INTRODUCTION

Decisions concerning seismic safety are complex, involving as they do life safety, community values, and a relatively uncommon hazard. What makes these decisions particularly difficult to deal with is the fact in many areas of potentially great seismic risk in the United States, only a few moderate- to major-size earthquakes have occurred in urban areas during the lifetime of today's citizens and relatively few lives have been lost in this country as a result of earthquake during the past 100 years.[1]

Nevertheless, according to the historical record of seismic events, many highly developed communities now exist where damaging earthquakes have occurred in the past. (See Figure 1.)

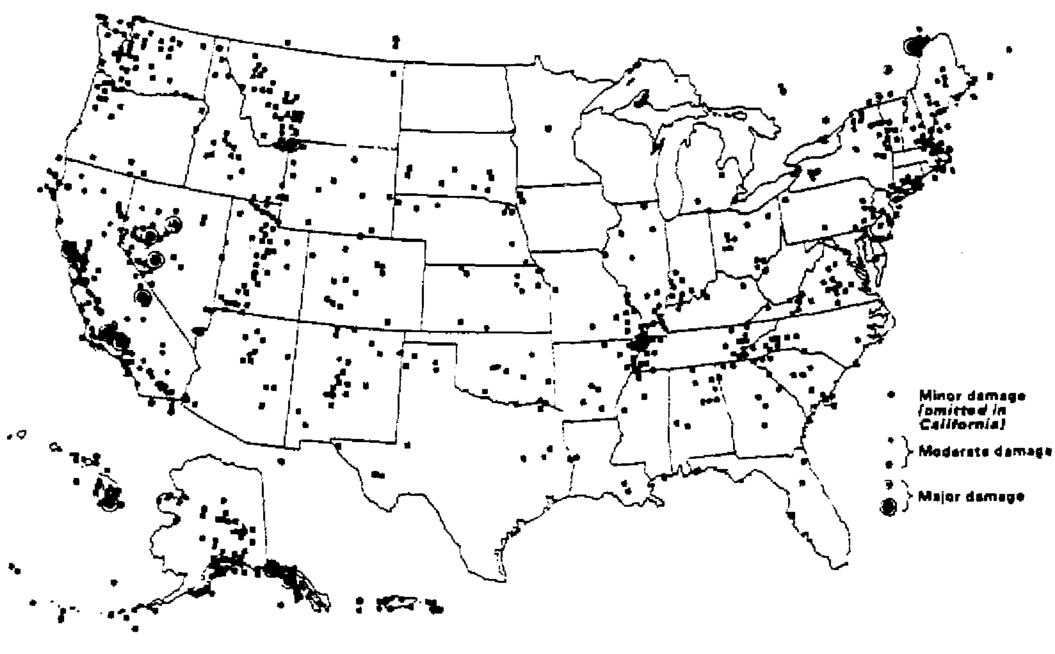

FIGURE 1 Location of damaging earthquakes in the United States. (Reproduced from Christopher Arnold's article, "Quake Codes," in the spring 1984 issue of Architectural Technology.)

---

[1]During the twentieth century about 1,400 lives have been lost as a result of earthquakes and property damage has amounted to approximately $5 billion (in 1979 dollars). (From Mary L. Snell and Darrell G. Herd's 1984 report, National Earthquake Hazard Reduction Program: Overview (FY 1983), Report to Congress, USGS Circular 918, U.S. Geological Survey, Reston, Virginia.)

Future earthquakes in St. Louis, for example, may cause far more damage than the earthquakes that occurred in the early nineteenth century when population density was low and there were no high-rise buildings. As Dr. Otto Nuttli reports in his paper on the St. Louis area in the selected readings volume, one needs to remember that:

> There were only 2,000 people living in the metropolitan area in 1811 as opposed to 2,400,000 today. Previously there were no pipelines, bridges, dams, manufacturing plants with toxic materials, or high-rise buildings to be affected. Further, there was no great dependence on electricity, telephone, highways, and airports and the economic impact of disruptions of such facilities must be considered.

A community therefore needs to research its local seismic situation to determine its precise seismic hazard. Once this is done, the community will have a rational basis for deciding how much seismic risk it is willing to accept and the degree to which it wishes to lessen the risk. The use of new or improved seismic safety design provisions--especially the NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions--in developing local regulations for new buildings is generally considered to be one significant way of lessening the earthquake risk to life safety by bringing to bear the best available set of guidance for designing and constructing new buildings in a manner that will prevent their structural collapse during an earthquake.

The adoption and enforcement of local seismic regulations for new buildings can affect a community in various ways and to various degrees. Among the major factors to be considered are:

- The buildings designed and constructed in accordance with these regulations can be expected to reduce the loss of life, injuries, and property damage resulting from an earthquake. This, in turn, will reduce the costs of emergency response and of recovery.

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

- The costs of design and construction of new buildings could increase.

- These increased costs could result (1) in a reduced supply of housing and of industrial and commercial facilities; (b) in reduced availability of housing or other facilities to a particular income segment of the market, and/or (3) in a loss of business development (and the accompanying jobs and tax revenues) to neighboring jurisdictions that do not require cost-increasing seismic regulations.

- New or significantly improved seismic design provisions could affect the various construction materials differently, possibly, although not probably, resulting in changes in market share that could, in turn, result in the closing of manufacturing plants, layoffs, or both. Since loss of market share by one material implies that other materials will be substituted, this could require labor retraining and/or some capital expenditures for new manufacturing facilities, either of which would result in an increase in construction cost.

The degree to which these effects will be felt by a community depends on several factors including:

- The precise nature of the community's seismic hazard,

- The extent to which it has already done something to mitigate the hazard, and

- The degree of seismic risk that the community deems to be acceptable given its particular circumstances.

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.

The remainder of this handbook is structured to provide community decision-makers with information they can use in assessing to some degree the extent to which these effects will be felt in their community and in making more reasoned decisions. Because it is intended for a broad audience of lay readers, detailed explanations of technical concepts and organizational relationships are kept to a minimum and, when appropriate, the reader is referred to papers in the selected readings volume or to other sources of information.

HOW DO I DETERMINE MY COMMUNITY'S SEISMIC HAZARD?

The building process participants and seismic specialists who met with the BSSC committee in Charleston (South Carolina), Memphis (Tennessee), St. Louis (Missouri), and Seattle (Washington), emphasized that as a first step a community should assess its seismic situation by increasing its awareness of and knowledge about:

- The seismic hazard in the community,
- The risk to life and property in and around the community, and
- The vulnerability of the community.

These subjects are related directly to the objective, scientifically determined risk resulting from seismic activity in areas with dense concentrations of people and buildings. Even in the two communities with ongoing seismic safety information projects and seismic regulations for new buildings (Charleston and Seattle), large segments of the communities were considered to be unaware of the degree of risk they faced.

WHO IS AT RISK?

Scientific seismic hazard information that is understandable to non-scientists often is not available; therefore, public officials, building community professionals, and the general public may not even realize that a seismic hazard exists, let alone understand the risk it poses.

Several misconceptions contribute to the relatively low level of appreciation for the seismic risk in many U.S. communities. For example:

- MYTH--Many persons believe that earthquakes usually occur in only a few places, especially in California and in Alaska.

  FACT--About 40 of the 50 states as well as many U.S. territories and possessions are at some risk from seismic hazard.

- MYTH--Relatively few persons in the United States have experienced a large, damaging earthquake and, therefore, many are tempted to conclude that one will not occur during their lifetime.

  FACT--Geologic time is vastly different from that generally used to judge "immediacy." Records show that some seismic zones experience moderate to major earthquakes about every 200 to 400 years while other areas have "repeat intervals" of about 50 to 70 years. However, the probabilities or "odds" cited by the scientists are simply best estimates, and one or several seismic events could occur in a much shorter-than-average period.

- MYTH--Many of those aware of seismic risk to their community think that their local codes and regulations include seismic safety provisions.

  FACT--Many codes include no seismic provisions.

WHERE WILL IT HAPPEN AND WHAT WILL IT DO?

Relatively few lives have been lost in the United States during the past century as a result of earthquakes. Further, it is especially difficult for scientists to predict the occurrence of a damaging earthquake or to anticipate accurately the range of damaging effects.

This lack of detailed knowledge about earthquakes and their potential effects leads some people to believe the risk is minimal. This is especially true for the area east of the Rocky Mountains.

Nevertheless, several of the largest seismic events recorded to date in the United States occurred hundreds of years ago in areas east of the Rockies. For example:

- The New Madrid, Missouri, earthquakes of 1811-12 had an estimated modified Mercalli intensity[2] of VII, and

- The Cape Anne, Massachusetts, earthquake of 1755 had an estimated modified Mercalli intensity of VIII.

The forces that caused these major shakes in the eastern and central states have not dissipated, and seismic specialists expect damaging earthquakes with widespread effects to occur again in these areas even though they cannot predict exactly when they will happen.

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 earthquake that occurred in the New Madrid area in 1811 were to occur again today, it would affect 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 would disrupt

---

[2]Earthquakes are described in terms of their magnitude and their intensity. The often-referred to Richter scale describes the magnitude of an earthquake while the modified Mercalli intensity scale describes the apparent effect of an earthquake at a specific location. Modified Mercalli values range from I, which describes an earthquake as being "not felt" in a specific location, to XII, which describes an earthquake as resulting in "nearly total" damage in a specific location. Chapter 8 includes a fuller description of both the modified Mercalli intensity values and the Richter magnitude scale.

major commercial distribution networks, oil and gas pipelines, and interstate commerce to a very significant extent in addition to causing thousands of casualties. Further, the several major tremors that occurred in 1811 were followed by two years of aftershocks that were sizeable tremors in their own right.

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 precise nature of the hazard in a specific community be understood. One cannot simply adopt the ordinances, programs, or approach of a community in one seismic zone and expect that it will be technically appropriate or useful in a different community in another seismic zone. What works in a medium-size community in California, for example, is unlikely to work in a small community in Missouri.

In short, even moderate earthquakes can do a significant amount of harm. This was the case in Coalinga, California, in May 1983 when an earthquake with a locally estimated modified Mercalli intensity of VIII occurred. The small city was severely damaged and many of the older, unreinforced masonry buildings in the central business district were destroyed in a matter of minutes. Therefore, communities throughout the United States 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 in the eastern and southern United States 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 precisely a community's seismic situation, contact:

- Local academic institutions for geologists, geophysicists, and seismologists
- State geologists
- Regional offices of the U.S. Geological Survey and FEMA
- National earthquake information centers
- State and regional seismic safety organizations

The names and addresses of the last three types of organizations are included in Chapter 7.

For a general discussion of seismic phenomena and hazards, see the publications listed below:

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

Bolt, Bruce A. 1978. Earthquakes: A Primer. San Francisco, California: W. H. Freeman and Company.

Hays, Walter W. 1981. Facing Geological and Hydrologic Hazards: Earth Science Considerations. U.S. Geological Survey Professional Paper 1240-B. Washington, D.C.: U.S. Government Printing Office.

Shah, H.. and James Gere. 1984. Terra Non Firma. Stanford, California: Stanford University.

The selected readings volume published with this handbook includes additional information on the seismic hazard of specific areas. Bollinger discusses the Charleston area, Johnston and Nava discuss the Memphis area, Nuttli discusses the St. Louis area, and Smith discusses the Puget Sound area. The paper by Hays has a national focus.

WHAT WILL A SEISMIC BUILDING CODE DO?

Many people have a poor understanding of what a building code actually does and does not do. Basically, 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 the United States, the local political jurisdiction has the ultimate responsibility for determining whether or not a building code will be established and enforced. These local decisions are and must be political because they involve judgments concerning the level of risk to be taken by a community (the acceptable level) and the costs and benefits of building code adoption.

If a community decides that it should have a building code, there are several ways of developing one that the community will feel reflects its own best interests:

- It can develop its own code,
- It can adopt one of the three available model codes[3] in its entirety, or
- It can use a model code as a foundation upon which to build its own code, making modifications that include the levels of performance to be sought in consideration of the community's seismic, historical and political character and the requirements that will be imposed to achieve that performance.

If a community decides to incorporate seismic safety provisions, whether new or improved, into its building code, the purpose and limitations of these provisions must be made very clear. Otherwise, considerable misunderstanding may result if an earthquake occurs and results in damage not expected by the community.

Building code development, adoption, and implementation are complex processes that are difficult to explain, and explaining only the seismic component in that process is equally difficult. However, a brief explanation of the more important aspects of seismic regulations or seismic codes is provided below. In addition, interested readers should

---

[3]The Basic Building Code published by the Building Officials and Code Administrators International, the Standard Building Code published by the Southern Building Code Congress, and the Uniform Building Code published by the International Conference of Building Officials.

refer to the papers by Dillon and Zsutty and Shah in the selected readings volume.

THE PURPOSE OF SEISMIC CODES

As with building codes in general, the principal purpose of seismic codes is to protect life, health, and public welfare. Some seismic codes also are concerned with the protection of property as a secondary objective. 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 codes regulating other than critical structures generally represent some compromise. The objectives of seismic codes generally are:

- Structures should resist minor earthquakes without damage.
- Structures should resist moderate earthquakes without structural damage but some nonstructural damage may occur.
- Structures should resist major earthquakes without collapse but some structural as well as nonstructural damage may occur.

This approach is based on experience gained in many earthquakes where it has been shown that structural collapse is the overwhelming cause of life loss and serious injury.

THE NATURE OF SEISMIC CODES

Seismic codes establish minimum standards for the resistance of building structures to ground-shaking that will be encountered in an earthquake. For a given building, the ground-shaking depends on a number of complex factors such as the magnitude (size) of the earthquake, the distance from the epicenter of the earthquake (where the ground slippage began), and whether the ground is hard (rock) or soft. During an earthquake, the base of a building moves with the ground. The building must resist the forces and deformations that occur throughout the structure as a result of this motion. A stiff structure, such as a low-rise masonry building, moves with the ground and experiences dynamic forces about equal to those associated with the ground acceleration. A flexible structure, such as a high-rise steel-frame building, may experience a dynamic force less than that associated with the ground acceleration. The weight or inertia of a building affects the forces experienced by the building--the greater the weight, the greater the force. Other factors affecting the force include the height and shape of the structure.

Seismic codes typically provide a simple formula that relates all these factors together. Some codes also include consideration of the importance of the building (e.g., whether it is essential like a hospital or fire station or densely occupied like an auditorium). One factor in the formula is an index that is derived from the historical pattern of previous earthquakes in a region. Newer codes also use estimates by geologists and seismologists of the probabilities of earthquakes of given intensities occurring in the future. Other factors include the softness of the supporting soil, the stiffness or flexibility of the building, and the weight of the building.

Although the variety of seismic codes use slightly different formulas and indexes, all of them essentially are based on the derivation of horizontal forces[4] by a formula that considers all or some of the above factors. While all seismic codes provide force levels for the design of the building structure, some of the newer codes also provide force levels for the design of mechanical and architectural (so-called nonstructural) components of the building since these represent a hazard when the building is shaken. A few examples of nonstructural elements that are important to consider with respect to resistance to shaking are elevators, suspended ceilings, and exterior wall panels.

OTHER NEEDS

To be effective, a code must be both adopted and enforced. This requires that building officials either themselves be trained to review plans and engineering calculations to ensure conformity with the seismic code requirements or that they engage professionals who are. In addition, they must inspect in the field to ensure that the building is constructed exactly as designed since quality of construction is an important aspect of ensuring seismic resistance. All the above requires training in seismic design procedures for building officials or their professional representatives and, in some cases, may require additional inspection personnel.

Even though the seismic code establishes minimum forces and requires some specific design and construction methods, developing the overall design to meet these requirements is the task of the building design engineer and architect. Consequently, these professionals must understand the nature and practice of seismic design since use of the code alone will not guarantee that a well-designed and safe building will result.[5]

---

[4]Earthquakes also produce vertical forces, but normal building design for vertical forces incorporates sufficiently large factors of safety that additional earthquake vertical forces are unlikely to be a problem. Hence, the focus in seismic design for normal buildings is on horizontal forces.

[5]As was noted T. C. Zsutty and H. C. Shah in their article, "The Purpose and Effects of Earthquake Codes," in the January-February 1982 issue of Building Standards: "...it is easy for unexperienced designers to misinterpret the provisions of the code and thereby create unsafe structures."

THE EFFECTIVENESS OF SEISMIC CODES

Although no specific quantitative information is available to determine the effectiveness of seismic codes, such as number of lives saved or injuries prevented, experience in recent earthquakes gives convincing proof that buildings properly designed to a seismic code will dramatically reduce the impact of a earthquake. The Coalinga, California, earthquake of May 1983 severely damaged or destroyed many of the downtown buildings that had been built prior to the city's use of a seismic code. Damage to buildings that had been constructed in accordance with the seismic code was negligible. Since the 1906 San Francisco earthquake, the most serious loss of lives in a U.S. earthquake occurred in 1971 when two pre-seismic code buildings collapsed at the Veteran's Hospital in San Fernando, California; 47 people were killed. Although many buildings were damaged in this severe widespread earthquake. casualties in code-designed buildings were almost nonexistent. (The one exception involved the death of three people in Olive View Hospital and they were killed under circumstances that probably would not have occurred had the building been designed to the current California Hospital Code.) In addition, since the adoption of the seismic code for California school buildings (the Field Act, 1935), no child has been killed or injured by an earthquake when in a California school.

In dealing with earthquakes, one must think in terms of probabilities. There is no question that in a properly designed seismic-resistant building, the probability of becoming a casualty is greatly reduced even if the building suffers damage.

THE PROBLEM OF EXISTING BUILDINGS

The NEHRP Recommended Provisions apply to the design and construction of new buildings. Clearly, when seismic design provisions for new buildings are incorporated into a building code, considerable time will pass before a substantial percentage of the building stock is constructed according to the new code. In the meantime, some existing buildings may remain a seismic hazard. Design requirements for other threatening forces such as strong wind may be sufficient to satisfy seismic requirements. The problem of making existing buildings seismically resistant is very different from the seismic design of new buildings; quite different codes, standards, and design concepts are required.

In areas of lesser seismic risk, where the probability of a significant earthquake occurring in the next 50 or so years are relatively low, the chances are good of nonseismic buildings being replaced before being tested by a seismic event. Each community must assess its own risk, in light of its own character, needs, and plans. However, if an existing building is restored and rehabilitated in such a way as to extend its probable life span to that of a new building, serious consideration should be given to seismic design. In addition, some sort of seismic retrofit for special or critical structures (e.g., schools, hospitals, fire stations) would be advisable.

As part of its program for FEMA, the BSSC is conducting a detailed assessment of the impact of the NEHRP Recommended Provisions on the regulatory process. Its report on this study, which should be available in late 1985, will help communities to define their specific needs and it should be examined by all those involved in efforts to improve the seismic safety of buildings.

The NEHRP Recommended Provisions, especially the commentary on the provisions, provides a considerable amount of information on seismic-resistant design. In addition, the BSSC is developing a lay-language version of the NEHRP Recommended Provisions that should be of considerable value in informing the general public about seismic-resistant design.

The papers by Dillon and Zsutty and Shah in the selected readings volume published with this handbook describe the seismic building code development process in some detail.

Location-specific information on seismic-resistant design and construction and seismic building codes is available from:

- The model code and seismic safety groups listed in Chapter 7
- Local building officials
- Local chapters of professional societies and associations

Additional information is available in the following publications:

California Seismic Safety Commission. 1979. Hazardous Buildings: Local Programs to Improve Life Safety. Report SSC 79-03. Sacramento: California Seismic Safety Commission.

Berg, Glen V. 1983. Seismic Design Codes and Procedures. Berkeley, California: Earthquake Engineering Research Institute.

International Conference of Building Officials. 1980. Issues Which Affect the Role of Building Departments in Earthquake Hazard Mitigation. Whittier, California: International Conference of Building Officials.