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Principal Investigator: David Okrent

RISK MANAGEMENT POLICY FOR EARTHQUAKE HAZARD REDUCTION

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RISK MANAGEMENT POLICY FOR EARTHQUAKE HAZARD REDUCTION

by

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ABSTRACT

This topical report deals with the formulation and evaluation of alternative risk management policies for the seismic safety problem faced by the city of Los Angeles with regard to its old masonry buildings. An aggregate analysis of risks to human health and property is conducted to show that these risks are significant. A detailed risk analysis compares the costs and benefits of the alternative policies. Alternatives ranging from strict regulation to free-market are examined. In order to evaluate the tradeoffs between additional cost and savings in lives, a direct willingness-to-pay and and an economic approach, based on property value differential, are used. Recommendations range from strict regulation for the residential and critical buildings (schools, hospitals, fire stations, etc.) to simply informing the occupants (in the case of commercial and industrial buildings) of the risks involved. Ethical issues in evaluating alternative risk management policies are discussed. Based on the case study, a guideline for a local risk manager in managing public risks, is provided.

PREFACE AND ACKNOWLEDGEMENTS

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The complete list of reports prepared in the project is as follows:

Final Report, Alternative Risk Management Policies for for State and Local Governments	UCLA-ENG-8240
Executive Summary, Alternative Risk Management Policies for State and Local Governments	UCLA-ENG-8241
Risk Management Practices in Local Communities: Five Alternatives, M.W. Meyer and K.A. Solomon	UCLA-ENG-8242
Management of Risks Associated with Drinking Water at the Local and State Levels, K.A. Solomon, M.W. Meyer, J. Szabo, P. Nelson and R. Tsai	UCLA-ENG-8243
Risk Management Policy for Earthquake Hazard Reduction, R.K. Sarin	UCLA-ENG-8244
Classification of Risks, K.A. Solomon, M.W. Meyer, P. Nelson and J. Szabo	UCLA-ENG-8245
Problems of State and Local Risk Management: An Overview, W. Bordas	UCLA-ENG-8246

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1.1. Seismic Hazards: An Historical Overview

1.1.1 World

A cursory look at any yearly New York Times Index under "Earthquakes" will reveal their devastating nature. The cruel impact of earthquake on mankind was most recently dramatized when 650,000 lives were lost in Tang-Shan, China (July 28, 1976). Earthquakes occur with alarming regularity. The long term average annual global frequency for the occurrence of earthquakes of magnitude of 7 or larger is approximately 18. Every few years earthquakes devastate cities with heavy loss of life and infliction of injury. In those lucky years when the impact of earthquakes is less severe, it is because these earthquakes are centered in areas of low population density and not because of their lesser number of occurrence. With the growth of population and the development of large cities, the potential for great earthquake destruction increases every year. In the United States the damaging effect of earthquakes has been relatively mild as compared to other seismically vulnerable regions such as Japan, China, the Middle East, and India. This is because the growth of large population centers in the United States is a recent phenomenon and statistically it may be argued that the U.S. has been extraordinarily fortunate to date. The potential for great destruction in the U.S. does exist, however.

1.1.2. United States

In the past century, several great earthquakes have struck the U.S. resulting in 1600 deaths and approximately $1.8 billion in property damages. The largest number of deaths in a single earthquake occurred in San Francisco in 1906. Table 1 lists the lives lost in major U.S. earthquakes during the period 1811-1975. The potential for much larger destruction exists in the years ahead.

The notion that earthquakes strike predominantly on the West Coast is a popular misconception. According to the U.S. Geological Survey, there have been 3500 quakes recorded east of the Mississippi River since 1700, including one in Charleston, South Carolina, in 1886, that caused 60 deaths and extensive damage. A recent earthquake, in July, 1980, which registered 5.1 on the Richter Scale struck Kentucky and was felt in a large area of the East and Midwest. Even though the East and Midwest are not free from seismic hazard, earthquake peril is largely ignored.

While the earthquake hazard is by no means negligible in the other regions of the U.S., a greater hazard exists in the West, and particularly in California. In a study conducted by J.H. Wiggins Company (1974), the potential losses to structures for the four regions of the U.S. were estimated as shown in Table 2. As is seen from Table 2, the annual loss increases from $631 million in 1970 to $1.3 billion in the year 2000; the annual percent loss decreases over the same period. This is based on the assumption that improved structures will replace the more hazardous

TABLE 1. Lives Lost in Major U.S. Earthquakes

Year	Locality	Lives Lost
1811	New Madrid, Mo	several
1812	New Madrid, Mo	several
1812	San Juan Capistrano, Calif	40
1868	Hayward, Calif	30
1872	Owens Valley, Calif	27
1886	Charleston, S.C.	60
1899	San Jacinto, Calif	6
1906	San Francisco, Calif	700
1915	Imperial Valley, Calif	6
1918	Puerto Rico (tsunami from earthquake in Mona Passage)	116
1925	Santa Barbara, Calif	13
1926	Santa Barbara, Calif	1
1932	Humboldt County, Calif	1
1933	Long Beach, Calif	115
1934	Kosmo, Utah	2
1940	Imperial Valley, Calif	9
1946	Hawaii (tsunami from earthquake in Aleutians)	4
1949	Puget Sound, Wash	8
1952	Kern County, Calif	14
1954	Eureka-Arcata, Calif	1
1955	Oakland, Calif	1
1958	Khantaak Island and Lituya Bay, Alaska	5
1959	Hebgen Lake, Mont	28
1960	Hilo, Hawaii (tsunami from earthquake off Chile coast)	61
1964	Prince William Sound, Alaska (tsunami)	131
1965	Puget Sound, Wash	7
1971	San Fernando, Calif	65
1975	Hawaii	2

TABLE 2. Estimate of Earthquake Losses in the U.S.

Region	Value of structures (millions of 1970 dollars)	Loss (percent)	Loss (in millions of 1970 dollars)
Northeast:			
1970	475,785	.02306	109.7
1980	680,559	.02059	140.1
1990	919,823	.01828	168.1
2000	1,993,577	.01765	210.7
North Central:			
1970	430,924	.00668	28.8
1980	612,682	.00563	34.5
1990	824,243	.00479	39.5
2000	935,317	.00709	66.3
South:			
1970	370,623	.00827	30.7
1980	531,462	.00772	41.0
1990	719,693	.00724	52.1
2000	935,317	.00709	66.3
West:			
1970	338,782	.13639	462.1
1980	497,437	.12390	616.3
1990	85,755	.11441	784.6
2000	903,736	.11004	994.5

structures. The Western region of the U.S. is expected to suffer 75 percent of the total cumulative loss.

1.1.3. California

Many experts share the belief that a great California earthquake is imminent. This belief is based on the historic record of large earthquakes and on knowledge of the movement of major continental plates. Bolt (1978) estimates the likelihood of a great earthquake somewhere in California within the next 10 years to be greater than 50 percent. He further observes that this likelihood progressively increases as more time elapses since the last great earthquake. Historically, California has suffered a higher loss due to earthquakes. As seen from Table 1, about half of the major U.S. earthquakes occurred in California, resulting in 1219 of 1600 total lives lost. Because of the relatively recent heavy urbanization of California, these same earthquakes would cause a much greater devastation, and the threat of a damaging earthquake becomes increasingly serious. The older structures in the state are especially susceptible to collapse causing a greater harm to the occupants of these buildings. These buildings are located throughout California and a large number are located in densely populated areas of Los Angeles.

1.1.4. Los Angeles and vicinity

The most recent damaging earthquake in Los Angeles occurred in 1971, causing 58 lives lost and 511 million dollars in damage (see John Wiggins and Company [1974]). In Table 3, earthquakes affecting Los Angeles and vicinity are listed. It can be seen from this table that five earthquakes of Modified Mercalli Index (MMI) VII or greater occurred in this region in the past 57 years. A description of the MMI scale is given in Table 4. The MMI scale is a qualitative measure of the intensity of an earthquake. In view of the imminent danger of a life-threatening earthquake, Los Angeles has paid considerable attention to the design of buildings to protect against seismic forces. A recent ordinance requires upgrading the older buildings so that these can withstand moderate seismic forces. A detailed discussion of the seismic safety problem for the city of Los Angeles will be given in Section 3.

1.2. Significance of Structural Seismic Resistance of Buildings

1.2.1. Seismic standards--a general discussion

Many cities and counties in the United States and particularly in California face a potential risk of death and injury to their residents by partial or complete collapse of buildings in the event of an earthquake. It is possible to reduce these risks by raising the standards for structural seismic resistance of the buildings. This, however, would require costly modifications by the private owners of these buildings or by the City or State government, in the case of public buildings. In the earthquake-prone West, considerable attention is paid to designing buildings for seismic forces. California, in particular, has produced a greater recognition and response to the earthquake hazard problem.

TABLE 3. Earthquakes Affecting Los Angeles and Orange Counties: 1769-1972

Year	Date	Lat(°N)	Long(°W)	Mag	I_o*	I_{LA}**	Location and Damage
1769	July 28	34	118	-	X	-	Los Angeles area. Four violent shocks. Many more during the following week. Alarmed the native Indians.
1812	Dec.8	-	-	-	VIII-IX	-	San Juan Capistrano. Church at San Juan Capistrano destroyed, killing 40 persons.
1812	Dec.21	34	120	-	X	-	Santa Barbara Channel. Damage in Santa Barbara, Ventura, and northern Los Angeles counties. Many mission buildings destroyed or damaged.
1827	Sept.23(?)	34	118	-	-	-	Los Angeles. People ran outdoors in panic.
1852	Nov.27-30	34.5	119	-	VIII-IX	-	Lockwood Valley. Fissures 30 miles long in Lockwood Valley.
1855	July 11 or 12	34	118.5	-	VIII	-	Los Angeles County. Almost every building in Los Angeles damaged.
1857	Jan.9	35	119	-	X-XI	-	Fort Tejon. Buildings and trees thrown down at the Fort. In Los Angeles, motion slow and caused hanging grapes to swing up to the rafters.
1872	March 26	36.5	118	-	X-XI	-	Owens Valley. At Lone Pine, 27 were killed and most houses destroyed.
1889	Aug.28	34	118	-	VI	VI	Near Pomona. At Los Angeles, clocks stopped, ceilings cracked and people ran into the streets.

TABLE 3. Earthquakes Affecting Los Angeles and Orange Counties: 1769-1972 (continued)

Year	Date	Lat(°N)	Long(°W)	Mag	I_o*	I_{LA}**	Location and Damage
1890	Feb.9	34	117.5	-	VI	-	Los Angeles area. At Los Angeles, most people were awakened and windows rattled.
1892	Feb.24	31.5	116.5	-	VIII-IX (in USA)	-	Baja California. Intensity probably X near epicenter in Mexico. Felt at Los Angeles.
1893	Apr.4	34.5	118.5	-	VIII-IX	-	Newhall-Pico Canyon. Earth fissured and chimneys wrecked in Newhall and Pico Canyon, but strong at Los Angeles.
1894	July 30	35	118	7	VI	VI	Los Angeles area. Broke some panes of glass in Los Angeles.
1899	July 22	34.5	117.5	-	VIII	VI	Cajon Pass. Slides in mountains 20 miles from Pass.
1899	Dec.25	33.5	116.4	-	IX	-	San Jacinto and Hemet. Nearly all brick buildings severely damaged at Hemet. Six killed near San Jacinto. People badly frightened in Los Angeles.
1902	July 28 and 31	34.5	120.5	-	VIII	-	Near Santa Barbara. Some buildings damaged, pipeline twisted and broken, two oil tanks destroyed, ground fissured.
1903	Dec.25	34	118	-	VI	VI	Los Angeles area. In Los Angeles, some plaster and bricks thrown down.
1907	Sept.20	34.2(?)	117.1	6	VII	-	Near San Bernardino. Damage to buildings in San Bernardino and San Jacinto. Large buildings swayed in Los Angeles.

TABLE 3. Earthquakes Affecting Los Angeles and Orange Counties: 1769-1972 (continued)

Year	Date	Lat(°N)	Long(°W)	Mag	I_o*	I_{LA}**	Location and Damage
1910	May 15	33.77	117.4	6.0	VII	-	Lake Elsinore District.
1916	Oct.23	34.9	118.9	6	VII	III	Tejon Pass.
1918	Apr.21	33.8	117.0	6.8	IX	-	San Jacinto and Hemet. $200,000 property damage in two places.
1920	June 22	34	118.5	-	VIII	III-VIII	Inglewood. Wrecked some buildings. Upset cemetery monuments.
1920	July 16	34	118.5	-	VI	VI	Los Angeles. Seven shocks with origins just northwest of the Los Angeles business district. Broke street lamps; knocked bricks from cornices.
1922	Mar.10	34.8	120.3	6.5	IX	III	Cholame Valley. Felt feebly in Los Angeles.
1923	July 23	34.0	117.25	6.25	VII	-	San Bernardino Valley. Damage to masonry buildings and many chimneys in San Bernardino.
1925	June 29	34.3	119.8	6.3	VIII-IX	-	Santa Barbara. $8 million in Santa Barbara.
1927	Nov.4	34.5	121.5	7.5	IX-X	I-III	West of Point Arguello. Chimneys wrecked at Lompoc.
1929	July 8	34	118	4.7	VII	-	Whittier. Felt in downtown Los Angeles, but little damage; windows broken, pictures and other swinging objects swayed. Chimneys fell in Whittier.
1930	Aug.31	33.9	118.6	5.2	VII	VII	Santa Monica Bay. At Los Angeles, minor cracks in building; fallen plaster; broken dishes.

TABLE 3. Earthquakes Affecting Los Angeles and Orange Counties: 1769-1972 (continued)

Year	Date	Lat(°N)	Long(°W)	Mag	I_o*	I_{LA}**	Location and Damage
1933	Mar.11	33.6	118.0	6.3	IX	VII	Long Beach. $41,000,000 damage. 120 killed. Buildings collapsed in Long Beach and Compton.
1933	Oct.2	33.8	118.1	5.4	VI	VI	Signal Hill. Cracked plaster, some damaged street lamps and broken dishes and windows in Los Angeles.
1934	June 8	35.8	120.4	6.0	VIII	-	Parkfield.
1934	Dec.30	32	114.8	7.1	X	IV	Lower California. Crevices opened. Telephone poles shaken down.
1937	Mar.27	33.5	116.5	6.0	VII	-	Terwilliger Valley.
1939	Dec.27	33.8	118.1	4.5	VI	V	Long Beach. Considerable minor damage at Long Beach.
1940	Oct.11	33.8	118.4	4.7	VI	V	Off Redondo Beach. Minor damage at a few places.
1941	July 1	34.3	119.6	5.9	VIII	V	Santa Barbara Channel. $100,000 total damage, 25% of it to drug and liquor stocks and 10% to plate glass.
1941	Oct.22	33.8	118.2	4.9	VII	VI	Gardena. Damage estimated at $10,000 in Gardena.
1941	Nov.14	33.8	118.2	5.4	VII-VIII	-	Torrance-Gardena. Damage approximately $1,000,000.

TABLE 3. Earthquakes Affecting Los Angeles and Orange Counties: 1769-1972 (continued)

Year	Date	Lat(°N)	Long(°W)	Mag	I_o*	I_{LA}**	Location and Damage
1944	June 19	33.9	118.2	4.5	VI	V	Near Dominguez Junction. Two shocks. Overturned objects, cracked plaster and broken windows at several localities.
1944	June 19	33.9	118.2	-	V	IV	Near Dominguez Junction. One report of slight plaster cracks in Gardena.
1946	Mar.15	35.7	118.1	6.25	VII	V	Walker Pass. Felt by many in Pasadena and Los Angeles. Near Walker Pass, damage to adobe structures, cracks in brick chimney, fall of plaster.
1951	Dec.25	32.8	118.4	-	VI	V	San Clemente Island. Slight damage. Plaster cracks in Gardena.
1952	July 21	35.0	119.0	7.7	XI	VII	Kern County. Damage estimates upward of $50 million. Twelve persons killed, nine of them from the fall of a brick wall in Tehachapi.
1952	July 21	35.0	119	6.4	V	IV	Major aftershock of Kern County earthquake.
1952	July 23	35.4	118.6	6.1	VII	IV	Major aftershock of Kern County earthquake.
1952	July 29	35.4	118.9	6.1	VII	III	Major aftershock of Kern County earthquake.
1952	Aug.22	35.3	118.9	5.8	VIII	IV	Heavy damage at Bakersfield. Aftershock of 7.7 mag. July 21 shock.
1952	Nov.22	35.8	121.2	6.0	VII	IV	-

TABLE 3. Earthquakes Affecting Los Angeles and Orange Counties: 1769-1972 (continued)

Year	Date	Lat(°N)	Long(°W)	Mag	I_o*	I_{LA}**	Location and Damage
1961	Apr.4	-	-	-	IV	-	Terminal Island. On Terminal Island, subsurface damage to oil well pipes estimated at approximately $4.5 million.
1961	Oct.20	33.6	118.0	4.3	VI	IV	Near Huntington Beach. Series of shocks. Slight damage, mainly cracked plaster, broken windows, and loss of stock in a number of stores.
1964	Aug.30	34.25	118.5	4.0	V	IV	Los Angeles County. Switchboard jammed with calls.
1965	Apr.15	34.1	117.5	4.5	VI	IV	San Bernardino Valley. Slight damage. Cracked plaster and broken windows.
1965	Nov.12	34.0	118.2	3.0	VI	VI	Los Angeles County. Plaster cracked slightly.
1967	Jan.8	33.6	118.4	3.8-4	V	-	Los Angeles County coastal area. First of series of 13 shocks.
1967	June 15	34.0	118.0	4.1	VI	V	Los Angeles and Orange Counties. Underground telephone cables twisted. Hairline foundation cracks at San Gabriel.
1968	Apr.9	33.2	116.1	6.5	VII	VI	Borrego Mountain. In two downtown Los Angeles buildings, the only damage was reopened or slightly enlarged plaster cracks from the 1933 and 1952 shocks.

TABLE 3. Earthquakes Affecting Los Angeles and Orange Counties: 1769-1972 (continued)

Year	Date	Lat(°N)	Long(°W)	Mag	I_o*	I_{LA}**	Location and Damage
1969	Feb.28	34.5	118.1	4.3	VI	IV	Palmdale. At Palmdale, fluorescent lights fell and windows broke.
1969	Apr.28	33.35	118.35	5.9	VII	-	Borrego Springs. In Los Angeles, tall buildings swayed. Brick walls cracked at Borrego Springs.
1969	Oct.24	33.3	119.2	5.1	V	V	Los Angeles, Orange, and Ventura Counties. Very slight plaster cracking at Downey.
1970	Sept.12	34.3	117.5	5.4	VII	V	Lytle Creek. At Lytle Creek, ground cracks, landslide, disturbed water. Chimneys, tombstones, elevated water tanks, etc., cracked, twisted and overturned.
1971	Feb.9	34.4	118.4	6.4	VIII-IX	VII	San Fernando. Collapse and severe damage at Veterans Hospital and Olive View Hospital. In downtown Los Angeles, moderate damage, especially to older type buildings with brick and masonry facings; portions of old buildings collapsed, killing one person.
1971	Mar.31	34.3	118.5	4.6	VII	IV	West end of San Fernando Valley. Most damaging aftershock of San Fernando earthquake. Over 300 homes and business establishments damaged. Foundations cracked, walls shifted; many chimneys damaged and windows broken.

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*Maximum Modified Mercalli Intensity for the earthquake

**Modified Mercalli Intensity in central Los Angeles

TABLE 4. Modified Mercalli Intensity (Damage) Scale (Abridged)

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale.)

IV. During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects oveturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI possi-Forel Scale.)

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)

VII. Everybody runs outdoors. Damage neglibible 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 motorcars. (VIII Rossi-Forel Scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly-built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX Rossi-Forel Scale.)

TABLE 4. Modified Mercalli Intensity (Damage) Scale (Abridged) (continued)

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped over banks). (X Rossi-Forel Scale.)

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

XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown upward into the air.

Nevertheless, a large number of older buildings, especially those built with unreinforced masonry, are found here. These buildings are subject to collapse or severe damage in case of earthquakes.

Even though the East and Midwest are not free from seismic hazard, earthquake peril is largely ignored. Massachusetts is an exception in developing a good earthquake building-code program over the last decade. A recent earthquake in Kentucky, in July, 1980, which registered 5.1 on the Richter scale, did generate some concern about the adequacy of seismic-design criteria for building, dams, and nuclear power plants. It is, however, unlikely that the building-code provisions will be modified to account for seismic forces, since such modifications may raise the cost of construction by 10%. These incremental costs for making buildings earthquake resistant should be compared with the incremental benefits of reduced risks to life and property in the event of an earthquake.

California has shown a greater degree of concern for seismic safety with earthquake-resistant design, state seismic safety measures relating to public schools and hospitals on building across faults, seismic planning by local governments, and improved dam safety procedures. In 1975, a state Seismic Safety Commission was established. In spite of these efforts, many experts feel that California's earthquake preparedness is not up to an acceptable level. This is especially true with respect to older structures.

1.2.2. Significance to East and Midwest

The problem of seismically substandard buildings is clearly an acute one for the city of Los Angeles and for many other communities in California. Even in Los Angeles, only part of the problem is being addressed, namely pre-1933 masonry buildings which contain many dwelling units or are frequented by large numbers of people. There may be similarly high individual risks to people living in smaller old masonry buildings. And, there may be many post-1933 buildings whose design is inadequate for the substantial seismic shaking which is likely to occur during the coming years.

Is this problem unique to Los Angeles, San Francisco and some other cities in California? Only in degree. Earthquakes can, and do, occur almost anywhere in the United States.

The Federal Disaster Assistance Administration has had earthquake loss studies prepared, not only for Los Angeles and San Francisco, but also for Salt Lake City and for the Puget Sound area.

Interesting insight into the widespread nature of the problem can be obtained from a report, prepared in 1975, on earthquake-resistant design requirements for Veterans Administration hospital facilities. This report was prepared by a committee established as a result of actions taken following the 1971 San Fernando earthquake in which considerable loss of life was associated with failure of a VA hospital. (See Veterans Administration [1975]).

The scope of work for the committee was defined by the following statement:

> "It has been the Veterans Administration policy to follow the professionally accepted local and national building codes as they have been progressively developed over the years for the design of new buildings and other structures to resist the forces of earthquakes and high intensity winds. It also has been the Veterans Administration policy to follow these codes as a basis for strengthening buildings when this work was done at existing stations. It should be noted that some buildings and other structures were designed and constructed prior to the inclusion of earthquake and high intensity wind resistance requirements in local and national codes for the area in which they were located. As a consequence, there is in the Veterans Administration's total plant a wide variety of buildings and other structures conforming to the code requirements which were in existence for the locale at the time they were designed and also some buildings that were strengthened on the basis of codes which came into being during later years.
>
> "The failure of the buildings and the consequent loss of life at the Veterans Administration San Fernando Hospital have given rise to the questions, from both within the Veterans Administration and by members of the Congress and other public officials, as to whether the Veterans Administration should continue the policy of following local and national codes or whether the Veterans Administration should establish its own codes for the design of new and for the strengthening of existing Veterans Administration hospital buildings and other structures to resist the forces of earthquakes and high intensity winds anywhere in the United States,"
>
> Some comments made by the committee include the following:
>
> "The collapse of buildings and the consequent loss of life at VAH, San Fernando emphasized the need for identifying and strengthening hazardous structures in seismic regions. The definition of structural hazard from future earthquakes is quite a complicated one for a number of reasons:
>
> "1. It is difficult to determine the seismic risk to a structure as a function of its lifetime. Seismic risk maps, such as the map prepared by S.T. Algermissen in the 1973 Edition of the Uniform Building Code, show that almost every area in the United States is subject to earthquakes. These maps classify large geographical areas as Zones 0, 1, 2, and 3, and the projected damage from earthquakes in zones varies from "No Damage" in Zone 0 to "Major Damage" in Zone 3. The use of the Zone Factor does not consider, in relation to a specific site, geological structure, the proximity of active

> faults, or soils. Furthermore, available Seismic Risk Maps for the U.S. consider the intensity of shaking of earthquakes that have occurred in the past but give little weight to frequency of occurrence. Thus, Western California, Upper New York State and Charleston, South Carolina, are classified as Zone 3 or "Major Damage" areas, although historically earthquakes in California occur more frequently than in the other areas. Finally, the seismic risk maps do not distinguish between earthquakes in terms of their most damaging effects on structures of different types. For these reasons, when dealing with major structures such as VA hospitals, methods of identification of seismic areas were especially developed. These considered the local geological conditions and frequency of earthquake occurrence.
>
> "2. The great majority of existing VA facilities, particularly those not in California, were not designed to resist earthquake forces. Such facilities might be hazardous in the event of a major nearby earthquake. Procedures for evaluating such facilities were developed.
>
> "3. There were no precendents for a nation-wide program to evaluate and strengthen existing buildings to resist seismic forces. Agencies in California have inaugurated such programs, but on a small scale. Many of the older VA stations have twenty or more buildings, so each station requires a major investigative effort. Many are far below an acceptable level of seismic resistance as calculated by conventional methods, yet are in regions of very infrequent damaging earthquakes. A prudent program of corrective work had to be developed that would consider the strength of the structure and the level of ground-shaking expected during the life of the structure."

As part of the study, recommendations were obtained from consulting organizations for the earthquake intensity and design basis accelerator to be used at various VA sites throughout the country. This is reproduced from the report in Table 5.

It is of some interest to note that, while the proposed seismic design bases are substantial at many of the sites, the values recommended are generally far less than the Nuclear Regulatory Commission requires for nuclear reactors at similar sites. For example, both the Los Angeles VA hospital and the San Onofre nuclear generating station are several miles from the Newport-Inglewood fault (or an extension thereof). The recommended acceleration for the VA hospital is 0.25g, while San Onofre is designed for 0.67g, a major difference. Similarly, the recommended acceleration for the VA facility in Manchester, New Hampshire is only 0.12g while the required seismic design basis for the Seabrook nuclear plant is 0.25g. This provides a kind of calibration in that the design basis earthquakes for nuclear power plants are often estimated to have a frequency of exceedance falling between one in a thousand to one in ten

TABLE 5. Peak Horizontal Ground Accelerations at VA Sites

Location (Consultant)	Intensity (MM)	Acceleration (g)
Albany, NY (E. D'Appolonia Consulting Engrs.)	VI-VII	0.07
Albuquerque, NM (John A. Blume)	VIII-	0.20
American Lake, WA (Dames & Moore)	VIII	0.20
Atlanta, GA (Law Engineering Testing Co.)	VII	0.13
Augusta, (F.H. Div.), GA (Law Engineering Testing Co.)	VII+	0.18
Augusta (Lenwood Div.), GA (Law Engineering Testing Co.)	VII+	0.18
Batavia, NY (Dames & Moore)	VII-VIII	0.20
Bath, NY (Dames & Moore)		0.05
Bedford, MA (Dames & Moore)	VII	0.10
Birmingham, AL (Woodward-Lundgren)	VII	0.11
Boise, ID (Woodward-Lundgren)		0.15
Boston, MA (Dames & Moore)	VII	0.10
Brockton, MA (Dames & Moore)	VII	0.10
Buffalo, NY (Dames & Moore)	VI	0.07
Canandaigua, NY (Dames & Moore)		0.05
Charleston, SC (Woodward-Lundgren)	VIII	0.25
Cincinnatti, OH (Woodward-Lundgren)	VI	0.06
Columbia, SC (Love & Cobb Architects & Lockwood Green Engineers, Inc.)	VII	0.10
Dayton, OH (Woodward-Lundgren)	VI	0.05
Erie, PA (A.C. Ackenheil & Associates)	VIII	0.15
Ft. Harrison, MT (John A. Blume & Assocs.)	VIII+	0.30
Fresno, CA (Woodward-Lundgren)		0.23
Indianapolis (10th St.), IN (Woodward-Lundgren)	V	0.02
Indianapolis (Cold Spring), IN (Woodward-Lundgren)	V	0.02
Lincoln, NB (E. D'Appolonia Consulting Engineers)	VI-VII	0.10
Livermore, CA (Dames & Moore)	VIII	0.25
Long Beach, CA (Woodward-Lundgren)		0.39
Los Angeles, CA (Dames & Moore)	VIII	0.25
Louisville, KY (Woodward-Lundgren)	VII	0.11
Manchester, NH (John A. Blume & Assocs.)	VII+	0.12

TABLE 5. Peak Horizontal Ground Accelerations at VA Sites (continued)

Location (Consultant)	Intensity (MM)	Acceleration (g)
Marion, IL (Woodward-Lundgren)	VII	0.11
Martinez, CA (Woodward-Lundgren)		0.48
Martinsburg, WV (E. D'Appolonia Consulting Engineers)	VI-VII	0.07
Memphis, TN (Woodward-Lundgren)	VIII	0.25
Mt. Home, TN (E. D'Appolonia Consulting Engrs.)	VII	0.10
Northampton, MA (John A. Blume & Associates)	VII	0.10
Oklahoma City, OK (E. D'Appolonia Consulting Engineers)	VII	0.10
Oteen, NC (E. D'Appolonia Consulting Engineers)	VI	0.07
Palo Alto, CA (Woodward-Lundgren)		0.50
Palo Alto (Menlo Park), CA (Dames & Moore)	IX	0.40
Phoenix, AZ (John A. Blume & Associates)	IV	0.05
Poplar Bluff, MO (Woodward-Lundgren)	VIII	0.25
Portland, OR (Dames & Moore)	VII	0.12
Prescott, AZ (John A. Blume & Associates)	VII+	0.15
Providence, RI (John A. Blume & Associates)	VII+	0.10
Reno, NV (John A. Blume & Associates)	IX+	0.50
Roseburg, OR (Shannon & Wilson, Inc.)	VI	0.08
Salem, VA (E. D'Appolonia Consulting Engineers)	VII-VIII	0.15
Salisbury, NC (E. D'Appolonia Consulting Engrs.)	VI	0.07
Salt Lake City, UT (Dames & Moore)	VIII	0.30
San Diego, CA (Dames & Moore)	VII	0.15
San Francisco, CA (Dames & Moore)	VIII	0.30
San Juan, PR (E. D'Appolonia Engineers, Inc.)	VII-VIII	0.12
Seattle, WA (Dames & Moore)	VIII	0.20
Sepulveda, CA (Woodward-Lundgren)		0.45
Spokane, WA (Agbabian-Jacobsen Associates)	VII	0.10
St. Louis, MO (Woodward-Lundgren)	VII	0.11
St. Louis (Jeff. Brks.), MO (Woodward-Lundgren)	VII	0.11
Syracuse, NY (E. D'Appolonia Consulting Engrs.)	VI	0.05
Togus, ME (John A. Blume & Associates)	VII	0.10
Tucson, AZ (John A. Blume & Associates)	IV	0.05
Tuscaloosa, AL (Woodward-Lundgren)	VI	0.06
Vancouver, WA (Dames & Moore)		0.12
Walla Walla, WA (Dames & Moore)	VI	0.15
West Roxbury, MA (Dames & Moore)		0.10
White City, OR (Shannon & Wilson, Inc.)	VI	0.07
White River Junction, VT (Dames & Moore)	VI	0.07
Wichita, KA (E. D'Appolonia Consulting Engrs.)	VI-VII	0.07

thousand per year. Hence, presumably, for many of the VA sites in Table 5, the frequency of exceedance of the proposed design bases is substantially larger.

Hence, most if not all cities in the United States face some risk from earthquakes. Many have buildings lacking in any seismic design. Many do not have personnel who are cognizant either of seismic design or seismic safety matters. Nevertheless, some seismic risk exists. And for individuals inhabiting substandard masonry buildings, the risk may be significant or even substantial compared to others for which the community (or higher governmental entities) is taking active steps to control or reduce.

1.3. Policy Issues

1.3.1. An overview of policy alternatives

Society can reduce the adverse effects of earthquakes by requiring adequate earthquake resistance in the design and construction of new buildings, by strengthening the existing buildings, and by better earthquake information and disaster preparedness.

Each of these activities requires resources and therefore the social advantage of reducing the likelihood of damage to human life and property must be balanced against the social cost. The focus of this report is exclusively on the technological policy options for mitigating earthquake hazard.

Principal technological policy options to mitigate earthquake hazards are earthquake resistant design and construction of buildings. The standards for structural seismic resistance will vary with the type of building, its location, occupancy, etc. The crucial determinant in the choice of a standard is the acceptable tradeoff between cost and reduced likelihood of damage to human life and property. Table 6 gives a rough estimate of additional cost required to achieve various degrees of safety for new construction in California. Estimating costs for strengthening the existing buildings can only be done on a case-by-case basis. In a later section, we will provide such cost estimates for pre-1933 unreinforced masonry buildings located in Los Angeles.

A natural question arises: what institutional mechanisms should society employ to determine policies consistent with the acceptable levels of tradeoffs between economics and levels of risk to human life? At one extreme are the strict regulations for the design and construction of all buildings that are based on the best information and evaluation by the government. The other extreme is to treat safety as an economic commodity and let the free market mechanism along with professional codes of practice and existing liability laws determine the acceptable levels of standards for each type of building. The former policy option suffers from the difficulty of monitoring and enforcement; whereas, the latter presupposes that the individual members of the society can assess and evaluate possible risks (through free market mechanism such as insurance

Table 6

Classification of Acceptable Risks

Level of Acceptable Risk	Kinds of Structures	Extra Project Cost Probably Required to Reduce Risk to an Acceptable Level
1. Extremely low(1)*	Structures whose continued functioning is critical, or whose failure might be catastrophic; nuclear reactors, large dams, power intertie systems, plants manufacturing or storing explosives or toxic materials.	No set percentage (whatever is required for maximum attainable safety)
2. Slightly higher than under level 1(1)*	Structures whose use is critically needed after a disaster; important utility centers; hospitals fire, police, and emergency communication facilities; fire stations; and critical transportation elements such as bridges and overpasses; also smaller dams	5 to 25 percent of project cost(2)*
3. Lowest possible risk to occupants of the structure(3)*	Structures of high occupancy, or whose use after a disaster would be particularly convenient: schools, churches, theaters, large hotels, and other high-rise buildings housing large numbers of people, other places normally attracting large concentrations of people, civic buildings such as fire stations, secondary utility structures, extremely large commercial enterprises, most roads, alternative or noncritical bridges and overpasses	5 to 15 percent of project cost(4)*
4. An "ordinary" level of risk to occupants of the structure(3,5)*	The vast majority of structures: most commercial and industrial buildings, small hotels and apartment buildings, and single family residences	1 to 2 percent of project cost, in most cases (2 to 10 percent of project cost in a minority of cases)(4)*

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*Refer to notes to this table; see following pages.

Notes to Table 6:

1. Failure of a single structure may affect substantial populations.

2. These additional percentages are based on the assumption that the base cost is the total cost of the building or other facility when ready for occupancy. In addition, it is assumed that the structure would have been designed and built in accordance with current California practice. Moreover, the estimated additional cost presumes that structures in this acceptable-risk category are to be sufficiently safe to remain functional following an earthquake.

3. Failure of a single structure would primarily affect only the occupants.

4. These additional percentages are based on the assumption that the base cost is the total cost of the building or facility when ready for occupancy. In addition, it is assumed that the structures would have been designed and built in accordance with current California practice. Moreover, the estimated additional cost presumes that structures in this acceptable-risk category are to be sufficiently safe to give reasonable assurance of preventing injury or loss of life during an earthquake, but otherwise not necessarily to remain functional.

5. "Ordinary risk": Resist minor earthquakes without damage; resist moderate earthquakes without structural damage, but with some non-structural damage; resist major earthquakes of the intensity or severity of the strongest experienced in California, without collapse, but with some structural as well as non-structural damage. In most structures, it is expected that structural damage, even in a major earthquake, could be limited to repairable damage. (Structural Engineers Association of California)

Source: California, Legislature, Joint Committee on Seismic Safety, *Meeting the Earthquake Challenge* (1974) p. 9.

companies or building inspection companies) and further the total cost of information dissemination will be cheaper than the cost of regulation. Besides, the monetary costs, there are ethical arguments in favor and against each of these extreme positions. The arguments in favor of regulation are often based on the imperfection of the market caused by the inability of the people to process information about risks, the greed of some who may unfairly take advantage of the others, and that at certain levels of risk, safety is not an economic commodity but a basic right of all members of the society. The arguments in favor of market mechanism often rest on the premise that in a capitalistic country, government should not adopt a paternalistic attitude and that a majority of the market imperfections can be corrected by supplying information to the consumers or by instruments other than regulations that require what to do and how.

Intermediate policy options include some form of government intervention in specifying seismic resistance requirements for critical facilities (schools, hospitals, etc.) and possibly for new construction; while providing information to the owners and the occupants about earthquake hazard and mitigation alternatives for the existing buildings. In evaluating alternative risk management policies for Los Angeles, we consider several of these policy options.

1.3.2. Role of the federal, state, and local government

The federal government recognizes the importance of seismic safety for the country as a whole. An Earthquake Hazard Reduction Act was enacted in 1977 to reduce the risks to life and property from future earthquakes in the United States. A brief description of this act is given below.

> The bill would establish a national earthquake hazards reduction program under the direction of the President to minimize the loss and disruption resulting from future earthquakes. Further earthquakes in the United States are likely to be more destructive than past ones because of population growth and concentration. The program has several objectives: the development of technologically and economically feasible design and construction methods to make new and existing structures earthquake resistant; the implementation of a system to predict earthquakes in areas of high or moderate seismic risk; the development of model codes and other means to make information about seismic risk available for consideration in land-use and building decisions; the improvement of the understanding of earthquake related issues; the education of the public concerning earthquake hazard reduction measures; the development of research leading to better ways to use existing scientific and engineering knowledge, better understanding of the social, economic, legal and political consequences of earthquake prediction, and development of ways to assure the availability of earthquake insurance or some functional substitute; and the development of an improved understanding of earthquake control or alternation.

The state governments have to play a crucial role in ensuring seismic safety. California has taken several steps in providing for the seismic safety of public schools, hospitals, dams, and freeways, in regulating construction in fault zones, and in mandating city and county seismic safety plans (see Stanley Scott [1979]). The role of state governments for seismic safety falls under several categories:

- to assess earthquake risks and to determine acceptable levels of protection to human life and property
- to set minimum safety standards for each type of building
- to identify major fault zones and provide guidelines for land use and construction in these zones
- to review and monitor the performance of state and local government agencies responsible for some aspect of seismic safety
- to prepare emergency measures in the event of a disaster.

To coordinate various seismic safety efforts, California created a state-level body "Seismic Safety Commission" in 1975. It is however, recognized that the local governments are responsible for enforcing building and construction code requirements and land use regulations.

Local governments play a pivotal role in implementing seismic safety programs. In California, cities and counties are required to incorporate seismic hazards in their planning program. A review by the Seismic Safety Commission, however, found that several cities and counties did not have a seismic safety element in their general plans.

1.3.3. Key tradeoffs in policy formulation

The local governments will ultimately be responsible for ensuring compliance with the state's seismic safety standards and for designing appropriate policies that suit their local conditions. A higher level of seismic safety can be achieved by incurring higher costs for improved seismic resistance of the buildings. The key tradeoff therefore is between additional cost and improved safety. A local government will have to consider issues such as damage to human lives and property; public outrage in case of disaster; distribution of costs on the owners, the occupants, and the general public; governmental subsidy; socio-economic effects of preventive measures; and ethical considerations. The realistic constraints on the ability of the local government to monitor and enforce policies may require incentives, cost-sharing, tax subsidies, etc., to encourage compliance and acceptance of a policy. We will illustrate how these issues can be considered formally in the design and evaluation of alternative seismic risk management policies for a local government.

2. ELEMENTS OF A RISK MANAGEMENT POLICY

In this report we propose a framework for developing a consistent risk management policy for earthquake hazard. This approach is applied in the design and evaluation of alternative risk management policies for the city of Los Angeles. The framework is, however, general enough to be useful to other cities.

A consistent risk management policy attempts to answer the following questions:

(1) What should be the standards for structural seismic resistance for various types of buildings?

(2) What risk regulation policies should the state or local government undertake to enforce these standards in order to promote public safety and welfare?

These two questions are intertwined. However, Question 1 primarily deals with the tradeoffs between incremental benefits due to savings in life, injury, and property and the incremental costs of upgrading the buildings. The second question explicitly incorporates the actions of the parties affected (e.g., owner of the building, tenants, etc.) in the design of an implementable regulation.

The formulation of a consistent risk management policy entails the following three important steps

(1) Risk Assessment

(2) Risk Evaluation

(3) Policy Formulation

These three steps are necessary prerequisites for designing a risk management policy and enforcement procedures to ensure public safety and the interests of the diverse groups affected by the city or state's risk management policy.

2.1. Risk Assessment

The first step of risk assessment requires a synthesis of available scientific knowledge to identify and quantify all possible risks of the hazard under consideration. In earthquake hazard, for example, the risk assessment step will require an estimation of the likelihoods of various magnitudes of earthquakes occurring in a given time period, an estimation of the likelihoods of various magnitudes of property damage, injuries and loss of life, etc. In risk assessment it is necessary to rely on the knowledge and experience of experts since the "objective" data is often unavailable or is insufficient. The process of risk assessment can be broken down in the following steps:

2.1.1. Establishment of the objective of the risk assessment task

The first step in any risk assessment procedure is to answer the following two simple questions:

(1) Why are we carrying out the risk assessment?

(2) How would the results of risk assessment be utilized?

In earthquake hazard risk assessment, the objective is to set standards for the seismic resistance of buildings that protect the public health and welfare. In order to evaluate the alternative building standards, a key input is the relationship between a standard and the risks to life and property if this standard is established. Risk assessment is also useful in informing the public and the policy maker about the seriousness of the risks involved in a particular hazard.

2.1.2. Determination of an appropriate level of decomposition

The risk assessment task is considerably simplified if the problem is decomposed in simple parts. For example, one level in decomposition is to estimate the probabilities of various magnitudes of earthquakes. Then, given an earthquake of a certain magnitude, the number of people exposed can be estimated. The extent of property damage and number of deaths and injuries are estimated as a function of the earthquake intensity, the number of people exposes, and so on.

Besides decomposing the problem, it is also important to stratify the population and divide the city into representative regions (e.g., council districts).

The main ideas in determining a level of decomposition are that:

- realistic responses can be elicited
- cost/time considerations are acceptable
- the area of inquiry is limited so that rationale for differing viewpoints can be identified.

In various phases of the decomposition different experts such as seismologists, demographers, geologists, structural engineers etc., need to be consulted.

2.1.3. Probability assessments

Once the risk assessment problem is appropriately decomposed, the next step is to interview the experts and perform statistical analyses on the data available to obtain the probability distributions on various components of the problem. For example, historical frequency of the occurrence of earthquakes can be used to determine the probability of future earthquakes. However, both past data and subjective opinion of experts may be used in estimating property damages. No data may be available to forecast the reaction of tenants and, therefore, only intelligent guesses, based on some field interviews, can be made for this aspect of the problem.

If subjective opinion is deemed necessary, an important step is the careful selection of experts. These experts should represent a wide spectrum of views, and must be well-respected in their area of expertise.

Similarly, it is important that the analyst be aware of the psychological biases that may distort the elicited probability distributions. For example, it has been observed that, if the subjects are directly asked to report their probability distributions, the interquartile range is often tight (Lichtenstein, Fischhoff, and Phillips [1977]). A familiar technique of forcing the subject to think harder by focusing the attention on inside and outside bets in fractile method may alleviate this bias. We feel that, in risk assessment, probability judgments should be obtained through personal interviews. Therefore, if the analyst is aware of the presence of biases (e.g., see Tversky [1974]), a considerable improvement will result. Yet another kind of bias, not so often discussed in the literature, should also be borne in mind. This bias is strategic misrepresentation by an expert. Decomposition of the problem and a carefully designed interrogation procedure may reduce this bias.

2.1.4. Data analysis

For decision making purposes, the data need to be analyzed and presented in many different forms. For example, it may be useful to calculate incremental costs of various policies and incremental savings in expected deaths, injuries, and property damage. Similarly, individual, group, and social risks for alternative policies may provide important input to the decision makers. The specific form of data analysis would depend on the evaluation model used. In fact, risk analysis and risk evaluation are intertwined, and often there is considerable feedback between these two steps.

2.2. Risk Evaluation

In the risk evaluation phase, the objective is to compare the costs and benefits of the alternative policies, and to select the policy that is most preferred with respect to the preferences of the decision makers or society. Risk evaluation typically consists of the following steps:

2.2.1. Identification of alternative policies

In this step, various possible actions protecting the public from the hazard are identified. For example, posting signs to inform the public about the seismic safety of a building is one action that a local government can take. Other alternatives are upgrading of buildings to some specific standard, or demolition of unsafe buildings. The city may choose to have different regulations for different types of buildings. These alternatives are often generated through public debates, political process, or by a government agency. A creative generation of alternatives is the most important step in the entire process of risk management.

2.2.2. Objectives of risk management policy

In order to formulate a consistent risk management policy, the objectives of the policy should be clearly specified. Often, there are multiple conflicting objectives. For example, one objective in earthquake hazard management problems is to reduce the likelihood of deaths and injuries, while the other is to reduce the cost of rehabilitating unsafe buildings. These objectives cannot simultaneously be met. Welfare of landlords may be in conflict with the welfare of tenants, and so on. It is, therefore, important to identify all diverse groups that may be affected by a policy and the attributes, such as cost, property damage, lives saved, injuries prevented, number of people displaced, etc., that are needed in evaluating alternative policies.

2.2.3. Tradeoffs among objectives

It is inevitable that the tradeoffs must be made between various objectives, e.g., additional costs and expected lives saved. A formal model may be useful in this step to ensure consistency. These tradeoffs will have to be made by policy makers and sometimes by the society through political process such as direct ballotting. We will assume here that the society has delegated the responsibility to make such tradeoffs to a decision maker. The purpose in a formal analysis is to ensure that implications of various tradeoffs are well-understood and that such tradeoffs are consistent with the decision maker's preferences. We will discuss some critical issues involved in making these tradeoffs.

2.2.4. Sensitivity analysis

Since many inputs to the risk assessment and risk evaluation model are subjective, a sensitivity analysis must be carried out to ensure the robustness of a policy. The range for reasonable variation in various values can be estimated during the assessment process. For example, it may be worthwhile to vary the cost of rehabilitation to test how the cost-effectiveness of a policy varies. Sensitivity analysis will also point out whether a disagreement amongst different experts on a particular value matters and where additional efforts should be expanded to collect more information.

2.3. Policy Formulation

Once the process of risk evaluation is complete, a risk management policy can be formulated. The critical issue in formulating a policy is to ensure that it can be implemented and that enforcement is possible within the means of the city. For example, a report by Stanley Scott of the Institute of Governmental Studies (1975) points out "a crucial weak point in seismic safety policy is the enforcement of seismic design regulations".

2.3.1. Monitoring and enforcement

After the disastrous Sylmar earthquake in 1971, California's basic urban planning legislation was amended to require that each city and county should incorporate seismic safety as part of its general plan.

> "The effect of...(the law) is to require cities and counties to take seismic hazards into account in their planning programs. All seismic hazards need to be considered, though only ground and water effects are given as specific examples. The basic objective is to reduce loss of life, injuries, damage to property, and economic and social dislocations resulting from future earthquakes."

There was, however, no provision in the law for enforcement. It is therefore not surprising to find that many building owners do not ensure adequate seismic safety in the design and construction of their buildings.

Most local governments have been reluctant to allocate resources to monitor and enforce seismic demands. A risk management policy should recognize this limitation.

2.3.2. Legal aspects

A risk management policy should be consistent with the laws of the land. Unfortunately, because of too few precendents and because risk management is a relatively recent phenomenon, the laws are unclear. It is possible for a city to require older buildings to meet some safety standards that were promulgated after the building was built. However, if the owner of the building does not cooperate, the city may be involved in a long legal battle. The following is an excerpt from a John Wiggins and Company report (1977):

> "The State Supreme Court on February 4, 1966, upheld the City of Bakersfield in the application of that City's Uniform Building code against a hotel owner. The case involved a lengthy dispute between the City Council and the owner of the Hotel Padre which was built in downtown Bakersfield before fire hazards were thoroughly recognized and incorporated into building codes. The case started in 1955 when the owner was advised that his building was a fire hazard.
>
> In concluding its decision, the Court noted the following points:
>
> (a) City legislative bodies are empowered by Government Code Section 38771 to declare what constitutes a nuisance.

(b) Health and Safety Code Section 17951 specifically provides that a city or county may impose standards which equal or exceed the state regulations.

(c) The fact that a building was constructed in accordance with all existing statutes does not immunize it from subsequent abatement as a public nuisance.

(d) It would be an unreasonable limitation on the powers of the city to require that this danger be tolerated ad infinitum merely because the hotel did not violate the statutes in effect when it was constructed 36 years ago.

(e) It has been recognized that a building code may constitutionally impose stricter standards for newly constructed buildings than for those which existed at the time the code was enacted. The Uniform Building Code makes such a distinction. However, the constitutional criteria to be applied in either case are whether the expenses necessarily incurred in complying with this statute and the sanctions imposed for noncompliance are reasonable in relation to the public health or safety interest being protected.

(f) In this case compliance with the ordinance would in all probability result in increased value of the hotel rather than diminution or destruction."

2.3.3. Real-world constraints

A risk management policy should address several real-world institutional, socio-economic, and political constraints. Public acceptability and institutional mechanisms to carry out a policy often decide the success or the failure of a risk management policy. Could a policy that deprives hundreds of poor and old people of housing in a city where the housing shortage is severe be politically acceptable? Could a policy that is clearly unacceptable to the builders, owners, and the real-estate interest group be successfully implemented? Could a policy that is not timely with respect to the public awareness be carried out? An explicit consideration of what are all possible hurdles that could impede the implementation of a policy must be well thought out. A full ventilation of the diverse and differing opinions and a full awareness of the potential problems before a policy is finally adopted is a requisite for its success. Needless to say, all discontent cannot be eliminated and all affected parties cannot be fully satisfied. An understanding of their concerns would greatly improve the design of a policy.

A word of caution is warranted here. A good policy is not the one that attempts to incorporate every single concern of the time. But a good policy recognizes what can be changed and attempts to do so if such a change is in the greater welfare of the society; simultaneously, it recognizes the boundaries within which it must operate.

3. BACKGROUND OF THE SEISMIC SAFETY PROBLEM FOR THE CITY OF LOS ANGELES

Los Angeles, like many other cities in the state and the nation, has a large number of existing earthquake hazardous buildings. These buildings were built before earthquake standards were incorporated in the building codes. In case of a major earthquake, these buildings are most susceptible to collapse, causing death and injuries to the occupants. This report specifically deals with the unreinforced masonry buildings that were built before 1933--prior to code requirements designed to withstand earthquakes. We have chosen to focus on these buildings for two reasons:

(1) Sufficient information on the type, use, occupancy, etc., for these buildings has been compiled by the city. Similar information for the other buildings is unavailable at this time.

(2) These buildings pose the greatest hazard to human life and property.

Our analysis, however, is applicable to other types of buildings. We now provide some factual information on these pre-1933 buildings and what has been done to date to mitigate earthquake hazards in these buildings.

3.1. Hazardous Buildings

3.1.1. Number and location

Los Angeles has approximately 7,863 old buildings made of reinforced masonry that were built before 1933. Excluded from these figures are detached dwellings and detached apartment houses containing fewer than 5 dwelling units. Figure 1 shows the distribution of these buildings throughout the city of Los Angeles. A detailed breakdown of these buildings by council districts is given in Table 7. It can be seen from Table 7 that a large number of these buildings are located in the central city.

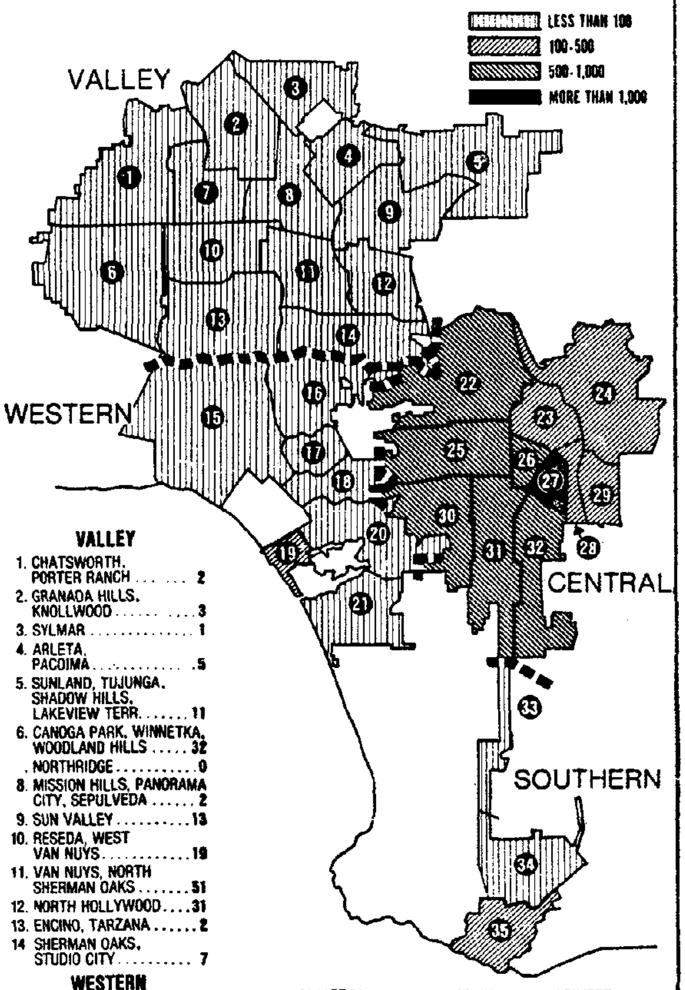
3.1.2. Occupancy and type of use

In Table 8, a breakdown of these buildings by type of use is given. Approximately 10% of the buildings are residential. A majority of these residential buildings are located in the Hollywood, Wilshire, and Westlake communities while most of the industrial buildings are located in the Central City-Downtown area. Table 9 gives the areas of buildings in each council district. As can be seen from Table 10, occupancy of these buildings exceeds 1 million people.

3.1.3. Classification by risk classes

According to the occupancy load and the use of the buildings, all buildings are classified in one of four risk classes: Essential, High Risk, Medium Risk, and Low Risk. A description of each of these risk classes is given in Table 11. In Table 12, the number of buildings in each risk class in each of the 15 council districts is given. Risk classes III and IV are grouped together.

UNREINFORCED MASONRY BUILDINGS
In City of Los Angeles



VALLEY	
1. CHATSWORTH, PORTER RANCH	2
2. GRANADA HILLS, KNOLLWOOD	3
3. SYLMAR	1
4. ARLETA, PACOIMA	5
5. SUNLAND, TUJUNGA, SHADOW HILLS, LAKEVIEW TERR.	11
6. CANOGA PARK, WINNETKA, WOODLAND HILLS	32
. NORTHRIDGE	0
8. MISSION HILLS, PANORAMA CITY, SEPULVEDA	2
9. SUN VALLEY	13
10. RESEDA, WEST VAN NUYS	19
11. VAN NUYS, NORTH SHERMAN OAKS	51
12. NORTH HOLLYWOOD	31
13. ENCINO, TARZANA	2
14 SHERMAN OAKS, STUDIO CITY	7
WESTERN	
15. BRENTWOOD, PACIFIC PALISADES	15
16. BEL-AIR, BEVERLY CREST	0
17. WESTWOOD	25
18 W. LOS ANGELES, CENTURY CITY, RANCHO PARK	77
19. VENICE	163
20. PALMS, MAR VISTA, DEL REY	24
21. WESTCHESTER, PLAYA DEL REY	4
CENTRAL	
22. HOLLYWOOD	835
23. SILVER LAKE, ECHO PARK	195
24. NORTHEAST LOS ANGELES	460
25. WILSHIRE	911
26. WESTLAKE	547
27. CENTRAL CITY	1194
28. N. CENTRAL CITY	481
29. BOYLE HEIGHTS	346
30. W. ADAMS, LEIMERT, BALDWIN HILLS	514
31. SOUTH CENTRAL LOS ANGELES	857
32. SOUTHEAST LOS ANGELES	774
SOUTHERN	
33. TORRANCE-GARDENA CORRIDOR	17
34. WILMINGTON, HARBOR CITY	94
35. SAN PEDRO	185

THE CONCENTRATIONS—*Map key gives concentrations of masonry structures; heavy dotted lines indicate general city areas*

Times map by Bob Allen

FIGURE 1. Unreinforced masonry buildings in the City of Los Angeles.

TABLE 7. Uses of Pre-1934 Unreinforced Masonry Buildings Surveyed by Council District

Council District	Commercial	Industrial	Residential	Mixed	Garages	Public Buildings	Churches	Theaters	Other	Total
1	14	11	0	4	4	0	1	0	0	34
2	27	13	6	4	3	1	0	1	0	55
3	39	0	0	1	5	2	0	1	0	48
4	325	71	281	229	57	16	8	0	8	995
5	164	55	8	56	26	2	1	2	0	314
6	93	25	38	65	22	6	5	0	0	254
7	42	5	1	3	5	1	0	0	0	57
8	169	62	10	102	59	9	18	2	0	431
9	713	1309	140	614	139	29	35	3	9	2991
10	274	156	157	229	51	8	12	3	5	895
11	40	4	7	12	6	0	0	2	0	71
12	2	0	0	0	0	0	0	0	0	2
13	390	59	117	129	66	14	3	5	2	785
14	297	136	16	130	36	9	10	0	7	641
15	180	38	9	35	23	3	1	0	1	290
TOTALS	2769	1944	790	1583	503	100	92	19	32	7863
%	35	25	10	20	7	1	1			

TABLE 8. Classification of Pre-1933 Buildings in Los Angeles

Type	Number
Commercial	2769
Industrial	1944
Residential	790
Mixed Use	1583
Garages	502
Public Buildings	100
Churches	92
	19
Other	32
Total	7863

TABLE 9. Building Areas by Council Districts (in '000 square feet)

Council District	Total	Residential (apartments & hotels)	Industrial	Commercial	Others
1	203	11	92	97	3
2	445	229	33	169	14
3	164	0	0	150	14
4	13951	8585	1031	3980	355
5	2128	254	592	1259	23
6	1520	525	195	745	55
7	357	22	41	294	0
8	2707	433	639	1430	205
9	37223	5539	21802	9074	808
10	8681	3960	1778	2717	226
11	434	70	38	326	0
12	16	0	0	16	0
13	8237	3765	638	3653	181
14	6006	616	3012	2049	329
15	1874	238	280	1301	55
Totals	83946	24247	30171	27260	2268

TABLE 10. Occupants and Employees by Council District

Council District	Occupants	No. of Employees
1	4015	185
2	4859	266
3	5483	229
4	147630	7805
5	30323	2579
6	20008	1216
7	7517	473
8	51623	2563
9	381000	29888
10	106029	6032
11	9654	721
12	242	24
13	105733	5057
14	84942	11184
15	30691	1663
Totals	990110	69887

TABLE 11. Risk Classes for Buildings

Class I: Essential Buildings

Those structures or buildings that are to be used for emergency purposes after an earthquake, in order to preserve the peace, health and safety of the general public.

Class II: High Risk Buildings

Any building other than an essential building having an occupant load of 100 occupants or more, wherein the occupancy is used for its intended purpose for more than 20 hours per week.

Class III: Medium Risk Buildings

Any building having an occupant load of 20 or more occupants that is not classified as Class I or Class II.

Class IV: Low Risk Building

Any building, other than Class I, having an occupant load of less than 20 occupants.

TABLE 12. Classification of the Buildings by Type and Distribution

City Council District	Building Type I	II	III & IV
1. East San Fernando Valley	-	8	26
2. Hollywood Hills	-	2	53
3. S.W. San Fernando Valley	2	2	44
4. Wilshire	7	106	882
5. West Los Angeles	1	31	282
6. Venice to Crenshaw	2	13	239
7. Central San Fernando Valley	2	40	51
8. South Central Los Angeles	4	40	387
9. Central City	21	454	2516
10. S.W. Los Angeles	4	73	818
11. Brentwood to Encino	-	-	71
12. N.W. San Fernando Valley	-	-	2
13. Hollywood	8	94	683
14. East Los Angeles	6	12	623
15. Watts to San Pedro	2	13	275
Totals	59	852	6952

3.2. Proposed Ordinance

The Los Angeles City Council has passed an ordinance that will require rehabilitation of the unreinforced masonry buildings to some specified standards. This ordinance covers large apartment houses, hotels, stores, industrial property, factories, theaters, and public assembly buildings, etc. Apartment houses of fewer than five units and detached dwellings are exempted. A copy of this ordinance is attached as Appendix 1.

4. STRUCTURING THE DECISION PROBLEM

4.1. Attributes of the Decision Problem

The city of Los Angeles is faced with the decision problem of taking some action (including do nothing) with respect to approximately 8000 old buildings so as to maximize public welfare. Several conflicting objectives and the conflicting interests of various affected groups need to be considered in the choice of an action. The principal attributes in this decision are: cost of rehabilitation, property damage, public safety (likelihoods of deaths and injuries), and displacement of the people. We will not consider the displacement of the occupants of these buildings at the first stage of analysis. Once a cost-effective risk management policy is chosen, the sequence of implementation can be such as to minimize the displacement of people.

4.2. Impact on the Constituents

A decision by the city for rehabilitating the old buildings will impact several interest groups. The interest groups who are directly affected are the renters and the owners. Owners of the buildings will have to pay the cost of upgrading, or share it with the city if some financial incentives are offered. They would, however, receive benefits in reduced property damage, a possible appreciation in the value of the building, reduced liability in case a renter gets injured or killed, and possibly higher future rents. Clearly, if the benefits to an owner were to be higher than the cost, he would have upgraded the building without any government intervention. If the owner is unaware of the benefits, since much of these benefits occur in the future and are uncertain, proper information could induce him to undertake upgrading of his building. It seems that the owners are quite resistant to upgrading the buildings, so it is possible that they do not perceive the benefits to be greater than the costs.

The renters of these buildings would have an advantage of greater safety if the buildings are upgraded. However, some of them may have to vacate the premises temporarily or permanantly if a major reconstruction is undertaken. They also may have to incur higher rents for the use of these buildings.

Policy makers and planners constitute the third group who are indirectly affected by the city's action. If the city requires costly upgrading, the sentiments of the owners run against them. The letter of an owner, Robert M. Lawson, to Councilman John Ferraro with regard to the city ordinance requiring upgrading of the buildings is representative of how a majority of the owners feel about upgrading, "...the passage of such an ordinance would destroy one of the principal remaining assets in my family. This is a poor reward for 53 years of highly productive participation in the economic growth and development of Los Angeles". If the city leaves these buildings alone, and if a major earthquake does destroy them causing deaths and injuries to the occupants, then the policy makers will be held responsible for their infraction.

Finally, the public-at-large is also an affected party. Since the group that suffers the most damage in case of an earthquake is identifiable a priori, the members of the society who do not live or work in these buildings would be willing to pay some amount for the safety of the occupants of these buildings. The benevolent considerations become especially important if the public perceives that the residents of the hazardous buildings are unfairly treated because of their age, income, or other social conditions. A risk management policy will have to consider the impact on all the affected parties.

4.3. Alternatives for Rehabilitation

Buildings are divided into four risk classes: Essential, High Risk, Medium Risk, and Low Risk. In each risk class several upgrading alternatives can be undertaken. These alternatives are: leave the buildings to their present Masonry C status, upgrade to Masonry B standard, upgrade to Masonry A standard, and upgrade to Today's Standards. Construction qualities A, B, and C refer to the degree of earthquake resistance provided.

> Construction Quality A. This includes good workmanship, mortar and design; reinforcement, especially lateral, bound together using steel, concrete, etc., designed to resist lateral forces (sideways shaking).
>
> Construction Quality B. This includes good workmanship and mortar; has reinforcement, but not designed to resist strong lateral forces.
>
> Construction Quality C. This includes ordinary workmanship and mortar; no extreme weaknesses, such as failing to tie in at corners, but not designed or reinforced to resist lateral forces.
>
> Today's Standards. Buildings are restored to conform to current earthquake resistant design and construction practices. The incremental hazard to these buildings, in relation to the recently constructed buildings, is essentially negligible.

Thus, there are four upgrading alternatives for each of the four risk classes of the buildings. For the purposes of our analysis, Class III and Class IV are considered together since there is no significant difference between these two classes. Thus, we will evaluate 12 upgrading alternatives.

4.4. Time Horizon

We will consider 10 years as a planning horizon. This planning horizon is selected because the original code amendments regarding earthquake hazardous buildings developed by the city, stipulated a 10-year period for a phased compliance with the code. In addition, a shorter time horizon would not reflect the earthquake damages accurately. A longer time horizon would require additional data on natural attrition of the buildings, and the possibility of more than one earthquake will have to be formally included in the analysis.

4.5. Uncertain Events

The uncertainties that must be considered in the analysis are:

- occurrence of an earthquake and its intensity
- number of people exposed
- the extent of damage to structures
- the number of people injured and killed.

We have obtained the estimates of the probabilities of these events from published sources, as well as used our own judgment.

In Table 13, key elements of the decision problem are summarized.

TABLE 13. Key Elements of the Decision Problem

Time Horizon	10 years
Alternative Policies	12
Attributes	o cost of rehabilitation o property damage o deaths o injuries
Uncertain Events	o occurrence of earthquake o people exposed o property damage and people killed and injured

5. AGGREGATE ANALYSIS OF THE EARTHQUAKE PROBLEM

In aggregate analysis the risks involved with various upgrading alternatives are quantified. For simplicity it is assumed that all buildings will be subjected to the same upgrading level. The upgrading alternatives are evaluated in comparison with Today's Standards. Thus, the property damage, deaths, and injuries are assumed to be negligible if the buildings are restored to Today's Standards. The upgrading alternatives are defined as follows:

- Today's Standards (TS): Buildings are restored to today's standards.
- Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
- Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
- Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Existing buildings are of Masonry C standard. The following information is useful in evaluating the four alternatives:

5.1. Cost of Upgrading

The cost of upgrading for each of the four alternatives is shown below:

Alternative	Cost of Upgrading (Million dollars)
TS	1680
Masonry A	840
Masonry B	420
Masonry C	-

These costs are obtained by assuming an upgrading cost of $5/sq.ft., $10/sq. ft., and $20/sq.ft., respectively, for Masonry B, Masonry A, and TS alternatives. Total area of buildings is 83,946 sq. ft. Total cost is simply the total area x cost/sq. ft. The figures for cost of upgrading are based upon a sample study by the consulting firm of Wheeler and Gray. The total area is obtained from Table 9.

5.2. Earthquake Probability

Our planning horizon is 10 years. Therefore, we would like to know the probability of various magnitudes of earthquakes within 10 years in the Los Angeles area. An earthquake of less than VII intensity on the Modified Mercalli Scale (VII MMI) is not expected to cause loss of life and therefore is ignored in our analysis. There have been 5 earthquakes of MMI VII or greater intensity in the past 57 years. If the occurrence of the earthquakes is assumed to be exponentially distributed, then probability of a VII MMI or more earthquake in ten years = $1 - e^{\frac{10}{11}} = .6$. We also know that in Southern California, in this century, there have been 17 earthquakes of VII MMI at the epicenter, 7 of VIII MMI, and 6 of IX MMI. Thus, it can be assumed that the probability of VIII and IX MMI earthquakes is approximately the same, and one of VII MMI is three times the probability of either VIII or IX MMI. Thus, we obtain:

Earthquake Intensity	Probability
Below VII MMI	.40
VII MMI	.36
VIII MMI	.12
IX MMI	.12

5.3. Property Damage

Property damage depends on the intensity of the earthquake and the standard of the building. Obviously, a lower standard such as Masonry C and a higher intensity of earthquake such as IX MMI would cause the greatest damage. In Table 14, the percentage of property value damaged by various intensities of earthquake and for each of the four alternatives is given. This table is based on the definition of MMI scale.

TABLE 14. Damage Factors (% of total value damaged)

Earthquake Intensity (MMI)	Masonry C	Masonry B	Masonry A	TS
VI	-	-	-	-
VII	10%	-	-	-
VIII	50%	10%	-	-
IX	90%	50%	10%	-

The average value of a residential building excluding the land is \$34,100, and that of a non-residential building is \$101,520. These estimates are based on the selling price of recently sold buildings. The total value of all 7863 buildings is \$745 million. The property damage is calculated using the damage factors in Table 14 and is given in Table 15.

Table 15

Property Damage (million dollars)

Earthquake Intensity	Masonry C	Masonry B	Masonry A
VII	74.5	-	-
VIII	372.5	74.5	-
IX	670.5	372.5	74.5

The expected property damage is obtained by simply multiplying the damages with earthquake probabilities.

Building Standard	Expected Damages
Masonry C	151.90 million
Masonry B	53.64 million
Masonry A	8.94 million

5.4. Deaths and Injuries

Deaths and injuries caused by an earthquake depend on the number of people exposed and the extent of the damage suffered by the buildings. Historical data suggests that the injuries are approximately five times the number of deaths.

Deaths have been related to property damage. In aggregate analysis we assume that a 10% damage to buildings causes 1 death per 3 million dollars, a 50% damage causes 1 death per .4 million dollars, and a 90% damage causes 1 death per .15 million dollars. For comparison it should be noted that Lee et al. (1979) conclude, based on a correlation with past data, that on an average there was 1 death per \$2.9 million property damage due to earthquakes for buildings that were not built with seismic building codes. The Long Beach earthquake of 1933 killed 120 people and caused \$41 million damage, an average of \$.34 million/death.

Based on this data the expected number of deaths and injuries are given in Table 16.

Table 16

Deaths and Injuries

Building Standard	IX MMI	VIII MMI	VII MMI	Expected Value	
				Deaths	Injuries
Masonry A	25	-	-	3	15
Masonry B	931	25	-	115	575
Masonry C	4470	931	25	657	3285

5.5 Analysis

A summary of costs and benefits of alternative policies is given in Table 17. From this table, incremental costs and benefits can be computed. For example, upgrading the existing buildings (Masonry C) to Masonry B would cost approximately 420 million dollars. This upgrading would result in about 100 million dollars reduction in property damage, 540 reduction in deaths, and 2710 reduction in injuries. If the society is willing to pay 0.5 million dollars for each life saved and $50,000 for each injury prevented, then upgrading to Masonry B will be a preferred alternative.

Table 17

Costs and Benefits

Policy	Cost of Upgrading	Property Damage (millions)	Deaths	Injuries
TS	1680	-	-	-
Masonry A	840	8.94	3	15
Masonry B	420	53.64	115	575
Masonry C	-	151.98	657	3285

5.6. Risks Involved

The risks involved in various alternatives are given in Table 18. There are approximately 200,000 individuals who live or work in these buildings. Individual risk is defined as the probability of death for an individual due to earthquake in the next 10 years. Social risk is simply the expected deaths and expected injuries.

Table 18

Risks Due to Earthquake

		Social Risk	
Policy	Individual Risk	Deaths	Injuries
Masonry A	$1.5 * 10^{-5}$	3	15
Masonry B	$5.75 * 10^{-4}$	115	575
Masonry C	$3.3 * 10^{-3}$	657	3285

We see from Table 18, that under the alternative of no upgrading each individual has a 3.3 in one thousand chance of dying. This is about 10 times the chance of dying by fire and flames and about 33 times the chance of dying by electricity current in homes. Building codes and regulations, such as a recent regulation for requiring smoke detectors, attempt to provide safety from fire and electric hazards. It is therefore reasonable to consider appropriate measures to protect against earthquake hazard.

In the next section we carry out a detailed analysis to determine the cost-effective policy for the earthquake hazard problem.

6. A DETAILED RISK ANALYSIS

In detailed analysis we will allow the possibility that a different upgrading alternative may be used for different classes of the buildings. Under the four possible scenarios of different intensities of earthquakes along Newport-Inglewood and the San Andreas Fault, the twelve upgrading policies are evaluated. Since an earthquake of say X MMI on Newport-Inglewood produces varying degrees of intensity in different council districts, such variation is accounted for in the computation of property damage, deaths, etc.

6.1. Cost of Upgrading

The number of residential and non-residential buildings in each of the four risk classes of buildings are as follows:

Class	Buildings	Non-Residential Buildings
I	-	59
II	147	646
III & IV	643	6368

Since the average area of a residential building is 22,471 sq. ft., and of a non-residential building is 8,783 sq. ft., the total cost of upgrading is calculated by assuming an upgrading cost of $5/sq. ft. for Masonry B, $10/sq. ft. for Masonry A, and $20/sq. ft. for Today's Standards. This cost is given in Table 19.

Table 19

Cost of Upgrading Buildings

(Residential & Non-Residential)

(Millions of Dollars)

	Today's Standards		Masonry A		Masonry B	
	Res.	Non-Res.	Res.	Non-Res.	Res.	Non-Res.
Class I	-	10.36	-	5.18	-	2.59
Class II	66.06	113.46	33.03	56.73	16.51	28.36
Class III & IV	2.89	1118.6	144.5	559.3	72.25	279.65

6.2. Earthquake Scenarios

We examine four scenarios of earthquake in the Los Angeles Basin. These are:

- IX MMI (7.5 Richter Scale) earthquake on the Newport-Inglewood Fault (Scenario 1)
- VIII MMI (6.5 Richter Scale) earthquake on the Newport-Inglewood Fault (Scenario 2)
- X MMI (8.3 Richter Scale) earthquake on the San Andreas Fault (Scenario 3)
- No earthquake (Scenario 4)

Here, MMI refers to the Modified Mercalli Index which is a measure of the intensity of an earthquake (see Wood and Neumann [1931] for a detailed description). (Figure 2 shows MMI distribution for Scenario 1, and Figure 3 shows MMI distribution for Scenario 3.) Based on the U.S. Department of Commerce report [1973], distribution of earthquake intensity in each council district is shown in Table 20. (An outline map of the districts appears as Figure 4.)

In order to compute the probability of each of the four scenarios, we use the historical frequency of the occurrence of earthquakes along the two faults. Based on the historical record, a return period of 19 years is assumed for a VIII MII or more earthquake in downtown Los Angeles. If the interval time between earthquakes is assumed to be exponentially distributed, then, based on a return period of 19 years, the probability of a VIII MII or greater intensity earthquake in 10 years is:

$1-e^{\frac{-10}{19}} = .41$. Based on the FEMA [1981] report, the probability of Scenario 1 is .01, and the probability of Scenarios 3 is between .2 to .5. We consulted seismologist Dr. Clarence Allen of the California Institute of Technology to seek his subjective probability. He considers that Scenario 2 is likely to happen with .1 probability. Therefore, Scenario 3 has .3 probability of occurrence. Dr. Allen's subjective probability for Scenario 3 was .25, and for Scenario 1 it was .01. We assume the probabilities of Scenarios 1 to 4 as .01, .1, .3, and .59, respectively.

It should be noted that these four scenarios are not the only possible scenarios for earthquakes in Los Angeles. In fact, several other possibilities, such as an earthquake on the Malibu Coast Fault or the Whittier Fault, could also cause damage. These four scenarios are chosen simply because they are representative of the range of possible damaging earthquakes in the area.

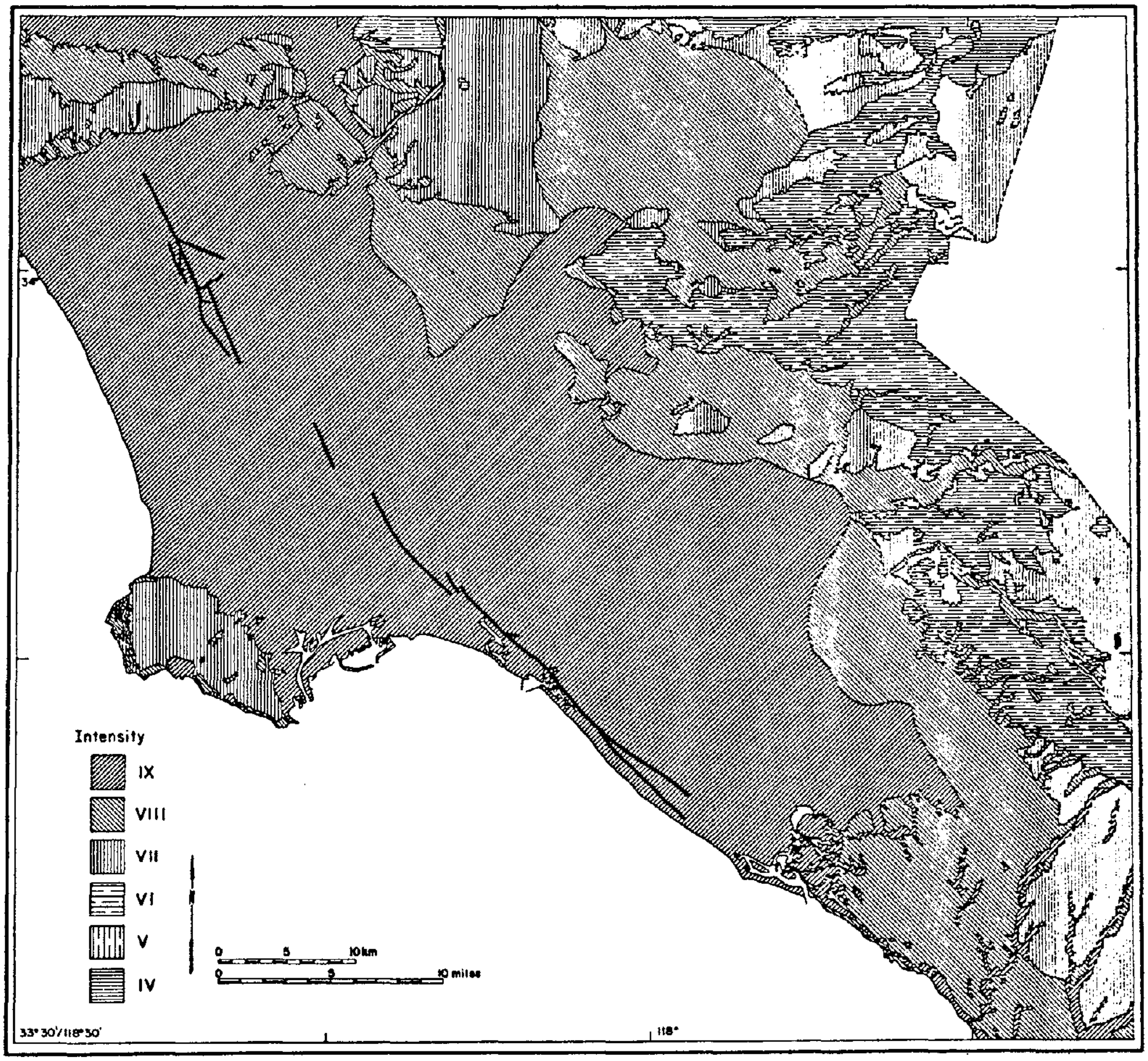


FIGURE 2. Estimated Modified Mercalli distribution in the Los Angeles Basin resulting from an earthquake of magnitude 7.5 on the Newport-Inglewood Fault. Only mapped portions of the fault shown.

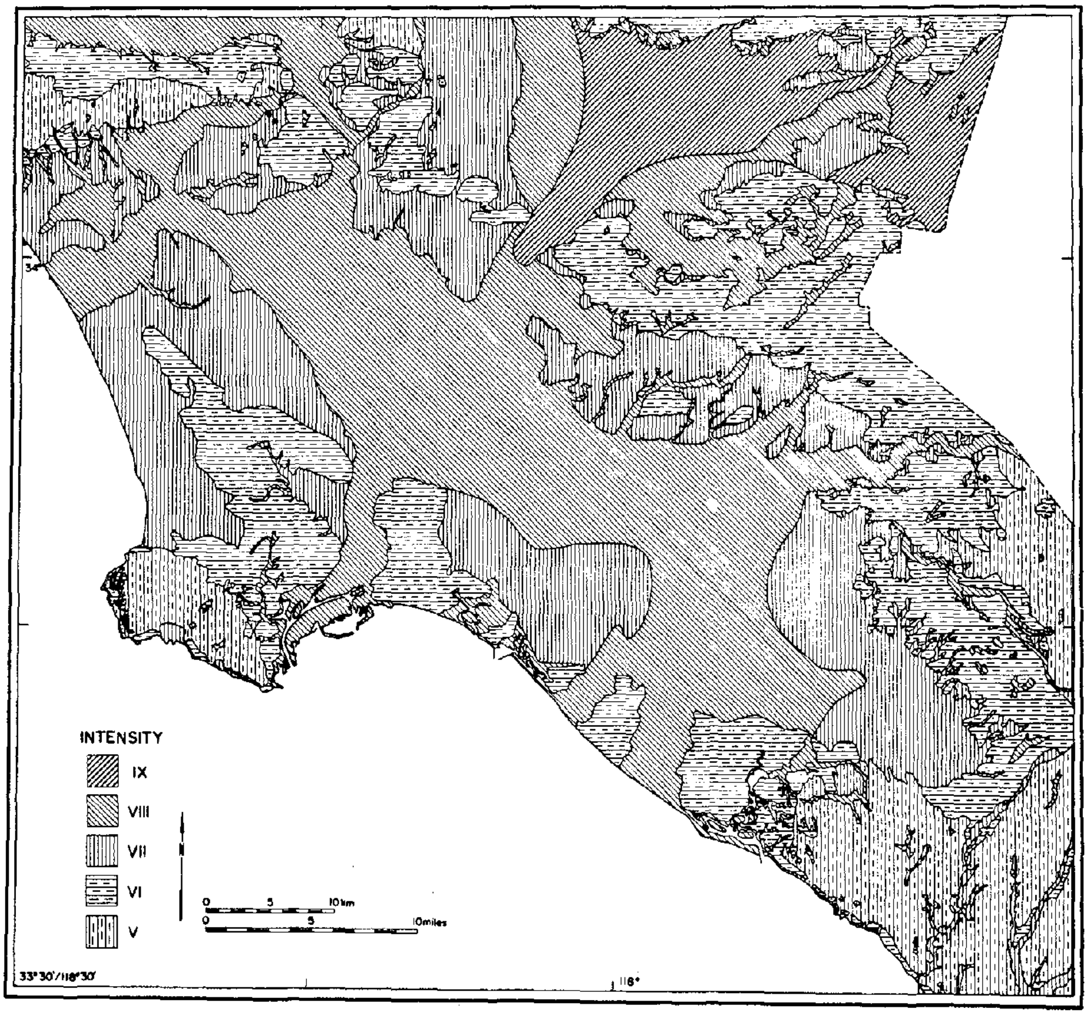


FIGURE 3. Estimated Modified Mercalli Intensity distribution in the Los Angeles Basin for an earthquake of magnitude 8.3 on the San Andreas Fault

TABLE 20. Distribution of Earthquake Intensity

	MMI Estimate		
	8.3 on San Andreas	7.5 on Newport-Inglewood	6.5 on Newport-Inglewood
1. East San Fernando Valley	VIII	IX	VIII
2. Hollywood Hills	VI	VIII	VII
3. S.W. San Fernando Valley	VIII	IX	VIII
4. Wilshire	VII	IX	VIII
5. West Los Angeles	VII	IX	VIII
6. Venice to Crenshaw	VIII	IX	VIII
7. Central San Fernando Valley	VIII	IX	VIII
8. South Central Los Angeles	VIII	IX	VIII
9. Central City	VIII	IX	VIII
10. S.W. Los Angeles	VIII	IX	VIII
11. Brentwood to Encino	VI	IX	VIII
12. N.W. San Fernando Valley	VIII	IX	VIII
13. Hollywood	VII	IX	VIII
14. East Los Angeles	VII	VIII	VII
15. Watts to San Pedro	VI	IX	VIII

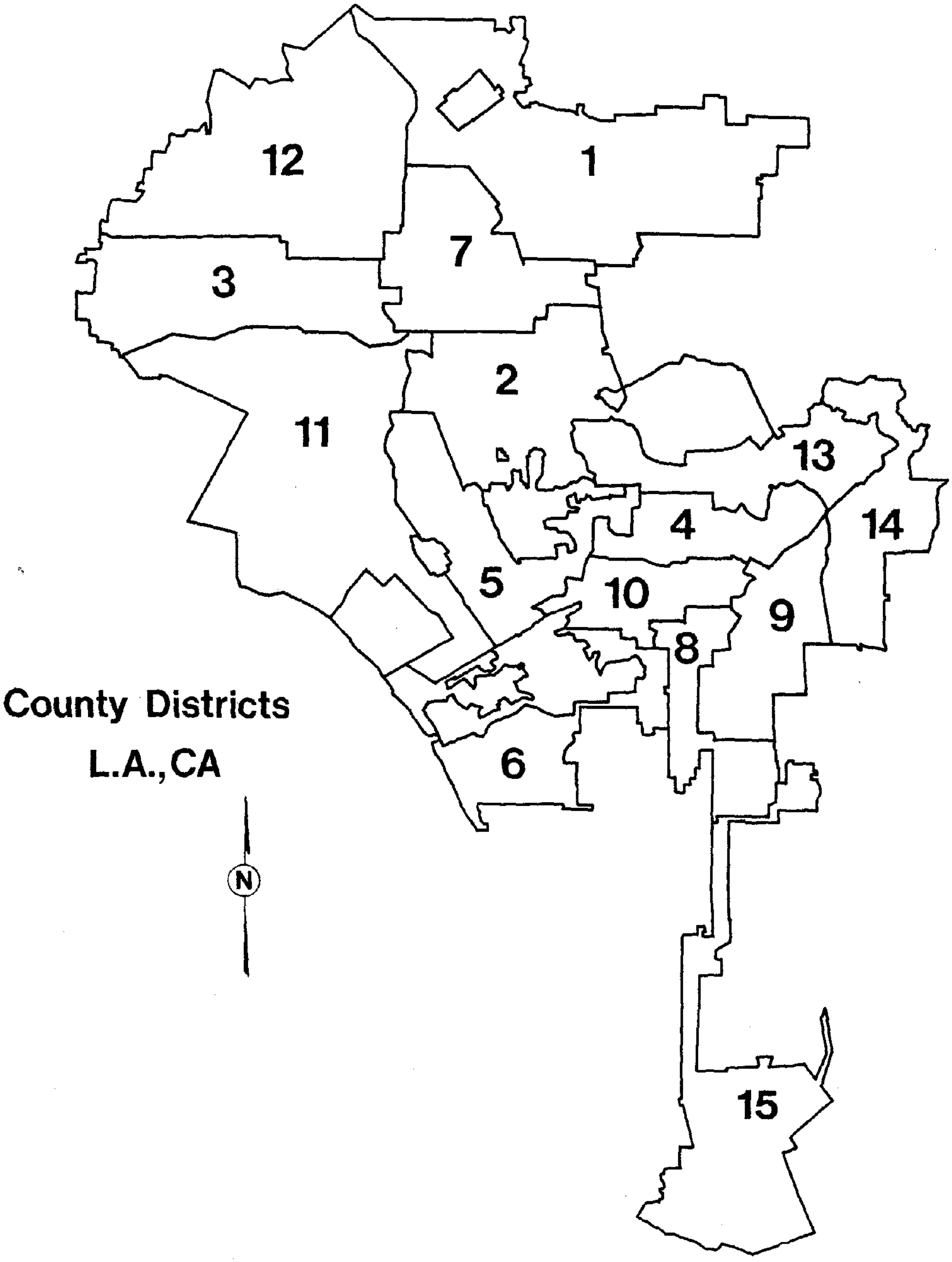


FIGURE 4. Outline map showing council districts of the County of Los Angeles

6.3 Property Damage

Property damage will vary for each upgrading alternative and for each scenario of earthquake. Based on a sample of 61 residential buildings and 60 non-residential buildings, the average value of a residential building is $34,100, and that of a non-residential building is $101,520. The property value in each council district is shown in Table 21. The total property value is 745 million dollars.

Damage factor table (Table 14) gives the percent of property damaged under various degrees of earthquake intensities. We know the earthquake intensity in each council district under the four scenarios. From Table 21 we can get the damage weights for each council district.

$$\text{damage weight} = \frac{\text{number of buildings in a council district}}{\text{Total number of buildings}}$$

Council District	Residential Damage Weights	Non-Residential Damage Weights
1	-	.0048
2	.0076	.0069
3	-	.0068
4	.3557	.1009
5	.0101	.0433
6	.0481	.0305
7	.0013	.0079
8	.0127	.0595
9	.1772	.4031
10	.1987	.1043
11	.0089	.0090
12	-	.0003
13	.1481	.0944
14	.0202	.0886
15	.015	.039

Using the above damage weights and the damage factors, the value of property damaged in each council district as a percentage of total value of 745 million can be calculated. These figures for each scenario are given in Table 22. Notice that Masonry A suffers damage only under Scenario 1. Masonry B suffers no damage under Scenario 4.

TABLE 21. Value of Buildings

Council District	No. of Residentials	Value of Residentials	No. of non-Residentials	Value of non-Residentials
1	-	-	34	3,451,680
2	6	204,600	49	4,974,480
3	-	-	48	4,872,960
4	281	9,582,100	714	72,485,280
5	8	262,800	306	31,065,120
6	38	1,295,800	216	21,928,320
7	1	34,100	56	5,685,120
8	10	341,000	421	42,739,920
9	140	4,774,000	2,851	284,433,520
10	157	5,353,700	738	74,921,760
11	7	238,700	64	6,497,280
12	-	-	2	203,040
13	117	3,989,700	668	67,815,360
14	16	545,600	625	58,450,000
15	9	306,900	281	28,527,120
Totals	760	26,939,000	7,073	718,050,960

TABLE 22. Property Value Damaged as a % of Total Value

Alternative	Scenario	Building	Property Damage
Masonry A	1	Residential	8.88%
Masonry B	1	Residential	43.74%
		Non-Residential	41.30%
	2	Residential	8.88%
		Non-Residential	8.31%
	3	Residential	4.14%
		Non-Residential	6.01%
Masonry C	1	Residential	86.19%
		Non-Residential	78.40%
	2	Residential	43.74%
		Non-Residential	41.30%
	3	Residential	25.43%
		Non-Residential	32.60%
	4	Residential	4.14%
		Non-Residential	6.02%

Based on Table 22, the property damage in millions of dollars for each of the four scenarios is given in Table 23. Based on the opinion of a real estate expert, the content value is assumed to be 25% of the value of the property. Total value damaged is thus 1.25 x property value damaged.

TABLE 23. Value of Property Damage (million dollars)

Class	Upgrading Alternative	Property Damage			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
I	TS	-	-	-	-
	A	.5	-	-	-
	B	2.5	.5	.4	-
	C	4.7	2.5	2	-
II	TS	-	-	-	-
	A	6.4	-	-	-
	B	32	6.4	4.5	-
	C	60	32	25	-
III & IV	TS	-	-	-	-
	A	56	-	-	-
	B	277	56	40	-
	C	526	277	216	-

6.4. Deaths and Injuries

Deaths and injuries occur because of collapse or partial collapse of buildings. Number of buildings in each class that are affected by varying degrees of intensity of earthquakes under the four scenarios, are given in Table 24.

Table 24

Number of Buildings Affected

	Scenario 1		Scenario 2		Scenario 3		Scenario 4
Intensity:	IX	VIII	VIII	VII	VIII	VII	-
Class							
I	53	6	53	6	35	19	-
II	838	14	838	14	630	243	-
III & IV	6276	676	6276	676	4083	2470	-

In Table 25, probability of percent of property damaged is given. This information is based on a U.S. Department of Commerce study. For a given percent of property damage, the expected percentage of deaths is also given. For example, from Table 25, an earthquake of IX intensity in an area has a 20% chance of causing 60-90% damage to a Masonry B building; 60-90% damage is expected to cause death to 2% of the occupants of these buildings.

Table 25

% of Deaths as a Function of Property Damage

		Probability of Damage			
Alternative	% of Property Damaged	Intensity IX	Intensity VIII	Intensity VII	% of Deaths
Masonry A	<10%	.75	.9	-	
	10-30%	.2	.1	-	
	>30%	.05	-	-	
Masonry B	<10%	.05	.75	.9	-
	10-30%	.2	.2	.1	-
	30-60%	.5	.05	-	.5%
	60-90%	.2	-	-	
	>90%	.05	-	-	
Masonry C	<10%	-	.05	.75	-
	10-30%	-	.2	.2	-
	30-60%	.05	.5	.05	.5%
	60-90%	.2	.2		
	>90%	.75	.05		

The number of people exposed to the earthquake depends on the time of its occurrence. There are, on an average, 125 people/building. We will assume that, at any time, half of the occupants/building are exposed.

Using the information on exposure and Tables 24 and 25, expected deaths are computed. Injuries are assumed to be five times the number of deaths. The figures for deaths and injuries are given in Table 26.

TABLE 26. Number of Deaths and Injuries

Class	Upgrading Alternative	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
		D	I	D	I	D	I	D	I
I	TS	-	-	-	-	-	-	-	-
	A	-	-	-	-	-	-	-	-
	B	30	150	-	-	-	-	-	-
	C	145	725	30	150	20	100	-	-
II	TS	-	-	-	-	-	-	-	-
	A	5	20	-	-	-	-	-	-
	B	470	2,350	15	75	10	50	-	-
	C	2,195	10,975	470	2,350	360	1,800	-	-
III & IV	TS	-	-	-	-	-	-	-	-
	A	20	100	-	-	-	-	-	-
	B	2,040	10,200	80	400	65	325	-	-
	C	16,755	83,775	3,540	17,700	2,335	11,675	-	-

D = Deaths I = Injuries

7. ANALYSIS

We will first conduct the analysis from the viewpoint of the owners of the buildings who have to pay for the upgrading costs. Next, we will examine the problem from the society's viewpoint. We will then do the analysis using the assumption that the occupants of these buildings are informed of the risks involved and therefore they may pay a lower rent for higher risk buildings. Finally, we will consider the residential buildings separately.

7.1. Owner's Viewpoint

A typical owner faces the decision problem depicted in Figure 5. for Class II buildings. The City could take any of the four actions. The owner may comply or may choose not to comply. Actually, the owner also has the four alternatives available to him but the alternative of not upgrading at all is clearly advantageous to him. For every scenario, the alternative of not upgrading dominates the upgrading alternative. This finding is clearly supported by owners' opposition to any ordinance that requires them to upgrade the buildings. It should be noted that, in this analysis, we have assumed that the occupants of these buildings are unaware of the hazard.

7.2. Society's Viewpoint

Society has to consider all costs involved, as well as the interest of all parties that are affected by an ordinance. In Table 27, cost of rehabilitation, expected property damage, and expected deaths are given for each of the 12 policies. The expected values are computed by multiplying the outcome (such as number of deaths) under a given scenario with the scenario probability.

The choice of a policy depends on the society's willingness to pay in order to reduce the number of deaths and injuries. The willingness to pay, however, depends on the risk that the individuals face. In Figure 6, a hypothetical curve illustrating the society's willingness to pay to prevent one expected death as a function of the probability of death is given. This curve shows, for example, that if the individuals face a 5-in-one-thousand chance of dying, then the society is willing to pay 1 million dollars to prevent one expected death. But, if the individuals face only a 5 in 10,000 chance of dying, then the society will pay only 500,000 dollars to prevent one expected death. The probability of death that an individual faces under alternative policies is given in Table 28.

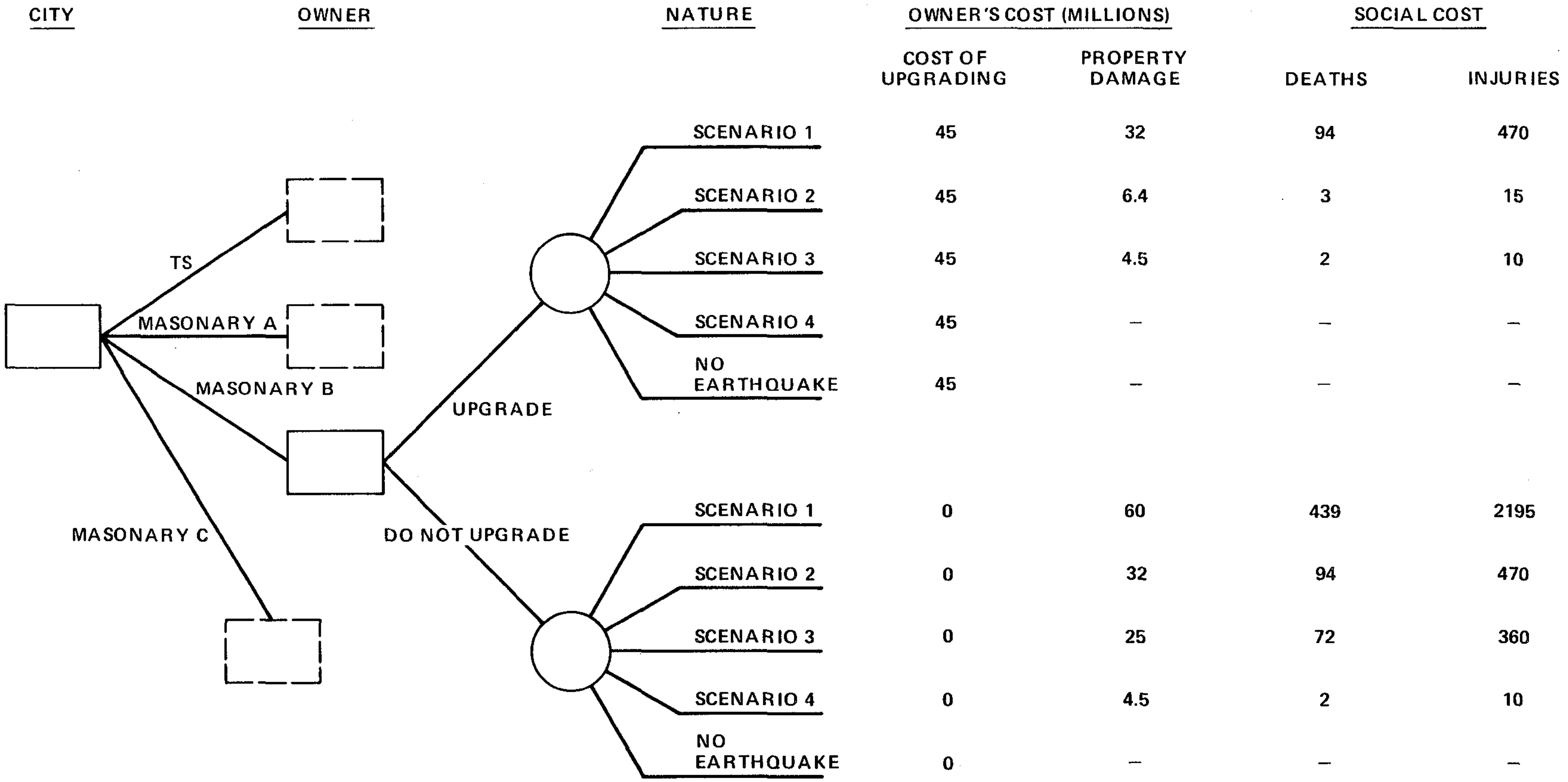


FIGURE 5. Analysis from the Owner's Viewpoint

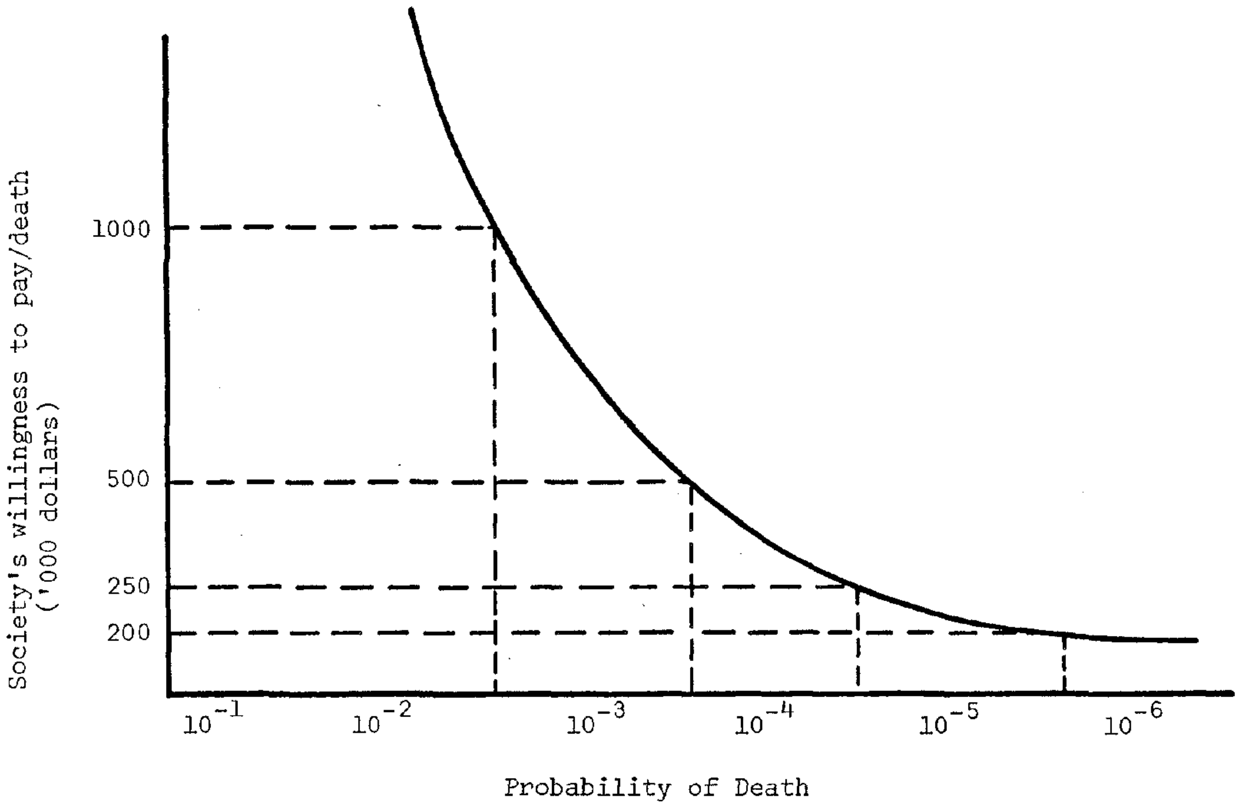
TABLE 27. Social Costs and Benefits

Class	Policy	Cost of Rehabilitation (millions)	Expected Property Damage	Expected Deaths	Expected Injuries
I	TS	10.36	-	-	-
	A	5.18	.09	-	-
	B	2.59	.58	.3	1.5
	C	-	1.61	10.4	52
II	TS	179.5	-	-	-
	A	89.75	1.15	.05	.25
	B	44.9	7.45	9.2	46.0
	C	-	20.1	176.9	884.5
III & IV	TS	1,407.6	-	-	-
	A	703.8	10.08	.2	1
	B	351.9	64.74	47.9	427.5
	C	-	175.26	1222	6110

TABLE 28. Individual Probability of Death

Class	Alternative	Individual Probability
I	TS	-
	A	-
	B	7.2×10^{-4}
	C	4.53×10^{-3}
II	TS	-
	A	8×10^{-6}
	B	8.16×10^{-4}
	C	4.83×10^{-3}
III & IV	TS	-
	A	4×10^{-6}
	B	4.44×10^{-4}
	C	4.45×10^{-3}

FIGURE 6. <u>Willingness-to-pay curve</u>



From Table 28, and using the approximate figures from the willingness-to-pay curve, the incremental costs and benefits are computed in Table 29. For precise computations, the willingness-to-pay curve should be analytically expressed and the willingness to pay in going from one policy to another (e.g., Masonry C to Masonry B) should be computed using integration. Our calculations are based on simple approximations. For example, in Class III and IV, to go from Masonry C to Masonry B, the individual probability of death improves from 4.5×10^{-3} to 4.5×10^{-4}. We then take the willingness to pay to be $(1+.5)/2 = .75$ million dollars per expected death. Total willingness to pay is $(788.2-78.6)\ .75=532.2$ million dollars.

A similar curve can be estimated for injuries. For simplicity, we will, however, assume that the society is willing to pay $50,000 per injury prevented. In Table 29, incremental social costs and benefits are given. Following the table is a list of conclusions that can be drawn from it.

TABLE 29. Incremental Social Costs and Benefits (million dollars)

		Cost	Benefits			
Class	Policy	Additional Cost of Upgrading	Property Damage	Value of Deaths	Value Value of Injuries	Benefit-Cost
	A to TS	5.18	.09	-	-	-5.09
I	B to A	2.59	.49	.15	.037	-1.9
	C to B	2.59	.73	7.9	1.3	7.34
	A to TS	89.74	1.15	-	-	-88.60
II	B to A	44.9	6.30	4.57	1.15	-32.88
	C to B	44.9	12.65	125.7	22.1	115.55
	A to TS	703.8	10.08	.02	.025	-693.67
III & IV	B to A	351.9	54.66	23.85	10.68	-262.71
	C to B	351.9	110.52	880.5	152.75	791.87

- For Class II and Class III and IV buildings, upgrading to Masonry B standard deserves consideration. For the other two alternatives (Masonry A and Today's Standards), additional costs outweigh the additional benefits.
- For Class I buildings, although the net benefit is negative for Today's Standards upgrading policy, the magnitude of the negative benefit is relatively small. Other qualitative considerations, (e.g., that Class I buildings provide essential service to the community in case of an earthquake) may dictate that these buildings be upgraded to Today's Standards.
- It should be noted that, even though net benefit in going from Masonry C standard to Masonry A standard is positive for Class II and Class III and IV buildings, it is not cost-effective to upgrade to Masonry A. This is because most of the benefits of upgrading are reaped in going to Masonry B standard and the additional benefit of further improvement to Masonry A does not justify the additional cost.

7.3. Analysis with Public Awareness of the Earthquake Hazard

In this analysis, we will assume free-market conditions where there is no rent control by the city, and the tenants are aware of the earthquake hazard of their buildings. Based on our empirical study, we further assume that a tenant is willing to pay $25/month in additional rents for an 800 sq.ft. apartment if it is upgraded (chances of a tenant's death in the next 10 years are reduced at least from 1 in 1,000 to 1 in 10,000). Thus, the increased value of rental is 37.5 cents/sq. ft./yr. The total area of the buildings is 83.946 million sq. ft.

We also assume that the property damage can occur in any of the 10 years with equal probability, and the cost of upgrading is incurred in the beginning of the planning horizon. The present value of the property damage, and the increased rental income is calculated using a 10% discount rate. Present values of costs and benefits are summarized in Table 30.

From Table 30, it is easily seen that upgrading to Today's Standards is clearly unattractive, in spite of the increased rents. However, upgrading to Masonry B standards could be attractive for some buildings, even though, in aggregate, the net benefit is negative.

7.4. Residential Apartment Buildings

We now examine whether it is reasonable to have a separate policy for the residential buildings. Based on Environmental Impact Report [1979] of the Los Angeles City Planning Department, there are 137,000 apartment dwellers who live in 45,622 earthquake-unsafe units. We

TABLE 30. Present Values of Costs and Benefits (million dollars)

Class	Policy	Cost of Upgrading	Property Damage	Increased Rental
I	TS	10.36	-	1.5
	A	5.18	.05	1.5
	B	2.59	.35	1.5
	C	-	.95	-
II	TS	179.5	-	21
	A	89.75	1	21
	B	44.90	5	21
	C	-	12	-
III & IV	TS	1,407.6	-	171
	A	703.8	6	171
	B	351.9	40	171
	C	-	108	-

assume that, on an average, two-thirds of the residentials are exposed to earthquake. This exposure estimate may be high for a normal population, but is reasonable in this case because a majority of the residents of these buildings are old and retired. Based on the exposure, we can now calculate the expected deaths and injuries, as discussed earlier. We already provided the cost of upgrading for residential buildings in Table 30. Since we know the distribution of these buildings among council districts, the expected property damage can be calculated. The costs and benefits of the residential buildings are given in Table 31.

TABLE 31. Costs and Benefits of Residential Buildings

Policy	Cost of Upgrading (million dollars)	Expected Property Damage (million dollars)	Expected Deaths	Expected Injuries
TS	355.06	-	-	-
A	177.53	3.28	.04	.2
B	88.76	21.1	10.7	53.5
C	-	57.12	262.1	1,310.5

It is seen from this table that, if the society is willing to pay $200,000 per life saved and $10,000 per injury prevented, then upgrading to Masonry B is cost-effective. Further, the additional cost of upgrading, net of property damage, for upgrading to Masonry B is 52.74 million dollars. This cost is easily recouped in 10 years even if, for each dwelling unit, the rents are raised by $20/month. The break-even rental increase at a discount rate of 10% for 10 years is approximately $16/month. In our survey, the residents were willing to pay this amount for increased safety.

8. EMPIRICAL ESTIMATION OF WILLINGNESS TO PAY FOR SAFETY

In this section, we will discuss two approaches that we used in estimating the willingness of the occupants of the hazardous buildings to pay for safety. In one approach, a questionnaire was used to directly elicit how much an occupant is willing to pay for a decrease in probability of death and injury due to earthquake. In the other approach, market-determined price of the hazardous buildings was compared with the price for similar buildings. The difference in the market price, when adjusted for the quality of the building, provided an estimate on how much premium market is attaching for the safer buildings.

8.1. Direct Estimation of Willingness to Pay for Safety

In this approach, twelve residents were individually interviewed to obtain their willingness to pay additional monthly rent if the buildings are strengthened. Each resident was asked background information on age, income, monthly rent, number of years in the building and his general comments on the earthquake safety issue. To estimate willingness to pay, the following question was asked:

"Your building is known to be unsafe with regard to earthquakes. There are 10,000 people living in such buildings in your neighborhood. If nothing is done to strengthen the buildings, 10 of these residents are going to die in the next 10 years when the earthquake will strike. You or your family members could also become fatalities. Are you prepared to pay an increased rent to help strengthen the buildings so that 9 out of the 10 residents would be saved? ________ How much? ________ How much are you prepared to pay so that none of your 10,000 neighbors will get killed? _______."

The above scenario estimates the willingness to pay for decreasing the probability of death from 1 in 1000 to 1 in 10,000. Alternative scenarios were presented to estimate willingness to pay for different levels of decreases in the probability of death. A copy of the questionnaire is attached as Appendix 2.

The results of this survey were as follows:

- The willingness to pay in increased monthly rents varied from $0 to $25/month.
- The willingness to pay did not depend on the initial probability of death. Respondents took the position that the amount paid is the same whether 1 of 10,000 people are killed or 10 or 100 of 10,000 people are killed.
- Older residents (above 70) were willing to pay little or nothing for the improved safety.

8.2. Property Value Differential Approach for Willingness to Pay for Safety

Market-determined price as a measure of willingness-to-pay which, in turn, is taken as an indicator of consumer satisfaction, summarizes widespread practice in applied welfare economics or benefit-cost analysis. The recent emergence of statistical procedures (see below) to measure hedonic (or implicit) prices has permitted an extension of welfare analysis, in that prices which had not been heretofore observable, can now be used to measure the consumer satisfaction associated with what many call "intangible" goods and services.

The hedonic technique derives from the fact that economists have formed a theory which permits the modelling of consumer preferences for characteristics of goods through an examination of the relationship between the transaction price of the good and the measured amounts of its characteristics. In the case of housing, price-quality regressions have been performed; the estimated coefficients are often interpreted as hedonic prices. The application to urban housing is of particular interest because it is not the asset itself which is transacted, but rather the right to use a durable and immobile asset. Thus, a number of external and/or intangible characteristics come into play. These include neighborhood schools, air quality, traffic noise, etc. It is suggested that risk of hazard exposure could be treated similarly. Most of the applied work has focused on the quest for the dollar value of cleaner air or lower levels of noise. A typical study (Ridker and Henning, [1967]) of a hedonic regression leads the authors to conclude:

> "This information can be interpreted as meaning that if the sulfation levels to which any single family dwelling unit is exposed were to drop by 0.25 mg./100 sq. cm./day, the value of that property could be expected to rise by at least \$83 and more likely closer to \$245. Using the latter figure and assuming the sulfation levels are reduced by 0.25 mg. but in no case below 0.49 mg. (taken as the background level) the total increase in property values for the St. Louis metropolitan statistical area could be as much as \$82,790,000...If our model of the housing market is reasonably correct, householders should be willing to pay at least this amount for the specified reduction in pollution levels."

The procedure is certainly not uncontroversial. Yet, it is quite within the boundaries of cost-benefit practice where indirect measures of valuations are used as first-order approximations.

More recent work (see, for example, Brookshire et al., [1982]) makes the point that the estimated relationship between price and the quantities of characteristics should be non-linear. There are two reasons for this. First, if there are interaction effects such that, for example, larger windows add more to the value of a home which has a view, then perhaps a semi-logarithmic relationship may be more appropriate. Sonstelie and Portney, in fact, perform a Box-Cox transformation on the dependent variable, testing all possible forms of the relationship between the linear and the log-linear (they settle on a form about midway between).

A second reason for a possible non-linear relationship is the possibility of market segmentation or multiple equilibria. If, for example, individuals in the housing market, when beginning a search for new quarters, restrict the neighborhoods to be searched in advance (as many do), then prices may be formed in various sub-markets of some metropolitan area which are almost independent and not subject to arbitrage. In that case, many prices (multiple equilibria) can be found, and a single linear regression (just one slope in the direction of each quantity) would not be appropriate.

The following section of this essay takes the position that comprehensive risk analysis is not really possible without an analytically defensible benefit measure. In many cases, beneficial changes in risk exposure may be comparable to changes in local levels of air quality or noise pollution in that they are not directly priced; yet they are associated with a transacted durable and immobile asset, namely housing. If so, then the hedonic technique may have a place in formal risk analysis. We will proceed with an illustration which considers the exposure of certain older residences in Los Angeles to unusual seismic risk.

The simplest application of the hedonic technique is via the use of a sample of matched pairs. For this study, each pair consisted of a pre-1933 (unreinforced masonry) residential apartment building and a post-1933 residential apartment building located close to the first building, adjacent or at least on the same block. This procedure holds fixed almost all neighborhood, environmental and social service quality levels. The remaining differences for each pair in the sample would be:

(1) building differences

(2) size differences

(3) the difference in exposure to seismic risk.

The first item is an obvious oversimplification for what may be very complex (and hard to measure) differences. Yet, in this phase of the research, we were more concerned with introducing a technique than in refining the input data. As such, field work by project staff was undertaken to compile subjective ratings on the "differences in quality" between all matched pairs. The resulting "rating" variable became the independent variable of the hedonic regression. Size differences were taken care of via normalization: the dependent variable of the regression became value per square foot of building space.

The value data came from Los Angeles County Assessor's records and also includes some obvious difficulties. Because of the recent passage of Proposition 13, assessments in our sample were really of two different sorts. The new law requires that the assessments referred either to any post-1975 purchase (if the property was transacted since 1975), or to the assessment that stood in 1975. Further work would have to partition the sample such that these effects do not obscure the systematic variation of the dependent variable. Yet again, data refinements were not yet our primary interest. Corrections of the assessment data which were carried out were two-fold. First, since the local assessment ratio is 25% of market value, multiplication by a factor of four had to be carried out. Second, the value data had to be annualized in order to convert them to a yearly cost of shelter series.

The regression of value-per-square foot (y) on rating (x) was actually carried out with a transformation on the dependent variable, similar to that carried out by Sonstelie and Portney. That is, a new dependent variable was created,

$$y^{[\lambda]} \equiv \frac{y^{\lambda}-1}{\lambda}$$

Various values of λ were tested. The best results were for $\lambda = 0.9$, and were as follows:

	estimate	t-value
intercept	1.105	5.95
coefficient of x	-0.086	-4.27

$R^2 = 0.32$

$F = 18.22$

All statistics were highly significant. Our interest focuses on the intercept term because it can be interpreted as: property value differences that exist for the case of no difference in the quality rating. Unfortunately, the coefficient of the independent variable had the "wrong" sign. Subsequent plottings of the data revealed that this was due to a straight line being forced through two clusters of points; a straight line through each cluster would have pointed in the proper direction. As suspected, the sample really contains two different sub-samples. Partitioning would require more sampling and more field work. Prior to that, however, the nature of the technique can be further demonstrated.

The sign of the intercept term is "correct". Both, intercept and coefficient estimate, have to be multipled by

$$\bar{y}^{(1-0.9)}$$

where $\overline{y}$ is the sample mean value, to compensate for the non-linearization. The intercept term becomes 1.03. As mentioned, compensation for the use of the 25% assessment ratio yields 4.12. Annualizing at 10% yields \$0.41/square foot. An 800 square-foot apartment would rent for \$328 per year (\$27 per month) more if it is not exposed to the higher seismic risk, all other things held constant.

It should be mentioned that our paired-sample technique is not as accurate as the traditional method of actually measuring amounts of (internal and external) dwelling unit characteristics. Sonstelie and Portney, for example, measure number of rooms, number of bathrooms, quality of construction, age, crime incidence, etc. A stronger demonstration of the hedonic technique would take this approach.

There are many other problems with the sampled data, possibly vitiating the significance of any of the findings. Yet, a formal and on-going risk management effort (perhaps not as constrained in its investigative capacities) should carry out these sorts of efforts simply because there is no other simple way to compare benefits with costs.

For example, accepting, for the moment, the earlier results and invoking the previously cited upgrading cost of \$5/sq. ft. (the same could be done for cost scenarios involving \$10/sq. ft. or \$20/sq. ft., the following analyses are made possible:

> The upgrading costs must also be annualized to be comparable. Using the 10% rate, we have \$.50/sq. ft. Comparing costs to benefits, the upgrading would be cost-ineffective and would have to be justified on non-economic grounds. Note that the "non-economic" part of the argument would have to be significantly larger in the case of the higher cost upgrading schemes.
>
> In focusing on possible non-economic arguments, the actual case would have to be further clarified. For example, if rental housing markets are "tight" enough and landlords pass on the costs of improvements to tenants in the form of higher monthly rent, then the landlord is really unaffected (presuming no initial cash-flow difficulties) and the tenant loses \$0.09/sq. ft. per month. If this is really the size of the economic loss, society might still insist that it be absorbed. Society might feel differently if the loss were larger.
>
> A looser rental market may mean that tenants earn \$0.41/sq. ft. per month extra safety, but pay less than \$0.50/sq. ft. since the landlord has trouble passing on the entire incremental cost. Some societies might then feel better about engaging in what is still a cost-ineffective policy.

> For either of these cases, a public subsidy would have quite different ramifications. In the first case, a subsidy to landlords (recalling their possible cash-flow problems) yields them a net gain, while the renters are left with their net loss. Of course, renters could, as well, be subsidized.
>
> Where only some extra costs are passed forward, a subsidy to owners is less likely to yield them a net gain.

These hypothetical cases could be extended. Yet, the point is simply that conclusions on cost-effectiveness (derived in the prescribed manner) must be tempered with some knowledge of the actual incidence of costs and benefits before the full implications of policies are clear.

The suggested methods help to signal imminent resource losses (costs greater than benefits), possible resource gains (positive net benefits--or "cost-effective" policies), or cases where the differences of costs and benefits are small. In the latter event, a minor resource loss may be "acceptable" in some political sense, depending on the incidence of the loss. It may be possible that society is willing to accept a resource loss if that loss is absorbed by a group that is less likely to be considered "needy". Clearly, this sort of "merit" good situation introduces the gains that accrue to third parties--or society-at-large. One example (part of the first scenario) which illustrates the merit goods notion is the initiation of policy which leaves renters with a small welfare loss, but which has the advantage of making seismic risk less a function of poverty and, thereby, achieves a "social" goal. In other words, the interests of renters, owners <u>and</u> society-at-large are all at stake.

We have tried to show that the hedonic technique, data demanding though it is, opens avenues of risk management analysis not otherwise possible. It is not presumed that the approach takes the place of policymaking. Rather, it is simply an input which should enhance the quality of policymaking by providing new information.

9. FORMULATION OF A RISK MANAGEMENT POLICY

Our study shows that the risks to the occupants of the unreinforced masonry buildings are significant. If no upgrading of these buildings is undertaken, an individual occupant faces approximately five-in-a-thousand chance of death, and 25-in-a-thousand chance of serious injury due to earthquake in the next 10 years. This risk is about 10 times the risk due to fire and flames, and about 40 times the risk due to electricity current in the home, during the same period. Moreover, this risk could be 10 times higher if we assume that a 90% collapse of the building would cause deaths to 25% of its occupants.

Our estimated total cost of upgrading these buildings to Masonry B standard is approximately 400 million dollars. Of course, an upgrading of these buildings will result in a lower property damage to the owners of these buildings (125 million dollar savings), but this gain clearly does not offset the costs involved. A policy that does not account for the owners' interests has low likelihood of success. Besides, the cost of implementing a policy that disregards the owners' interests would be tremendous. This is because the unwilling owners will find all sorts of ways (legal, political, unethical) for not complying with the policy.

Past experience suggests that owners have ignored the upgrading of buildings because of the high cost of rehabilitation. There is also evidence that the city has been unable to enforce seismic design regulations because of financial problems and trained manpower shortage. Therefore, a seismic safety policy should provide an incentive for the owners to cooperate.

Keeping in view the interests of both the owners and the occupants of the buildings, we provide the following recommendations:

- o Class I buildings constitute essential buildings such as schools, hospitals, fire stations, etc. These buildings should be upgraded to Today's Standards. A negative net benefit of upgrading reported in our analysis does not include the benefits to the general public, due to uninterrupted operation of these emergency facilities in the event of an earthquake.
- o Residential buildings should be upgraded to Masonry B standard. The net benefit of this policy is positive if an individual occupant is willing to pay $16/month for the reduced risk. We recommend that the owner should be allowed to increase the rents to partially offset the cost of upgrading.

We feel that approximately $10/month/dwelling increase in rent is a fair cost sharing by the owners and the tenants. This is because the owner receives other benefits; e.g., tax advantage, increase in the life of the building, increased property value, protection against lawsuits, insurance benefits, etc., that were not included in our calculations. The city should also ensure that adequate financing through conventional channels is made available to the owners for undertaking the upgrading.

We do not recommend that the city should simply post signs to make the residents aware of the hazard, on the belief that the market mechanism will determine the optimal action. This is because, for an average resident, it is relatively difficult to assess the risks involved. Besides, because of the housing shortage in Los Angeles, in the short run, the residents may not have a real choice of paying a higher rent for a safer building. An ordinance based on a cost sharing scheme between the tenants and the owners would reduce the resistance of the owners to upgrading. Such a scheme would, therefore, be beneficial to both the owners and the tenants.

- Buildings other than Class I and residentials should not be regulated. For these buildings we recommend that occupants be made aware of the hazard. The final course of action should be allowed to be decided by the market mechanism.

A scheme to inform the public about the seismic hazard of a building has been opposed by the owners of the buildings. It is our belief that the risks involved are substantial and, therefore, it is the responsibility of the city to inform the public about the risks involved. We conjecture that some owners will decide to upgrade the buildings to avoid adverse public reaction and pressure from the occupants once earthquake hazard information is made public.

The city ordinance requires all buildings to be upgraded to specified design standards that, in our terminology, amount to an upgrading to somewhere between Masonry A and Today's Standards. The owners are given two options; in Option 1, they must meet the standards within three years from the date they are notified to upgrade the buildings. The actual notification date varies, depending on the building classification. In Option 2, the owners could undertake a reduced upgrading, (wall anchoring) that corresponds to somewhere between Masonry C and Masonry B standards, within a year of the notification. Once this reduced upgrading is undertaken, an additional 3 to 9 years is permitted for full compliance.

It is not possible to compare the relative success of implementation of our recommendations with the provisions of the city ordinance. It can, however, be said that the ordinance provides little, if any, incentives to the owners. As reported in the Los Angeles Times [1981], the owners oppose the ordinance. The owners' lack of cooperation will, undoubtedly, make the enforcement tedious.

City ordinance does not distinguish between residential and commercial/industrial buildings. Our recommendations would provide an adequate level of safety to the residents, while allowing the market mechanism, public opinion, and occupant/owner negotiations to determine the acceptable course of action for the non-residential buildings. One possible result may be that some buildings are upgraded while some others are put to alternate use with low people exposure, e.g., warehouse, etc.

Finally, our recommendations are based on an analysis of costs and benefits of each alternative. Admittedly, all costs and benefits were not quantified in the formal analysis. Nevertheless, the results of a social decision analysis could be quite useful in formulating a policy.

10. A GUIDE FOR A LOCAL RISK MANAGER

The elements of risk analysis for earthquake safety problems discussed in this report are also applicable to many other hazardous situations. Based on our experience in this study, the following guide for a local risk manager in conducting a study with the purpose of formulating a policy for the situations that involve risks to human health and environment.

10.1. Is the Risk Significant?

The risk manager should first ascertain whether the risks in a given situation are significant to warrant a closer scrutiny and any governmental action. Estimates of the likelihood and severity of harm as well as the number of people that may be affected, will have to be made. A small risk to a large number of people and a large risk, even to a small number of people, may support the need for a possible action.

10.2. What are the Mitigation Alternatives?

If risk is found to be significant, the risk manager must generate alternatives for reducing the risk. In some cases, even if public risk is judged to be small, but if it can be mitigated with low cost (e.g., supplying information on the proper use of a product), there may be a need for action. In the consideration of alternatives for mitigating risks, both regulatory (such as banning a product, specifying a standard, etc.) as well as market oriented actions, must be considered. In some cases, supplying information to the public may be sufficient. In others, a producer can be given incentive to act such that risks are reduced. Some cases may require regulatory action. A careful investigation of all possible means for reducing the risk is a necessary prerequisite for a good policy choice.

10.3. What are the Costs and Benefits?

Costs associated with each mitigation alternative and the benefits for reducing risks must be quantified in an economic evaluation of the alternatives. Benefits are often in reduced probability of deaths and injuries. The translation of these benefits in economic units requires assumption on the social willingness to pay for safety. Considerations must be given, not only to the willingness to pay by the individuals affected by the risk, but also to the willingness to pay by other members of the community who are benevolent toward the group endangered. Estimation of the social willingness-to-pay poses several problems. Nevertheless, in recent years, several alternatives have been suggested to quantify such benefits. We discussed two alternatives in our earthquake safety study.

10.4. Legal/Social/Political Ramifications

Economic considerations alone cannot determine the final choice of a policy. Public awareness of the risk and social emotions often force public action in cases where the net benefits are relatively low, while other cases where potential benefits of a public action may be high remain unnoticed. Legal constraints preclude some cost-effective actions and facilitate the implementation of some less attractive but better than status quo alternatives. Political considerations also play a major role in the determination of a risk mitigation policy. Such constraints must be considered in a policy formulation. Sometimes it may be worthwhile to pursue whether a constraint can be relaxed if the economic benefits are substantial. In other situations, these constraints serve as good approximations for incorporating considerations that are difficult to quantify in economic terms.

10.5. A Balanced Approach

A risk manager will have to explicitly consider the interests of different constituent groups. These interests may often be conflicting. Owners or producers, for example, may have to bear a higher cost than the consumers for reducing risks in some regulatory alternatives. In some cases, a particular population group may be more severely affected, while the benefits accrue to some other group. In principle, if transfer mechanisms exist or can be designed, the differing impacts of costs and benefits on different groups can be adjusted. In practice, a risk manager may have to choose a compromise alternative that may not be optimal with respect to net aggregate social benefits, but in some sense is more fair. A cost-sharing scheme could be an explicit policy for risk mitigation. In earthquake safety study, for example, we recommend that both the renters and the owners should bear a part of the upgrading costs of the buildings.

10.6. Enforcement and Implementability

Careful attention must be given to the monitoring and enforcement of a selected risk management policy. Costs of monitoring as well as resources such as trained manpower should be considered along with practicality (is it possible to verify who caused what damage?). A large number of regulations suffer from the impracticality of their implementation. A full range of implementation problems that may arise must be considered in advance of a policy determination.

11. ETHICAL ISSUES IN RISK MANAGEMENT

In a world with perfect information about present and future risks and benefits of a product or service, there probably will be little need for governmental intervention in the choice of a risk management policy. Unfortunately, however, the users are often not aware of the possible risks and are inexperienced in appreciating the likelihood and severity of the harm even if the information is made available to them. Government has therefore a significant role to play in prescribing policies for societal problems that involve risks to human health and environment.

One consideration that often makes the risk analysis for societal problems complex is the equity of risks. The risks are distributed unequally among different population groups and among generations. In earthquake safety study, for example, the occupants of the hazardous buildings bear a significantly higher risk of deaths and injuries than the rest of the population. Ethical issues involved in such situations have no simple answer. It can be argued that government intervention is unnecessary if the population group that bears the higher risk has been informed of the risks and is free to choose actions that involve lower risks possibly at higher costs. The moral dilemma is that, because of their circumstances (income, age, etc.), they may be unable to choose less risky options. At some levels of risks it may be a moral responsibility of the government to treat safety as a basic right rather than an economic commodity.

Besides inequity of risk, a risk manager will have to consider the question of who pays and who benefits by a public policy. If a transfer mechanism exists for redistributing the costs and benefits, and if it is easily implementable, then the problem of unequal distribution may not be serious. Even in this case, redistribution can only compensate for injuries and deaths in monetary terms, and this may not be considered ethical. A risk manager may have to choose policies that compromise maximation of the net benefits to the society, with the distribution of these benefits among different groups.

A risk manager will also have to exercise the moral judgment on whether the social willingness to pay for reducing a risk should be substantially larger than the ability to pay of the individuals affected by the risk. Care of retarded children and patients requiring kidney dialysis are two such examples. In some situations a priori risks may be fairly distributed but ex post positions will differ significantly. This asymmetry in suffering caused by the nature of technology requires some form of government intervention. Is it ethical to say that the care of a retarded newborn is the responsibility of the parents alone?

We have barely touched the surface of the complex ethical issues that arise in risk analysis for societal problems. Our main point has been that, beyond economic analysis, several other issues that can be classified under ethical or moral judgments need to be considered in prescribing a risk management policy. What principles should be used in incorporating ethical issues in policy analysis? We have no answer.

12. RELATIONSHIP OF THE CASE STUDY WITH OVERALL STUDY

The overall project deals with Risk Management Policies for Local and State Government. This case study provided a useful insight into the issues that a local government may face in designing a risk management policy. The choice of the earthquake safety problem for old buildings was timely since the city was considering an ordinance for upgrading these buildings at the time this study was commenced. The City Council approved an ordinance a few months before the study was completed. The study was not meant to provide any input to this decision, but the timing improved the quality of data that was obtained from the city. Inputs from Mr. Earl Schwartz, who has been involved with the earthquake safety issues for several years and is a member of our Advisory Committee, were also helpful. It can be argued that this case study deals with a problem that a local government is actively facing, and the problem is of sufficient magnitude (in terms of likelihood and severity of harm) to warrant a formal analysis.

The lessons learned from this case study are generally applicable to many other technological hazards that the population of a city, county, or state faces, and that require some intervention by the local and state government. These lessons can be summarized as follows:

- Determination of risks (likelihood and severity of harm is difficult, but can be done by using both objective data and subjective opinions of engineers, scientists, and other experts. Assessment of risks and to whom these risks accrue is the first step for risk management.

- A local policy maker must consider all possible alternatives for reducing the risks to the population. Regulation is only one alternative, and it may be undesirable in some situations. Information to the constituents of possible hazards, and providing incentives so that market mechanism balances the risks with benefit, are other alternatives.

- Benefits of reducing risks must be weighed against the costs involved. Some assessment of tradeoffs between levels of risk reduction and willingness-to-pay must be made. The economic criterion is an important evaluation measure for risk management policies.

- A local government will have to consider legal (state and federal), social, and political constraints that restrict its choice of risk management policy.

- An analysis of who pays and who benefits, distribution of risks, and impact on different constituents must be made before a risk management policy is chosen. A practical scheme will consider balancing of costs and benefits to different parties or population groups affected.

- A local risk manager must consider monitoring and enforcement of a risk management policy. Too often a local government lacks resources to implement policies that may be desirable in some sense. A scheme that provides the incentives to the affected parties to act in accordance with the goals of the risk management policy, clearly has a higher probability of success in manipulation.

A question can be raised that a local government often lacks resources to conduct a detailed study for determining a risk management policy. It may therefore be more appropriate for a state level agency to conduct an analysis as we have proposed. This reservation has merit. We recommend that an extensive effort must only be undertaken for problems posing significant risks to the constituents, and where choice of a risk management policy is not clear. In many situations, a quick and aggregate analysis along the lines of the approach discussed here may reveal a dominating risk management policy. In some situations, available data can be used to establish whether a problem needs urgent action or simply occasional monitoring. In conclusion, we recommend that, even if a local government lacks resources to determine risk management policies based on quantitative analysis, the steps of our approach provide a guideline for developing simple rules for risk management.

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TABLE NO. 68-A
RATING CLASSIFICATIONS

Type of Building	Classification
Essential Building	I
High Risk Building	II
Medium Risk Building	III
Low Risk Building	IV

SEC. 91.6805. GENERAL REQUIREMENTS:

The owner of each building within the scope of this Division shall cause a structural analysis to be made of the building by a civil or structural engineer or arthitect licensed by the State of California; and, if the building does not meet the minimum earthquake standards specified in this Division, the owner shall cause it to be structurally altered to conform to such standards; or cause the building to be demolished.

The owner of a building within the scope of this Division shall comply with the requirements set forth above by submitting to the Department for review within the stated time limits:

a. Within 270 days after the service of the order, a structural analysis. Such analysis which is subject to approval by the Department, shall demonstrate that the building meets the minimum requirements of this Division; or

b. Within 270 days after the service of the order, the structural analysis and plans for the proposed structural alterations of the building necessary to comply to the minimum requirements of this Division; or

c. Within 120 days after service of the order, plans for the installation of wall anchors in accordance with the requirements specified in Section 91.6808(c); or

d. Within 270 days after the service of the order, plans for the demolition of the building.

After plans are submitted and approved by the Department, the owner shall obtain a building permit, commence and complete the required construction or demolition within the time limits set forth in No. Table 68-B. These time limits shall begin to run from the date the order is served in accordance with Section 91.6806(a) and (b).

TABLE NO. 68-B
TIME LIMITS FOR COMPLIANCE

Required Action By Owner	Obtain Building Permit Within	Commence Construction Within	Complete Construction Within
Complete Structural Alterations or Building Demolition	1 year	180 days*	3 years
Wall Anchor Installation	180 days	270 days	1 year

*Measured from date of building permit issuance.

Owners electing to comply with Item c of this Section are also required to comply with Items b or d of this Section provided, however, that the 270-day period provided for in such Items b and d and the time limits for obtaining a building permit, commencing construction and completing construction for complete structural alterations or building demolition set forth in Table No. 68-B shall be extended in accordance with Table No. 68-C. Each such extended time limit, except the time limit for commencing construction shall begin to run from the date the order is served in accordance with Section 91.6806 (b). The time limit for commencing construction shall commence to run from the date the building permit is issued.

TABLE NO. 68-C
EXTENSIONS OF TIME AND SERVICE PRIORITIES

Rating Classification	Occupant Load	Extension of Time if Wall Anchors are Installed	Minimum Time Periods for Service of Order
I (Highest Priority)	Any	1 year	0
II	100 or more	3 years	90 days
III	100 or more	5 years	1 year
	More than 50, but less than 100	6 years	2 years
	More than 19, but less than 51	6 years	3 years
IV (Lowest Priority)	Less than 20	7 years	4 years

SEC. 91.6806. ADMINISTRATION:

(a) Service of Order. The Department shall issue an order, as provided in Section 91.6806(b), to the owner of each building within the scope of this Division in accordance with the minimum time periods for service of such orders set forth in Table No. 68-C. The minimum time period for the service of such orders shall be measured from the effective date of this Division. The Department shall upon receipt of a written request from the owner, order a building to comply with this Division prior to the normal service date for such building set forth in this Section.

(b) Contents of Order. The order shall be written and shall be served either personally or by certified or registered mail upon the owner as shown on the last equalized assessment, and upon the person, if any, in apparent charge or control of the building. The order shall specify that the building has been determined by the Department to be within the scope of this Division and, therefore, is required to meet the minimum seismic standards of this Division. The order shall specify the rating classification of the building and shall be accompanied by a copy of Section 91.6805 which sets forth the owner's alternatives and time limits for compliance.

(c) Appeal From Order. The owner or person in charge or control of the building may appeal the Department's initial determination that the building is within the scope of this Division to the Board of Building and Safety Commissioners. Such appeal shall be filed with the Board within 60 days from the service date of the order described in Section 91.6806(b). Any such appeal shall be decided by the Board no later than 60 days after the date that the appeal is filed. Such appeal shall be made in writing upon appropriate forms provided therefor, by the Department and the grounds thereof shall be stated clearly and concisely. Each appeal shall be accompanied by a filing fee as set forth in Table 4-A of Section 98.0403 of the Los Angeles Municipal Code.

Appeals or requests for slight modifications from any other determinations, orders or actions by the Department pursuant to this Division, shall be made in accordance with the procedures established in Section 98.0403.

(d) Recordation. At the time that the Department serves the aforementioned order, the Superintendent of Building shall file with the Office of the County Recorder a certificate stating that the subject building is within the scope of Division 68 — Earthquake Hazard Reduction in Existing Buildings — of the Los Angeles Municipal Code. The certificate shall also state that the owner thereof has been ordered to structurally analyze the building and to structurally alter or demolish it where compliance with Division 68 is not exhibited.

If the building is either demolished, found not to be within the scope of this Division, or is structurally capable of resisting minimum seismic forces required by this Division as a result of structural alterations or an analysis, the Superintendent of Building shall file with the Office of the County Recorder a certificate terminating the status of the subject building as being classified within the scope of Division 68 — Earthquake Hazard Reduction in Existing Buildings — of the Los Angeles Municipal Code.

(e) Enforcement. If the owner or other person in charge or control of the subject building fails to comply with any order issued by the Department pursuant to this Division within any of the time limits set forth in Section 91.6805, the Superintendent of Building shall order that the entire building be vacated and that the building remain vacated until such order has been complied with. If compliance with such order has not been accomplished within 90 days after the date the building has been ordered vacated or such additional time as may have been granted by the Board and the Superintendent may order its demolition in accordance with the provisions of Section 91.0103(o) of this Code.

SEC. 91.6807. HISTORICAL BUILDINGS:

(a) General. The standards and procedures established by this Division shall apply in all respects to an historical building except that as a means to preserve original architectural elements and facilitate restoration, an historical building may, in addition, comply with the special provisions set forth in this Section.

(b) Unburned Clay Masonry or Abode. Existing or re-erected walls of abode construction shall conform to the following:

1. Unreinforced abode masonry wall shall not exceed a height or length to thickness ratio of 5, for exterior bearing walls and must be provided with a reinforced bond beam at the top, interconnecting all walls. Minimum beam depth shall be 6 inches and a minimum width of 8 inches less than the wall width. Minimum wall thickness shall be 18 inches for exterior bearing walls and 10 inches for abode partitions. No abode structure shall exceed one story in height unless the historic evidence indicates a two-story height. In such cases the height to thickness ratio shall be the same as above for the first floor based on the total two-story height and the second floor wall thickness shall not exceed the ratio 5 by more than 20 percent. Bond beams shall be provided at the roof and second floor levels.

2. Foundation footings shall be reinforced concrete under newly reconstructed walls and shall be 50 percent wider than the wall above, soil conditions permitting, except that the foundation wall may be 4 inches less in width than the wall above it a rock, burned brick, or stabilized adobe facing is necessary to provide authenticity.

3. New or existing unstabilized brick and abode brick masonry shall test to 75 percent of the compressive strength as set forth in Section 91.2405(f) of this Code. Unstabilized brick may be used where existing bricks are unstabilized and where the building is not susceptible to flooding conditions or direct exposure. Abode may be allowed a maximum value of 3 pounds per square inch for shear with no increase for lateral forces.

4. Mortar may be of the same soil composition and stabilization as the brick in lieu of cement mortar.

5. Nominal tension stresses due to seismic forces normal to the wall may be neglected if the wall meets thickness requirements and shear values allowed by this subsection.

(c) Archaic Materials. Allowable stresses for archaic materials not specified in this Code shall be based on substantiating research data or engineering judgment subject to the Department's satisfaction.

(d) Alternative materials and SHBC Advisory Review. Alternative materials, design or methods of construction will be considered as set forth in Section 91.6809(d). In addition, when a request for an alternative proposed design, material or method of construction is being considered, the Department may file written request for opinion to the State Hitorical Building Code Advisory Board for its consideration, advice or findings in accordance with the SHBC.

SEC. 91.6808. ANALYSIS AND DESIGN

(a) General. Every structure within the scope of this Division shall be analyzed and constructed to resist minimum total lateral seismic forces assumed to act noncurrently in the direction of each of the main axes of the structure in accordance with the following equation:

$$V = IKCSW \qquad (68\text{-}1)$$

The value of IKCS need not exceed the values set forth in Table No. 68-D based on the applicable rating classification of the building.

TABLE NO. 68-D
HORIZONTAL FORCE FACTORS BASED ON RATING CLASSIFICATION

Rating Classification	IKCS
I	0.186
II	0.133
III and IV	0.100

(b) Lateral Forces on Elements of Structures. Parts or parts of structures shall be analyzed and designed for lateral loads in accordance with Section 91.2305(d) of this Code but not less than the value from the following equation:

$$F_p = IC_pSW_p \qquad (68\text{-}2)$$

For the provisions of this subsection, the produce of IS need not exceed the values as set forth in Table No. 68-E.

EXCEPTION: Unreinforced masonry walls in buildings not having a rating classification of I may be analyzed in accordance with Section 91.6809.

TABLE NO. 68-E
HORIZONTAL FORCE FACTORS "IS"
FOR PARTS OR PORTIONS OF STRUCTURES

Rating Classification	IS
I	1.50
II	1.00
III and IV	0.75

(c) Anchorage and Interconnection. Anchorage and interconnection of all parts, portions and elements of the structure shall be analyzed and designed for lateral forces in accordance with Table No. 23-B of this Code and the equation $F_p = IC_pSW_p$ as modified by Table No. 68-E. Minimum anchorage of masonry walls to each floor or roof shall resist a minimum force of 200 pounds per linear foot acting normal to the wall at the level of the floor or roof.

(d) Level of Required Repair. Alterations and repairs required to meet the provisions of this Division shall comply with all other applicable requirements of this Code unless specifically provided for in this Division.

(e) Required Analysis.

1. General. Except as modified herein, the analysis and design relating to the structural alteration of existing structures within the scope of this Division shall be in accordance with the analysis specified in Division 23 of this Code.

2. Continuous Stress Path. A complete, continuous stress path from every part or portion of the structure to the ground shall be provided for the required horizontal forces.

3. Positive Connections. All parts, portions or elements of the structure shall be interconnected by positive means.

(f) Analysis Procedure.

1. General. Stresses in materials and existing construction utilized to transfer seismic forces from the ground to parts or portions of the structure shall conform to those permitted by the Code and those materials and types of construction specified in Section 91.6809.

2. Connections. Materials and connectors used for interconnection of parts and portions of the structure shall conform to the Code.

3. Unreinforced Masonry Walls. Unreinforced masonry walls shall be analyzed as specified in Section 91.2417 to withstand all vertical loads as specified in Division 23 of this Code in addition to the seismic forces required by this Division. Such walls shall meet the minimum requirements set forth in Sections 91.2418 and 91.2419 of this Code. The 50 percent increase in the seismic force factor for shear walls as specified in Table No. 24-H of this Code may be omitted in the computation of seismic loads to existing shear walls.

No allowable tension stress will be permitted in unreinforced masonry walls. Walls not capable of resisting the required design forces specified in this Division shall be strengthened or shall be removed and replaced.

EXCEPTIONS:

1. Unreinforced masonry walls in buildings not classified as Rating I pursuant to Table No. 68-A may be analyzed in accordance with Section 91.6809.

2. Unreinforced masonry walls which carry no design loads other

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than its own weight may be considered as veneer if they are adequately anchored to new supporting elements.

(g) Combination of Vertical and Seismic Forces.

1. New Materials. All new materials introduced into the structure to meet the requirements of this Section which are subjected to combined vertical and horizontal forces shall comply with Section 91.2305(k) of this Code.

2. Existing Materials. When the stress in existing lateral force resisting elements are due to a combination of dead loads plus live loads plus seismic loads, the allowable working stress specified in the Code may be increased 100 percent. However, no increase will be permitted in the stresses allowed in Section 91.6809 and the stresses in members due only to seismic and dead loads shall not exceed the *values permitted by Section 91.2301(g) of this Code.*

3. Allowable Reduction of Bending Stress by Vertical Load. In calculating tensile fiber stress due to seismic forces required by this Division, the maximum tensile fiber stress may be reduced by the full direct stress due to vertical dead loads.

SEC. 91.6809. MATERIALS OF CONSTRUCTION.

(a) General. All materials permitted by this Code including their appropriate allowable stresses and those existing configurations of materials specified herein may be utilized to meet the requirements of this Division.

(b) Existing Materials.

1. Unreinforced Masonry Walls. Unreinforced masonry walls analyzed in accordance with this Section may provide vertical support for roof and floor construction and resistance to lateral loads. The bonding of such walls shall be as specified in Section 91.2412(b) of this Code.

Tension stresses due to seismic forces normal to the wall may be neglected if the wall does not exceed the height or length to thickness ratio and the in-plane shear stresses due to seismic loads as set forth *in Table No. 68-F.*

TABLE NO. 68-F
ALLOWABLE VALUE OF UNREINFORCED
MASONRY WALLS WITH MINIMUM QUALITY MORTAR(1)

Rating Classification	Maximum Ratio Unsupported Height or Length to Thickness	Seismic In-Plane Shear Stress Based on Gross Area
I	Not applicable (2)	Not applicable (2)
II	9	3 psi (3)
III	10	3 psi (3)
IV	12	3 psi (3)

NOTES:

(1) Minimum quality mortar shall be determined by laboratory testing in accordance with Section 91.6809(e).

(2) Walls of buildings within rating classification I shall be analyzed in accordance with Section 91.6808(f).

(3) Allowable shear stress may be increased in accordance with Section 91.6809(g).

The wall height or length may be measured horizontally to supporting elements provided the stiffness of the supporting member is at least *twice as stiff as the tributary wall. Stiffness shall be based on the* gross section.

2. Existing Roof, Floors, Walls, Footings, and Wood Framing. Existing materials including wood shear walls utilized in the described configuration may be used as part of the lateral load resisting system, provided that the stresses in these materials do not exceed the values shown in Table No. 68-G.

TABLE NO. 68-G
VALUES FOR EXISTING MATERIALS

Materials or Configuration of materials (1)	Allowable Values
1. Horizontal Diaphragms	
a. Roofs with straight sheathing and roofing applied directly to the sheathing.	150 lbs. per foot for seismic shear.
b. Roofs with diagonal sheathing and roofing applied directly to the sheathing.	400 lbs. per foot for seismic shear.
c. Floors with straight tongue and groove sheathing.	150 lbs. per foot for seismic shear.
d. Floors with straight sheathing and finished wood flooring.	300 lbs. per foot for seismic shear.
e. Floors with diagonal sheathing and finished wood flooring.	400 lbs. per foot for seismic shear.
f. Floors or roofs with straight sheathing and plaster applied to the joist or rafters.(2)	Add 50 lbs. per foot to the allowable values for Items 1a and 1c.
2. Shear Walls	
a. Wood stud walls with wood lath and plaster.	50 lbs. per foot each side for seismic shear.
b. Wood stud walls with plaster and lath other than wood lath.	100 lbs. per foot each side for seismic shear.
3. Plain Concrete Footings	f_c = 1,500 psi unless otherwise shown by tests.
4. Douglas Fir Wood	Allowable stress same as No. 1 D.F.
5. Reinforcing Steel	f_t = 20,000 lbs. per square inch maximum
6. Structural Steel	f_t = 20,000 lbs. per square inch maximum.

NOTES:

(1) Material must be sound and in good condition.

(2) The wood lath and plaster must be reattached to existing joists or rafters in a manner approved by the Department.

(c) Strengthening of Existing Materials. New materials including wood shear walls may be utilized to strengthen portions of the existing *seismic resisting system in the described configurations provided* that the stresses do not exceed the values shown in Table No. 68-H.

TABLE 6[illegible]
ALLOWABLE VALUES OF NEW MATERIALS USED
IN CONJUNCTION WITH EXISTING CONSTRUCTION

New Materials or Configuration of Materials	Allowable Values
1. Horizontal Diaphragms	
Plywood sheathing applied directly over existing straight sheathing with ends of plywood sheets bearing on joists or rafters and edges of plywood located on center of individual sheathing boards.	Same as specified in Table No. 25-J of this Code for blocked diaphragms.
2. Shear Walls	
a. Plywood sheathing applied directly over existing wood studs. No value shall be given to plywood applied over existing plaster or wood sheathing.	Same as values specified in Table No. 25-J for shear walls.
b. *Dry wall or plaster* applied directly over existing wood studs.	*75 percent of the values* specified in Table No. 25-N.
c. Dry wall or plaster applied to plywood sheathing over existing wood studs.	33-1/3 percent of the values specified in Table No. 25-N.
3. Shear Bolts	
Shear bolts and shear dowels embedded a minimum of 8 inches into unreinforced masonry walls. Bolt centered in a 2-1/2 inch diameter hole with dry-pack or non-shrink grout around circumference of bolt or dowel. (1)	100 percent of the values for plain masonry specified in Table No. 24-F. No values larger than those given for 3/4 inch bolts shall be used.
4. Tension Bolts	
Tension bolts and tension dowels extending entirely through unreinforced masonry walls secured with bearing plates on far side of wall with at least 30 sq. inches of area. (2)	1,200 lbs. per bolt or dowel.
5. Infilled Walls	
Reinforced masonry infilled openings in existing unreinforced masonry walls with dowels to match reinforcing.	Same as values specified for unreinforced masonry walls.
6. Reinforced Masonry	
Masonry piers and walls reinforced per Section 91.2418 and designed for tributary loads.	Same as values specified in Table No. 24-G
7. Reinforced Concrete	
Concrete footings, walls and piers reinforced as specified in Division 26 and designed for tributary loads.	Same as values specified in Division 26 of this Code
8. Existing Foundation Pressure	
Foundation pressures for structures exhibiting no evidence of settlement.	Calculated existing foundation pressures due to maximum dead load plus live load may be increased 25 percent for dead load, and may be increased 50 percent for dead load plus seismic load required by this Division.

NOTES:

(1) Bolts and dowels shall be tested as specified in Section 91.6809(f).

(2) Bolts and dowels shall be 1/2 inch minimum in diameter.

NOTES:

(1) Bolts and dowels shall be tested as specified in Section 91.6809(f).

(2) Bolts and dowels shall be 1/2 inch minimum in diameter.

(d) Alternate Materials. Alternate materials, designs and methods of construction may be approved by the Department in accordance with the provisions of Division 5 of Article 8 of Chapter IX of the Los Angeles Municipal Code.

(e) Minimum Acceptable Quality of Existing Unreinforced Masonry Walls.

1. *General Provisions. All unreinforced masonry* walls utilized to carry vertical loads and seismic forces parallel and perpendicular to the wall plane shall be tested as specified in this Subsection. All masonry quality shall equal or exceed the minimum standards established herein or shall be removed and replaced by new materials. The quality of mortar in all masonry walls shall be determined by performing in-place shear tests or by testing eight inch diameter cores. Alternative methods of testing may be approved by the Department. Nothing shall prevent pointing with cement mortar of all masonry wall joints before the tests are first made. If the exterior joints are pointed then the inside face must also be pointed. Prior to any pointing, the wall surface must be sand or water blasted to remove loose and deteriorated mortar. All preparation and cement mortar pointing shall be done under the continuous inspection of a Registered Deputy Building Inspector. At the conclusion of the inspection, the inspector shall submit a written report to the licensed engineer or architect responsible for the seismic analysis of the building setting forth the result of the work inspected. Such report shall be submitted to the Department for approval as part of the struc*tural analysis. All testing shall be performed in accordance with the* requirements specified in this Subsection by a testing agency approved by the Department. An accurate record of all such tests and their location in the building shall be recorded and these results shall be submitted to the Department for approval as part of the structural analysis.

2. Number and Location of Tests. The minimum number of tests shall be two per wall or line of wall elements resisting a common force, or 1 per 1,500 square feet of wall surface, with a minimum of eight tests in any case. The exact test or core location shall be determined at the building site by the licensed engineer or architect responsible for the seismic analysis of the subject building.

3. In-Place Shear Tests. The bed joints of the outer wythe of the masonry shall be tested in shear by laterally displacing a single brick relative to the adjacent bricks in the wythe. The opposite head joint of *the brick to be tested shall be removed and cleaned prior to testing.* The minimum quality mortar in 80 percent of the shear tests shall not be less than the total of 30 psi plus the axial stress in the wall at the point of the test. The shear stress shall be based on the gross area of both bed joints and shall be that at which movement of the brick is first observed.

4. Core Tests. A minimum number of mortar test specimens equal to the number of required cores shall be prepared from the cores and tested as specified herein. The mortar joint of the outer wythe of the masonry core shall be tested in shear by placing the circular core section in a compression testing machine with the mortar bed joint rotated 15 degrees from the axis of the applied load. The mortar joint tested in shear shall have an average ultimate stress of 20 psi based on the gross area. The average shall be obtained from the total number of cores made. If test specimens cannot be made from cores taken then the shear value shall be reported as zero.

(f) Testing of Shear Bolts. One-fourth of all new shear bolts and dowels embedded in unreinforced masonry walls shall be tested by a Registered Deputy Building Inspector using a torque calibrated *wrench to the following minimum torques:*

1/2" diameter bolts or dowels	40 foot-lbs
5/8" diameter bolts or dowels	50 foot-lbs
3/4" diameter bolts or dowels	60 foot-lbs

No bolts exceeding 3/4" shall be used. All nuts shall be installed over malleable iron or plate washers when bearing on wood and heavy cut washers when bearing on steel.

g. Determination of Allowable Stresses for Design Methods Based on Test Results.

1. Design Shear Values. Design seismic in-plane shear stresses greater than permitted in Table No. 68-F shall be substantiated by tests performed as specified in Section 91.6809(e) 3 and 4.

Design stresses shall be related to test results obtained in accordance with Table No. 68-I. Intermediate values between 3 and 5 psi may be interpolated.

TABLE NO. 68-I
ALLOWABLE SHEAR STRESS FOR
TESTED UNREINFORCED MASONRY WALLS

Eighty Percent of Test Results in psi Not Less Than	Average Test Results of Cores in psi	Seismic In-Plane Shear Based on Gross Area
30 plus axial stress	20	3 psi*
40 plus axial stress	27	4 psi*
50 plus axial stress or more	33 or more	5 psi*

*Allowable shear stress may be increased by addition of 10 percent of the axial stress due to the weight of the wall directly above.

2. Design Compression and Tension Values. Compression stresses for unreinforced masonry having a minimum design shear value of 3 psi shall not exceed 100 psi. Design tension values for unreinforced masonry shall not be permitted.

SEC. 91.6810. INFORMATION ROUIRED ON PLANS:

(a) General. In addition to the seismic analysis required elsewhere in this Division, the licensed engineer or architect responsible for the seismic analysis of the building shall determine and record the information required by this Section on the approved plans.

(b) Construction Details. The following construction details shall be made part of the approved plans:

1. All unreinforced masonry walls shall be anchored to all floors and roofs with tension bolts through the wall or by exsting rod anchors at the maximum anchor spacing of six feet. All existing rod anchors shall be secured to joists or rafters by bolting to develop the required forces. The Department may require testing by an approved testing *agency to verify adequacy embedded ends of existing rod anchors.*

2. Diaphragm chord stresses of horizontal diaphragms shall be developed in existing materials or by addition of new materials.

3. Where wood roof or floor members other than rafters or joists are supported in masonry pockets, ledgers or columns shall be installed to support vertical loads of the roof or floor members.

4. Parapets and exterior wall appendages not capable of resisting the forces specified in this Division shall be removed, stabilized or braced to insure that the parapets and appendages remain in their original position.

5. All deteriorated mortar joints in unreinforced masonry walls shall be pointed with cement motar. Prior to any pointing, the wall surface must be sand or water blasted to remove loose and deteriorated mortar. All preparation and pointing shall be done under the continuous inspection of a Registered Deputy Building Inspector certified to inspect masonry or concrete. At the conclusion of the project, the inspector shall submit a written report to the Department setting forth the portion of work inspected.

6. Repair details of any cracked or damaged unreinforced masonry wall required to resist forces specified in this *Division.*

(c) Existing Construction. The following existing construction information shall be made part of the approved plans:

1. The appropriate age of building.

2. The typical footing width, depth and maximum soil bearing for dead plus live loads.

3. The type and dimensions of existing walls and the size and spacing of floor and roof members.

4. The extent and type of existing wall anchorage to floors and *roof.*

5. The extent and type of parapet corrections which were performed in accordance with Section 91.0103(b) of this Code.

6. Accurately dimensioned floor plans and masonry wall elevations showing dimensioned openings, piers, wall thickness and heights.

7. The location of cracks or damaged portions of unreinforced masonry walls requiring repairs.

8. The type of interior wall surfaces and if reinstalling or anchoring of ceiling plaster is necessary.

9. The general condition of the mortar joints and if the joints need pointing.

Sec. 2. The City Clerk shall certify to the passage of this ordinance and cause the same to be published in some daily newspaper printed and published in the City of Los Angeles.

I hereby certify that the foregoing ordinance introduced at the meeting of the Council of the City of Los Angeles of December 16, 1980 and was passed at its meeting of January 7, 1981.

REX E. LAYTON,
City Clerk,
By Charles J. Port, Deputy.

Approved January 7, 1981.

JOEL WACHS,
Acting Mayor

File No. 73-721, 74-4395, and 79-4244
(JO26841) Jan 13

APPENDIX 2. Questionnaire

Willingness to pay for earthquake safety upgrading - Questionnaire

1. How long have you been living here? ______________________________

2. How long do you intend to live here? ____________________________

3. How much do you pay rent?________________ What proportion of your income goes to rent?__________________________________

4. Your building is known to be unsafe with regard to earthquakes. There are 10,000 people living in such buildings in your neighborhood. If nothing is done to strengthen the buildings, 10 of those residents are going to die in the next 10 years when the earthquake will strike. You or your family members could also become fatalities. Are you prepared to pay an increased rent to help strengthen the buildings so that 9 out of the 10 residents would be saved?________ How much?___________ How much are you prepared to pay so that no one of your 10,000 neighbors will get killed?___________

	Probability to			
	from	0	1/10,000	1/1,000
Mild	1/10,000 (1)	(0)	---	---
Medium	1/1,000 (10)	(0)	(1)	---
Strong	1/100 (100)	(0)	(1)	(10)

5. Comments (Who has the responsibility to strengthen? How important is the problem?; etc.)

6. Age__________; # of people in the family ____________________

Address ____

____.