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Seismic Considerations—Health Care Facilities

EARTHQUAKE HAZARDS REDUCTION SERIES 35

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

BUILDING SEISMIC SAFETY COUNCIL

Program on Improved Seismic Safety Provisions

SEISMIC CONSIDERATIONS: HEALTH CARE FACILITIES

Revised Edition

BSSC Program on Improved Seismic Safety Provisions

SEISMIC CONSIDERATIONS:

HEALTH CARE FACILITIES

Revised Edition

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

BUILDING SEISMIC SAFETY COUNCIL
Washington, D.C.
1990

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

Abatement of Seismic Hazards to Lifelines: Proceedings of the Building Seismic Safety Council Workshop on Development of an Action Plan, 6 volumes, 1987

Action Plan for the Abatement of Seismic Hazards to New and Existing Lifelines, 1987

Guide to Use of the NEHRP Recommended Provisions in Earthquake-Resistant Design of Buildings, 1990

Improving the Seismic Safety of New Buildings: Societal Implications: Selected Readings, 1986

NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for the Development of Seismic Regulations for New Buildings, 1988 Edition, 2 volumes, 1988

Seismic Considerations for Communities at Risk, 1990*

Seismic Considerations: Elementary and Secondary Schools, Revised Edition 1990

Seismic Considerations: Health Care Facilities, Revised Edition, 1990

Seismic Considerations: Hotels and Motels, Revised Edition, 1990

Seismic Considerations: Apartment Buildings, 1988

Seismic Considerations: Office Buildings, 1988

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)

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.

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*This publication replaces *Improving the Seismic Safety of New Buildings: A Community Handbook of Societal Implications*, Revised Edition, 1986, and *Improving the Seismic Safety of New Buildings: A Non-Technical Explanation of the NEHRP Recommended Provisions*, 1986.

FOREWORD

The Federal Emergency Management Agency (FEMA) is pleased to have sponsored the development and the updating of this publication, one of a series of five devoted to the seismic safety of specific building types with special occupancy and functional characteristics (i.e., schools, lodging facilities, health care facilities, office buildings, and apartment buildings). Owners, developers, designers, and regulatory officials concerned with such buildings are encouraged to become aware of their particular seismic vulnerabilities and of cost-effective means to alleviate such vulnerabilities through the selective use of the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*. This revised edition of *Seismic Considerations: Health Care Facilities* reflects the content of the 1988 Edition of the *Provisions*.

Special thanks are due to Christopher Arnold, Building Systems Development, Inc., San Mateo, California, who authored the initial edition of this publication, and to the BSSC staff and Board of Direction for their efforts in producing this revision.

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., for his contributions in developing and promoting the first edition of this publication; to John F. Meehan, past Chief Structural Engineer for California's Office of the State Architect, for his technical review of the original publication and for his contribution of photographs; and to Ivan Viest, Consulting Engineer, Bethlehem, Pennsylvania, who developed material for later reports in the *Seismic Considerations* series that has been used in this revision.

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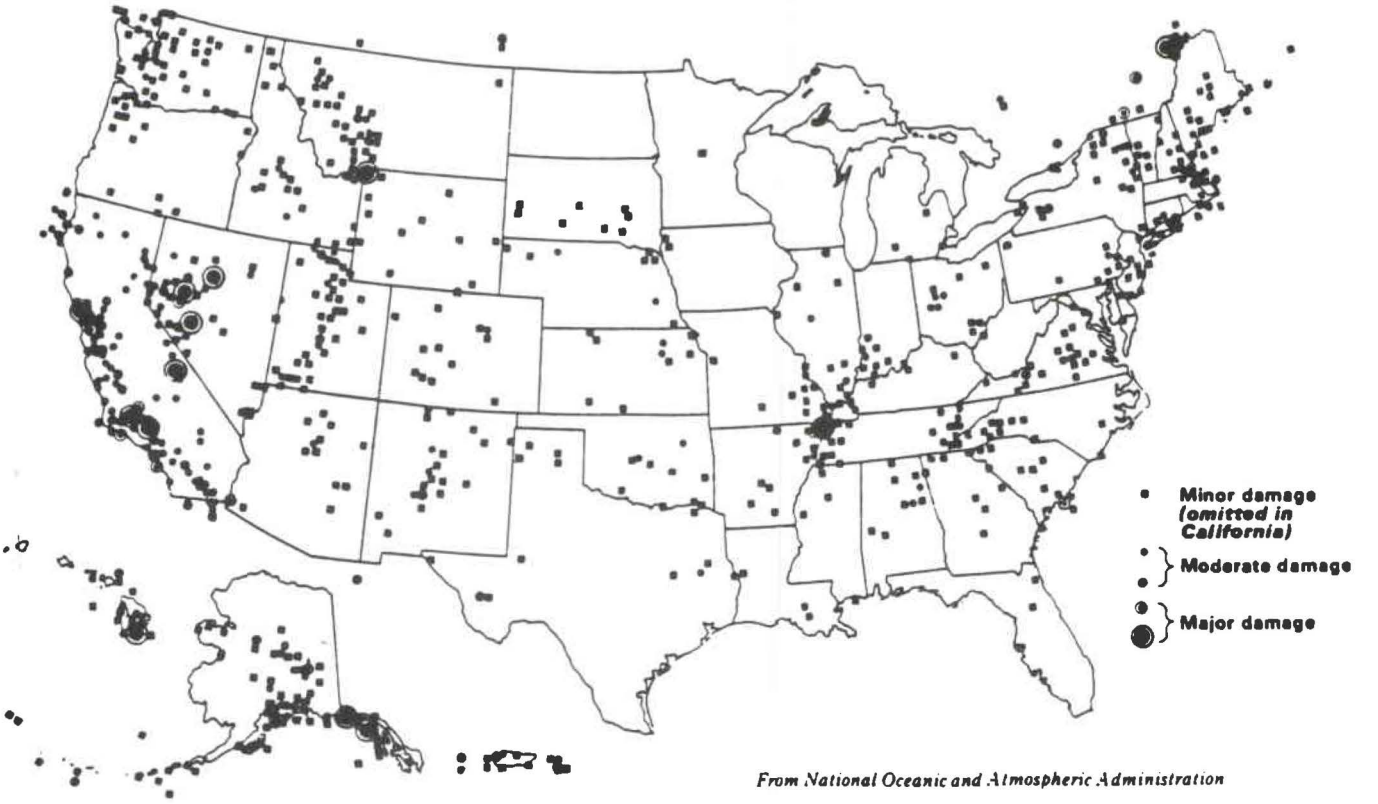
OVERVIEW

Need for Seismic Hazard Awareness

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 Building Seismic Safety Council (BSSC) firmly believes that increased building earthquake resistance is in the best interest of all building owners and developers. The Council also is convinced that, once these individuals and organizations seriously consider the social, economic, and legal implications of the earthquake risk to their facilities and operations, they will actively support efforts to improve the seismic resistance of their buildings by requiring that their designers follow up-to-date seismic-resistant design guidelines in all earthquake-prone areas of the nation.

Many building owners and developers, like many Americans in general, tend to associate earthquakes only with California. They are unaware that earthquakes are a national hazard. In fact, earthquakes have occurred and continue to occur in the majority of states and some of the most severe earthquakes recorded in this nation have occurred, not on the West Coast, but in the Midwest and East.

Damaging U.S. earthquakes.



From National Oceanic and Atmospheric Administration

The NEHRP Recommended Provisions

Specific guidance for overcoming the structural and, to some extent, the nonstructural seismic problems specific to health care facilities is available in the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*. This set of guidelines was first issued with the consensus approval of the BSSC membership (see the back of this publication for a list of current members) in 1985; a planned three-year update effort produced the 1988 Edition; and work on the 1991 Edition is under way. The *Provisions* contains information on such technical topics as ground motion and site geology, building occupancy and configuration considerations, structural systems and the connection of system elements, building materials, and nonstructural components and contents.

Economics of Seismic Design

Earthquake resistance need not be expensive. In fact, seismic safety provisions, when incorporated in a sound design from the very beginning of the planning effort by a competent team, usually amount to only about 1.5 percent of the cost of construction whereas a mere one-week loss of operational capability for a 400-bed hospital with 80 percent occupancy can amount to more than five times that amount.

Decision-maker Concerns

The BSSC, on behalf of the Federal Emergency Management Agency and concerned organizations in both the public and private sectors of the building community, urges each health care facility decision-maker to give full consideration to the implications of seismic risk in the design of their facilities. This enlightened self-interest will bear many tangible and intangible returns.

Contents of This Publication

General information concerning the seismic hazard and seismic design for health care facilities is contained in Part I of this publication and more technical details are presented in Part II. Appendixes provide information on related topics.

PART I

SEISMIC CONSIDERATIONS FOR HEALTH CARE FACILITY DECISION-MAKERS

1

EARTHQUAKES AND HEALTH CARE FACILITIES

Earthquakes--A National Hazard

A severe earthquake is one of nature's most terrifying and devastating events, and collapsing structures and falling debris do most of the killing. Media coverage of the 7.1 magnitude Loma Prieta earthquake in 1989 showed the nation just how horrifying an earthquake can be while also illustrating that modern buildings, designed and constructed under up-to-date seismic regulations, will perform well. Such regulations, however, have not been imposed in many areas of high to moderate seismic risk.

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 Figure 1 and Appendix B 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.

Between 1900 and 1986, about 3,500 lives were lost as a result of earthquakes in the United States and property damage has 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 Los Angeles 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.

Further, consider the tremendous social and economic loss to the nation if just one earthquake comparable, for example, to the New Madrid event occurred today where a number of high-density urban areas such as Memphis and St. Louis stand in place of log cabins and Indian settlements. In St. Louis, for example, future earthquakes 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. One needs to remember that there were only 2,000 people living in the St. Louis metropolitan area in 1811, as opposed to 2,400,000 today.

Further complicating the national seismic problem is the fact that science and technology have not yet generated a technique for accurately predicting when an earthquake will occur. Earthquakes are therefore a natural hazard even more difficult to deal with from a life safety standpoint than hurricanes or floods since one has no relatively immediate warning and cannot evacuate the area. However, geologic studies on a nationwide basis are rapidly advancing knowledge on the probability and nature of future earthquakes. These studies eventually should provide a more precise basis for establishing the relationship between seismic risk and appropriate seismic design.

The way in which buildings are designed and constructed ultimately determines the probability and extent of earthquake damage, and observation and experimentation have generated a considerable amount of information on effective seismic-resistant design and construction.

As a result of the study of buildings in and after earthquakes and experimental research in laboratories, where structures can be shaken to simulate the effects of earthquakes, a great deal is known about the relative safety of different types of construction. To accurately assess the seismic performance of a building requires considerable engineering expertise, but one need not be an expert to understand that a building constructed of bricks using poor quality mortar is much more likely to collapse than one that employs a well-engineered steel or reinforced concrete frame to provide integrity.

Nevertheless, since seismic safety is a complex issue that involves a relatively uncommon hazard and community values as well as life safety, this knowledge is not always applied even in areas of high risk. In California, for example, earthquakes have been a constant concern for many years and seismic building codes, although initially inadequate by today's standards, have been in effect for over 50 years. In other parts of the country, however, where the last major earthquake was well before anyone's memory, this is not so and even a moderate earthquake may do devastating damage.

Health Care Facilities Pose Special Earthquake Problems

This situation is especially critical with respect to hospitals and other health care facilities. Although health care facility construction is similar to that of other buildings, the size, occupancy and purpose of these buildings dictate that seismic safety (like fire safety) be given special attention:

- Health care facilities are heavily occupied buildings; they house patients, staff, medical personnel, and visitors and are occupied 24 hours a day. Many patients are helpless and need trained care. In addition, they may be surrounded by special equipment, using potentially hazardous gases such as oxygen, or they may be connected to life support equipment, which is dependent on power.

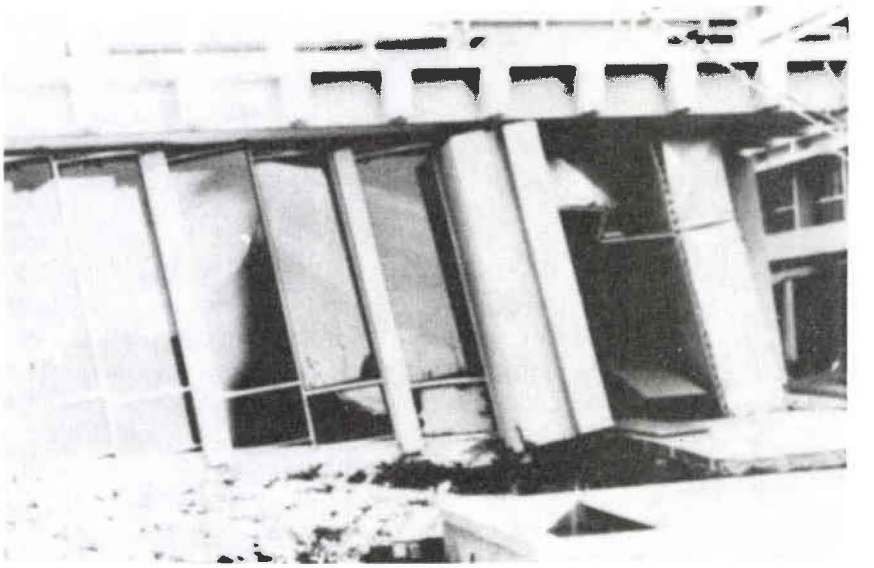
Decision-Maker Concerns

Given these factors, it is apparent that earthquake resistance should be given serious attention during the design and construction of health care facilities in areas at risk from earthquakes. An unsafe hospital structure may incur structural damage during an earthquake and may collapse. If collapse occurs, there is a major disaster. Major structural damage, short of collapse, will result in evacuation as a precaution against later collapse, and the consequences of evacuation are a service loss--probably for months or even years. Even without building collapse and no injuries, earthquake damage to hospital equipment and contents can approach 50 percent of the worth of the facility.

In the United States, relatively few health care facilities have experienced an earthquake. Because of this lack of experience, few people concerned with health care facilities have any sense of what may actually happen to their building in an earthquake. Out of ignorance comes speculation that may result in ignoring the possibility ("it can't happen to us!") or in grossly exaggerating the effects ("the whole medical center will be flattened!"). Appendix A presents reports on the earthquake experiences of health care personnel and others that may help to provide a sober and balanced view of the prospects. Several of the accounts are by staff members of a three-story hospital severely damaged (and subsequently demolished and rebuilt) during the 1971 San Fernando earthquake; these accounts especially illustrate how the occupancy and functional characteristics of a hospital make what is already a difficult situation far worse.

In the 1964 Alaska and the 1971 San Fernando, California, earthquakes, health care facilities suffered significant damage (Figure 3), and most of the deaths in San Fernando occurred in hospitals. As a result, California passed the *Hospital Act* in 1972. This law, administered by the Office of Statewide Health Planning and Development, requires that all new hospitals and extensive additions and renovations be designed and constructed to a special seismic standard. Structural plan review and construction supervision for acute hospitals and certain skilled nursing facilities are provided by the Structural Safety Section of the Office of the State Architect.

FIGURE 3
Olive View Hospital after 1971 earthquake.



throughout the six year period, during which time the hospital's cash situation was seriously affected and a bond issue was necessary.

- Holy Cross Hospital consisted of a main building of seven stories and appendages of one, two, and three stories. The building contained 209 beds and was occupied in 1967, 4 years prior to the earthquake. Although structural damage was considerable, the building was not close to collapse, and there were no deaths or injuries. The combined loss of the building and equipment was estimated at 55 percent of the replacement cost of $9 million. The building was demolished and a replacement hospital constructed at a cost of $24 million was completed in 1977.

- Panorama City Medical Center, a 10-story structure with 275 beds owned by a major HMO, was located 15 miles away from the epicenter of the earthquake. There was considerable structural damage, but within a few hours of the earthquake a consultant structural engineer declared the building safe and it was not evacuated. The initial estimate of dollar loss for this building, in structure and equipment, was $250,000. Ultimately, the total expenditure for direct costs of repair was over $3.5 million and over six years elapsed before final payment of financial assistance from the federal government. Repairs were carefully scheduled so as not to impair hospital operation during this period.

2

SEISMIC HAZARD MITIGATION AND THE COST/BENEFITS OF SEISMIC DESIGN

Need for Local Seismic Hazard Assessment

Those responsible for health care facilities need to research their local seismic situation to determine the precise seismic hazard. Once this is done, they will have a rational basis for deciding how much seismic risk they are willing to accept and the degree to which they wish to lessen the risk.

The use of up-to-date seismic design provisions--especially the *NEHRP Recommended Provisions*--in developing requirements for health care facilities generally is considered to be one significant way of lessening the risk to life by bringing to bear the best available guidance for designing and constructing new buildings in a manner that will prevent their structural collapse during an earthquake.

Life Safety Considerations

Health care facility design must be concerned not only with life safety in terms of death or injury due to building collapse or property damage but also with the safe emergency egress of patients, staff, and visitors. Although promulgation of a seismic building code based on statistical probabilities can contribute significantly to building and occupant safety in an earthquake, it is not possible to describe on firm scientific ground the strongest earthquake that might occur at any specific location and, therefore, there always remains some degree of risk. This risk may be small, but it is greater than zero.

For an individual building designed in accordance with *NEHRP Recommended Provisions*, the intent is to ensure a level of safety such that in the "design earthquake" (i.e., one that has only a 10 percent probability of being exceeded in 50 years), structural damage will be limited. There may, however, be some nonstructural and contents damage but such damage will not be life--threatening. Any damage, structural or nonstructural, generally will be repairable. For a large earthquake of low probability of occurrence (e.g., one with a predicted occurrence interval of thousands of years), there may be structural damage and considerable nonstructural damage, but life-threatening collapse, while possible, is improbable. It must be emphasized, however, that it is not practical to obtain absolute safety from any natural or man-made hazard. A major earthquake may produce some damage (both structural and nonstructural) in even the most earthquake-resistant structures, but use of the *NEHRP Recommended Provisions* will provide a high level of life safety when applied by competent engineers knowledgeable about earthquake matters.

Economics of Seismic Design

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 health care facilities provide an essential community service, are expensive to build and operate and produce revenue (if privately owned), the economics of seismic design are particularly critical. Beyond the consideration of life loss, economic analysis on a conventional real estate basis can provide some useful guidance concerning the effects of seismic design on health care facility economics.

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 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--The structural system of a typical health care facility 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.

The average increase in cost of health care facilities conforming to the *NEHRP Recommended Provisions* should be less than 1.5 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 a hospital, 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 hospital 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.

Design/Construction Team Concerns

The complexity of health care facility design places a special burden on the design and construction team. In particular, the coordination of the structural system with mechanical, electrical, and plumbing systems and equipment requires careful design and information exchange between the design consultants. The introduction of seismic design requirements further increases the demands on the team.

Effective team work starts with recognition by the owner of the special requirements of the building type. Seismic design starts at the inception of the building program, and appropriate seismic design decisions must be made at each phase of the design process. Because seismic performance is also dependent on construction quality and, in particular, on correct construction of critical details, the contractor also is an essential member of the team. Good seismic performance therefore requires understanding and correct decision-making by the owner, affects all participants in the design process, and ultimately depends on correct construction execution by the contractor and the building force.

PART II

SEISMIC CONSIDERATIONS FOR HEALTH CARE FACILITY DESIGNERS

3

EARTHQUAKE DESIGN PROBLEMS OF HEALTH CARE FACILITIES

Health Care Facility Inventory

Health care facilities include a wide variety of building types, ranging from the residential scale of a rural hospital to the high-rise conglomeration of a large urban medical center. Nationally, there are currently over one million beds contained in 5,800 community hospitals. Although the average hospital size is 174 beds, about 65 percent of the beds are in hospitals that are over 200 beds in size (approximately 30 percent of the buildings) and almost 25 percent of the beds are in hospitals that are over 500 beds in size (a little over 5 percent of the buildings). Thus, it appears that hospital occupants tend to be concentrated in relatively large buildings.

For purposes of this publication, health care facilities (Figure 4) are considered to include:

- Urban Medical Centers--Dense groupings of predominantly large buildings built over a considerable period of time with different phases of construction. Buildings are often adjacent to one another or directly connected; small ancillary buildings often form part of the complex. Such centers provide a wide range of services, including teaching.

- Large General Hospitals--Mid- to high-rise structures with connected or adjacent support facilities. They provide a wide range of services including acute care and specialized diagnostic or treatment capability.

- Community Hospitals--Low-rise structures offering a wide range of services.

- Special Hospitals--Generally low- or mid-rise structures, residential in nature, that focus on a particular medical specialty, such as cancer or drug addiction, or a particular population, such as children.

- Convalescent Homes--Similar to large houses, multifamily housing, or hotels/motels and residential in nature. They focus on the elderly and provide long-term care and limited medical services.

Each of these building types presents different earthquake-related problems because of its construction and occupancy. Because of developments in health care methods and economics, the general hospital is becoming more of an acute care facility; other kinds of facilities deal with minor surgery on an outpatient basis or provide for long-term residential health care needs.

The basic design problems affecting the seismic performance of health care facilities are:

- Building form irregularities in both the horizontal and vertical planes,
- Discontinuities in strength between the major structural elements of the building,
- Inadequate diaphragms,
- Effects of nonstructural elements on the structural system,
- Deficiencies in the connections that tie the elements of the building together, and
- Damage to the nonstructural components (including utility systems) and contents of the building.

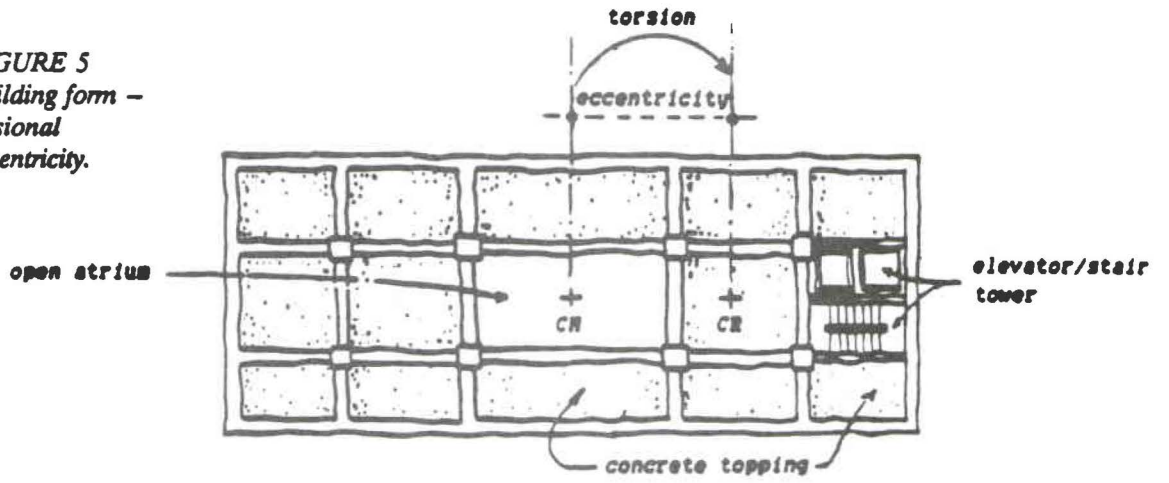
Egress complications and the disruption of post-earthquake operations are also major concerns.

Building Form Irregularities

Those who have studied the performance of buildings in earthquakes generally agree that the building's form greatly influences its performance under ground motion. This is because the shape and proportion of the building have a major effect on the distribution of earthquake forces--that is, on the relative size and nature of the forces as they work their way through the building.

A simple and symmetrical building form allows for the most even and balanced distribution of forces, but symmetry of form will not ensure low torsional effects. For instance, even in simple symmetrical rectangular buildings the location of stiff stair and elevator cores, solid and glazed walls, or other design elements that add mass to only one part of the building can result in different locations of the center of mass and the center of rigidity, and the torsion or twisting that results during an earthquake (Figure 5) has frequently caused substantial damage.

FIGURE 5
Building form – torsional eccentricity.



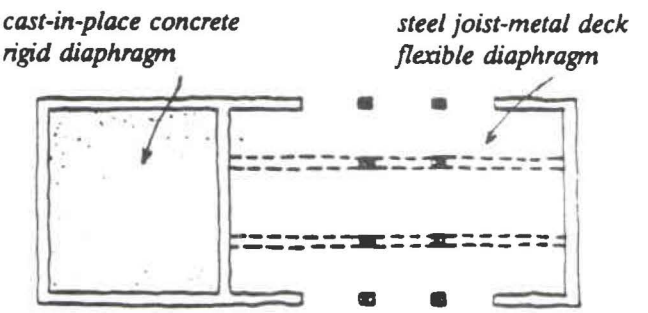
- The use of narrow wings, which can cause torsional effects and stress concentrations at the re-entrant corners.

- The placement of a tall nursing floor structure above a broad base of diagnostic and treatment areas, which can result in problems associated with vertical setbacks.

Structural Discontinuities

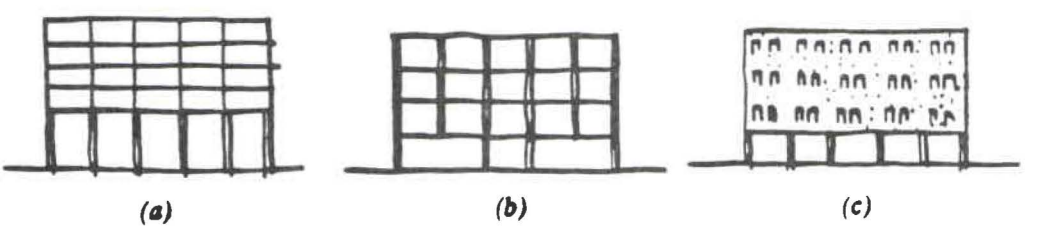
It is not generally recognized that large discontinuities (or abrupt changes) in the strength (Figure 8) or stiffness of a building can cause adverse seismic response effects. This is particularly the case where there are abrupt changes in the vertical arrangement of the structure that result in discontinuities (changes) of strength or stiffness from floor to floor.

FIGURE 8
Discontinuity in strength.



The most prominent of the problems caused by such a discontinuity is that of the "soft" first story (Figure 9), a term applied to a ground level story that is more flexible than those above. Although a "soft" story at any floor creates a problem, a stiffness discontinuity between the first and second floors tends to result in the most serious condition because forces generally are greatest near the base of a building.

FIGURE 9
"Soft" first story: (a) tall, flexible columns, (b) interrupted vertical columns, (c) heavy superstructure over slender frame.

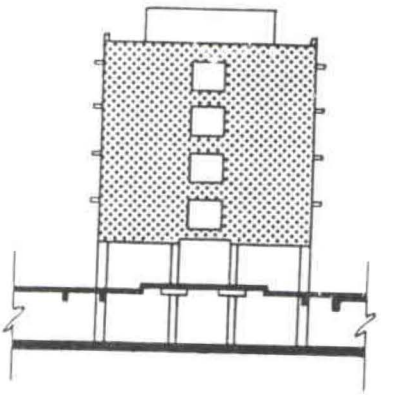


Three conditions typically create a "soft" story:

- The first occurs when there is a significant discontinuity of strength and stiffness between the vertical structure of one floor and the remainder of the structure. This discontinuity may occur because one floor, generally the first, is significantly taller than the remainder, resulting in decreased stiffness (Figure 9a).

FIGURE 11
"Soft" story at Olive View Hospital.

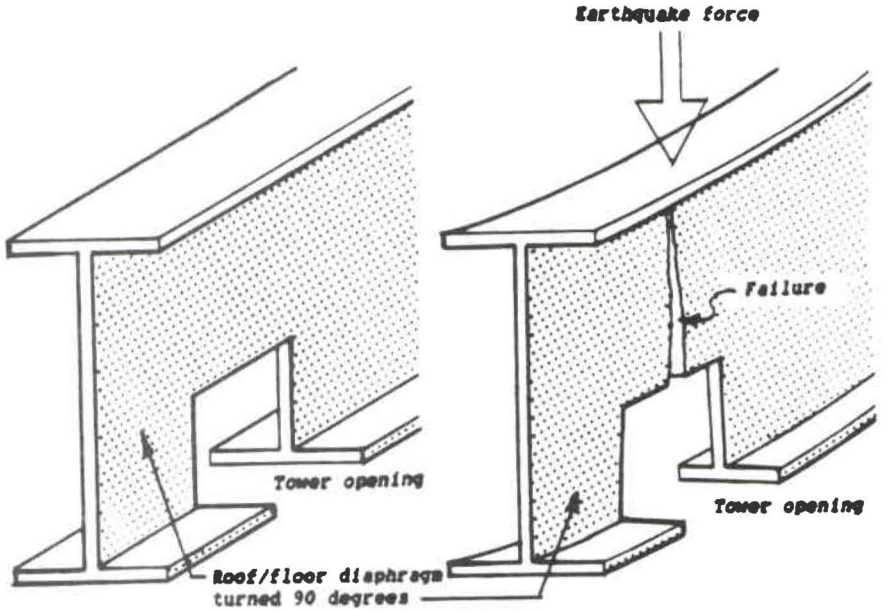
FIGURE 12
Cross section of Olive View Hospital.



Roof and Floor Diaphragms

The earthquake loads at any level of a building will be distributed to the vertical structural elements through the roof and floor diaphragms. The roof/floor deck or slab (the horizontal diaphragm) responds to loads like a deep beam. The deck or slab is the web of the beam carrying the shear and the perimeter spandrel or wall is the flange of the beam resisting bending (Figure 15).

FIGURE 15
Openings in diaphragms.



Three factors are important in diaphragm design:

- The diaphragm must be adequate to transfer the forces and must be tied together to act as one unit.
- The collectors (members or reinforcing) must transfer the loads from the diaphragm into the shear wall.
- Openings or re-entrant corners in the diaphragm must be properly placed and adequately reinforced.

Inappropriate location or excessive size of openings (elevator or stair cores, atria, skylights) in the diaphragm create problems similar to those related to cutting a hole in the web of a beam. This reduces the natural ability of the web to transfer the forces and may cause failure in the diaphragm.

Displacement and Drift

Drift is the lateral displacement of one floor relative to the floor below. Buildings subjected to earthquakes need drift control to restrict damage to interior partitions, elevator and stair enclosures, glass, and envelope cladding systems and, more importantly, to minimize differential movement demands on the seismic resisting structural elements.

Particular problems in terms of the effect nonstructural components can have on the structural system in health care facilities are as follows:

- The location of rigidly connected elevator or stair cores within more flexible long span spaces (diagnostic or treatment areas) can modify the assumed deflection of the columns surrounding the cores, creating torsion and attracting a disproportionate load to the core or stairway structure (Figure 17).

- The use of infill walls between columns (forming windows in patient rooms) can effectively stiffen the beams and shorten the columns, attracting higher loads into the columns and beams than assumed in the design calculations (Figure 18).

- The addition of rigid infill nonstructural walls between columns separating rooms can increase the stiffness of the columns far above what was assumed in the structural design.

FIGURE 17
Effect of elevator and stairway placement.

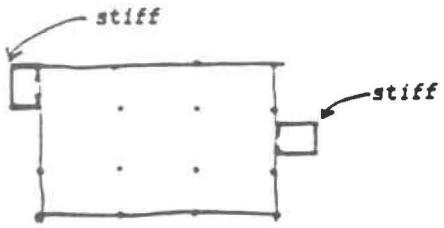
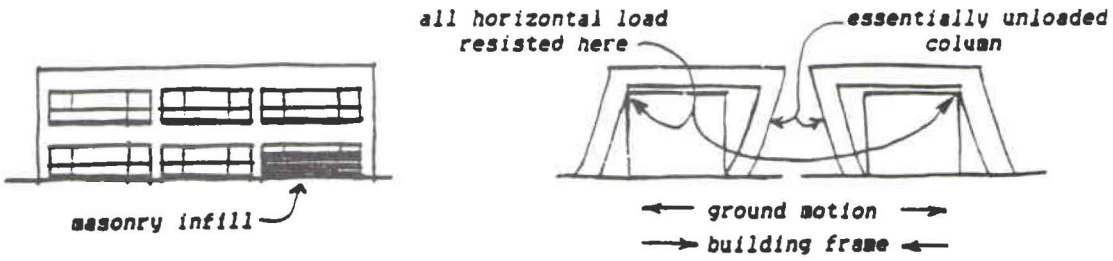


FIGURE 18
Effect of infill walls.



Connections

Structural member connections are among the most critical elements of earthquake-resistant design. Probably the most important single attribute of an earthquake-resistant building is that it is tied together to act as a unit, but no set of seismic provisions issued before the *NEHRP Recommended Provisions* (and its predecessor, the Applied Technology Council's ATC 3-06) stated this requirement. It is generally accepted by structural engineers that to develop adequate connections between structural elements is more difficult than to provide strength in the members themselves. This has been demonstrated clearly in past earthquakes where considerable damage originated at connections rather than in the structural members.

- Use of limited numbers of columns (longer spans) in large open spaces (diagnostic or treatment areas, cafeteria), causing these elements to become extremely critical.

- Discontinuity of the uniformity of the structural system through the location of large, long-span areas.

- Placement of openings (stacked, uniform patient room doors and windows) in the interior and exterior shear walls causing large forces to be concentrated in certain weak elements.

Damage to Nonstructural Components and Building Contents

Severe earthquake damage can occur even if the building structure remains essentially intact. During recent earthquakes, many buildings with no serious structural damage have suffered nonstructural damage totaling as much as 50 percent of the building replacement value. The Bay Area Regional Earthquake Preparedness Project (BAREPP) reports that the 1983 6.5 magnitude Coalinga, California, earthquake resulted in nonstructural damage totalling $2 million. At the Coalinga Hospital, X-ray equipment was rendered inoperative and the cost of repair of this and other sensitive equipment exceeded $100,000. One convalescent facility in South Coalinga had major structural damage and was declared a total loss. According to BAREPP, the 1987 5.9 magnitude Whittier Narrows, California, earthquake caused almost $16 million of damage, much of which was nonstructural. For example, of the 116 acute care hospitals in the Los Angeles County Health Department System, 20 had significant nonstructural damage.

To understand the magnitude of the problem one need only consider that the structural system (foundation, floors, structural walls, columns, beams, etc.) constitutes only 15 to 25 percent of health care facility construction cost; therefore, the nonstructural architectural, mechanical, and electrical elements make up between 75 and 85 percent of the building's replacement value. In addition, health care facilities depend on their utility systems for their ability to function much more so than do other facility types. Schools, offices, and stores can continue with a minimum of power and light, but the modern hospital becomes virtually useless under such circumstances. In the 1971 San Fernando earthquake, two patients at Olive View Hospital died when their life support systems failed.

The nonstructural components with both life safety and major property damage consequences include exterior nonbearing walls, exterior veneers, infill walls, interior partition systems, windows, ceiling systems, elevators, mechanical equipment, and electrical and lighting equipment. All these components are subject to damage, either directly due to shaking or because of movement of the structure (which may be an intentional part of the seismic design). Health care facility occupants are particularly vulnerable to nonstructural damage. While school children and office workers may duck under desks and be safe from falling objects like light fixtures or glass, the patient in a bed or wheelchair has no such option. Ceiling tile and wall finishes that fall on hallways and stairs can make movement difficult, particularly if combined with power failure and loss of lights.

FIGURE 20
Ceiling/lighting system collapse.

Heating equipment located on roofs or hung in open spaces or service areas typically is not designed for lateral forces. These pieces of equipment can easily fall and cause considerable damage or injury. Mechanical system grills and diffusers also can fall from ceilings.

Even such nonstructural components as glazing systems can create additional hazards. Although damage patterns for glazing systems have not been well researched, glass breakage is related to support conditions, the temper of the glass and its thickness and size, and the type and direction of loading. Large windows usually break at somewhat lower loads than smaller windows since large windows behave like a membrane or diaphragm. With sufficient space for movement within the frame, a frame that does not rack, low glass loading, and reasonably careful design and placement, good performance can be expected. Glass joint treatment also is a factor in the overall performance of a curtain wall or window unit system; if the edges are restrained, failure is likely. In this context, it also should be remembered that the sealants and gasket materials providing flexibility can lose their resiliency with age and exposure and therefore may require periodic replacement.

Much of the contents of a health care facility is essential to its diagnostic and treatment function. The overturning of an office file cabinet may be a temporary nuisance for a commercial company, but the overturning of a patient records cabinet can be a critical problem in a hospital since these records are an essential aspect of treatment. Many other supplies such as medications or instrument packs are essential for emergency treatment that may be necessary immediately after an earthquake.

Seismic design is continuously evolving as a result of design innovations and lessons learned from earthquakes and earthquake damage repair. A significant design innovation--"base isolation"--has been researched extensively and is now in use. This method employs "base isolators" that provide for vertical support but offer very little lateral resistance. Thus, the transmission of seismic forces from the ground to the building is greatly reduced in magnitude. When base isolation is properly applied in an appropriate building, additional costs for foundation design and bearings are offset by economies in the design of the building superstructure.

Base isolation is of particular value in hospital design because it offers the prospect of reducing nonstructural and equipment damage and, consequently, of decreasing the potential for loss of function. In addition, the technique is appropriate for buildings between 4 and 12 stories with a low height to width ratio to obviate the possibility of overturning. Many hospital buildings meet these criteria and design studies that exploit the benefits of the base isolation technique are now under way for several hospitals in seismic risk areas.

Post-Earthquake Egress Problems

Egress complications can be summed up by a statement made in a report on the 1964 Alaska earthquake:

> ...the final measure of a well constructed building is the safety and comfort it affords its occupants. If, during an earthquake, the occupants must exit through a shower of falling light fixtures and ceilings; maneuver through shifting and toppling furniture; stumble down dark corridors and stairs; and then be met at the street by falling glass, veneers, or facade elements...then the building certainly cannot be described as a safe building.

Problems of egress are especially critical for health care facilities because of the patient population. As hospitals evolve into predominantly acute care facilities, the greater is their population that will be completely helpless in the post-earthquake situation (Figure 22).

With elevators most likely inoperative, emergency stairs become the critical means of egress from a health care facility during and after an earthquake. Several things can happen to stairwells during an earthquake. First, stairs tend to act as diagonal bracing between floors and interstory drift can induce damaging loads and racking that may result in collapse or failure if the stair framing is anchored to the structural system without sliding joints at the end. Second, masonry or concrete fire walls surrounding stairs can fracture leaving egress pathways strewn with debris. In the case of Olive View Hospital, staircase towers collapsed independently of the building they were expected to serve.

FIGURE 23
Blocked egress route.

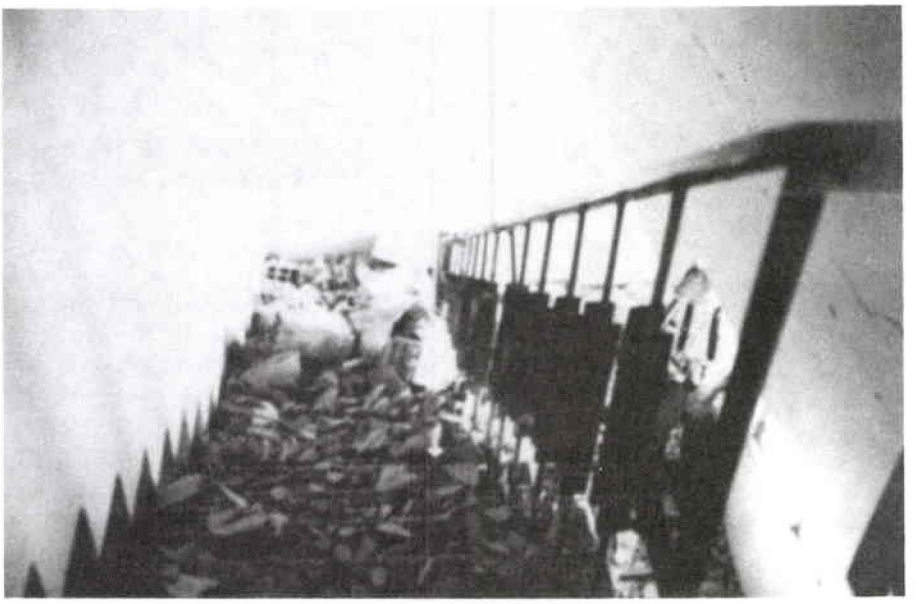


FIGURE 24
Ambulance crushed by collapsed canopy at Olive View Hospital.

4

THE NEHRP RECOMMENDED PROVISIONS AND HEALTH CARE FACILITY SEISMIC DESIGN

Achieving Good Seismic Design

In order to achieve good seismic design:

- The design team needs to be both experienced in and supportive of earthquake design, and
- Building owners must require such design as an integral part of the design of their buildings.

Although building owners obviously cannot and do not need to understand all the technical aspects of earthquake design, they should be familiar with the range of strategies and solutions that are available to protect their buildings.

The *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*, developed by recognized researchers and practitioners of seismic design and having the consensus approval of the BSSC membership, provides an authoritative set of seismic design concepts and details. The *Provisions* covers the following major topics:

- Earthquake design characteristics,
- Structural design requirements,
- Procedures for analysis of building response to earthquake forces,
- Soil-structure interaction,
- Foundation design requirements,
- Nonstructural component design, and
- Basic materials of construction--wood, steel, reinforced concrete, and masonry.

The discussion that follows is a broad look at the strategies expressed in the *NEHRP Recommended Provisions* that are aimed at providing an acceptable and affordable level of safety for health care facilities. For a general description of some of the fundamental principles of earthquake effects and seismic design, see the BSSC's *Seismic Considerations for Communities at Risk*; technical issues are explored in the *Provisions* document itself and in the BSSC's *Guide to Use of the Provisions in Earthquake-Resistant Design of Buildings*. All BSSC publications are available free upon request.

The differences in the two maps relate to whether they show effective peak accelerations (which generally are less than the peak or maximum accelerations that may occur) or effective peak velocities (which represent another aspect of ground motion that is mathematically derived from acceleration).

In any specific location, the map showing A_v (effective peak velocity) or A_a (effective peak acceleration) may govern, the choice being primarily related to the size of the building involved. The accelerations shown on both maps range from 5 to 40 percent and are illustrated in the form of contour lines indicating areas of equal acceleration (similar to elevation contours on a topographical map). Figure 25 is a small-scale reproduction of one of these maps. The large-scale maps supplied with the *Provisions* superimpose contours on a background of county lines to clarify jurisdictional issues.

Although based on extensive studies, these maps reflect a number of assumptions. The general criterion is that the risk at any location has only a 10 percent probability of being exceeded in 50 years, which translates into a mean recurrence interval of 475 years. This is a statistical number, however, and unfortunately there is no assurance that at a given location the given ground motion will not occur at any time. Studies are constantly being conducted in an effort to provide more accurate information on this crucial point, and new maps reflecting the results of these studies are being developed.

In order to determine the degree of protection to be provided the building and its occupants, a building is assigned to a Seismic Hazard Exposure Group based on its occupancy or use. The intent is for important buildings--such as hospitals or police stations--and for buildings with large numbers of occupants or where the occupants' mobility is restricted--such as auditoriums, schools, and hotels--to receive a higher standard of seismic protection than other buildings where the seismic hazard is less critical. Thus, every building is assigned to one of three Seismic Hazard Exposure Groups (identified as I, II, and III). Hospitals having surgery and emergency treatment functions are assigned to Group III while other hospital facilities are assigned to Group II.

These two factors, effective peak velocity and Seismic Hazard Exposure Group, lead to identification of the building's Seismic Performance Category, the level of seismic performance to which the building must be designed. This is done using the following table that relates the location's effective peak velocity, A_v, to the building's Seismic Hazard Exposure Group (I-III):

Effective Peak Velocity	Seismic Hazard Exposure Group		
	I	II	III
$0.20 \leq A_v$	D	D	E
$0.15 \leq A_v < 0.20$	C	D	D
$0.10 \leq A_v < 0.15$	C	C	C
$0.05 \leq A_v < 0.10$	B	B	C
$A_v < 0.05$	A	A	A

It can be seen that east of the Rockies, where A_v is nearly always less than 0.20 (Figure 25), hospitals will belong to Seismic Performance Category A, B, C, D, or E (1988 Edition of the *NEHRP Recommended Provisions*). This procedure provides reasonable seismic protection for all buildings and reflects the varying hazards for alternative locations around the country.

Site Geology

The use of the design ground motion shown on the *NEHRP Recommended Provisions* maps is sufficient for most design purposes. For large or important buildings or where significant earthquake activity is suspected, the building owner should require that geological surveys be performed on the building site to evaluate more accurately the level of seismic hazard to be expected.

It is convenient to classify earthquake effects into four distinct categories:

- When faults shift, causing an earthquake, the split in the fault often appears as a crack or vertical step on the earth's surface. Major displacements (movements of up to 21 feet have been recorded) can occur along the fault line. No economical building design can withstand displacements of this magnitude. Nevertheless, many buildings are located and continue to be located astride faults because of lack of fault identification. Where fault locations are accurately mapped, as is the case in California, the building owner should make certain that the building is not located over a fault and geological studies should be undertaken before making the final site decision.

- The second category of earthquake effects involves ground motion. Ground motion does not damage a building by externally applied loads or pressure as in gravity or wind loads, but rather by internally generated inertial forces caused by vibration of the building's mass. The natural tendency of any object to vibrate back and forth at a certain rate (generally expressed in seconds or fractions of a second) is its fundamental or natural period. Low- to mid-rise buildings have periods in the 0.10 to 0.50 second range while taller, more flexible buildings have periods between 1 and 2 seconds or greater. Harder soils and bedrock will efficiently transmit short period vibrations (caused by near earthquakes) while filtering out longer period motions (caused by distant earthquakes) whereas softer soils will transmit longer period vibrations.

  As a building vibrates under ground motion, its acceleration will be amplified if the fundamental period of the building coincides with the period of the vibrations being transmitted through the soil. This amplified response is called resonance. Natural periods of soil are usually in the range of 0.5 to 1.0 second so that it is entirely possible for the building and ground to have the same fundamental period and, therefore, for the building to approach a state of resonance. This was the case for many 5- to 15-story buildings in the 1985 earthquake in Mexico City. An obvious design strategy, if one can predict approximately the rate at which the ground will vibrate, is to ensure that buildings have a natural period different from that of the expected ground vibration to avoid amplification.

Following this approach, the *NEHRP Recommended Provisions* identifies three Seismic Hazard Exposure Groups:

- Group III includes those buildings having essential facilities that are necessary for post-earthquake recovery.
- Group II includes those buildings having a large number of occupants and those buildings in which occupants' movements are restricted or their mobility impaired.
- Group I includes all other buildings not included in Groups III and II.

As noted above, hospitals are assigned to Group II or III.

Building Configuration

One set of decisions most critical to the ability of a health care facility building to resist earthquake damage is, as noted earlier, the choice of building configuration: its size, shape, and proportion. Since the shape of the site, functional requirements, and community aesthetic aspirations can present constraints to an optimal configuration for seismic safety, it is important to understand how the building's form affects the building's earthquake performance.

Some of the major issues were outlined in Chapter 3. The basic problem can be expressed by focusing on two conditions that have consistently caused severe damage and collapse:

- The unbalanced plan resistance of the building--Any plan configuration that has a center of rigidity (resistance) that does not approximately coincide with the center of mass (weight) will undergo significant torsional rotation during an earthquake (Figure 26).
- Unbalanced or random rigid resisting elements--Any configuration that concentrates forces on a small number of rigid element(s) of the building risks failure of those elements (Figure 27).

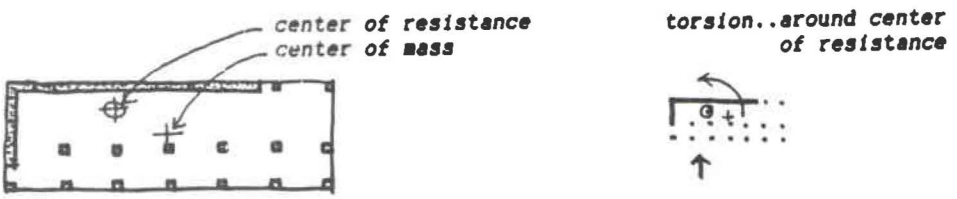


FIGURE 26
Centers of mass and resistance do not coincide causing torsion under earthquake motion.

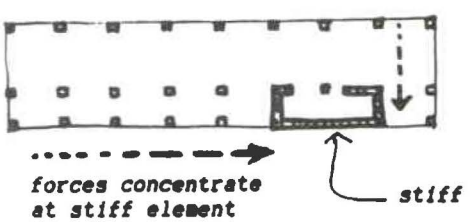


FIGURE 27
Rigid elements in plan will attract earthquake forces.

Structural Systems

Selecting and designing a structural system that will perform well within the range of unknowns of earthquakes is a demanding task:

- The goals for the performance of the structure must be established,
- The geological and site characteristics must be considered,
- An appropriate building form responsive to the needs of the potential users and to earthquake-resistance requirements must be developed,
- A structural system compatible with these needs must be selected and analyzed,
- The structural details must be developed, and
- The structure must be correctly constructed.

This process must be a joint effort between the three main parties involved: the building owner, the architect, and the consulting engineer.

Earthquake lateral loads are resisted by three alternative vertical structural systems: shear walls, braced frames, and moment frames. A fourth system for lateral load resistance, the so-called dual system, is a combination of moment frames and shear walls or braced frames. Horizontal diaphragms (floors and roofs) connect the individual shear walls and frames and assist in transferring the loads to the foundation.

Each of the four vertical structural systems has certain characteristics:

- Moment frames resist earthquake forces by providing strong joints. This system, with its absence of structural walls, provides great interior planning advantages but also can result in a more flexible structure that may contribute to nonstructural and contents damage. Because of the importance of the joints, their construction tends to be expensive.
- Shear wall systems provide very stiff structures. Unless the shear walls can be confined to the exterior envelope and the communication cores, they represent an impediment to the interior planning flexibility provided by the favored open floor spaces of modern buildings.
- Braced frame systems combine some of the features of the two other systems. They provide a more open structure than one based on shear walls, but the braces may be some impediment to interior planning. The system may not be as stiff as a shear wall system, but it can be more economical than a moment frame system.
- In a dual system, a moment frame provides a secondary defense with a higher degree of redundancy and ductility. The prescribed forces are assigned either to the overall system or to the shear walls/braced frames alone. The dual system offers certain advantages in that it provides high stiffness for moderate earthquakes and an excellent second line of defense for major earthquakes.

The performance of poured-in-place reinforced concrete buildings in past earthquakes has ranged from very poor to excellent, depending on the type of structural system and the quality of detailing. Buildings with well designed shear walls can be expected to perform well, particularly if openings are small relative to the wall. In moment resisting frames, detailing has proven to be a critical aspect of performance. Particularly important is adequate confinement of the concrete through the use of spiral or closely spaced stirrup ties (reinforcement), which increases the system's ductility (the ability of the system or material to distort without collapsing). Major problems with reinforced concrete buildings have occurred in frame structures with inadequate ductility where system collapse occurred after some seconds of earthquake motion.

The expected good performance of modern reinforced masonry buildings contrasts with the highly publicized and dramatic failures of older unreinforced masonry buildings. The proper design and construction of walls and the proper connection of walls to floor and roof diaphragms are critical to the successful performance of these materials during an earthquake. Precast concrete elements, whether they are conventionally reinforced or prestressed, have exhibited significant structural failures in earthquakes, primarily because they were not fastened together sufficiently to provide the equivalent of monolithic construction. Since these systems are often used for long spans, issues of redundancy and concentration of stresses must be given serious consideration.

The *NEHRP Recommended Provisions* contains specific seismic design and detailing requirements for wood, steel, reinforced concrete, and reinforced masonry.

Connections

Recognizing the fact that few buildings are designed to resist severe earthquake loads elastically (the ability of the structure to deform, absorb the earthquake energy, and return to its original condition), ductility must be provided whenever the elastic resistance is expected to be exceeded. The need for ductility applies not only to the structural elements but also to the connections between the elements.

Where ductility has not been provided, failures have occurred in connections where the capacity of ductile structural elements was reached or in connections that were too weak to transfer the forces developed in the structural elements (Figure 28). Specifically, connection failures have occurred in inadequately anchored exterior precast panels, between walls and diaphragms, between beams and walls, between columns and beams, and between columns and foundations--indeed, at any location where two or more different structural elements interact in transferring the loads.

It should be possible to follow direct paths for the vertical and horizontal forces all the way through the building to the foundation and for this path to be thoroughly tied together at each intersection. What those responsible for a health care facility must recognize is that this type of design and detailing process is not normally a consideration when architects and structural engineers design a nonseismic building.

FIGURE 29
Hallway in
Olive View Hospital
after 1971 earthquake.

Nonstructural Components and Contents

In building codes, nonstructural systems and components (except for fire protection systems) are not given the same importance for life safety as the structural system and elements. However, for health care facilities, the protection of these elements is of great importance due to the nature of the occupants and the structure of the building.

For relatively little cost in the design and construction of a new building (or even in the remodeling of an existing building), considerable potential injury and costly damage (including loss of function) can be avoided. The more common nonstructural elements in health care facilities that should be given special design attention include:

Appendages	Entrance canopies, overhangs, balconies/roof-mounted mechanical units and signs/roofed walkways
Enclosures	Exterior nonbearing walls/exterior infill walls/veneer attachments/curtain wall system attachments
Partitions	Stairs and shafts/horizontal exits/corridors/fire separation partitions
Ceilings	Fire-rated and non-fire-rated
Doors/Windows	Room-to-hallway doors/fire doors/lobby doors and glazing/windows and curtain walls/atrium spaces and skylights/glass elevator enclosures
Lighting	Light fixtures/emergency lighting

- Mass reduction--Reducing the weight of the component to reduce the inertial forces on it.

- Relocation--Changing the location of a component in order to reduce its vulnerability or threat to occupants (e.g., moving a heavy tank from roof to basement).

FIGURE 30 Earthquake strategies for nonstructural components: o identifies possible strategies and •, strategies with high potential.

Nonstructural Systems	Flexibility/Deformation	Anchorage	Bracing	Stability	Strengthening	Separation/Isolation	Slip/Control Joints	Reduced Mass	Containment	Incorporation	Location
Exterior Elements		•	•		•			•	o	o	•
Enclosure Systems	•						•	•		•	
Finishes/Veneers	•	•					o	•			
Partitions	o	•				•	•				
Ceiling Systems		•	•		o	•		o		•	
Lighting Systems		•	•		o	o				o	
Glazing	•				•	•					•
Transportation System					•	•	•				•
Mechanical Systems	•	•	•					•			•
Furnishings/Equipment		•		•	•			•			

Construction Quality

Building failures during earthquakes that are directly traceable to poor quality control during construction are innumerable. The literature is replete with reports pointing out that collapse could have been prevented had proper inspection been exercised to ensure that construction was in accord with building plans and specifications.

Severe building damage and collapse have been caused by poorly executed construction joints in reinforced concrete, undersized welds in steel construction, and the absence of nuts on anchor bolts in timber construction, to name just a few deficiencies. Recognizing that there must be coordinated responsibility during construction, the *NEHRP Recommended Provisions* delineates the role each party is expected to play in construction quality control:

- The building designer is expected to specify the quality assurance requirements,

5

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To obtain the information needed to define precisely a 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.

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GLOSSARY

General Terms

ACCELERATION The rate of increase in ground velocity as seismic waves travel through the earth. The ground moves backward and forward; acceleration is related to velocity and displacement.

ACCEPTABLE RISK The probability of social or economic consequences due to earthquakes that is low enough (for example, in comparison with other natural or man-made risks) to be judged by appropriate authorities to represent a realistic basis for determining design requirements for engineered structures or for taking certain social or economic actions.

AMPLITUDE The extent of a vibratory movement.

ARCHITECTURAL SYSTEMS Systems such as lighting, cladding, ceilings, partitions, envelope systems, and finishes.

COMPONENT Part of an architectural, electrical, mechanical, or structural system.

CONNECTION A point at which different structural members are joined to each other or to the ground.

DAMAGE Any economic loss or destruction caused by earthquakes.

DEFLECTION The state of being turned aside from a straight line. See drift.

DESIGN EARTHQUAKE In the *NEHRP Recommended Provisions*, the earthquake that produces ground motions at the site under consideration that have a 90 percent probability of not being exceeded in 50 years.

DESIGN EVENT, DESIGN SEISMIC EVENT A specification of one or more earthquake source parameters and of the location of energy release with respect to the site of interest; used for earthquake-resistant design of a structure.

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

DRIFT Lateral deflection of a building caused by lateral forces.

DUCTILITY Capability to be drawn out without breaking or fracture. Flexibility is a very close synonym.

FRAME SYSTEM, DUAL A structural system with an essentially complete space frame providing support for vertical loads. A moment resisting frame that is capable of resisting at least 25 percent of the prescribed seismic forces should be provided. The total seismic force resistance is provided by the combination of the moment resisting frame and the shear walls or braced frames in proportion to their relative rigidities.

FRAME SYSTEM, MOMENT RESISTING A structural system with an essentially complete space frame providing support for vertical loads. Seismic force resistance is provided by special, intermediate, or ordinary moment frames capable of resisting the total prescribed seismic forces.

INTENSITY The apparent effect that an earthquake produces at a given location. In the United States, intensity is frequently measured by the Modified Mercalli Index (MMI). The intensity scale most frequently used in Europe is the Rossi-Forell scale. A modification of the Mercalli is used in the Soviet Union. See the following section of this Glossary, "Measures of Earthquake Magnitude and Intensity."

JOINT A point at which plural parts of one structural member are joined to each other into one member.

LIQUEFACTION The conversion of a solid into a liquid by heat, pressure, or violent motion.

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

LOAD, LIVE Moving or movable external loading on a structure. It includes the weight of people, furnishings, equipment, and other things not related to the structure. It does not include wind load, earthquake load, or dead load.

LOSS Any adverse economic or social consequences caused by earthquakes.

MASS A quantity or aggregate of matter. It is the property of a body that is a measure of its inertia taken as a measure of the amount of material it contains that causes a body to have weight.

MERCALLI SCALE Named after Giuseppe Mercalli, an Italian priest and geologist, it is an arbitrary scale of earthquake intensity related to damage produced. See the following section of this Glossary, "Measures of Earthquake Magnitude and Intensity."

PERIOD The elapsed time of a single cycle of a vibratory motion or oscillation.

RESONANCE The amplification of a vibratory movement occurring when the rhythm of an impulse or periodic stimulus coincides with the rhythm of the oscillation (period). For example, when a child on a swing is pushed with the natural frequency of a swing.

TORSION The twisting of a structural member about its longitudinal axis. It is frequently generated by two equal and opposite torques, one at each end.

VALUE AT RISK The potential economic loss (whether insured or not) to all or certain subsets of structures as a result of one or more earthquakes in an area.

VELOCITY The rate of motion. In earthquakes, it is usually calculated in inches per second 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 magnitude or intensity, which is usually expressed on a scale of from 0 (no damage) to 10 (total loss).

WALL, BEARING A wall providing support for vertical loads; it may be exterior or interior.

WALL, NONBEARING A wall that does not provide support for vertical loads other than its own weight as permitted by the building code. It may be exterior or interior.

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 force resistance is provided by shear walls or braced frames.

WAVES A ground motion best described as vibration that is created or generated by a fault rupture. Earthquakes consist of a rapid succession of three wave types: the "P" or primary wave followed by both the "S" or secondary wave and a surface wave.

Measures of Earthquake Magnitude and Intensity

The following excerpt from the 1976 thesis, Seismic Design of a High-Rise Building, prepared by Jonathan Barnett and John Canatsoulis at the Worcester Polytechnic Institute explains the Richter magnitude scale and the Modified Mercalli Intensity (MMI) scale:

> There are two important earthquake parameters of interest to the structural engineer. They are an earthquake's magnitude and its intensity. The intensity is the apparent effect of an earthquake as experienced at a specific location. The magnitude is the amount of energy released by the earthquake. The magnitude is the easiest of these two parameters to measure as, unlike the intensity which can vary with location, the magnitude of a particular earthquake is constant. The most widely used scale to measure magnitude is the Richter magnitude scale. Using this scale, the magnitude, measured in ergs, can be found from the equation $\text{Log } E = 11.4 + 1.5\ M$, where M is the Richter magnitude.

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 structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious 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.

Masonry definitions, from C. F. Richter's 1958 book, *Elementary Seismology* (W. H. Freeman and Company, San Francisco, California), 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.

APPENDIX A

THE EARTHQUAKE EXPERIENCE AND ITS AFTERMATH

What an Earthquake Feels Like

For an idea of what an earthquake feels like, here are two accounts from occupants of a large modern office building--a "structure" not unlike a health care facility--in El Centro, California, that suffered severe, but not life-threatening damage, in the moderate earthquake of 1979 (Arnold et al., 1982):

> At the time of the earthquake I was convinced that the building was going to collapse and that I was going to die. Because of this feeling I felt it was unnecessary to get under my desk. When the shaking increased, I could no longer stand up and crawled under my desk. After the shaking stopped, I wondered if I could get down the stairway without being trampled to death. When I got out, I crossed the street, was counted and told to go home. I had no concept of time and was in a state of shock. I started walking home (I live 12 or 13 miles from work) and was found by my husband.
>
> -- *Second Floor Occupant*

> This was the most up and down earthquake that I have experienced. When I realized that the earthquake was not just another window rattler, I was seated at my desk. After several hard jolts, I felt as though I were falling through space before coming to a stop, still in my chair. I am certain that sensation was related to the building falling on that side. I then rose from my chair and staggered to my supervisor's office because there was a new wood door with no doorknob and I was afraid she would be trapped in her cubicle. Her office was about 10 feet behind my desk but the rolling motion made walking very difficult. I opened the door by flinging it against the wall and together we staggered back to my desk and the adjoining empty desk in the Social Services room where we crawled under the desk. I was under my desk for several more shocks and then the motion ceased. Someone said "let's get the hell out of here" so I grabbed my purse and lunch bag and walked the route we have practiced for bomb scares.
>
> -- *Third Floor Occupant*

The following accounts about the 1971 San Fernando earthquake are by the staff at a three-story hospital. At the time of the earthquake, there were 109 patients in the hospital. No one was injured, but the hospital suffered severe structure damage and was subsequently demolished and rebuilt. Here are the experiences of two of the nursing staff (Arnold and Durkin, 1983):

somewhere did not work, but she was able to grope and salvage some dressings. She also confirms the report that in the Nursery a nurse put three babies in each of two bassinets and stabilized them. Evidently the Emergency Room had not been badly damaged and it could be put into commission fairly quickly with a little bit of cleaning up (Figure A-1).

She mentioned that the night clerk in the hospital office had not typed up a census of those in the hospital, so one of their first activities after making rounds was to sit down and type up the census from reports from each of the floors. This was then used as a basis to designate where people were sent. When the pediatrics patients were moved to a house owned by the hospital, located across the street from the hospital, some of them had taken off their ID bands, and there was a tremendous problem in identifying the newborn infants.

FIGURE A-1
Emergency waiting room of Olive View Hospital after 1971 earthquake.

Finally, here is an account from the Director of Nursing at the same hospital; it shows some of the problems associated with building damage and evacuation (Arnold and Durkin, 1983):

> She was at her home preparing to leave for the morning shift. She proceeded to the hospital and arrived there at 6:45 a.m. Upon arriving she found the atmosphere chaotic. She quickly made rounds and found most of the patients were still in their rooms. She felt that the patients were somewhat apprehensive and indicated that a number of the patients did not want to be moved out of their rooms because they felt their medical care would be interrupted, and they would lose their doctor. The counseling of nursing staff convinced them that care would not be interrupted. She then went to Administration to meet with the administrator, where they concluded that evacuation of the nursing floors was necessary. At that time there were no elevators functioning, no electricity, and the condition of the hospital's oxygen supply was in question. Her initial feeling was one of disbelief. Some of the general areas of damage that she noted were: blown out windows; beds thrown

Appendix B

SEISMICITY OF THE UNITED STATES

Introduction

The U.S. Geological Survey (USGS) conducts the major national effort in earthquake-related studies in seismology, geology, and geophysics. At present, the USGS has identified nine areas in the United States as priority study areas:

- The Wasatch Front of Utah
- Puget Sound, Washington
- Anchorage, Alaska
- Southern California
- Northern California
- The central Mississippi Valley
- Charleston, South Carolina
- The northeastern United States including Massachusetts and New York
- Puerto Rico

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. Studies of seismicity provide answers to the questions where, how big, how often, and why earthquakes occur.

The remainder of this appendix features information on U.S. seismicity produced by S. T. Algermissen of the U.S. Geological Survey in 1983 and presented in a 1987 paper by Walter W. Hays of the U.S. Geological Survey, Reston, Virginia (the paper appears in its entirety in Volume 6 of *Abatement of Seismic Hazards to Lifelines: Proceedings of a Workshop on Development of an Action Plan* (FEMA Earthquake Hazard Reduction Series No. 31).

This seismicity information 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; the regional offices of the USGS and FEMA; the national earthquake information centers; and state and regional seismic safety organizations.

Terminology

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

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 (Bollinger, 1977). The distribution (number) of earthquakes with respect to MMI through 1976 in the southeast region is as follows: V = 133, VI = 70, VII = 10, VIII = 2, IX = 0, X = 1. Important earthquakes of the southeast region include:

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	Gadsden, 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, NC	VI-VII	
Oct. 18, 1916	Northeastern AL	VII	
July 8, 1926	Mitchell County, NC	VI-VII	
Nov. 2, 1928	Western NC		

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. The distribution (number) of historic earthquakes with respect to MMI in the western mountain region is as follows: V = 474, VI = 149, VII = 26, VIII = 22, IX = 0, X = 1. The important earthquakes of the western mountain region include:

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	Near Helena, MT (Aftershock)	VIII	6.0
Nov. 23, 1947	Southwest MT	VIII	
Aug. 18, 1959	West Yellowstone-Hegben Lake	X	7.1
Aug. 18, 1959	West Yellowstone-Hegben Lake (Aftershock)	VI	6.5
Aug. 18, 1959	West Yellowstone-Hegben Lake (Aftershock)	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

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 occurred in the region, the two 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. Currently, speculation is occurring over whether a great earthquake can occur as a consequence of the interaction of the Juan de Fuca and the North American tectonic plates. The distribution of earthquakes in the Washington and Oregon region is as follows: V = 1,263, VI = 487, VII = 170, VIII-IX = 2, IX = 8, IX-X = 3. The important earthquakes of Washington and Oregon include:

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	
Mar. 17, 1904	About 60 km NW of Seattle	VII	
Jan. 11, 1909	North of Seattle, near Washington/British Columbia border	VII	
Dec. 6, 1918	Vancouver Island, B.C.	VIII	7.0
Jan. 24, 1920	Straits of Georgia	VII	
July 16, 1936	Northern OR, near Freewater	VII	5.7
Nov. 13, 1939	NW of Olympia (depth of focus about 40 km)	VII	5.8
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	6.3
June 23, 1946	Vancouver Island	VIII	7.2
Apr. 13, 1949	Between Olympia and Tacoma (depth of focus about 70 km)	VIII	7.1
Apr. 29, 1965	Between Tacoma and Seattle (depth of focus about 59 km)	VIII	6.5

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). The distribution of earthquakes in terms of maximum MMI is as follows: V = 56, VI = 9, VII = 9, VIII = 3, IX= 1, X = 1. The important earthquakes causing significant damage in Hawaii include:

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

THE BSSC PROGRAM ON IMPROVED SEISMIC SAFETY PROVISIONS

Purpose of the Council

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:

- 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.

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 acknowledged that a careful assessment was needed.

Following the issuance of the *Tentative Provisions* in 1978, NBS released a technical note on the document 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 as its final submission to NSF. 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 predict 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 events significant for this effort were taking place. In October 1977, Congress passed the *Earthquake Hazards Reduction Act* (P.L. 95-124) and the National Earthquake Hazards Reduction Program (NEHRP) was released by the Administration on June 22, 1978. The concept of an independent agency to coordinate all emergency management functions at the federal level also was under discussion. When this concept was effected and FEMA was created, FEMA became the implementing agency with NSF retaining its research-support role. Thus, the future disposition of the *Tentative Provisions* and the 1978 NBS plan shifted from NSF to FEMA.

The emergence of FEMA as the agency responsible for implementation of P.L. 95-124 (as amended) and the NEHRP also required establishment of a mechanism for obtaining a 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 early 1979 with a broadly representative organizing meeting at which a charter and organizational rules and procedures were thoroughly debated and agreed upon.

The BSSC provided the mechanism--in essence the 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.

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 draft provisions reflected the initial amendments to the original ATC document as well as further refinements made by the Overview Committee. They represented an interim set of provisions pending their balloting by the BSSC member organizations, which began in July 1984.

The first ballot was conducted in accordance with the BSSC Charter and was organized on a chapter-by-chapter basis. 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 reservation" and "no" votes were compiled, and proposals for dealing with them were developed for consideration by the 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 in August 1985.

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 differences as possible. The 1985 Edition of the *NEHRP Recommended Provisions* then was transmitted to FEMA for publication in December 1985.

The BSSC's information dissemination efforts also provide for conduct of seismic mitigation demonstration projects. The goal of these activities is to enrich the ongoing information dissemination efforts by providing tangible examples of the willingness and ability of various political jurisdictions in targeted geographic areas to consider, adopt, and implement the *NEHRP Recommended Provisions*. The first such project, being conducted by The Citadel in Charleston, South Carolina, involves development, by the U.S. Geological Survey, of a site-specific seismic risk map of the area; formulation of a set of provisions for the most common types of buildings being and expected to be constructed in the area on the basis of the *NEHRP Recommended Provisions*; and use of the resources assembled to date by the BSSC and other seismic mitigation materials in a way that targets the specific needs of the community and stimulates action on the part of influential segments of that community. In September 1989, the BSSC received funding from FEMA to initiate a second demonstration project aimed at demonstrating the usability, practicability, and technical validity of the procedure in the "Appendix to Chapter 1" of the 1988 Edition of the *NEHRP Recommended Provisions* and to document the economic impact of its utilization.

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 30,000 publication requests were filled between December 1987 and April 1990, and this number is above and beyond those requests for BSSC documents directed to FEMA.

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 re-issuance in 1988 began in January 1986. During the update effort, nine BSSC Technical Committees were formed to focus on seismic risk maps, structural design, foundations, concrete, masonry, steel, wood, architectural/mechanical/electrical systems, and regulatory use. The Technical Committees (TCs) 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 Board to provide balance. It served as the effort coordinator and was charged to deal with global issues; to provide the continuing liaison between the TCs and the BSSC Board of Direction; to consider and respond to all comments and negative votes received as a result of the balloting for the 1988 Edition; and to prepare recommendations for resolving issues raised as a result of the balloting.

The TCs were composed of individuals nominated by organizations deemed by the BSSC Board to have both an interest and expertise in the various subjects to be addressed. When additional technical expertise was deemed necessary, the Board made additional appointments. Basically, the TCs were charged to consider new developments (e.g., newly issued standards) and experience data that had become available (e.g., as a result of the 1985 Mexico City earthquake) since issuance of the 1985 Edition of the *Provisions* as well as issues left unresolved when the 1985 Edition was published.

Improving the Seismic Safety of Existing Buildings

In October 1989, with funding from FEMA, the BSSC initiated a project to provide consensus-backed approval of publications on seismic hazard evaluation and strengthening techniques for existing buildings. This effort involves:

- Identifying and resolving major technical issues in ATC-22, *Handbook for Seismic Evaluation of Existing Buildings*, and a supporting engineering report on methodologies for the seismic evaluation of existing hazardous buildings prepared by the Applied Technology Council (ATC) and in *Techniques for Seismically Rehabilitating Existing Buildings (Preliminary)*, a report on procedures for seismically retrofitting existing buildings prepared by URS/John A. Blume and Associates, Engineers (URS/Blume);

- Revising the three documents as necessary for balloting by the BSSC membership;

- Balloting the three documents in accordance with the BSSC Charter;

- Assessing the ballot results, developing proposals to resolve the issues raised, and 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, the consensus project is being 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. Drafts of the subject documents were received in April 1989. By April 1990, the Retrofit of Existing Buildings Committee had met three times, each committee member had conducted a detailed review of the subject documents, and subcommittees had been established to address all the comments received as a result of this review. Once committee consensus on needed changes is achieved, the modified documents will be submitted to the BSSC membership for balloting.

Earlier, the BSSC was involved in a joint venture with the ATC and the Earthquake Engineering Research Institute to develop an action plan for reducing earthquake hazards to existing buildings and it was this action plan that prompted FEMA to fund development of the ATC and URS/Blume documents.

Following the workshop, the various participants further contributed to the agenda being developed by the panel or group to which they had been assigned and all the agendas were submitted to the BSSC Action Plan Committee in early 1987. They then were reviewed and refined and the final action plan document for FEMA was drafted and distributed once again to all workshop participants for comment. The final action plan report then was developed and transmitted to FEMA in May 1987. The workshop proceedings were published in six volumes--one covering each of the five lifeline categories and one covering political, social, economic, legal, and regulatory issues and including the general workshop presentations.

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 that should be taken during the next three to six years to initiate the program.

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