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Seismic Considerations—Elementary and Secondary Schools

EARTHQUAKE HAZARDS REDUCTION SERIES 34

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

BUILDING SEISMIC SAFETY COUNCIL

Program on Improved Seismic Safety Provisions

SEISMIC CONSIDERATIONS:

ELEMENTARY AND SECONDARY SCHOOLS

Revised Edition

This report was prepared under Contract EMW-C-0903 between the Federal Emergency Management Agency and the National Institute of Building Sciences.

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

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: Elementary and Secondary Schools* reflects the content of the 1988 Edition of the *Provisions*.

Special thanks are due to Christopher Arnold, Building Systems Development, Inc., San Mateo, California, and Earle Kennett, Kennett/Nanita Associates, Gaithersburg, Maryland, 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., and Earle Kennett of Kennett/Nanita Associates for their 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.

CONTENTS

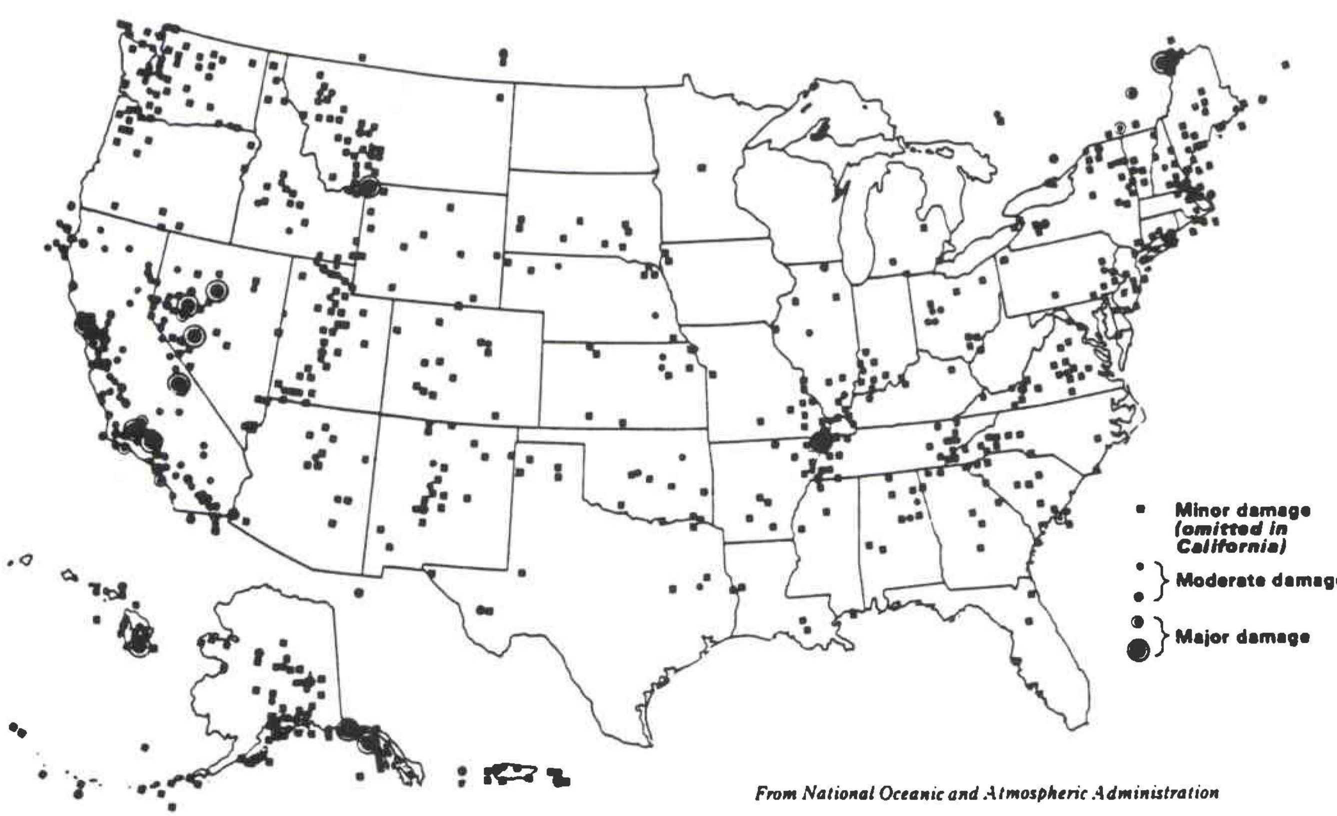
OVERVIEW

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

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. In the case of a $3,000,000 school, for example, seismic design would add only about $37,500 to the construction cost--an amount that would have to be invested at 13 percent per year for 25 years to provide sufficient funds to pay for typical earthquake damage.

California's Experience

Experience has shown that seismic design for school buildings pays off. A large number of California school buildings have been constructed to comply with the *Field Act* of 1933--an act that has set stringent seismic requirements for school facility design and construction. Since the *Field Act* was implemented, school buildings in California have been tested in a number of earthquakes, and, to date, no students or teachers have been killed or injured in a post-*Field Act* school building during an earthquake.

The damaging Kern County earthquakes of 1952 involved one earthquake of Richter magnitude 7.6 followed a month later by one of magnitude 5.8. Of the 40 area schools constructed prior to the *Field Act*, 40 percent suffered severe damage, 33 percent suffered moderate damage, 25 percent suffered slight damage, and 2 percent had no damage. Of the 18 schools constructed in accord with the *Field Act*, 61 percent had no damage, 33 percent suffered slight damage, and only 6 percent had moderate damage. The 6.7 magnitude earthquake in Coalinga in 1983 and the 5.9 magnitude earthquake in Whittier Narrows in 1987 tended to confirm the adequacy of *Field Act* structural requirements in that damage to *Field Act* schools, while not insignificant, was almost completely nonstructural. In the 1989 Loma Prieta earthquake, of the 1,544 public schools surveyed in the impacted area, only three suffered serious damage and there were no casualties. The fact that some non-life-threatening damage is suffered by *Field Act* schools tends to indicate that the requirements are not too restrictive, but emphasizes the need for attention to nonstructural elements and building contents.

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 elementary and secondary school 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 elementary and secondary schools 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 ELEMENTARY AND SECONDARY SCHOOL DECISION-MAKERS

1

EARTHQUAKES AND SCHOOLS

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.

Schools Pose Special Earthquake Problems

This situation is especially critical with respect to elementary and secondary schools. Although school 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:

- The occupancy of elementary and secondary schools by society's most precious resource, its children, is required by law and, therefore, the moral and legal responsibility for properly protecting occupants is very great. The occupancy density also is one of the highest of any building type (1 person per 20 square feet) and, after an earthquake, the children are very likely to be frightened, which can make emergency egress difficult at best and virtually impossible if the structure is badly damaged.

- Schools often are very complex facilities featuring both relatively small classrooms, laboratories, and offices and large assembly areas.

Thus, during the next 10 years, an astonishing 50 percent of existing school buildings will be between 40 and 80 years old. This aging school facility inventory presents a unique seismic problem since, even in California, seismic design of schools started only in 1934. In other areas of the country at risk from earthquakes, seismic design remains a rare occurrence even today.

The need to replace aging school facilities and the major regional migrations that are causing increased school enrollment in some areas suggest that there will be a resurgence of school building construction and, in fact, there is already strong evidence of such an increase on a national scale. This opportunity to protect the nation's children from seismic hazards by applying seismic design in the construction of new school facilities in much the same way that they are protected from fire and other hazards by higher standards of safety should not be missed.

2

SEISMIC HAZARD MITIGATION AND THE COST/BENEFITS OF SEISMIC DESIGN

Need for Local Seismic Hazard Assessment

Those responsible for elementary and secondary schools 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 elementary and secondary schools 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. (Appendix A presents a review of the California experience with seismic-resistant school design that illustrates just how great a difference it can make.)

Life Safety Considerations

School 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 students, faculty, 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 school facilities provide an essential community service and are expensive to build and operate, 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 school 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--For a typical school, the structural system usually represents between 10 and 15 percent of the building cost.

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

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

The average increase in cost of school 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 an elementary school, for example, is only about 50 percent of the total project cost, which also includes technical expenses, administrative expenses, land cost, and site development. The cost of equipping a modern school 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.

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

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

In addition, although they cannot yet be quantified, liability risks must be considered by school boards and others responsible for schools. Few data are available that reflect the magnitude of the risks that educational facility decision-makers face in terms of liability for casualties incurred in their buildings during an earthquake, but this will almost certainly be decided by the courts after the next earthquake that causes life loss. As soon as the earthquake threat is identified and means of reducing its effect are documented, the school that makes no reasonable provision for seismic design will be in a very tenuous legal situation when the earthquake occurs.

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

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

PART II

SEISMIC CONSIDERATIONS FOR SCHOOL DESIGNERS

3

EARTHQUAKE DESIGN PROBLEMS OF ELEMENTARY AND SECONDARY SCHOOLS

School Building Inventory

There are over 80,000 elementary and approximately 30,000 secondary schools in the United States. The post World War II "baby boom" caused major school construction during the 1950s and 1960s followed, in the 1970s and early 1980s, by major declines in school construction and large numbers of school closings. Since about 1985 there has been an increase in school construction due to the obsolescence of older facilities, internal migration from the Northeast to the West and Sun-belt states, new foreign immigrations, and a slight increase in school age populations.

In 1983, schools accounted for approximately 6,000 million square feet of space or almost 12 percent of the total nonresidential space in the nation. At the same time, schools are estimated to represent only 4.5 percent of the actual number of nonresidential buildings, meaning that they account for a very significant amount of square footage per building. In addition, only assembly buildings, which provide 14 square feet of space per person, have a higher occupancy density than schools, which provide 20 square feet per person. (For comparison, note that the occupant density of office buildings is 100 square feet per person and of lodging, health care, and retail facilities is 50 square feet.)

The age of a facility is of considerable importance with respect to seismic performance and, as indicated earlier, fully half of the nation's existing schools will be between 40 and 80 years old by the end of the century. Even in California, seismic design based on analysis only dates back about 50 years. Even buildings constructed as late as the early 1970s may have major seismic deficiencies. This is because of discoveries made through study of the performance of buildings in earthquakes in the 1960s and early 1970s (notably Alaska, 1964; Caracas, Venezuela, 1967; San Fernando, California, and Managua, Nicaragua, 1971). These earthquakes were the first to test modern methods of construction and, as a result, seismic codes and construction practices have improved since the 1970s.

Although this publication is not intended to be an engineering design manual, several problems of building design should be recognized by the school owner, administrator, planner, architect, or engineer as factors that may substantially increase the earthquake risk to their building. Some of these problems are addressed in seismic building codes, but their solutions reside more in the designer's understanding of seismic-resistant design than in specific code provisions. Others, such as damage to building contents, are outside the scope of any seismic code.

A common building form that presents seismic design problems is that of the "re-entrant corner." The re-entrant corner is the common characteristic of overall building configurations that, in plan, assume the shape of an L, T, U, H, +, or a combination of these shapes (Figure 4). These building shapes permit large plan areas to be accommodated in relatively compact form while still providing a high percentage of perimeter rooms with access to air and light. Because of these characteristics, they are commonly used in school design. These configurations are so common and familiar that the fact that they represent one of the most difficult problem areas in seismic design may seem surprising, but examples of earthquake damage to re-entrant corner type buildings are common. First noted before the turn of the century, this earthquake problem was generally acknowledged by the experts of the day in the 1920s.

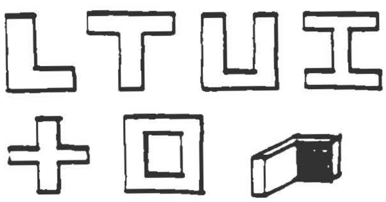


FIGURE 4
Re-entrant corner plan forms.

These shapes tend to produce variations of rigidity and, hence, differential motions between different portions of the building that result in a local stress concentration at the "notch" or re-entrant corner (Figure 5a). In addition, the wings of a re-entrant corner building often are of different heights so that the vertical discontinuity of a setback in elevation is combined with the horizontal discontinuity of the re-entrant corner in plan, resulting in an even more serious problem. The setback form--a tower on a base or a building with "steps" in elevation--also has intrinsic seismic problems that are analogous to those of the re-entrant corner form. The different parts of the building vibrate at different rates, and where the setbacks occur, a "notch" is created that results in stress concentration (Figure 5b).

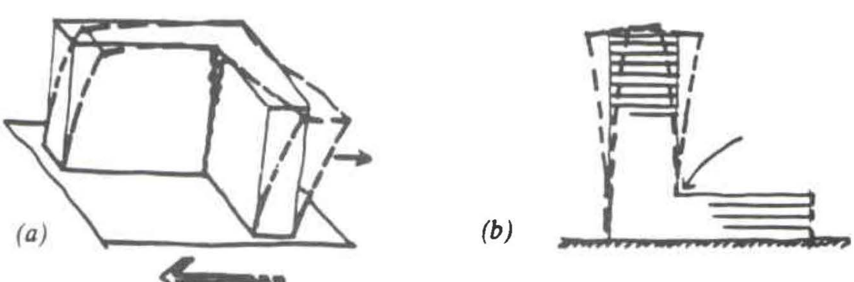
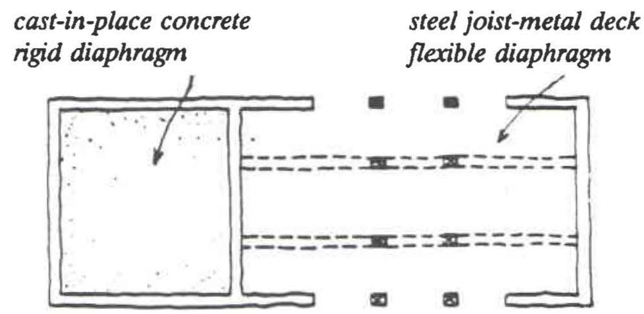


FIGURE 5
(a) movement of L-shaped building under ground motion and (b) point of stress concentration in setback building.

Structural Discontinuities

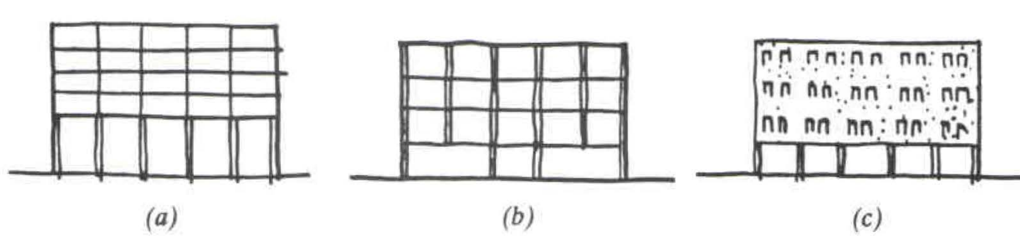
It is not generally recognized that large discontinuities (or abrupt changes) in the strength (Figure 7) or stiffness of a building can cause adverse seismic response effects. This is particularly the case where there are abrupt changes in the vertical arrangement of the structure that result in discontinuities (changes) of strength or stiffness from floor to floor.

FIGURE 7
Discontinuity in strength.



The most prominent of the problems caused by such a discontinuity is that of the "soft" first story (Figure 8), 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 8
"Soft" first story: (a) tall, flexible columns, (b) interrupted vertical columns, and (c) heavy superstructure over slender frame.



Three typical conditions create a "soft" story:

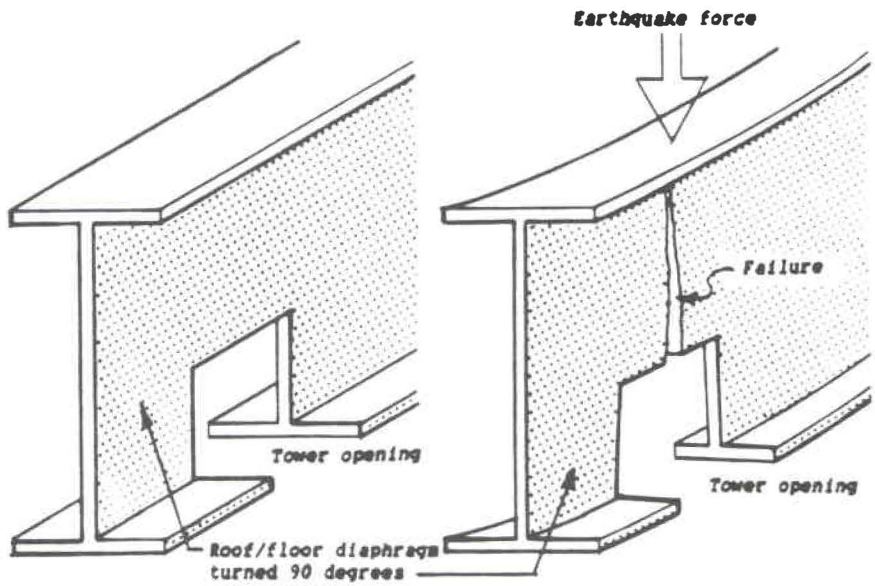
- The first occurs when there is a significant discontinuity of strength and stiffness between the vertical structure of one floor and the remainder of the structure. This discontinuity may occur because one floor, generally the first, is significantly taller than the remainder, resulting in decreased stiffness (Figure 8a).

- Discontinuity also may occur when some vertical framing elements are not brought down to the foundation but are stopped at the second floor to increase the openness at ground level. This condition creates a discontinuous load path resulting in an abrupt change of strength and stiffness at the point of change (Figure 8b).

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 11).

FIGURE 11
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.

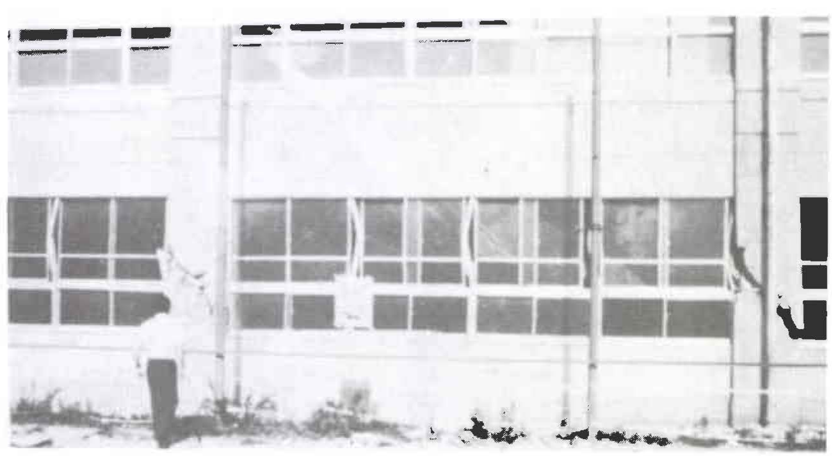
Displacement and Drift

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.

The use of infill walls dramatically shortened the columns at the Recido School in Managua, Nicaragua (Figure 13). During the 1973 earthquake, the columns above the infill walls suffered extensive damage and barely escaped complete failure and roof collapse. Numerous other examples of damage attributed to such "shortened" columns were reported in Japanese schools following earthquakes in 1968 and 1978 (Figure 14).

FIGURE 13
Recido School after 1973 earthquake.

FIGURE 14
Japanese school building after 1978 earthquake.



Furthermore, properly designed structural elements are usually ductile--i.e., their failure is preceded by large permanent deformations that dissipate a considerable amount of energy. On the other hand, connections often are relatively brittle. Therefore, a good structural design requires connections to be stronger than the members they connect so as to force failure to take place in the ductile members rather than in the relatively brittle connections.

A structural element cannot transmit forces in excess of the capacity of the connections used to join the elements together. Thus, structural members and the elements that connect them should be of approximately equal strength to be fully effective. If there is a weak link, the earthquake will find it.

The issue of connections is particularly important for structures that rely on a small number of supporting members, such as a roof supported by four columns. If one column or its connection fails, the roof falls. If the same roof is supported by eight columns, the loss of one column may not be serious. Engineers refer to the attribute of having more than the minimum number of structural members as "redundancy." It provides an important additional safety factor.

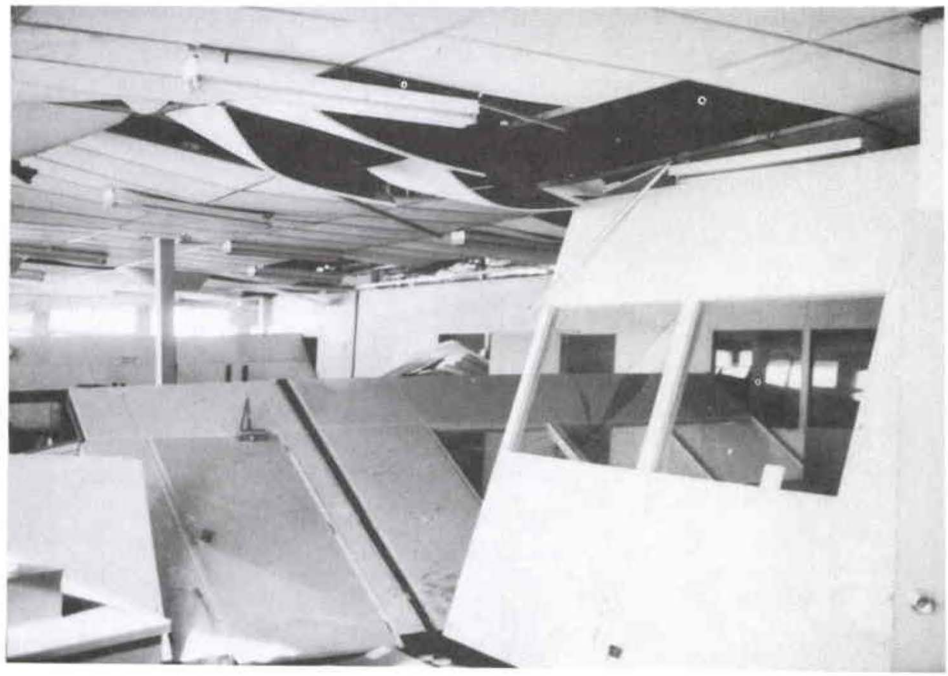
The large open spaces common in schools often completely lack redundancy which means that every component must remain operative to ensure the integrity of the structural system under lateral loads. Thus, appropriate connections should be used and consideration should be given to the use of higher performance connections (ductile, in particular).

A public school in Melipilla, Chile, suffered severe structural and architectural damage during a 1985 earthquake (Figure 17) because the masonry facade was not properly anchored to the structural system. Collapse occurred and classrooms were showered with glass and ceiling light fixtures. Many schools of similar design also were significantly damaged in the earthquake.

Redundant characteristics can be obtained by providing several different types of seismic-resisting systems in a building; however, the designer must be careful to consider the relative stiffness and strength of the various systems in order to avoid problems. Redundancy also can be provided by increasing the number of elements (columns, shear walls), adding new elements (cross frames, bracing), or modifying some elements (increasing reinforcement and anchoring the framing to change interior nonstructural walls and panels into shear walls).

In a moment resisting frame system, redundancy can be achieved by making all joints of the vertical load-carrying frame moment resisting. Of course, proper ductility must be provided in the members of the structural system. These multiple points of resistance can prevent a catastrophic collapse due to failure of a member or joint. However, if this system is designed with the moment resisting connections limited to exterior columns (a common practice) clad only in lightweight architectural curtain walls, the building may experience large deformations during an earthquake and, consequently, a great deal of interior damage.

FIGURE 18
Collapse of interior structural partitions.



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. For example, the Bay Area Regional Earthquake Preparedness Project reports that the 1983 6.5 magnitude Coalinga, California, earthquake resulted in nonstructural damage totalling $2 million and that the 1987 5.9 magnitude Whittier Narrows, California, earthquake caused almost $16 million of damage, most of which was nonstructural. 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 educational facility construction cost; therefore, the nonstructural architectural, mechanical, and electrical elements make up between 75 and 85 percent of the building's replacement value.

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). School occupants will be particularly vulnerable to nonstructural damage. Although school children may duck under desks and be safe from falling objects like light fixtures or glass, 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.

Free-standing kitchen equipment and electrical equipment such as transformers, switchboards, emergency generators, and lighting fixtures can fall, causing injuries as well as fires (Figures 20-21).

FIGURE 20
Electrical equipment collapse.

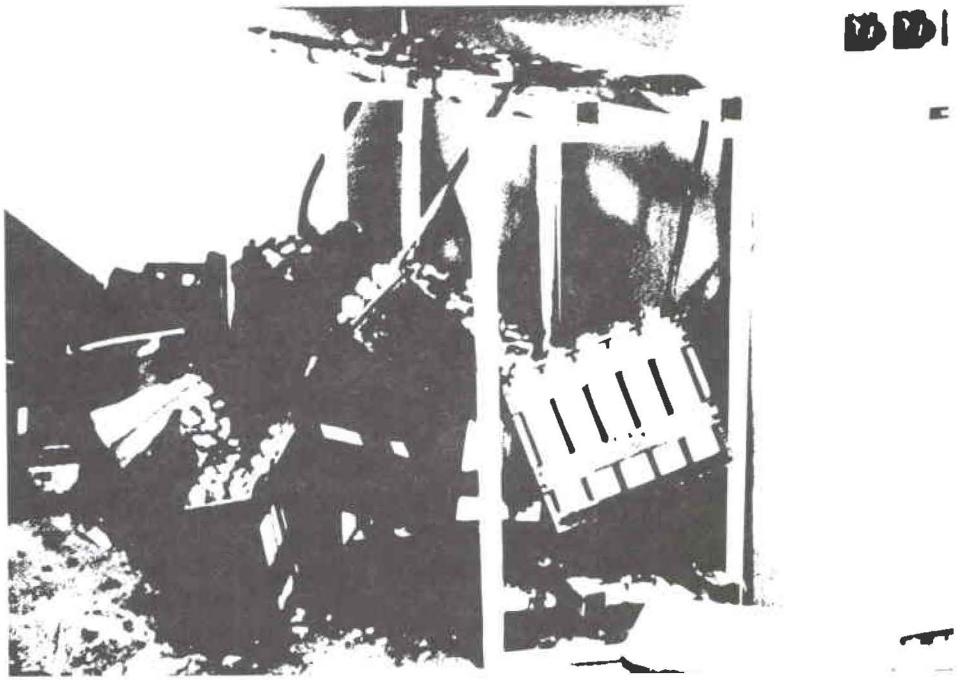


FIGURE 21
Ceiling/lighting system collapse.

Heating equipment located on roofs or hung in open spaces such as gymnasiums and auditoriums or service areas such as shops and kitchens 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 (Figure 22).

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.

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.

The problems of egress are most critical in multistory buildings and therefore, tend to apply to larger schools. Stairs are the critical means of egress out of a multistory school during and after an earthquake, but several things can happen to stairwells during an earthquake:

- Stairs tend to act as diagonal bracing between floors, and damaging loads and racking induced in them by interstory drift may result in collapse or failure.

- Stairs usually are anchored to the floors and their stiffness tends to attract forces that may cause severe damage or collapse (Figure 24).

- Masonry or concrete fire walls surrounding the stairs can fracture leaving the egress pathway littered with debris that may be impassable.

Experience indicates that doors and frames often jam in earthquakes and cannot be opened (especially by children). Heavy fire doors leading to egress routes are especially vulnerable because fire safety regulations require a heavy and tight assembly that becomes immovable when the door frame is distorted by earthquake motion.

Safe, direct, unobstructed exit routes should be planned so students and teachers can safely exit a school. Lockers, ceiling systems, lighting systems, ventilation systems, and windows that enclose these routes must be designed as critical components and be located so that their failure will not impede egress (Figure 25).

Disruption of Post-earthquake Operations

School buildings are often viewed by the community as local refuge, collection, or safe areas after a major disaster. This function may be formally recognized in a disaster response plan or the school may just be seen this way by neighborhood residents. And, of course, parents will want to ascertain that their children are safe as soon as possible after an earthquake. Thus, many people can be expected to converge on neighborhood schools searching for information, medical attention, or safe refuge during major power failure and inclement weather.

Disruption of regular or emergency operations can occur after an earthquake due to avoidable property damage. Some of the less critical elements (in terms of life safety and therefore codes) can cause inordinate amounts of delay in using the school as a safe refuge. Examples of these are mechanical, power, and communications system (public address or telecommunications) failure and lighting and ceiling collapse. Such damage can be minimized by designing to appropriate seismic provisions, which will save the public large sums in replacement costs.

Conclusion

The kinds of problems outlined above all stem from lack of attention to the seismic problem during design. While, as noted, design to a seismic code cannot guarantee freedom from seismic problems, adherence to such a code will ensure a basic level of safety that is difficult to obtain in any other way. Beyond the mandated requirements of a code, which set a minimum rather than a preferred standard of seismic design, the very act of designing to a seismic code requires a rational approach to design that focuses attention on those seismic issues discussed above which are not dealt with directly in code provisions.

The next chapter discusses the ways in which the *NEHRP Recommended Provisions* in particular and understanding of seismic design issues in general can work to protect elementary and secondary schools against these problems.

4

THE NEHRP RECOMMENDED PROVISIONS AND SCHOOL 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 elementary and secondary schools. 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 26 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). Schools 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
$0.20 \le A_v$	D	D	E
$0.15 \le A_v < 0.20$	C	D	D
$0.10 \le A_v < 0.15$	C	C	C
$0.05 \le A_v < 0.10$	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 26), school buildings will belong to Seismic Performance Category A, B, C, or D (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.

Building Occupancy

Building code occupancy classifications historically have been based on the potential hazards associated with fire. Because of the characteristics of the earthquake problem, a specific occupancy classification is necessary. The approach in the *NEHRP Recommended Provisions* defines occupancy exposure to seismic hazards based on, but not limited to, the following:

- The typical number, age, and condition of the occupants within the building type and its immediate environs;
- The typical size, height, and area of the building type;
- The spacing of the building type in relation to public rights-of-way; and
- The degree of built-in or brought-in hazards based on the typical use of the building type.

These groupings allow for increased seismic performance requirements to be used for specific buildings when deemed necessary.

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, schools are assigned to Group II.

Building Configuration

One set of decisions most critical to the ability of a school 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 28).

Elevator cores and staircases can be designed as lightweight framed elements or detached from the surrounding structure so that they do not provide unwanted stiffness in the wrong location. Of course, a correctly designed and located core also may be effectively used as a major resistance element.

The conceptual design must be evaluated for its ability to provide balanced seismic resistance or for the possibility that unbalanced resistance or discontinuity may be inherent in the design. If found at an early conceptual stage (and it is quite easy to determine at this design stage), such a problem can be eliminated easily by modifying the structural/architectural design.

Based on the building's occupancy type and seismicity, the *NEHRP Recommended Provisions* requires that consideration be given to the potentially adverse effects that can occur when the ratio of the strength provided in any part of the building to the strength required is significantly less than that ratio for an adjacent part (i.e., where one part is weaker than another). This requirement is one way of ensuring balanced resistance throughout the building.

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.

Building Materials

There are noticeable differences in the types and extent of earthquake damage observed in relation to different structural materials. As was shown by the 1987 Whittier Narrows and the 1989 Loma Prieta earthquakes as well as many earlier earthquakes, buildings constructed of unreinforced masonry perform poorly and are especially vulnerable. Buildings with steel or wood structural systems that can deform considerably before failing have a basic structural advantage, but they have suffered severe damage or failure when the elements have not been connected adequately. The combination of inherently brittle materials (masonry or concrete) with properly designed and fabricated reinforcement has led to buildings that have performed very well in earthquakes. Although the inherent properties of the structural material is important, the performance of the building depends to a great extent on the quality of the design, the detailing, and the construction. Properly executed, any combination of materials, with the exception of unreinforced masonry, can provide good seismic performance.

Steel buildings, particularly those designed according to modern seismic code requirements, generally have performed well in severe earthquakes. The structural damage that has occurred usually has involved localized failures in structural elements that creates distortion but seldom leads to collapse. However, flexible moment frames that have performed well structurally often have resulted in considerable nonstructural and contents damage, thus pointing toward the use of dual systems. 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.

Science laboratories should be designed to protect occupants from falling heavy equipment and hazardous chemicals should be stored so that they do not fall from shelves or spill. Industrial or vocational areas should be designed to be safe by anchoring and restraining all heavy, stationary equipment. Kitchen, chemistry, and shop hoods must be properly designed and anchored to resist falling. Canopies at exits should be checked to ensure that they will not collapse, and exit routes should not adjoin exterior glass areas. The safety of staff in mechanical rooms should be evaluated and precautions taken.

FIGURE 30
Overturned book stacks.

FIGURE 31
Sylmar High School after 1971 San Fernando earthquake.

There were gas leakages in a number of schools, but no fires resulted. In the third-floor lab at the high school, cupboard doors flew open and chemicals spilled to the floor; they reacted with each other and burned through to the first floor. Noxious fumes--hydrogen sulfide among them--from the spilled chemicals permeated the building. Latches on file cabinet drawers did not hold and drawers "flew across the room."

Bookcases, free-standing cabinets, and shelving fell. Movie screens and maps became projectiles. Storage cabinets attached to walls with molly bolts fell over.

The 5.9 magnitude earthquake that shook areas of East Los Angeles, Whittier, and Rosemead on October 1, 1987, also struck when schools were not in session. At 7:42 a.m., no students and only a few staff members were in the approximately 100 school buildings that sustained damages. Damages in K-12 public school buildings, most of which were nonstructural, accounted for $16 million in losses. The majority of the damage to public schools consisted of cracking in plaster walls or other finish materials that were installed previous to more stringent code requirements, or failure of light fixture supports, suspended ceilings, and duct work either not designed or not constructed according to current codes. Broken window and skylight glass was substantial at a number of schools. Water and gas lines were ruptured in some places but no fires ensued. At California State University, Los Angeles, chemicals spilled and caused a fire, creating toxic fumes. Buildings had to be closed and clean-up operations took several days. Free-standing library shelves at Cal State LA swayed and buckled, and books were damaged or strewn about. Unreinforced masonry incinerator chimneys failed at several schools. Pockets of encapsulated asbestos were dislodged by earthquake shaking at some public schools, releasing airborne fibers into ventilation systems.

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 elementary and secondary schools that should be given special design attention include:

Appendages	Entrance canopies, overhangs, and 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

- 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 of being 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 $\log E = 11.4 + 1.5 M$, 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

EARTHQUAKE EXPERIENCES OF CALIFORNIA SCHOOLS

Stimulus for the Field Act

Although the magnitude of the earthquake that occurred in 1933 in Long Beach, California, was moderate (6.3), the damage to buildings was widespread. One of the occupancies to suffer the worst were the public schools (Figure A-1). Within seconds, an estimated 75 percent of the public school buildings were heavily damaged and many collapsed. It was readily apparent to responsible public officials that a horrifying number of students and teachers would have been killed and injured if the earthquake had occurred during regular school hours.

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

The California legislation stimulated by the Long Beach earthquake, the *Field Act*, became effective as an emergency measure one month after the earthquake. In creating this unprecedented legislation in a hurry, the drafters modeled their act on the *State Dam Safety Act*, which had been stimulated by a dam collapse in 1929. The *Field Act* applied only to the design and construction of public school buildings used for elementary, secondary, or community college purposes; private schools, the state college system, and the University of California campuses were not involved. Thus, the act related to facilities at which attendance was compulsory (with the exception of community colleges).

The act's principal provisions require that all construction plans be prepared by qualified persons (architects or structural engineers) and that the designs be checked by an independent state agency, which was identified as the Structural Safety Section of the Office of the State Architect. The plan checking is financed by fees, based on the cost of construction, charged against school districts submitting plans for approval.

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

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

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

Results

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

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

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

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

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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