns or walls may fail by *buckling* when the mass of the building exerts its gravity force on a member distorted or moved out of plumb by the lateral forces. This phenomenon is known by engineers as the *P-e or P-delta* effect, where *P* is the gravity force or weight and e or delta is the eccentricity or the extent to which the force is offset. All objects that overturn do so as a result of this phenomenon.

The geometrical proportions of the building also may have a great influence on whether the *P-delta* effect will pose a problem since a tall slender building is much more likely to be subject to overturning forces than a low squat one. However, in earthquakes, buildings seldom overturn. This is because structures are not homogeneous but are composed of many elements connected together; the earthquake forces will pull the components apart and the building will fall *down*, not over. Strong, homogeneous structures such as filing cabinets, however, will fall over.

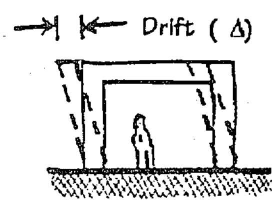
Strength, Stiffness, and Drift


STIFFNESS, STRENGTH

Two important related characteristics of any structure are its *strength* and its *stiffness*. Two structural beams may be equally strong (or safe) in supporting a load but may vary in their stiffness – the extent to which they bend or *deflect* in doing so. Stiffness is a material property but it also is dependent on *shape*. This concept can be easily understood by visualizing the flexibility of a long ruler placed where it has to support a load; how well it supports the load will depend on whether the load is placed on the ruler's flat surface or on its edge.

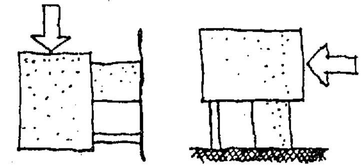

DEFLECTION

The measure of stiffness is *deflection*, the extent to which a structural element moves or bends when loaded. For vertical gravity loads, this is usually the only aspect of stiffness that is of concern. When floor joists are designed for a house, for example, it is often deflection rather than strength that dictates the size of the joists – that is, the depth of the joists is determined by how much they will bend under load rather than by whether they can safely support the floor loads. Typically, an unacceptable amount of bending will occur well before the joists are stressed to the point at which they may break because of the loads. (Stress refers to the internal forces within a material or member. The stress is created as the structural member resists the applied load. Stress is expressed in force per unit area – for example, pounds per square inch. Codes provide stress limits that are not to be exceeded for commonly used materials.)

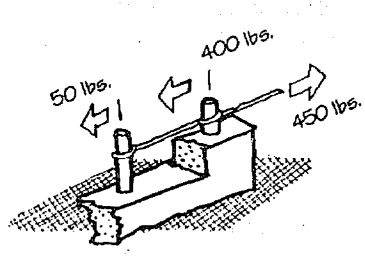


DRIFT

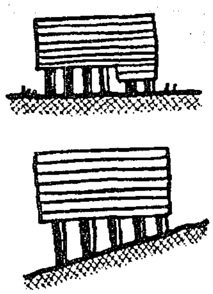
The analogous lateral force condition occurs when limitations on *drift*, the horizontal story-to-story deflection, impose more severe requirements on members than the strength requirements. Drift limits serve to prevent possible damage to interior or exterior walls that are attached to the structure and which might be cracked or distorted if the structure deflects too much laterally. The strength issue involves using a material strong enough to resist a load without exceeding a safe stress in the material while the drift issue involves preventing a structure from moving out of vertical alignment more than a given amount.


Vertical Horizontal

In seismic design, there is another very important aspect to stiffness. The problem of determining the overall lateral force on the building by multiplying the building weight by its acceleration has already been discussed. But how is this force distributed among the various elements of a building? The engineer needs to know this so that each member and connection can be properly designed to withstand the forces it may encounter. *Relative stiffness* enters into this issue because the applied forces are "attracted to" and concentrated at the stiffer elements of the building – in engineering terms, the forces are *distributed in proportion to the stiffness of the resisting elements.*



Why this is so can be understood by visualizing a heavy block supported away from a wall by two short beams. Clearly, the thick, stiff beam will carry much more load than the slender one, and the same is true if they are turned 90 degrees to simulate the lateral force situation.

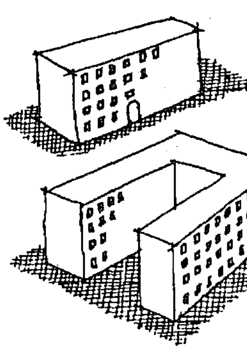

SHORT COLUMNS

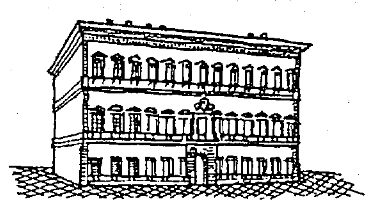
An important aspect of this for column lateral stiffness is illustrated in the next sketch. Mathematically, the stiffness of a column approximately varies as the cube of its length. In this diagram, the columns have the same cross-section but the short column is half the length of the long one. Therefore, the short column will be *eight* times stiffer (2^3) instead of *twice* as stiff and will take *eight times the horizontal load* of the long column. This concept has serious implications for buildings with columns of different lengths, and in designing a building, the engineer tries to equalize the stiffness of the resisting elements so that no one member or small group of members takes a disproportionate amount of the load. If this cannot be done (for architectural reasons, for example), then the designer must make sure that stiffer members are appropriately designed to carry their proportion of the load.

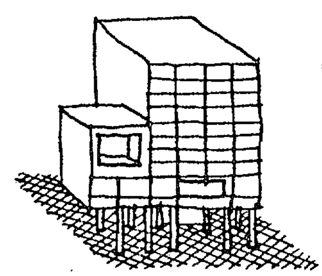
Building Size and Shape

The size, shape, and geometrical proportions of a building are termed its *configuration*. How the building configuration relates to its structural systems has a major influence on the building's ability to withstand shaking.

Many years ago when engineers first started studying the earthquake problem in a systematic way, they noticed that buildings with certain shapes and proportions seemed to be more prone to damage in earthquakes than others no matter what construction materials or structural systems had been used. In general, the more *irregular* the building – that is, the more the building deviated from a regular simple symmetrical shape – the more likely it seemed to suffer damage.


Regular
Irregular

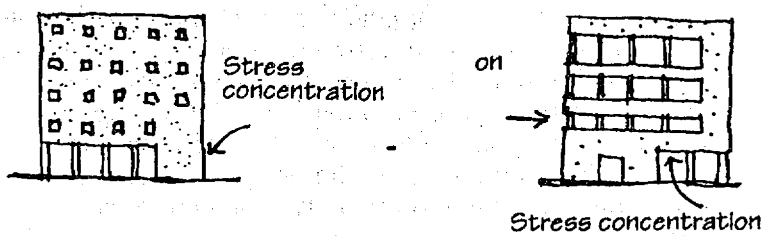

Decorated box


Modern structure

In the past, buildings tended to have simple configurations because traditional materials such as stone and brick did not allow for much more than superficial or surface decorative irregularity in design. (Sometimes, as in a medieval Gothic cathedral or a Renaissance Italian palace, this surface "irregularity" achieved the highest and most enduring form of art.) But starting in the late nineteenth century, modern steel and reinforced concrete frame construction allowed for increased structural daring and permitted architects to conceive designs that would have been impossible with traditional masonry. Configuration irregularity results in two main effects – stress concentrations and torsional forces.

Stress Concentrations

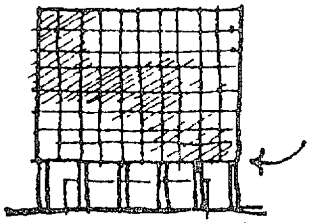
Irregularities tend to create abrupt changes in strength or stiffness that may concentrate forces in an undesirable way. These can be very difficult to deal with even in a modern structure. So, although the size of the overall force that the building must withstand is determined by the $F = MA$ equation, the way in which this is *distributed and concentrated* is determined by the configuration.



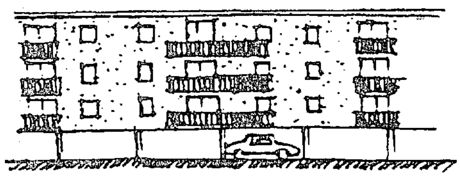
Stress concentration means that an undue proportion of the overall forces is concentrated at one or a few points of the building such as a particular set of beams, columns, or walls. These few members may fail and, by a chain reaction, bring down the whole building. Because, as has been noted, forces are attracted to the stiffer elements of the building, these also tend to be locations of stress concentration. People who are in the building demolition business know that if they weaken a few key columns or connections in a building, they can bring it down. An earthquake also tends to "find" these "weak links."

Stress concentration can also be created by vertical irregularity. The most serious condition of vertical irregularity is that of the *soft*, or weak, story in which one story, usually the first, is significantly weaker or more flexible than those above. A high first story is often architecturally desirable to accommodate larger rooms – lobbies, banking floors, or hotel meeting rooms. The design creates a major stress concentration at the points of discontinuity and, in extreme circumstance, may lead to collapse unless adequate design is provided at such points. A common example of the soft first story occurs in apartment houses, which often allocate all or most of the first floor to parking, with widely spaced columns and a minimum of walls.

The first floor of the Northridge Meadows apartments, designed before the problem of the soft first story was fully understood, collapsed in the 1994 Northridge earthquake, with considerable loss of life. Many other similar apartments also collapsed or were severely damaged, but fortunately only automobiles were destroyed.



Soft story

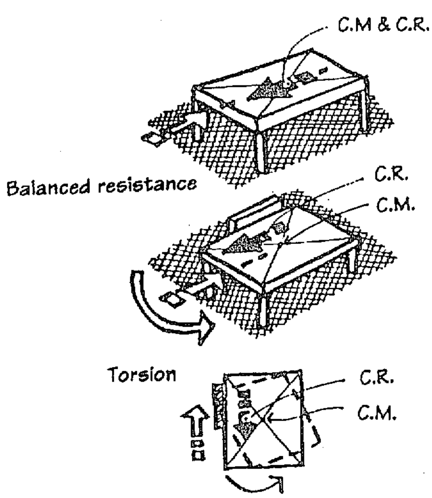


NORTHRIDGE MEADOWS APARTMENTS

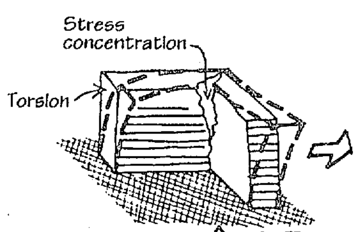
Torsional Forces

In addition to stress concentrations, irregularities, particularly in plan, may permit what are called *torsional* or twisting forces to develop, which contributes a significant element of uncertainty to an analysis of building resistance. ("Plan" refers to the horizontal layout of the building which may be a simple square or rectangular or an irregular shape with wings of different shapes and proportions.)

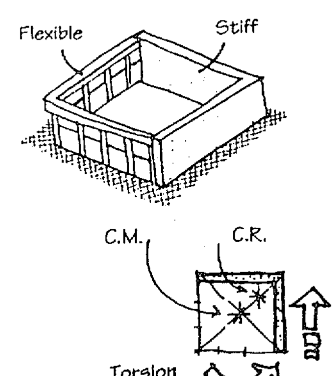
Torsional forces are created in a building by a lack of balance between the location of the resisting elements and the arrangement of the building mass. Engineers refer to this as *eccentricity* between the *center of mass* and the *center of resistance*, which tends to make the building rotate around the latter and creates torsion in the resisting elements. In a building, the main lateral force is contributed by the weight of the floors, walls, and roof, and this force is exerted through the center of mass, usually the geometric center of the floor (in plan). If the resistance provided by walls and columns pushes back through this point (the center of resistance), then there is no torsion and balance is maintained. If not, torsion is introduced and dangerous concentrations of stress can be created. This is the reason why it is recommended that buildings in areas of seismic risk be designed to be as symmetrical as possible.



TORSION



L-SHAPED BUILDING



PERIMETER VARIATION

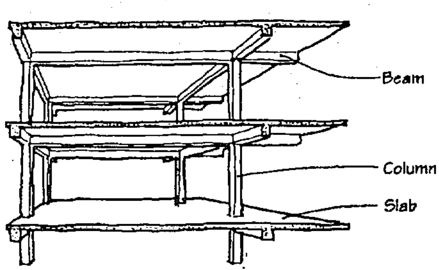
One building configuration that is most likely to produce torsion features *re-entrant corners* (buildings shaped like an L or a T for example). The wings of such buildings tend to twist and produce torsional forces. In addition, re-entrant corner buildings also tend to produce *stress concentration* at the "notch" where the wings meet because this location often is stiffer and therefore attracts a higher proportion of the forces.

Buildings that have large *variations in their perimeter resistance* on different sides of the building also tend to produce torsion. This form of variation in perimeter resistance occurs often in buildings such as stores in which side and end walls may be masonry or concrete party walls while the front wall may be largely glass. The centers of mass and resistance do not balance and, in extreme cases, the building can tear itself apart.

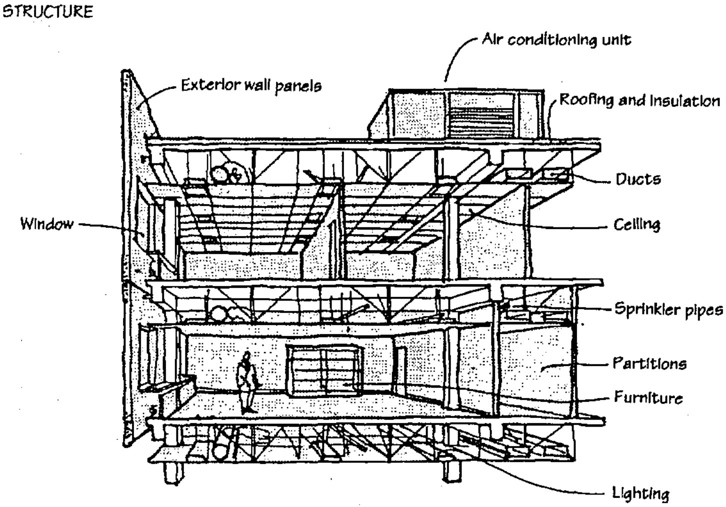
Nonstructural Components

For a long time, seismic building codes focused exclusively on the *structure* of the building – that is, the system of columns, beams, walls and diaphragms that provides resistance against earthquake forces. Although this focus remains dominant for obvious reasons, experience in more recent earthquakes has shown that damage to *nonstructural components* is also of great concern. In most modern buildings, the nonstructural components account for 60 to 80 percent of the value of the building.

Nonstructural components surround us at work or at home – ceilings, partitions, light fixtures, windows, and exterior walls. They are also the components that enable the building to function – the power, heating, cooling, and elevator systems and, for buildings like hospitals, the medical equipment that maintains or saves lives. Damage to nonstructural components



STRUCTURE



NONSTRUCTURE (shaded)

can result in great economic loss, in terms of both the cost of repair and the loss of building use and business interruption while the building is closed for repair. If the building is a critical facility such as a hospital, damage to utility systems providing such things as water and power may shut the building down when it is most needed.

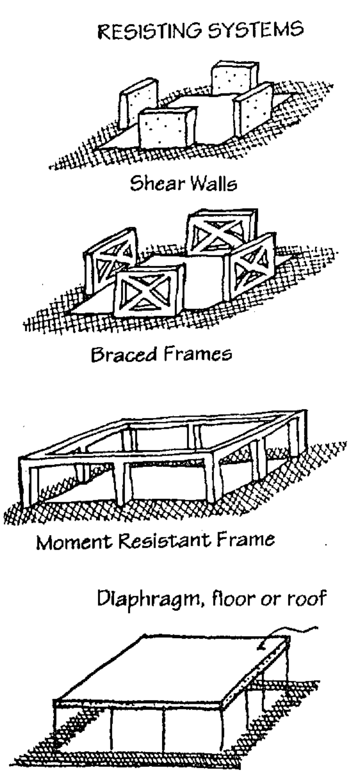
Nonstructural damage often is caused by movement of the building structure that is perfectly acceptable as far as the safety and stability of the structure is concerned. But the nonstructural components and finishes that are rigidly attached to the structure are bent and twisted in way that they cannot accommodate with the result that tiles fall off walls and plaster partitions and ceilings crack. This kind of damage is hazardous to occupants and can be difficult and expensive to repair.

Construction Quality

One other characteristic that applies to any building must be mentioned: it must be constructed well if it is to perform well. The materials from which it is constructed must have the necessary basic strength and expected properties. Most important, all the building's components must be securely connected together so that as they push and pull against one another during the earthquake, the connections are strong enough to transfer the earthquake forces and thereby maintain the integrity of the structure.

Framing Systems

How does an engineer design a building to resist all the forces that are produced by ground motion? Essentially, he must choose from a small set of components and then combine them in his design to form a complete resistance system.



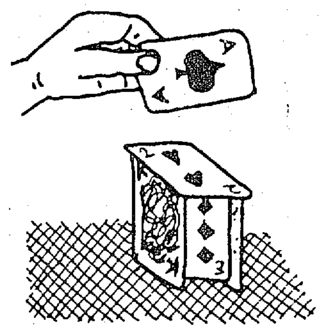
Three kinds of framing systems can resist the lateral forces generated in a building by an earthquake – *shear walls, braced frames*, and *moment resisting frames* (sometimes called rigid frames). These three types of framing system are really alternatives. Although designers sometimes mix components, using one type in one direction and another type in the other, this is inadvisable, mainly because the different systems have different stiffnesses and it is difficult to obtain balanced resistance when they are mixed.

Thus, the designer generally chooses only one type of framing system to resist the applied loads. This must be done at an early stage in the design because the different characteristics of these components have a considerable effect on the architectural design, both functionally and aesthetically. For example, if shear walls are chosen as the *seismic force resisting system*, the building will feature a pattern of permanent structural walls that run through every floor from roof to foundation. While this may be acceptable if the building is to be an apartment house or hotel, it will not work well if the building is to be a rental office building where internal space requirements will change regularly.

It should be noted that moment resistant frames sometimes are combined with one of the other systems to produce a *dual system*, in which the moment resistant frame backs up the other system. In this case, the two systems interact to share the load.

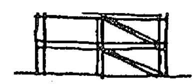
In the horizontal plane, *diaphragms,* generally formed by the floor and roof elements of the building, are necessary. (Sometimes, however, horizontal bracing systems independent of the roof or floor structure serve as diaphragms.) Diaphragms transfer the lateral forces to the vertical resistant elements – the shear walls or frames.

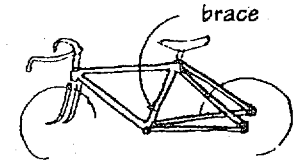
Shear walls are designed to receive lateral forces from diaphragms and transmit them to the ground. The forces in these walls are predominantly shear forces in which the material fibers within the wall try to slide past one another. A card house is a shear wall structure, and sufficient "card" walls must be placed at right angles to one another or the house will collapse. It is a very inefficient structure because the connections between the walls and between the walls and the diaphragms are nonexistent. If the walls are connected by slots or by tape, the structure is transformed into one that is very efficient for its size and weight. Similarly, the connections between the walls and floor and roof diaphragms in a building must be very strong and ductile.



Card House
- a shear wall structure

Braced frames act in the same way as shear walls; however, they generally provide less resistance but better ductility depending on their detailed design. Bracing provides lateral resistance through triangulated geometry, which prevents the frame from folding up if given a sideways push. A bicycle is a familiar example of a braced frame; without the connecting diagonal brace, the other members and connections would have to be much stronger to prevent the frame from folding up.

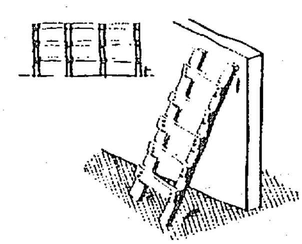




BRACED FRAME

In a building with a braced frame, lateral forces may cause the bracing to successively elongate and compress causing it to lose its effectiveness and experience large distortions that ultimately lead to collapse of the vertical structure it is trying to brace. Ductility therefore must be designed into the bracing so that it will deform but not snap.

A *moment resistant frame* is the engineering term for a frame structure in which the lateral forces are resisted primarily by bending in the beams and columns that is mobilized by strong rigid joints between columns and beams. (To engineers, a "moment" of a force about a point is the force multiplied by the distance between the point and the line of action of the force.) A simple ladder is an example of a moment resistant frame. In a building that uses a moment resistant frame, no walls or braced frames are required. The joints, however, become highly stressed and the details of their construction are very important in both steel and reinforced concrete.



MOMENT RESISTANT FRAME

As a last resort, moment resistant frames use the energy absorption obtained by ductility – that is, the permanent deformation of the structure prior to ultimate failure. For this reason, moment resistant frames generally are steel structures with bolted or welded joints in which the natural ductility of the material is an advantage. However, properly reinforced concrete frames that contain a large amount of precisely located steel reinforcing also are effective as ductile moment frames.

THE *NEHRP RECOMMENDED PROVISIONS*

This appendix has outlined the ways in which earthquake ground motion affects buildings and the ways in which building characteristics affect the response of buildings to this shaking. What the *Provisions* does is present procedures in the form of simple mathematical formulas and advisory precepts that the building designer uses as criteria for the building design. In doing this, the *Provisions* remains, however, focused the goal of providing a uniform level of safety for all building types in all areas of the United States even though there is great variability in the potential ground shaking hazard around the country.

As noted at the beginning of this appendix, readers interested in finding out more about the *Provisions* are encouraged to order FEMA Publication 99, *A Nontechnical Explanation of the 1994 NEHRP Recommended Provisions*.

Appendix D

OVERVIEW OF U.S. SEISMICITY

INTRODUCTION

The U.S. Geological Survey (USGS), together with the National Science Foundation (NSF), conducts and sponsors the major national effort in earthquake-related studies in seismology, geology, and geophysics. At present, the USGS has identified nine geographic areas in the United States as priority study areas: the intermountain seismic belt including the Wasatch Front of Utah; Puget Sound, Washington; Alaska; southern California; Hawaii; the central Mississippi valley; the southeastern United States including Charleston, South Carolina; the northeastern United States including Massachusetts and New York; and Puerto Rico and the Virgin Islands. A considerable amount of data on the earthquake hazard in these areas is available from the USGS and ongoing studies are continually adding to the store of information. When integrated with geologic data, studies of seismicity provide answers to the questions *where*, *how big*, *how often*, and *why* earthquakes occur. The information on U.S. seismicity included here is based on ongoing research by the USGS National Earthquake Information Center. It is presented to alert the reader to the national nature of the seismic hazard. Detailed information about specific areas can be obtained from geologists, geophysicists, and seismologists affiliated with area academic institutions; regional offices of the USGS and FEMA; national earthquake information centers; and state and regional seismic safety organizations.

The Modified Mercalli intensity scale (MMI) is used in the seismicity information presented here as the reference when instrumental data to define Richter and surface wave magnitudes were unavailable. See Appendix A for a brief explanation of these terms.

NORTHEAST REGION

The record of earthquakes in the United States (and the Northeast) is believed to have started with the Rhode Island earthquake of 1568. Including earthquakes originating in the St. Lawrence River Valley in Canada, 16 important earthquakes have occurred in the northeast region since 1568.

Important Earthquakes of Eastern Canada and New England

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
1534-1535	St. Lawrence Valley	IX-X	
June 11, 1638	St. Lawrence Valley	IX	
Feb. 5, 1663	Charlevoix zone	X	7.0
Nov. 10, 1727	New Newbury, MA	VIII	7.0
Sept. 16, 1732	Near Montreal	VIII	
Nov. 18, 1755	Near Cape Ann, MA	VIII	
May 16, 1791	East Haddam, CT	VIII	
Oct. 5, 1817	Woburn, MA	VII-VIII	
Oct. 17, 1860	Charlevoix zone	VIII-IX	6.0
Oct. 20, 1870	Charlevoix zone	IX	6.5
Mar. 1, 1925	Charlevoix zone	IX	7.0
Aug. 12, 1929	Attica, NY	VIII	5.5
Nov. 18, 1929	Grand Banks of Newfoundland	X	8.0
Nov. 1, 1935	Timiskaming, Quebec	VIII	6.0
Sept. 5, 1944	Massena, NY; Cornwall, Ont.	VIII	6.0
Jan. 9, 1982	North Central New Brunswick	V	5.7 (m_b)

SOUTHEAST REGION

The southeastern United States is an area of diffuse, low-level seismicity. It has not experienced an earthquake having an MMI of VIII or greater in nearly 80 years. The largest and most destructive earthquake in the region was the 1886 Charleston earthquake which caused 60 deaths and widespread damage to buildings. It had an epicentral intensity of X and a magnitude (M_S) of approximately 7.7.

Important Earthquakes of the Southeast Region

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Feb. 21, 1774	Eastern VA	VII	
Feb. 10, 1874	McDowell County, NC	V-VII	
Dec. 22, 1875	Arvonia, VA area	VII	
Aug. 31, 1886	Near Charleston, SC	X	7.7
Oct. 22, 1886	Near Charleston, SC	VII	
May 31, 1897	Giles County, VA	VIII	6.3
Jan. 27, 1905	Gadsen, AL	VII-VIII	
June 12, 1912	Summerville, SC	VI-VII	
Jan. 1, 1913	Union County, SC	VII-VIII	5.7-6.3
Mar. 28, 1913	Near Knoxville, TN	VII	
Feb. 21, 1916	Near Asheville, TN	VI-VII	
Oct. 18, 1916	Northeastern AL	VII	
July 8, 1926	Mitchell County, NC	VI-VII	
Nov. 2, 1928	Western NC		

CENTRAL REGION

The seismicity of the central region is dominated by the four great earthquakes that occurred in 1811-1812 near New Madrid, Missouri. These earthquakes had magnitudes (M_S) ranging from 8.4 to 8.7 and epicentral intensities ranging from X to XII. Some 15 of the thousands of aftershocks that followed had magnitudes greater than 6.

Important Earthquakes of the Central Region Through 1980

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Dec. 16, 1811	New Madrid, MO	XI	8.6
Jan. 23, 1812	New Madrid, MO	X-XI	8.4
Feb. 7, 1812	Mew Madrid, MO	XI-XII	8.7
June 9, 1838	Southern IL	VIII	5.7
Jan. 5, 1843	Near Memphis, TN	VIII	6.0
Apr. 24, 1867	Near Manhattan, KS	VII	5.3
Oct. 22, 1882	West Texas	VII-VIII	5.5
Oct. 31, 1895	Near Charleston, MO	VIII-IX	6.2
Jan. 8, 1906	Near Manhattan, KS	VI-VIII	5.5
Mar. 9, 1937	Near Anna, OH	VIII	5.3
Nov. 9, 1968	Southern IL	VII	5.5
July 27, 1980	Near Sharpsburg, KY	VI	5.1

WESTERN MOUNTAIN REGION

A number of important earthquakes have occurred in the western mountain region. These include earthquakes in the Yellowstone Park-Hebgen Lake area in western Montana, in the vicinity of the Utah-Idaho border, and sporadically along the Wasatch front in Utah. The largest earthquake in the western mountain region in historic times was the 1959 Yellowstone Park-Hebgen Lake earthquake which had a magnitude (M_S) that is now believed to be in excess of 7.3. The strongest earthquake in 24 years occurred at Borah Peak in Idaho in October 1983; it had a magnitude of 7.3.

Important Earthquakes of the Western Mountain Region Through 1980

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Nov. 9, 1852	Near Ft. Yuma, AZ	VIII?	
Nov. 10, 1884	Utah-Idaho border	VIII	
Nov. 14, 1901	About 50 km east of Milford, UT	VIII	
Nov. 17, 1902	Pine Valley, UT	VIII	
July 16, 1906	Socorro, NM	VIII	
Sept. 24, 1910	Northeast AZ	VIII	
Aug. 18, 1912	Near Williams, AZ	VIII	
Sept. 29, 1921	Elsinore, UT	VIII	
Sept. 30, 1921	Elsinore, UT	VIII	
June 28, 1925	Near Helena, MT	VIII	6.7
March 12, 1934	Hansel Valley, UT	VIII	6.6
March 12, 1934	Hansel Valley, UT	VIII	6.0
Oct. 19, 1935	Near Helena, MT	VIII	6.2
Oct. 31, 1935 (Aftershock)	Near Helena, MT	VIII	6.0
Nov. 23, 1947	Southwest MT	VIII	
Aug. 18, 1959	West Yellowstone-Hegben Lake	X	7.1
Aug. 18, 1959 (Aftershock)	West Yellowstone-Hegben Lake	VI	6.5
Aug. 18, 1959 (Aftershock)	West Yellowstone-Hegben Lake	VI	6.0
Aug. 18, 1959	West Yellowstone-Hegben Lake	VI	6.5
Mar. 28, 1975	Pocatello Valley, ID	VIII	6.1
June 30, 1975	Yellowstone National Park	VIII	6.4
Oct. 28, 1983	Borah Peak, ID	VII est.	7.3

CALIFORNIA AND WESTERN NEVADA REGION

The highest rates of seismic energy release in the United States, exclusive of Alaska, occur in California and western Nevada. The coastal areas of California are part of the active plate boundary between the Pacific and North American tectonic plates. Seismicity can be correlated with the well-known San Andreas fault system as well as many other active fault systems. A number of major earthquakes have occurred in this region; the most recent ones were the 1989 Loma Prieta and the 1992 Landers-Big Bear earthquakes. The following generalizations can be made: the earthquakes are nearly all shallow, usually less than 15 km (9 miles) in depth, the recurrence rate for a large (M_S greater than 7.8) earthquake on the San Andreas fault system is of the order of 100 years, the recurrence rates for large earthquakes on single fault segments in the Nevada seismic zone are believed to be in the order of thousands of years, and almost all of the major earthquakes have produced surface faulting.

Important Earthquakes of California and Western Nevada

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Dec. 21, 1812	Santa Barbara Channel	X	
June 10, 1836	Hayward fault, east of San Francisco Bay	IX-X	
June 1838	San Andreas fault	X	
Jan. 9, 1857	San Andreas fault, near Fort Tejon	X-XI	
Oct. 21, 1868	Hayward Fault, east of San Francisco Bay	IX-X	
Mar. 26, 1872	Owens Valley	X-XI	
Apr. 19, 1892	Vacaville, CA	IX	
Apr. 15, 1989	Mendocino County, CA	VIII-IX	
Dec. 25, 1899	San Jacinto, CA	IX	
Apr. 18, 1906	San Francisco, CA	XI	8.3
Oct. 3, 1915	Pleasant Valley, NV	X	7.7
Apr. 21, 1918	Riverside County, CA	IX	6.8
Mar. 10, 1922	Cholame Valley, CA	IX	6.5
Jan. 22, 1923	Off Cape Mendocino, CA	(IX)	7.3
June 29, 1925	Santa Barbara Channel	VIII-IX	6.5
Nov. 4, 1927	West of Point Arguello, CA	IX-X	7.3
Dec. 21, 1932	Cedar Mountain, NV	X	7.3
Mar. 11, 1933	Long Beach, CA	IX	6.3
May 19, 1940	Southeast of El Centro, CA	X	7.1
July 21, 1952	Kern County, CA	XI	7.7
July 6, 1954	East of Fallon, NV	IX	6.6
Aug. 24, 1954	East of Fallon, NV	IX	6.8
Dec. 16, 1954	Dixie Valley, NV (2 shocks)	X	7.3
Feb. 9, 1971	San Fernando, CA	XI	6.4
Oct. 15, 1979	Imperial Valley, CA	IX	6.6
May 2, 1983	Coalinga, CA	VIII	6.5
Oct. 1, 1987	Whittier Narrows, CA	VIII	6.1
Oct. 17, 1989	Loma Prieta, CA	VII	7.1
June 28, 1992	Landers, CA	VII	7.4
June 29, 1992	Big Bear, CA	VII	6.5
Jan. 17, 1994	Northridge, CA		6.6

WASHINGTON AND OREGON REGION

The Washington and Oregon region is characterized by a low to moderate level of seismicity in spite of the active volcanism of the Cascade range. With the exception of plate interaction between the North American and Pacific tectonic plates, there is no clear relationship between seismicity and geologic structure. From the list of important earthquakes that have occurred in the region, two of the three most recent damaging earthquakes in the Puget Sound area (M_S = 6.5 in 1965, M_S = 7.1 in 1949) occurred at a depth of 60 to 70 km. The third, the 1992 Petrolia earthquake (M_S = 7.1) occurred in the Mendocina triple junction where the Gorda, Pacific, and North American plates converge. Currently, speculation is occurring over whether a great earthquake can occur as a consequence of the interaction of these tectonic plates.

Important Earthquakes of Washington and Oregon

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Dec. 14, 1872	Near Lake Chelan, WA (probably shallow depth of focus)	IX	(7.0)
Oct. 12, 1877	Cascade Mountains, OR	VIII	
Mar. 7, 1893	Umatilla, OR	VII	7.0
Mar. 17, 1904	About 60 km NW of Seattle	VII	
Jan. 11, 1909	North of Seattle, near Washington/British Columbia border	VII	(5.7)
Dec. 6, 1918	Vancouver Island, B.C.	(VIII)	(5.8)
Jan. 24, 1920	Straits of Georgia	(VII)	
July 16, 1936	Northern OR, near Freewater	VII	
Nov. 13, 1939	NW of Olympia	VII	6.3
Apr. 29, 1945	About 50 km SE of Seattle	VII	
Feb. 15, 1946	About 35 km NNE of Tacoma (depth of focus 40-60 km)	VII	7.2
June 23, 1946	Vancouver Island	(VIII)	7.1
Apr. 13, 1949	Between Olympia and Tacoma (depth of focus about 70 km)	VIII	
Apr. 29, 1965	Between Tacoma and Seattle (depth of focus about 59 km)	VIII	6.5 7.1
Apr. 25, 1992	Petrolia (depth of focus about 10 km)	VII	

ALASKA REGION

The Alaska-Aleutian Island area is one of the most active seismic zones in the world. The Queen Charlotte Island-Fairweather fault system marks the active boundary in southeast Alaska where the Pacific plate slides past the North American plate. The entire coastal region of Alaska and the Aleutians have experienced extensive earthquake activity, even in the relatively short time period (85 years) for which the record of seismicity is well known. The most devastating earthquake in Alaska occurred on March 28, 1964, in the Prince William Sound. This earthquake, which has recently been assigned a moment magnitude of 9.2, also probably was the largest historical earthquake. It caused 114 deaths, principally as a result of the tsunami that followed the earthquake. The regional uplift and subsidence covered an area of more than 77,000 square miles.

Important Earthquakes of Alaska

Date	Location	Magnitude (Approx. M_S)
Sept. 4, 1899	Near Cape Yakatage	8.3
Sept. 10, 1899	Yakutat Bay	8.6
Oct. 9, 1900	Near Cape Yakatage	8.3
June 2, 1903	Shelikof Straight	8.3
Aug. 27, 1904	Near Rampart	8.3
Aug. 17, 1906	Near Amchitka Island	8.3
Mar. 7, 1929	Near Dutch Harbor	8.6
Nov. 10, 1938	East of Shumagin Islands	8.7
Aug. 22, 1949	Queen Charlotte Islands (Can.)	8.1
Mar. 9, 1957	Andreanof Islands	8.2
Mar. 28, 1964	Prince William Sound	8.4
Feb. 4, 1965	Rat Islands	7.8

HAWAIIAN ISLANDS REGION

The seismicity in the Hawaiian Islands is related to the well known volcanic activity and is primarily associated with the island of Hawaii. Although the seismicity has been recorded for only about 100 years, a number of important earthquakes have occurred since 1868. Tsunamis from local as well as distant earthquakes have impacted the islands, some having wave heights of as much as 15 meters (55 feet).

Important Earthquakes Causing Significant Damage in Hawaii

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Apr. 2, 1868	Near south coast of Hawaii	X	
Nov. 2, 1918	Mauna Loa, HI	VII	
Sept. 14, 1919	Kilauea, HI	VII	
Sept. 25, 1929	Kona, HI	VII	
Sept. 28, 1929	Hilo, HI	VII	
Oct. 5, 1929	Honualoa, HI	VII	6.5
Jan. 22, 1938	North of Maui	VIII	6.7
Sept. 25, 1941	Mauna Loa, HI	VII	6.0
Apr. 22, 1951	Kilauea, HI	VII	6.5
Aug. 21, 1951	Kona, HI	IX	6.9
Mar. 30, 1954	Near Kalapana, HI	VII	6.5
Mar. 27, 1955	Kilauea, HI	VII	
Apr. 26, 1973	Near northeast coast of Hawaii	VIII	6.3
Nov. 29, 1975	Near northeast coast of Hawaii	VIII	7.2
Nov. 16, 1983	Near Mauna Loa, HI		6.6

PUERTO RICO AND THE VIRGIN ISLANDS REGION

The seismicity in the Puerto Rico and Virgin Islands region is related to the interaction of the Caribbean and the North American tectonic plates. The Caribbean plate is believed to be nearly fixed while the North American plate is moving westward at the rate of about 2 cm/year. Earthquakes in this region are known to have caused damage as early as 1524-1528. During the past 120 years, major damaging earthquakes have occurred in 1867 and 1918; both earthquakes had tsunamis associated with them.

Important Earthquakes on or Near Puerto Rico

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Apr. 20, 1824	St. Thomas, VI	(VII)	
Apr. 16, 1844	Probably north of PR	VII	
Nov. 28, 1846	Probably Mona Passage	VII	
Nov. 18, 1867	Virgin Islands (also tsunami)	VIII	
Mar. 17, 1868	Location uncertain	(VIII)	
Dec. 8, 1875	Near Arecibo, PR	VII	
Sept. 27, 1906	North of PR	VI-VII	
Apr. 24, 1916	Possibly Mona Passage	(VII)	
Oct. 11, 1918	Mona Passage (also tsunami)	VIII-IX	7.5

Appendix E

WHERE TO GO FOR INFORMATION

INTRODUCTION

This appendix is designed to provide the concerned individual and community with additional sources of information on various topics. It begins with a list of national, regional, and federal government sources of information on seismology, seismic design and construction, seismic building code provisions, and disaster assistance. A list of publications on various subjects addressed in this book appears next following by a list of Internet information sources. Much information is best obtained at the local level; therefore, the reader is urged to contact local academic institutions and the local chapters of the various professional, materials, and building officials' organizations as well as the national and regional sources named here.

NATIONAL AND REGIONAL ORGANIZATIONS

American Concrete Institute
P.O. Box 19150/22400 W. Seven Mile Road
Detroit, Michigan 48219-1849
(313)532-2600

American Consulting Engineers Council
1015 15th Street, N.W., Suite 802
Washington, D.C. 20005
(202)347-7474

American Forest and Paper Association
1250 Connecticut Avenue, N.W., Suite 200
Washington, D.C. 20036
(202)463-2700

American Institute of Architects
1735 New York Avenue, N.W.
Washington, D.C. 20006
(202)626-7300

American Institute for Architectural Research
1735 New York Avenue, N.W.
Washington, D.C. 20006
(202)879-7750

American Institute of Steel Construction
1 East Wacker Drive, Suite 3100
Chicago, Illinois 60601-2001
(312)670-2400

American Insurance Association
1130 Connecticut Avenue, N.W., 10th Floor
Washington, D.C. 20036
(202)828-7100

American Insurance Services Group, Inc.
85 John Street
New York, New York 10038
(212)669-0400

American Iron and Steel Institute
671 Newcastle Road, Suite 1
Newcastle, California 95658-9702
(916)663-1989

American Planning Association
1776 Massachusetts Avenue, N.W.
Washington, D.C. 20036-1997
(202)872-0611

American Plywood Association
7011 South 19th Street, Box 11700
Tacoma, Washington 98411-0700
(206)565-6600

American Public Works Association
Council of Emergency Management
1313 East 60th Street
Chicago, Illinois 60637
(312)667-2200

American Red Cross
National Office of Disaster Assistance
18th and E Streets, N.W.
Washington, D.C.
(202)857-3718

American Society of Civil Engineers
345 East 47th Street
New York, New York 10017
(212)705-7496

Applied Technology Council
555 Twin Dolphin Drive, Suite 550
Redwood City, California 94065
(415) 595-1542

Associated General Contractors of America
1957 E Street, N.W.
Washington, D.C. 20006
(202)393-2040

Association of Bay Area Governments
P.O. Box 2050
Oakland, California 94604
(510)464-7900
e-mail: jeanncp@abag.ca.gov

Association of Engineering Geologists
323 Boston Post Road, No. 2D
Sudbury, Massachusetts 01776
(617)443-4639

Association of Major City Building Officials
505 Huntmar Park Drive, Suite 210
Herndon, Virginia 22070
(703)437-0100

Association of the Wall and Ceiling Industries International
1600 Cameron Street
Alexandria, Virginia 22314-2705
(703)684-2924

Battelle Human Affairs Research Centers
4000 N.E. 41st Street
Seattle, Washington 98105
(206)525-3130

Brick Institute of America
11490 Commerce Park Drive, Suite 300
Reston, Virginia 22091-1532
(703)620-0010

Building Officials and Code Administrators International
4051 West Flossmoor Road
Country Club Hills, Illinois 60478-5795
(708)799-2300

Building Owners and Managers Association, International
1201 New York Avenue, N.W., Suite 300
Washington, D.C. 20005
(202)408-2662

Building Seismic Safety Council
1201 L Street, N.W., Suite 400
Washington, D.C. 20005
(202)289-7800
e-mail: cheider@nibs.org

Canadian National Committee on Earthquake Engineering
National Research Council of Canada
Division of Research Building
Ottawa, Ontario, Canada K1A 0R6
(416)996-5845

California Seismic Safety Commission
1900 K St., Suite 100
Sacramento, California 95814
(916)322-4917

Center for Earthquake Research and Information
Memphis State University
Memphis, Tennessee 38152
(901)678-2007
e-mail: stevens@ceri.memphis.edu

Center for Earthquake Studies
One University Plaza
Cape Gerardeau, Missouri 63701-4700
(314)651-2000

Central U.S. Earthquake Consortium
2630 E. Holmes Road
Memphis, Tennessee 38118-8007
e-mail: cusec@ceri.memphis.edu

Concrete Masonry Association of California and Nevada
6060 Sunrise Vista Drive, Suite 1875
Citrus Heights, California 95610
(916)722-1700

Concrete Reinforcing Steel Institute
933 North Plum Grove Road
Shaumburg, Illinois 60173-4758
(312)517-1200

Council of American Building Officials
5205 Leesburg Pike, Suite 708
Falls Church, Virginia 22041
(703)931-4533

Earthquake Engineering Research Center
University of California at Berkeley
1301 South 46th Street
Richmond, California 94844-4698
(415)231-9403
e-mail: eerclib@berkeley.edu

Earthquake Engineering Research Institute
449 14th St., Suite 320
Oakland, California 94612-1902
(510)451-0905

Earthquake Engineering Research Library
California Institute of Technology
Mail Code 104-44
Pasadena, California 91125
(818)395-4227
e-mail: eerlib@caltech.edu

Insurance Information Institute
110 Williams Street, 24th Floor
New York, New York 10038
(212)669-9200

Insurance Institute for Property Loss Reduction
73 Tremond Street, Suite 510
Boston, Massachusetts 02108-3910
(617)722-0200

International City Management Association
777 N. Capitol St., N.E.
Washington, D.C. 20002-4201
(202)289-4262

International Conference of Building Officials
5360 South Workman Mill Road
Whittier, California 90601
(213)699-0541

Masonry Institute of America
2550 Beverly Boulevard
Los Angeles, California 90057
(213)388-0472

Metal Building Manufacturers Association
1230 Keith Building
Cleveland, Ohio 44115-2180
(216)241-7333

National Association of Independent Insurers
2600 River Road
Des Plaines, Illinois 60018
(708)297-7800

National Association of Home Builders
15th and M Streets, N.W.
Washington, D.C. 20005
(202)822-0200

National Center for Earthquake Engineering Research
c/o Science and Engineering Laboratory.
SUNY-Buffalo
342 Copen Hall
Buffalo, New York 14260
(716)636-3379
e-mail: nernceer@ubvms.cc.buffalo.udc

National Committee on Property Insurance
10 Winthrop Square
Boston, Massachusetts 02110
(617)423-4620

National Concrete Masonry Association
2302 Horse Pen Road
Herndon, Virginia 22070-0781
(703)435-4900

National Conference of States on Buildings Codes and Standards
505 Huntmar Park Drive, Suite 201
Herndon, Virginia 22070
(703)437-0100

National Coordinating Council on Emergency Management
7297 Lee Highway, Suite N
Falls Church, Virginia 22042
(703)533-7672

National Elevator Industry, Inc.
185 Bridge Plaza, North, Suite 310
Ft. Lee, New Jersey 07024
(201)944-3211

National Emergency Managers Association
c/o Executive Director, Commonwealth of
P.O. Box 59
Kentucky, Department of Military Affairs, Division of Disaster and Emergency Services
Lexington, Kentucky 40501-0059
(502)564-8680

National Fire Sprinkler Association
Route 22 and Robin Hill Park, Box 1000
Patterson, New York 12563
(914)878-4200

National Institute of Building Sciences
1201 L Street, N.W., Suite 400
Washington, D.C. 20005
(202)289-7800

Natural Hazards Research and Applications Information Center
University of Colorado
Campus Box 482
Boulder, Colorado 80309-0482
(303)492-6818
e-mail: hazctr@colorado.edu

National Research Council Board on Natural Disasters
2101 Constitution Avenue, N.W., Room HA286
Washington, D.C. 20418
(202)334-1964
e-mail: cclarke@nas.edu

Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077
(312)966-6200

Precast/Prestressed Concrete Institute
175 West Jackson Boulevard, Suite 1859
Chicago, Illinois 60604
(312)786-0300

Rack Manufacturers Institute
8720 Red Oak Boulevard, Suite 201
Charlotte, North Carolina 28217
(704)522-8644

School Education Safety and Education Project
State Seismologist
Geophysics Department, AD-50
University of Washington
Seattle, Washington 98195
(206)545-7563

Seismological Society of America
201 Plaza Professional Building
El Cerrito, California 94530
(415)525-5474

Southern Building Code Congress International
900 Montclair Road
Birmingham, Alabama 35213
(205)591-1853

Steel Deck Institute, Inc.
P.O. Box 9506
Canton, Ohio 44711-9506
(216)493-7886

Steel Plate Fabricators Association, Inc.
2400 South Downing Avenue
Westchester, Illinois 60154-5102
(708)562-8750

Southeastern United States Seismic Safety Consortium
Department of Civil Engineering
The Citadel, The Military College of South Carolina
Charleston, South Carolina 29401
(803)792-7677

Southern California Earthquake Center
University of Southern California
University Park
Los Angeles, California 90089-0740
(213)740-5849
e-mail: jandrews@coda.usc.edu

The Masonry Society
2619 Spruce Street
Boulder, Colorado 80302
(303)939-9700

Western Seismic Safety Council
Washington State Department of Emergency Services
4220 East Martin Way
Olympia, Washington 98504
(206)459-9191

Western States Clay Products Association
9210 South, 5200 West
West Jordan, Utah 84084
(801)561-1471

Western States Seismic Policy Council
1995 Arizona Administrative Support Offices
Northern Arizona University
P.O. Box 4099
Flagstaff, Arizona 86011
(800)628-6754
e-mail: wsspc@vlshnu.glg.nau.edu

Utah Seismic Safety Commission
c/o Utah Geological Survey
2362 South Foothill Drive
Salt Lake City, Utah 84109
(801)467-7970

FEDERAL AGENCIES

Federal Emergency Management Agency

Mitigation Directorate, Program Development Branch
500 C Street, S.W.
Washington, D.C. 20472
(202)646-2794

Region I (Boston)
J. West McCormack Building, Room 442
Boston, Massachusetts 02109-4595
(617) 223-9540

Region II (New York)
26 Federal Plaza, Room 1338
New York, New York 10278-0002
(212) 255-7209

Region III (Philadelphia)
Liberty Square Building, 2nd Floor
105 S. Seventh Street
Philadelphia, Pennsylvania 19106-3316
(215) 931-5608

Region IV (Atlanta)
1371 Peachtree Street, N.E., Suite 700
Atlanta, Georgia 30309-3108
(404) 853-4200

Region V (Chicago)
175 West Jackson Boulevard, 4th Floor
Chicago, Illinois 60604-2698
(312) 408-5500

Region VI (Dallas)
Federal Regional Center, North Loop 288
Denton, Texas 76201-3698
(817) 898-5104

Region VII (Kansas City)
911 Walnut Street, Room 200
Kansas City, Missouri 64106
(816) 283-7061

Region VIII (Denver)
Denver Federal Center
Building 710, Box 25267
Denver, Colorado 80225-0267
(303) 235-4811

Region IX (San Francisco)
Building 105
Presidio of San Francisco
San Francisco, California 94129-1250
(414) 923-7100

Region X (Seattle)
Federal Regional Center
130 228th Street, S.W.
Bothell, Washington 98021-9796
(206) 487-4604

National Geophysical Data Center
National Oceanic and Atmospheric Administration
325 Broadway
Boulder, Colorado 80303
(303)497-6084

National Institute of Standards and Technology
Center for Building Technology
Room B168, Building 226
Gaithersburg, Maryland 20899
(301)975-5296
e-mail: dtodd@enh.nist.gov

National Science Foundation
Earthquake Systems
4201 Wilson Boulevard
Arlington, Virginia 22230
(703)306-1236
e-mail: Wanderso@nsf.gov

U.S. Geological Survey, Office of Earthquakes, Volcanoes and Engineering

905 National Center, M.S.101
12201 Sunrise Valley Drive
Reston, Virginia 22092
(703)648-4000

345 Middlefield Road
Menlo Park, California 94025
(415)853-8300

USGS National Earthquake Information Center
Denver Federal Center
Mail Stop 966, Box 25046
Denver Federal Center
Denver, Colorado 80225
(303)236-1586

PUBLICATIONS

The Earthquake Problem in General

Bolt, B. A. 1992. Earthquakes: a Primer . San Francisco, California: W. H. Freeman and Company.

Gere, J. M., and Shah, H. C. 1984. *Terra Non Firma: Understanding and Preparing for Earthquakes*. Stanford, California: Stanford University Alumni Association.

These two books are the best general surveys of the earthquake problem and very easy to understand. Bolt's book emphasizes the seismological aspects and Gere and Shah emphasize engineering, but both are comprehensive.

Levy, M., and Salvadori, M. 1995. *Why the Earth Quakes*. New York: W. W. Norton and Company.

This is a good general up-to-date survey of the world's earthquake problem and how engineers are dealing with it. It has been written by two distinguished engineers with a gift for simple explanation of technical issues.

Steinbrugge, K. 1882. *Earthquakes, Volcanoes, and Tsunamis, an Anatomy of Hazards*. New York: Skandia American Group.

This is a detailed but readable summary of the earthquake problem in the United States by one of the leading earthquake engineers and researchers.

The Seismic Hazard in the United States

For the information needed to define a specific location's seismic situation, contact local academic institutions for geologists, geophysicists and seismologists, state geologists, regional offices of the USGS and FEMA, national earthquake information centers, and state and regional seismic safety organizations. Also see the following section on Internet resources.

Algermissen, S. T. 1984. *An Introduction to the Seismicity of the United States*. Oakland, California: Earthquake Engineering Research Institute.

Seismic Codes and Provisions

For information about the seismic building code provisions in effect in a specific location, contact local building officials. Additional information is available from the three national model code groups: the Building Officials and Code Administrators International, the International Conference of Building Officials, and the Southern Building Code Congress International.

Federal Emergency Management Agency/Building Seismic Safety Council. 1994. *NEHRP Recommended Provisions for Seismic Regulations for New Buildings*, 2 volumes and maps, Publications 222A and 223A. Washington, D.C.: FEMA.

This is the current edition of this resource document. It is reflected in the seismic provisions of the model building codes and in the American Society of Civil Engineers national load standard.

Harris, James R. 1992. "An Overview of Seismic Codes." *Civil Engineering Practice* (Fall).

This is an excellent summary of the basis of seismic codes and their historical evolution.

Seismic Design

American Institute for Architectural Research. 1994. *Buildings at Risk: Seismic Design Basics for Practicing Architects*. Washington, D.C.: American Institute for Architectural Research.

This is a self-study course on seismic design for architects, but it provides a good overview of the subject for anyone interested in buildings. The materials include a videotape and an accompanying publication.

Arnold, C., and Reitherman, R. 1982. *Building Configuration and Seismic Design*. New York: John Wiley and Sons.

This is a summary of seismic design from an architectural viewpoint with emphasis on architectural decision-making as a determinant of seismic performance. It also contains a clear nontechnical explanation of the nature of ground motion and how it affects buildings.

Federal Emergency Management Agency/Building Seismic Safety Council. 1995. *Guide to Application of the 1991 NEHRP Recommended Provisions in Earthquake-Resistant Design of Buildings*, Publication 140. Washington, D.C.: FEMA.

This companion document to the 1991 Edition of the *NEHRP Recommended Provisions* is used in courses on application of the provisions requirements.

Federal Emergency Management Agency/Building Seismic Safety Council. 1995. *A Nontechnical Explanation of the 1994 NEHRP Recommended Provisions*, Publication 99. Washington, D.C.: FEMA.

An introduction to the current edition of the *Provisions* for those without an engineering background.

Federal Emergency Management Agency. 1994. *Reducing the Risk of Nonstructural Earthquake Damage: A Practical Guide*, Publication 74. Washington, D.C.: FEMA.

This is a complete survey of the nonstructural problem aimed at building and facilities managers. It includes a clear explanation of earthquake effects on buildings and nonstructural components and systems.

Lagorio, H. J. 1990. *Earthquakes – An Architect's Guide to Nonstructural Seismic Hazards*. New York: John Wiley and Sons.

This book is an excellent general survey of seismic design, hazard, and risk from an architectural and planning viewpoint. The title is really a misnomer, however, because only one chapter on "nonstructural building elements" describes in detail types of damage to equipment and building contents and even this is more of a general survey of the problem.

Stratta, J. L. 1986, *Manual of Seismic Design,* Prentice-Hall, Englewood, NJ

This manual written by an experienced California engineer presents practical advice on seismic design for design professionals.

Reports on Significant Earthquakes and Earthquake Damage

Ayres, J. M., Sun, T. Y., and Brown, F. R. 1967. *Report on Nonstructural Damage to Buildings Due to the March 27, 1964, Alaska Earthquake*. Washington, D.C.: National Academy of Sciences.

Ayres, J. M., and Sun, T. Y. 1973. *Nonstructural Damage, San Fernando, California, Earthquake of February 9, 1971*, Vol. 1, Part B. Edited by L. M. Murphy. Washington, D.C.: National Oceanic and Atmospheric Administration.

These two documents are pioneer reports by a mechanical and electrical engineering team that, for the first time, showed the serious effects of earthquakes on the nonstructural components and systems of modern buildings. They remain the best studies on nonstructural earthquake damage that have been published.

Bennett, J. H., and Sherburne, R. W., Eds. 1983. *The 1983 Coalinga, California Earthquakes,* Special Publication 66. Sacramento: California Department of Conservation , Division of Mines and Geology.

California Seismic Safety Commission. 1995. *Turning Loss to Gain: the January 17, 1994 Northridge Earthquake.* Sacramento: California Seismic Safety Commission.

Earthquake Engineering Research Institute. 1980. *Reconnaissance Report, Imperial County, California, Earthquake of August 13, 1978.* Oakland, California: EERI.

Earthquake Engineering Research Institute. 1980. *Reconnaissance Report, Northern Kentucky Earthquake, July 27, 1980.* Oakland, California: EERI.

Earthquake Engineering Research Institute. 1983. *A Preliminary Report, Miramichi, New Brunswick, Canada, Earthquake Sequence of 1982.* Oakland, California: EERI.

Earthquake Engineering Research Institute. 1984. *Coalinga, California, Earthquake of May 2, 1983: Reconnaissance Report.* Oakland, California: EERI.

Earthquake Engineering Research Institute. 1988. "The 1985 Mexico Earthquake." *Earthquake Spectra* 4(3,5).

Earthquake Engineering Research Institute. 1988. "The Whittier Narrows Earthquake of October 1, 1987." *Earthquake Spectra* 4(1,2).

Earthquake Engineering Research Institute. 1990. "Loma Prieta Earthquake of October, 1989: Reconnaissance Report." *Earthquake Spectra,* Supplement to Vol. 6 (May).

Earthquake Engineering Research Institute. 1995. "Northridge Earthquake of January 17, 1994. Reconnaissance Report." *Earthquake Spectra*, Supplement C to Vol. 11 (April).

Earthquake Engineering Research Institute. 1995. "Nonstructural Damage, Chapter in Northridge Earthquake of January 17, 1994, Reconnaissance Report." *Earthquake Spectra,* Supplement C to Vol. 11 (April).

Earthquake Engineering Research Institute. 1995. *The Hyogo - Ken Nanbu Earthquake: Great Hanshin Earthquake Disaster January 17, 1995, Preliminary Reconnaissance Report.* Oakland, California: EERI.

Housner, George, Chairman. 1990, *Competing Against Time, Report to Governor Deukmejian from the Governor's Board of Inquiry on the 1989 Loma Prieta Earthquake .* Sacramento, California: Governor's Board of Inquiry.

Jennings, P. C., Ed. 1971. *Engineering Features of the San Fernando Earthquake, February 9, 1971.* Pasadena: California Institute of Technology.

Moehle, J. P., Ed. 1994. *Preliminary Report on the Seismological and Engineering Aspects of the January 17, 1994 Northridge Earthquake.* Berkeley, California: Earthquake Engineering Research Center.

Murphy, L. 1973. *San Fernando, California, Earthquake of February 9, 1971*. Washington, D.C.: National Oceanic and Atmospheric Administration.

National Academy of Sciences Committee on the Alaska Earthquake. 1970. *The Great Alaska Earthquake of 1964*. Washington, D.C.: National Academy of Sciences.

National Institute of Standards and Technology. 1990. *Performance of Structures During the Loma Prieta Earthquake of October 17, 1989*, Publication 778. Washington, D.C.: U.S. Government Printing Office.

National Institute of Standards and Technology. 1994. *1994 Northridge Earthquake: Performance of Structures, Lifelines, and Fire Protection Systems*, Publication 5396. Washington, D.C.: U.S. Government Printing Office.

Nuttli, Otto, et al. 1986. *The 1886 Charleston, South Carolina, Earthquake – a 1986 Perspective*, Circular 98. Washington, D.C.: U.S. Geological Survey.

Oakeshott. G. B., Ed. 1975. *San Fernando , California, Earthquake of 9 February, 1971*, Bulletin 196. Sacramento: California Division of Mines and Geology.

Earthquake Loss Estimation Studies

Major loss estimation studies sponsored by governmental agencies are listed below. Some of these studies are now somewhat dated, but it is expected that a number of new studies will be conducted in the future once a new loss estimation methodology being developed for FEMA by the National Institute of Building Sciences is completed in 1996.

Davis, J. F., et al. 1982. *Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in the San Francisco Bay Area*, CDMG Special Publication 61. Sacramento: California Division of Mines and Geology.

Davis, J. F., et al. 1982. *Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in Southern California*, CDMG Special Publication 60. Sacramento: California Division of Mines and Geology.

Federal Emergency Management Agency. 1985. *An Assessment of Damage and Casualties for Six Cities in the Central United States Resulting from Earthquakes in the New Madrid Seismic Zone*. Washington, D.C.: FEMA.

Federal Emergency Management Agency/Central U.S. Earthquake Preparedness Project. 1990. *Estimated Future Earthquake Losses for St. Louis City and County, Missouri*, FEMA Publication 192, Earthquake Hazards Reduction Series 53. Washington, D.C.: FEMA.

National Oceanic and Atmospheric Administration. 1972. *A Study of Earthquake Losses in the San Francisco Bay Area: Data and Analysis*. Washington, D.C.: NOAA.

National Oceanic and Atmospheric Administration. 1973. *A Study of Earthquake Losses in the Los Angeles, California Area*. Washington, D.C.: NOAA.

Reichle, M. S., et al. 1990. *Planning Scenario for a Major Earthquake, San Diego-Tijuana Metropolitan Area*, CDMG Publication 100. Sacramento: California Division of Mines and Geology.

Steinbrugge, K. V., et al. 1987. *Earthquake Planning Scenario for a Magnitude 7.5 Earthquake on the Hayward Fault in the San Francisco Bay Area*, CDMG Special Publication 78. Sacramento: California Division of Mines and Geology.

Toppozada, T. R., et al. 1988. *Planning Scenario for a Major Earthquake on the Newport-Inglewood Fault Zone*, CDMG Special Publication 99. Sacramento: California Division of Mines and Geology.

U.S. Geological Survey. 1975. *A Study of Earthquake Losses in the Puget Sound, Washington Area*, USGS Open File Report 75-375. Washington, D.C.: USGS.

U.S. Geological Survey. 1976. *A Study of Earthquake Losses in Salt Lake City, Utah Area*, USGS Open File Report 76-89. Washington, D.C.: USGS.

U.S. Geological Survey. 1980. *Metropolitan San Francisco and Los Angeles Earthquake Loss Studies: 1980 Assessment*, USGS Open File Report 81-113. Washington, D.C.: USGS.

The Economics of Earthquakes

Federal Emergency Management Agency/VSP Associates. 1991. *A Benefit-Cost Model for the Seismic Rehabilitation of Hazardous Buildings*, FEMA Publications 227, 228, 255. Washington, D.C.: Federal Emergency Management Agency.

These publications and their accompanying computer software enable the user to estimate the benefit-costs of rehabilitation programs for a variety of existing building types for any region in the United States. FEMA 227 and 228 deal with privately owned buildings and FEMA 255 covers federally owned buildings.

National Research Council Committee on Earthquake Engineering. 1992. *The Economic Consequences of a Catastrophic Earthquake*. Washington, D.C.: National Academy Press.

This report includes a number of papers that review the economic impacts of large earthquakes. The focus is on indirect economic effects.

Weber, Stephen F. 1985. "Cost Impact of the *NEHRP Recommended Provisions* on the Design and Construction of Buildings." In *Societal Implications: Selected Readings*, Publication 84. Washington, D.C.: FEMA.

This is the best reference to date for evaluating the effect on building design and construction costs of implementing seismic design.

Earthquake Hazard Mitigation Programs

Building Systems Development Inc. 1989. *Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings,* FEMA Publications 45 and 46. Washington, D.C.: Federal Emergency Management Agency.

These reports focus on the kinds of programs that may be used to mitigate the hazard of existing buildings, how to establish priorities, and provides examples of programs that have been implemented.

INTERNET RESOURCES

World Wide Web (WWW) Sites

http://adder.colorado.edu/~hazctr/Home.html (be sure to spell "Home" with a capital "H")

The **Natural Hazards Research and Applications Center's Home Page** provides an introduction to the many programs and services provided by Hazards Center; current and back issues of the center's electronic newsletter, *Disaster Research;* our lists of hazard information sources and institutions, useful hazard periodicals, GIS hazard researchers, center publications, new books on hazards and disasters, upcoming hazards conference around the world; as well as an annotated inventory of other Internet resources.

http://www.fema.gov/

The **Federal Emergency Management Agency's Home Page** contains a lot of information (over 500 pages)-about the agency itself; current disaster situations; and disaster preparedness, response, recovery, and mitigation for families and businesses. The site includes dozens of hypertext links to other Internet resources via its Global Emergency Management Service (GEMS) page (http://www.fema.gov/fema/gems.html).

http://www.ngdc.noaa.gov/seg/hazard/hazards.html

The **National Geophysical Data Center (NGDC) Natural Hazards Data Page** includes databases, slide sets, and publications available from NGDC on geophysical hazards such as earthquakes, tsunamis, and volcanoes, as well as the *Natural Hazards Data Resources Directory* at (http://www.ngdc.noaa.gov/seg/hazard/resource/hazdir.html), published jointly with the Natural Hazards Center in 1990.

http://www/usgs.gov

The **U.S. Geological Survey Home Page** contains much useful information, including a natural hazards page (http:info.er.usgs.gov/research/environment/hazards/index.html) that provides information on earthquakes, volcanoes, coastal erosion, hurricanes, floods, and radon hazards.

http://www.fedworld.gov/

FedWorld is designed to provide a window to virtually all U.S. federal information services, including those dealing with disasters. It lists all agency Internet servers, provides access to the National Technical Information Service and the numerous reports available from that agency, as well as and many other federal reports.

Gophers

nisee.ce.berkeley.edu/1

The **Earthquake Information Gopher** maintained by the National Information Service on Earthquake Engineering (NISEE) offers information on all aspects of earthquakes and earthquake engineering, other organizations involved in earthquake hazard mitigation, and links to many other interesting gopher sites.

nceer.eng.buffalo.edu

The **National Center for Earthquake Engineering Research (NCEER) Gopher** presents even more general earthquake and earthquake engineering information, a raft of downloadable information, and access to NCEER's QUAKELINE database.

Lists/Newsletters/Discussion Groups

FEMA E-Mail News Service

To subscribe, send the e-mail message "subscribe news" to majordomo@fema.gov.

QUAKE-L

Quake-L includes discussions concerning recent earthquake events. To subscribe, send the e-mail message "subscribe QUAKE-L [your name]" to listserv@vml.noDak.edu.

BUILDING SEISMIC SAFETY COUNCIL

Of the National Institute of Building Sciences

THE COUNCIL AND ITS PURPOSE

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 (see page 10 for a current membership list). 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:

- Promotes the development of seismic safety provisions suitable for use throughout the United States;
- Recommends, encourages, and promotes the adoption of appropriate seismic safety provisions in voluntary standards and model codes;
- Assesses progress in the implementation of such provisions by federal, state, and local regulatory and construction agencies;
- Identifies opportunities for improving seismic safety regulations and practices and encourages public and private organizations to effect such improvements;
- 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;
- Advises government bodies on their programs of research, development, and implementation; and
- Periodically reviews and evaluates research findings, practices, and experience and makes recommendations for incorporation into seismic design practices.

The BSSC's area of interest encompasses all building types, structures, and related facilities and includes explicit consideration and assessment of the social, technical, administrative, political, legal, and economic implications of its deliberations and recommendations. The BSSC believes that the achievement of its purpose is a concern shared by all in the public and private sectors; therefore, its activities are structured to provide all interested entities (i.e., government bodies at all levels, voluntary organizations, business, industry, the design profession, the construction industry, the research community, and the general public) with the opportunity to participate. The BSSC also believes that the regional and local differences in the nature and magnitude of potentially hazardous earthquake events require a flexible approach to seismic safety that allows for consideration of the relative risk, resources, and capabilities of each community.

The BSSC is committed to continued technical improvement of seismic design provisions, assessment of advances in engineering knowledge and design experience, and evaluation of earthquake impacts. It recognizes that appropriate earthquake hazard risk reduction measures and initiatives should be adopted by existing organizations and institutions and incorporated, whenever possible, into their legislation, regulations, practices, rules, codes, relief procedures, and loan requirements so that these measures and initiatives become an integral part of established activities, not additional burdens. Thus, the BSSC itself assumes no standards-making or -promulgating role; rather, it advocates that code- and standards-formulation organizations consider the BSSC's recommendations for inclusion in their documents and standards.

IMPROVING THE SEISMIC SAFETY OF NEW BUILDINGS

The BSSC program directed toward improving the seismic safety of new buildings has been conducted with funding from the Federal Emergency Management Agency (FEMA). It is structured to create and maintain authoritative, technically sound, up-to-date resource documents that can be used by the voluntary standards and model code organizations, the building community, the research community, and the public as the foundation for improved seismic safety design provisions.

The BSSC program began with initiatives taken by the National Science Foundation (NSF). Under an agreement with the National Bureau of Standards (NBS; now NIST, the National Institute for Standards and Technology), *Tentative Provisions for the Development of Seismic Regulations for Buildings* (referred to here as the *Tentative Provisions*) was prepared by the Applied Technology Council (ATC). As the ATC noted, the document was the product of a "cooperative effort with the design professions, building code interests, and the research community." Its purpose was to "...present, in one comprehensive document, the current state of knowledge in the fields of engineering seismology and engineering practice as it pertains to seismic design and construction of buildings." The document included many innovations, however, and the ATC explained that a careful assessment was needed.

Following the issuance of the *Tentative Provisions* in 1978, NBS released a technical note calling for ". . . systematic analysis of the logic and internal consistency of [the *Tentative Provisions*]" and developed a plan for assessing and implementing seismic design provisions for buildings. This plan called for a thorough review of the *Tentative Provisions* by all interested organizations; the conduct of trial designs to establish the technical validity of the new provisions and to assess their economic impact; the establishment of a mechanism to encourage consideration and adoption of the new provisions by organizations promulgating national standards and model codes; and educational, technical, and administrative assistance to facilitate implementation and enforcement.

During this same period, other significant events occurred. In October 1977, Congress passed the *Earthquake Hazards Reduction Act of 1977* (P.L. 95-124) and, in June 1978, the National Earthquake Hazards Reduction Program (NEHRP) was created. Further, FEMA was established as an independent agency to coordinate all emergency management functions at the federal level. Thus, the future disposition of the *Tentative Provisions* and the 1978 NBS plan shifted to FEMA. The emergence of FEMA as the agency responsible for implementation of P.L. 95-124 (as amended) and the NEHRP also required the creation of a mechanism for obtaining broad public and private consensus on both recommended improved building design and construction regulatory provisions and the means to be used in their promulgation. Following a series of meetings between representatives of the original participants in the NSF-sponsored project on seismic design provisions, FEMA, the American Society of Civil Engineers and the National Institute of Building Sciences (NIBS), the concept of the Building Seismic Safety Council was born. As the concept began to take form, progressively wider public and private participation was sought, culminating in a broadly representative organizing meeting in the spring of 1979, at which time a charter and organizational rules and procedures were thoroughly debated and agreed upon.

The BSSC provided the mechanism or forum needed to encourage consideration and adoption of the new provisions by the relevant organizations. A joint BSSC-NBS committee was formed to conduct the needed review of the *Tentative Provisions,* which resulted in 198 recommendations for changes. Another joint BSSC-NBS committee developed both the criteria by which the needed trial designs could be evaluated and the specific trial design program plan. Subsequently, a BSSC-NBS Trial Design Overview Committee was created to revise the trial design plan to accommodate a multiphased effort and to refine the *Tentative Provisions*, to the extent practicable, to reflect the recommendations generated during the earlier review.

Trial Designs

Initially, the BSSC trial design effort was to be conducted in two phases and was to include trial designs for 100 new buildings in 11 major cities, but financial limitations required that the program be scaled down. Ultimately, 17 design firms were retained to prepare trial designs for 46 new buildings in 4 cities with medium to high seismic risk (10 in Los Angeles, 4 in Seattle, 6 in Memphis, 6 in Phoenix) and in 5 cities with medium to low seismic risk (3 in Charleston, South Carolina, 4 in Chicago, 3 in Ft. Worth, 7 in New York, and 3 in St. Louis). Alternative designs for six of these buildings also were included.

The firms participating in the trial design program were: ABAM Engineers, Inc.; Alfred Benesch and Company; Allen and Hoshall; Bruce C. Olsen; Datum/Moore Partnership; Ellers, Oakley, Chester, and Rike, Inc.; Enwright Associates, Inc.; Johnson and Nielsen Associates; Klein and Hoffman, Inc.; Magadini-Alagia Associates; Read Jones Christoffersen, Inc.; Robertson, Fowler, and Associates; S. B. Barnes and Associates; Skilling Ward Rogers Barkshire, Inc.; Theiss Engineers, Inc.; Weidlinger Associates; and Wheeler and Gray.

For each of the 52 designs, a set of general specifications was developed, but the responsible design engineering firms were given latitude to ensure that building design parameters were compatible with local construction practice. The designers were not permitted, however, to change the basic structural type even if an alternative structural type would have cost less than the specified type under the early version of the *Provisions*, and this constraint may have prevented some designers from selecting the most economical system.

Each building was designed twice – once according to the amended *Tentative Provisions* and again according to the prevailing local code for the particular location of the design. In this context, basic structural designs (complete enough to assess the cost of the structural portion of the building), partial structural designs (special studies to test specific parameters, provisions, or objectives), partial nonstructural designs (complete enough to assess the cost of the nonstructural portion of the building), and design/construction cost estimates were developed.

This phase of the BSSC program concluded with publication of a draft version of the recommended provisions, the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*, an overview of the *Provisions* refinement and trial design efforts, and the design firms' reports.

The 1985 Edition of the *NEHRP Recommended Provisions*

The draft version represented an interim set of provisions pending their balloting by the BSSC member organizations. The first ballot, conducted in accordance with the BSSC Charter, was organized on a chapter-by-chapter basis. As required by BSSC procedures, the ballot provided for four responses: "yes," "yes with reservations," "no," and "abstain." All "yes with reservations" and "no" votes were to be accompanied by an explanation of the reasons for the vote and the "no" votes were to be accompanied by specific suggestions for change if those changes would change the negative vote to an affirmative.

All comments and explanations received with "yes with reservations" and "no" votes were compiled, and proposals for dealing with them were developed for consideration by the Technical Overview Committee and, subsequently, the BSSC Board of Direction. The draft provisions then were revised to reflect the changes deemed appropriate by the BSSC Board and the revision was submitted to the BSSC membership for balloting again.

As a result of this second ballot, virtually the entire provisions document received consensus approval, and a special BSSC Council meeting was held in November 1985 to resolve as many of the remaining issues as possible. The 1985 Edition of the *NEHRP Recommended Provisions* then was transmitted to FEMA for publication in December 1985.

During the next three years, a number of documents were published to support and complement the 1985 *NEHRP Recommended Provisions.* They included a guide to application of the *Provisions* in earthquake-resistant building design, a nontechnical explanation of the *Provisions* for the lay reader, and a handbook for interested members of the building community and others explaining the societal implications of utilizing improved seismic safety provisions and a companion volume of selected readings.

The 1988 Edition

The need for continuing revision of the *Provisions* had been anticipated since the onset of the BSSC program and the effort to update the 1985 Edition for reissuance in 1988 began in January 1986. During the update effort, nine BSSC Technical Committees (TCs) studied issues concerning seismic risk maps, structural design, foundations, concrete, masonry, steel, wood, architectural and mechanical and electrical systems, and regulatory use. The Technical Committees worked under the general direction of a Technical Management Committee (TMC), which was composed of a representative of each TC as well as additional members identified by the BSSC Board to provide balance.

The TCs and TMC worked throughout 1987 to develop specific proposals for changes needed in the 1985 *Provisions.* In December 1987, the Board reviewed these proposals and decided upon a set of 53 for submittal to the BSSC membership for ballot. Approximately half of the proposals reflected new issues while the other half reflected efforts to deal with unresolved 1985 edition issues.

The balloting was conducted on a proposal-by-proposal basis in February-April 1988. Fifty of the proposals on the ballot passed and three failed. All comments and "yes with reservation" and "no" votes received as a result of the ballot were compiled for review by the TMC. Many of the comments could be addressed by making minor editorial adjustments and these were approved by the BSSC Board. Other comments were found to be unpersuasive or in need of further study during the next update cycle (to prepare the 1991 *Provisions*). A number of comments persuaded the TMC and Board that a substantial alteration of some balloted proposals was necessary, and it was decided to submit these matters (11 in all) to the BSSC membership for reballot during June-July 1988. Nine of the eleven reballot proposals passed and two failed.

On the basis of the ballot and reballot results, the 1988 *Provisions* was prepared and transmitted to FEMA for publication in August 1988. A report describing the changes made in the 1985 edition and issues in need of attention in the next update cycle then was prepared. Efforts to update the complementary reports published to support the 1985 edition also were initiated. Ultimately, the following publications were updated to reflect the 1988 Edition and reissued by FEMA: the *Guide to Application of the Provisions*, the handbook discussing societal implications (which was extensively revised and retitled *Seismic Considerations for Communities at Risk*), and several *Seismic Considerations* handbooks (which are described below).

The 1991 Edition

During the effort to produce the 1991 *Provisions*, a Provisions Update Committee (PUC) and 11 Technical Subcommittees addressed seismic hazard maps, structural design criteria and analysis, foundations, cast-in-place and precast concrete structures, masonry structures, steel structures, wood structures, mechanical-electrical systems and building equipment and architectural elements, quality assurance, interface with codes and standards, and composite structures. Their work resulted in 58 substantive and 45 editorial proposals for change to the 1988 *Provisions*.

The PUC approved more than 90 percent of the proposals and, in January 1991, the BSSC Board accepted the PUC-approved proposals for balloting by the BSSC member organizations in April-May 1991.

Following the balloting, the PUC considered the comments received with "yes with reservations" and "no" votes and prepared 21 reballot proposals for consideration by the BSSC member organizations. The reballoting was completed in August 1991 with the approval by the BSSC member organizations of 19 of the reballot proposals.

On the basis of the ballot and reballot results, the 1991 *Provisions* was prepared and transmitted to FEMA for publication in September 1991. Reports describing the changes made in the 1988 edition and issues in need of attention in the next update cycle then were prepared.

In August 1992, in response to a request from FEMA, the BSSC initiated an effort to continue its structured information dissemination and instruction/training effort aimed at stimulating widespread use of the *NEHRP Recommended Provisions*. The primary objectives of the effort were to bring several of the publications complementing the *Provisions* into conformance with the 1991 Edition in a manner reflecting other related developments (e.g., the fact that all three model codes now include requirements based on the *Provisions*) and to bring instructional course materials currently being used in the BSSC seminar series (described below) into conformance with the 1991 *Provisions*.

The 1994 Edition

The effort to structure the 1994 PUC and its technical subcommittees was initiated in late 1991. By early 1992, 12 Technical Subcommittees (TSs) were established to address seismic hazard mapping, loads and analysis criteria, foundations and geotechnical considerations, cast-in-place and precast concrete structures, masonry structures, steel structures, wood structures, mechanical-electrical systems and building equipment and architectural elements, quality assurance, interface with codes and standards, and composite steel and concrete structures, and base isolation/energy dissipation.

The TSs worked throughout 1992 and 1993 and, at a December 1994 meeting, the PUC voted to forward 52 proposals to the BSSC Board with its recommendation that they be submitted to the BSSC member organizations for balloting. Three proposals not approved by the PUC also were forwarded to the Board because 20 percent of the PUC members present at the meeting voted to do so. Subsequently, an additional proposal to address needed terminology changes also was developed and forwarded to the Board.

The Board subsequently accepted the PUC-approved proposals; it also accepted one of the proposals submitted under the "20 percent" rule but revised the proposal to be balloted as four separate items. The BSSC member organization balloting of the resulting 57 proposals occurred in March-May 1994, with 42 of the 54 voting member organizations submitting their ballots. Fifty-three of the proposals passed, and the ballot results and comments were reviewed by the PUC in July 1994. Twenty substantive changes that would require reballoting were identified. Of the four proposals that failed the ballot, three were withdrawn by the TS chairmen and one was substantially modified and also was accepted for reballoting. The BSSC Board of Direction accepted the PUC recommendations except in one case where it deemed comments to be persuasive and made an additional substantive change to be reballoted by the BSSC member organizations.

The second ballot package composed of 22 changes was considered by the BSSC member organizations in September-October 1994. The PUC then assessed the second ballot results and made its recommendations to the BSSC Board in November. One needed revision identified later was considered by the PUC Executive Committee in December. The final copy of the 1994 Edition of the *Provisions* including a summary of the differences between the 1991 and 1994 Editions was delivered to FEMA in March 1995.

1997 Update Effort

In September 1994, NIBS entered into a contract with FEMA for initiation of the 39-month BSSC 1997 *Provisions* update effort. Late in 1994, the BSSC member organization representatives and alternate representatives and the BSSC Board of Direction were asked to identify individuals to serve on the 1997 PUC and its TSs.

The 1997 PUC was constituted early in 1995, and 12 PUC Technical Subcommittees were established to address design criteria and analysis, foundations and geotechnical considerations, cast-in-place/precast concrete structures, masonry structures, steel structures, wood structures, mechanical-electrical systems and building equipment and architectural elements, quality assurance, interface with codes and standards, composite steel and concrete structures, energy dissipation and base isolation, and nonbuilding structures.

As part of this effort, the BSSC is developing a revised seismic design procedure for use by engineers and architects for inclusion in the 1997 *NEHRP Recommended Provisions*. Unlike the current design procedure, which is based on U.S. Geological Survey (USGS) peak acceleration and peak velocity-related acceleration ground motion maps developed in the 1970s, the new design procedure will be based on USGS spectral response maps presently being revised.

The proposed design procedure may take the form of a separate design map based on the new USGS hazard maps or may involve a process specified within the body of the *NEHRP Recommended Provisions* that uses the new USGS maps as a starting point. In developing the design procedure, the BSSC will utilize a process that includes a mechanism to allow for public input, and the draft design procedure will be submitted to the PUC for inclusion in the draft of the 1997 Edition for consensus balloting by the BSSC member organizations.

This task is being conducted with the cooperation of the USGS (the BSSC and USGS have signed a Memorandum of Understanding that formalizes the process) and is being guided by a five-member Management Committee (MC). A Resource Group (RG) consisting of interested members from the design, construction, and earth science communities also has been established to provide continuing input. A Seismic Design Procedure Group (SDPG) is responsible for development of the design procedure. In November-December 1995 the BSSC will conduct five regional workshops to solicit, examine, and resolve regional issues related to the development of the design procedure and to introduce and begin to obtain consensus on the framework of the design procedure. Workshops are planned for the following regions of the country: Northeast/Southeast, Central States, Wasatch Fault, Pacific Northwest, and California.

All final TS and SDPG proposals for change are expected to be submitted to the PUC by the fall of 1996. The PUC will meet twice to consider these proposals and to formulate its recommendations to the BSSC Board of Direction concerning proposals to be submitted to the BSSC member organizations for balloting. Two rounds of balloting are planned (in February-March 1997 and August 1997).

The balloting by the BSSC member organizations will be conducted according to the BSSC Charter. The results of this ballot will be assembled for review by the PUC and its TSs. These committees will assess the ballot results; resolve, insofar as practicable, any remaining issues for reballoting by BSSC member organizations; and, if necessary, identify technical issues in need of study during subsequent updating of the *NEHRP Recommended Provisions*.

The final consensus version of the 1997 *NEHRP Recommended Provisions* (including as an appendix a report on the differences between the 1994 and 1997 Editions) will be prepared, reviewed, and transmitted to FEMA no later than December 31, 1997.

Information Dissemination/Technology Transfer

In 1987 a special effort was mounted to stimulate widespread use of the *Provisions*. Particular emphasis was placed on developing the seismic hazard awareness of building owners, developers, insurers, and investors; building and community officials; and key public interest groups.

A series of *Seismic Considerations* handbooks was developed to generate interest in seismic hazard mitigation among the owners and other decision-makers and the design professionals responsible for five building types – apartment buildings, elementary and secondary schools, health care facilities, hotels and motels, and office buildings.

These specific efforts were supported by the participation of BSSC representatives in a wide variety of relevant meetings and conferences, BSSC participation in development of curriculum for a FEMA Emergency Management Institute course on the *Provisions* for structural engineers and other design professionals, issuance of a number of press releases, development of in-depth articles for the publications of relevant groups, and the establishment of a computer data base to permit the quick retrieval of various types of information.

In October 1989, the BSSC received from FEMA a request for a proposal to continue its information dissemination effort with emphasis on promoting a seminar series on application of the *NEHRP Recommended Provisions* (based on the Train-the-Trainer Program prepared by FEMA's Emergency Management Institute with the assistance of several BSSC Board members and volunteers) among relevant professional associations, stimulating interest in cosponsorship of the seminars, and conducting the seminars in various locations.

The proposal for initiating this effort was submitted in December 1989, and a contract was received in March 1990. It provided for increasing substantive knowledge about the *NEHRP Recommended Provisions* among a variety of audiences through the organization and conduct of 12 seminars in a variety of locations. In June 1991, in response to a request from FEMA, the BSSC submitted a proposal for continuation of the series with an additional 12 seminars.

By October 1995, 82 seminars will have been held. Cosponsors included the AIA Building Performance and Regulations Committee, the American Society of Civil Engineers, the American Concrete Institute, the American Institute of Steel Construction, the Building Officials and Code Administrators International (BOCA), the Earthquake Engineering Research Institute Great Lakes Chapter, the Interagency Committee for Seismic Safety in Construction, the Maine Emergency Management Institute, the Masonry Institute of Tennessee, the Materials Handling Institute, the Mississippi State University Continuing Education Department, the Panama Canal Commission, the Portland Cement Association, the Southern Building Code Congress International and Rust International, the Structural Engineers Association of Colorado, the Structural Engineers Association of Illinois, the University of Arkansas Continuing Education Department, and the Virginia Structural Engineers Council.

Although it is difficult to determine precisely how effective these various efforts have been, the number of BSSC publications distributed certainly provides at least one measure of the level of interest generated. In this respect, the BSSC can report that more than 65,000 publications have been requested since December 1987, and this number is above and beyond those requests for BSSC documents directed to FEMA. Further, many requests for information and other forms of technical support are received and responded to monthly.

Further, in 1989, the Building Officials and Code Administrators International (BOCA) appointed an ad hoc committee to review and study the 1988 Edition of the *Provisions* in order to develop a comprehensive and consistent position on code requirements for earthquake loads reflecting technology, design practices, and national codes and standards. In addition to six building officials selected by BOCA, the committee included six individuals representing the BSSC (five of whom were Board members). By October 1990, this group had developed proposed code changes that reflect approximately 90 percent of the content of the *Provisions*. At its annual meeting in September 1991, BOCA adopted new seismic provisions for the *National Building Codes* based on changes proposed by the ad hoc committee. The Southern Building Code Congress International also acted to approve similar seismic provisions for the *Standard Building Code* on October 30, 1991, during its annual meeting. SBCCI's action on the new seismic provisions must be confirmed by a majority of the active members by written ballot. Thus, in essence all three model codes now reflect the *NEHRP Recommended Provisions*. In addition, the *NEHRP Recommended Provisions* were adapted for use in the 1993 Edition of Standard ASCE 7 (formerly ANSI A-58.1) and the process is continuing for the 1995 Edition.

IMPROVING THE SEISMIC SAFETY OF EXISTING BUILDINGS

In August 1991, NIBS entered into a cooperative agreement with FEMA for a comprehensive program leading to the development of a set of nationally applicable guidelines for the seismic rehabilitation of existing buildings. Under this agreement, the BSSC serves as program manager and will cooperate with the American Society of Civil Engineers and the Applied Technology

Council in what is expected to be a five-year effort. Initially, FEMA provided funding for a program definition activity designed to generate the detailed work plan for the overall program.

The work plan was completed in April 1992 and in September FEMA contracted with NIBS for the remainder of the effort. The major objectives of the project are to develop a set of technically sound, nationally applicable guidelines (with commentary) for the seismic rehabilitation of buildings; develop building community consensus regarding the guidelines; and develop the basis of a plan for stimulating widespread acceptance and application of the guidelines.

The guidelines document produced as a result of this project is expected to be formulated to serve as a primary resource on the seismic rehabilitation of buildings for the use of model code and standards organizations, state and local building regulatory personnel, design professionals, and educators. The project work, as delineated in the workplan, will, as a minimum, involve ASCE and ATC as subcontractors as well as groups of volunteer experts and paid consultants. The workplan covers all the tasks specified in the cooperative agreement in terms of accomplishment of the three project objectives. The work is structured to ensure that the technical guidelines writing effort will benefit from: consideration of the results of completed and ongoing technical efforts and research activities as well as societal issues, public policy concerns, and the recommendations presented in an earlier FEMA-funded report on issues identification and resolution; cost data on application of rehabilitation procedures; the reactions of potential users; and consensus review by a broad spectrum of building community interests.

To ensure continuing project oversight, a Project Oversight Committee (POC) is responsible to the BSSC Board of Direction for accomplishment of the project objectives and the conduct of project tasks. Further, a Seismic Rehabilitation Advisory Panel composed of approximately 20 individuals (plus corresponding members) selected for their knowledge of various aspects of project work (architectural components, systems, cladding; codes and standards; concrete; contractors and constructors; earthquake research; economics; electrical; federal agencies; financing/insurance; historic properties; legal concerns; masonry; mechanical; property owners and managers; seismic hazards; societal concerns and public policy issues; state and local government; steel; structural design/analysis; wood) has been established to review project products and to advise the POC and, if appropriate, the BSSC Board, on the approach being taken, problems arising or anticipated, and progress being made.

While overall management remains the responsibility of the BSSC, responsibility for conduct of the specific project tasks will be shared by the BSSC with ASCE and ATC. Specific BSSC tasks are being completed under the guidance of a BSSC Project Committee.

An earlier FEMA-funded project was designed to provide consensus-backed approval of publications on seismic hazard evaluation and strengthening techniques for existing buildings. This effort involved identifying and resolving major technical issues in two preliminary documents developed for FEMA by others – a handbook for seismic evaluation of existing buildings prepared by the Applied Technology Council (ATC) and a handbook of techniques for rehabilitating existing buildings to resist seismic forces prepared by URS/John A. Blume and Associates (URS/Blume); revising the documents for balloting by the BSSC membership; balloting the documents in accordance with the BSSC Charter; assessing the ballot results; developing proposals to resolve the issues raised; identifying any unresolvable issues; and preparing copies of the documents that reflect the results of the balloting and a summary of changes made and unresolved issues. Basically, this consensus project was directed by the BSSC Board and a 22-member Retrofit of Existing Buildings (REB) Committee composed of individuals representing the needed disciplines and geographical areas and possessing special expertise in the seismic rehabilitation of existing buildings. The consensus approved documents (the *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* and the *NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings*) were transmitted to FEMA in mid-1992.

The BSSC also was involved in the joint venture with the ATC and the Earthquake Engineering Research Institute to develop an action plan for reducing earthquake hazards to existing buildings. The action plan that resulted from this effort prompted FEMA to fund a number of projects, including those described above.

IMPROVING THE SEISMIC SAFETY OF NEW AND EXISTING LIFELINES

Given the fact that buildings continue to be useful in a seismic emergency only if the services on which they depend continue to function, the BSSC developed an action plan for the abatement of seismic hazards to lifelines to provide FEMA and other government agencies and private sector organizations with a basis for their long-range planning. The action plan was developed through a consensus process utilizing the special talents of individuals and organizations involved in the planning, design, construction, operation, and regulation of lifeline facilities and systems. Five lifeline categories were considered: water and sewer facilities, transportation facilities, communication facilities, electric power facilities, and gas and liquid fuel lines. A workshop involving more than 65 participants and the preparation of over 40 issue papers was held. Each lifeline category was addressed by a separate panel and overview groups focused on political, economic, social, legal, regulatory, and seismic risk issues. An Action Plan Committee composed of the chairman of each workshop panel and overview group was appointed to draft the final action plan for review and comment by all workshop participants. The project reports, including the action plan and a definitive six-volume set of workshop proceedings, were transmitted to FEMA in May 1987. In recognition of both the complexity and importance of lifelines and their susceptibility to disruption as a result of earthquakes and other natural hazards (hurricanes, tornadoes, flooding), FEMA subsequently concluded that the lifeline problem could best be approached through a nationally coordinated and structured program aimed at abating the risk to lifelines from earthquakes as well as other natural hazards. Thus, in 1988, FEMA asked the BSSC's parent institution, the National Institute of Buildings Sciences, to provide expert recommendations concerning appropriate and effective strategies and approaches to use in implementing such a program.

The effort, conducted for NIBS by an ad hoc Panel on Lifelines with the assistance of the BSSC, resulted in a report recommending that the federal government, working through FEMA, structure a nationally coordinated, comprehensive program for mitigating the risk to lifelines from seismic and other natural hazards that focuses on awareness and education, vulnerability assessment, design criteria and standards, regulatory policy, and continuing guidance. Identified were a number of specific actions to be taken during the next three to six years to initiate the program. In September 1990, FEMA asked for additional NIBS guidance concerning the feasibility of establishing a national lifelines seismic safety council.

MULTIHAZARD ACTIVITIES

Multihazard Assessment Forum

In 1993, FEMA contracted with NIBS for the BSSC to organize and hold a forum intended to explore how best to formulate an integrated approach to mitigating the effects of various natural hazards under the National Earthquake Hazards Reduction Program. More than 50 experts in various disciplines concerning natural hazards risk abatement participated in the June 1994 forum and articulated the benefits of pursuing an integrated approach to natural hazards risk abatement. A BSSC steering committee then developed a report, *An Integrated Approach to Natural Hazards Risk Mitigation*, based on the forum presentations and discussion that urged FEMA to initiate a program definition and initiation effort to create a National Multihazard Mitigation Council structured and charged to integrate and coordinate public and private efforts to mitigate the risk from natural hazards. All public and private agencies and organizations with a significant interest in natural hazards risk mitigation are to be involved in establishing the council and in drafting its detailed mission statement and workplan. This report was delivered to FEMA in early 1995.

EMI Multihazard Building Design Summer Institute

In 1994, NIBS, at the request of FEMA's Emergency Management Institute (EMI) of FEMA, entered into an additional contract for BSSC to provide support for the administration, management, development and delivery of the EMI Multihazard Building Design Summer Institute (MBDSI). The MBDSI is attended by university and college professors of engineering and architecture and is intended to provide them with instructional tools for use in creating/updating building design courses. The aim is to encourage widespread use of mitigation techniques in designing and rehabilitating structures to withstand forces generated by both natural and technological hazards. The 1995 MBDSI conducted in July consisted of four one-week courses focusing on designing building fire safety, earthquake protective design, flood protective design, and wind protective design.

BSSC PUBLICATIONS

Available in limited quantity free of charge from the Building Seismic Safety Council, 1201 L Street, N.W., Suite 400, Washington, D.C. 20005

New Buildings

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) – 1995

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

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

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

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) – 1995

Societal Implications: Selected Readings, 1985 (FEMA Publications 84)

Existing Buildings

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)

Lifelines

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:

- *Papers on Water and Sewer Lifelines*, 1987 (FEMA Publication 135)
- *Papers on Transportation Lifelines*, 1987 (FEMA Publication 136)
- *Papers on Communication Lifelines*, 1987 (FEMA Publication 137)
- *Papers on Power Lifelines*, 1987 (FEMA Publication 138)
- *Papers on Gas and Liquid Fuel Lifelines*, 1987 (FEMA Publication 139)
- *Papers on Political, Economic, Social, Legal, and Regulatory Issues and General Workshop Presentations*, 1987 (FEMA Publication 143)

Multihazard Considerations

An Integrated Approach to Natural Hazard Risk Mitigation, 1995 (FEMA Publication 261/2-95)

BSSC MEMBER ORGANIZATIONS

AFL-CIO Building and Construction Trades Department
AISC Marketing, Inc.
American Concrete Institute
American Consulting Engineers Council
American Forest and Paper Association
American Institute of Architects
American Institute of Steel Construction
American Insurance Services Group, Inc.
American Iron and Steel Institute
American Plywood Association
American Society of Civil Engineers
Applied Technology Council
Associated General Contractors of America
Association of Engineering Geologists
Association of Major City Building Officials
Bay Area Structural, Inc.*
Brick Institute of America
Building Officials and Code Administrators International
Building Owners and Managers Association International
Building Technology, Incorporated*
California Geotechnical Engineers Association
Canadian National Committee on Earthquake Engineering
Concrete Masonry Association of California and Nevada
Concrete Reinforcing Steel Institute
Earthquake Engineering Research Institute
General Reinsurance Corporation*
Interagency Committee on Seismic Safety in Construction
International Conference of Building Officials
Masonry Institute of America
Metal Building Manufacturers Association
National Association of Home Builders
National Concrete Masonry Association
National Conference of States on Building Codes and Standards
National Elevator Industry, Inc.
National Fire Sprinkler Association
National Institute of Building Sciences
National Ready Mixed Concrete Association
Permanent Commission for Structural Safety of Buildings*
Portland Cement Association
Precast/Prestressed Concrete Institute
Rack Manufacturers Institute
Seismic Safety Commission (California)
Southern Building Code Congress International
Southern California Gas Company*
Steel Deck Institute, Inc.
Steel Joist Institute*
Steven Winter Associates, Inc.*
Structural Engineers Association of Arizona
Structural Engineers Association of California
Structural Engineers Association of Central California
Structural Engineers Association of Colorado
Structural Engineers Association of Illinois
Structural Engineers Association of Northern California
Structural Engineers Association of Oregon
Structural Engineers Association of San Diego
Structural Engineers Association of Southern California
Structural Engineers Association of Utah
Structural Engineers Association of Washington
The Masonry Society
U. S. Postal Service*
Western States Clay Products Association
Western States Council Structural Engineers Association
Westinghouse Electric Corporation*

* Affiliate (non-voting) members.

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