Natural Hazard Research

ECONOMIC ANALYSIS OF NATURAL HAZARDS: A PRELIMINARY STUDY OF ADJUSTMENTS TO EARTHQUAKES AND THEIR COSTS

by

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PREFACE

This paper is one in a series on research in progress in the field of human adjustments to natural hazards. It is intended that these papers will be used as working documents by the group of scholars directly involved in hazard research as well as inform a larger circle of interested persons. The series is now being supported mainly from funds granted by the U.S. National Science Foundation to the University of Colorado, Clark University and the University of Toronto.

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A. Economic Dimension of the Earthquake Problem

Earthquakes throughout history have ranked high among natural hazards which have caused severe damage to life and property. In the last 1100 years there have been 57 major earthquakes with the total deaths estimated to exceed 3 million.[1] The United States has been subjected to several large earthquakes -- 1964, Alaska; 1959, Hebgen Lake, Montana; 1949, Seattle, Washington; 1906, San Francisco, California; 1886, Charleston, South Carolina; 1857, Fort Tejon, California; 1811-1812, New Madrid, Mo.; 1755, Cape Ann, Massachusetts.[2]

In terms of loss of life the United States has been extremely fortunate. In the present century there have been only three quakes in which more than a hundred people were killed -- San Francisco (1906) -- 700 deaths; Long Beach (1933) -- 120 deaths; and Alaska (1964) -- 114 deaths. In all three cases at the time of occurrence most people were at home -- San Francisco -- 5:12 a.m.; Long Beach -- 5:45 p.m.; and Alaska -- 5:36 p.m.[3]

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[1] The largest casualty was in the Shanshi, China quake with 830,000 deaths. M. R. Hill, Earth Hazards -- an Editorial, California Division Mines and Geology Mineral Information Service, 1965, Vol. 18, No. 4, p. 55.

[2] Committee on Earthquake Engineering Research, Earthquake Engineering Research, National Academy of Sciences, 1969, p. 1.

[3] Working group for Earthquake Research of the Federal Council for Science and Technology, Proposal for a Ten-Year National Earthquake Hazards Program, Office of Science and Technology, Washington, D.C. December 1968, p. 36.

The estimated loss of assets[4] for earthquakes in the United States in the forty year period of 1925 to 1965 is around $792 million. This amounts to about 6% of the total losses from natural hazards for the same period. This is not a very high percentage compared to that from floods and hurricanes.[5] However, the damage potential from major earthquakes remains very high in the United States.[6]

With the increase in occupancy of hazard areas and increase in wealth, damage from natural disasters have been on the rise in the United States for several decades. The average annual rate of increase in damages as a result of hurricanes, floods, tornadoes, and earthquakes, as estimated by Dacy and Kunreuther, amounts to about 2.5% a year. Compared to this, the rate of increase of earthquake damage has been 5.8% a year.[7]

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[4] These estimates do not include loss of income and other types of losses to be considered in this paper.

[5] Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters: Implications for Federal Policy, The Free Press, New York, 1969, p. 28.

[6] Committee on Earthquake Engineering Research, op. cit., p. 63.

[7] Dacy and Kunreuther, op. cit., p. 17.

The earthquake problem depends not only on the seismicity of the region,[8] but also the population density, the character of structures, the level of wealth and income. Obviously, if an earthquake hits an unpopulated area it may hardly be classified as a hazard. With the assumption that the seismicity remains the same, the damage to life and property increases with increases in population and economic development.[9]

B. Various Adjustments to Earthquakes and Their Costs

There are eight possible adjustments to the earthquake hazard. 1) Warning system, 2) earthquake prevention, 3) structural protection, 4) insurance, 5) land use change, 6) relief, 7) rehabilitation, and 8) loss bearing or inaction. The first five may be classified as pre-disaster types and the last three as post-disaster types.

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[8] Earthquakes may be classified as destructive if they are above 5.0 Richter in magnitude. On the average there are about 700 quakes of 5.0 Richter or greater; 90 earthquakes of 6.0 Richter or greater, and about 12 earthquakes of magnitude 7.0 Richter or greater. Roughly 1 or 2 per cent of the world's earthquakes occur in the United States. Thus, in a ten year period, we may expect 70 quakes of magnitude 5.0 Richter or more; 10 quakes of 6.0 Richter or more; and 1 shock of magnitude 7.0 or greater. Committee on Earthquake Engineering Research, op. cit., p. 5 and 6.

[9] In the United States the annual expenditure on construction is about 70 billion dollars a year. Out of this about 10 billion dollars is spent in zones 2 and 3 -- the more seismic areas of this country (Figure 1). In the next thirty years, it is estimated that $500 billion out of a total of $3000 billion, in 1969 prices, will be spent in these areas. Ibid., p. 16.

Historically, loss bearing (inaction) has been perhaps the most common adjustment practiced by communities exposed to seismic hazard. During a quiet period when there are no damaging earthquakes, most likely an attitude of "it can't happen here" develops in a community. Immediately following an earthquake there is a great deal of response from the public and demand for various types of pre-disaster type adjustments increases. However, after a lapse of some time, as the memory of the event fades, a certain amount of complacency returns to the people. It is my impression that this has been the case in the San Francisco area. However, in the wake of the recent Los Angeles earthquake a great deal of concern has developed among various groups in the Bay area.

In this chapter each of these adjustments, except for loss bearing will be discussed.

1. Warning System

Recent research in Japan has given encouragement that an earthquake prediction system can be developed. The progress has been of three different types -- first, ability to monitor microearthquakes; second, results of studies of fracture mechanisms of the earth's crust; and third, some evidence of high incidence of microearthquakes preceding major earthquakes.

The Japanese scientists have proposed a ten-year research program in earthquake prediction. Significant correlation between the several processes monitored and occurrence of earthquakes is expected. Similar proposals have also been made by U.S. scientists.[10]

It calls for: i) the development of advanced instrumentation for monitoring faults and installation and use of these in California and Alaska; ii) carrying out of geological and geophysical surveys of fault zones; iii) research in prediction of geophysical phenomenon; and iv) research in earthquake engineering.

The Ad Hoc panel on earthquake prediction in their proposal estimated that a ten-year earthquake prediction program would cost about 137 million dollars.[11] The proposed expenditures in dollar terms for five major types of work were:

a. Geological and Geophysical Field Studies

	First Year	Second Year	Ten Years (Total)
California-Nevada region	$ 1,165,000	$ 1,165,000	$ 6,920,000
Alaska region	765,000	1,315,000	5,170,000
			$ 12,090,000

b. Instrumentation of Seismic Zones

	First Year	Second Year	Ten Years (Total)
	7,200,000	11,300,000	14,400,000

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[10] Earthquake Prediction: A Proposal for a Ten-Year Program of Research, September, 1965, Office of Science and Technology, Washington, D.C., working group for earthquake research, Proposal for a Ten-Year National Earthquake Hazards Program, Office of Science and Technology, Washington, D.C., December, 1968.

[11] Earthquake Proposal: A Proposal for a Ten Year Program of Research, op. cit., p. 29-39.

		First Year	Second Year	Ten Years (Total)
c.	Physical Basis of Earthquakes			
		$ 1,100,000	$ 1,200,000	$ 15,000,000
d.	Research and Earthquake Engineering			
		1,300,000	1,980,000	19,600,000
e.	Miscellaneous Projects			
		1,300,000	1,650,000	16,000,000
	TOTAL	$13,000,000	$19,000,000	$137,000,000

The success of a prediction system depends to a great extent on the amount of warning time it provides prior to the incidence of the quake.[12] Besides the time span, the reliability of the warning is of great importance, since a record of false warnings would dampen the public's confidence and may actually result in substantial economic losses if an evacuation results from such warnings.

Assuming that predictions are reliable, a few hours warning would allow broadcast of messages on T.V. and radio, informing people how best to protect themselves and get people off the streets. Also, police, fire departments, and emergency organizations could be put on alert. With a one day warning, hazardous public buildings could be closed for a certain period. Wholesale evacuation with a one day warning will neither be practical nor desirable. However, selected hazardous areas may be evacuated.

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[12] My formulation of a loss function would be: Loss = f [reliability of prediction, warning time, speed of mobilization of emergency measures, speed of evacuation, intensity and duration of the seismic shocks]; given local geological conditions, construction practices, and population density.

Fuel tanks, nuclear reactors, storage tanks for dangerous chemicals and rupture of dams pose serious threats to life and property in the wake of an earthquake. Recent earthquakes in Peru resulted in severe loss of life as a result of disastrous flooding from rupture of dams. With warnings of several days, protective measures against fire and pollution hazards may be effectively taken; water levels may be lowered in reservoirs, supply in tanks may be moved or reduced, and nuclear reactors may be closed down.

It is apparent that the success of a warning system in terms of loss minimization, besides length of the warning time, would depend a great deal upon the ability of the public and private authorities to coordinate several types of adjustments such as evacuation, closing down of public buildings, storage facilities and dangerous plants. The primary objective of any warning system is to save lives and minimize damage to assets. But, in order for these to be feasible the public has to appreciate the severity of the hazard and the various public organizations have to develop emergency procedures to be implemented prior to and during earthquakes and also develop long-range plans to prevent damage in the hazard area.

The Environmental Sciences Administration of the U.S. Department of Commerce has been operating a Tsunami warning system since 1948. It may be worthwhile to take a brief look at the workings of the system in order to obtain an idea of the costs.[13]

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[13]Details of the ESSA Tsunami warning system were obtained from Dr. James Taggart, Seismologist, Environmental Sciences Administration, Department of Commerce, Boulder, Colorado, in July, 1970.

The ultimate objective of the Tsunami service (TWS) is to reliably predict the wave-heights and other effects for Tsunamis at any distance from generating source anywhere in the world so that necessary steps may be taken to protect lives and property.

As hazards from Tsunamis are international in scope the warning service is supported by several nations. In 1962, Chile, the Fiji Islands, Hong Kong, the Philippines, and Taiwan joined the TWS. French Polynesia, Japan, and New Zealand joined in 1963, Western Samoa and Canada in 1964 and 1965, respectively.

The TWS is a network of tide and seismic data gathering stations in the rim of the Pacific basin and on islands in that ocean. The headquarter at Honolulu has the responsibility for collection and evaluation of seismic and tidal data and issuing of warnings. It also develops and coordinates communication networks between Hawaii and the overall network of stations (Figure 2).

As a result of the 1964 Alaskan earthquake, it became apparent that for helping the residents in regions close to the epicenter of the tsunamigenic earthquake, warnings from Honolulu consumed too much time. Regional evaluation centers were established in order to alleviate this shortcoming. In 1967, the Alaskan Regional Tsunami warning system (ARTWS) was established. At present regional warning systems for Washington, Oregon, California coasts and for local Tsunamis in Hawaii are in their developmental stages. The Japanese, outside of their participation in the TWS, have their own regional system.

Tsunami warnings are passed on to the public in various ways. In the U.S. the key contacts between the TWS and the public for transmitting Tsunami watches and warnings are with State Civil Defense Organizations, State Disaster Offices, State Police, the Office of Civil Defense, and the Office of Emergency Planning. Transmission of messages to these organizations trigger plans that exist in the various regions of the country.

The direct cost of the U.S. Tsunami Warning Service in 1960 amounted to $207,000; in 1969 it amounted to about $640,000; and in 1970 it is expected that the cost will rise to $727,000.[14] (See Figure 3). Research and development have continued to play an important part in the TWS. About 71% of the funds were spent for that purpose in 1964; it is expected that in 1970 it will amount to 34% of the budgeted expenditure.

The obvious benefit from an earthquake prediction and warning system are reduction of loss of life and property in future earthquakes. The San Francisco earthquake and fire of 1906 caused property damage in the city alone, amounted to 500 million dollars in 1906 prices and would amount to 2.6 billion dollars in 1966 prices. Latest earthquake prediction calculations show that for the San Francisco Bay region great earthquakes can be expected at

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[14] The expenditures do not include the use of state and local organizations who fulfill a very important part of the warning service. Personnel in the program have grown from 2 in 1960 to 23 in 1970.

intervals of 60 to 100 years. The intensity of the 1906 earthquake appears to be at the upper limit; whereas, it is possible that the duration may be longer than the recorded one minute of the 1966 earthquake.[15]

Between 1970 and 2,000, we may expect a major earthquake in the San Francisco Bay area of magnitude around 8 Richter and duration of more than a minute. The expected damage to assets would run 25 billion dollars in 1970 prices and loss of life may be in the hundreds or thousands depending upon the time of day the quake strikes and the adjustments that are made prior to the disaster and afterwards. It seems fairly easy to justify the expenditures on an earthquake prediction system on the basis of such an expected outcome. Since the earthquake prediction program includes seismic mapping, calculations of probable frequencies of earthquake, and research and development on understanding the causes and mechanisms of earthquakes, measures could be taken to reduce further losses through better land use planning; better basis for earthquake insurance rates which hopefully would result in widespread use of earthquake insurance; and improved techniques in building design and foundation engineering.

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[15]Karl V. Steinbrugge, Earthquake Hazard in the San Francisco Bay Area: A Continuing Problem in Public Policy. Institute of Governmental Studies, University of California, Berkeley, 1968.

2. Earthquake Modification

In theoretical terms the most promising human adjustment to earthquakes would be to prevent them. Very little work appears to have been done in this area and only the future will tell us the feasibility of prevention as a viable adjustment.

An interesting incident at the Rocky Mountain Arsenal in Denver may provide some interesting possibilities in this area. As a result of injecting fluids into rocks below the arsenal a series of small earthquakes were triggered.[16] One may speculate on the basis of this unintentional human intervention that these may release stored strain energy in active fault zones and thereby eliminate the occurrence of major earthquakes.

3. Structural Protection

Perhaps the most effective area for action to reduce the damage to assets and loss of life from future earthquakes is in setting guidelines for future construction and design of earthquake resistant structures.

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[16] Earthquakes have also been precipitated by the construction of dams, water repressuring operations in oil fields, and detonation of large underground nuclear explosions. Louis C. Pakiser, Jr., "Earthquake Prediction and Modifications: Research in Progress" in Geologic Hazards and Public Problems, Conference proceedings, May 1969, Office of Emergency Preparedness, Santa Rosa, California, U.S. Government Printing Office, Washington, D.C.

Earthquake resistant designs involve economic considerations and probabilities. It is possible to design structures which will withstand the earthquake of greatest magnitude experienced so far with very little or no damage. However, in view of the small probability of occurrence of major earthquakes the incremental cost of a high degree of earthquake proofing for severe earthquakes may not be justifiable.[17]

The current viewpoint on seismic building risk is to take structural engineering steps which would minimize life hazard and limit assets damage to reasonable levels. There is little consensus on what is a "reasonable limit" on property damage. The uniform building code of the Seismology Committee of the Structural Engineers Association of California provides the basis of earthquake provisions. The code recommends that structures should resist major earthquakes without collapse with damage limited to repairable damage. The design codes

[17]Karl V. Steinbrugge, op. cit., p. 38.

for earthquake resistant structures have consistently used allowable design stress 30% greater than normal stresses.[18]

The most common structural system subjected to earthquake damage in the U.S. is the multi-story building. When a building is subjected to seismic motion its base has a tendency to move with the ground. As the motions are rapid, stresses and deformations are caused throughout the structure. In order to survive the seismic shocks the structure has to be either strong enough to resist the forces resulting from the shocks if it were to be rigid; or flexible enough to absorb the deformations without collapse.

A large number of the existing buildings in zone 3 in this country have non-earthquake resistive construction. It is estimated that there are approximately 200,000 such buildings in the high hazard zone.

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[18] The uniform building code recommends that buildings be designed to withstand a minimum total lateral seismic force of magnitude:

$$V = ZKCW$$

where

W = weight of building

$C = \frac{0.05}{3\sqrt{T}}$

T = fundamental period of vibration in seconds in the direction under consideration

Z = numerical coefficient dependent upon the zone as determined by Figure 1. For locations in zone 1, Z = 0.25; for zone 2, Z = 0.5; and for zone 3, Z = 10.

Value of K is determined from a table provided in the uniform building code.

Source: Recommended Lateral Force Requirements and Commentary, Seismology Committee of the Structural Engineers Association of California, 1967.

However, not all such buildings are prone to damages. Table 1 provides a comparison of damageability of the various types of non-earthquake resistive buildings.

Results of the enactment of the California Field Act are interesting in evaluating the usefulness of building codes. The Field Act was passed after the disastrous earthquake in Long Beach in 1933. It has set very high standards of construction of new public schools against the earthquake hazard. (Steinbrugge, op. cit., p. 56).

Crumlish in his study found that damage to pre-1933 school buildings were considerably greater than to the post-Field Act structures. (Figure 4). The areas in California that were investigated were Kern County (Earthquake of August 1952; 7.7 Richter magnitude), Los Angeles area (Earthquake of November 1941; 6.0 Richter magnitude), Imperial Valley (Earthquake of May 1940; 7.1 Richter magnitude), Daly City (Earthquake of March 1957; 5.3 Richter magnitude). Damage figures for post-1933 earthquakes were obtained through examining school records, construction data, and insurance valuation.[19]

It was found that in Kern County, damage to pre-Field Act buildings amounted to 74.3% of total value as compared to 0.3% to post-Field Act buildings.[20] Figure 4 clearly shows the success of the Field Act in reducing damage to buildings.

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[19] J. D. Crumlish, "Some Economic Considerations in Evaluating Engineering Seismology Efforts," ESSA Symposium on Earthquake Prediction, February, 1966, U.S. Department of Commerce, Washington, D.C., p. 121.

[20] J. D. Crumlish, op. cit., p. 122.

Similar studies of schools in Seattle, Washington, which had adopted a strict version of the uniform building code in 1949 show that the 1965 earthquake resulted in 0.07% damage to post-1949 buildings compared with 3.0% damage to pre-1949 buildings. (J. D. Crumlish, op. cit., p. 122)

The cost of introducing earthquake resistance to school buildings as a result of the Field Act in California has been estimated at an addition of 1 to 3% of the total value of the building.[21] Similar estimates were obtained by the author as a result of consultations with structural engineers.

Mr. William Sallada[22] of Denver estimates that in the case of zone 1 (Denver area) a 20 story high-rise building valued at $1,800,000 (average cost of 13 dollars per square foot) would require an additional expenditure of 1% of total value to make it earthquake resistant. He further estimates that for zone 3 (San Francisco Bay area) the additional outlay for earthquake resistance would be about 4% total value.[23] Professor James Chinn of the Department of Civil Engineering at the University of Colorado also gave an estimate of 1% of total value as additional cost of earthquake resistance for zone 1 construction.

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[21] J. D. Crumlish, op. cit., p. 122

[22] Sallada and Hanson, Consulting Engineers, Denver, Colorado.

[23] For the Denver area the additional 1% also provides resistance to wind damage.

4. Insurance

In the face of unpredictability of the earthquake hazard, insurance is a highly desirable adjustment. In the case of insurance the loss is broadbased. The shock of heavy loss upon an individual is absorbed with little strain by the group as a whole.

The earthquake insurance problem is different from other types of hazards' insurance such as fire. In the latter case the fire insurance industry has a very large number of policies in force running into the millions on negotiated claims on thousands of fires each year. In an earthquake hazard area, such as San Francisco, each policy holder desires to insure against the same major earthquake. A large claim may amount to $30 billion if, say, the quake hits a place like San Francisco -- an amount which private companies would not be able to handle. Statistically, in terms of determining the risk and rates, a few years of fire insurance experience is like a century of earthquake experience. The rates that are presently available are most likely not indicative of the true risk.[24]

The industry has had to rely mostly upon the theoretical reports of seismologists in order to establish earthquake insurance rates. In spite of the inadequacy of the basis of setting rates, earthquake insurance is available in most of the United States.[25]

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[24]Earthquake and Engineering Research, op. cit., p. 72.

[25]Dacy and Kunreuther, op. cit., p. 235.

Rates are based upon the seismic zones according to risk (Figure 1) and the type of construction (Table 1). The 1965 rates for wood frame houses for each region of the country are given in Table II. In all cases, except Washington, an 80% coinsurance is required.

Freeman has estimated that for zone 3 in the United States the average annual damage from earthquakes is about 10 cents per $100 of structural value. For zones 1 and 2 his estimate is 1 cent per $100 value.[26] According to Table II this rate for the western region is about 12.5 cents per $100 of structural value for wood frame houses -- considerably less than the 1932 estimate of Freeman if we transform his data in terms of 1970 prices.

In high earthquake hazard areas of the United States residents have not been encouraged to take out insurance as damage potential is very high in case of a major quake. In the state of California less than 5% of the property insured against fire is also insured against earthquakes. In the period 1960-1966 the total number of earthquake policies written for earthquakes in the state of Alaska is less than 12% of the amount written against the fire hazard. This lack of coverage against earthquakes in Alaska cannot be attributed to high cost of insurance, since annual premium for a wood frame house amounts to $1-10 per $1,000 value. In the aftermath of the

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[26] J. R. Freeman, Earthquake Damage and Earthquake Insurance, McGraw Hill, New York, 1932.

Good Friday earthquake of 1964 a substantial increase in demand for earthquake policies did not occur in Anchorage, most likely due to the feeling on the part of the homeowners that another major earthquake would not occur in their lifetime.[27]

It is apparent that earthquake insurance cannot be handled by private companies on the same basis as fire insurance. The federal government must assume a substantial role in an earthquake insurance program if it is to be available widely in the United States.[28]

If an earthquake insurance program is to be successful in this country the insurance rates should portray the hazard and potential damages for various seismic regions of this country, and earthquake resistance of the structure involved. Specific research is required for information on damage potential for the different seismic regions. Earthquake insurance is not to be a replacement for earthquake resistant construction methods. A good insurance program should reward good structural practices by establishing preferential rates.

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[27] Dacy and Kunreuther, op. cit., p. 236-237.

[28] New Zealand has had a successful disaster insurance program in which the government has had a significant role. A surcharge is collected by private insurance companies from all fire and extended coverage policies. This is channeled into a federal government fund which covers damages from flood, storm, war and earthquakes. Since its beginning about $1 million has been paid out for earthquake damages.

5. Land Use Change and Zoning

Certain building sites are more prone to earthquake damage than others because of proximity to active faults, possibility of surface fault displacements, potential for landslides, poor ground conditions which may result in liquification of soil, and so on. With increase in population there is a tendency to build on less desirable sites. Prime examples of such development are the building of homes on the bluffs along the southern California Coast and the housing developments in reclaimed land in the San Francisco Bay area.

There is great need for land use planning in hazard areas in order to avoid future economic losses as a result of earthquake damage. The need for land use planning is particularly critical near fault zones. For example, in California the San Andreas fault has been associated with three major earthquakes: 1838, 1865, and 1906; the Hayward fault has been associated with two major earthquakes: 1836 and 1868. Both of these faults are amidst heavily populated areas. At present there are no sound guidelines for city building departments and planning agencies in order to control land use around fault zones. (Steinbrugge, op. cit., p. 13)

Recently, major structures have been erected in the Hayward and the San Adreas fault zones. A telephone building with underground trunk lines has been constructed in the Hayward fault zone.

San Francisco Bay Area Rapid Transit system (BART) is constructing a tunnel through the Hayward fault zone. Major freeways run along through portions of the San Andreas and Hayward faults. This potentially hazardous situation has resulted from lack of land use planning. It is essential that planning should guide future construction in the fault zone and provide policies for existing structures in the hazard area in order to lower possible losses from earthquakes. (Steinbrugge, op. cit., p. 14-15)

It is necessary to develop planning maps for a given locality. It would have to consider the seismicity of the area, the local geological setting, and the details of local soil and subsoil foundation conditions. Construction criteria should be developed after risk zones have been established around a fault. Steinbrugge has suggested the following guideline for new construction.

Three grades of risk with respect to surface faulting are to be developed ranked from lowest to highest. Grades 3, 2, and 1, highest number denoting greatest hazard.

Grade Three is on the trace of the last known faulting and on the trace of the fault creep. In this area no new structures should be built across the trace of the last known rupture, unless the structure were to be designed for maximum displacement in the maximum probable earthquake. Buildings could not be constructed in this area economically under normal circumstances. Pipelines and roadways could be economically feasible to construct in this area as they could be designed for large lateral offsets. For the purpose of long range planning, grade 3 area should be zoned for parks, golf courses, and roadways. All construction should be minimized in this area.

Grade Two is in the fault zone but not across the traces of the last known rupture. In this area new buildings should be limited to one and two story frame wooden dwellings, and one and two story wooden frame mercantile and office buildings with areas not exceeding 7500 square feet. In this area large lot sizes should be required in order to reduce the population density. Warehouses, storage areas, and other low population density occupancies are to be allowed in this area but location of these firms should be located elsewhere.

Grade One is not in the fault zone and no restrictions are to be imposed in this area.

Recently, a community, which is to reach a population of 10,000 in 20 years, has been planned south of San Jose which contains a part of the Hayward-Calaveras fault zones after critical consideration of the fault zoning problem. The designers of the community[29] have recommended that active fault zones be utilized for roadways, parks, and golf courses.

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[29] Woodward, Clyde, Sherard and Associates are designers. Steinbrugge, op. cit., p. 20.

6. Relief and Rehabilitation

Relief and rehabilitation has played a steadily increasing role in the United States in aiding the victims to recover from natural disasters. Statistical time series reflects this trend. In 1953 total damages from natural disasters in the United States amounted to 352 million dollars. Federal relief in that year amounted to 3.2 million dollars and that from the Red Cross 4.5 million dollars. In 1965 total damages from natural disasters amounted to 2721 million dollars; the aid from the federal government and the Red Cross amounted to 2739 million dollars and 21.0 million dollars respectively.[30]

Since its inception the American Red Cross has dispersed around $300 million to individual victims of natural disasters in this country. The Red Cross aids in emergency assistance and rehabilitation. In the former case the activities are concerned with offering food, shelter, clothing and medical care to the disaster victims. Rehabilitation involves grants for building and repair and furnishing of households and occupational supplies.

Federal disaster assistance has increased greatly in the past decade or so. There are at present nearly fifty federal organizations involved in domestic relief and rehabilitation of natural disaster victims. The federal government aids

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[30] Dacy and Kunreuther, op. cit., p. 32.

whole communities with grants for restoring public properties and it also provides loans and grants to individuals or businesses. Usually it intervenes through the Federal disaster act but it can also act as the Corps of Engineers or the Public Health Service. (Dacy and Kunreuther, op. cit., p. 38-39)

C. Losses from Earthquakes and Economics of Adjustment to Earthquakes

A natural hazard is a product of nature and human adjustments to the particular event. Losses from natural events depend upon the severity of the event (in this case of earthquakes -- intensity and duration of the seismic waves and onset of secondary hazards) and the accompanying preparation. Any study of losses from natural hazards such as earthquakes must recognize the fact that losses are a joint product of Man and Nature.

Total losses from a natural disaster then is equal to the sum of the direct and indirect losses that will accrue from the event under conditions of no adjustment together with the net benefit or loss from the adjustments (or set of adjustments).[31] It is essential to bear in mind that in most cases several human adjustments are in use simultaneously.

[31] W. R. D. Sewell, John Dans, A. D. Scott, and D. W. Ross, Resources for Tomorrow -- A Guide to Benefit Cost Analysis, Ottawa, Queen's Printer, 1962, p. 1-13. (For definitions of Direct and Indirect losses, see these pages.)

One possible equation in evaluating total losses from natural disasters would be as follows:

$Loss_{nh}$ = (Direct losses due to the hazard + indirect losses due to the hazard) under conditions of no adjustment + (direct cost of adjustment + indirect cost of adjustment - direct benefit of adjustment - indirect benefits of adjustment) + (intangible cost due to hazard under conditions of no adjustment + intangible cost due to adjustment - intangible benefit due to hazard under conditions of no adjustment - intangible benefits due to adjustment.)

The above equation is not very useful in terms of evaluating total losses from a disaster since the data on losses reported include the impact of all adjustments. It is next to impossible to obtain damage data under conditions of no adjustment, since in almost all situations some form of adjustment invariably takes place. For these reasons we will not bother further with the above equation and proceed to outline the costs and benefits of the various adjustments themselves. Items appearing with a * mark in this outline are difficult if not impossible to assess in economic terms. They are, nevertheless, included for the sake of completeness, and also point towards the limitations of cost-benefit analysis.

1. <u>Costs and Benefits of Earthquake Prediction (Warning) System</u>:

<u>Costs</u> a) Direct cost of the warning system -- capital costs; operating costs including administrative expenses; research and development costs.

b) Direct cost of transportation and the cost of resettling in a new area as a result of evacuation.

<u>Benefits</u> a) Direct benefits -- amount of damage prevention to assets and income; prevention of loss of life and injury.*

b) Indirect benefits -- increase in employment due to the installation and development of the warning system; innovations and improvements in technology; spillover effects -- such as use of research data in setting insurance rates, in land zoning and in the design of earthquake resistant structures.*

2. <u>Costs and Benefits of Earthquake Prevention System</u>

<u>Costs</u> a) Direct cost of the prevention system -- capital and operating costs including administrative expenses; research and development costs.

<u>Benefits</u> a) Direct benefits -- damage prevention to assets; prevention of loss of life and injury*; prevention of income loss.

b) Indirect benefits -- increases in employment due to implementation of the project; benefits accruing from external economies due to advances in technology.

3. <u>Costs and Benefits of Structural Protection</u>

<u>Costs</u> a) Direct cost of structural modification in terms of material and labor; costs of research and development.

<u>Benefits</u> a) Direct benefits -- amount of damage prevention to structures; prevention of loss of life and injury*; prevention of income loss.

b) Indirect benefit -- the structure is rendered wind and blast resistant.

4. <u>Costs and Benefits of Insurance</u>

<u>Costs</u> a) Premium -- total amount spent on insurance until damage occurs = x.

<u>Benefits</u> a) Amount guaranteed in case of loss of asset, i.e., the value of the policy = A. (Net gain or loss to the policy holder = A - x).

5. <u>Costs and Benefits of Land Use Change</u>

Case I We will first consider the case of land abandonment.

<u>Costs</u> a) Loss in output as a result of moving to a less favorable location (alternately this may also be considered as loss in wages, salaries, rents, and interests; double counting must be avoided here.)

b) Costs of relocation and resettling -- this involves public and private costs. The private costs are cost in abandonment of assets, cost of purchase of new assets, transportation costs, costs in terms of loss of friends and community*; public costs -- loss of the existing physical infrastructure, expenditure on the construction of new infrastructures.

Benefits a) Direct benefits -- amount of damage prevention to assets and incomes; prevention of loss of life and injury*.

b) Indirect benefits -- improvement of existing physical infrastructure; improvements in the quality of life and environment as a result of better planning and construction*.

Case II Land zoning on the basis of seismic risk.

Costs a) Direct costs -- cost of seismic mapping, expenses of the zoning organization.

b) Indirect cost -- loss in rent as a result of underuse of land or total unuse of land.

Benefits a) Amount of damage prevention to assets and income, prevention of loss of life and injury*.

6. Costs and Benefits of Relief

Costs a) Direct costs -- capital costs; operating costs (including administrative costs, and expenses on consummables).

b) Indirect costs -- costs of communication bottleneck as a result of convergence of excess volunteers to the scene of disaster and large volume of queries*. Loss in welfare of groups as a result of inequities as a result of change in income distribution or of the method of extending relief-grants vs. low interest loans or some combination of the two.

<u>Benefits</u> a) Direct benefits -- lives saved as a result of medical care*; alleviation of pain and suffering*.

b) Indirect benefits -- prevention of induced hazards such as elimination of dangerous structures; prevention of epidemics*.

7. <u>Costs and Benefits of Rehabilitation</u>

<u>Costs</u> a) Direct costs -- capital costs; operating costs.

<u>Benefits</u> a) Direct benefits -- number of people resettled and rehabilitated and resulting increase in output which otherwise would not have taken place.

b) Indirect benefits -- Increase in employment by the number of people engaged in rehabilitation work; external economies due to training of some of the victims.

8. Losses with Inaction or Loss Bearing

Direct Losses

a) Physical damage to the assets; loss of life*
and associated investment in human beings.
Injury* and associated loss.
(Opportunity cost of the injury).

Indirect Losses

a) Loss due to decline in economic opportunity
(income loss) -- fall in wages, salaries, revenue.

b) Alternately we could measure loss in output.
(Double counting has to be avoided here).

Loss due to Biological Effects

a) Loss due to changes in the ecology*.

In the case of most disasters adjustments take place in various combinations and as a result complications are bound to occur in estimating costs and benefits of the adjustments. For example, the warnings most likely occur concurrently with evacuation or structural modifications. Insurance may go hand in hand with earthquake proofing of structures and land use change. In most cases various combinations of adjustments take place simultaneously, and existence of these complications should be taken into account while carrying out the cost analysis.

In the above framework of cost-benefit analysis, it goes without saying that in case of many of the adjustments, many of the indirect costs and benefits are difficult if not impossible to assess. However, in order to facilitate decision making which would enhance human welfare, the indirect effects and externalities have to be taken into account as much as practicable.

It is almost essential that cost-benefit analysis of the type outlined above be made on an interdisciplinary basis. Engineers, geographers, economists, sociologists, and other specialists need to work together in order to make more realistic cost benefit analysis.[32]

D. A Sample Calculation*

Two of the methods for preparing for the eventuality of earthquakes as discussed in preceding sections are warning systems, and structural modification. This analysis will be a brief examination of the costs and benefits of both of these adjustments to the City of San Francisco in the framework of the preceding section.[33]

[32] Report of the Task Force on Earthquake Hazard Reduction, September, 1970, Executive office of the President, Office of Science and Technology, Washington, D.C.

*This section was written by Stanley Yon, senior at Callison College, University of the Pacific, Stockton, California.

[33] This being a hypothetical model, where data was not readily accessible for San Francisco, data from the Alaska earthquake of 1964 has been extrapolated for the larger population.

THE WARNING SYSTEM. Implicit in the implementation of an earthquake warning system is the assumption of accurate forecasting. This reliability therefore necessitates the capability to mobilize all available resources for the facile and immediate evacuation of the city. The direct costs of this system, consequently, are the costs of the system itself, the cost of transportation for evacuation, and the cost of temporary resettlement.[34] For the purpose of illustration, San Francisco will be examined in terms of per capita costs and in terms of the installation of the forecasting system proposed by the Office of Science and Technology.

The period of implementation for this system is ten years at a cost of $137 million[35] or a per capita cost to San Franciscans of $185.[36] In the eventuality of a warning we assume that the entire population must be evacuated within twenty-four hours a

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[34] The costs of relief and rehabilitation are not herein discussed because this evacuation occurs in sufficient time and is well-prepared so that the inherent costs are minimized so as not to be considerably above the "normal" day-to-day costs of relief.

[35] This figure is for the Alaska and California-Nevada Regions as indicated in Earthquake Prediction, op. cit., but is here indicated as being just for San Francisco because the hypothesis does not indicate whether other portions of the populace from the Aleutions to Baja California would endorse such a proposal.

[36] The population of San Francisco is taken to be 748,700 based on the 1968 population estimate in the 1969 California Fact Book, County Supervisors Association of California.

distance of eighty miles. With this minimum time for evacuation, the population can take few personal belongings and, it is assumed, travels, on the average of groups of four per unit of mode of transportation. At ten cents per mile, the total cost of transportation is approximately $3 million or four dollars per capita to the temporary site of relocation and back to the city. If it is further assumed that the period of relocation is six weeks the per capita cost for food, housing, and medical care is found to be approximately $140.[37]

If the forecasting system is begun immediately and if the earthquake does not hit for another ten years, the per capita cost would amount to $330. With the minimum warning time there is little damage prevented to assets and income but considerable savings in life and injury. Given the density of the population in San Francisco, the amount of building on fault areas and the inadequacy of present earthquake precautions, an 8 Richter earthquake in that location has the potential to be the greatest catastrophe in terms of injury and

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[37] Resettlement Costs:

Food -- USDA low-cost food plan for a four person household is $130 monthly or $48.75 per capita for six weeks.

Housing -- San Francisco-Oakland for a four person family in 1967 is $2411 annually or $75.00 per capita for six weeks.

Medical care -- San Francisco-Oakland for a four person family in 1967 is $555 annually or $17.34 per capita for six weeks.

Statistical Abstract of the United States 1970, U.S. Department of Commerce.

loss of life that man has ever known. The total damage from the 1906 Earthquake (in 1970 dollars) was $5000 per capita while the damage from the 1964 Alaska Earthquake rose to $7500 per capita. With increased wealth and residence in the hazard areas of San Francisco it is fairly safe to extend the Alaskan per capita costs of $7500 to San Francisco and suggest the relatively small additional investment of $330 just to prevent phenomenal injury and loss of life.

STRUCTURAL MODIFICATION. It is estimated that structural modification for earthquake resistance in Zone 3 construction areas, such as San Francisco, costs approximately 4% of the total value of the structures in that area.[38] Extrapolation from the data on Anchorage given by Dacy and Kunreuther,[39] the total value of San Francisco's structures may be assumed to be approximately $3.8 billion. Without structural modification, J. D. Crumlish points out, the damage accompanying an 8 Richter earthquake is on the average 74.3% of the total value.[40] In this illustration, therefore, the damage without structural

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[38] William Sallada, op. cit., p. 12.

[39] The total value in Anchorage prior to the 1964 earthquake was $539 million, The Economics of Natural Disasters, 1969, p. 71

[40] See p. 14 of this manuscript.

modification would be $2.8 billion or $3700 per capita. By spending 4% of the total value for structural modification and reducing damage to 0.3% of the total value[41] the per capita cost would only be $215.[42] In other words, a direct cost for structural modification of $200 (plus $15 for damages not eliminated) creates a direct benefit of $3485 per capita. In addition to this benefit there is the prevention of loss of income, injury and loss of life.

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[41] Ibid.

[42] 4.3% of $3700 per capita is $215 per capita.

APPENDIX I

by

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APPENDIX II

Source: Boulder, Colorado Earthquake Research Society

Earthquakes	-	violent vibrations that shake the earth.
Foreshocks	-	from minor fault movement that precedes a major shock, can be a considerable length of time in advance, epicenter may be somewhat removed from that of major displacement, no recognizable pattern.
Major Shock	-	the one that results in greatest displacement along a fault -- may not be able to identify until after series of shocks have run their course.
After Shocks	-	follow major shock, strength varies with size of main shock, number will increase as magnitude of shock increases.
Tectonic Earthquakes	-	shocks caused by sudden rupture or rock slips and elastic recoil along deep faults.
Volcanic Earthquakes	-	shocks resulting from volcanic activity -- violent subterranean explosion.
Faults	-	a fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture. The displacement may be a few inches or many miles. They may or may not be visible from the surface.
Focus	-	point of origin of an earthquake within a fault where it begins to slip.
Deep Focus	-	at depths as great as 400 miles.
Intermediate Focus	-	at depths from 27 to 150 miles.
Shallow Focus	-	at depths less than 27 miles.
Epicenter	-	a point on the earth's surface directly above the focus of an earthquake -- not necessarily along the fault line (such as when fault plane does not run perpendicular to the surface).

Earth's Crust	-	outer shell of the earth -- extends to a depth of 25 miles (rather brittle).*
Earth's Mantle	-	section of earth beneath the crust extending about 1800 miles deep (basically rock which is plastic and flows under pressure).*
Earth's Core	-	outer section of central core of earth around 1360 miles deep; inner section around 815 miles deep (believed to consist of iron and nickel).*

*Above depths and compositions from "Elements of Geology" by James H. Zumberge.

Richter Magnitude Scale	-	system for measuring energy released by an earthquake developed by Dr. C. F. Richter. "The magnitude of any shock is taken as the logarithm of the maximum trace amplitude, expressed in microns (thousandths of a millimeter) with which the standard short-period torsion seismometer would register that shock at an epicentral distance of 100 kilometers (62 miles)." The scale begins at "0" with no specific upper limit. "0" does not necessarily mean no earthquake but is one whose strength at greatest amplitude will register no more than one micron (about .04 thousandths of an inch) at a seismograph station 100 kilometers from the epicenter.
Modified Mercalli Intensity Scale	-	a system to indicate the degree of damage caused by earthquakes. It is indicated by a Roman Numeral.
Rossi-Forel Scale	-	another scale to measure damage intensity -- generally superceded by the Mercalli scale.
Tsunami (soo-nom-ee)	-	seismic sea waves, the destructive oceanic offspring of earthquakes and volcanic eruptions (erroneously referred to as "tidal waves"); two main categories are storm waves and seismic waves.
Storm Waves	-	catastrophic wind -- generated waves accompanying wind systems such as hurricanes and typhoons.
Seismic Wave	-	produced by earthquakes and displacement of submarine blocks of the earth's crust.

Uniform Building Code	-	adopted by International Conference of Building Officials (establishes standards for soil engineering, foundation design and construction design) which is recommended for adoption by municipal and state governmental agencies.
National Building Code	-	adopted by National Board of Fire Underwriters, stresses fire control and life safety.
Seismograph	-	a vibration measurement instrument; consists of a seismometer, a recorder and a timer.
Seismometer	-	the transducer that converts mechanical motion of the ground to a signal of some type.
Seismogram	-	the written record of a seismograph; it gives particle velocity.
Seismoscope	-	simple instrument for measuring motion in a single component.
Strong Motion Seismograph	-	an instrument for measuring motion in three simultaneous components.
Seismology	-	study of shakes or earthquakes; also study of wave motion.
Frequency	-	number of cycles per second.
Period	-	time for one complete cycle.
Wave Velocity	-	rate at which disturbance propagates through the medium.
Particle Velocity	-	the rate at which the constituent particles of the medium oscillate above their equilibrium position when excited by wave energy.
Transcient Type Wave	-	characteristic of mediums response to a sudden pulse-like excitation (such as a blast).
Periodic Type Wave	-	repetitive in nature, recurring in exactly the same form at fixed time increments (the simplest type is called harmonic or sinusoidal), such as pile driving or delay element blasting.

Random Type Wave	-	amplitude of vibration is predictable only on a probabilistic basis, such as seismic background noise (called microseisms).
Standing Wave	-	result when superpose 2 harmonic waves of same amplitude, frequency and propagation velocity but travelling in opposite directions.
Types of Elastic Waves	-	body waves and surface waves.

Fundamental types of Deformation of an elastic body are:

compression and shear
compression alters volume but not shape
shear alters shape but not volume.
These deformations are transmitted as body waves.

Compression Waves	-	the "P" wave, primary, or first to arrive, has highest velocity.
Shear Wave	-	the "S" wave, secondary, arrives after the P wave.
P Wave	-	is in line of direction of wave, does not show up in transverse component.

Transverse Component gives arrival of S wave.

Surface Waves are of two fundamental types: Rayleigh and Love waves.

Rayleigh Waves	-	velocity about 0.9 that of S wave, come in after the S wave, particle motion on the surface is elliptical (up and forward, down and backward).
Love Waves	-	velocity approaches that of shear waves, velocity is greater than Rayleigh waves, particle motion is in horizontal transverse only.
Zones	-	used to describe areas of probable earthquake damage and also to describe construction requirements for such areas.

Zone 1 = No damage

Zone 2 = Minor damage

Zone 3 = Moderate damage

Zone 4 = Heavy damage

ECONOMIC ANALYSIS OF NATURAL HAZARDS: A PRELIMINARY STUDY OF ADJUSTMENTS TO EARTHQUAKES AND THEIR COSTS

by

Tapan Mukerjee

Callison College
University of the Pacific
Stockton, California

TABLES AND FIGURES

Working Paper No. 17

TABLE 1

HAZARD COMPARISON OF NON-EARTHQUAKE-RESISTIVE-BUILDINGS *

Note: This table is intended for buildings not containing earthquake bracing, and in general, is applicable to most older construction. Unfavorable foundation conditions and/or dangerous roof tanks can increase the earthquake hazard greatly.

Simplified Description of Structural Type	Relative Damageability (in order of increasing susceptibility to damage
Small wood-frame structures, i.e., dwellings not over 3,000 sq.ft., and not over 3 stories................	1
Single or multistory steel-frame buildings with concrete exterior walls, concrete floors, and concrete roof. Moderate wall openings........................	1.5
Single or multistory reinforced-concrete buildings with concrete exterior walls, concrete floors, and concrete roof. Moderate wall openings................	2
Large area wood-frame buildings and other wood-frame buildings..	3 to 4
Single or multi-story steel-frame buildings with unreinforced masonry exterior wall panels, concrete floors and concrete roof............................	4
Single or multi-story reinforced-concrete frame buildings with unreinforced masonry exterior wall panels, concrete floors and concrete roof..........	5
Reinforced concrete bearing walls with supported doors and roof of any materials (usually wood)......	5
Buildings with unreinforced brick masonry having sand-lime mortar, and with supported floors and roof of any materials (usually wood)....................	7 up
Bearing walls of unreinforced adobe, unreinforced hollow concrete block, or unreinforced hollow clay tile..	Collapse hazards in moderate shocks

* Abridged from Pacific Fire Rating Bureau Tariff Rules

source: Karl V. Steinbrugge, Earthquake Hazard in the San Francisco Bay Area: A Continuing Problem in Public Policy. Institute of Governmental Studies, University of California, Berkeley, 1968.

TABLE II

REGIONAL COMPARISON OF ANNUAL EARTHQUAKE INSURANCE RATES FOR WOOD-FRAME HOMES, 1965, PER $100 OF INSURANCE

Region	Earthquake Rate
Northeast	.038
Southeast	.032
Ohio Valley	.028
North Central	.034
South Central	.024
Western	.125

source: D.C. Dacey and H. Kunreuther, The Economics of Natural Disasters. The Free Press, New York, 1969, p. 236.

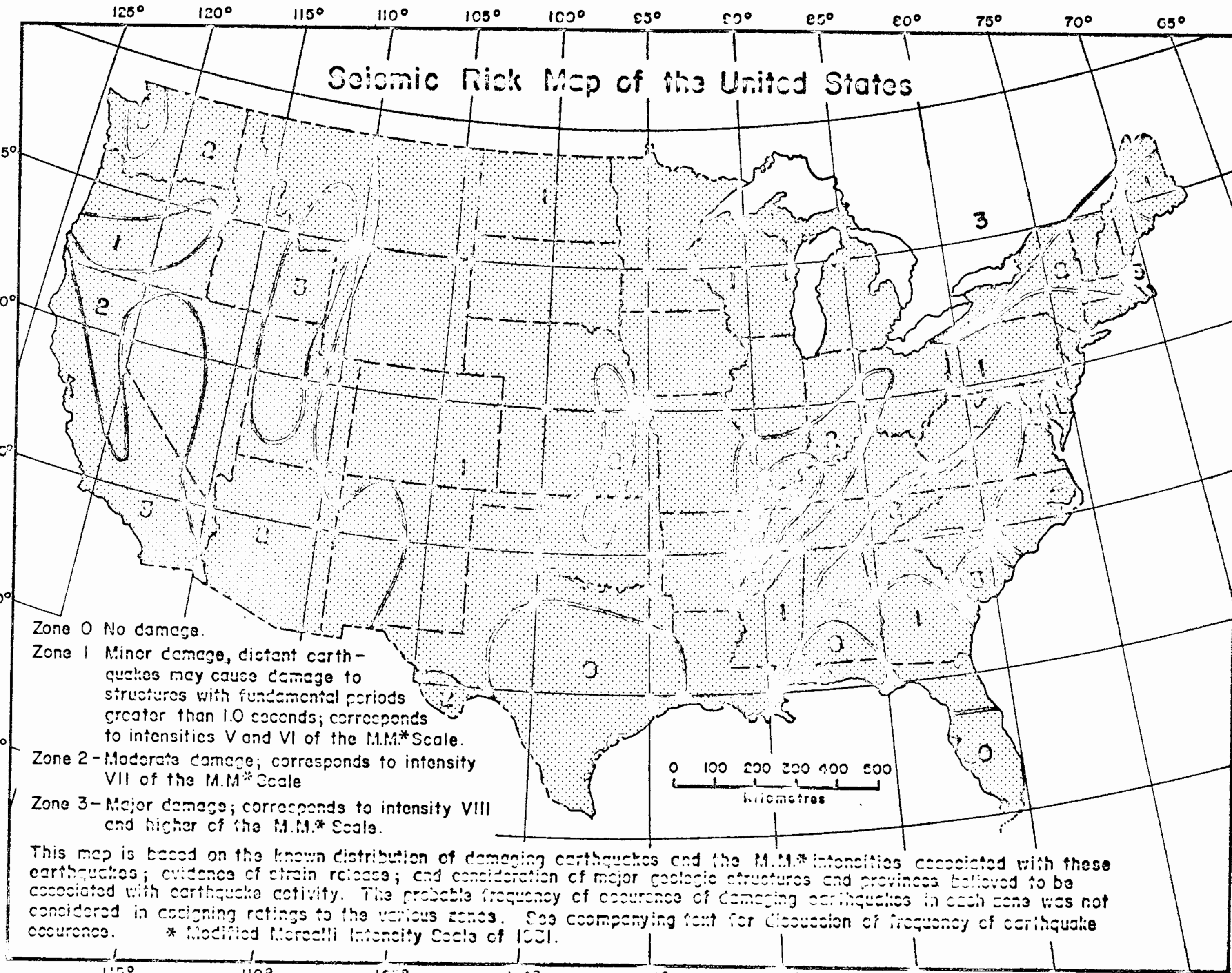


Figure 1.

From "Seismic Risk Studies in the United States" by S.T. Algermissen, Fourth World Conference on Earthquake Engineering, 1:26 (1969).

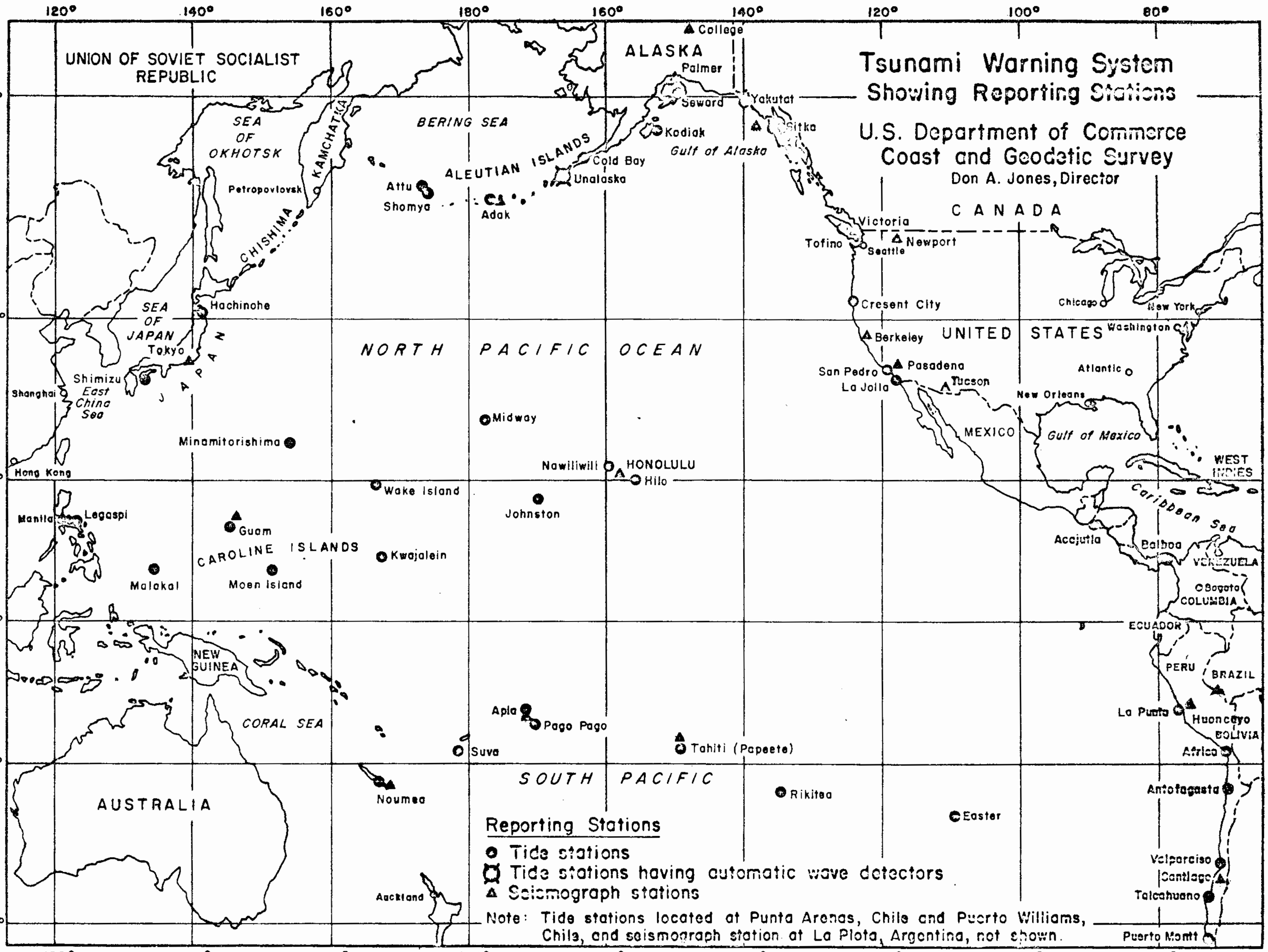

Tsunami Warning System
Showing Reporting Stations
U.S. Department of Commerce
Coast and Geodetic Survey
Don A. Jones, Director
UNION OF SOVIET SOCIALIST REPUBLIC
SEA OF OKHOTSK
KAMCHATKA
BERING SEA
ALEUTIAN ISLANDS
ALASKA
CANADA
UNITED STATES
MEXICO
Gulf of Alaska
Gulf of Mexico
Caribbean Sea
WEST INDIES
SEA OF JAPAN
JAPAN
CHISHIMA
East China Sea
NORTH PACIFIC OCEAN
SOUTH PACIFIC
CAROLINE ISLANDS
NEW GUINEA
CORAL SEA
AUSTRALIA
VENEZUELA
COLUMBIA
ECUADOR
PERU
BRAZIL
BOLIVIA
College
Palmer
Seward
Yakutat
Sitka
Kodiak
Cold Bay
Unalaska
Attu
Shomya
Adak
Petropovlovsk
Hachinohe
Tokyo
Shimizu
Shanghai
Hong Kong
Manila
Legaspi
Minamitorishima
Guam
Malakal
Moen Island
Kwajalein
Wake Island
Midway
Johnston
Nawiliwili
HONOLULU
Hilo
Apia
Pago Pago
Suva
Noumea
Auckland
Tahiti (Papeete)
Rikitea
Easter
Victoria
Tofino
Seattle
Newport
Cresent City
Berkeley
San Pedro
La Jolla
Pasadena
Tucson
Chicago
New York
Washington
Atlantic
New Orleans
Acajutla
Balboa
Bogota
La Punta
Huancayo
Africa
Antofagasta
Valparaiso
Santiago
Talcahuano
Puerto Montt
Reporting Stations
Tide stations
Tide stations having automatic wave detectors
Seismograph stations
Note: Tide stations located at Punta Arenas, Chile and Puerto Williams, Chile, and seismograph station at La Plata, Argentina, not shown.
60°
40°
20°
0°
120°
140°
160°
180°
100°
80°

Figure 2.

Figure 3

Funding History of the Tsunami Warning System

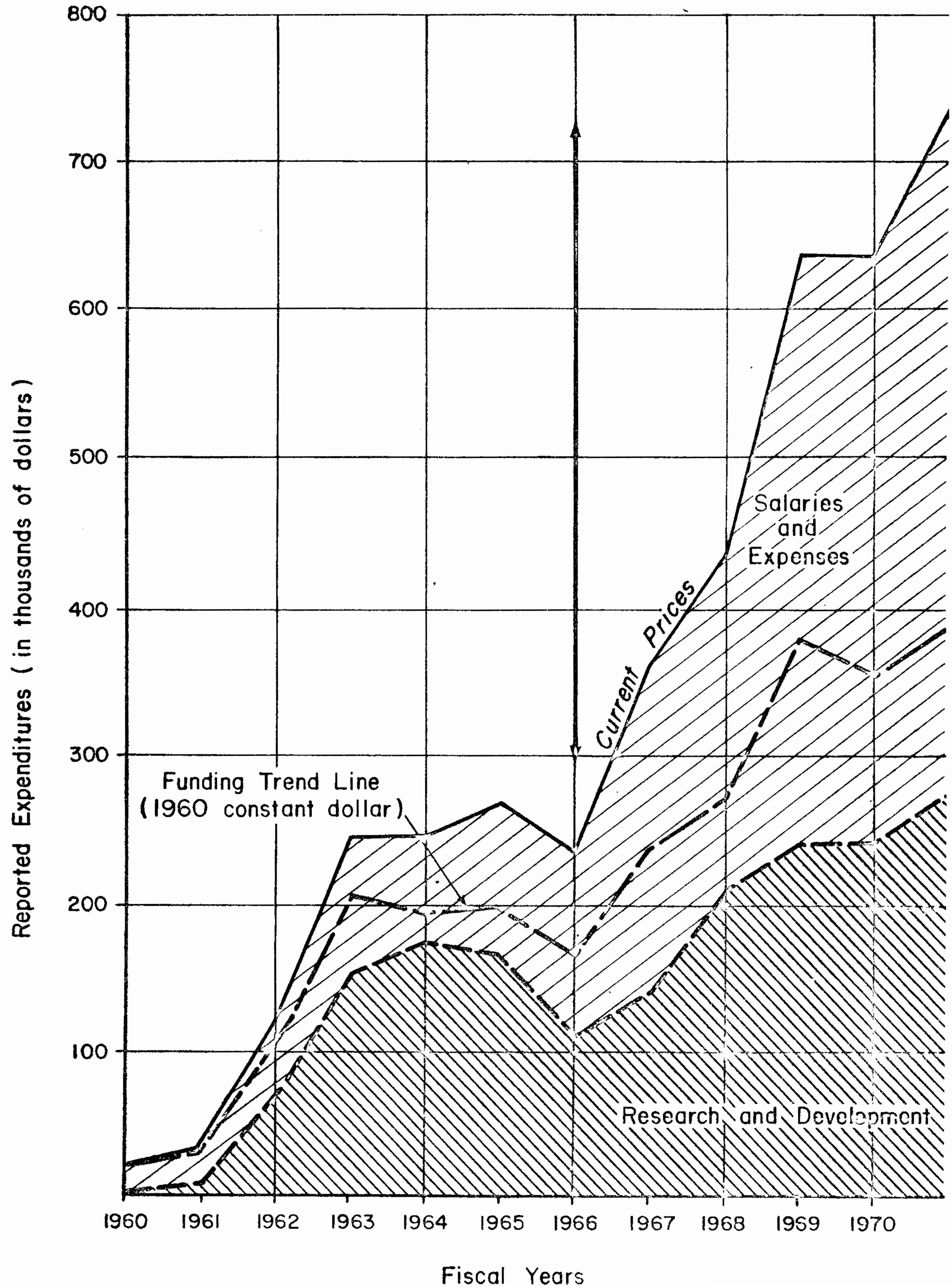
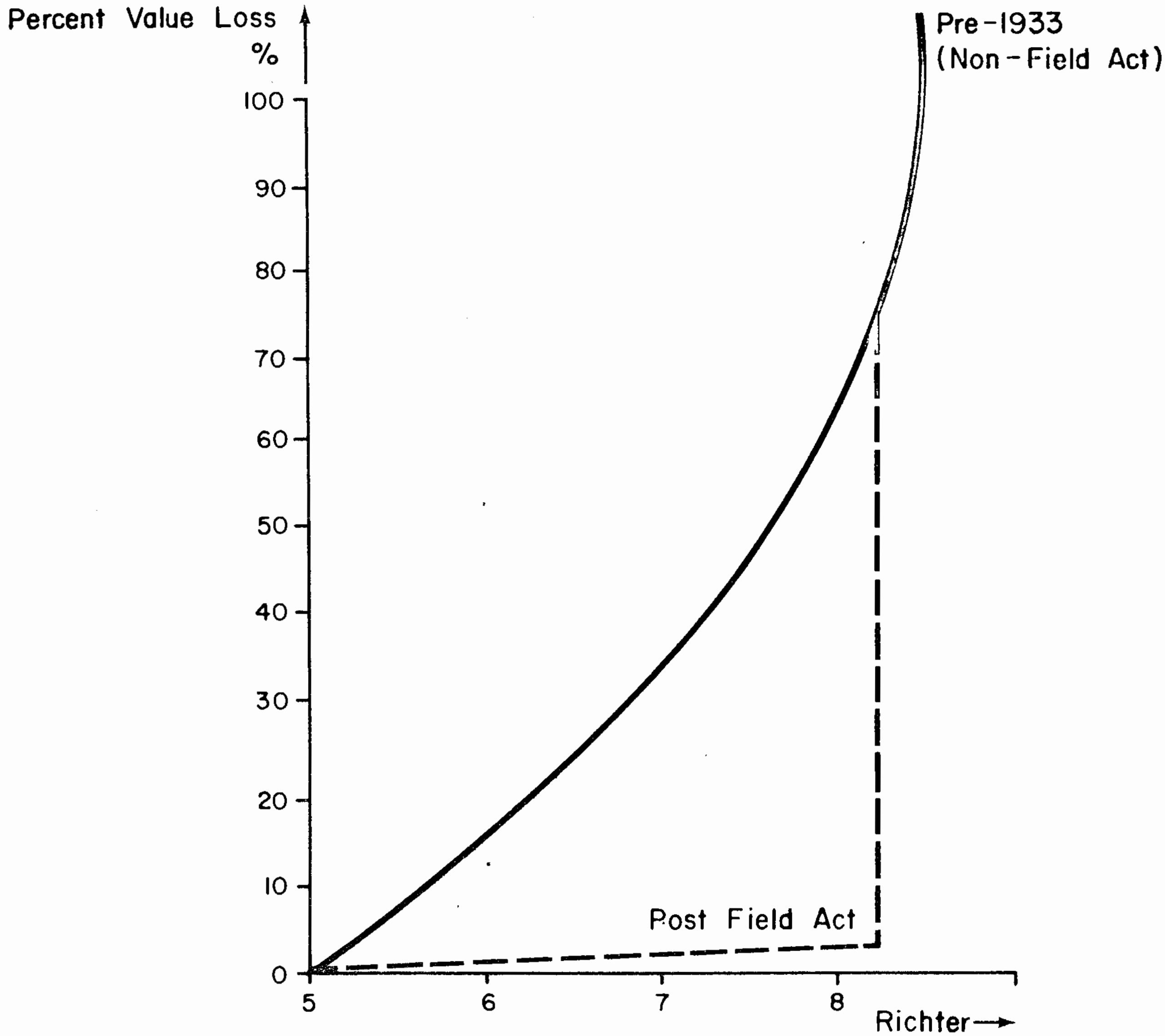


Figure 4.

Impact of the Field Act of 1933 on earthquake damage in California



Source:

J. D. Crumlish, "Some Economic Considerations in Evaluating Seismology Efforts" in ESSA Symposium on Earthquake Prediction, in February 1966, U.S. Department of Commerce, Washington D.C.