EXPECTED SEISMIC PERFORMANCE OF BUILDINGS

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INTRODUCTION

Tens of millions of us spend much of our lives in the buildings and structures where we work, reside, worship, and go for entertainment, relaxation, or medical care. Local and state government elected officials and administrators adopt and enforce the codes and standards governing the design and construction of these buildings. Insofar as building safety is concerned, these codes are the "law of the land." The seismic design provisions of the codes are especially important to the performance of buildings in areas subject to earthquakes. We have a right to know how the buildings we occupy will perform in earthquakes.

The Earthquake Engineering Research Institute, a national professional organization dedicated to improved earthquake resistant design, prepared this document. Its purpose is to help policy-makers, code administrators, and others involved in the design, construction, and building maintenance processes understand how the seismic design provisions of the codes, knowledge and practices of our architects and engineers, and quality of construction affect the thousands of buildings of various types, sizes, and designs that we use daily. This paper attempts to establish expected levels of damage for buildings built to the 1991 Uniform Building Code (UBC 91), under various earthquake conditions.

First, we must dispel a myth: There is no "earthquake-proof" building. Although we are continuously improving our understanding of earthquakes and how buildings perform, there are limitations to building codes. Many older buildings were not built for earthquake resistance, and codes do not apply to many aspects of construction and use. As a result, we must expect losses from future earthquakes. These losses may take many forms: total or partial collapse due to shaking and ground failures, interior damage to nonstructural systems and elements, and damage to contents and equipment. While failures receive great media attention, we are heartened by the greatly improved performance of newer buildings constructed to recent building codes. But even new buildings are not immune to damage. Given the wide range of building types, site conditions, and earthquake characteristics, the performance of all building, even new ones, will not be the same. Many new buildings may suffer damage in a major earthquake, and a few should be expected to suffer serious damage.

The following sections cover the most important aspects that influence building safety. They include a discussion on earthquake causes and the accompanying shaking, fault rupture, and other ground failures. A brief summary is provided of common strategies for reducing earthquake hazards through planning, locating structures, and regulating construction. Building codes will be described in detail and the expected earthquake performance of new buildings built to the UBC 91 or older unreinforced masonry buildings retrofit to the 1991 Uniform Code for Building Conservation (UCBC) will be discussed. Initially, damage estimates have been limited to buildings in UBC Zone 4, because of the high probability of seismic events and the corresponding interest in this kind of information in this zone.

BACKGROUND

The crust of the earth, although solid and monolithic in appearance, is actually made of many individual pieces called plates. Continuous cooling and movement of the earth's molten interior forces surface plates to move, relative to each other. Some movement occurs gradually along certain plate boundaries—but most often, the plates stick together until the forces are large enough to cause sudden slippage, resulting in an earthquake. The slippage emits large amounts of energy in the form of waves that travel across the surface and through the interior of the earth, much like the waves emanating from a rock thrown into a still pond. Sometimes the slippage occurs along planes completely beneath the surface, as much as 15 miles deep, but often the boundary movement is visible, on the surface, in the form of horizontal or vertical offsets along surprisingly thin and straight lines. These offsets at the surface at plate boundaries are called surface fault ruptures.

Damage from earthquakes can be caused by the effects of surface fault rupture on structures built immediately over the fault, by (tsunami) sea waves caused by submarine ground failure, by the back and forth motion of the ground caused by the passing of waves (normally called ground shaking) or by the effects of soil failures (liquefaction or landslides) caused by the shaking. Additional damage can be caused by fires started by the shaking or by flooding from dam or reservoir failures.

Traditionally, control of construction practices through building codes has addressed only the shaking hazard. The hazards of seismic sea waves and surface fault rupture can best be reduced by planning and general avoidance of areas that are at risk. Areas prone to landslides similarly can be identified and avoided, although potential slides of small volumes may be stabilized with engineered structures. Liquefaction, the phenomena of certain wet sands turning essentially liquid when shaken, has been recognized as a potential seismic hazard for some time, but since accurate prediction is difficult, mitigation is often expensive, and the actual risk relatively undefined, code provisions in this area have been lacking. Hazards other than shaking can be mapped and should be included in the planning process. For example in California, all hazards are required to be mapped and incorporated into a community's General Plan as part of the Seismic Safety Element. Also in California, surface fault ruptures are mapped by the state as part of the Alquist-Priolo Special Studies Zones Act, designed to identify surface faults and potentially dangerous adjacent areas to each side of the fault.

Attempting to predict probable shaking at a site from a given earthquake is a complicated process and is influenced by the size of the earthquake, the distance from the source of slippage, the geology and topography of the path the wave travels between the source and the site, and the type of soil at the site. Building codes attempt to simplify this process by the use of broad zones, which influence the design criteria for seismic loading.

THE UNIFORM BUILDING CODE

The Uniform Building Code (UBC) is one of three model codes used by local and state jurisdictions throughout the United States to regulate construction of buildings. The UBC is most commonly used in the western and mid-western regions of the country including California and Utah. The UBC is updated annually and published every third year by the International Conference of Building Officials (ICBO). The principal issues that the building code addresses in its regulations are those of fire and occupant safety and structural adequacy. The regulation of the electrical, plumbing, and mechanical components of buildings are contained in separate, closely-related, companion codes.

The code's principal purpose as stated in its Administrative Chapter is:

> *"...to provide minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of buildings..."* (emphasis added).

For the Uniform Building Code to be effective in meeting this purpose it must be adopted as law and enforced through effective administration by a city, county or state government. During the adoption process jurisdictions may decide to modify certain code requirements to address unique local conditions that the model code did not consider as common or universally necessary. These changes are in most cases more restrictive than those found in the standard code provisions and hence enhance the level of safety provided.

Changes to the UBC can be proposed by any interested person but are normally suggested by groups of building officials who enforce the code, or by associations representing design professionals and other construction industry associations who use the code. The process for a proposed change to become part of the code is arduous and filled with opportunities for review and challenge. As a result of this careful, deliberative code change process, major changes may take as many as 10 years to successfully complete the full cycle of development, review, approval, publication, adoption, and enforcement.

The seismic provisions of the Uniform Building Code are of primary interest in this report. The UBC contains a map that locates the boundaries of six seismic zones in the US. These zones are based on scientific studies of the intensity of ground motion and damage patterns produced in past earthquakes and the location of the fault zones where these earthquakes have occurred. The six seismic zones within the Uniform Building Code are: 0, 1, 2A, 2B, 3, and 4. Zone 0 represents minimum seismic risk with higher numbers representing increasing risk up to Zone 4, the maximum seismic risk zone. (See Figure 1) The basis for this map as well as other seismic design requirements in the UBC is subject to review and change as better information on these subjects becomes available.

FIGURE 1 1991 UNIFORM BUILDING CODE

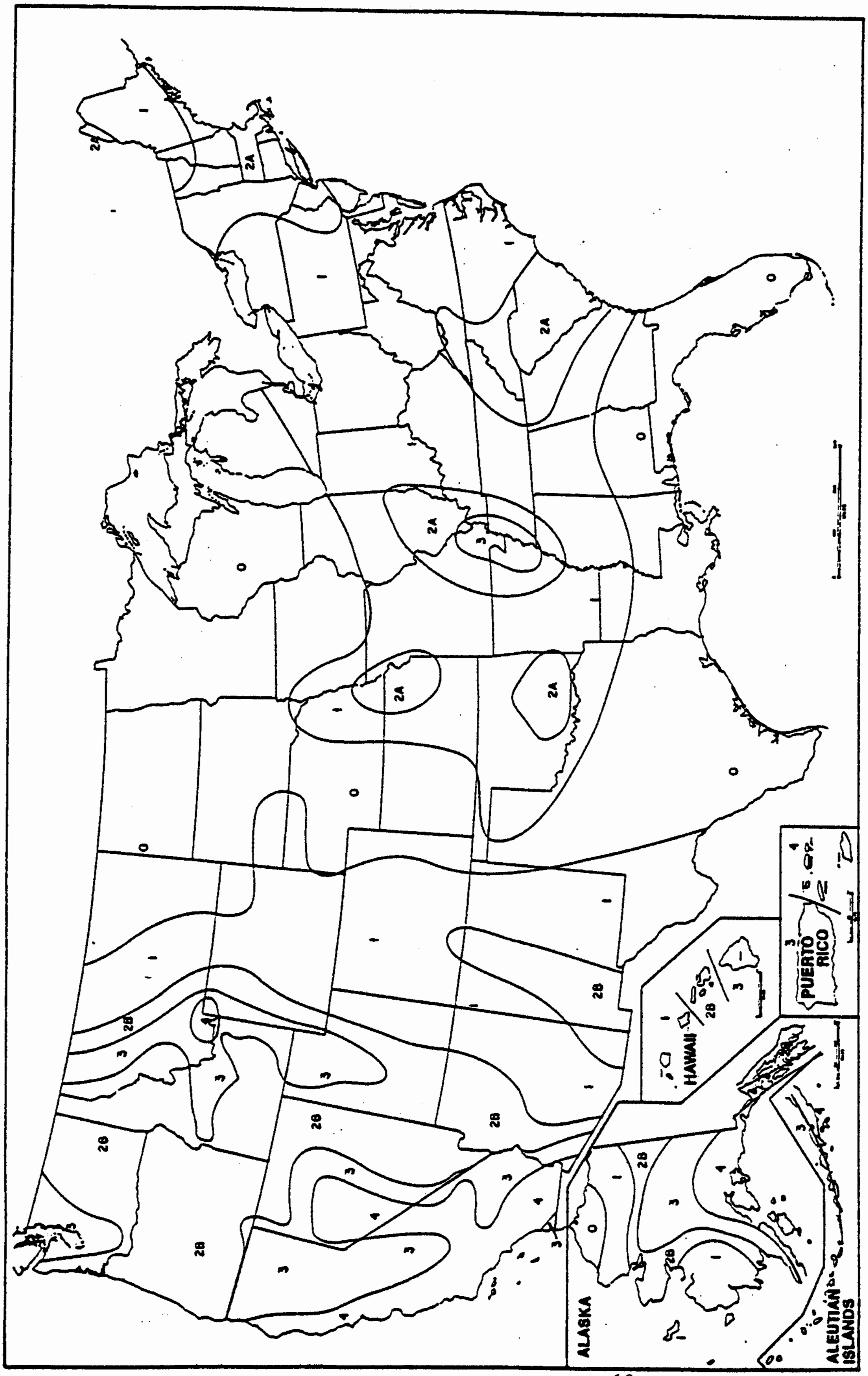


FIGURE NO. 23-2—SEISMIC ZONE MAP OF THE UNITED STATES

The seismic zone boundaries in the western U.S. have been revised twice since the 1979 edition of the UBC. Substantial changes in the zone boundaries took place in the 1988 edition partially based on the mapping prepared as a result of research conducted under the federally funded National Earthquake Hazards Reduction Program. The purpose of these changes was to provide a more accurate basis for successfully meeting the basic intent of the code. An additional seismic zone change, affecting southern Arizona, was approved in 1992.

Provisions for seismic-resistant design contained in the UBC were developed largely in response to the damage and casualties in past earthquakes. The 1933 Long Beach, 1940 Imperial Valley, 1952 Kern County, and 1971 San Fernando earthquakes made great impressions on code writers and structural engineers. The 1964 Alaska, 1979 Imperial Valley, 1985 Mexico City and 1989 Loma Prieta earthquakes also significantly influenced the thinking of the US structural engineering community regarding building performance.

In all of these earthquakes, buildings collapsed, lives were lost and injuries sustained. However, just as striking to the trained observer, and to building officials and code writers, was the observation that not all buildings collapsed. In fact, in spite of media emphasis on disastrous collapses in every one of these earthquakes, only a small minority of structures failed. And after each of these events, engineers learned valuable lessons and made changes to the building codes. Major improvements to the seismic design provisions were made in 1973 and again in 1988 to incorporate lessons that had been learned.

What has resulted from this series of landmark seismic events is a set of minimum requirements for the design of buildings that are likely to be subjected to seismic ground shaking. For the most part, the seismic design provisions were written by practicing structural engineers, who first looked at the patterns of failure and who then determined which changes in design practice would be necessary to avoid collapse. In many cases, they tried to answer the question of why one type of building failed, and another type directly across the street suffered only minor damage.

The design provisions that resulted were thus "empirical" in nature — as opposed to "rational." This means that they were developed less by the application of scientific principles, and more by judgement based on observation of what "worked" and what didn't work in structures that had been subjected to real earthquakes. The empirical provisions that were developed included requirements for providing minimum levels of strength and stiffness in a structure, and also some very prescriptive requirements governing the details of design and construction and intended to prevent collapse in the largest earthquakes.

Engineers who developed the early seismic provisions were impressed by the observation that many structures would distort, crack, yield and spall. However, as long as no weak links pulled loose or failed prematurely, the buildings, damaged though they might be, did not collapse and the occupants were usually unhurt. They observed that when controlled and distributed, this damage actually appeared to be effective in absorbing the energy of the earthquake, and thus, the damage actually helped prevent collapse and protected building occupants.

Two key conclusions can be drawn from the preceding discussion. These are as follows:

1. The primary intent of seismic design procedures contained in current building codes is to protect the life safety of building occupants.

2. Although seismic-resistant design procedures may reduce the severity of damage in small or moderate earthquakes, they do not prevent buildings from experiencing damage in large earthquakes, but actually presume damage, and indeed, rely upon it for protection of life safety

Reasonable trade-offs between initial cost of construction and damage in relatively rare earthquakes therefore have been a part of code development. The commentary to the Structural Engineers Association of California's booklet upon which the UBC provisions are based (SEAOC, 1988) gives the following expectations of seismic performance of code-designed buildings:

> *Structures designed in conformance with these Recommendations should, in general, be able to:*
>
> 1. *Resist a minor level of earthquake ground motion without damage;*
>
> 2. *Resist a moderate level of earthquake ground motion without structural damage, but possibly experience some nonstructural damage;*
>
> 3. *Resist a major level of earthquake ground motion having an intensity equal to the strongest either experienced or forecast for the building site, without collapse, but possibly with some structural as well as nonstructural damage.*

Although the goal stated above is to protect the life safety in any event that might be expected in California, the variables discussed above will occasionally combine to create a hazardous condition, even for buildings that "meet the code." Although variations in damage between apparently similar buildings are to be expected and forms an important part of an understanding of damage estimations, all variables cannot be considered in a simplified presentation of estimated damage.

The UBC addresses the design of new construction. The primary code does not specifically address the evaluation or the upgrade of older existing buildings in a comprehensive way. Exceptions to this generalization are the provisions contained in the Uniform Code for Building Conservation (ICBO 1991) that prescribe a minimum level of seismic retrofit for unreinforced masonry bearing wall construction. Similar provisions have been adopted by several cities, including Los Angeles. Few other standards exist for upgrading of older buildings.

By a wide consensus, unreinforced masonry (URM) construction, is one of the most dangerous types of construction present in our older cities. Not permitted in the most seismically active areas in California since the 1933 Long Beach earthquake, existing URM buildings, particularly in UBC Seismic Zone 4, must be considered hazardous and their occupants at great risk.

The UCBC-type provisions for the retrofit of existing unreinforced masonry buildings are less stringent requirements than are demanded for new construction, and were developed considering and balancing the expense of retrofit, the value of the existing building stock and the desired reduction in seismic risk. The code for new buildings had been described above as a minimum legal basis for design of buildings—one that provides a reasonable minimum assurance for life safety. The UCBC, therefore, should be expected to provide less than minimum assurance of life safety.

The UCBC-type URM retrofit provisions should, on a statistical basis, result in a major reduction in collapsed buildings and therefore in casualties. Studies have theorized that retrofit to UCBC provisions should reduce casualties by as much as one to two orders of magnitude (factors of 10 to 100). However, not only is there no "guarantee" of protection against damage, there is also no "guarantee" against collapse of individual retrofit URM buildings. The basis commonly used for strengthening URM buildings is thus not totally a "life safety" basis, but may legitimately be called a "risk reduction" basis.

SEISMIC PERFORMANCE ESTIMATIONS

Damage from any one earthquake in the United States has, in general, been highly variable. Buildings are usually found in many different states of damage, even in close proximity. This is because damage to any one building is dependent on many variables. The most obvious is the intensity of the shaking itself. Several factors, in turn, would be expected to affect shaking intensity, primarily the size of the earthquake (normally measured in Richter Magnitude) and the distance from the building to the portion of the fault that moved to cause the earthquake (the origin of which is called the epicenter). However, many other variables—individually or in combination—may also affect shaking as much as these two primary factors. The soil type under the building is now recognized to have a significant effect on shaking. In addition, shaking at a given site can be influenced by local geology and topography, all along the path from the earthquake source to the site.

In addition to variations in shaking itself, characteristics of structures, even of the same age, and designed using the same building code, will have a primary effect on damage levels. Combinations of structural materials (steel, concrete, wood), structural systems (braced frame, shear wall, moment frame), height, and architectural design create an endless variety of buildings; each will possess subtle differences that, when combined with the unique shaking at any one site in a given earthquake, can cause the variety of damage observed. Damage from earthquakes in other countries often leaves an impression of much more consistent damage patterns. This is often because there is far less variation in building shapes and types, and often the seismic resistance of the local construction is so far exceeded that damage is essentially complete. The Tangshan, China earthquake of 1976 destroyed thousands of very similar unreinforced brick masonry structures, and the Armenia earthquake of 1988 similarly destroyed many poorly reinforced concrete structures. The 1985 earthquake in Mexico City also may have been perceived to create complete destruction, but, in fact, most collapses were all of a similar building type, and all were located over an ancient lake bed; low rise buildings and buildings off the lake bed were practically unaffected.

The extent of damage to buildings can also be affected by the extent of code compliance, plan review, and quality of construction.

In order to present an understandable overview of expected damage to buildings, only the size of earthquake and the approximate distance from the earthquake source will be considered. All buildings are also assumed to be located on an intermediately hard soil—not rock as found in hilly areas, nor soft, saturated soils found near bodies of water.

In order to describe the estimated effect of earthquakes on code-designed buildings with these variations, and also consider the probable variations in damage discussed above, it is necessary to define several standardized states of damage, as shown in Table 1. These descriptions of states of damage do not include detailed conditions of building elements such as columns, beams, and walls, but rather place a building in certain categories with regard to risk of death or injury and the potential for continued use or extent of repair required for the building.

Table 1 - Proposed Damage States

A	No Damage -- could be shifted contents. Only incidental hazard.
B	Minor Damage to nonstructural elements. Building may be temporarily closed but could probably be reopened after minor cleanup in less than 1 week. * Only incidental hazard.
C	Primarily nonstructural damage; also could be minor but non-threatening structural damage; building probably closed for 2-12 weeks. Times are difficult to assign because they are largely dependent on the size of building; remote chance of life threatening situation from nonstructural elements.
D	Extensive structural and nonstructural damage. Long term closure should be expected, either due to amount of repair work or uncertainty on economic feasibility of repair. Localized, life threatening situations would be common.
E	Complete collapse or damage that is not economically repairable. Life threatening situations in every building of this category.

*Times are difficult to assign because they are largely dependent on the size of building.

Damage State A represents essentially no damage, although some amount of internal disruption could always occur due to planters, office furniture, bookshelves, or other items that are free to shift around during shaking. Although essentially no injuries would be expected in these buildings, there is always a remote possibility that shaking objects could shift or topple in such a way as to cause an "incidental" hazard. It would be expected that these buildings could be reused immediately.

Damage State B would include the shifted contents discussed in State A, but in addition some permanent building elements such as ceilings, lighting fixtures, or partitions may be slightly damaged. Damage may require clean-up and minor repair to the extent that the building cannot be normally used immediately. Only incidental hazard to occupants could be expected.

Buildings in Damage State C would suffer more extensive damage to internal elements, and may also have minor structural damage such as cracks in concrete or masonry walls. However, the building would not be considered in any danger of structural failure, but a slight risk of injury would be presented by fallen ceilings, light fixtures, or other equipment. The damage would be sufficient to require repair, and the building could be partially or completely closed by the Building Department pending repairs. Partial closure would be expected in any case while repairs and clean-up are completed. Photographs 1 and 2 show the type of damage that may be characteristic in State C.

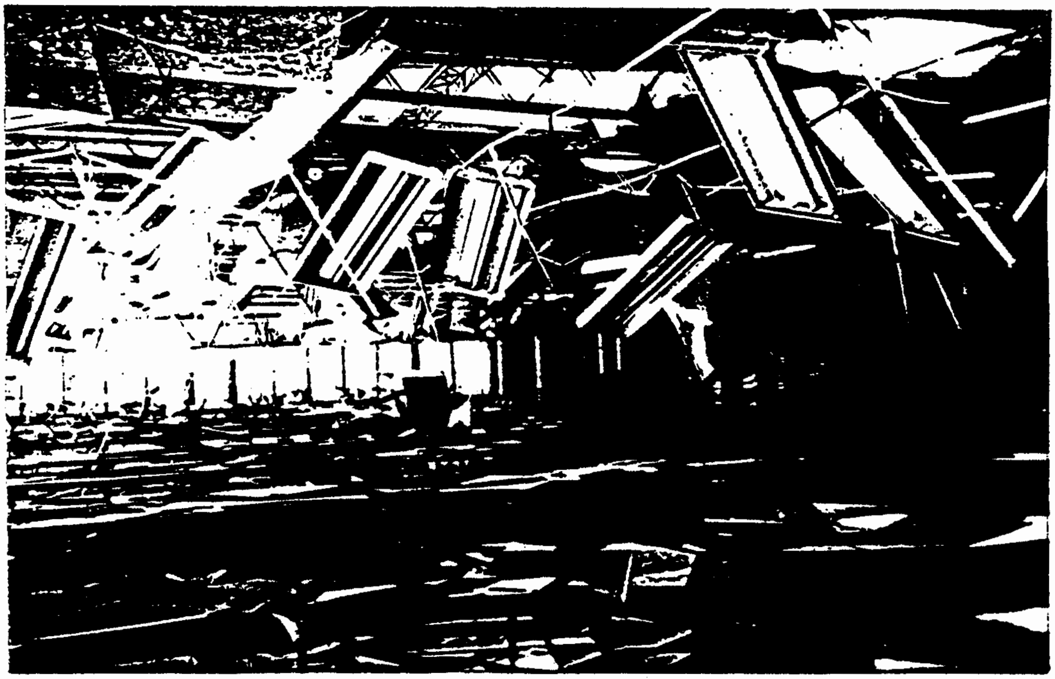
Damage to structural elements of the building such as walls, columns and beams would be expected in Damage State D. Buildings may be leaning or certain floor levels may be out-of-plumb. Internal elements may be damaged beyond repair. These buildings would be closed by the building department until structural repairs are completed. Occupants or passersby may have been injured or killed by falling debris. Owners of buildings that have been damaged this severely often must wait for engineering and economic studies to be completed to determine if it is economically justifiable to repair the building or whether to simply demolish it. See Photographs 3 and 4.

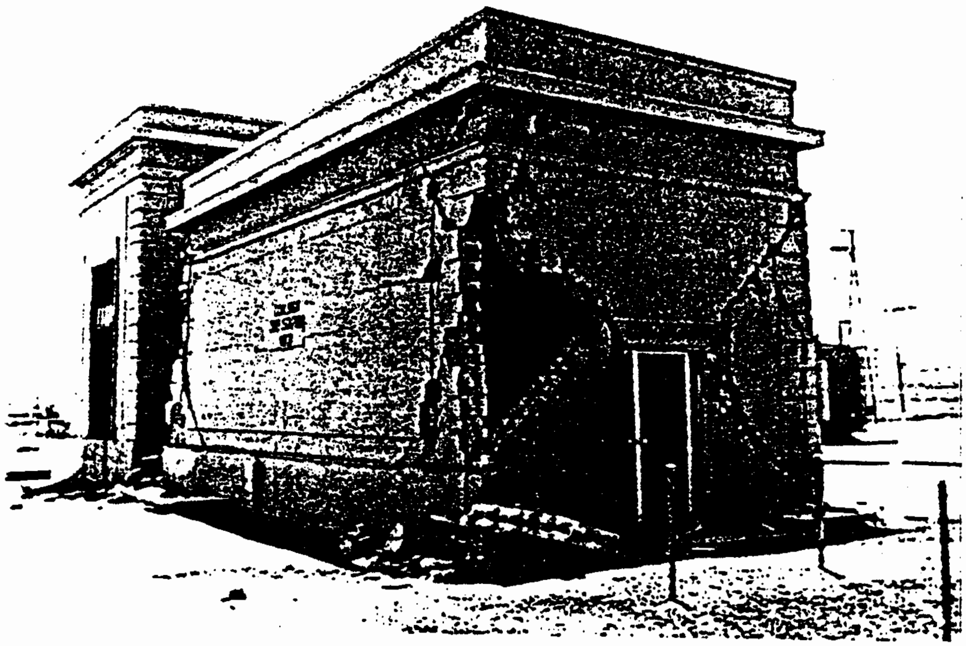
Damage State E includes both collapsed buildings and those that are so severely damaged that repair is clearly uneconomical. Life-threatening situations caused by falling internal elements or collapsing floors would occur in every building in this category. Damage state E is shown in Photographs 5 and 6. Because of the many controls placed in the code for new buildings aimed directly at preventing collapse, this damage state is expected to occur only rarely.

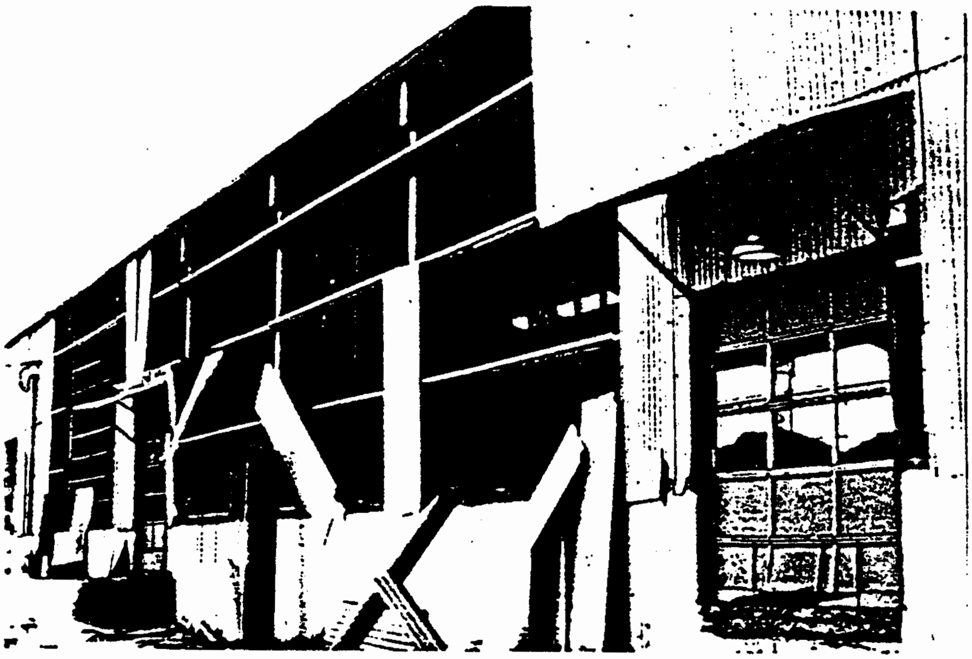
The number of buildings in each damage state will vary with the intensity of shaking. The intensity of shaking, in turn, is primarily dependent on the size of the earthquake and the distance from the fault which has slipped. A subjective measurement used by earthquake engineers that describes the shaking intensity in any particular area is the Modified Mercalli Intensity (MMI) scale as shown in Table 2. As can be seen, MMI levels are indicated by Roman numerals and are determined by what damage the shaking has caused. The standard MMI levels were set by investigation and comparison of similar patterns in many earthquakes. Richter magnitude, on the other hand, is a characteristic of the earthquake itself and does not vary from place to place. Studies of the patterns of MMI on past earthquakes allow engineers to estimate what MMI might be expected at various distances from future earthquakes of

PHOTOGRAPHS 1 AND 2

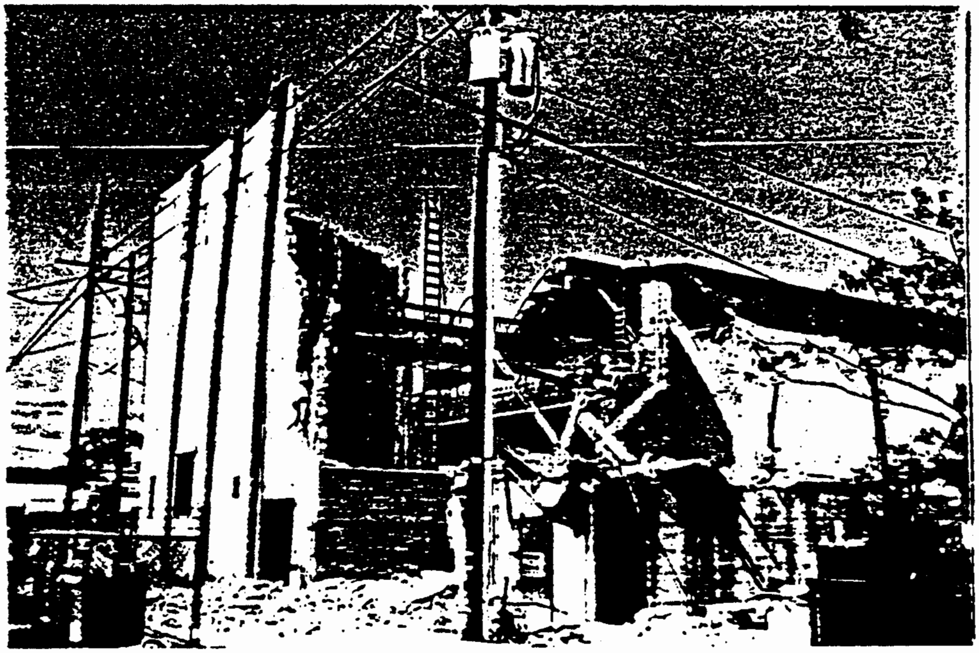
DAMAGE STATE C







PHOTOGRAPHS 3 AND 4
DAMAGE STATE D



PHOTOGRAPHS 5 AND 6
DAMAGE STATE E

TABLE 2

MODIFIED MERCALLI INTENSITY SCALE

The severity of an earthquake is described by the Modified Mercalli Intensity scale introduced in 1931 by American seismologists Harry Wood and Frank Neumann. They established 12 categories of intensity. The following is a condensed version:

I. Not felt except by a very few under favorable circumstances.

II. Felt only by a few persons at rest, especially on the upper floors of buildings. Suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but not necessarily recognized as an earthquake. Standing cars may rock slightly. Vibration similar to that of a passing truck.

IV. If during the day, felt indoors by many; outdoors by few. If at night, few awakened. Dishes, windows, and doors rattle, walls creak. A sensation such as a heavy truck striking the building. Standing cars rock noticeably.

V. Felt by nearly everyone, many awakened. Some dishes and windows broken, some plaster cracked, unstable objects overturned. Disturbance of trees, poles, and other tall objects. Pendulum clocks may stop.

VI. Felt by all, many people run outdoors. Fallen plaster, minor chimney damage. Movement of moderately heavy furniture.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary structures, considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings. Panel walls thrown out of frame structures. Chimneys, factory stacks, monuments, walls, and columns fall. Heavy furniture overturned and damaged. Changes in well water. Sand and mud ejected in small amounts. Persons driving cars are disturbed.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great damage in substantial buildings, which suffer partial collapse. Buildings shifted off foundations, ground noticeably cracked, underground pipes broken.

X. Some well-built wooden structures destroyed, most masonry structures destroyed, foundations ruined; ground badly cracked. Rails bent. Considerable landslides from steep slopes and river banks. Water splashed over banks. Shifted sand and mud.

XI. Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipes out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Total damage. Waves seen on ground surfaces. Lines of sight and level are distorted. Objects thrown into the air.

Wood, H.O., and Neumann, Frank, 1931, Modified Mercalli Intensity scale of 1931: Bulletin of the Seismological Society of America, v. 20, p. 277-283.

different sizes. Figure 2, for example, shows the shaking intensities that occurred for a magnitude 7.1 earthquake on the San Andreas fault in Northern California in 1989. If a certain MMI is expected for firm soil in a given area, the presence of soft soils at a site could increase the intensity by an entire MMI level, or more.

Table 3 relates damage expected for buildings designed in accordance to the 1991 UBC for various shaking intensities. Also shown in the table are examples of Richter magnitudes and distances which might produce the given MMI on sites of moderate and firm ground. The values shown in the table are percentages of buildings that are expected to be in each damage state, assuming all building in the area are designed in accordance with the 1991 UBC. Because of the variations in damage between building and structural types and lack of data upon which to base precise numbers, the values are given in ranges. However, Table 3 should provide a rough picture of the damage patterns for various conditions.

TABLE 3

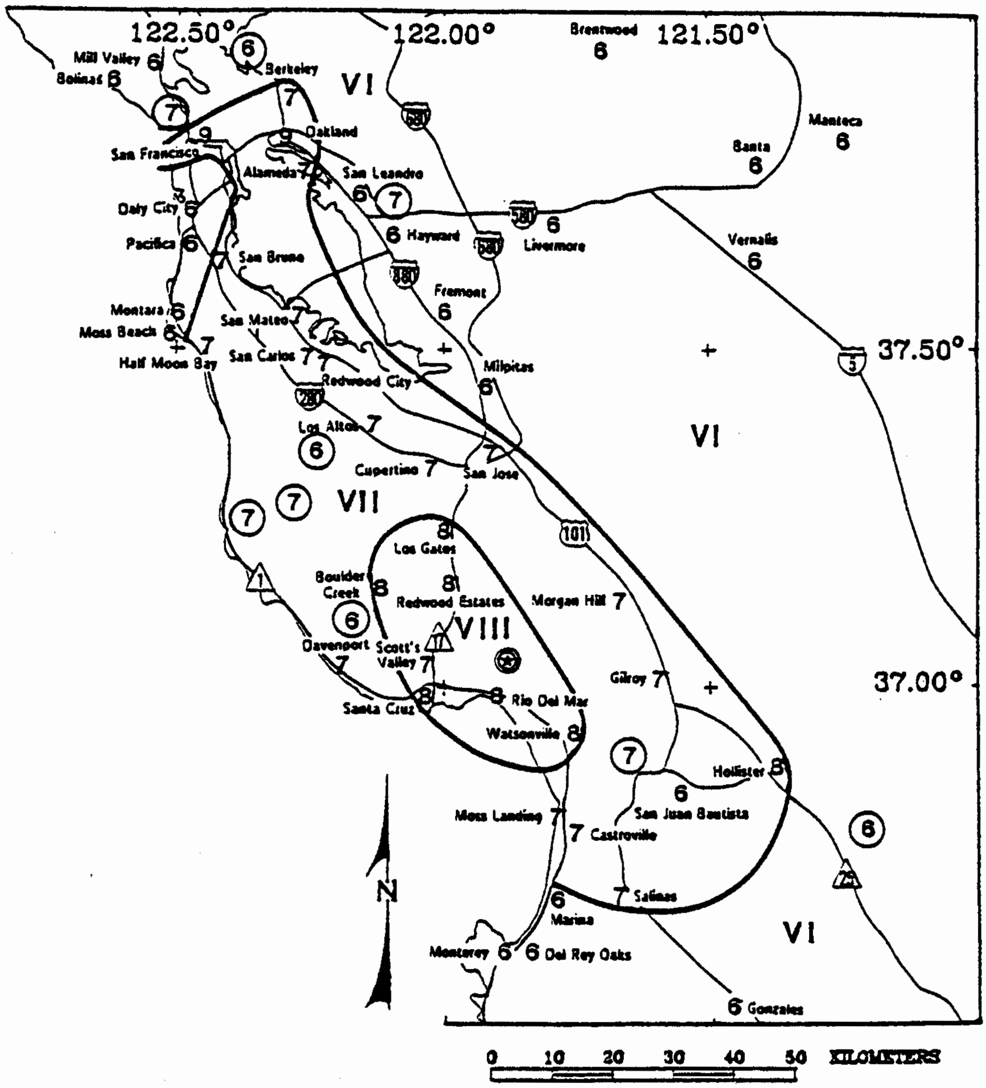
Expected Damage to Buildings (in percent of buildings) Designed in Accordance with the 1991 UBC

MMI	EQ Size in Richter Magnitude		DAMAGE STATE				
	6.0-6.5	7.5-8.0	A	B	C	D	E
	Distance						
VII	30 mi.	50 mi.	60-90	10-40	1-5	< 1	0
VIII	3 mi.	40 mi.	35-60	35-45	10-30	1-5	0-1
IX	1 mi.	30 mi.	25-40	25-40	20-40	3-10	0-2
- X	——	3 mi.	7-25	7-25	40-70	10-30	0-5

Table 4 presents similar information for unreinforced masonry buildings originally built between about 1870 and 1935 and seismically strengthened in accordance with the requirement for such buildings in the Uniform Code for Building Conservation. It will be noted that damage to these URM buildings is projected to be considerably higher than for new buildings. The benefit to retrofit cost relationships considered in the development of this code, as well as the inherent unknown quality of these older buildings accounts for these differences.

FIGURE 2

Preliminary Map Showing the Distribution of Modified Mercalli Intensity for the 1989 Loma Prieta Earthquake



Roman numerals represent the intensity level between isoseismal lines. Location of the earthquake epicenter is shown by the circled star. Numbers enclosed in circles have been added since original publication. (Pflaker and Galloway, 1989)

TABLE 4

Retrofitted URM

Expected Damage to Buildings (in percent of buildings)
Retrofitted in Accordance with the 1991 UCBC

MMI	EQ Size in Richter Magnitude		DAMAGE STATE A	B	C	D	E
	6.0-6.5	7.5-8.0					
	Distance						
VII	30 mi.	50 mi.	50	30	15	5	< 1
VIII	3 mi.	40 mi.	20	20	25	30	5
IX	1 mi.	30 mi.	3	7	30	50	10
X	-----	3 mi.	< 1	5	15	60	20

Earthquakes occur infrequently, and detailed damage statistics are expensive to collect. The estimates given here are based on the best judgement of a group of structural engineers experienced in earthquake investigations and in writing building codes. An ad hoc group was formed at the request of the Earthquake Engineering Research Institute by the Structural Engineers Association of California (SEAOC) for the purpose of estimating building performance for use in this publication. The original raw data generated by the SEAOC group were combined and slightly modified by EERI for ease of presentation. The damage estimates shown in Tables 3 and 4 do not represent an official position of the Structural Engineers Association of California. The raw data originally proposed by the SEAOC group by building type are given in Appendix A.

APPENDIX

The development of accurate damage statistics for buildings constructed to the 1991 UBC or retrofitted to the 1991 UCBC is a very difficult task. Few of these buildings have been subjected to earthquakes, and even less have experienced earthquakes of moderate or large magnitude. Thus there is insufficient damage data available to perform meaningful statistical analyses. Furthermore, most of the data that has been collected is descriptive of the type of damage without any quantification of the level of damage. Often available damage data omits essential information such as structural type, year of construction, and site location. Thus most of the available damage data have deficiencies that preclude their use in any meaningful analysis.

In light of the above mentioned problems, the EERI Committee on Seismic Performance solicited expert opinion with respect to damage statistics for eight building types when subjected to different levels of ground shaking. The experts consisted of 7 experienced structural engineers who met for a one day workshop to gain consensus on their opinions. The experts were contacted with the help of SEAOC. Their names are found in Table A1. The experts were given background information before the workshop, such as the purpose of the resulting white paper, damage probability matrices from ATC-13, and limited descriptions of damage states, building types and earthquake size.

Table A1 - Experts Solicited for Damage Statistics

Eugene Cole
Ronald Gallagher
Edwin Johnson
Melvyn Mark
Donald Strand
Thomas Wosser
Nabih Youssef

The experts were asked to describe damage using the five damage states, A through E, described earlier in this document. However, the experts felt that it was difficult to distinguish between states A and B, and thus they combined these two damage states in developing their consensus opinion. The descriptions of the damage states as modified by the experts are listed in Table A2. The consensus opinions of the experts without modification are found in Tables A3 through A10 shown below.

Several modifications to the expert opinion were made in formulating the ranges of expected damage to buildings found in Tables 3 and 4 of the text. Keeping in mind that the statistics developed by the experts are rough estimates, the EERI Committee on Seismic Performance felt that the modifications would not affect the credibility of the results.

First, the damage statistics for all buildings designed to the 1991 UBC (Table A3-A9) were combined. The ranges in Table 3 of the text consist of using the lowest and highest values of Tables A3 to A9. Secondly, the combined damage states A and B were separated. In most cases it was assumed that half of the buildings would be in state A and half in state B. However, for low-rise wood frame structures subjected to less intense shaking, it was felt that a significant portion of these buildings would end up in State A. Thirdly, UBC 91 buildings, damage statistics for MMI VII were generated by combining the expert opinion with the judgment of the EERI committee. Finally, damage states A and B were separated for retrofitted URM buildings using the judgment of the EERI committee...

Table A2 - Descriptions of Damage States as Modified by Experts

Damage State	Description	Damage
A & B	No damage or minor damage to nonstructural elements. Only incidental hazard.	<1%
C	Primarily nonstructural damage; also could be minor non-threatening structural damage. Remote chance of life threatening situation from structural elements	<5%
D	Extensive structural and nonstructural damage. Localized, life threatening situations would be common.	<30%
E	Complete collapse or damage that is not economically repairable. Life threatening situations in every building of this category	100%

Tables A3-A10 - Percent of Buildings Damaged vs. MMI

(A3) High-rise moment frame ('91 UBC)

Damage Category	Percent of Buildings (%) VIII	IX	X
A & B	90	70	50
C	10	30	40
D	1	3	10
E	<1	<1	<1

(A4) Mid-rise moment frame ('91 UBC)

Damage Category	Percent of Buildings (%) VIII	IX	X
A & B	70	50	15
C	30	40	70
D	2	5	15
E	<1	<1	<2

(A5) Mid-rise concrete shear walls ('91 UBC)

Damage Category	Percent of Buildings (%) VIII	IX	X
A & B	90	70	40
C	10	30	50
D	2	5	10
E	<1	<1	<1

(A6) Low-rise steel frame ('91 UBC)

Damage Category	Percent of Buildings (%) VIII	IX	X
A & B	90	50	20
C	10	40	60
D	1	5	20
E	<1	<1	<1

(A7) Tilt-up and low-rise concrete block ('91 UBC)

Damage Category	Percent of Buildings (%) VIII	IX	X
A & B	75	60	25
C	20	30	40
D	5	10	30
E	1	2	5

(A8) Low-rise wood frame ('91 UBC)

Damage Category	Percent of Buildings (%) VIII	IX	X
A & B	90	75	50
C	10	20	40
D	1	5	10
E	<1	<1	<1

(A9) Mid-rise reinforced masonry ('91 UBC)

Damage Category	Percent of Buildings (%) VIII	IX	X
A & B	80	60	25
C	15	30	50
D	5	10	20
E	1	2	<5

(A10) Retrofitted URM ('91 UCBC)

Damage Category	Percent of Buildings (%) VII	VIII	IX	X
A & B	80	40	10	5
C	15	25	30	15
D	5	30	50	60
E	<1	5	10	20