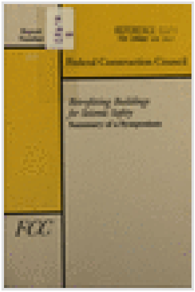

Retrofitting Buildings for Seismic Safety: Summary of a Symposium (1991)

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PREFACE

This report comprises papers and summaries of papers presented at a symposium held in November 1990 at the National Academy of Sciences in Washington, D.C. The symposium was organized by the Federal Construction Council Consulting Committee on Civil and Structural Engineering to help federal agencies understand seismic risks, share information on solving seismic safety problems, and establish seismic retrofit programs in support of the decade of natural disaster reduction.

The need for the symposium was revealed in a survey conducted by the committee in 1989 to determine the policies and practices of federal agencies on retrofitting buildings for seismic safety. The survey disclosed that while some agencies have initiated comprehensive programs to identify and correct deficiencies in the earthquake resistance of existing buildings, other agencies have done relatively little. The committee concluded that some federal agencies--like many state and local government agencies and private corporations--might be unaware of the nature and magnitude of the risks associated with inaction or uncertain about how best to proceed.

The papers included in the report were prepared by the speakers themselves.

INTRODUCTORY REMARKS

James R. Hill
Department of Energy

The Federal Construction Council Symposium on Retrofitting Buildings for Seismic Safety is one of the 1990 events that marks the entry of the United States into the International Decade for Natural Disaster Reduction. The retrofitting of existing buildings will be an important element in realizing the goals of the decade. Those involved in planning the symposium have put together an outstanding program of major speakers from a cross-section of organizations involved with earthquake hazards as well as key representatives from agencies who make up the Consulting Committee on Civil and Structural Engineering.

The first group of speakers discusses earthquake hazards, threats to existing buildings, methods for making fixes, and federal requirements. The second group shows examples of retrofit innovations that date back over 20 years and tell how the fixes were made efficiently and economically.

True, much has been done, yet much more remains. I believe that past retrofitting resulted because of commitments made by individuals and organizations. The stage is set and the need exists for retrofit; however, it will take a personal and professional commitment to get involved. You need to provide retrofit leadership within your agency to make the goals of the decade a reality. Let's focus on those goals. The results of our efforts can save lives and reduce property loss for us and future generations.

THE EARTHQUAKE HAZARD IN THE UNITED STATES

Walter W. Hays
U.S. Geological Survey

ABSTRACT

The Loma Prieta earthquake, which struck the northern California region on October 17, 1989, reminded the nation that individual earthquakes pose the greatest threat of any natural hazard in terms of societal impacts, economic loss, and potential loss of life. To counteract this threat and the threat from other natural hazards, the United States will lead a cooperative worldwide program during the 1990s, called the International Decade for Natural Disaster Reduction (IDNDR). The goal is to reduce the risk from earthquakes, floods, windstorms, landslides, volcanic eruptions, tsunamis, and wildfires. The IDNDR will call for: increased awareness and education concerning natural hazards; research to deepen understandings; natural hazard and risk assessment; preparedness for emergency response, recovery, and reconstruction; prediction and warning; and implementation of mitigation measures through improved siting, design, and construction practices. The goal is to make the nation safer from all natural hazards.

INTRODUCTION

An earthquake, the sudden motion or trembling of the earth, is caused by an abrupt release of slowly accumulating strain energy in the earth's crust. This energy is released on active fault systems (e.g., the San Andreas fault zone in California, which was the source of the 1989 Loma Prieta earthquake) or on seismotectonic structures (e.g., the New Madrid seismic zone, which was the source of three great earthquakes in 1811-1812).

The nation has more than 100 seismogenic zones that have generated earthquakes in the past and that will generate earthquakes in the future as a function of their seismic cycle. When a fault breaks or ruptures, seismic waves are propagated in all directions from the earthquake source. As the compressional (P), shear (S), Love, and Rayleigh waves impinge upon the surface of the earth, they cause the ground to vibrate at frequencies ranging from about 0.1 to 20 Hertz (0.05-10 seconds). Depending on their geometries and the period range properties of the underlying or enclosing soils, buildings and lifeline systems are induced to vibrate up and down and side to side as a consequence of the amplitude, frequency compositions, and duration of the ground shaking. Damage results when the buildings or lifeline systems are not designed and constructed to withstand the elastic and inelastic forces triggered by the vibrations of the P, S, Love, and Rayleigh waves.

The well-being of a community requires that its essential buildings and lifeline system be sited, designed, and constructed so that they continue to function after a damaging earthquake. Lifeline systems include energy (electricity, gas, liquid fuel, steam), water (potable, flood, sewage and solid waste, fire-fighting water), transportation (highways, bridges, railways, airports, harbors, transit), and communications (telephone, telegraph, radio, television, telecommunications, mail, press). These systems, which collectively provide the essential functions of supply, disposal, transportation, and communication required by a community, are potentially vulnerable from both permanent ground displacements and ground shaking, unless appropriate siting, design, and construction practices are followed.

Permanent ground displacement (surface fault rupture, liquefaction, landsliding, lateral spreading, compaction, regional tectonic deformation) are more important in the design of buried lifeline systems than the effects of ground shaking; however, dynamic ground shaking is more important for the design of buildings and lifeline system components above ground.

THE LOMA PRIETA, CALIFORNIA, EARTHQUAKE

At 5:04 p.s.t. on Tuesday, October 17, 1989, a magnitude 7.1 earthquake struck northern California. impacting dwellings, buildings, and lifeline systems. The Loma Prieta earthquake, which occurred on the San Andreas fault system, had its epicenter in the Santa Cruz mountains about 70 miles south of San Francisco (U.S. Geological Survey, 1989, and Earthquake Engineering Research Institute and National Research Council, 1989). The preliminary estimates of the economic impacts, deaths and injuries were:

- at least $8.3 billion in direct losses.
- 62 confirmed dead, with 41 deaths attributed to the collapse of the Cypress Street structure of the Nimitz Freeway in Oakland, California; and
- 3,757 injured.

The Loma Prieta earthquake generated strong ground shaking and permanent ground displacements over a wide area. The level of ground shaking reached 64 percent g in the epicentral region and 10 to 30 percent g in San Francisco and Oakland, depending on whether the underlying site geology was rock or bay mud. The level of peak ground acceleration at sites underlain by bay mud or soft alluvium was higher than that observed at rock sites by a factor of about 2.50. Numerous landslides occurred, especially in the epicentral region. Liquefaction was triggered at locations underlain by unengineered fill as far as 70 miles from the epicenter. Amplification of ground shaking (from the bay mud and soft alluvium) and liquefaction of unengineered fill contributed to damage to underground utilities, dwellings, buildings, and transportation structures.

The magnitude 7.1 Loma Prieta earthquake brought to memory the December 7, 1988, Spitak earthquake in Armenia, which, although about one-half the former's size (Ms = 6.8), caused an estimated 25,000 deaths and 18,000 injuries. Reconstruction costs for the Spitak earthquake are estimated to reach $16 billion (Earthquake Engineering Research Institute, 1989).

The difference in impacts between the Loma Prieta and Spitak earthquakes is related directly to differences in earthquake preparedness and mitigation measures in American and Soviet communities located in design, and construction practices during the past two decades in the San Francisco Bay region kept buildings from collapsing in the Loma Prieta earthquake, thereby saving many lives.

ASSESSMENT OF EARTHQUAKE HAZARDS AND RISK

An assessment of the earthquake hazards (physical phenomena accompanying an earthquake) and risk (chance of loss from these phenomena) is a complex task (Figures 1-5)[1] requiring multidisciplinary investigations on national, regional, urban, and site-specific scales (Figure 1). Hazard investigations are designed to assess the location, severity, and, to the extent possible, the frequency of occurrences of physical effects (Figure 2).

The following questions are typical in earthquake hazard investigations:

- Where have earthquakes happened in the past (Figure 4)?
- What levels of ground shaking and permanent ground displacements were triggered in past earthquakes?
- What levels of ground shaking are expected to be triggered in future earthquakes (Figure 5)?
- How frequently on the average do earthquakes capable of generating strong ground shaking and permanent ground failures occur?

The following questions are typical in seismic risk investigations:

- What kinds of damage will ground shaking and permanent ground failure cause to the buildings, facilities, and lifeline systems that are at risk in a community?
- What have communities done to control damage, deaths, injuries, economic loss, and loss of function from ground shaking and permanent ground failure (Figure 6)?
- What societal, scientific, and technical actions will reduce the vulnerability of existing buildings and lifeline systems in each community?

---

[1]Figures are at the end of the paper.

- What is the risk from secondary hazards such as seiches, fire, flooding from dam failure, and aftershocks?

Assessment of the record of historical seismicity (see Appendix A) is an important element of these investigations. By analyzing the geologic, geophysical, seismological, and engineering data, realistic assessments can be made of the potential severity and spatial extent of ground shaking and permanent ground displacements.

When the spatial and temporal characteristics of the physical effects are fully integrated with a community's inventory of buildings, facilities, and lifeline systems, the risk can be determined (Figure 3). Realistic loss-reduction measures can then be adopted and enforced through siting, design, and construction practices.

Peak ground acceleration, response spectra (spectral acceleration, velocity, and displacement), and duration are the parameters used most frequently to characterize ground motion for earthquake-resistant design. Design spectra are broadband and adjusted for local soil conditions. They can be either site independent (applicable for sites having a wide range of local geologic and seismologic conditions) or site dependent (applicable to a particular site having specific geologic and seismological conditions). The elastic response spectra typically are anchored at the "zero period" to a value of ground acceleration, which is typically a reduced value of the maximum Modified Mercalli Intensity used when instrumental ground-motion data are not available. Under certain conditions the structure or lifeline can modify the ground motion through the phenomenon of soil structure or soil-lifeline interaction.

The spatial distribution of horizontal and vertical ground motions is a very important consideration when designing lifeline systems. Also, values of the spectral velocity and displacement are more important than values of spectral acceleration for long linear lifelines, such as long bridges and pipelines. The depth dependency of ground motion also can be an important design parameter because subsurface locations require lower design levels than surface locations.

THE INTERNATIONAL DECADE FOR NATURAL DISASTER REDUCTION

On December 22, 1989, the United States joined with 155 nations to approve a resolution at the 44th General Assembly of the United States naming the 1990s as the IDNDR. The goal is for each nation to develop a hazard-reduction program and all nations to work cooperatively in reducing loss of life and economic impacts from natural hazards throughout the world. These hazards--earthquakes, floods, severe windstorms, drought, landslides, volcanic eruptions, tsunamis, and wildfires--are currently causing annual losses of $17 billion in the United States (Hays, 1981 and 1990) and losses that are many times greater throughout the world.

The United States will have a program for the IDNDR that calls for

- increased awareness and education;
- research to deepen insight on the physical and social nature of natural hazards;
- Assessments of hazard and risk on national, regional, and urban scales;
- Improved preparedness, prediction, and mitigation; and
- Implementation of mitigation measures through improved practices in siting, design, and construction.

The United States program will emphasize three strategies: (1) anticipation rather than just reaction to disasters (e.g., an emphasis on reduction of vulnerability before the event to lessen losses); (2) continuous improvement with time of preparedness, prediction, and mitigation applications; and (3) coordinated action among a variety of public and private agencies and organizations having individual program responsibilities for research and development, policy formulation and regulations, education and awareness, prediction and warning, emergency management, and recovery and reconstruction.

By the twenty-first century the United States program should lead to a deeper understanding of three interrelated factors:

- The physical character of each hazardous event, including its cause and its relationship to largerscale and longer-term physical processes that determine its predictability.

- The role of engineering practice in siting, design, and construction of hazard-resistant buildings and lifeline systems.
- The opportunity for societal action to introduce changes in behavior, including incorporation of hazard and risk assessments into community development plans, adoption of hazard safety policies, implementation of preparedness and mitigation measures, and creative use of financial incentives such as insurance and tax credits.

SUMMARY

All parts of the United States are at risk from earthquakes. The IDNDR is a unique opportunity for the United States to collaborate with other nations to learn more rapidly how to save lives and reduce losses from earthquakes and other natural disasters.

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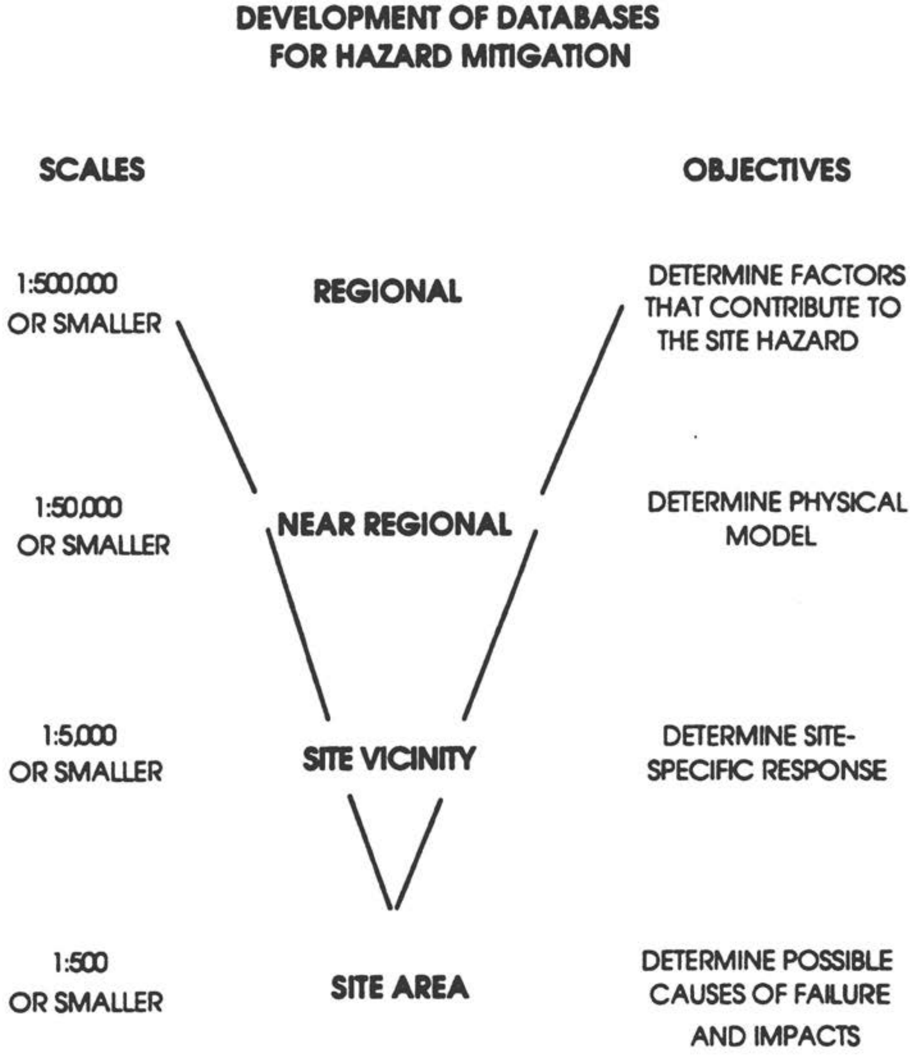

Figure 1. Databases on several different scales must be developed for earthquake hazard and risk assessments.

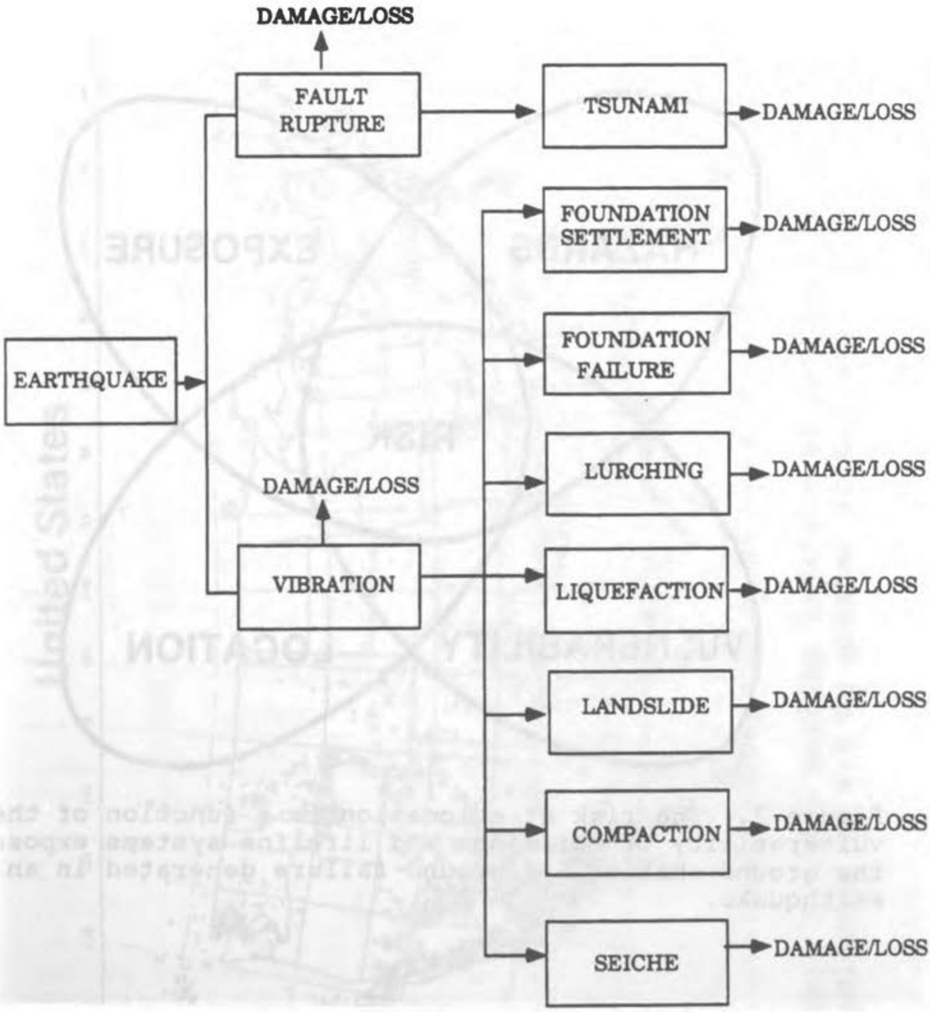

Figure 2. Type of physical effecte generated in an earthquake.

Figure 3. The risk at a location is a function of the vulnerability of buildings and lifeline systems exposed to the ground shaking and ground failure generated in an earthquake.

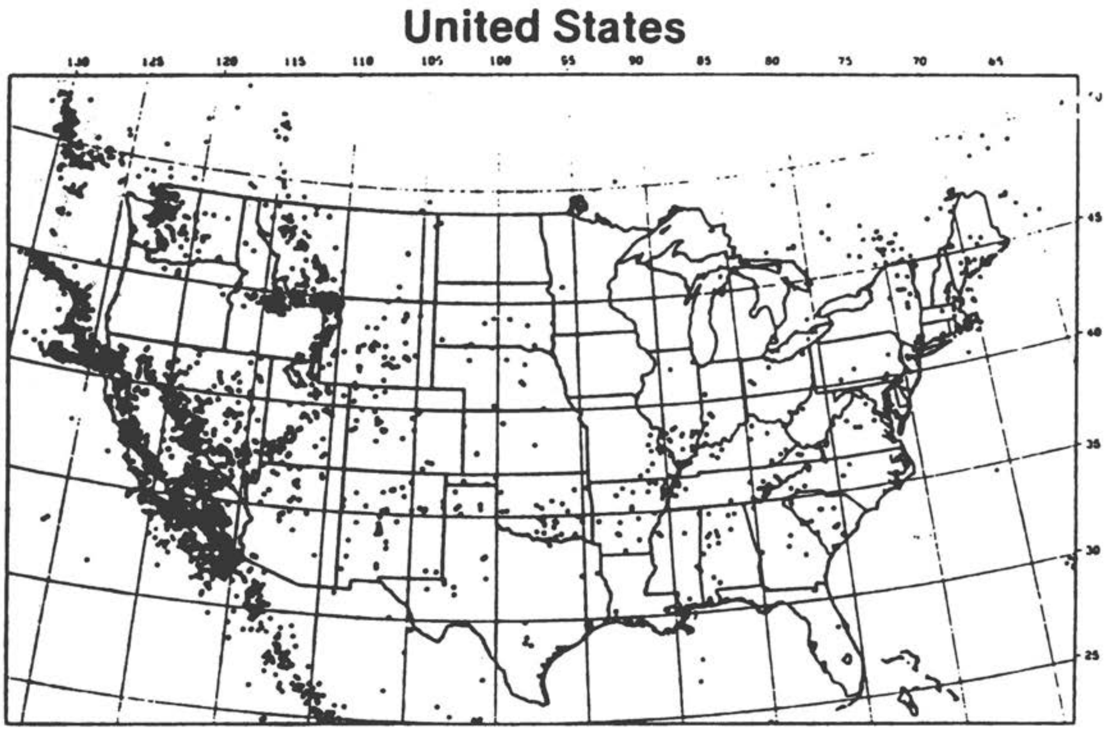

Figure 4. Map showing location of earthquakes having magnitudes of 4.0 or greater in the past 20 years.

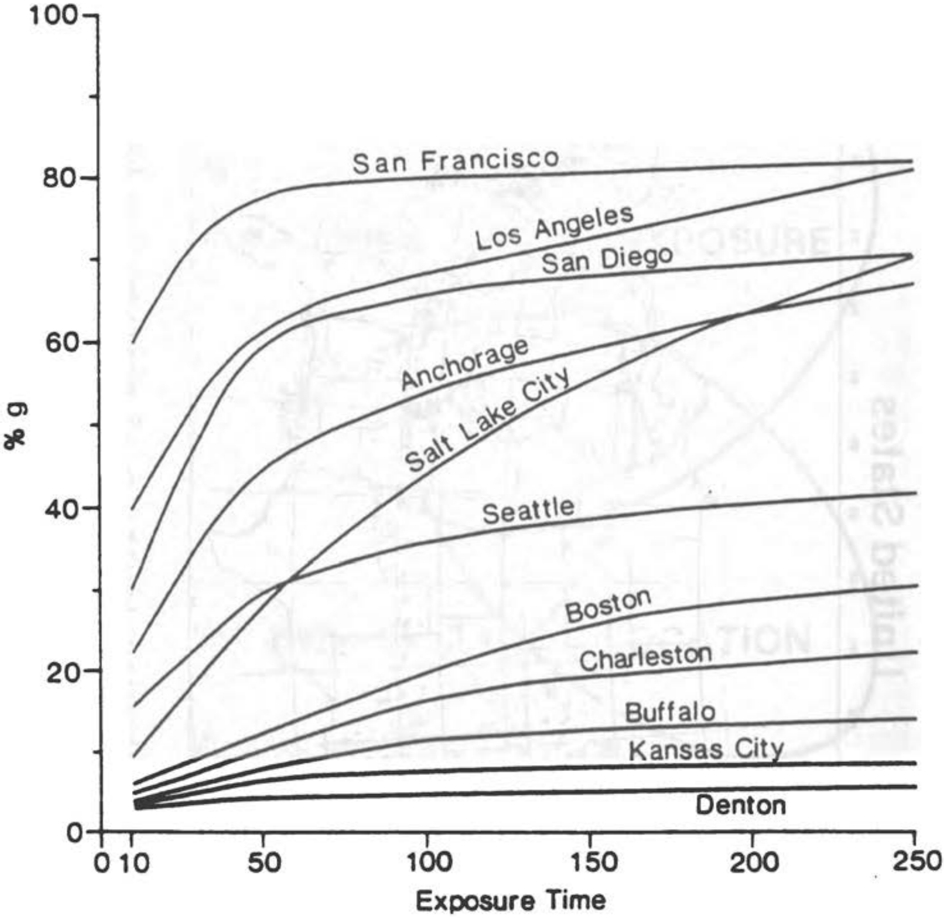

Figure 5. Graph showing levels of peak bedrock ground acceleration expected at various locations. The values have a 10 percent probability of exceedance in a given exposure time. (Algermissen and others, 1982)

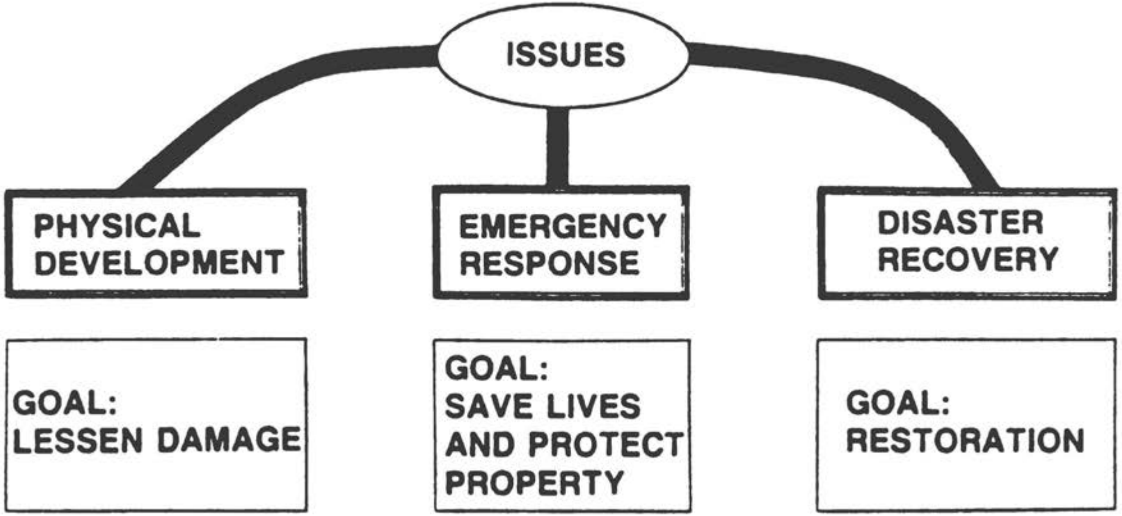

Figure 6. Communities must resolve issues regarding new and existing development, emergency response, and disaster recovery in order to reduce their risk from earthquakes.

APPENDIX

IMPORTANT HISTORICAL EARTHQUAKES IN THE UNITED STATES

Northeastern Region

The record of earthquakes in the United States (and the Northeast) is believed to have started with the Rhode Island earthquake of 1568. The distribution of earthquakes with respect to the maximum MMI in the northeastern United States, excluding Canada and offshore epicenters, is shown in Table 1.

TABLE 1
IMPORTANT EARTHQUAKES FOR EASTERN CANADA AND NEW ENGLAND
[m_b, MAGNITUDE FROM BODY (P AND S) WAVES.
FROM ALGERMISSEN (1983)]

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

Modified Mercalli Intensity	Number
V	120
VI	37
VII	10
VIII	3

Southeastern Region

The southeastern United States is an area of diffuse low-level seismicity that has not experienced a MMI VII or greater earthquake 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 from surface waves (M_S) of approximately 7.7 (Bollinger, 1977). Important earthquakes of the southeastern region are listed in Table 2. The distribution of earthquakes through 1976 in the southeastern region is as follows:

TABLE 2
IMPORTANT EARTHQUAKES OF THE SOUTHEASTERN REGION
[FROM ALGERMISSEN (1983)]

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	
Jun 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	
Jul 8, 1926	Mitchell County, NC	VI-VII	
Nov 2, 1928	Western NC	VI-VII	

Modified Mercalli Intensity	Number
V	133
VI	70
VII	10
VIII	2
IX	0
X	1

Central Region

The seismicity of the central region is dominated by the three great earthquakes that occurred in 1811-12 near New Madrid, Missouri. These earthquakes had magnitudes (M_S) ranging from 8.4 to 8.7 and epicentral intensities ranging from X to XII (Nuttli, 1973). About 15 of the thousands of aftershocks that followed had magnitudes greater than M_S = 6. A distribution of earthquakes through 1976 in the central region is given below as well as a listing of the important earthquakes through 1980 (Table 3).

TABLE 3
IMPORTANT EARTHQUAKES OF THE CENTRAL REGION THROUGH 1980
[FROM ALGERMISSEN (1983)]

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

Modified Mercalli Intensity	Number
V	275
VI	114
VII	32
VIII	5
IX	1
X	0
XI	2
XII	1

Western Mountain Region

A number of important earthquakes have occurred in the western mountain region--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 (see Table 4). The largest earthquake in the western mountain region in historic times was the 1959 Yellowstone Park-Hebgen Lake earthquake, which had a magnitude now believed to be in excess of $M_s = 7.3$. The strongest earthquake in 24 years occurred at Borah Peak in Idaho in October 1983; it had a magnitude of $M_S = 7.3$. The distribution of historic earthquakes in the western mountain region is as follows:

TABLE 4
IMPORTANT EARTHQUAKES OF THE WESTERN MOUNTAIN REGION
THROUGH 1983
[FROM ALGERMISSEN (1983)]

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, Utah	VIII	
Nov 17, 1902	Pine Valley, UT	VIII	
Jul 16, 1906	Socorro, NM	VIII	
Sept 24, 1910	Northeastern Arizona	VIII	
Aug 18, 1912	Near Williams, AZ	VIII	
Sept 29, 1921	Elsinore, UT	VIII	
Sept 30, 1921	Elsinore, UT	VIII	
Jun 28, 1925	Near Helena, MT	VIII	6.7
Mar 12, 1934	Hansel Valley, UT	VIII	6.6
Mar 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	Southwestern Montana	VIII	
Aug 18, 1959	West Yellowstone-Hebgen Lake	X	7.1
Aug 18, 1959	West Yellowstone-Hebgen Lake (Aftershock)	VI	6.5
Aug 18, 1959	West Yellowstone-Hebgen Lake (Aftershock)	VI	6.0
Aug 18, 1959	West Yellowstone-Hebgen Lake (Aftershock)	VI	6.0
Aug 18, 1959	West Yellowstone-Hebgen Lake	VI	6.5
Mar 28, 1975	Pocatello Valley, ID	VIII	6.1
Jun 30, 1975	Yellowstone National Park VIII		6.4
Oct 28, 1983	Borah Peak, Idaho	VII	7.3

Modified Mercalli Intensity	Number
V	474
VI	149
VII	26
VIII	22
IX	0
X	1

California and Western Nevada Region

The highest rates of seismic energy release in the United States, exclusive of Alaska, occur in California and western Nevada. The coastal areas of California are part of the active plate boundary between the Pacific and North America tectonic plates. Seismicity occurs over the well-known San Andreas fault system as well as many other fault systems. A number of major earthquakes have occurred in this region (Table 5). The following generalizations can be made: (1) the earthquakes are nearly all shallow, usually less than 15 kilometers in depth, (2) the recurrence rate for a large (M_S greater than 7.8) earthquake on the San Andreas fault system is about every 100 years, (3) the recurrence rates for large earthquakes on single fault segments in the Nevada seismic zone are believed to be in the order of thousands of years, and (4) most of the major earthquakes have produced surface faulting. Excluding offshore earthquakes, the distribution in California and western Nevada is given below:

TABLE 5
MAJOR EARTHQUAKES OF CALIFORNIA AND WESTERN NEVADA
[FROM ALGERMISSEN (1983)]

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Dec 21, 1812	Santa Barbara Channel	X	
Jun 10, 1836	Hayward fault, east of San Francisco Bay	IX-X	
Jun 1838	San Andreas fault	X	
Jan 9, 1857	San Andreas fault, near Fort Tejon	X-XI	
Oct 21, 1868	Hayward fault, east of San Francisco Bay	IX-X	
Mar 26, 1872	Owens Valley	X-XI	
Apr 19, 1892	Vacaville, CA	IX	
Apr 15, 1898	Mendocino County, CA	VIII-IX	
Dec 25, 1899	San Jacinto, CA	IX	
Apr 18, 1906	San Francisco, CA	XI	8.3
Oct 3, 1915	Pleasant Valley, NV	X	7.7
Apr 21, 1918	Riverside County, CA	IX	6.8
Mar 10, 1922	Cholame Valley, CA	IX	6.5
Jan 22, 1923	Off Cape Mendocino, CA	(IX)	7.3
Jun 29, 1925	Santa Barbara Channel	VIII-IX	6.5
Nov 4, 1927	West of Point Arguello, CA	IX-X	7.3
Dec 21, 1932	Cedar Mountain, NV	X	7.3
Mar 11, 1933	Long Beach, CA	IX	6.3
May 19, 1940	Southeast of El Centro, CA	X	7.1
Jul 21, 1952	Kern County, CA	XI	7.7
Jul 6, 1954	East of Fallon, NV	IX	6.6

California and Western Nevada Region (Continued)

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Aug 24, 1954	East of Fallon, NV	IX	6.8
Dec 16, 1954	Dixie Valley, NV (2 shocks)	X	7.3
Feb 9, 1971	San Fernando, CA	XI	6.4
Oct 15, 1979	Imperial Valley, CA	IX	6.6
May 2, 1983	Coalinga, CA	VIII	6.5
Oct 17, 1989	Loma Prieta, CA*	VIII	7.1

Modified Mercalli Intensity	Number
V	1,263
VI	487
VII	170
VIII	40
VIII-IX	2
IX	8
IX-X	3
X	5
X-XI	2

***Editor's Note**: Loma Prieta earthquake added after date of publication.

Washington and Oregon Region

This region is characterized by a low to moderate level of seismicity independent of the active volcanism of the Cascade Range. With the exception of plate interaction between the North American and Pacific tectonic plates, no clear relation is known between seismicity and geologic structure. From the list of important earthquakes that occurred in the region (Table 6), 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 60-70 kilometers. Currently, researchers are speculating that a great earthquake could 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 given below:

TABLE 6
IMPORTANT EARTHQUAKES OF WASHINGTON AND OREGON
[FROM ALGERMISSEN (1983)]

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Dec 14, 1872	Near Lake Chelan, WA	IX	(7.0)
Oct 12, 1877	Cascade Mountains, OR	VIII	
Mar 7, 1893	Umatilla, OR	VII	
Mar 17, 1904	About 60 km northwest of Seattle, WA	VII	
Jan 11, 1909	North of Seattle, WA near Washington-British Columbia	VII	
Dec 6, 1918	Vancouver Island, BC	(VIII)	7.0
Jan 24, 1920	Straits of Georgia	(VII)	
Jul 16, 1936	Northern Oregon, near Freewater	VII	(5.7)
Nov 13, 1939	Northwest of Olympia (Depth of focus about 40 km)	VII	(5.8)
Apr 29, 1945	About 50 km southeast of Seattle, WA	VII	
Feb 15, 1946	About 35 km north northeast of Tacoma, WA (Depth of focus 40-60 km)	VII	6.3
Jun 23, 1946	Vancouver Island	(VIII)	7.2
Apr 13, 1949	Between Olympia and Tacoma, WA (Depth of focus about 70 km)	VIII	7.1
Apr 29, 1965	Between Tacoma and Seattle, WA (Depth of focus about 59 km)	VIII	6.5

Modified Mercalli Intensity	Number
V	150
VI	57
VII	8
VIII	3
IX	1

Alaska Region

The Alaska-Aleutian Island area is one of the most active seismic zones in the world. The Queen Charlotte Island-Fairweather fault system marks the active boundary in southeastern Alaska where the Pacific plate slides past the North American plate. The entire coastal region of Alaska and the Aleutians have experienced extensive earthquake activity (Table 7) even in the relatively short (85 years) time period for which the seismicity is well known. The most devastating earthquake in Alaska occurred on March 28, 1964, in the Prince William Sound. This earthquake, which recently has been assigned a moment magnitude of 9.2, also probably was the largest historical earthquake in the region. It caused 114 deaths, principally as a consequence of the tsunami that followed the earthquake. The regional uplift and subsidence covered an area of more than 77,000 square miles. The distribution of earthquakes in Alaska in terms of magnitude (M_S) is as follows:

TABLE 7
MAJOR EARTHQUAKES OF ALASKA
[From Algermissen (1983)]

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

M_S	Number
5.0-5.9	757
6.0-6.9	344
7.0-7.9	63
Greater than or equal to 8.0	11

Hawaiian Islands Region

The seismicity in the Hawaiian Islands is related to the well-known volcanic activity and is associated primarily with the island of Hawaii. Although the seismicity has been recorded for about 100 years, a number of important earthquakes have occurred since 1868 (Table 8). Tsunamis from local, as well as distant, earthquakes have impacted the islands; some tsunamis had wave heights of as much as 55 feet. The distribution of earthquakes in terms of maximum MMI is given below:

TABLE 8
EARTHQUAKES CAUSING SIGNIFICANT DAMAGE IN HAWAII
[FROM ALGERMISSEN (1983)]

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	
Sep 14, 1919	Kilauea, HI	VII	
Sep 25, 1929	Kona, HI	VII	
Sep 28, 1929	Hilo, HI	VII	
Oct 5, 1929	Honualoa, HI	VII	6.5
Jan 22, 1938	North of Maui	VIII	6.7
Sep 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 northeastern coast of HI	VIII	6.3
Nov 29, 1975	Near northeastern coast of HI	VIII	7.2
Nov 16, 1983	Near Mauna Loa, HI		6.6

Modified Mercalli Intensity	Number
V	56
VI	9
VII	9
VIII	3
IX	1
X	1

Puerto Rico and the Virgin Islands Region

The seismicity in Puerto Rico and the Virgin Islands region is related to the interaction of the Caribbean and the North American tectonic plates. The Caribbean plate is believed to be nearly fixed while the North American plate is moving westward at the rate of about 2 centimeters per year. Earthquakes in this region are known to have caused damage as early as 1524-28. During the past 120 years, major damaging earthquakes have occurred in 1867 and 1918; both earthquakes had tsunamis associated with them. The distribution of earthquakes affecting Puerto Rico is given below in terms of maximum MMI; Table 9 lists damaging earthquakes in Puerto Rico and the Virgin Islands region.

TABLE 9

DAMAGING EARTHQUAKES ON OR NEAR PUERTO RICO
[FROM ALGERMISSEN (1983)]

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

Modified Mercalli Intensity	Number
V	24
V-VI	4
I	5
VI-VII	1
VII	6
VIII	2
VIII-IX	1

ACTIVITIES OF THE INTERAGENCY COMMITTEE ON SEISMIC SAFETY IN CONSTRUCTION

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ABSTRACT

The Interagency Committee on Seismic Safety in Construction (ICSSC) assists federal agencies involved in construction to develop and incorporate earthquake hazards reduction measures in their ongoing programs. ICSSC proposed an executive order for seismic safety in construction that became the basis for Executive Order 12699, "Seismic Safety of Federal and Federally Assisted or Regulated New Building construction," dated January 5, 1990. The National Earthquake Hazards Reduction Program Reauthorization Act of October 20, 1990, calls for ICSSC to provide standards for existing federal and federally assisted buildings by 1994. ICSSC will participate in cooperative activities with the private sector to develop nationally recognized voluntary standards suitable for federal use in the assessment of the seismic resistance of existing buildings and the strengthening of those inadequately resistant.

INTRODUCTION

There now are substantive federal requirements for seismic safety of new buildings. In addition, there has been consideration by the Interagency Committee on Seismic Safety in Construction (ICSSC) of what should be done with existing buildings. I appreciate this opportunity in a meeting of the Federal Construction Council to discuss the activities of the ICSSC. Although about half of us are already involved in it, this is a good opportunity to stimulate more participation in its cooperative efforts to meet needs for the seismic safety of federal facilities.

The ICSSC is one of the oldest cooperative activities in the National Earthquake Hazards Reduction Program (NEHRP). The document [1] issued by the Executive Office of the president on June 22, 1978, to create NEHRP called for the creation of ICSSC. ICSSC's purpose is to assist the federal agencies involved in construction to develop and incorporate earthquake hazards reduction measures in their ongoing programs. ICSSC does not tell the federal agencies what to do but provides a means for them to work together to advise themselves on earthquake hazard reduction measures. ICSSC is open to all concerned federal agencies; 24 currently participate. The National Institute of Standards and Technology (NIST) provides the Secretariat and Chairman. The funding for the Secretariat is provided by the Federal Emergency Management Agency (FEMA). ICSSC reports to the Interagency Coordination Committee of NEHRP that is chaired by FEMA. ICSSC is organized in five subcommittees. The first, Standards for New and Existing Buildings, is the most involved with our discussions today. ICSSC also has subcommittees on Lifeline; Site Hazard Assessment, which serves both buildings and lifelines needs; Federal Domestic Assistance, Leasing and Regulatory Programs, which affects much private sector construction; and Post Earthquake Response Activities, which provide a mechanism for the federal agencies to prepare to collaborate following an earthquake emergency in dealing with the damages to and performance of federal facilities and to learn from the earthquake how to mitigate future damages.

The Interagency Committee on Seismic Safety in Construction has published several reports to assist federal agencies in their earthquake hazards reduction activities for existing buildings [2-7].

REQUIREMENTS FOR NEW FEDERAL AND FEDERALLY ASSISTED BUILDINGS

On January 5, 1990, the President issued Executive Order 12699, "Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction." The executive order is based on a proposal by ICSSC for an executive order dealing with existing buildings and lifelines as well. Because of our focus today on existing buildings, I will first describe the requirements of the executive order for new buildings and then the recommendations that ICSSC made for existing buildings. The recommendations are a point of departure for ICSSC's response to a recent legislative mandate.

The executive order responds to the policy requirements created by the Earthquake Hazards Reduction Act of 1977. The act requires "the development and promulgation of specifications, building standards, design criteria, and construction practices to achieve appropriate seismic resistance." It calls for "the examination of alternative provisions and requirements for reducing earthquake hazards through Federal and Federally financed construction, loans, loan guarantees and licenses." The act requires attention not only on federal facilities but also on federally assisted or regulated construction. The executive order does not place requirements on the agencies beyond those of the original legislation. Some, such as the Department of Defense and the Department of Veterans Affairs, already have done a great deal. Each agency is responsible for its own actions. Neither FEMA nor ICSSC are given authority over the agencies' programs.

The requirements for the earthquake safety of federal buildings have these purposes: to reduce risks to the lives of occupants; to reduce secondary risks of failures; to improve the capability for important federal buildings to be functional during or after an emergency; and to reduce losses of public buildings. These are to be accomplished in a cost-effective way. Any new federal buildings entering the detailed design stage after January 5, 1990, shall be designed and constructed in accord with appropriate seismic standards.

For federally leased, assisted, or regulated buildings, the purpose of the executive order is to reduce risk to lives of occupants of buildings leased for federal uses or purchased or constructed with federal assistance and to reduce risk to the lives of persons potentially affected by earthquake failures of federally assisted or regulated buildings; and to protect public investments. For space constructed and leased for federal occupancy, the executive order applies to agreements executed since January 5, 1990.

Federal domestic assistance programs affect most new residential construction because states, municipalities, and developers want to be eligible for VA or FHA mortgages. The executive order requires agencies, within

3 years, to plan and initiate measures to assure appropriate consideration of seismic safety in domestic assistance programs.

The concurrent requirements are extremely important to the private sector and to the federal agencies. Agencies and the ICSSC are not expected to develop federal standards for new building construction. Administration policy in OMB Circular A-119 for the use of nationally recognized standards to the extent possible in federal programs is reflected in the executive order. Agencies are to use nationally recognized private sector standards unless none that meet special agency requirements are available. The local building code may be used if the agency determines it provides adequate seismic safety. ICSSC is working collectively to provide guidance to the agencies so that each agency itself does not have to carry out an assessment of the more than 15,000 local building codes in the country.

Each agency is responsible for issuing its regulations or procedures, planning for implementation through its own budget process, and regularly reviewing its regulations and procedures. FEMA will report on the execution of the order to Congress and the Administration. It will support the secretariat of ICSSC to assist the federal agencies in working together on useful practices. FEMA is to request from each agency annually the status of its work and to report on execution of the order annually to Congress.

ICSSC is now working on implementation of the executive order. Guidelines for implementation of the executive order are being updated to apply to the executive order as issued. The guidelines are now being balloted among the federal agencies.

ICSSC is working with the private sector, particularly with the Building Seismic Safety Council, in implementation of the executive order. NEHRP has developed, in cooperation with the private sector, "Recommended Provisions for Development of Seismic Regulations for New Buildings." These are being reflected in the national standards and model codes. The Uniform Building Code already substantially reflects the NEHRP provisions. The National Building Code and the Standard Building Code are developing changes that are expected to make their 1991 versions reflect up-to-date seismic provisions. The Council on American Building Officials is preparing a change for the One and Two-Family Dwelling Code, which will be applicable nationwide and is expected to incorporate improved seismic provisions. The American Society of Civil Engineers is considering the NEHRP provisions in revision of its widely used national Standard A7, "Minimum Design Loads for Buildings and Other Structures."

These nationally recognized private sector standards will become important resources for new federal buildings. ICSSC also is working with the private sector in preparing guidance documents for the federal agencies to use to assess the adequacy of the local building codes in dealing with the seismic safety of federally assisted or regulated facilities. A study with the National Conference of States on Building Codes and Standards looks at the status in the United States of the adoption and enforcement of adequate seismic provisions. A study with the Council of American Building Officials compares model code provisions to NEHRP-recommended provisions. This may show some areas where the model codes are better and some where the model codes need strengthening to become equivalent.

REQUIREMENTS AND RECOMMENDATIONS FOR EXISTING FEDERAL BUILDINGS

The National Earthquake Hazards Reduction Program Reauthorization Act of October 20, 1990, has substantial requirements for the seismic safety of existing federal and federally assisted buildings:

> "The President shall adopt, not later than December 1, 1994, standards for assessing and enhancing the seismic safety of existing buildings constructed for or leased by the Federal Government which were designed and constructed without adequate seismic design and construction standards. Such standards shall be developed by the Interagency Committee on Seismic Safety in Construction, . . ."

Ugo Morelli will describe activities that the NEHRP with FEMA sponsorship has underway with the private sector to develop nationally applicable techniques for assessing and strengthening existing buildings. ICSSC will use these resources in carrying out its responsibilities under this legislation.

The reauthorization act also says: "The President shall report to the Congress, not later than December 1, 1994, on how the standards could be applied to Federally assisted and regulated existing buildings . . ." The Comptroller General is required to report to Congress in 18 months on the vulnerability of buildings owned or leased by the federal government and on the efforts of the federal agencies to improve the seismic resistance of the buildings they own or lease. The General Accounting Office is now visiting federal agencies in response to this assignment.

Now, let us review what ICSSC proposed in 1986 for the provisions of the proposed executive order that dealt with existing buildings. These are a point of departure for ICSSC response to the recent legislation and its 1994 deadline.

The proposed executive order requires, for existing federal buildings, that each agency plan and initiate within 3 years a systematic program for assessment of risks and correction of excessive risks. Priority attention is to be given to areas of high seismic hazard and to buildings of the highest potential for losses. It would not apply to buildings intended to be transferred to a nonfederal owner, such as a repossessed house that a federal agency intends to sell again to a private owner.

For leases in an existing building, the proposed executive order requires consideration of seismic safety in selection of leased space.

For federally assisted buildings, the proposed executive order would not apply to the financing of an existing one- to four-unit dwelling or to the financing of an existing cooperative or condominium dwelling unit. It would apply to grants, loans, or loan guarantees for repairing or renovating existing buildings only when the cost of repairing or renovating exceeds 50 percent of the fair market value before repairing or renovating the existing building.

SUMMARY

In summary, Executive Order 12699 requires federal agencies now to act aggressively for the seismic safety of new federal and federally assisted buildings. The National Earthquake Hazards Reduction Program Reauthorization Act requires seismic safety standards for existing federal and federally assisted buildings to be ready for implementation in December 1994.

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SOURCES OF TECHNICAL GUIDANCE ON SEISMIC SAFETY OF EXISTING BUILDINGS

Ugo Morelli
Federal Emergency Management Agency

In his remarks Ugo Morelli discussed a set of coordinated, self-reinforcing publications being sponsored by the Federal Emergency Management Agency that are intended to encourage action by both private and public entities to increase the seismic safety of existing buildings. Some details of the program and relevant publications follow.

THE OBJECTIVE AND APPROACH

The main objective of a seismic rehabilitation program is to save lives, with the secondary objectives of saving property and preserving community functions. The approach therefore involves

1. identifying the seismically hazardous buildings whose occupants are most vulnerable or whose functions are most essential;
2. selecting appropriate cost-effective strengthening approaches and techniques;
3. building a political consensus around the selected program; and
4. implementing the program.

The type of program that is selected will vary from community to community depending on a large number of historical, demographic, and socioeconomic conditions.

THE PROCESS

Seismic rehabilitation projects require community-wide participation because they entail economic and societal costs to a large number of people, including:

- Owners and occupants of residential, business, and professional buildings.
- Administrators and managers of public and private institutions, such as schools, health care facilities, and lodging accommodations.
- Managers of emergency services facilities.

Public discussion of and debate on a seismic rehabilitation program, therefore, entail many groups of local residents:

- Elected and appointed officials.
- Design and engineering professionals.
- Building owners and managers.
- Financial and investment managers.
- Emergency services managers.

Under the Earthquake Hazard Reduction Act of 1977, as amended (P.L. 95-124), the Federal Emergency Management Agency (FEMA) has funded the preparation of a widely backed, nationally applicable set of resource documents intended to help a community decide upon and effect a local seismic rehabilitation program. Both engineering and societal problems and issues are included in this set of handbooks and supporting reports.

The engineering books cover how to:

- Quickly screen buildings.
- Evaluate in detail those at risk.
- Strengthen seismically buildings at risk.

Additionally, an indication of the cost of seismic rehabilitation is available.

RAPID VISUAL SCREENING

A methodology for quickly identifying buildings posing risks of death, injury, or severe curtailment in use is presented in <u>Rapid Visual Screening of Buildings for</u>

Potential Seismic Hazards: Handbook and Supporting Documentation, prepared by Applied Technology Council, Redwood City, California.

Primary audiences are:

- building officials,
- engineers and architects,
- building owners and managers,
- emergency managers, and
- interested citizens.

The core of the handbook is the Rapid Screening Procedure (RSP), which can be used by trained personnel to identify the potentially hazardous buildings on the basis of a 15-30 minute exterior inspection and use of a data collection form. The form contains a procedure that begins with identification of 12 basic structural categories and leads the inspector to a numerical "structural core" for the building on the basis of visible structural information. It outlines a sequence of activities for implementing the RSP methodology, including:

- establishing the budget,
- prefield planning,
- training inspectors,
- collecting data,
- field inspection, and
- computation of the structural score indicating the level of seismic safety.

The supporting documentation offers a detailed methodology description and visual aids for identifying structural framing systems and significant building details.

SEISMIC EVALUATION OF EXISTING BUILDINGS

A nationally applicable methodology for identifying buildings or building components that present unacceptable risks in case of an earthquake is presented in: A Handbook for Seismic Evaluation of Existing Buildings and Supporting Documentation, prepared by Applied Technology Council, Redwood Ciity, California.

The handbook is designed for engineers.

The handbook's methodology requires the engineer to consider a series of predefined evaluation statements for 15 structural categories (consistent with the categories throughout the series). The statements relate to each subsystem, and the engineer determines whether each statement is true or false. Conditions designated "false" lead to identification of deficient elements requiring additional investigation and possible rehabilitation.

Deficient elements may be found in any of four structural subsystems:

- vertical elements resisting horizontal loads,
- horizontal elements resisting lateral loads,
- foundations, or
- connections between structural elements or subsystems.

The methodology also covers nonstructural elements. Checklists, diagrams, and sketches to aid the user are included. The supporting materials review other methodologies.

SEISMICALLY REHABILITATING EXISTING BUILDINGS

A state-of-the-art summary of techniques used in the United States to rehabilitate buildings and their elements posing unacceptable risks in an earthquake are presented in Techniques for Seismically Rehabilitating Existing Buildings, prepared by URS/John A. Blume and Associates, San Francisco, California.

The primary audiences for this document are:

- engineers and architects and
- building officials.

The handbook systematically identifies and describes nationally applicable seismic rehabilitation techniques for a broad spectrum of building types and building components. Rehabilitation techniques for both the structural and the nonstructural components of the buildings are presented.

The rehabilitation techniques for structural elements that are presented are of two basic kinds:

- strengthening of load resisting components and
- decreasing demand on load resisting components.

Strengthening techniques are described in detail, and most of them are illustrated with suitable sketches. The relative merits of each are discussed.

The handbook is organized by building components, which are grouped in the same subsystems used in the Handbook on Seismic Evaluation that is discussed on the preceding page.

TYPICAL COSTS FOR SEISMIC REHABILITATION

An analysis of the costs of more than 600 seismic rehabilitation projects throughout the United States are presented in Typical Costs for Seismic Rehabilitation of Existing Buildings: Summary and Supporting Documentation, prepared by Englekirk and Hart Consulting Engineers, Inc., Los Angeles, California.

Costs per square foot are presented for the following building structural types and their subtypes:

- unreinforced masonry,
- reinforced masonry,
- reinforced concrete,
- precast concrete,
- wood, and
- steel.

The costs for these six types vary widely, with typical costs from about $3.75 to about $13.00 per square foot. A sensitivity analysis is presented to support the fact that structural type is the critical parameter of cost per square foot.

The supporting documentation contains the basic data used in the analysis, including a discussion of the limitations of the database (e.g., it underrepresents many structural categories, it includes principally West Coast projects, and many of the costs are estimated rather than incurred). A cost breakdown by work category is provided for a subsample of Los Angeles buildings.

The primary audiences for both volumes are government policymakers at all levels, engineers and architects, and building owners and managers.

ESTABLISHING PROGRAMS AND PRIORITIES

Questions and political issues raised during formulation of a seismic rehabilitation program are explored in Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings--A Handbook and Supporting Report, prepared by Building Systems Development, Inc., San Mateo, California, with Integrated Design Services, Concord, California, and Claire B. Rubin, Washington, D.C.

The documents discuss both technical and societal issues.

Primary users of these documents are those charged with design and development of a program for seismic rehabilitation. Additional audiences include state and local policymakers and private stakeholders.

The handbook suggests four steps in program development:

- earthquake vulnerability analysis and loss estimation;
- program design--from minimal voluntary programs to broader mandatory ones covering different types of building and different occupancies;
- technical issues related to strengthening methods, costs, and effectiveness; and
- societal issues of both direct and indirect costs of rehabilitation, including relocation dislocations and implications of building inventory losses.

It also presents a social impact assessment process to identify, marshall, and resolve major societal issues, plus a simplified cost/benefit analysis for evaluation of seismic rehabilitation programs.

The supporting report presents additional information, commentaries, and bibliographies on relevant subjects.

FINANCIAL INCENTIVES FOR SEISMIC REHABILITATION

The current status of incentives for seismic rehabilitation at the federal, state, and local levels, in both the public and private sectors, and an agenda for action to encourage seismic rehabilitation are presented in Financial Incentives for Seismic Rehabilitation of Hazardous Buildings--An Agenda for Action (Report and Appendices), prepared by Building Technology Inc., Silver Spring, Maryland.

The audiences for these two volumes are:

- policymakers, budget officials, planners, housing officials, and historic preservationists at all levels of government;
- state and local building regulatory officials;
- public and private building owners and managers and risk managers;
- lenders and insurers; and
- associations representing the above constituencies.

Incentives include those encouraging the community as a whole and those encouraging individual owners, developers, financiers, insurers, and other business persons to undertake seismic strengthening of existing buildings.

No financial incentives for seismic strengthening of buildings of any kind, whether their source be government (federal, state, or local), associations, or the private sector, were found to be in use outside of California. Nevertheless, in many parts of the country there are opportunities to institute or pursue seismic mitigation programs that will lead to seismic strengthening of buildings. These opportunities differ from location to location. They reflect unique local circumstances and are supported by groupings of local private and public sector individuals and organizations.

The report covers the following states and selected cities in each:

- Massachusetts,
- Missouri,
- South Carolina,
- Tennessee,
- Utah, and
- Washington.

The report includes findings and recommendations that will encourage seismic rehabilitation of hazardous buildings. These recommendations are aimed at both private and public sector organizations.

The recommendations form the basis for workshops held in each state--workshops to formulate local action plans leading to seismic strengthening of buildings. The organizing and conducting of the workshops are documented in a third report intended for use by communities interested in undertaking similar seismic rehabilitation programs.

The capstone publication in this series will consist of a compendium of specific guidelines on the seismic rehabilitation of existing buildings. It will be comparable in scope to the NEHRP Recommended Provisions on the seismic safety of new buildings that has become a nationally recognized reference document on this subject. The effort to formulate the guidelines on existing buildings is expected to start in the summer or early fall of 1990 and to continue for several years, given the difficulties associated with the subject and the state of technology. Phase 1 of the effort--identification and indications of possible solutions of major overarching technical and societal issues infringing on the actual formulation of the specific guidelines--is already being conducted by a joint effort of the Applied Technology Council, the American Society of Civil Engineers, and the Earthquake Engineering Research Institute.

POLICIES AND PRACTICES FOR RETROFITTING POSTAL BUILDINGS FOR SEISMIC SAFETY

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U.S. Postal Service

I. SUMMARY

Current and Completed Activities

1. Developed procedures for evaluation of existing postal buildings.
2. Developing postal retrofit criteria (structural and nonstructural).
3. Completed evaluation and retrofit cost projections.

Planned Activities

1. Develop and conduct evaluation and retrofit training.
2. Field test evaluation procedures.
3 Develop tracking system.

General Procedures

1. Screen using facilities management system data and evaluate structure: questionnaire.
2. Evaluate structure: preliminary and detailed.
3. Evaluate nonstructural elements.
4. Develop schematic of retrofit with estimated cost.
5. USPS evaluates options.
6. Choose option and then fund and implement.

II. CURRENT POLICY

1. New construction owned and leased to be in accordance with seismic provisions of UBC, BOAC, or SBC codes as minimum.

2. Selection of new leased space in existing building requires seismic resistance as a consideration. Minimum of 75 percent seismic design forces as defined in latest UBC required.

III. CURRENT ACTIVITIES

Developing cost projections for evaluating and retrofitting inventory of buildings. Developing procedures for structural screening and prioritization. Involves over 35,500 facilities and 750,000 employees. Evaluation criteria based on seismic force level of 75 percent of NEHRP requirements.

Screening and Prioritization

1. Use facilities management system (FMS) data base (type of quarters, type of construction, building area, location, date of occupancy).
2. Use supplemental questionnaire (confirm county, type of construction, building area, number of stories, and building age).
3. Use zip codes to sort by NEHRP map seismic area.
4. Screen out:

- Buildings in map areas 1 and 2, except important ones.
- Nonbuildings (self-service postal center, land on-grade parking, unattended post office boxes).
- Building designed in accordance with the seismic provisions of the 1976 (or later) UBC (structural evaluation only).
- One-story wood-frame structures (structural evaluation only).

5. Prioritize by map area, building importance, type of construction, and size.

Preliminary Structural Evaluation

1. Screen out buildings that have a complete lateral force-resisting system that meets minimum strength requirements (based on ATC-22).
2. Look at drawings.

3. Visit site to determine lateral support conditions and building type.

4. Make quick checks of:

- Drift in moment frames.
- Shearing stress in concrete frame columns.
- Shearing stress in shear walls.
- Axial compression in diagonal bracing.
- Seismic/geological risks.

5. Complete report (evaluation statement).

Detailed Structural Evaluation

1. Address issues discovered in preliminary evaluation.
2. Use static code approach (recommended for ordinary buildings) or post yield approach (for special buildings and buildings required to have a capacity greater than can be provided readily by code approach).

Evaluation of Nonstructural Elements

These include parts and portions of structures, permanent nonstructural components, and attachments to them. Included are architectural features, fire protection systems, mechanical and electrical equipment, utilities, storage racks, communication systems, exterior cladding, tanks, mail transport systems, mail processing equipment, etc.

Assessment of Earthquake-Related Geologic Phonomena

This includes:

- Surface fault rupture,
- Soil liquefaction,
- Differential compaction,
- Landsliding, and
- Flooding.

Development of Cost Projections

Approximately 35,500 facilities listed in FMS screened out:

- Facilities in map areas 1 and 2.
- Single-story wood-frame structures in map areas 3 to 7.
- Buildings constructed under 1976 (or later) UBC nonbuilding facilities.

Costs are expected to be affected by:

- Number of buildings to be evaluated;
- Number of buildings to be retrofitted;
- Whether the building is leased or owned;
- Type of construction;
- Size of facility;
- Rehabilitation criteria (life safety vs. code compliance);
- Regional differences in construction;
- Age of building;
- Number of stories;
- Type of quarters (building use);
- Other factors--phasing, unanticipated field conditions, and removal and relocation of electrical, mechanical, and plumbing;
- USPS administration costs;
- A/E fees;
- Construction management;
- Staged construction; and
- Temporary relocation.

Except for seismic map areas 1 and 2, all buildings screened out received nonstructural evaluation.

SEISMIC RETROFITTING EFFORTS OF THE NAVY

Howard D. Nickerson
Naval Facilities Engineering Command

OVERVIEW

The Navy has a large number of facilities located in high seismic risk areas. There are approximately 95 Navy activities in seismic zones 3 and 4 within the United States and a few overseas locations, which includes about 18,000 buildings. In 1972 the Naval Facilities Engineering Command (NAVFAC) initiated a pilot study at the Puget Sound Naval Shipyard to determine the condition of its existing buildings with respect to earthquake safety.

Subsequently, a systematic evaluation program evolved from the pilot study. There are two major divisions of the Program. Phase I (Preliminary Evaluation) consists of: (1) screening and selection of buildings for evaluation; (2) a rapid seismic analysis procedure (RSAP) to identify inadequate buildings; and (3) performance of a cursory evaluation of site hazards and utilities. Phase II (Detailed Evaluation) includes: (1) detailed analysis of buildings and (2) development of upgrade concepts and costs. NAVFAC has found that this earthquake safety program deals with a large inventory of buildings with reasonable effort and cost.

The implementation of NAVFAC'S Earthquake Safety Program for evaluation of existing Navy facilities is accomplished through combined efforts, as follows: (1) NAVFAC Headquarters provides funding and policy guidance for the program; (2) each of NAVFAC's Engineering Field Divisions (EFD) handles the program for the specific geographic area it serves; (3) the majority of the studies are done through A&E contracts; (4) our Western Division EFD assists NAVFAC Headquarters with coordination and planning; and (5) the Naval Civil Engineering Laboratory provides R&D and consultation support.

Various mitigation guidance was issued starting in the early 1970s. This recognized that the evaluation of existing buildings and the implementation of any needed retrofitting was a long-term endeavor. A NAVFAC directive was issued that specified mandatory upgrading requirements for repair, rehabilitation, and modernization projects for seismically deficient buildings. Also, expedient measures were issued for utilities and non-structural items. These focused on simple, low cost items that could be done with station forces.

PROGRAM DETAILS

Not all of NAVFAC's Earthquake Safety Program evaluation studies are done in exactly the same way, but the usual division and sequence of events are listed below.

PHASE I (PRELIMINARY EVALUATION)

1. Computer screening:

   - o used to identify buildings to be evaluated at an activity (zones 3 and 4)
   - o usually completed before A&E contract prepared
   - o effective inventory reduction
   - o uses Navy's automated database for real property
   - o database includes building data: age, size, cost, type construction, etc.
   - o process normally eliminates 60 percent to 80 percent of buildings
   - o elimination criteria:

     - buildings designed after 1973
     - one-story preengineered metal buildings
     - one-story timber buildings
     - floor area less than 3,000 sq. ft. (unless mission essential)
     - replacement cost less than $200,000
     - replacement scheduled within 5 years
     - family housing

2. Consultation with the activity:

- o make modifications to screened computer list
- o usually completed before A&E contract prepared
- o identify errors in list
- o identify duplicate buildings (investigate one)
- o add buildings by request if justified

3. Field screening and data collection for structures:

- o refine list of buildings to be evaluated
- o site visit
- o walk-through inspection
- o note special concerns
- o collect available dwellings and call for review
- o photos taken

4. Preliminary evaluation of site hazards and utilities:

- o focus on overall situation
- o visual inspection
- o discussions with activity
- o review existing soil reports and utility maps

5. Site seismicity studies:

- o establish site-specific response spectra
- o EQ with 20 percent probability of exceedence in 50 years

6. Preliminary structural evaluation:

- o uses rapid seismic analysis procedure (RSAP)
  - developed in 1972 pilot study
  - by Blume Associate
  - modified and computerized by NCEL

- o assesses percentage damage to buildings expected from demand EQ
  - compares building capacity and EQ demand at yield and ultimate levels
  - calculations done, simply and quickly, graphically or by NCEL's computer program

- o for details of method refer to:

- DoD Tri-service Design Manual (NAVFAC P-355.2,1 September, 1988), Appendix D
- "Seismic Design Guidelines for Upgrading Existing Buildings"

o note RSAP for preliminary evaluation only

- identifies buildings susceptible to damage
- gives relative vulnerability

7. Preliminary evaluation report:

o summary of RSAP results
o nonstructural upgrade recommendations
o recommendations for Phase II work:

- follow-up site hazard and utilities studies
- buildings requiring detailed analysis:

  * selection based on RSAP results and good engineering judgment
  * all buildings w/30 percent or more damage may warrant analysis
  * essential buildings w/30 percent or more damage are done
  * all buildings w/60 percent or more damage are done
  * do some buildings w/less than 30 percent damage w/special concerns (unusual features/poor structural connections)
  * consider buildings for which RSAP was not applicable (complexity)

PHASE II (DETAILED EVALUATION)

1. Detailed analysis of structures:

o analysis method--determined by investigator
o objectives

- verify Phase I results that upgrading is required (that deficiencies exist and their extent)
- minimize analysis effort (entire structure or typical elements)

2. Recommendation for mitigations:

- o determine effective upgrade concepts
- o develop cost estimates for various concepts

3. Follow-up investigation of site hazard and utilities

4. Final evaluation report:

- o summarizes results of all investigations
- o sent to activity for planning purpose

UPGRADING PROCEDURES

Projects to provide seismic upgrading of existing buildings are initiated and prioritized at the various Navy activities in conjunction with all of their other requirements. There are, however, special mandatory seismic upgrading requirements for repair, rehabilitation, and modernization projects when these structures are seismically inadequate. A NAVFAC directive, first issued in 1973, requires that earthquake safety be investigated when rehabilitation costs equal 10 percent of replacement cost or $150,000 (whichever is greater). It recommends using RSAP results, when available, to make decisions.

STATUS

NAVFAC has made substantial progress in identifying buildings vulnerable to earthquake damage and has been taking steps to mitigate seismic deficiencies. We have completed 80 percent of the Phase I (Preliminary Evaluation) studies and about 30 percent of the Phase II (Detailed Analysis) work. A total of approximately 14,000 buildings were screened; 1,500 buildings required seismic analysis. Approximately 5 percent of the Navy's inventory of buildings in zones 3 and 4 are identified as being vulnerable to 30 percent or more potential damage from the maximum probable earthquakes at the sites. The percentage of buildings requiring upgrading will reduce as the Phase II studies are completed. Buildings are being upgraded as funding becomes available.

IBM SEISMIC RETROFIT

Charles M. Russo[2]
IBM Corporation

HISTORY

The impetus for the seismic program at IBM is concern for the safety of employees and the protection of shareholder assets. Through proper planning and protection adequate safeguards are provided to avoid or minimize personal injuries, protect company assets, provide for the continuity and recovery of vital business processes, and expedite the restoration of facilities after an earthquake. A corporate instruction on emergency planning has been issued to carry out this policy. Corporate instructions are issued by corporate staff executives.

The February 9, 1971, magnitude 6.6 San Fernando earthquake was a major earthquake from an engineering point of view, even though it was only a moderate shock in seismological terms. As a result of the effects of this earthquake, various government agencies, the public, and private businesses became frightfully aware of the fragility of our buildings and infrastructure, even those built to modern code.

In January 1972 the Office of Emergency Preparedness published The Disaster Preparedness Study, which stated: "Land use and construction regulations containing strong disaster mitigation features can in the long run alleviate losses caused by natural disaster." The National Workshop on Building Practices for Disaster Mitigation was held

[2]Senior Engineer, Real Estate and Construction Staff, International Business Machines Corporation.

during August/September 1972. The proceedings of that workshop was published 1973.

One of the many recommendations was that top priority be given to updating seismic codes to bring practice into line with the current state of knowledge. The National Academy of Sciences study, Earthquake Prediction and Public Policy was published in 1975. One year later the Earthquake Prediction Council was created within the U.S. Geological Survey.

The genesis of IBM's seismic program was the formation of a Policy Committee on Seimic Prediction at our San Jose, California, plant during the mid 1970s. Discussions with structural consultants, geologists, sociologists, and disaster preparedness specialists covered such topics as seismic prediction, building standards, safety practices, and personnel and public relations issues. Realizing that the idea of reliable earthquake prediction was some time in the future, it was decided that the best preparation for the advent of earthquake prediction must include preparedness for the earthquake itself. To that end recommendations were to develop detailed emergency control plans and perform an engineering review of all facilities and equipment at San Jose to determine their vulnerability to earthquakes.

The IBM San Jose site is located approximately 50 miles southeast of San Francisco. The site now contains several million square feet of office, manufacturing, development laboratory, and warehousing space. The site is located between the San Andreas Fault on the west and Calaveras Fault on the east, with numerous other smaller faults within a short distance.

The engineering review was a two-phase program. The first phase was a broad review of all buildings and equipment at the site. The second phase was a detailed investigation of specific buildings based on the outcome of the phase one review. Also, at that time, the projected seismic activity along the faults that would affect the site was developed. Seismic activity was developed for a "probable occurrence" and a "credible occurrence" earthquake. The probable occurrence event was used to define an earthquake that can reasonably be expected to occur during the lifetime of the building. The credible occurrence event was based on the fact that there was geological evidence from nearby faults of known seismic history to indicate that such an earthquake may occur at the site.

In June 1978 the Applied Technology Council published ATC 3-06, titled Tentative Provisions for the Development of Seismic Regulations for Buildings. The Applied Technology Council is a nonprofit corporation established in 1971 through the efforts of the Structural Engineering Association of California. ATC 3-06 was prepared under contract with the National Bureau of Standards with funding from the National Science Foundation. The document is also known as NBS Special Publication 510. The methods, procedures, and philosophy developed were the basis for seismic thinking during the decade that followed. The basic philosophy is that in the event of a severe earthquake, life safety is the paramount consideration in the design of buildings. Seismic design regulations should enable most buildings to resist minor earthquakes without damage, resist moderate earthquakes without significant structural damage but with some nonstructural damage, and resist a major or severe earthquake without failure of the structural framework of the building or its component members and to maintain life safety.

One year later IBM's Environmental Planning Department at our San Jose plant issued Earthquake Resistant Design and Construction Standard or ERDACS. This document provided a more site-specific look at requirements for San Jose and generally followed the methods of ATC 3-06. In addition to life-safety concerns, the effect of an earthquake on business operations was taken into account. The document has undergone several revisions over the years. Seismic design criteria for two levels of earthquakes, moderate level and severe level are identified for the San Jose site. Buildings and other structures, equipment, and nonstructural components are classified in one of three seismic categories to facilitate a different level of design for systems that have a different level of life safety or economic importance (Table 1).[3]

Seismic design criteria for San Jose and the remainder of the corporation are defined in our Corporate Facilities Practice, titled Earthquake Resistant Design. Corporate Facilities Practices are issued by the Real Estate and Construction Staff to specify IBM's real estate procedures and define corporate design objectives and criteria. This

[3]Tables and figures are at the end of the paper.

specific practice identifies geotechnical and seismic exposure investigation criteria and design basis earthquake requirements. A moderate-level earthquake has a 50 percent probability of being exceeded in 50 years. This corresponds to a return period of 72 years. A severe-level earthquake has a 10 percent probability of being exceeded in 50 years. This corresponds to a return period of 475 years. The criteria are now being revised to reflect a more global approach to earthquake resistant design. In the United States alone it has long been assumed that for engineering purposes, the only difference between the East and the West is the probability of occurrence for a given event. Differences between these areas include the cause of earthquakes, the definition of "hard" rock, the energy released during an event and the attenuation of that energy, the amplification through the soil, and the return period.

Seismic performance for the various categories of buildings, structures, and equipment under the two-level earthquake criteria are defined in the Corporate Facilities Practice and the San Jose EARDACS document (Table 2).

The seismic retrofit programs for two buildings at the San Jose site will be discussed.

RESEARCH LABORATORY

The Research Laboratory was designed in 1969 to the 1967 Uniform Building Code (UBC). The original laboratory has 256 KSF of floor area and is composed of four two-story buildings with partial basements that are arranged to form a triangle approximately 500 feet on a side. The structure is reinforced and posttensioned concrete framed with one-way joist/girder floors and roof. The lateral load resisting system is the concrete frame and the concrete slab/joist diaphragms, which transfer horizontal load to the frame. The foundations are spread footings.

The site-wide seismic review directed by the recommendations of the policy committee report was completed in 1977 and checked the buildings' compliance with the 1976 UBC. The seismic performance of the building was found to be poor, primarily because the design of the building predated the requirements for ductile frame design. A more detailed investigation was undertaken. Although not damaged after the August 6, 1979, magnitude 5.8 Coyote Lake earthquake, a seismic upgrade program was started. This was a three-phase program to establish criteria and concepts and, finally, the detail design.

The design criteria used the 1979 UBC as the minimum requirements and established site-specific criteria for the San Jose site. The moderate-level earthquake initially had a peak ground acceleration (PGA) of 16 percent of gravity. This was later changed during the detailed concept analysis to 20 percent. During this level of earthquake, there would be no yielding of the structure and no structural damage. The major or severe-level earthquake used 30 percent and 40 percent of gravity PGA for the various elements. Under this loading there could be some residual distortions but no collapse of the structure.

The concepts investigated included an internal scheme using shear walls, a buttress scheme using large exterior buttresses to limit lateral movement of the existing building, and a new building concept (Figure 1). The internal and buttress schemes were dropped from consideration because of disruption to operations within the lab, which would be kept in operation during the upgrade, and for aesthetic and economic reasons. The new building concept placed new buildings around and between the various existing buildings that made up the laboratory complex. The area between the existing buildings and the new structures is an open courtyard. The structural framing of these new buildings would limit the movement of the existing concrete buildings and transfer the lateral loads to new drilled pier foundations (Figures 2 and 3). The new structure was attached to the existing with horizontal bracing at two levels that was through-bolted into the existing concrete frame.

The final design added 113 KSF floor area to the building. Initial occupancy took place 14 months after the start of construction, with final occupancy taking an additional year. The work included an upgrade to the cafeteria and a new curtain wall for all exterior exposed surfaces.

ADMINISTRATION BUILDING

The main site lobby and administration offices are located in a building designed in 1968 to the 1964 UBC. The building is a five-story structure containing 266 KSF of floor area. The square building, approximately 225 feet on a side, has a second-story terrace and a nonstructural central core (Figure 4). The structure is a reinforced concrete frame with waffle slab floors and roof. The lateral load-resisting system is composed of the frame and the floor and roof diaphragms. Foundations are spread footings.

The site-wide seismic review found that the building was not in compliance with the then-current UBC. The construction of this building also predated the requirements for a ductile moment frame. However, structural analysis based on site-specific criteria indicated that the building would be damaged but would not collapse during a major earthquake. There was no damage to the building following the August 1979 Coyote Like earthquake. In 1981 an experimental study was performed to determine the dynamic characteristics of the building. The results of the study showed that a "soft story" existed at the second floor. A soft story is a story having a lateral stiffness less than 70 percent of the stiffness of the story above. This type of condition was responsible for some of the problems encountered by the Olive View Hospital during the San Fernando earthquake of 1971. A detailed analysis was completed in 1984 about the time of the April 24, magnitude 6.2, Morgan Hill earthquake along the Calaveras Fault. The building exhibited the soft-story response noted during the experimental study, and the building experienced some inelastic deformations because of the earthquake. Based on the detailed analysis and the effects of the earthquake, personnel were relocated and a seismic upgrade program was initiated.

Design criteria for the upgrade was similar to the Research Laboratory criteria. Moderate level earthquake criteria were 20 percent of gravity PGA, severe-level earthquake criteria were 40 percent of gravity PGA.

Concepts that were developed included both internal and external schemes. A large number of underground utilities entered the building. Also located within this building was a critical telecommunications facility that had to be kept in operation during the upgrade. The internal schemes included the addition of braced steel frames and the use of base isolation (Figure 5). External schemes included structures built on two sides and four sides of the existing building (Figure 6).

The final design was a new braced steel structure onthe east and west ends of the existing building. Nine braced bays were located on each side. In the north-south direction one braced line was provided on each addition adjacent to the exterior column line of the existing building (Figure 7). Attachment between the new and existing buildings used epoxy adhesives and through-bolts. Prestressed concrete piles were used in the new foundation, which had 6-foot-thick pile caps and grade beams. A total of 133 KSF of floor area was added to the building. A new site lobby was built on the first floor, and a new curtain wall enclosed the existing building and new additions. Final occupancy was completed 29 months after the start of construction.

TABLE 1
SEISMIC CATEGORIES

Category	Buildings	Structures	Equipment
I	Process large amounts of hazardous materials. Safety related. Lifeline or power generation.	Emergency siren tower. Cooling towers. Support Category I equipment	Fire, communications, security. Piping and tanks which contain hazardous materials. Manufacturing equipment which uses hazardous materials.
II	Office Manufacturing Laboratory	Support Category II equipment	Essential to manufacturing process
III	Non-production warehouses	Support Category III equipment	Small diameter piping that contains non-hazardous materials

TABLE 2
SEISMIC PERFORMANCE REQUIREMENTS

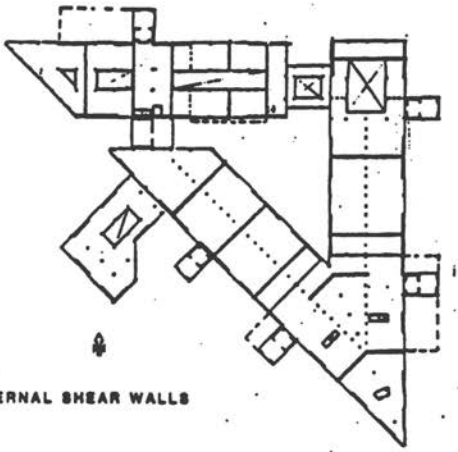
Seismic Category	Design Basis Earthquake		
	Minimum	MLE	SLE
I	Requirement 1		Requirement 2A & 3
II	Requirement 1	Requirement 2B	Requirement 3
III	Requirement 1		

MLE: Moderate level earthquake
SLE: Severe level earthquake

Requirement 1: Conform to seismic requirements of UBC and any other applicable design code or regulation.

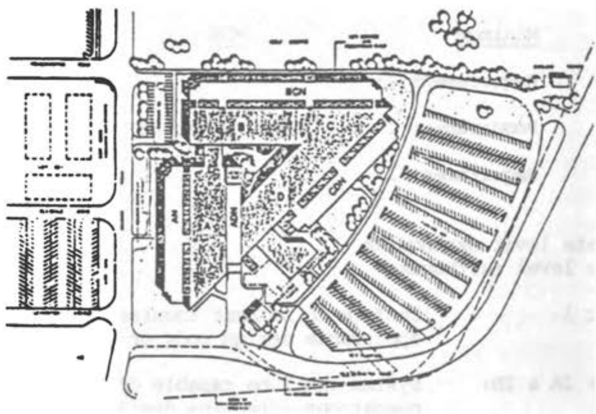
Requirement 2A & 2B: System shall be capable of immediately resuming operations after the design-basis earthquake.

Requirement 3: System shall remain stable and shall not sustain life-threatening damage.



INTERNAL SHEAR WALLS

BUTTRESS



NEW BUILDING

FIGURE 1 RESEARCH LABORATORY - CONCEPTS

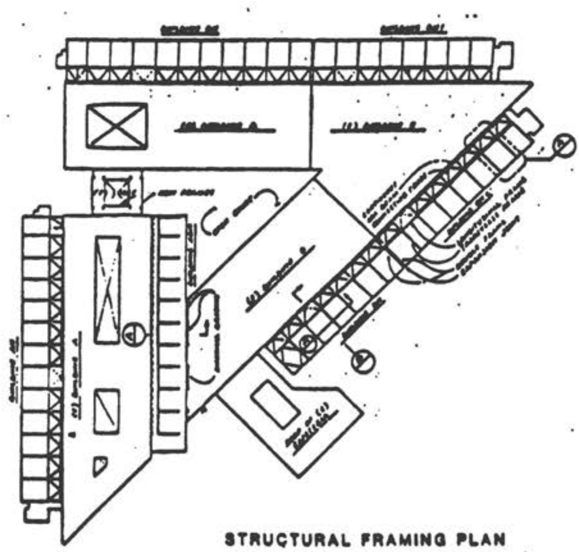


FIGURE 2 RESEARCH LABORATORY - STRUCTURAL PLAN

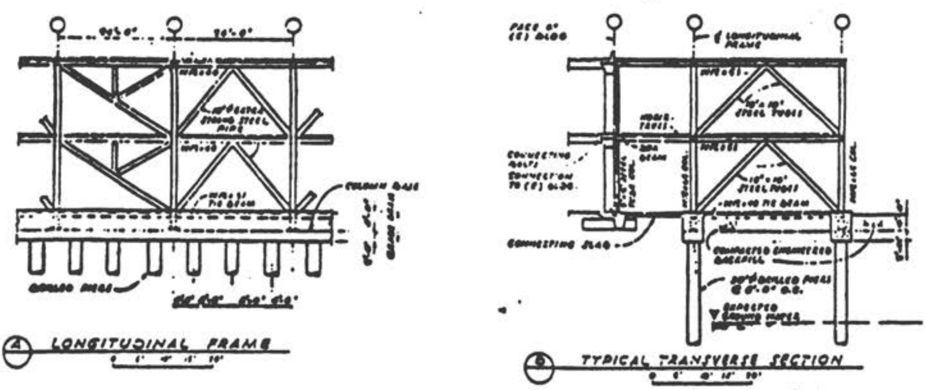
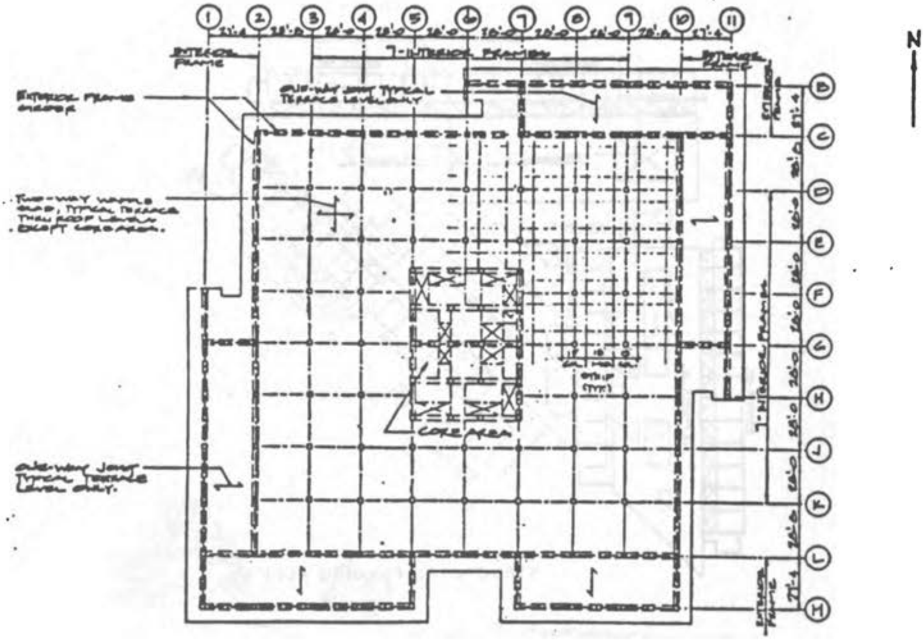
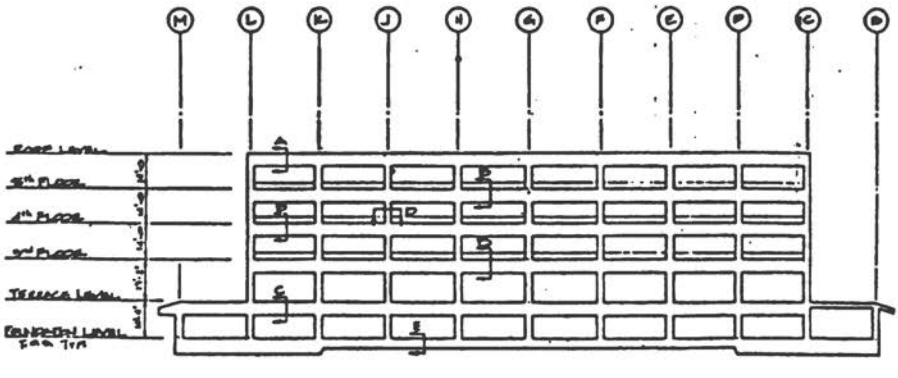


FIGURE 3 RESEARCH LABORATORY - STRUCTURAL SECTIONS

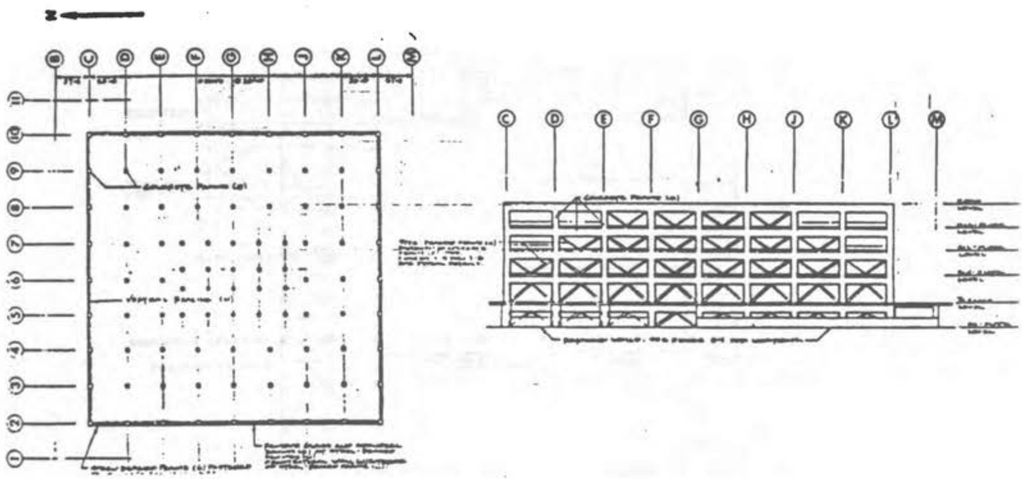


TERRACE LEVEL

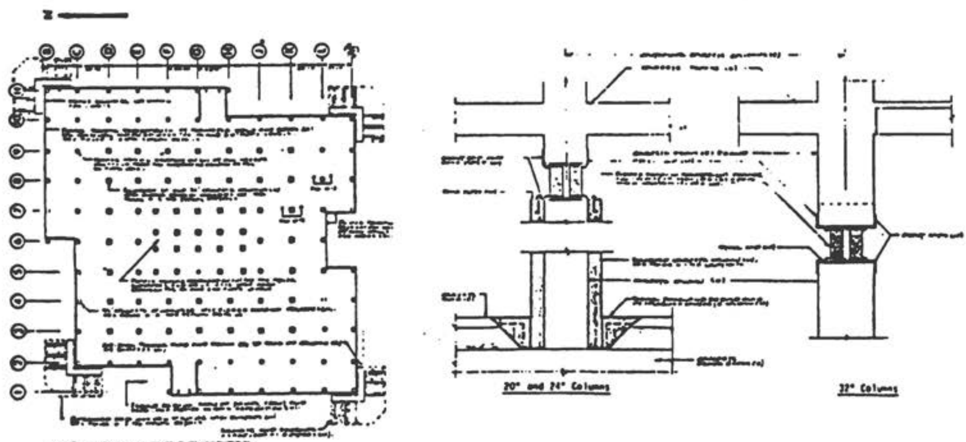


ELEVATION

FIGURE 4 ADMINISTRATION BUILDING - PLAN AND ELEVATION

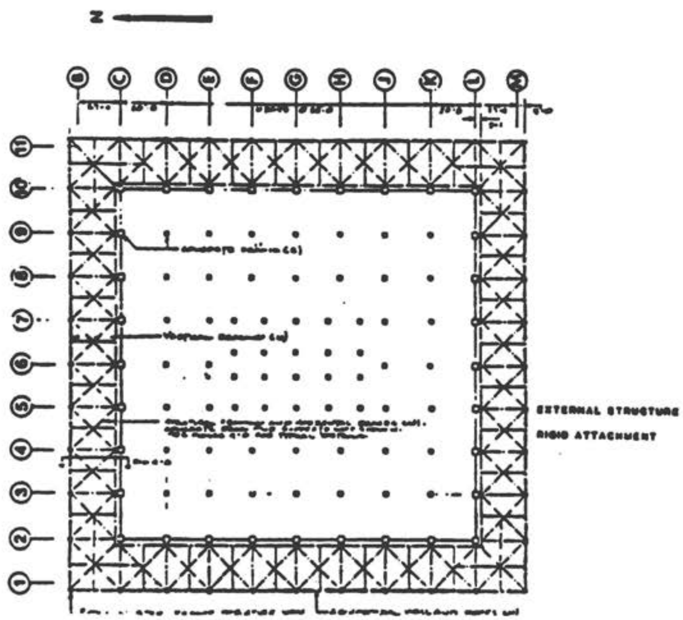


BRACED STEEL FRAME



BASE ISOLATION

FIGURE 5 ADMINISTRATION BUILDING - INTERNAL CONCEPTS



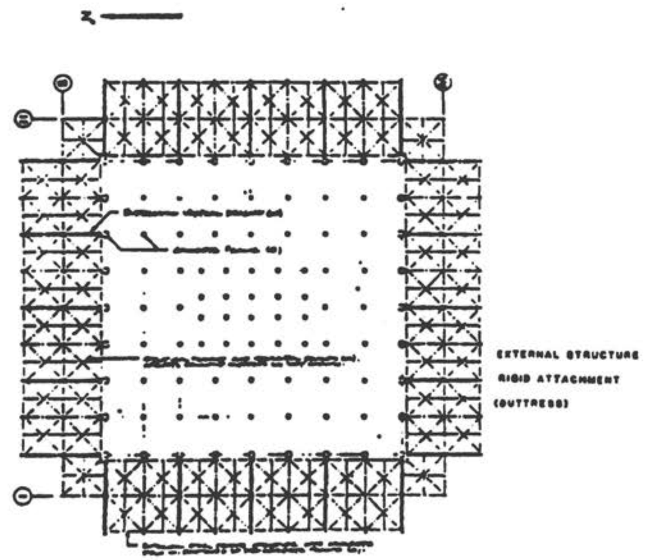
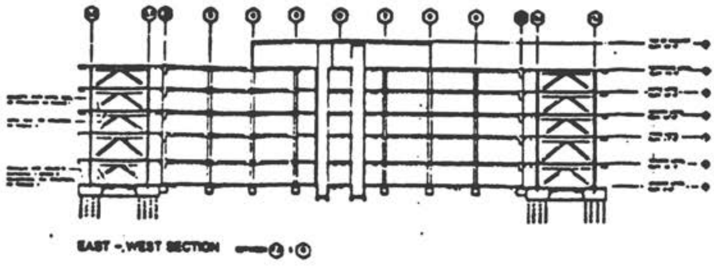
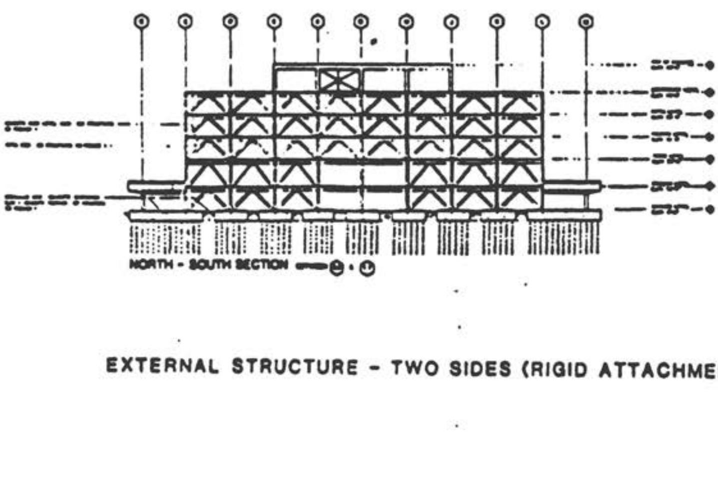


FIGURE 6 ADMINISTRATION BUILDING - EXTERNAL CONCEPTS



EXTERNAL STRUCTURE - TWO SIDES (RIGID ATTACHMENT)



EXTERNAL STRUCTURE - TWO SIDES (RIGID ATTACHMENT)

FIGURE 7 ADMINISTRATION BUILDING - FINAL DESIGN

THE LAWRENCE BERKELEY LABORATORY SEISMIC SAFETY PROGRAM AND THE LOMA PRIETA EARTHQUAKE OF OCTOBER 17, 1989

Donald G. Eagling
Lawrence Berkeley Laboratory

The Lawrence Berkeley Laboratory (LBL) initiated a comprehensive seismic safety program in 1971 immediately following the destructive San Fernando Earthquake. Since then, 34 buildings have been strengthened, emergency facilities and life-lines hardened, nonstructural elements and equipment braced, and emergency response provisions and operations improved significantly.

The 7.1 magnitude Loma Prieta earthquake, centered about 65 miles south of Berkeley, produced .12 g ground acceleration on the Hill at LBL as opposed to .65 g near the epicenter. This 15-second earthquake caused only nonstructural damage at LBL because those buildings susceptible to structural damage from minor ground shaking had been strengthened. For example, two of LBL's major laboratory buildings would have sustained diagonal tension cracking in brittle reinforced concrete bearing-wall window piers if they had not been buttressed to prevent damaging deflections. In the aftermath of the earthquake, it would have been mandatory (as it was for the Oakland City Hall) to evacuate these two buildings and find 130,000 GSF of laboratory and office space off site to lease for 350 people. It would have then taken 2 years until these buildings could be repaired and strengthened before they could be reoccupied. It is estimated that research would have been disrupted for about 1 year in this process. Not counting the loss of research time, DoE would have suffered a loss of approximately $30M if these two buildings had not been buttressed.

Including other facilities that would have also suffered structural damage, it is estimated that the LBL Seismic Safety Program saved DoE over $50M in total at a cost of less than $4M expended over a period of 15 years following 1971.

LBL plans to spend another $10M over the next few years to complete its seismic upgrade program in preparation for the "big one". In the meantime, the work accomplished has produced large dividends for DoE.

[The visual aids used in Mr. Eagling's talk follow.]

LBL Physical Data

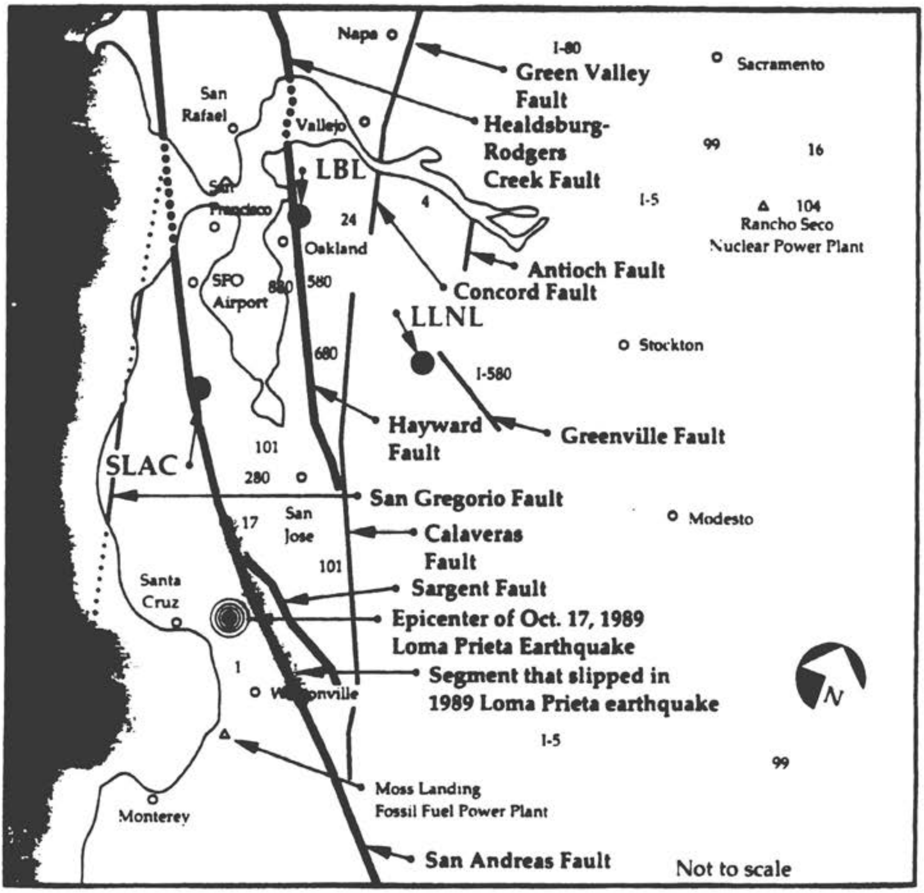
- **130 acre main-site on hill above UC Berkeley (80 Buildings)**
- **2.11 million gross square feet (mgsf) of total space**
  - **1.60 mgsf on the main site**
  - **.37 mgsf on the UC Berkeley campus**
  - **.14 mgsf in off-site leased space**
- **Total population of 3,943 including visitors**
  - **3,055 on the main site**
  - **770 in UC Berkeley campus buildings**
  - **118 in off-site leased space**

Seismic Safety Program
Construction 1971 Through 1990

- 34 buildings strengthened
- New fire station
- 4 buildings evacuated and demolished
- Trailers tied down
- Emergency facilities hardened
    - 3 command centers
    - 2 medical centers
- Hazardous materials, seismic retrofits
    - Radioactive storage vault
    - Tritium Labeling Facility
    - Air handling equipment for isotope systems
    - Propane tank
    - Plating shop tanks
- Shielding blocks tied down based upon shaking table research
- Life lines
    - 3 alternative water service lines from 2 municipal sources
    - 2 - 200,000 gal water tanks and emergency pumping stations constructed on site in case municipal sources are lost
    - Earthquake shutoff valves installed in natural gas lines
    - Electrical transformers tied down
    - Underground site utilities moved out of unstable ground
    - Communications systems tied down
- Hillside stability
    - 15 landslides stabilized
- Miscellaneous
    - Elevator guide rails braced
    - Hung ceilings braced
    - Crane runway "keepers" added
    - Building equipment tied down
    - Experimental equipment tied down
    - Machine tools, cabinets, book cases, movable partitions tied down
    - Entrance canopies strengthened
    - Earthquake damping systems for major electron microscopes

Elements of the LBL Seismic Safety Program

- Formal design criteria
- Independent third party reviews of designs
- Review of existing buildings and facilities
- Review of operational seismic hazards
- Site seismicity study and geological map
- Site specific time history response spectra
- Strong motion seismograph instrumentation
- Slope stability investigation of LBL site
- Slope stabilization program
- Model earthquake scenario for emergency planning
- Earthquake emergency preparedness and recovery program
- Structural rehabilitation program
- Tie down program
- Shaking table research (shielding blocks)
- Procedures for noncode seismic criteria
- Membership in ICBO (Uniform Building Code)
- Seismic Safety Committee



Active faults local to the San Francisco Bay Area

LBL Seismic Design Criteria
Dynamic Analysis

"BOLTQUAKE" July 1979 by Bruce Bolt

Site Specific Synthesis of Hayward Fault Time Histories

- Magnitude 7-1/4

- Peak ground acceleration of 0.7g horizontal, 0.4g vertical

- Maximum credible earthquake physically feasible at LBL

- Includes longer period pulse following the S wave arrival that models the "fling" of fault rebound as the rupture goes by the site (very near field)

- Bolt's evaluation of "BOLTQUAKE" after Loma Prieta Earthquake

  - Checks well with near field records at Loma Prieta

  - Conservative for design of short period buildings and structures in near field

Seismic Risk Assessment
Comparison DOE and LBL Design Criteria for Dynamic Analysis

	DOE Facility Use Categories			
	I General Use Facilities	II Important or Low Hazard Facilities	III Moderate Hazard Facilities	IV High Hazard Facilities
Hazard Exceedance Probability	2×10^{-3}	1×10^{-3}	1×10^{-3}	2×10^{-4}
Return Period, Yrs	500	1,000	1,000	5,000
Performance Goals	1×10^{-3}	5×10^{-4}	1×10^{-4}	1×10^{-5}
Return Period, Yrs	1,000	2,000	10,000	100,000
Performance Goal Exceedance Probability	2	2	10	20
DOE Criteria Max Acceleration LBL Site	0.55	0.64	0.64	Not Available from DOE Reference
LBL Criteria* BOLTQUAKE Max Acceleration	0.70	0.70	No Category III Facilities	No Category IV Facilities
DOE Peer Review Guideline	Not Required	Not Required	Required	Required
LBL Peer Review Guideline	Required	Required	No Category III Facilities	No Category IV Facilities

*Maximum Creditable Earthquake on Hayward Fault

Table 2-1 Usage Category Guidelines

Usage Category	Description
General Use Facilities	Facilities that have a non-mission-dependent purpose, such as administration buildings, cafeterias, storage, maintenance and repair facilities which are plant- or grounds-oriented
Important or Low Hazard Facilities	Facilities that have mission-dependent use (e.g., laboratories, production facilities and computer centers) and emergency handling or hazard recovery facilities (e.g., hospitals, fire stations)
Moderate Hazard Facilities	Facilities where confinement of contents is necessary for public or employee protection. Examples would be uranium enrichment plants, or other facilities involving the handling or storage of significant quantities of radioactive or toxic materials
High Hazard Facilities	Facilities where confinement of contents and public and environment protection are of paramount importance (e.g., facilities handling substantial quantities of in-process plutonium or fuel reprocessing facilities). Facilities in this category represent hazards with potential long-term and widespread effects

Table 2-3 Performance Goals for Each Usage Category

Usage Category	Performance Goal Description	Performance Goal Annual Probability of Exceedance
General Use	Maintain occupant safety	10^{-3} of the onset of major structural damage to the extent that occupants are endangered
Important or Low Hazard	Occupant safety, continued operation with minimal interruption	5×10^{-4} of facility damage to the extent that the facility cannot perform its function
Moderate Hazard	Occupant safety, continued function, hazard confinement	10^{-4} of facility damage to the extent that the facility cannot perform its function
High Hazard	Occupant safety, continued function, very high confidence of hazard confinement	10^{-5} of facility damage to the extent that the facility cannot perform its function

Seismic Design Criteria
Static Analysis

Basic Premise

M7.2 Earthquake on Hayward Fault

M8.3 Earthquake on San Andreas Fault

	LBL Criteria	1988 UBC	DOE Criteria
Equivalent Static Lateral Force Base Shear			
General Use Facilities	.20W	.14W	.15W
Essential, Important Low Hazard Facilities	.28W	.18W	.21W
Non-structural Elements (Mechanical, Electrical, Architectural, Machinery, etc)	.50W	.30W	.41W
Research Equipment Using Highly Toxic Materials	2.00W	.45W	.72W
Static Base Shear for Shielding Blocks			
Non-ductile Bracing Systems	0.70W	-	-
Ductile Bracing Systems	0.50W	-	-

The Loma Prieta Earthquake
Near Santa Cruz
October 17, 1989
Effects at LBL

- **Ground acceleration**

  Horizontal E-W = 12%g, N-S = 5%g

  Vertical = 4%g

- **No structural damage**

- **Non-structural damage:**

  Building 90

  Spalling plaster in stairwells

  Fluorescent bulbs and light lenses fell

  Building 72 High Voltage Electron Microscope

  Internal displacement of aluminum equipotential rings

  Special seismic damping system worked

  Building 51 Irradiation Stereotactic Apparatus for Humans

  Minor damage to adjustment mechanism

Loma Prieta Earthquake Triggered Backlog of Concern for Liability

- Engineers have become more vocal about building types that are hazardous

- Owners and managers have become more aware of their corporate and personal liabilities

- When earthquake damage reveals a building is a potential collapse hazard, evacuation is dictated by concerns for liability

- The costs of relocating people and operations are high

- Disruptions to programs and operations can be very serious

- Examples

    Capwells Oakland

    Stanford University

    Oakland City Hall

The Loma Prieta Earthquake, October 17, 1989

What if LBL Had Not implemented Its Earthquake Safety Program?

- **Buildings 50A and 50B would probably have to be evacuated due to cracks in bearing wall window piers**

  350 people including research laboratories would be displaced for about 2 years

  Space requirement 130,000 GSF off site

  Research disruption about 1 year

  Probable costs

5M$	Lease, modifications, moving
5M$	Repairs to Buildings 50A and 50B
20M$	Lost time (wages)
30M$	Total

- **Building 25 would have sustained structural damage**

  31 people including Mechanical Technology Shop and Printed Circuit Shop would be displaced for about 2 years

  Space requirement 20,000 GSF off site

  Probable costs

4M$	Lease, modifications, moving
10M$	New building
6M$	Lost time (wages)
20M$	Total

- **Building 55 rear addition would have sustained structural damage at back wall**

- **Probable collapse of reinforced concrete cantilevered entrance canopies at Buildings 50 and 70 (potential personal injury or death to someone exiting)**

Benefit Cost Ratios For Loma Prieta Earthquake ($K)

- **Buildings 50A and 50B Seismic Bracing**

Cost Avoidance	30,000
Project Cost (1990 $)	1,500
Benefit Cost Ratio	20
Replacement Cost	60,000

- **Building 25 Seismic Bracing**

Cost Avoidance	20,000
Project Cost (1990 $)	350
Benefit Cost Ratio	57
Replacement Cost	12,000

Seismic Safety Program
To Do List

- Stabilize landslides above the Bevatron (Building 51) and Mechanical Shops (Building 77). Scheduled for FY 1990 start

- Stabilize landslides below either end of Building 90. Scheduled for FY 1992

- Complete mitigation of non-structural hazards in Building 90. Scheduled for FY 1990 and 1991

- Add external bracing system to stiffen Building 90 against seismic deflections. Scheduled for FY 1991

- Building 10 Phase II Seismic Rehab (Phase I completed)

- Free columns trapped in concrete shielding at the Bevatron

- Continue to tie down shielding blocks when experimental modifications take place

- Continue to inspect building contents for non-structural hazard mitigation

Getting the Job Done

- Usually, poor building construction is simply the result of not implementing what has been known about earthquake engineering for many years

- Hazardous buildings are often typical types well known to earthquake engineers

- Most hazardous deficiencies in existing buildings are relatively simple to diagnose

- Sophisticated analyses of existing buildings are normally unnecessary for diagnosis

- Standard solutions are available for strengthening some hazardous building types

- Many buildings can be strengthened from the outside minimizing disruption to internal uses

- The key to low cost analysis and strengthening is to utilize structural engineers who have observed damaged buildings in the aftermath of earthquakes

Earthquake Preparedness
Planning Premises

- Major Earthquake on Hayward Fault

- All Entrances Blocked by Slides or Fault Movement

- Internal Road System Temporarily Blocked by Landslides

- Power and Gas Outages

- No Outside Help for 2 to 3 Days

- LBL Professional Emergency Units Overwhelmed with Multiplicity of Fires, Injuries and Spills

- Self Help Critical to Occupants of Buildings for Several Hours

Emergency Preparedness
Summary Outline

- Formal site wide emergency plan
- Formal emergency plans for each facility
- Building manager system
- Emergency command and medical centers

  Hardened for seismic resistance
  Emergency power
  Emergency provisions
  Training

- Mobile command center (Protective Services)
- Hardened fire station on-site
- Cafeteria emergency provisions
- Strategically stored emergency equipment and supplies
- Emergency response teams (multi-disciplinary)
- Lateral Force Systems Manual for each building
- Helicopter landing
- Annual emergency exercises

Earthquake Preparedness
Emergency Organizations

- **Professional Response Departments (In-House)**
  - Fire Station
  - Police
  - Medical
  - Environmental Health and Safety
  - Plant Engineering
  - Construction and Maintenance
  - Transportation
  - Communications
- **Emergency Command Centers (3)**
- **On-site Emergency Medical Centers**
  - Medical Services, Upper Hill Building 26
  - Secondary Resource, Lower Hill, Building 55
    Research Medicine Division
- **Off-site Medical Assistance**
  - Donner Lab (LBL/Campus)
  - Cowell Hospital - Reciprocal Aid Agreement
  - Alta Bates Hospital - Memo of Understanding
  - CALSTAR Med-Evac Helicopter Service

Earthquake Preparedness
Provisions for Self Help

- **Building Manager Organization and Training**

  Labwide Emergency Plan

  Building Manager; Deputies for Each Building

  Assistants for Floors or Wings of Larger Buildings

  336 Individuals in the Building Manager System

  Emergency Plans for Each Building

  Training

  First Aid, CPR, Earthquake Safety
  Use of Fire Extinguishers and Hoses
  Annual Earthquake Response and Evacuation Drill

- **All Employees**

  Earthquake Awareness Month

  Available Training

  Earthquake Safety
  CPR
  First Aid
  Use of Fire Extinguishers and Hoses

Earthquake Preparedness
Emergency Equipment and Supplies

- Rescue and First Aid Equipment Boxes (22)
- Communications

  On-site Telephone System

  FM Radios on 8 Nets

  Radio Page System via Telephone Access

  Labwide Public Address System
- Emergency Supplies Storage
- Personnel Trained In Shelter Management

Earthquake Preparedness
Auxiliary Response Teams

	No. of People
• Amateur Radio Team	9
• Firefighting Team	7
• Ambulance Team	2
• Traffic Team	19
• First Aid Team	20
• Multi-discipline Building Inspection Teams	32
• Heavy Rescue Rigging Team	4