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Editor

Walter W. Hays
U.S. Geological Survey
Reston, Virginia 22092

Compiled by
Carla Kitzmiller

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PREFACE

MEETING THE NEEDS OF THE INSURANCE INDUSTRY FOR REALISTIC EARTHQUAKE HAZARDS AND RISK INFORMATION

Earthquakes are a unique natural hazard for the insurance industry because of their capability to strike an urban center with little or no warning and to cause great economic loss reaching billions of dollars within only a few seconds to a few minutes. Hundreds of thousands can be killed and injured and left homeless after a large damaging earthquake.

The United States Geological Survey, as the Nation's geologist, seismologist, geological engineer, and map maker, manages and sponsors several hundred research projects each year that are designed to increase the fundamental base of knowledge and to develop methodologies for assessment of earthquake hazards (the physical phenomena) and earthquake risk (chance of loss) in every part of the Nation. These projects are organized in five ongoing program elements, all having benefit for the insurance industry. They are:

1) Current Tectonics and Networks - Perform geologic and seismological analyses of current earthquake activity, including the seismic cycle of active faults and estimates of the earthquake potential in earthquake-prone regions of the United States.

The July 1988 press conference held in California on "Probabilities of Large Earthquakes Occurring in California on the San Andreas Fault" (see summary in this document) is an example of work under this element.

2) Earthquake Prediction Research - Conduct field, laboratory, and theoretical studies of earthquake phenomena with the goal of reliable prediction of time, place, and magnitude of damaging earthquakes.

The prediction for a magnitude 6.2 earthquake between 1988-1991 at Parkfield, California, is an example of the work under this element.

3) Regional Earthquake Hazards Assessments - Create, compile, and synthesize new and existing data needed for making hazard maps and assessing the risk in broad geographic regions containing important urban areas. Assessments are made for the hazards of ground shaking, ground failure, tectonic deformation, and surface faulting, and to some degree tsunamis, and seiches. The goal is to foster the development and enactment of loss-reduction measures including seismic microzonation within the framework of State and local government responsibilities.

The national ground shaking hazard maps and the studies underway in Utah and in the Puget Sound, Washington-Portland, Oregon area are examples of the work under this element.

4) Engineering Seismology - Deploy strong motion accelerographs to acquire records of ground shaking, both in free field locations and within buildings, for a range of magnitudes, distances, and foundation materials. These instruments are also deployed in areas expected to experience liquefaction and in comprehensive post earthquake investigations.

Accelerograms recorded in the October 1, 1987, Whittier-Narrows earthquake are an example of the work under this element.

5) Data and Information Services - Provide data on the occurrence of earthquakes throughout the world, communicating with the media, other Federal agencies, State and local governments, emergency response organizations, and the scientific and engineering communities.

Data provided after the September 19, 1985, Mexico earthquake and the October 1, 1987, Whittier-Narrows earthquake are examples of the work under this element.

The following references are available now for use by the insurance industry.

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Alaska (see reference 25)

California (see references 1, 2, 6, 36, 38)

Ground Failure (see reference 35)

Ground Motion Maps (see references 3, 4, 28)

Loss Studies (see references 1, 2, 5, 33, 34)

Mississippi Valley (see references 5, 8, 12, 18, 26, 32)

Northeastern United States (see references 20, 22)

Northwestern United States (see references 24, 31, 33)

Preparedness (see references 9, 15, 16, 30)

Puerto Rico-Virgin Islands Area (see references 10, 11, 23, 29)

Scientific Status (see reference 14)

Soil Effects (see reference 17)

Southeastern United States (see reference 7, 19)

Utah (see references 13, 21, 27, 34)

Worldwide Earthquake Management (see reference 37)

EXECUTIVE SUMMARY

EARTHQUAKE RISK: INFORMATION NEEDS OF THE INSURANCE INDUSTRY

This workshop was sponsored by the U.S. Geological Survey and the California Department of Insurance. It was designed to bring together individuals who are knowledgeable in both the technical operations of earthquake insurance and the broad aspects of earthquake hazards mapping and risk assessment. The meeting, the first of its kind, had three primary goals:

1) To identify the types of scientific and engineering information which the insurance industry should have in order to improve its capability to underwrite and price insurance coverages relating to the earthquake hazard and to determine which needs are within the capability of the U.S. Geological Survey (USGS) to provide on urban, regional, national, and international scales.

2) To produce a document, that will be published a few months after the meeting, containing explicit statements of the needs, capabilities, and short- and long-term goals of the insurance industry which can be used to guide future work and to set policy, as appropriate.

3) To begin to establish a useful continuing dialogue between the insurance industry and leading scientists and engineers.

Earthquakes are only one of the natural hazards insurers must consider in their corporate planning. However, earthquakes are a unique natural hazard because of their capability to strike an urban center with little or no warning and to cause great economic and life loss over a broad region within only a few seconds to a few minutes. Nothing can be considered to be immune from destruction--dwellings, commercial and industrial facilities, public facilities, etc. Many people can be killed, injured, or left homeless and jobless unless mitigation measures are in place.

Given that major earthquakes are inevitable in many parts of the United States and throughout the world, the basic question is how to cover the financial cost of recovery and rebuilding in the affected urban centers. In order for insurance to be an effective mitigation option, the best available information on the spatial and temporal effects of the primary earthquake hazards of ground shaking and permanent ground displacement is needed. This information must be formatted in a way useful to the insurance industry, permitting:

- Uniform comparison of the critical parameter(s) independent of scale.
- Quantification of the frequency of occurrence.
- Quantification of the expected severity of the primary hazards: ground shaking and permanent ground displacement.
- Quantification of the expected severity of secondary hazards such as fire, dam failure, tsunamis, seiches, and aftershocks.
- Accurate assessment of the expected losses and their distribution.

Useful information will enable the insurance industry to deal more effectively with the earthquake threat.

EARTHQUAKE RISK:
INFORMATION NEEDS OF THE INSURANCE INDUSTRY--
FROM A REGULATORY PERSPECTIVE

By
Richard J. Roth, Jr.
California Department of Insurance
Los Angeles, California

The California Insurance Department has a strong interest in studying the potential damage from earthquakes for a variety of reasons. First, we want to know how much earthquake damage exposure is being insured and whether the insurers will be able to pay the claims. Second, we want to learn more about the damage causal relationship between types of faults, types of soil conditions, and types of building construction. This will enable insurers to price and evaluate risks more accurately, such as is now done in fire insurance. Third, we want to make earthquake insurance available and at a low premium for the large number of homes and businesses in which the risk of earthquake damage is low. For the homes and businesses in which the risk of earthquake damage is high, we want to be able to prescribe mitigation procedures that should be taken in order to make the risk insurable (again, like in fire insurance where fireproofing and sprinklers are required.). And fourth, we want to work with international insurance companies and governments to develop efficient procedures for compensating victims and for replenishing capital for businesses after a major earthquake.

Only 15-20% of the homes and businesses in California are insured for earthquake damage. Yet, even at this level the world insurance market probably cannot insure any more prudently. The insurance industry is making a formal proposal to the Federal Government to form a financial partnership in the event of a major earthquake. Such a financial partnership would enable more earthquake coverage to be available and at lower rates.

On the other hand, more insurance can be sold if the risk is reduced. There is a wide gap in understanding between the scientific community and the insurance industry, but this gap is slowly narrowing. The knowledge possessed by the scientific community must be conveyed to the insurance industry in a way that the insurance industry can use to evaluate accurately the risks. Also, the knowledge must be used to know how to repair or reinforce existing buildings and to avoid mistakes in future construction.

The area of greatest lack of knowledge to the insurance industry is in the physics of soil conditions, including liquefaction. The problem also encompasses non-seismic land movement and flooding. We now know how to design buildings to mitigate the effects of an earthquake, or at least the effects are predictable. This is not so with soil conditions. Some soil conditions are safe for all buildings, some soil conditions are safe for short buildings, but not tall buildings, and some soil conditions are not safe for any buildings.

Insurance can be purchased to cover a wide variety of earthquake caused losses, from damage to buildings and contents to loss of profits. Insurance also covers life, health, workers' compensation, automobile, losses from power failure, and even liability coverage. Damage to power supply and computers can be especially costly. The contents of a building are especially important if the contents are high valued or are not fastened down properly. A well designed building and be destroyed by the shifting of heavy contents. So, the insurance industry is very much interested in preparedness and mitigation in order to reduce all types of losses.

The October 1, 1987, Whittier Narrows earthquake caused $73 million of insured losses, broken down as follows:

Earthquake	37%
Homeowners	21%
Commercial	13%
Fire	10%
Other	19%

There were 8,417 claims. This shows that even a small earthquake can cause losses.

In the event of a major earthquake, the expected insured losses to structures, based on an annual survey of insurers, are expected to be:

		1986	1987
A.	San Francisco	$ 3,694m	$ 4,031m
B.	Los Angeles	4,932	5,214

'Considering fire and other insurance coverages, the total exposure is much higher.

EARTHQUAKE HAZARD AND RISK ASSESSMENT--SOME APPLICATIONS TO PROBLEMS OF EARTHQUAKE INSURANCE

By
S. T. Algermissen
U.S. Geological Survey
Denver, Colorado

INTRODUCTION

The U.S. Geological Survey (USGS) within the Office of Earthquakes, Volcanoes and Engineering conducts an extensive program in earthquake research. This program produces results that have direct application to many of the problems of earthquake insurance. At the present time the USGS program is organized into the following elements:

Element 1: Current tectonics and earthquake potential studies

Seismological and geological analyses of the current seismic activity, active geologic faults, and earthquake potential of all seismic regions in the United States.

Element 2: Earthquake prediction research

Laboratory and theoretical studies and field experiments in some areas identified in (1) above with the goal of establishing the procedures and knowledge needed in reliable prediction of the time, place, and magnitude of damaging earthquakes.

Element 3: Regional earthquake hazards assessments

Regional earthquake hazards assessments in urban areas identified in (1) above including analyses of potential ground shaking and ground failure on a regional scale and the demonstration of specific hazard assessment techniques unique to each region.

Element 4: Earthquake data and information services

Provides data on earthquake occurrence to the public, other Federal agencies, State and local governments, emergency response organizations, and the scientific community.

Element 5: Engineering seismology

Provides data and analyses of strong earthquake ground motion to other Federal agencies and the engineering community for the seismic-resistant design and construction of buildings, dams, and critical facilities.

External research

In addition to activities performed by USGS staff, expertise in earthquake research that exists outside the Federal Government is utilized through a substantial external research program of contracts with universities, State, regional and local governmental agencies, and private industry.

All of these elements provide important data and research results that are critical to the general problem of assessing the risk (loss) associated with the occurrence of damaging earthquakes.

In this paper I will attempt to outline some of the important USGS research in earthquake hazard and risk assessment that has applications to problems of earthquake insurance.

MEASURES OF EARTHQUAKE RISK

Definitions

Earthquake hazards are taken here to mean the effects of earthquakes that may (or may not) cause economic loss and/or life loss. Seismic risk, in the engineering context, is the likelihood of loss. Terminology used in scientific and engineering studies may not have the same meaning in property insurance usage. For example, in property insurance, "risk" may refer to a structure under insurance consideration. Earthquake insurance terminology makes extensive use of terms such as "Probable Maximum Loss," "Maximum Probable Loss," "Maximum Credible Earthquake," "Maximum Possible Loss." These terms are not widely used in engineering and scientific studies of seismic hazard and risk. Clearly, it is important to overcome any problems of definition and terminology between earthquake research and insurance practice so that research results can be of practical value to the insurance industry. It is believed that the scientific and engineering descriptions of earthquake hazard and risk used here can easily be applied and adapted to existing insurance needs and terminology.

Insurance Measures of Risk

Two measures of earthquake risk that appear to be useful to the insurance industry in the evaluation of possible losses to fixed property such as buildings are:

1. Average annual loss per structure (the pure premium)

2. Catastrophe potential - many losses resulting from the same event (a measure of variability of the risk)

The relative importance of the average annual loss as compared with the catastrophe potential varies with the nature of the earthquake hazard. For example, the average annual loss measured by the earthquakes that have occurred in the past 100 years in the Southeast Missouri portion of the Mississippi Valley is small but the catastrophe potential (in the event of a recurrence of three great earthquakes such as occurred in 1811-1812) is great. The average annual loss in the Imperial Valley of California is significant while the catastrophe potential is perhaps somewhat less than in the Mississippi Valley. This is based on the fact that while numerous damaging earthquakes (up to M_s 7.3) have occurred, no great earthquakes (M>8) have occurred historically in the Imperial Valley.

Catastrophe potential is probably the single most important aspect of the earthquake problem to the insurance community. It is important because of the large uncertainties in forecasting rare events, the difficulties in the accumulation of reserves to pay claims and the lack of quantitative data that might provide an upper bound to losses (and claims).

Estimates of annual average loss (pure loss premium) are an important factor in insurance rate development but it should not be assumed by the scientific and engineering community to be the only factor. The actual rate will be larger than the pure premium because of scientific and engineering costs to develop the pure premium plus administrative costs such as overhead, marketing and profit. Additionally, seismic and non-seismic risks may be interdependent, resulting in greater losses and a higher rate. An example might be the occurrence of a large earthquake in Southern California during a period of heavy rains which would aggravate the landslide problem in the Los Angeles area.

The accuracy of earthquake loss estimates is obviously important, but it may be important in ways not very obvious to the scientific and engineering community. As an example, consider the insurance deductible. An example given by Steinbrugge (1982) is interesting:

> "When the %PML is close to the percent deductible as in the case for wood frame dwellings, the percent loss over the deductible is very sensitive to any change in the %PML. Consider a 5% deductible with a 7% PML for wood frame dwellings. For $1 billion in wood frame dwelling liabilities, the loss over the deductible would be 2% of $1 billion, or $20 million. On the other hand should the maximum credible earthquake actually produce an 8% PML instead of 7%, then the loss over the deductible would be 3%, or $30 million. In this case, a 1% increase in the %PML creates a 50% change in the aggregate dollar PML."

Casualties

The insurance industry also has need for estimates of casualties likely to result from earthquakes because of the impact on other insurance lines such as life and health care coverages.

Other Issues

There are many other complex insurance issues related to secondary losses from earthquake such as loss of contents, suspension of business activity, increased cost of repair following an earthquake, etc. It is difficult to attack these issues in a realistic manner until the nature and extent of primary property losses from earthquakes are more clearly understood.

THE U.S. GEOLOGICAL SURVEY EARTHQUAKE PROGRAM AND PROBLEMS OF INSURANCE

Introduction

Traditionally the scientific and engineering results of the USGS earthquake research program of interest in insurance problems have been reported deterministically. Examples might be geological maps, particularly of Quaternary geology and Holocene faulting, spectra of strong ground motion, landslide potential, liquefaction potential, etc. Obviously, a tremendous amount of scientific information resulting from years of investigation of earthquake problems by the USGS in the United States is available. Of special interest for insurance purposes are major scenario type investigations that have been published for four regions of the United States with major earthquake hazards; the San Francisco Bay area and Los Angeles and Orange Counties in California (Algermissen and others, 1972, 1973); the Provo, Salt Lake City, Ogden Central Utah area (Rogers and others, 1976); and the Puget Sound, Washington region (Hopper and others, 1975). These investigations included Modified Mercalli (MM) intensity ground shaking maps simulated for a suite of large earthquakes in each region considered to be "maximum" type events. The emphasis in these four studies is on losses to facilities (such as hospitals, blood banks, etc.) critical to disaster preparedness. Losses were estimated based on the postulated level of MM intensity at each facility. Some of these reports included estimates of the probability of occurrence of the earthquakes for which MM intensity maps were simulated. A recent intensive earthquake hazard investigation of the Los Angeles area (Ziony, 1985) has provided a major new, principally deterministic assessment of the earthquake hazards in that area. A study of the distribution of MM intensity in the Mississippi Valley in the event of a repetition of the 1811-1812 sequence of shocks is also available (Hopper, editor, 1985); Algermissen and Hopper, 1984). Many other research results of the USGS program provide important information for insurance purposes. Indeed one of the major problems in applying research results to insurance problems may be the organization of the research results in a way meaningful for insurance application.

A probabilistic ground acceleration map of the contiguous United States was prepared by Algermissen and Perkins in 1976. This map forms the basis for the model seismic design provisions proposed in a national study by the Applied Technology Council (1978) and also the basis for NEHRP (National Earthquake Hazards Reduction Program) seismic design provisions recently published (Building Seismic Safety Council, 1985). Subsequently, probabilistic ground acceleration maps have been prepared for Alaska (Thenhaus and others, 1986) and the contiguous United States (Algermissen and others, 1982). (One of the six ground motion maps published in 1982 is shown in Figure 1.) These maps are important because they establish the relative levels of hazard from ground shaking throughout the United States for various time periods of interest and for a particular level of probability. In the modeling and computational process used in probabilistic hazard analysis, the hypothesized ground shaking history for all regions considered is also developed. Earthquake losses on a national basis can be computed using this "future average history" of shaking, appropriate inventory, and vulnerability relationships.

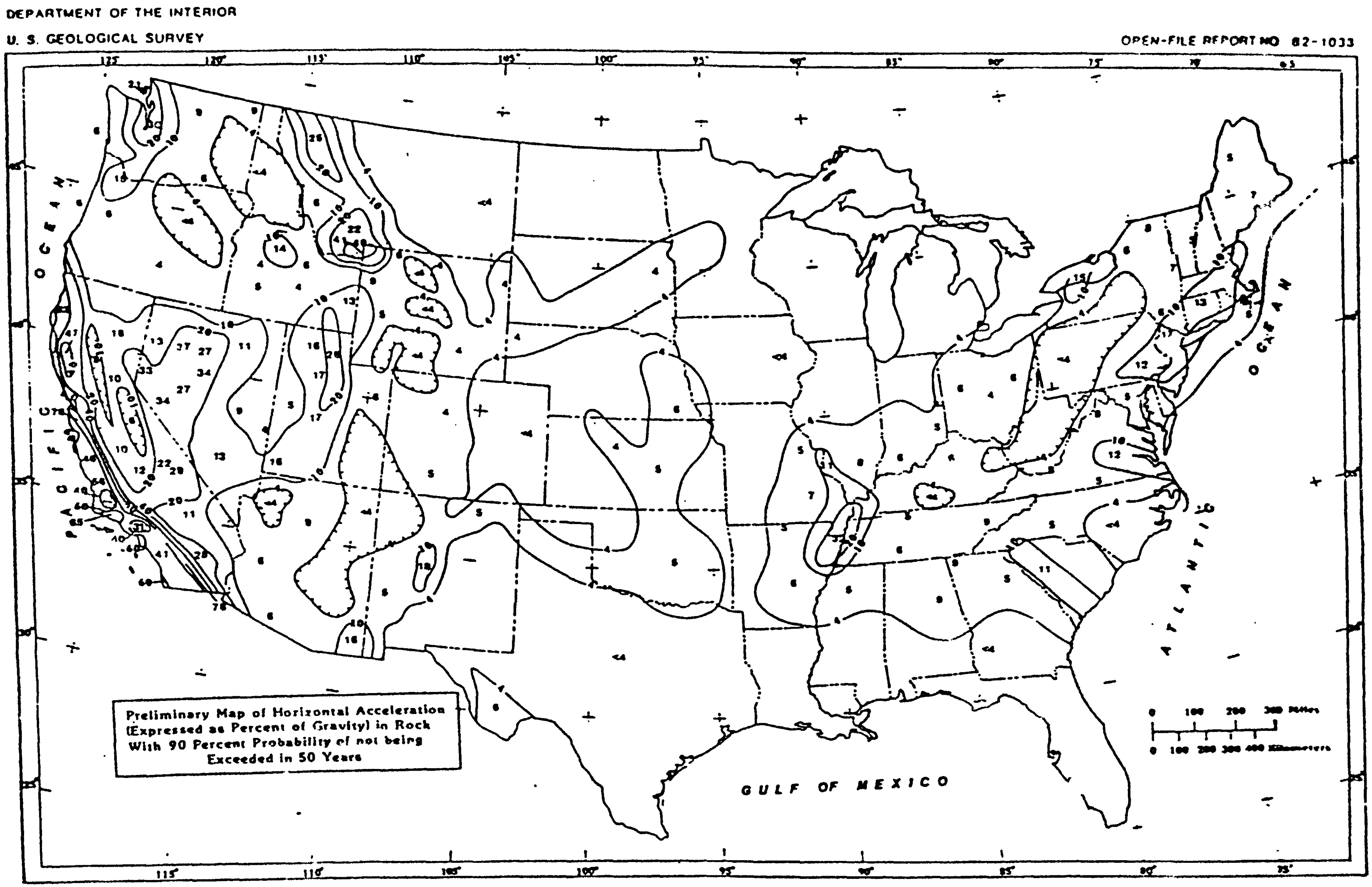


Figure 1. The maximum expected ground acceleration (in rock) in 50 years with a 10 percent chance of being exceeded. The acceleration is contoured in terms of the percent of the acceleration of gravity. (After Algermissen and others, 1982).

The U.S. Geological Survey has for a number of years carried out research on a limited basis on the estimation of monetary losses and casualties associated with earthquakes in the United States. Traditionally, leading experts in earthquake engineering and damage analysis from outside the Survey have participated in these studies and contributed greatly to them. Investigations have ranged from monetary loss estimates for various regions and urban areas of the United States to disaster preparedness and mitigation studies of the four large metropolitan areas already cited.

The data base for these and subsequent earthquake loss investigations was developed from field investigations and scientific and engineering reports of losses associated with a number of significant foreign as well as United States earthquakes. A list of relevant USGS risk publications is included in the "Selected Bibliography".

The conclusion that emerges from this brief summary of the very broad and comprehensive program of earthquake hazards investigations conducted by USGS over a period of years is that the results of a tremendous amount of very valuable research are available for application to the problems of insurance. The major problem is to design a program that builds on these research results and applies them in a way meaningful to the needs of the insurance industry. The following disussion outlines the application of some research results to the estimation of catastrophic potential and average annual loss.

Catastrophe Potential

The estimation of catastrophe potential requires the estimation of the size, probability of occurrence and the losses resulting from large earthquakes throughout the United States.

Estimation of catastrophe potential is a process involving estimation of:

1. the probability magnitude distribution of large shocks for each region;

2. the probability that these large shocks will occur in a given time period;

3. the distribution of ground motion and geologic effects associated with these large shocks; and

4. the losses (economic and casualty) associated with these earthquakes.

The insurance industry understands very well (for example, Friedman, 1970) that estimates of catastrophe potential based on the historic record of earthquakes in an area may be poor since large earthquakes are rare events. With the emergence of paleoseismic studies (identification and dating of evidence of major earthquake occurrences in the geologic record) it is now possible to extend the record of earthquakes into prehistory in many areas and thus improve the estimation of both the magnitude of the largest shock likely to occur and the probability that it will occur. In addition, the increased emphasis on studies of seismotectonics (relationship between earthquake occurrence and geologic structure) has improved our understanding of earthquake occurrence.

The accuracy of both the magnitude and the probability of occurrence of large earthquakes will obviously vary greatly in different parts of the country depending upon the nature of the available data. For example, California, where the USGS has recently published an assessment of the probability of large shocks (Working Group on California Earthquake Probability, 1988) is an area where extensive data are available. Little data are available for the forecasting of large shocks in many other areas (for example, New England, Kansas). Nevertheless, estimates of the magnitude and probability of occurrence of large shocks throughout the country are an essential component of any insurance oriented program.

Estimation of the magnitude distribution and probability of occurrence of large earthquakes by region are only the first two steps in the assessment of catastrophe potential. The third critical step is the estimation of the distribution of ground motion and geologic effects associated with the earthquake.

A number of estimates of the distribution ground motion would be useful. Some suggestions are:

1) Modified Mercalli (MM) intensity maps for the "maximum magnitude" earthquakes postulated for each region; MM intensity as a mapping parameter is important because much of the work on vulnerability has been cast in terms of MM intensity;

2) A maximum MM intensity map of the country based on the historical record of earthquake occurrences;

3) Maps depicting the geological hazards (landsliding, liquefaction, surface faulting, etc.) associated with the earthquakes and shaking postulated in (1 and 2) above.

The maps prepared under (1) and (3) above would provide an assessment of the distribution of ground motion and geologic hazards associated with possible large earthquakes throughout the country while the maximum intensity map of the country (2, above) provides a useful record of the maximum ground shaking that has been observed historically. USGS has published a number of risk studies that have included maps such as those described in (1) and (2) above (see Bibliography). Most of these studies need revision to provide greater detail in the light of new data.

Figure 2 is a schematic diagram showing the elements required for the estimation of economic losses and casualties associated with any large regional earthquakes postulated for the estimation of catastrophe potential. In addition to hazard assessment, evaluation of catastrophe potential depends on inventory and vulnerability. The following is a discussion of these two parameters.

The spatial distribution and characteristics of things or people at risk is here called inventory. In many ways, it is the most difficult and expensive parameter to estimate. For example, building classifications used in risk assessment must identify and reflect those building characteristics that are associated with damage. In contrast, casualty estimates are

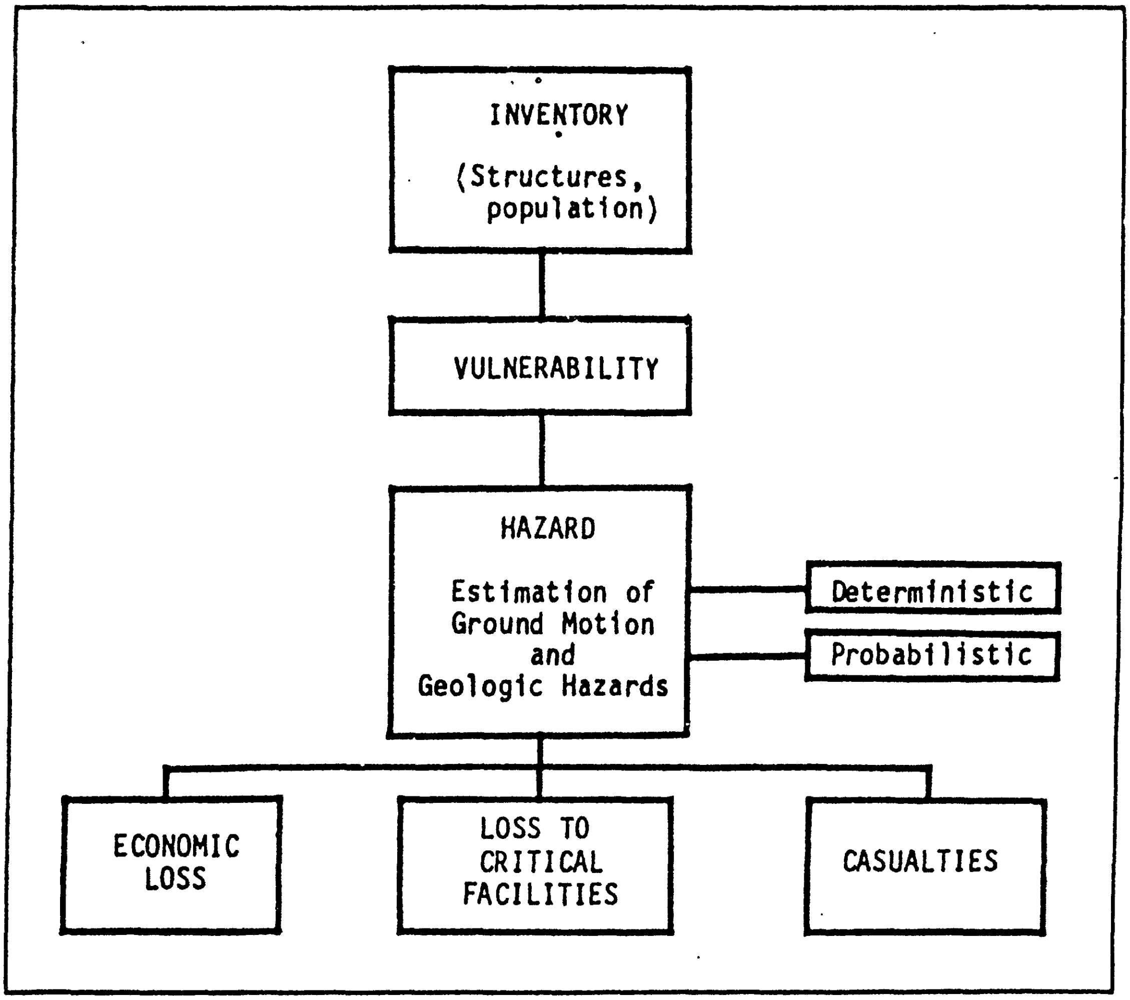


Figure 2. Elements in seismic risk analysis.

obviously related not only to the Figure 2 damageability of a building, but also to occupancy level. The near independence of building characteristics and occupancy considerably complicates the analysis of casualties. Building damage is largely dependent on framing characteristics and materials of construction whereas occupancy density is largely independent of these parameters. Many other complexities such as regional variation in engineering and construction practice, the spatial distribution of buildings, and other facilities such as lifelines are associated with the inventory parameter. The USGS in its loss (risk) studies has used a slightly modified version (Table 1) of a buildings classification developed by the Insurance Services Office (ISO). The ISO classification is generally used by the insurance industry. The building classification system in Table 1 is also used by USGS in its current investigations of earthquake damage and vulnerability. Thus, USGS is in an excellent position to apply the inventory methods it has used in the past and which it is currently developing to loss investigations of value in insurance studies. Since USGS uses the insurance industry building classifications, any inventory provided by the insurance industry could be easily used for loss estimation.

Vulnerability is the susceptibility of a structure or class of structures to damage. Vulnerability is often expressed as the percent of the total replacement cost of the building required to repair it when it is subjected to some specified level of ground shaking. A number of vulnerability relationships have been published. Some are based on analysis of earthquake damage in historic earthquakes, some on theoretical considerations, and others are based on both damage experience and theory. The principal problems in vulnerability analysis are: (1) very few damage studies of historical earthquakes are statistically based, and (2) the relative importance of various parameters of ground motion that can be reasonably measured and related to earthquake damage is still not well understood. The USGS has maintained a small but important in-house program aimed at analyses of vulnerability. In addition, significant research on vulnerability has been funded by the USGS on a contract basis. An example is a study of the damage resulting from the 1951, Kern County, California earthquake. USGS has underway statistical studies of damage data acquired through detailed field damage surveys of the 1971 San Fernando, the 1983 Coalinga, California and a number of smaller, but significant shocks (for example, the July 27, 1980 Sharpburg, Kentucky shock).

Average Annual Loss

The estimation of average annual loss is an important factor in premium development and for the establishment of deductible. Essentially, the estimation of catastrophe potential is a subset or part of the determination of average annual loss and the result of the research on catastrophe potential already discussed must be incorporated into average annual loss. The relative importance of average annual loss in the overall development of an earthquake insurance program is heavily dependent upon the deductible levels established and conversely, estimates of average annual rate are important in establishment of deductibles. A number of techniques have been used by USGS to estimate average annual losses. For example average annual losses can be approximated by:

Table 1--Building classification used in U.S. Geological Survey loss studies (based on Insurance Services Office classification)

Classes and Subclasses	Brief description of subclasses of five broad building classes
1A	Wood-frame and frame-stucco dwellings.
1B	Wood-frame and frame-stucco buildings not qualifying under 1A (usually large-area nonhabitational units); (not considered in this study).
2A	One story, all metal; floor area less than 20,000 feet^2.
2B	All metal buildings not considered under 2A.
3LA	Steel frame, superior damage-control features; less than four stories.
3LB	Steel frame; ordinary damage-control features; less than four stories.
3LC	Steel frame; intermediate damage-control features (between 3LA and 3LB); less than four stories.
3LD	Floors and roofs not concrete; less than four stories.
3HA, 3HB, 3HC, 3HD	Descriptions are the same as for 3LA, 3LB, 3LC, and 3LD except that buildings have four or more stories.
4LA	Reinforced concrete; superior damage-control features; less than four stories.
4LB	Reinforced concrete; ordinary damage-control features; less than four stories.
4LC	Reinforced concrete; intermediate damage-control features (between 4LA and 4LB); less than four stories.
4LD	Precast reinforced concrete, lift slab, less than four stories.
4LE	Floors and roofs not concrete, less than four stories.
4HA, 4HB, 4HC, 4HD, 4HE	Descriptions are the same as for 4LA, 4LB, 4LC, 4LD, and 4LE except that buildings have four or more stories.
5A	Dwellings, not over two stories in height, constructed of (a) poured-in-place reinforced concrete, with roofs and second floors of wood frame or (b) adequately reinforced brick or hollow-concrete-block masonry, with roofs and floors of wood (not considered in this study).
5B	One-story buildings having superior earthquake damage-control features, including exterior walls of (a) poured-in-place reinforced concrete, and (or) (b) precast reinforced concrete, and (or) (c) reinforced brick masonry or reinforced-concrete brick masonry, and (or) (d) reinforced hollow-concrete-block masonry. Roofs and supported floors are of wood or metal-diaphragm assemblies. Interior bearing walls are of wood frame or any one, or a combination, of the aforementioned wall materials.
5C	One-story buildings having construction materials listed for Class 5B, but with ordinary earthquake damage-control features.
5D	Buildings having reinforced concrete load-bearing walls and floors and roofs of wood, but not qualifying for Class 4E; and buildings of any height having Class 5B materials of construction, including wall reinforcement; also included are buildings with roofs and supported floors of reinforced concrete (precast or otherwise) not qualifying for Class 4.
5E	Buildings having unreinforced solid-unit masonry of unreinforced brick, unreinforced concrete brick, unreinforced stone, or unreinforced concrete, where the loads are carried in whole or in part by the walls and partitions. Interior partitions may be wood frame or any of the aforementioned materials. Roofs and floors may be of any material. Not qualifying are buildings having nonreinforced load walls of hollow tile or other hollow-unit-masonry, adobe, or cavity construction.
5F	Buildings having load-carrying walls of hollow tile or other hollow-unit-masonry construction, adobe, and cavity-wall construction, and any building not covered by any other class (not considered in this study).

1. Simulation of the ground motion associated with the historical record of earthquakes in an area. An example is the computation of average annual loss to dwellings in the San Francisco Bay area using three different time windows of historical earthquakes (Algermissen and Steinbrugge, 1978).

2. Assessment of losses using the data base and methods of the USGS in the preparation of national probabilistic ground motion maps. Figure 3 is a schematic indicating the general process of probabilistic ground motion hazard assessment. In Figure 3A, the earthquake activity believed to influence the ground motion at any site of interest has been grouped into areal sources called seismic source zones. These sources are constructed on the basis of seismotectonic information together with paleo- and historical seismicity. The earthquakes in each source are assumed to occur with uniform probability throughout each source or with uniform probability along any fault (line) sources. Line sources are frequently used to model the larger earthquakes while point sources are an adequate representation of smaller shocks. For each seismic source the magnitude distribution of earthquakes is approximated (Fig. 3(B1)) and using the attenuation of ground motion with distance from the earthquakes (Fig. 3(B2)), the distribution of shaking at every site of interest is calculated (shown in Figure 3C as the cumulative distribution function of intensity). Using any suitable probabilistic model for the occurrence of earthquakes in time (shown in Fig. 3D as a Poisson model of earthquake occurrence in time), the probability of any level of ground shaking (the ordinate in Fig. 3D is probability) in any time T can be computed. The quantity that is illustrated in Figure 3 as being mapped is intensity. Using vulnerability relationships such as shown in Figure 4, the maximum expected percent loss by class of construction for any time period and level of probability can be determined directly, provided suitable inventory is available. In addition, if the attenuation or change of percent loss (replacement cost) away from an earthquake source is known or can be developed, the distribution of percent losses or economic loss (if property values are known) can be determined as a byproduct of probabilistic ground motion hazard assessment. In Figure 5(B2), the attenuation of percent loss is shown instead of the attenuation of intensity as shown in Figure 3(B2). The use of the attenuation of percent loss away from an earthquake source has been suggested by Steinbrugge, Algermissen and Lagorio (1984). The development of this type of vulnerability relationship will, however, require extensive research.
Probabilistic ground motion maps of the United States have been prepared by Algermissen and Perkins (1976) and updated and revised by Algermissen and others (1982). Probabilistic intensity maps of the United States are now in the process of being prepared at USGS. Thus the calculation of average annual loss, probability of a certain level of loss or the level of losses for various levels of probability and exposure time can be developed as an additional product of the on-going national probabilistic seismic hazard mapping program in USGS. USGS is in a unique position to develop this kind of data. The considerable program investment in the assembly,

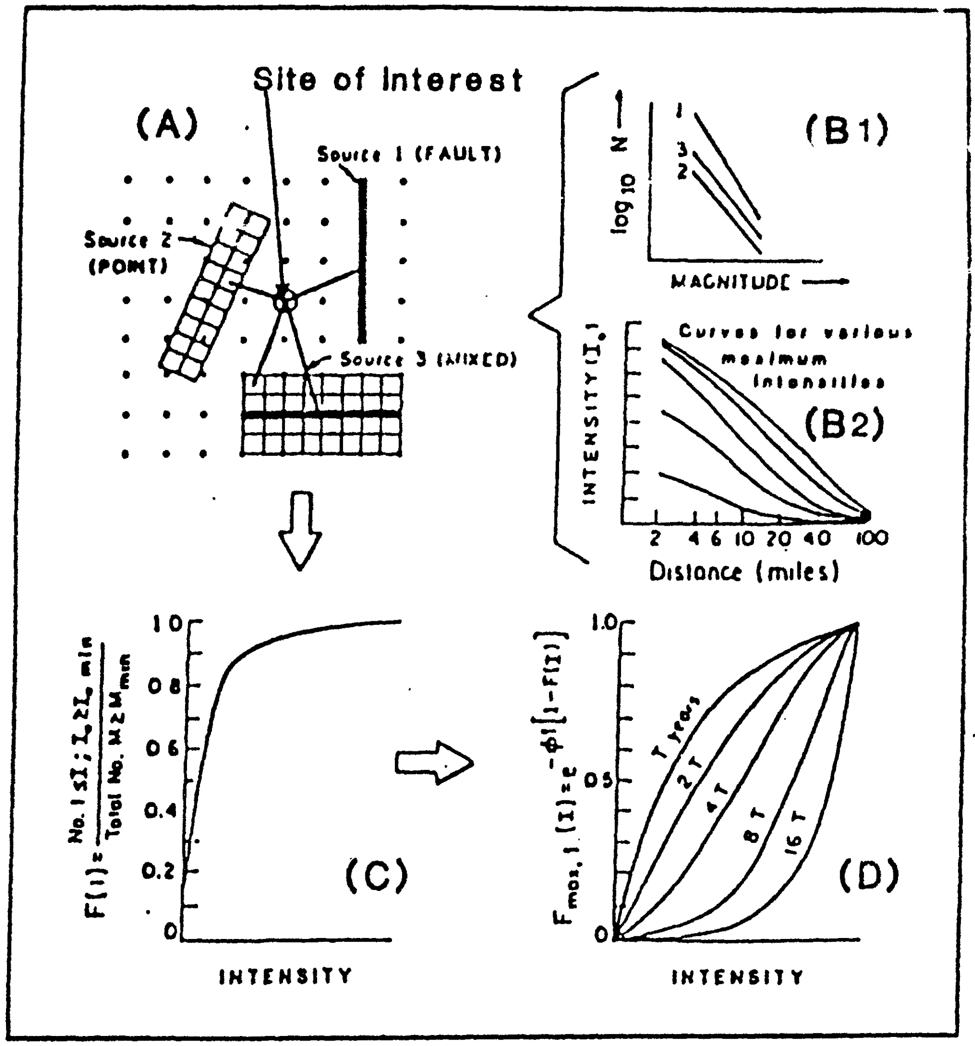


Figure 3. Schematic of the elements of probabilistic Modified Mercalli intensity calculation.

(A) Typical seismic source zones and grid of points at which the hazard is to be computed. In practice the source zones can have any shape. The "site of interest" means a particular site for which the ground motion is being calculated. The lines drawn to the source zones means that earthquakes are considered to occur with equal probability throughout each source (or along each fault) and that the ground motion from earthquakes occurring throughout each source must be attenuated to the "site of interest" using the intensity attenuation in (B2).

(B1) Magnitude distribution ($\log_{10} N = a - bM$, where N is the number of earthquakes greater than magnitude M) for the seismic source zones shown in (A).

(B2) Attenuation of intensity with distance from the simulated earthquakes.

(C) Cumulative conditional probability distribution of intensity. This is the distribution of ground shaking at the "site of interest" obtained from the model.

(D) The probability (ordinate) of occurrence of intensity (abscissa) for various time periods of interest. Any appropriate probability model can be used. The model illustrated is a Poisson model.

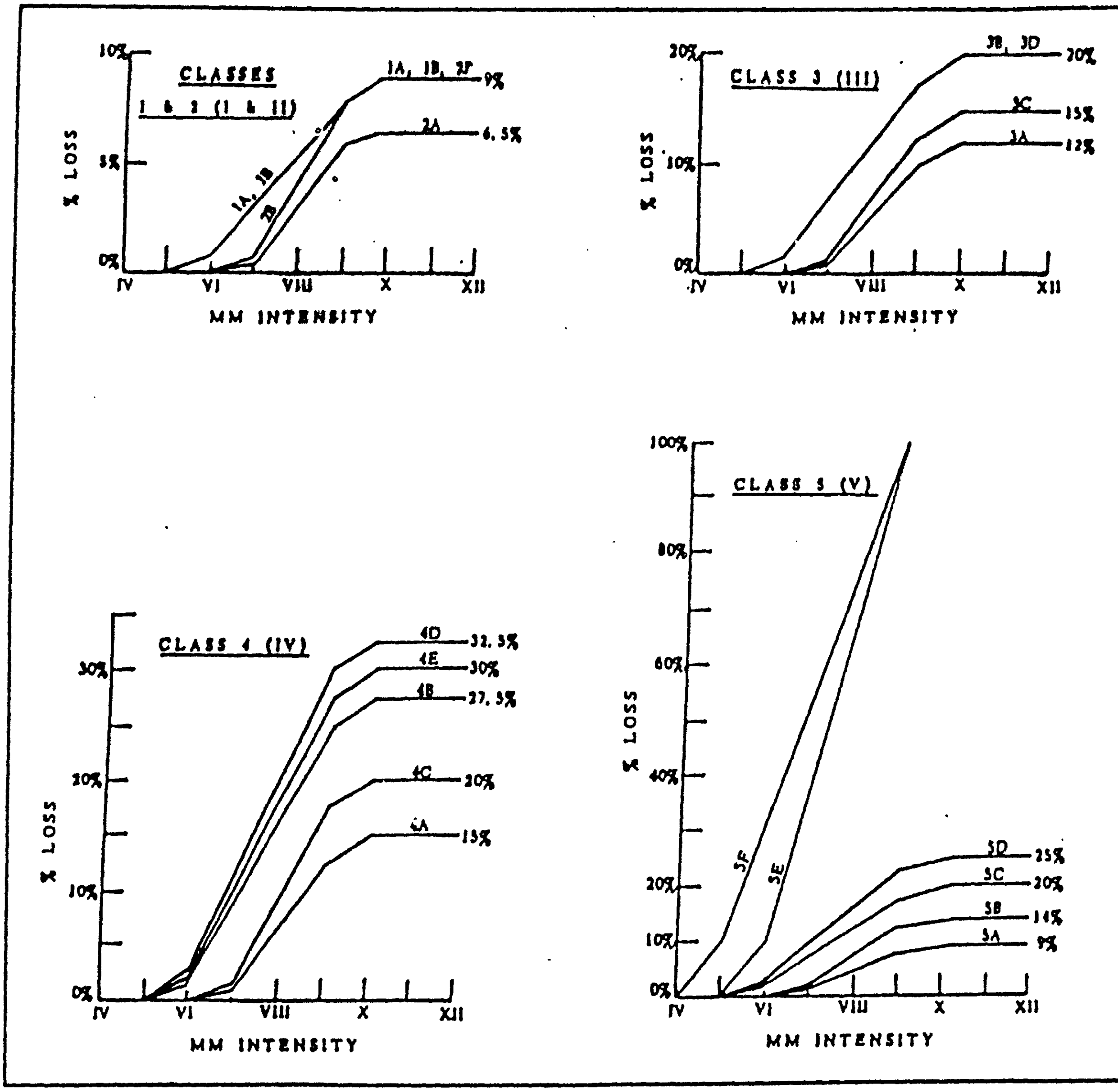


Figure 4. Vulnerability relationships (K.V. Steinbrugge, 1986) for the classes of construction in Table 1.

organization and interpretation of geological and geophysical data required for probabilistic seismic ground motion assessment has already largely been accomplished and represents a critical initial step in the computation of expected earthquake losses on a national basis.

3. Simulation of the annual losses associated with earthquake induced landslides and liquefaction. Considerable work has been done on the probabilistic estimation of liquefaction severity in the United States (see, for example, Youd and Perkins, 1987). Some progress has been made on the problem of estimating earthquake induced landslide potential (see, for example, Wilson and Keefer, 1985).

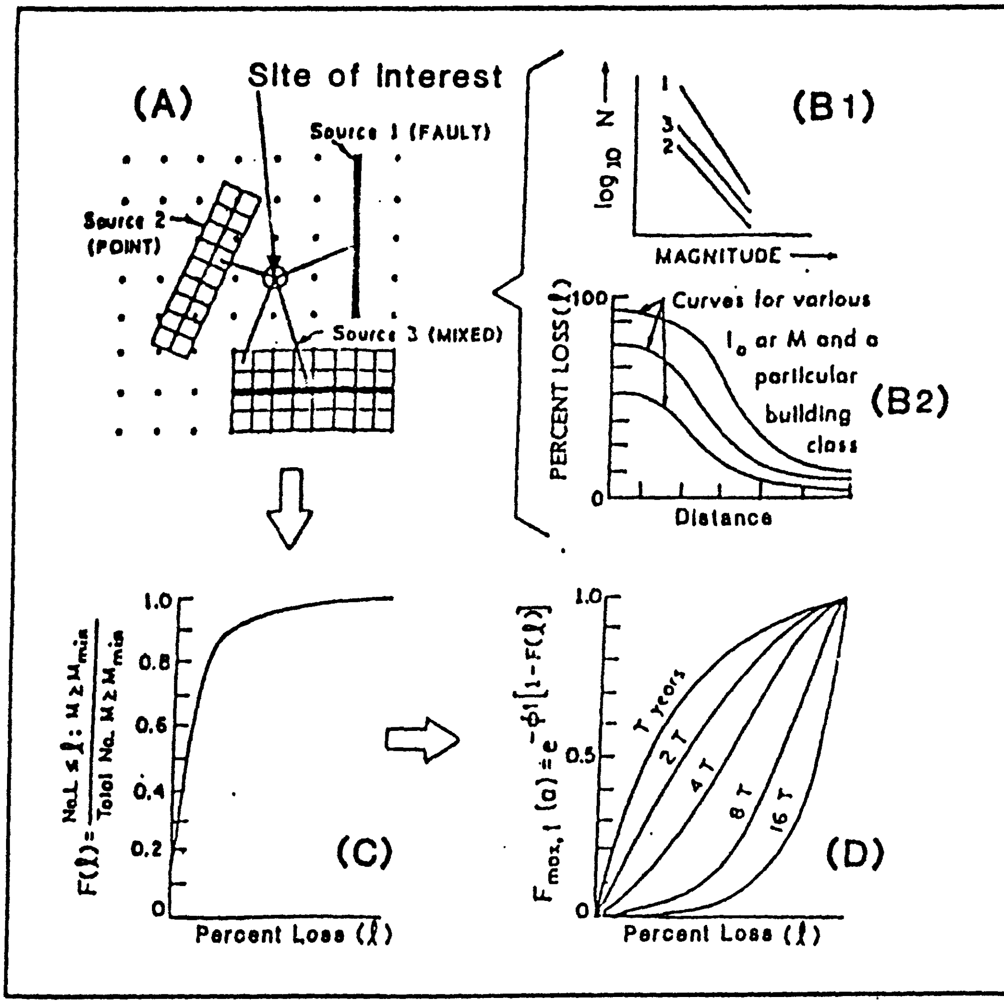


Figure 5. Schematic of probabilistic seismic (loss) assessment process. The model is the same as shown in Figure 3 with the exception that the quantity mapped is "percent loss" (part B2) of the illustration.

SOME ADDITIONAL ASPECTS OF RISK ASSESSMENT

The previous discussion has outlined in a general way the data and techniques available for the assessment of earthquake risk associated with ground shaking using intensity as a measure of ground shaking. I focus now on some of the problems in risk assessments, data bases that might be developed, examples of risk assessments and various presentations of results.

The Problem of Intensity

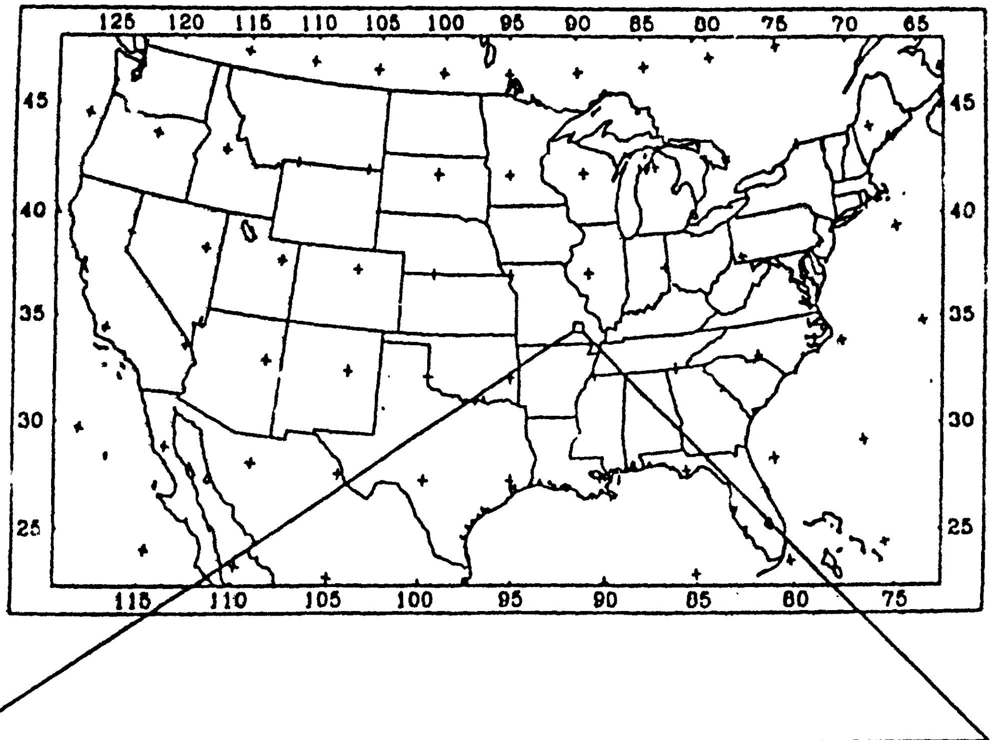
Risk assessments historically have used intensity scales such as the Modified Mercalli Intensity (MMI) in the United States as a measure of ground shaking and have used vulnerability relationships that depend on percent loss as a function of intensity. Unfortunately, the mapping of ground shaking in terms of intensity presents a number of problems. All intensity scales are subjective and many types of modern construction are not represented in the intensity scales in current use. In addition, the types of structures referred to in the MMI scale do not include many types of new construction and do not include effects on high-rise buildings. In particular for high-rise buildings it would be desirable to construct maps of the expected peak values of earthquake ground spectra at several periods of ground motion, say at periods of .2 and 1.0 seconds. Maps of this type would at least in theory lead to a much improved assessment of expected damage to tall structures. A more direct method of assessing loss would be to construct contour maps of damage (for example, percent of replacement cost) by class of construction for earthquakes of interest. This approach has been suggested by Steinbrugge, Algermissen and Lagorio (1984). There are, however, many problems in the implementation of this idea. Most of the research on vulnerability (the relationship between damage and ground shaking) has been done in terms of intensity. Development of relationships for direct mapping of damage as a function of distance from an earthquake would require a reinvestigation of virtually all the damage data available for historical earthquakes.

Site Response

It is now generally agreed that the modification of seismic waves caused by the surficial material beneath a site to depths of several hundred meters may result at many sites in the amplification of ground shaking of several times that experienced at other sites. These anomalies of several MMI degrees may occur locally. An extreme example of this phenomenon is the relatively large ground motion at wave periods of about 2 seconds that occurred in a portion of Mexico City in 1985 causing enormous damage. Information about the geotechnical properties of the near surface materials is important in assessing seismic risk, especially in the case of important and expensive structures.

Earth Science Data Base

One of the main problems in applying the data and research results available from the USGS program to the problems of earthquake risk assessment and insurance is organizing the available data in a useful manner. Figure 6 shows how data and research results relevant to risk assessment and insurance could be organized nationally. Critical information could be accumulated in



Each cell* to contain:

1. Historical earthquakes known to have occurred within each cell
2. Historically observed intensities
3. Intensity history simulated using probabilistic hazard analysis model
4. Known historical, Holocene and Quaternary faulting
5. Geotechnical properties of the cell – surface geology, depth to bedrock, void ratios, densities, seismic wave velocities, etc.
6. Population
7. Available inventory – type of construction, value, etc.

* Example: cells might be 10 x 10 km, census tracts or zip code zones

Figure 6. Data base for geological and seismological data critical for earthquake hazard and risk assessment.

geographic "cells" having useful dimensions. Examples might be cells 10km^2, census tracts, zip code zones, etc. Data accumulated in each cell might be: (1) the shaking history of the cell (extropolated from historical seismicity data); (2) the shaking history of the cell obtained from the probabilistic ground motion hazard calculation; (3) surface geology and thickness of surface material; (4) Quaternary, Holocene and historic faulting; (5) geotechnical properties (such as seismic wave velocities, densities, etc.); (6) population; (7) available inventory by class of construction and value; and (8) expected maximum ground shaking for various periods of time of interest.

Obviously, not all of the above information would be available for all cells. However, if properly planned, the data base could be periodically added to and expanded. This type of product lends itself well to the new Geographic Information System (GIS) data base and mapping system. USGS has been a leader in the development of GIS products.

Inventory and Damage Data Collection

The USGS is developing an integrated, microcomputer-based system for both inventory development and for the collection of earthquake damage data following an earthquake. The entire system is being designed for ease of operation in field surveys of either damage or inventory. The system is based on mark-sense sheets that are computer entered by means of an optical scanner and is designed so that the building characteristics recorded for inventory are those related to earthquake damage. The system is planned to acquire data for: 1) the statistical assessment of damage following significant earthquakes; 2) the development of inventory; and 3) the improvement of vulnerability relationships.

A sketch illustrating the concepts involved is shown in Figure 7. The importance of the damage and inventory acquisition methodology being developed is shown by the relationship between the "INVENTORY" and "VULNERABILITY" blocks in Figure 7. The concept is that the parameters or characteristics of buildings that are inventoried should be the same parameters that best describe damage to a building during an earthquake. Figure 8 shows a typical mark-sense sheet for use in damage estimation following an earthquake. It is obvious that by slight changes in the descriptions, the same form can be used for inventory development.

Figure 9 is a schematic showing the computer system and peripheral equipment. This system is designed to be transportable for use in the field for damage surveys. The current program in inventory development and analysis of damage data have important implications. This program is providing new statistical analyses of important earthquake damage sets not currently available for existing loss estimation techniques. A major problem in early loss studies was that vulnerability relationships had to be developed based solely on engineering judgement since historically, earthquake damage data have not been collected on a statistical basis. We now have available two excellent data sets (Coalinga and San Fernando, California) which are being analyzed statistically. These data sets, together with the implementation of the new, statistically based damage collection system will make possible much improved estimates of the statistical distribution of damage for buildings of every class for a particular level of ground shaking.

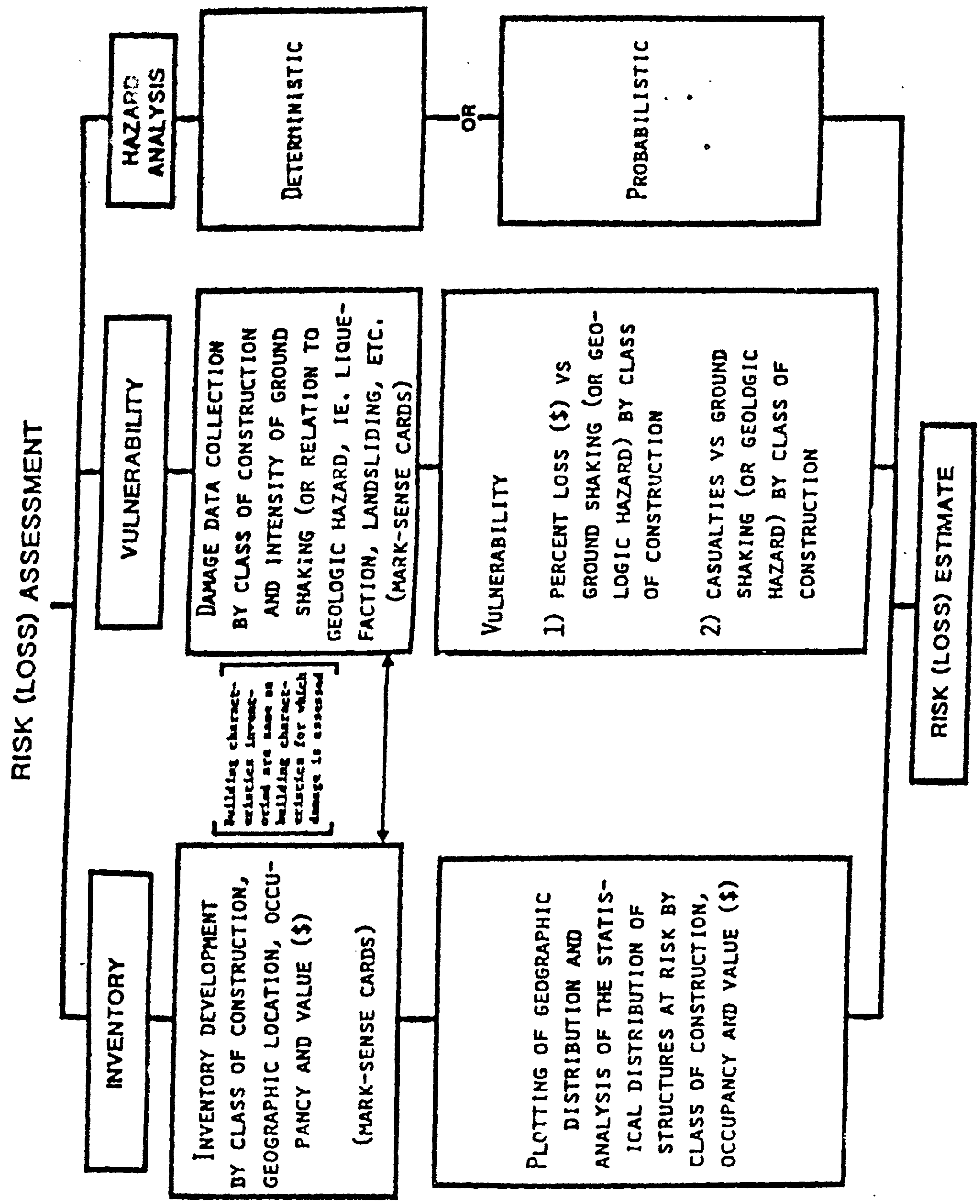


Figure 7. Elements in integrated seismic hazard and risk assessment program. Note that inventory is cataloged using the same general scheme as that used to catalog earthquake damage in the field following an earthquake. The same type mark-sense data card is used both for inventory development and earthquake damage assessment (Figure 8).

Class I - Wood Frame Structures (California)

Form Number

Block Number

Address ______________________

Inspector ______________________

	A	B	C	D	E	F
1) Subclass:	A-1	A-2	A-3	B		
2) Age Group and Special notes: (Two marks required)	Pre-1940	1940-1949	Post-1949		Notes	NoNotes
3) Number of Stories:	1	2	1 & 2	Split-Level	3	>3
4) First floor and foundation:	Wood joist	Concrete slab	Poured footing	Con-Blk footing	Pemt	N/I
5) Type of exterior finish:	Stucco	Wood	Masonry	Stone	Other (specify)	N/I
6) Type of interior finish:	Plaster	Gypsum	Panels	Other (specify)		N/I
7) Masonry veneer in percent.:	N/A	1-10%	11-25%	26-50%	>50%	N/I
8) Type of chimney & existance of damage: (Two marks required) If answer F, do not proceed.	None	One flue	Multiflue	Patent type	Damage	No Damage
9) Structural damage to frame:	None	Slight	Moderate	Severe	Total	N/I
10) Damage to foundation:	None	Slight	Moderate	Severe	Total	N/I
11) Did structure fall or slide off foundation & by how much? Was frame distorted (wracked) or not? (Two marks)	No	by < 6"	by > 6"	Frame wracked	Not wracked	N/I
12) Damage to exterior finish:	None	Slight	Moderate	Severe		N/I
13) Damage to interior finish:	None	Slight	Moderate	Severe		N/I
14) Damage to exterior veneer:	N/A	None	Slight	Moderate	Severe	N/I
15) Damage to chimney(s):	N/A	None	Slight	Moderate	Severe	N/I
16) If chimney(s) existed and damaged, was reinforcing used?	N/A	Yes	No			N/I
17) Geological hazards factoring in damage:	Lique-faction	Land-slide	Ground failure	Other (specify)		N/I

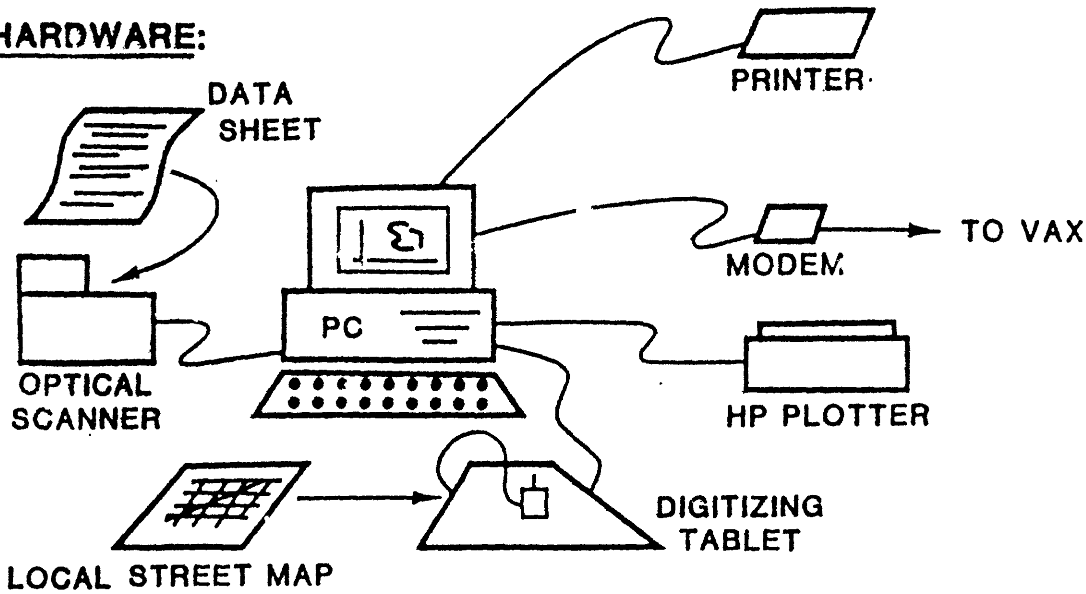
Class I - Wood Frame Structures v1.4

SCAN-TRON FORM NO. 3378-USGS

Figure 8. Mark sense card for cataloging inventory and damage.

FIELD DATA ACQUISITION SYSTEM
FOR
EARTHQUAKE LOSS DATA

HARDWARE:



SOFTWARE:

PROGRAMS TO -

1. DIGITIZE LOCAL MAPS
2. GRID, SURFACE, CONTOUR
3. DRAW MAP
4. COMMUNICATE WITH VAX
5. DRAW GRAPHS
6. SCAN OPTICAL FORMS

Figure 9. Schematic of computer and peripheral equipment used in the field acquisition of earthquake damage data and for development of inventory.

SUMMARY

A wide variety of data and applied research results of importance in earthquake loss estimation and insurance can be provided within the framework of existing technology. The following is a selective, annotated list of possible products:

1. <u>Earth science data base</u>
   National data base of information critical to loss estimation (see Figure 6 and previous description).

2. <u>Estimation of the magnitude distribution and probability of occurrence of large earthquake by region</u>
   Reliability of these estimates would vary widely depending on paleoseismic and historical seismicity data available (see Working Group on California Earthquake Probability, 1988 as an example).

3. <u>Expected ground shaking (in terms of intensity) for probability levels and time periods of interest</u>
   Probabilistic maps of maximum expected acceleration and velocity are currently available for a 90 percent probability of not being exceeded in time periods of 10, 50 and 250 years. Figure 10 is an example. Figure 10 shows how use of maps of this type can provide useful comparisons of the expected level of shaking in various areas.

4. <u>Deterministic and probabilistic estimates of earthquake risk (loss)</u>
   Losses might be estimated from analyses of hypothesized deterministic (scenario) type earthquakes or probabilistically by building on the USGS program of regional and national probabilistic ground motion estimation. Vulnerability information is being developed within the ongoing program of the USGS as already described. Inventory would depend on the needs of the user, but could be collected or adjusted to the formats being developed by USGS for inventory collection. Many different presentations of loss data are possible, including: (1) aggregate losses by class of construction for scenario type earthquakes; (2) average losses by class of construction regionally or nationwide; detailed investigations of losses in special areas of interest, etc. Figure 11 shows a specialized presentation of percent loss associated with the occurrence of a maximum intensity VII (Io=VII) earthquake anywhere in the San Francisco Bay Area (Algermissen, Steinbrugge and Lagorio, 1978). In Figure 11, percent losses for the Bay Area taken as a whole were computed assuming that an earthquake with Io=VII occurred at each of the grid points shown. The results were then contoured. It is therefore possible to estimate the <u>total</u> losses to a particular class of construction resulting from the occurrence of an Io=VII anywhere in the Bay Area by interpolation of the contours. For example, if the earthquake occurred at the Point marked A, the losses would be 7.6% of the total replacement cost value of all buildings of class 5E in the Bay Area. If the earthquake occurred at point B, the losses would be approximately 1.8%. (See Table 1 for a description of building class 5E.)

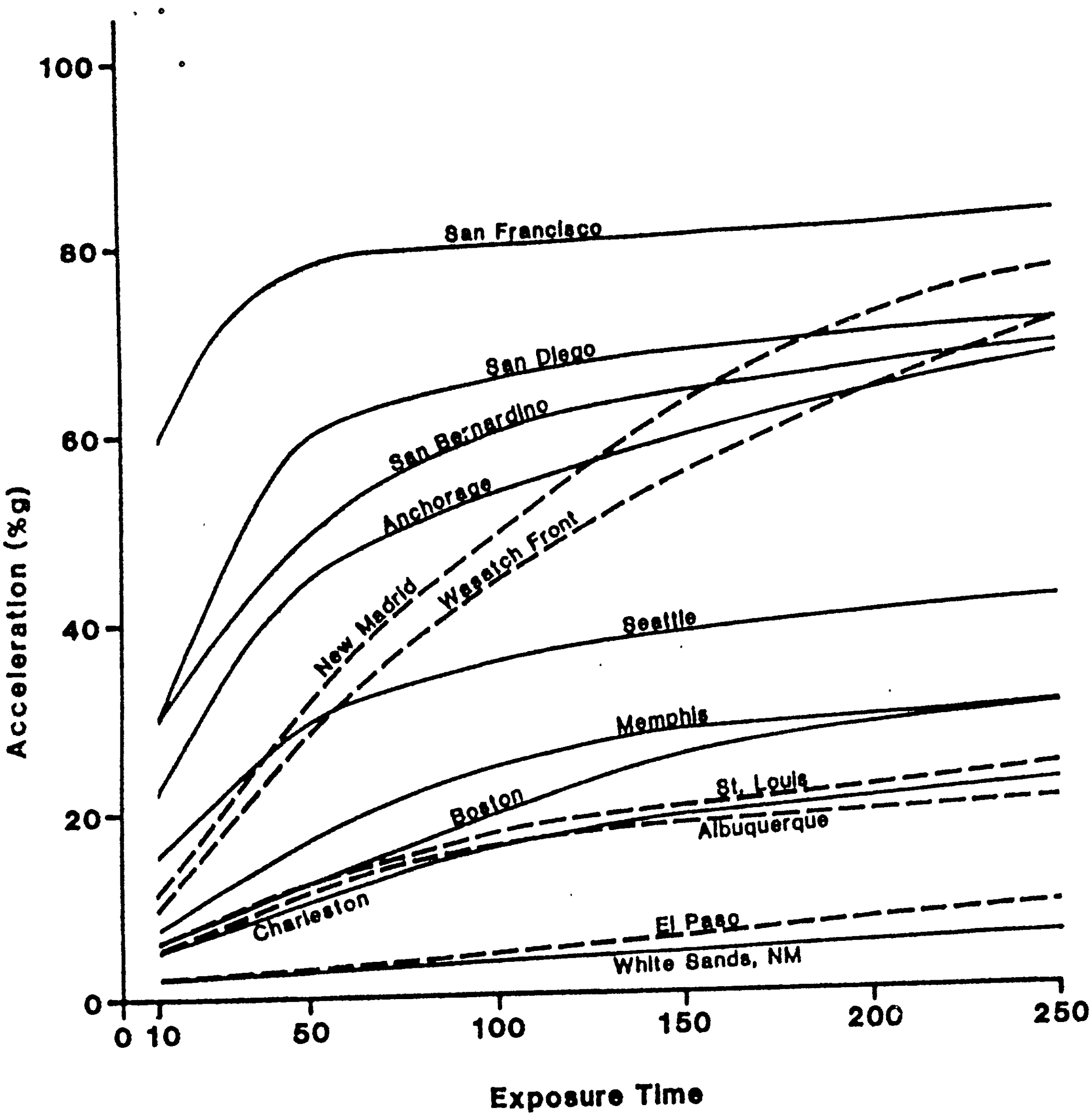


Figure 10. Comparison of the maximum expected ground acceleration in 10, 50 and 250 years at a number of sites in the United States. These data were derived from maps such as the one shown in Figure 1. The ground accelerations shown have a 10% chance of being exceeded in the time periods shown.

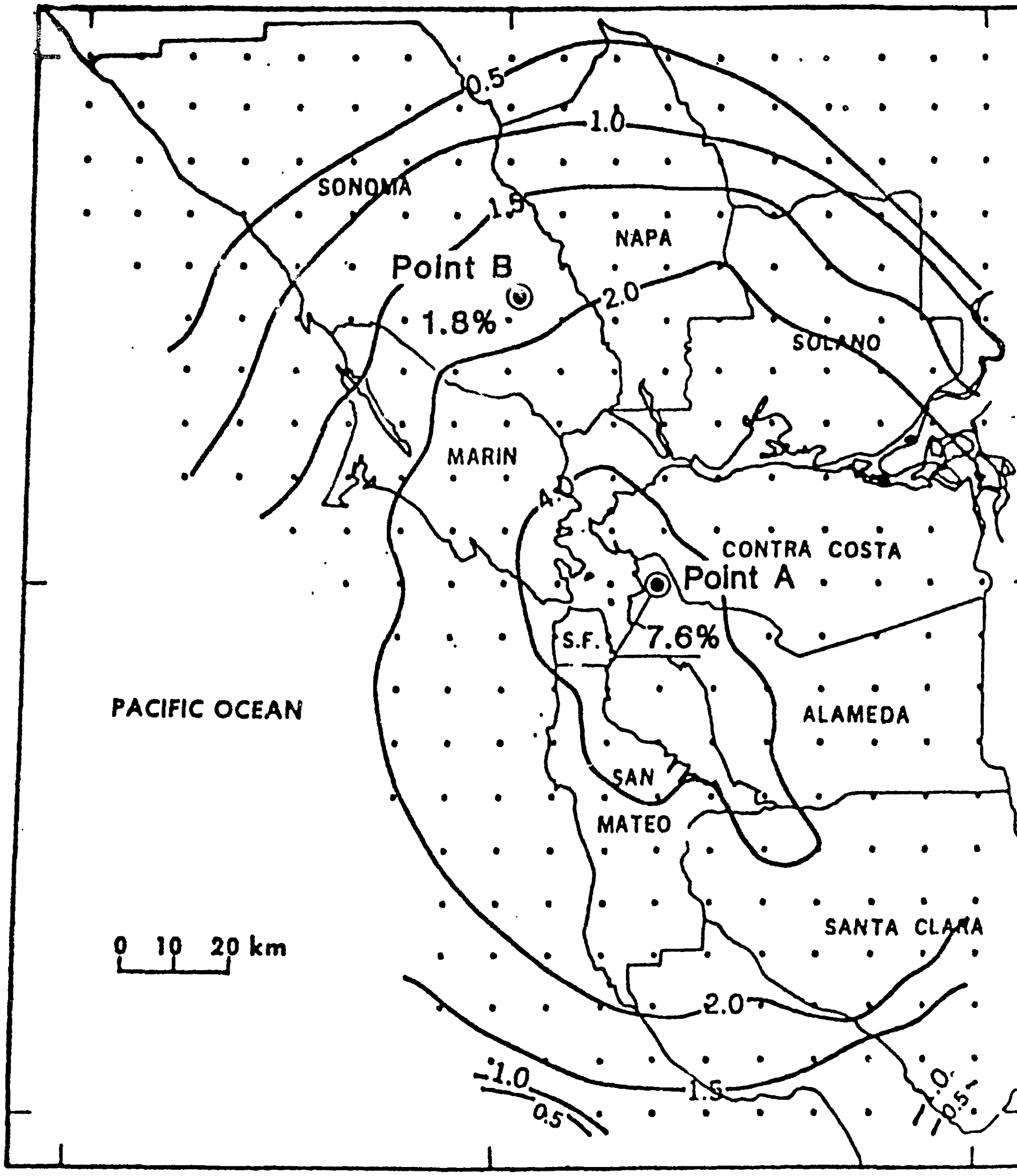


Figure 11. Percent losses (contours) to buildings in subclass 5E (Table 1) for an earthquake of maximum intensity (Io) = VII anywhere in the San Francisco Bay Area. For example, if the earthquake occurs at Point A, the loss to all 5E structures in the Bay Area is estimated at 7.6%. For a similar earthquake at Point B, the losses would be approximately 1.8%.

The purpose of this paper and the above summary has been to outline the potential for the improvement of our understanding of the nature and structure of future earthquake losses in the United States making use of the rapidly expanding base of data and research available, particularly within the USGS earthquake program. Obviously, much additional earth science research is conducted in other federal, state and local agencies, universities and the private sector. It is believed that the general ideas discussed here apply equally to all of the generally available data and research currently underway in the United States.

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Needs of the Insurance Industry

by

L. B. Falck
New Zealand Earthquake and War Damage Commission
Levin, New Zealand

The earthquake which occurred in the Bay of Plenty on the east coast of the North Island of New Zealand in March 1987 was a shattering reminder to all New Zealanders of the realities of earthquakes which they live with every day. When total costs had been analysed the facts were even more startling. In an area of low density population, low cost housing generally with only four industrial complexes, which could be considered large, the all up cost can be broken down as follows:

Earthquake and War Damage Commission	$130 million (N.Z.)
Private Insurers	$356 million
N.Z. Government	$350 million
	$836 million

Of its share of the losses, the Commission would estimate that only $20 million dollars can be attributed to losses in the domestic housing sector, (i.e., only one-sixth of its total losses). A loss of nearly $8 billion in total turned the Government's, Commission's and industry's attention to the problems that could be anticipated with future earthquakes. We all had been living in a dreamworld that the New Zealand Government would and could see us all rehabilitated. It was now obvious that we were in reality facing a scenario where the Commission and industry could face total financial collapse and further create a tax burden beyond the ability of the current and projected tax base of New Zealand to cope. Of even more concern, the picture in respect of insurance cover against this sort of natural disaster that emerged concerned all in the industry. Approximately 20% carried no cover and another 20% were underinsured. Because of the nature and small population base in New Zealand, it has also become a habit of Governments to rehabilitate these people. The sum involved and payouts in a historical context showed quite clearly that the person who had prudently insured and paid premium was at a distinct comparative disadvantage to those who had not. Resentment was rite and the philosophy "Don't insure and she'll be right" (a famous fore of Kiwi avoidance behavior) became a catchery. These socio-political factors therefore, have forced us all to reconsider our current positions. As a consequence, the New Zealand Government in an effort to reduce its involvement and contingent liability has announced that Earthquake insurance in New Zealand and the associated disasters which in New Zealand have traditionally been part of that package (vulcanism, tsunami, land cover and hydrothermal eruption) will in the future be compulsory in the domestic housing sector. In addition, in an attempt to increase the capacity for earthquake insurance currently available in the New Zealand market the Government further decided to remove the monopoly the Commission has had to date over this type of insurance.

Why did I outline all this at the beginning of an address to members of a workshop on the insurance and engineering needs of the industry?

The answer is because these moves have excited the industry and the Commission into the largest investment in earthquake and related research in our history. The Commission has already invested in excess $7 million this year with a similar projection for the next year. In proportion similar subs are being invested by the industry. We are all faced with finding answers to some or all the following questions.

i What is the extent of exposure? What is a reasonable expectation of after costs? How can these costs be minimized?

ii How are rates to be arrived at? Are the current zones adequate? The problems of liquefaction and its attendant hazards, how do we cope with the increasing evidence that our three largest cities are badly exposed? Volcanoes - where is Auckland in respect of the recently postulated "hot spot" and what are the chances of a new eruptions? etc.

iii Tsunamis - How frequent have they been? How much damage have they caused? The greenhouse effect coastal housing units and coastal erosion. "Ice quakes" in Antarctic etc.

iv Building and design codes - are they meaningful and what do we do about the housing stock erected prior to regulation?

v The main Alpine-Wellington fault - do we know enough about it? Two months ago they redrew its position on the map, should we not be able to expect accurate information on its position and potential behavior?

vi Disaster management programs. The banking industry, communications industry, how would they cope after a major earthquake with the insurers trying to arrange for liquidity and claims payments or would they collapse?

vii How much reinsurance should one purchase and what is the appropriate cap of liability?

viii The Maximum Possible Loss, Estimated Maximum Loss - Are our current models able to give us a clear picture of the problems we can expect when a large magnitude disaster strikes?

A lot of these questions are not relevant and do not need investigation in a country such as the United States where redundant systems and controls within the economy could deal with some of the difficulties I mentioned. In New Zealand because of the smallness and fragility of our economic and communications infrastructure they are pressing and require resolution.

The research projects I have just outlined are the current needs of the industry. They do not touch upon the ongoing progresses of a more theoretical nature (geophysical, seismological, etc.) which are both important and necessary if we are to gain a true understanding of earthquakes and better able to predict their onset. In New Zealand we are following with great interest the work currently being carried out in this area in California in respect of the future behavior of the San Andreas fault.

New Zealand has historically been very active in the various research disciplines associated with earthquake research. It has been low budget, high quality research. The questions studied have not always addressed the problems that the underwriter faces and wishes to resolve when confronted with a demand for earthquake insurance. The Government initiative has now given an impetus in the direction required by the industry. It is the Commission's intention to continue to fund larger term programs of theoretical research but in future will also require a research effort centered about its commercial objectives. The industry currently funds little theoretical research and has traditionally left this to the lot of the Government and Commission.

I would like to now spend some time addressing the issues and research needs I outlined earlier. When confronted with a new regime the fundamental question facing the industry immediately was identification of the value at risk. The Commission has always had a monopoly and did not have a clue as to its total aggregated risk essentially because it is a non policy issuing insurer - a creature of statute. Rapid research projects were established aimed at determining the current situation, the various locations of greatest risk and for reinsurance purposes a process whereby these aggregations could be coherently broken down. Further the problems of determining algarit has which could deal with loss of contents cover, replacement cover and the extremely difficult problems of plant and automobile covers, became vital for the forward planning of the industry. What was of great interest to me was having had to take a lot of criticism in the media from the private insurers over the past years for not knowing where and what the commission's risk was. It became very apparent early on once the actuaries and mathematicians got into the act that the Insurance companies were in just as bad a position if not worse even though they did issue policies. One problem was that their policies were for replacement and no one had determined how you established cost in event of a claim. Needless to say a lot of companies are spending considerable sums of money now in attempts to get relevant and accurate data.

Another major and pressing problem is determining Expected Maximum Loss (EML). Various rule of thumb methods have been applied and it is interesting to note that methodologies are now being developed which will allow an insurer to calculate within reasonable error limits the extent of loss in any specified event. I have great hopes for this brand of research because it will also be of assistance to the wider community in their preparations for a seismic event. Minimization of after casts is vital if we are to cope with the problems of a significant event. Examination of regulations and building codes is currently being undertaken to determine whether they are in accord with current research findings. The insurance industry lobby will now also have to focus upon the need for adherence and whether we will insure a client who refuses to bring that structure up to standard. A great deal of interest is now centered about the need for a set of minimum codes for the domestic market. Enforcement will be a problem. I note with interest that the emphasis in California concerning proximity to fault lines and the gradual adoption of rules creating no-go building areas is not the same in New Zealand. How else in Wellington could we now have most of our high rises hard up against or lying across the fault. In Christchurch work is currently being carried out to determine means of rejacking tall buildings as a means of avoiding constructive total loss. I am assured by the scientists that once the technique is proven that insurance costs will be reduced by 90%. As I am sure you are all aware the work upon timber frame high rises as a safer and more resistant style of construction is also proceeding rapidly.

Rating will become increasingly important as competitiveness hops up. The relationship between seismic danger zones and a rating scale is being explored. Never before has an attempt been made to determine a scale of rational rates for New Zealand. We currently have situations where replacement cover in excess of the Commission's indemnity cover is thrown in free as a sweetner to attract the remainder of the business. There has been little attention to the true costs and hence true rates in the past. As our knowledge of our risk area increases the problems multiply. For example a relatively low risk city in historical terms - Christchurch has been now determined as a high risk area for liquefaction, where up to 90% of the urban area could be subject to subsidence if a force 7+ (Richter) occurred. Auckland is now considered to have a considerable risk of vulcanism - houses are literally built upon the sides of what were once considered dormant volcanoes. As our knowledge grows and the potential for an eruption in the Auckland area rises so do the problems multiply. A small provincial city (New Plymouth) lies in the shadow of a cone (Mt. Taranaki) which is the splitting image of Mt. St. Helens - now research tells that this particular cone is long overdue for one of its characteristic explosive eruptions. There is Taupo - largest volcano in the world. Scientists are carefully studying this crater and trying to get to grips with its behavior. Then there is Wellington - I could continue, as our knowledge increases so do our risk areas. For the insurer the problems of setting a rate appropriate to the value at risk is becoming a nightmare. We need to know more about the earthquake potential, volcanic possibilities, etc., and the expectation we can expect in respect of them.

The insurance industry is also faced with the risk attendant to Tsunami whether it originates within New Zealand's territorial waters or not. Until recently little work had been done on this area in New Zealand. With the recent increase in coastal building, the insurance industry needs to determine what the effects of a decent sized tsunami would be. The greenhouse problem recently outlined has only increased our concern in this respect.

Ice quakes became an issue in New Zealand some years ago, Our nearness to the Antarctic Continent means we, like Australia are exposed to major seismic events occurring under the Ice shield. This phenomenon is the focus of continuing research and hence the joint venture work currently being carried out in respect of the seismicity of Antarctic. Research is also currently being done to determine the problems of immediate concern - the effect of the resulting tsunamis upon the southern and eastern coasts of the South Island.

The last area of research I would like to outline to you is a newcomer to the scene in New Zealand. Here I am referring to the increasing interest in research associated with the after effects of earthquake disaster. The work of the California Seismic Safety Commission is being carefully studied and indeed there is pressure for the creation of a similar body in New Zealand. At a time when our Government is moving to abolish as many of these type of bodies the problem of gaining support for such an organization has magnified. Some of the areas of concern are problems that are faced only by New Zealand because of the location of the Capital City. I just want to list some of the efforts I have had contact with briefly.

Banking Industry recovery - What would be the inherent problems?
Currency Management in a disaster - What are the scenarios?
Electricity Reticulation - What would be the likely effects upon the national grid?

Communications - modeling the effects of a large quake upon this vital area.
Behavior of the citizens - What do like disasters tell us about the potential behavior of the population etc.

These are just some of the projects being carried out by both private and public research agencies. A recently completed study of the aftermath of nuclear holocaust has caused a radical rethink of current practices when it pointed up the inadequacies and somewhat naive assumptions inherent in our current plans. This in fact led to the other radical change in the Commission's future activities - the removal of war cover as an insurable item. Insurance for this will now be unavailable and the recovery after war the responsibility of Government through a National Reconstruction process.

COLLECTED RECOMMENDATIONS AND VIEWPOINTS

By
Karl V. Steinbrugge
Consultant
El Cerrito, California

This presentation is a summary of recommendations and viewpoints gleaned from the written submittals by the insurance participants to this workshop in Albuquerque. Also included are recommendations made by insurance speakers at the Executive Briefing held in Washington, D.C. on March 8-9, 1988. Additional oral statements have also been included. Order does not indicate priority. Topics will be reorganized in the final draft.

Wording often is that of the participant, sometimes edited for brevity or context, or combined with those of others. In every case, the recommendations and viewpoints are those of the participant(s) and are not necessarily in agreement with those of others.

The intent is to offer these as discussion "strawmen" at the closing session of this workshop. Hopefully, audience participation will add to as well as revise the points made herein. Results of these discussions should assist the USGS in establishing priorities and help define programs which can be implemented within their agency's goals.

PMLs and Damage Ratios

The insurance industry commonly uses the term Probable Maximum Loss (PML) for earthquake loss purposes while engineers have often use the term Damage Ratio. These definitions are different. There is no commonly accepted transfer function (mathematical relationship) between these two definitions.

Personal lines underwriters understand PML as an aggregate loss figure (such as the loss for all dwellings in a postal ZIP) while the commercial lines underwriter considers PML on an individual risk basis. USGS research has used damage ratios in some loss estimation studies.

PML and damage ratios should be mathematically defined in terms useable by the insurance industry and by engineers and scientists in order to provide a basis for data commonality.

California has established property damage estimates for various construction classes. Assuming these estimates are correct, how do other factors (such as combustible loading, hazardous occupancies, outside exposures, e.g., flammable liquid tanks, elevated tanks, irregular shaped or closely adjoining building, etc.) adjacent to a site affect the estimated loss? What is the potential damage from a vapor cloud explosion at a chemical plant. Should a uniform system be established in other countries around the world?

Aftershock

Most insurance companies accept the definition that an earthquake event includes seismic activity within 72 hours of the initial shock. What intensity, location, and monetary loss can be expected for aftershock in relation to the major shock? What potential effect will it have on structures already weakened? Can these effects be related to individual building classes?

Microzonation

There is need to quantify the relative hazards shown on microzonation maps for the degree of expected damage by class of construction. This should be done on a consistent basis by all who prepare such maps so that monetary loss estimates derived from these maps will be numerically consistent. Words on maps such as "slight", "moderate", etc. have no consistent numerical meaning.

Incremental increases in PMLs and/or damage ratios of buildings based on soil conditions and earthquake size should be quantifiable from maps or from other sources. Preferably, all such information should be in computer data banks.

Time-Element Loss

A method is needed to better identify potential delays in resumption of commercial operations. There is no question that the life safety and health aspects must receive first priority, but prompt restoration of business is also essential.

Earthquake Building Damage vs. Other Earthquake Losses

Even if earthquake coverage is not provided, there will be fires, sprinkler leakage, collapse, contamination, etc. What political and legal ramifications should be expected as they relate to payments for damage resulting from earthquake involving other perils, particularly on locations that did not have earthquake coverage?

Site-specific Analysis

More information is needed to properly evaluate a particular location than can be gathered without an actual visit. Can analysis be made for such things as soil condition, landslide potential, land use (commercial and residential), predominent wind conditions, etc., from appropriate map data or from computer data banks?

Workers Compensation

Deaths and injuries in the workplace can be covered through workers compensation insurance. Casualties are normally the result of building collapse, falling shelving, and other building component failures. Deaths and injuries may also occur due to the release of toxic gases or due to explosion as a result of earthquake. Some sources have estimated that workers compensation losses could equal those of building damage.

Information on the number of deaths as a function of building damage is essentially lacking for United States earthquakes. The number, nature, and dollar loss consequences of earthquake induced injuries are also absent. This kind of information is also lacking for disaster response officials.

The USGS in conjunction with the medical profession and insurance industry should examine world-wide data on past earthquakes. They should make a determined effort to obtain such information after the next major earthquake wherever it occurs and where significant death to injury comparisons can be made. The input of the medical profession is a paramount need. Is this within the USGS goals? If not, which agency?

Commonality of Data

In other areas of the world, seismic information is presented using various techniques and parameters. It would be advantageous if a uniform format can be developed for seismic data publication useable for insurance purposes.

Fire Following Earthquake -- Individual Buildings or Plants

Estimating fire-loss potential for an insured location has been practiced for many years and is the basis for general underwriting. There is no question that some fire loss is expected following an earthquake. The extent of that fire loss is poorly established on an individual risk basis. Additional study is needed to investigate the industrial, commercial, and residential aspects of fire following an earthquake. A facility on 100,000 acres, much of it open space, that deals with non-combustible materials will certainly be rated far differently than a petrochemical company on densely occupied land.

Conflagration

With the use of modern materials in construction over the last 40 years, is a conflagration as occurred following the 1906 San Francisco earthquake a viable factor? Does it differ between congested residential areas and the more open industrial areas? Do external elements increase the conflagration potential? Existing published studies do not adequately address the problem, and are not entirely convincing in some respects.

The only systematic estimation approach is the AIRAC study. How can this be further developed?

Environmental Impact

Given the fact that an earthquake will occur and with the current emphasis on the environment, what effects will potential contamination or land deformation have, and who will be responsible for paying for the cleanup or restoration. Can it all be cleaned up or restored?

All Natural Hazards and Corporate Planning

For earthquakes, volcanic eruptions, floods, landslides, windstorms, tsunamis, and wildfires, the most important physical characteristics and key questions needing answers are as follows:

1. Affected Area: What is the size and shape of the area expected to be affected by the occurrence of an event?

2. Severity: How severe are the physical effects expected to be in both near-source and far-source regions?

3. Frequency: How often, on the average, is an event large enough to cause damage expected to occur?

4. Impact Time and Duration: How much lead time is expected between the first precursors and its peak impacts? When the event strikes, how long is it expected to last?

5. Primary and Secondary Physical Effects: What kinds of damaging physical phenomena (hazards) are expected when an event occurs?

Of insurance significance are the aggregate losses of several such major events occurring within a year or two. For example, a repeat of the 1906 earthquake in California plus a major destructive Atlantic Coast or Gulf hurricane occurring in the same year.

Recurrance Intervals

Return period estimates for earthquakes on various faults and expected magnitudes should be extended to all potentially destructive faults in California, and then to all of the seismically active United States having large populations at risk.

Community Lifelines

Community lifelines, such as public utilities, are normally damaged in a great earthquake. Governmental earthquake vulnerability studies have considered the damage to these facilities and have included time estimates necessary to restore them.

Should USGS and other agencies preparing vulnerability studies also quantify the expected dollar losses?

Post-Earthquake Studies

Post-earthquake damage surveys which quantify earthquake losses are vital for insurance purposes. These are real numbers and not theoretic assumptions. Opportunities to gather useful statistics have not been adequately captured by either the insurance industry or by government with the exception of the 1971 San Fernando earthquake. Data on the 1983 Coalinga losses are in press.

Both the insurance industry and the USGS have capabilities in gathering loss data.

It is recommended that the USGS, California Department of Insurance, and the insurance industry study the feasibility of obtaining significant amounts of monetary loss data after the next earthquake as well as in-depth data on causes of deaths and type of injuries.

Overview on Loss Estimation

A desirable loss estimation methodology is one which uses scientific and engineering data in the public domain, converts them into monetary losses and casualty estimates, and then provides the basis for rates which includes business decisions by individual insurance companies. Achieving this is a long term goal.

To accomplish this, data must be in measurable quantities. Where judgment is required, the USGS can undertake a unifying role such as it has recently done with its publication "Probabilities of Large Earthquakes Occurring in California on the San Andreas Fault". This publication will, no doubt, become the de facto criteria for most dollar loss estimation studies. It was written in a manner which does not inhibit further research or changes. It is desirable that the publication be periodically updated.

The Modified Mercalli Intensity Scale is differently interpreted, resulting in differently assigned intensities. Next, uncertainties are increased when PMLs are assigned to each intensity. Finally, uncertainties are further increased when a PML is assigned to a building class. These uncertainties can be reduced over time by quantifying monetary losses in the field after an earthquake, thereby obtaining data necessary to bypass the Modified Mercalli Intensity Scale.

The methodological concept requires four components:

1. Establish a %PML by class of construction for a maximum credible earthquake on each fault, with reduced %PMLs for lesser magnitudes.

2. Develop attenuation curves for each class of construction based on observed percent dollar loss. Strong ground motion records provide the shape of the curves where sparse (or no) data exist.

3. Modify the attenuation curves for buildings subject to long period effects, possibly as a function of simple parameters such as story height if building periods are unknown.

4. Modify the %PML at any point on the attenuation curve for microzonation effects.

It is recommended that the USGS consider as a long term goal an integrated program leading to the quantification of these components. Judgmental quantities, such as the Modified Mercalli intensities, should be replaced in time with measurable information.

Eventually, end products similar to "Probabilities of Large Earthquakes in California on the San Andreas Fault" could provide a loss estimation framework useable by insurance companies, other financial institutions, and consultants to these organizations.

LONG RANGE EARTHQUAKE PROBABILITIES AND INSURANCE INDUSTRY NEEDS

By
Paul C. Thenhaus and S. T. Algermissen
U.S. Geological Survey
Denver, Colorado

The basic concept of earthquake generation is one of cyclic stress accumulation and release along faults. Regeneracy of stresses along faults in coastal and western California result from differential movement between the Pacific and North American plates that occurs at a rate of centimeters per year and has persisted over a geologic time scale of millions of years. Ground displacements across fault segments in large earthquakes is on the order of meters. In general then, recurrences of large earthquakes along individual segments of faults is on the order of 100 to several hundred years. The probability of a large earthquake anywhere along the entire length of a fault is higher than the probability for any of the fault's constituent segments for a given time period of interest. Historical occurrences of large earthquakes provide a benchmark date for the last fault-segment rupture and allows calculation of the accumulated slip deficit (when slip-rate is known) that must be taken up in future earthquakes for conservation of the long-term slip rate along the entire fault. Thereby, the expected time to the next large event can be calculated. Once this information is developed, calculation of probabilities of large-earthquake occurrence during fixed time frames is possible.

In response to a National Earthquake Prediction Evaluation Council recommendation that the probability of occurrence of large ($M \geq 7.0$) earthquakes in California be evaluated, the USGS established the Working Group on California Earthquake Probabilities. The results of their initial evaluations and deliberations were recently released as USGS Open-File Report 88-398 and distributed to participants prior to the workshop. Figures in the Executive Summary of that report summarize the conditional probabilities for large earthquake occurrence between the years 1988-2018 developed for fault segments of the San Andreas, San Jacinto and Hayward faults of western California. Total probabilities for three regions of western California, developed by aggregating individual probabilities for individual segments, are summarized in the Executive Summary table for certain time periods of 5 through 30 years. Notably, the probabilities for all three areas are significant with southern California having the highest probability of experiencing a large earthquake along the southern San Andreas fault. Moreover, the regional probability estimates should be considered minimum values because only those faults having sufficiently developed geological data for recurrence estimation are evaluated. Other faults not having sufficiently developed data for time-dependent probability calculations are not addressed although they too contribute fractionally to the total probability of the given regions experiencing a large earthquake in the given time frames.

Other regions of western California, not in close proximity to the large strike-slip faults discussed above, are subject to major earthquakes from faults or fault systems that are presently only poorly understood and the geographic locations of which are imperfectly known. West of the San Andreas fault, the Transverse Ranges typifies such a region. Some major mapped faults in this region have estimated upper-bound earthquakes of M = 7.0 (Morton and Yerkes, 1987). Other faults in this complex region are not mappable at the surface but still have seismic potential as demonstrated by the Whittier Narrows earthquake of October 1, 1987 (M_l = 5.9). Faults in this region are of a oblique-thrust-type origin and are not as easily studied as the primary strike-slip faults of the San Andreas system. Nonetheless, their contribution to the long-term (i.e., 30 years) earthquake potential is considerable although not easily quantified in terms of time-dependent probabilities with presently available data.

The time-dependent probabilities for large earthquake occurrence along major faults in western California invite a probabilistic framework to discuss and assess the insurance industry needs for dollar-value estimates of Probable Maximum Loss, Catastrophe Potential, and Average Annual Loss. Certain insurance industry definitions, such as Probable Maximum Loss, appear in need of a time-frame reference to be meaningfully applied to long-range earthquake forecasts. Ideally, insurance industry needs and definitions would best be formulated in terms of probabilistic ground motion, or ground motion spectra hazard estimates. Procedures for incorporating time-dependent earthquake recurrences and for accounting for uncertainty in fault location and maximum magnitudes are easily accommodated in such a procedure.

One additional important point should be emphasized. The most significant aspect of the occurrence of damaging earthquakes from the viewpoint of the insurance industry should be the ground motion and geological hazards (landsliding and liquefaction) associated with the earthquakes, rather than the epicenter or fault upon which the earthquake occurs. Therefore, the recent estimates of the probabilities of large earthquakes in California just discussed must be convolved with attenuation and site response factors before the true nature of the earthquake risk is known.

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EARTHQUAKE INFORMATION NEEDS OF THE INSURANCE INDUSTRY

By
R. L. Odman
State Farm and Casualty Company
Bloomington, Illinois

Scientific and engineering information needs from our perspective would be limited to the United States and Canada and be adaptable to a computer assisted evaluation of earthquake exposures for dwellings and light commercial classes of business.

There is existing information available on some of the following subjects but it is difficult to assimilate, and in many cases it is not known to us if it is the latest and most authoritative data. Needs include:

1. Active fault locations and type of fault.

2. Soil conditions - microzonation information that is adaptable to computer search.

3. Incremental increases in damage ratios of buildings based upon soil conditions.

4. Return periods estimates for earthquakes on the various faults and the expected magnitudes.

5. Damage ratios for various types of building construction classes including dwellings for earthquakes of different magnitudes beginning for the smallest damaging earthquake up to the largest expected on that fault.

6. Loss distribution curves for classes of construction for different magnitudes by type of fault.

7. Damage estimates for public and private utilities (water, gas, key transportation facilities, etc.) with estimates of down time so that projections can be made for length of time it would take businesses to resume operation.

8. Attenuation patterns for given faults at expected magnitudes.

9. Post earthquake loss studies for classes of building with methodology to interpolate to types of faults and different magnitudes.

10. Earthquake aggravated earth movement; landslides and liquification on a micro basis.

An important aspect of this whole subject is the institutionalization of the basic data which then can be analyzed by an insurance company or other users to make reasonable judgments a respects rate levels, catastrophe exposures and individual risk susceptibility to earthquake loss.

Additionally there is interest in volcanic activity and direct damage to property, death and injury factors to determine benefits that could be paid under Workers' Compensation insurance and general liability policies as well as the potential effect of building codes or lack thereof on the earthquake damage ratios for buildings in earthquake prone areas.

Earthquake Hazards and Risk to Personal Lines (Dwellings): Intensity

By
Margaret G. Hopper
U.S. Geological Survey
Denver, Colorado

Introduction

After a modern earthquake strikes, the damaged area suddenly finds itself filled with experts studying the results. Studies can be quite detailed as to why various structures behaved the way they did and much useful information can be obtained to limit future damages. Studies frequently include recorded ground motion data. However, the rate of earthquake occurrence is low and we have a much larger data base of information about older earthquakes just waiting to be tapped. This information is not always as detailed as we would like, but there is a lot of it available and what we can learn from it is too valuable to ignore.

Most of this older earthquake information is in the form of anecdotal accounts of earthquake effects. We organize these into useful data by means of an *intensity scale*. An intensity scale is a list of common types of earthquake effects numbered in order from minor to severe. The scale in use in the United States since 1931 is the *Modified Mercalli* intensity scale. Here's a very short version of Modified Mercalli intensities (*MMI*'s):

- I–V No damage. Range from *not felt* up to *awakened sleepers.*
- VI–VII Threshold of damage, cosmetic damage. Cracked plaster and windows, fallen bricks.
- VIII–XII Structural damage to weak buildings up to the most severe damage. Important ground effects.

Contemporary intensity information comes from questionnaires filled out by people in the affected area, from the results of post-earthquake damage surveys presented in professional journals, and from reports by journalists, disaster-response officials, insurance investigators, and others. The questionnaire survey is designed so that information is obtained for the entire felt region; coverage is made denser closer to the epicenter and sparcer approaching the outer limits of the likely felt area. This means that there are no major gaps in information within the geographical area covered by the survey.

For earthquakes in the last several decades the intensity information is good enough that isoseismal maps (contours of equal intensities) have interestingly irregular contours showing protrusions of higher intensities and reentrants of lower intensities. Isoseismals of historical shocks are usually smoother and less detailed than contemporary shocks, but still provide useful information about rates of intensity attenuation and may also highlight areas of unusually high (or low) intensities.

For historical earthquakes, information is more limited. Some information is available from *Earthquake History of the United States*. For earthquakes since 1928 better information is contained in the annual publication *United States Earthquakes,* which compiles earthquake damage information on a regional scale and assigns *MMI*'s; in more recent decades isoseismal maps are also included for the more important shocks. Other possible sources of useful information are professional journals, nuclear site reviews, historical societies, newspapers, letters, and records kept by civilian, military, and church authorities. Almost any descriptive account of an earthquake's effects that can be obtained is potentially useful in the study of that earthquake.

What Types of Houses are Most Vulnerable?

Wood-frame houses perform extremely well in earthquakes. Damage is likely to be minor and cosmetic below *MMI* IX. Typical minor damage includes loss of chimney or cracked stucco, veneer, plaster, windows, masonry, or foundations. When more serious damage does occur to wood-frame houses at intensity levels below IX there are often unusual circumstances such as poor construction, unbraced cripple walls, or a house not bolted to its foundation.

For some other types of houses damage begins at much lower intensities. Houses of abobe, hollow clay tile, or unreinforced brick perform unusually poorly. They may have serious damage (collapsed walls) at intensities as low as VII or VIII. It is far more likely that these houses will be total losses than with wood-frame houses.

What Secondary Damage Happens to Houses?

In addition to damage caused directly by the shaking of the earthquake, houses are also liable to secondary damage from other effects caused by the shock. It is difficult to assign intensities to such damage; the vibration damage is frequently obscured by the other effect, and the other effect itself may occur over a wide range of *MMI*'s.

For example, earthquake vibrations can cause the ground to *settle, crack,* or *slide.* Ground cracks and settling may cause a house to settle differentially causing cracks in the house and in utility connections. Landslides, either above or below the property, may destroy a house or render it unsafe for habitation.

Repeated vibrations may cause susceptible buried layers of water-saturated sands to *liquefy*, loosing all of their supporting capacity. When this happens, buildings above the liquefied layers may sink or tilt; buried containers, such as septic tanks or pipe lines, may float upward; the liquefied layer may flow, taking houses on the upper layers with it; or the liquefied layer may erupt in sand blows, flooding yards and basements and damaging foundations.

Earthquakes may cause *flooding* by the destruction of dams or levees, by ponding due to landslides, by *seiches* (sloshing) in lakes or reservoirs, or by *tsunamis* (seismic sea waves) along coastal areas. The latter two may cause damage at great distances from the epicenter. Very large earthquakes sometimes shift the locations of rivers and lakes.

Houses may be damaged by the collapse of the walls, cornices, or chimneys of *adjacent buildings* onto them.

Fires may be started by earthquakes. In a great earthquake there is the possibility of *conflagration,* especially if water pipe lines are broken, fire equipment is damaged, fire fighters are injured, and streets are impassable.

House *contents* may be damaged by earthquakes starting as low as *MMI* V (dishes broken), with furniture overturned at VI and above.

What Controls the Intensity at a Site?

Intensity itself is a simple assignment of a number to an observed level of damage. However, the underlying causes that result in the observed damage at a particular location are many and involve complicated interactions. These interactions create complex patterns of isoseismals rather than simple "bull's-eye" maps. Contributions to the resultant damage come from:

Earthquake source parameters	Magnitude, depth, focal mechanism (orientation of fault plane and direction of slip on it)
Source to site path	Epicentral distance, attenuation of seismic waves (may vary in different regions of the country)
Site	Geotechnical properties of the site (seismic wave velocities, density, void ratios, layering, water content, etc.); duration of strong shaking; topography
Structure	Period of vibration of the structure; type and quality of construction (Variations due to structures are addressed to some extent in the *MMI* scale and are considered in the assignment of intensities.)

The first two items listed above (source and path) are the most important for regional differences in attenuation of intensities. The rate of intensity attenuation with distance from the epicenter of an earthquake varies from region to region. For example, in California intensity levels attenuate more rapidly than they do in the eastern United States from an earthquake of the same *magnitude* (strength, or amount of energy released at the source). Eastern United States earthquakes can have damage areas up to 25 times larger than their counterparts in California (although, fortunately, their recurrence periods are much longer than for California earthquakes).

The last two items in the chart above (site and structure) list the most important factors causing local intensity variations for a single earthquake. The designers of the Modified Mercalli scale attempted to eleminate structures as a cause of intensity variations by considering type and quality of structures in intensity assignments. However, intensities still tend to be higher in areas where there are many poor structures to be damaged. The dependence of intensity on the local site is so strong that certain areas fairly consistently have higher or lower than average intensities. Some of these variations can be explained—for example, higher intensities on deep alluvium, lower intensities on rock. The reasons for some of the variations may never be fully understood. However, variations of intensities from historical earthquakes can be used in estimating potential intensities for a hypothetical earthquake. The quality of the estimates will depend on the available intensity data and the related information for that region.

EVALUATING PROPERTY LOSS FROM EARTHQUAKE HAZARDS

By
Lowden Jessup
American Protection Insurance Company, Kemper Group
San Francisco, California

In this talk, I will attempt to present to the scientists and the engineers the problems the insurance underwriter is presented in underwriting - pricing of earthquake insurance.

How do the insurance underwriters rate earthquake risks?

1. Rating: - Two general categories -

   (A) Dwellings: generally speaking dwellings, or homes to use a more common term, we underwrite as a class (i.e. class rated) since the underwriter cannot justify the expense of inspections, all dwellings are assumed to be the same. In any particular earthquake zone there is a rating schedule applied to dwellings with rates assigned by the Rating Bureau, depending upon whether the risk is all frame construction or has frame with brick veneer, etc. Briefly, the rates assigned to these dwellings are ones that were derived in the early 1930's and have no relationship to the probability of loss, proximity to faults, whether or not the dwelling was actually constructed to code in force at that time, etc.

   The biggest problem the underwriter has in rating dwellings is they can't afford to inspect, which means they have to make assumptions, and in order to protect the company, we generally underwrite on the conservative side.

(B) Industrial:

The industrial properties can be further broken down into commercial lines written as "class rated" and those properties written by specialty underwriters, such as the highly protected risks underwriting companies. The difference being that the HPR underwriter inspects the property.

a. Commercial lines underwriting use "class rating", as in dwellings. Specific rates have been designated to buildings by their class of construction, depending upon the earthquake zone in which they are located. It can be said there is little credibility with reference to a typical class rate; Obviously, we have insufficient frequency to be able to establish a realistic rating from a frequency of loss history by class of construction input to the rating. The HPR underwriter has specific information as to the construction, age, and other general construction details. This allows him to apply a rate which might be described as more realistic to the specific risk. The HPR underwriter has the premium volume to be able to have the risk inspected.

As a general comment, it has to be said that while there are specific rates designated to a particular type of construction in an earthquake zone, whether or not the underwriter chooses to use this rate is unfortunately depended upon where he is at any given time in a so-called insurance cycle. During what is called the "soft market", when the insurance underwriters perceive that they want to underwrite as much premium as they can irregardless of the rate, the so-called designated or specific rates are done away with and are modified; generally speaking, by taking a percentage off these rates. This percentage varies depending upon how competitive the underwriter wants to be.

So, briefly, it can be said that in rating, the major problems are a lack of specific risk information (construction details, etc.,) and lack of frequency of earthquakes to be able to rate on the classic basis.

2. Earthquake Deductibles:

Original premise - to avoid controversial loss - cracks in plaster, etc.

(A) Dwellings -

Generally, the underwriters are using deductibles ranging from 5 to 10% of the value of the building. In other words, if there was a 10% deductible and the replacement value of the building without the land value is a $100,000., then a deductible would be $10,000. The interesting thing here is that of recent date the insurance companies have chosen to use exclusviely 10% deductibles. It is generally accepted that a reasonable PML on a frame dwelling is in the vicinity of 10 - 12%. On the face of it, it would appear then that the companies are expecting to pick up only around 2% of the PML and leave the property insurer (owner) with paying 10%. Having said this, it is also acknowledged that the PML is probably credible in nine out of ten cases, which would mean that the insurance company would be left with the tenth case, which would be conceivably a total loss.

(B) Commercial Properties -

The deductibles on commercial properties are varied from a dollar deductible to 10% of the values. Unfortunately, the competition often dictates the size of the deductible.

The major problem is the industry cannot decide if the purpose of the deductible is to avoid small losses or to avoid controversial losses.

Underwriting Commercial Properties:

1. On an assumption basis - this means that the peril of earthquake is assumed as a peril, the same way fire is, and that the amount of dollar coverage on the policy would equal the same amount as the fire coverage. This is generally done on dwellings and small commercial properties.

2. First loss cover - the term first loss cover is used on commercial properties where there is insufficient earthquake capacity available in the insurance market so that the property owner only buys what might be called a token amount of insurance. In some cases this can be perceived as EQ PML. As an example, a commercial property may be worth a $100 million, and it is only economically feasible to buy $10 million worth of coverage. This is generally referred to as first loss insurance. Of course, this is excess over a deductible, usually expressed in dollars.

3. Layering - This is an extension of the "first loss" coverage, wherein the coverage is placed in different layers. As an example, in the $10 million excess of $5 million and another layer of $5 million excess of $15 million gives a total of $20 million. The underwriters will price the coverage on a price per million dollar basis or a rate

applied to the 100% value. Each layer being higher up away from the bottom dollar will take less premium than the lower layers. Obviously, the first $5 million layer would be worth far more than the $5 million excess of the $15 million. Generally speaking, the pricing of this coverage is dictated by the market conditions. This price at the present time is between $2,000 to $50,000 per million. Having said this, there are a group of underwriters that maintain a fixed position as to their pricing of earthquake, and will not deviate. Generally speaking, they take this position since they have a limited amount of earthquake capacity available, and when that maximum amount is reached, then they take the position that they will provide this coverage at "their price" and since generally speaking they can obtain their price, they will sit there and write a maximum line at their specified price.

The major problem again is the lack of risk information, earthquake frequencies, and ability of the companies to offer full earthquake coverage - i.e. capacity.

3. Earthquake PMLs:

   (A) In determining the ultimate amount of earthquake capacity an insurance company wants to provide it is based upon a probable maximum loss, which would be a repeat of the 1906 San Francisco quake of 8.25. The company is restricted to writing earthquake insurance to 10% of its surplus by the State of California.

   (B) Earthquakes of less intensity than 8.02: Generally speaking while underwriters are concerned with earthquakes of less intensity than 8.02, they generally don't underwrite to it. What the underwriter fears is the large loss, the catastrophe loss that will put them out of business, that will exceed their treaty capacity with the ultimate loss of their job.

Other Problems:

Even within the insurance industry, there is no uniformity of terms and use of information. As an example, in dwellings there are PML's established by what is considered as the best engineering information available, and these PML's are expressed in a percent. While it is the intent of the engineer developing these percent PML's that they be applied to the 100% replacement value of the dwellings, it appears this value is not always available. As an example, most homeowner policies are written somewhere around 80% to value. That's to say, that the insurance company agrees that if the homeowner will buy 80% amount of insurance to the value of the building, that they will give them full replacement coverage. Unfortunately, it appears that in some cases the underwriters are inclined to apply the percent PML to the policy amount which is an 80% amount, which of course, gives an erroneous PML since they don't have the 100% value. The underwriters have similar problems in the commercial end, in that the plantsite might have multiple buildings involved, of different ages and different constructions, and that the practicality of determining a PML for each building, and applying that PML to the individual value of that building is not economically feasible. They also have the problem of the appropriate replacement value.

So while we have the problem of obtaining information from the engineer - scientist, I would have to say that the insurance companies are not all that sure as to what information they want to ask for. I believe it can be said that the insurance industry have a fairly good beginning of the ultimate catastrophe loss of the 1906 San francisco-San Andreas fault quake, but certainly don't have a good feel for the needed information on losses of less intensity. It could be said that earthquake risks in the Sacramento Valley are underwritten as if the risk is in downtown San Francisco or downtown Los Angeles and, of course, it is not exposed to the same type of catastrophe.

I have briefly attempted to present some of the problems that the insurance underwriters are attempting to deal with, and obviously we have a long way to go.

EARTHQUAKE LOSSES TO DOMESTIC STRUCTURES

By
E. P. Arnold
U.S. Geological Survey
Denver, Colorado

A number of studies are underway at the U. S. Geological Survey on the estimation of losses to housing that should be of use to the insurance industry; more details follow. It should be stated at the outset that these estimates are based on the notion that one works with what is available and that some result is better than none at all.

1. Types of Loss Calculation. There are essentially two types of estimations of loss that can be made for domestic structures, or for that matter, any structure. The first is to estimate losses to all structures in a given area either assuming an earthquake of a specified maximum intensity (a "scenario" event) or by specifying a probabilistic maximum acceleration or velocity. The second is to calculate for a single structure, given a location and a description of the building, the losses due to either a scenario earthquake or a probabilistic one.

2. Definitions. A *housing unit* is the shelter occupied by a single household.

Building Classes are defined in a way similar to those of the Insurance Services Office (Algermissen and others,1978).

The *percent loss* is defined to mean the average percentage of the total cash value required to fully repair or rebuild in kind any building of a particular class experiencing ground motion represented by a particular degree of the Modified Mercalli intensity scale.

The *vulnerability function* relates percent loss to MM intensity for a given class of structure. The relationships presented here are only for ground shaking damage.

3. Necessary Data. The data necessary for an overall loss estimation comprise several separate items: 1) A count of all housing units in a region; 2) An average or median replacement price for each housing unit; 3) A description of each unit's structural characteristics; 4) a vulnerability function for each type of structure; 5) A distribution of intensity in the region by either probabilistic or scenario methods; and 6) A distribution of ground amplification factors over the region in question.

Item 1 is relatively easy to obtain from the Bureau of the Census as of a decade year and may be updated in several ways. The first is to extrapolate from the last Census but this is likely to be quite erroneous since trends do not tend to repeat over a decade. Another is to obtain a record of housing permits in the region during the intervening years. The Census keeps these records, and lagging them by a year ought to produce a good estimate of total units in a given time frame. Item 2 is easier, one merely enquires of the local board of realtors. Generally these figures are kept on a monthly basis for several subregions. Item 3, which is most difficult can, in part, be deduced from Census data. It gives, for the decade year, breakdowns by number of units per structure and age of structure. From these, the proportion of single household structures, duplexes, &c. can be found and hence the number in, say, high-rises or in the various smaller structures. The important factor, as will be seen, is the proportion of dwellings constructed of brick or other masonry. At present the Survey is estimating this figure by polling boards of realtors and planning commissions. The various types of masonry structures can be subdivided according to the age of the building. Several sets of vulnerability functions (Item 4) have appeared in the literature. Other speakers will discuss Item 6.

To calculate the expected loss to a particular structure, one needs merely the replacement cost of the dwelling, its address if in a tracted area, its building classification, and items 5 and 6 above.

4. The Calculations. The Survey, in general, uses either the Census Tract or the County as the basic geographical unit of computation. The Census supplies geographical co-ordinates of the center of population for each thus enabling one to calculate a distance to a given fault trace. The tract is the smaller unit and is chosen to have about 4,000 inhabitants; the county is obvious. At present only the largest metropolitan areas are tracted but by the 1990 Census the entire country will be covered.

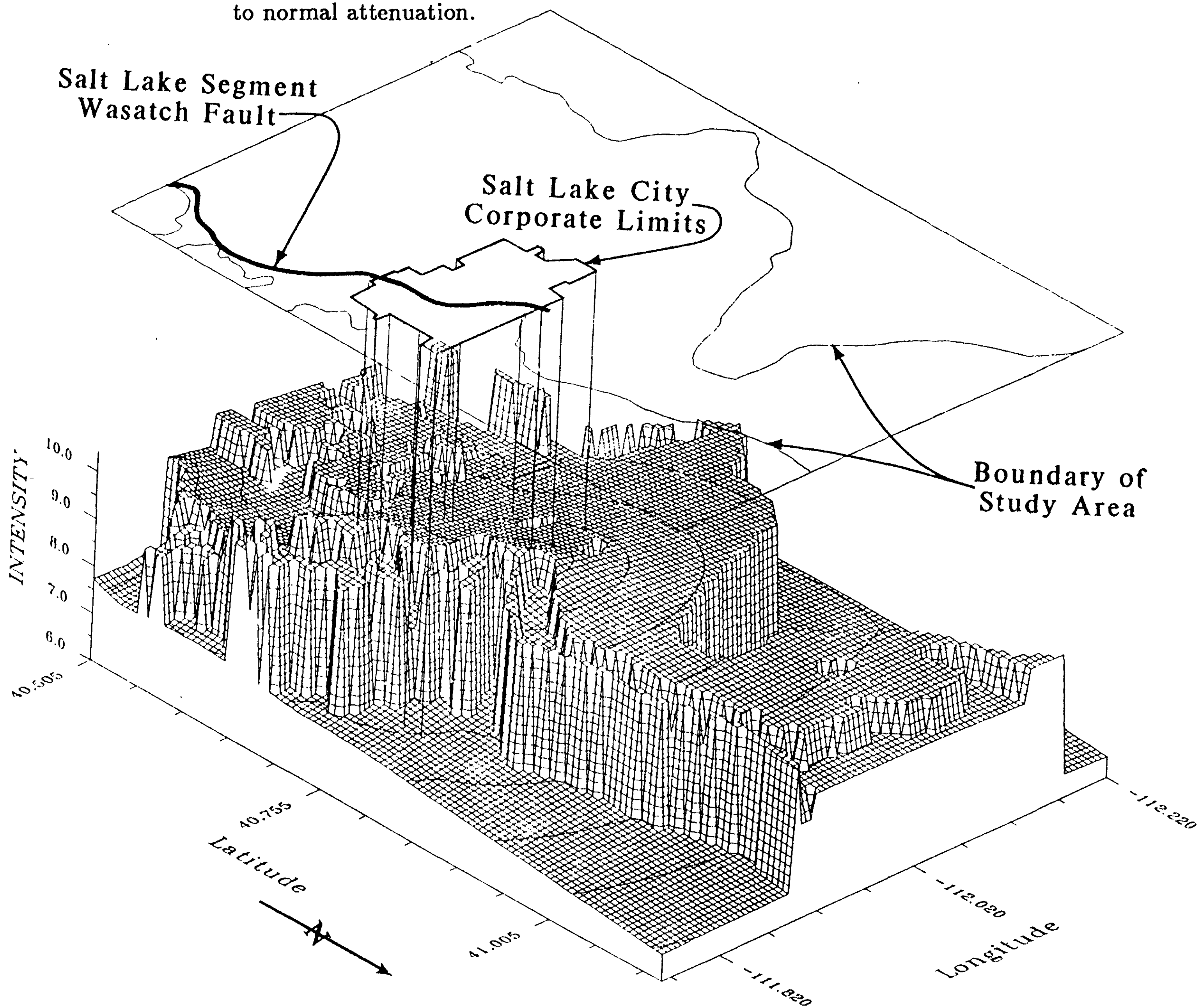
The calculations are then rather simple. For each tract (or county) the intensity is calculated at its center of population using an appropriate attenuation function and adjustment for ground amplification. The appropriate vulnerability function is then applied to each building classification in the proportion to its part of the whole housing stock. The percent damage to each is then converted to total losses.

5. Example. A study was recently completed estimating losses to housing in the event of a number of scenario earthquakes in the Utah urban corridor. Also a 50 year probabilistic maximum loss with a 10% chance of exceedance was calculated for the same area. Not only were expected losses given but also variations in losses with changes in intensity and with changes in vulnerability functions. Figure 1 is an isometric view of the surface representing the intensity for all points in a portion of the study area including Salt Lake City. The abrupt changes are caused by changes in the surface geology which, in turn, are reflected in the intensities.

6. Discussion. Since there is a large portion of masonry housing in the Utah urban corridor, it is, by far, the controlling factor in the loss estimates. For example, Algermissen and others (1988) project losses in the four county area to all housing for a M_S 7.5 earthquake in Salt Lake City (see Table 1) of $3,673.0 million using the vulnerability functions given in ATC-13. Of this total, $2666.9 million are losses to masonry dwellings and only $1006.1 million are to wood frame ones. Using other vulnerability curves the difference is even more striking. When the magnitude of the shock is smaller, the ratio of losses to masonry to losses to wood houses is greater still. One can presume that this sort of result would apply to all areas in which masonry housing is predominant, e.g., the Mid-West and Northeast.

A number of items of research remain to be done to "fine tune" these methods. The first is to obtain more accurate vulnerability functions and for regions other than California

Figure 1. The surface formed by the computed intensities over a part of the Salt Lake urban corridor from a magnitude 7.5 earthquake on the Salt Lake segment of the Wasatch Fault. Note that the "cliffs" are due to the changes in the response of the various surficial materials and are much greater in magnitude than those due to normal attenuation.



and Utah. The second is to fully automate the calculation of losses from raw data to end result for both sorts of calculation.

TABLE 1. SUMMARY OF ESTIMATED LOSSES,
MAXIMUM EARTHQUAKE ON SALT LAKE SEGMENT OF WASATCH FAULT ($M_S = 7.5$)

Losses in the Four County Area

	Number	Value $\$ \times 10^6$	Losses[1] $\$ \times 10^6$	Losses[2] $\$ \times 10^6$
Dwellings				
Wood Frame				
1–4 units (Class IA)	122,695	6,308.6	834.9	550.6
≥5 units (Class IB)	21,824	1,140.3	171.2	103.0
Masonry (Classes VB & VE)				
1–4 units	184,042	9,462.9	2,131.9	3,101.9
≥5 units	32,736	1,959.2	535.0	799.5
Totals	**361,296**	**18,871.0**	**3,673.0**	**4,555.0**

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[1] Losses computed using vulnerability relationships developed by the Applied Technology Council (1985).

[2] Losses computed using vulnerability developed by Steinbrugge (1986).

NEED FOR EVENT-ORIENTED EARTHQUAKE INFORMATION IN AN INSURANCE OPERATION

By
Don G. Friedman
Travelers Insurance Company
Hartford, Connecticut

Insurance Coverage of the Natural Hazards

The needs for information about the natural hazards (earthquakes, storms) vary by type of activity such as emergency preparedness, hazard mitigation, structural engineering and insurance. For an insurance operation there may be a need for much information because the natural hazards can greatly affect the activities of a multiple line company that may insure hundreds of thousands of lives and properties that are unevenly spread across hazard-prone areas of the United States. The spatial array of insured buildings may vary widely by age, condition, quality of construction and material, degree of exposure, and usage. Type and size of insured buildings can range from small single family dwellings to large individual complexes of engineered design. A company's aggregate exposure in insurance lines that are vulnerable to effects of the geophysical and atmospheric perils can range from millions to billions of dollars. Insured natural perils include wind, hail, earthquake ground motion and fire following it.

Natural hazards cause considerable property damage in the United States. A large percentage of this damage occurs as a result of infrequent geophysical or atmospheric events. If aggregate damage resulting from the event is exceptionally large, it is called a natural disaster. The number of natural disasters in the United States has increased over the years. Resultant property losses also have grown. Increases over time in the number of properties in hazard prone areas, their value, and costs of repair has raised the probability of natural disaster occurrence, even though frequency and severity of the events may not have changed. Insurance is one means of protection against the natural hazards.

Natural Hazards as Insured Damage Producers

Unfortunately, the commonly used multi-peril packaging of various coverages, such as the homeowners policy, makes it difficult to directly estimate the total amount of the earthquake and weather caused losses in any given year. However, the insurance industry's Property Claim Services does provide a useful information source through its catastrophe coding of weather and earthquake events that have caused significant insured losses in each of the past forty years. Prior to 1982, the threshold industrywide loss to be coded was $1 million. Since 1982, due to inflation, the minimum has been raised to $5 million.

In recent years, the annual insured property loss in the United States due to weather and earthquake catastrophes has averaged between $1 billion and $1.5 billion. Of the 820 coded events since 1949, hurricanes have accounted for 50 of these catastrophes and about 40 percent of the total losses if each of these past events were to recur in 1988 and affect the present portfolio of insured properties of the insurance industry. The present number and value of insured properties, their location and density in hazard prone areas, and their vulnerability to damage by storm or earthquake are important current exposure factors.

Fortunately, in the past four decades there were not many occurrences of earthquakes of sufficient magnitude and proximity to highly populated areas to cause significant amounts of insured losses. During this period, earthquakes accounted for 9 catastrophes and about 1 percent of the aggregate losses, if the 820 events were to recur in 1988 and affect the current book of business. Therefore, it is not surprising that some insurers may use this actual past experience as a reason for discounting the apparent damage potential of the earthquake risk to their portfolios of insured properties. This may be the case in spite of current warnings from the scientific community regarding the probable occurrence of a high magnitude event affecting highly urbanized areas of California in the foreseeable future. In the last forty years, hurricanes caused nearly six times more coded catastrophes and the equivalent of forty times more in total insured damages than earthquakes in the United States. It should also be noted that a much larger percentage of the insured properties were covered for the weather perils than for the earthquake peril. It is perhaps paradoxical that the estimated aggregate insured loss potential of a single event that might occur before the year 2000, a worst case scenario of a great California earthquake, could equal half or more of the total insured damages, $67 billion, resulting from a 1988 recurrence of each of the storm or earthquake events that caused the past 820 coded catastrophes (References 1-3).

Use of Past Experience as a Measure of Current Risk

To provide coverage and manage the natural hazard perils, an insurer needs information pertaining to its damage-producing potentials to its current book of business (Reference 4). In many cases, the classical actuarial procedure of using loss experience in a few years in the recent past does not provide an adequate estimate of present risk to the company's current portfolio as was illustrated above with respect to the earthquake peril to the insurance industry. This is because of small sample statistical problems inherent in attempting to analyze infrequent or rare events that may or may not have occurred in a short period of years. Even in a high hazard area, the frequency of extremely damaging geophysical or atmospheric events is slight. When a small sampling period is used, the risk estimates can be highly biased by the chance occurrence (or non-occurrence) of one of the infrequently occurring large damage-producing events during the short time interval. A much longer sampling period is needed to obtain a realistic estimate of the frequency and severity of the damage-producing earthquakes or storms.

Use of a longer sequence of past years increases the likelihood of obtaining a more representative measure of the expected frequency, severity and location of these geophysical and atmospheric events relative to the spatial array and density of insured lives and property (elements-at-risk) in the exposed portfolio. However, advantages of a longer sampling period are largely negated by the reduced applicability of the loss experience which rapidly decays in usefulness with age. Major reasons for this decay are the significant changes over time in the portfolio: the number of insured elements-at-risk, their geographical distribution and loss vulnerabilities. Consequently, a more useful measure of current risk to the 1988 portfolio of business in the San Francisco area is not what happened to 1906 population and buildings but what the estimated effects would be if there was a present day recurrence of the 1906 earthquake acting upon the currently insured elements-at-risk.

Natural Hazard Information Needs for an Insurance Activity

If past insured damage experience of the natural hazards is not a universally useful measure of current risk, what information can be used? To manage most perils, there are two insurance measures that the insurer must estimate. One is the average annual expected loss per property caused by the peril. For many perils, this is a site-orientated measure on a location-by-location basis. It is used, among other things, to calculate the amount of "pure premium" needed to cover the peril. This is the dominant index for most perils. The second measure is event-oriented. For the natural hazards, it is the catastrophe-producing potential of individual storms or earthquakes to the insurer's entire portfolio which is exposed to these perils. Catastrophe potential is of great importance for "natural hazard" perils because of the tendency for geophysical and atmospheric events to simultaneously affect a large number of insured properties at one time. By contrast, for other insured perils, such as dwelling fires and automobile physical damage, it is very unlikely that a single fire or auto accident would affect more than a few buildings or cars at one time. Consequently, catastrophe potential is not very important for these perils.

On the other hand, a great storm or earthquake could significantly affect most of the insured properties located in an area of many hundreds of square miles. Because of this possibility, an insurer must attempt to estimate the magnitude of the catastrophe-producing potential to its portfolio of insured properties and then decide how to cope with the potentially large aggregate losses that could result from the occurrence of a single geophysical or atmospheric event. This second measure -- catastrophe potential -- is a dominant factor in the management of earthquake and weather perils. As a result, insurers have a basic need for event-orientated earthquake information.

Knowledge of the potential characteristics of natural hazard damage production is helpful in answering the following questions:

1. What premium rate is needed to cover the average annual expected loss on each insured property? (site-orientated question)

2. How much of a reserve is needed in order to cover possible catastrophic losses from earthquakes or storms to the exposed book of business? (event-orientated question)

3. Is it advisable to reduce the risk of significant catastrophic losses by reinsuring some of the excess loss potential? (event-orientated question)

The relative importance of average annual loss as compared with catastrophe potential is different for each type of insured peril. For the dwelling fire and automobile physical damage perils, there is usually small year-to-year variation in losses, so average annual loss is dominant and catastrophe potential is of lesser significance. An extreme case, at other end of scale, would be a natural peril for which all losses occur as a result of a single event which occurs at random on the average of, say, once every 50 years. In this case, catastrophe potential is dominant and average annual expected loss is a much less meaningful insurance measure. The insured earthquake and weather perils lie somewhere between these extremes of frequent events involving only a few insured properties at one time and rare damage-producing events which involve a large number of the elements-at-risk.

For insured earthquake and storm perils, average annual expected loss and catastrophe potential are not closely related. Knowledge of one measure does not always imply the magnitude of the other. Each must be estimated separately. The magnitude of the catastrophe potential to an insurance portfolio is dependent upon the overlapping and interaction of the spatial severity pattern (ground motion or high wind speed) of the geophysical or atmospheric event with the geographical array of insured structures. On this basis, a high magnitude earthquake is not automatically a great insurance catastrophe producer unless many insured structures-at-risk susceptible to damage are in the area strongly affected by it.

Natural hazard risk, in this insurance context, is dependent upon unique features of earthquakes, hurricanes, tornadoes, hailstorms, and winter windstorms that distinguish them from other insured perils such as home fires and automobile accidents. These unique features of infrequent or rare occurrence, and the tendency to cause many losses when they do occur, make it desirable to find a supplementary means of estimating average annual loss and catastrophe potential rather than depending solely upon the traditional method of developing these measures using only past loss experience. The catastrophe potential of the earthquake peril would appear to be minimal if only insured loss experience in the past 40 years were considered.

Methods of Estimating Natural Hazard Risk

Alternate approaches to the use of past loss experience for evaluating the magnitude of the earthquake and weather perils can be either quantitative or qualitative. One quantitative approach is to construct a numerical approximation of the physical characteristics of earthquakes and storms which can then be used to generate simulated atmospheric or geophysical events and their attendant geographical patterns of ground motion or wind speed severity. These severity patterns are then superimposed on, and made to interact mathematically with, a computerized geographical mapping of insured properties to produce synthetic loss experience. Both of the insurance measures can be examined using this type of analysis: the site-orientated estimates of annual expected loss per structure and event-orientated estimates of catastrophe potential. However, most insurers still use less complicated quantitative or qualitative methods for making natural hazard risk assessments. Others utilize "outside" consultants to do the analysis.

All of these approaches attempt, to various degrees, to utilize and synthesize additional information that is not available in the sole use of past loss experience, such as: geophysical and atmospheric event information from the physical sciences; insured property information in the insurance company's current portfolio of business (elements-at-risk); loss relationships between peril severity such as ground motion intensity or wind speed and resultant damage based on claim records or engineering studies (vulnerability).

The numerical simulation approach, which of necessity is based on a large set of assumptions, can provide a detailed indication of the impact potential caused by a recurrence of past geophysical or atmospheric events or hypothetical new events upon present geographical arrays of insured property and their current damage vulnerabilities. Occasionally, a simulated "natural disaster" is produced. Qualitative scenarios have less flexibility and a lower capacity to incorporate and interpret possible implications to the insurance operation of the many bits and pieces of pertinent information obtained from a number of different sources. However, they are much simplier to develop and apply. In addition, there are a number of outside consultants who can make credible risk assessments of these perils to an insurer's portfolio using a variety of different approaches and sets of assumptions.

Decisions involving the impact potential of earthquakes and storms to an insurance portfolio are made on a day-to-day basis. It is not practical to wait until some poorly defined time in the future, perhaps years away, when more appropriate natural hazard risk information may become available. Decisions must be made without delay using whatever pertinent background data may be at hand. Unfortunately, the amount of available past loss information is usually small. This is especially true at the present time with respect to the earthquake hazard in the central and eastern United States. This is a major reason for the development of numerical modeling procedures which can quickly provide rough insights into possible alternative solutions to the particular problem at hand using an event-orientated analysis of the insurers portfolio. A wide variety of insurance activities can be directly or indirectly affected by the natural hazards. These include rating, underwriting, marketing, reserving, reinsurance, investment, claim and contingency planning.

Natural Hazard Simulations

To provide insurance management with the most useful available material for decision-making purposes involving the natural hazards, some insurers have attempted to obtain a better understanding of the mechanism that produces natural catastrophes (Reference 5). This background knowledge assists in identifying the major influencing factors and how they interact to occasionally create these large damage-producing situations (natural disasters). This information is provided to the insurance decision-maker to supplement risk assessment results obtained using standard actuarial techniques based purely upon past loss experience.

Estimation of the average annual loss and catastrophe-producing potential of earthquakes and storms depends upon the interactions of a large number of contributing factors. It is not possible to completely define, quantify and model all of them and their complicated interrelationships. However, useful insights have been gained by working with a mathematical approximation involving some of the more important ones. These are:

1. Physical properties of the earthquake or storm that determine the characteristics of a geographical severity pattern of the event: strong ground motion for an earthquake or high winds for a storm such as a hurricane. Pertinent physical properties of an earthquake include its moment magnitude, type of faulting, location and length of the rupture, direction and speed of rupture, depth of energy release, stress drop, and aftershock activity. Information on how these physical measures can be utilized to numerically generate realistic geographical patterns of ground motion severity is an important need of some insurers. For a hurricane, the shape, size and internal gradient in the high wind pattern is modeled to be dependent upon the storm's intensity (central barometric pressure), overall storm size, its rate of movement, and the direction and curvature of its path relative to the coastline.

2. Local influences that can affect the severity of the event (ground motion or wind speed) at a given location. For earthquakes, it is the local ground and water table conditions in addition to the effects of subsurface rock features between the site and fault rupture which modify the local site response characteristics. These conditions can influence the mixture, duration and severity of ground motions of various wave lengths. Various segmented areas of California apparently have widely different ground motion responses even when each of them is subjected to an earthquake with the same Richter or moment magnitude. For a hurricane, local influences that can affect the observed maximum wind speed associated with the passage of a hurricane are topography, rural versus urban environments, types and location of windbreaks such as trees and other obstacles to the wind.

3. Vulnerability of the elements-at-risk in an insurance portfolio to damage when ground motion of given wave length attains a specified level of severity and duration at the location of the insured property or when wind attains a given speed at the property site during passage of a hurricane.

Vulnerability of buildings to damage depends upon such things as their type, age, height, local exposure, class and quality of construction.

4. Number, type, and geographical distribution of the insured elements-at-risk in an insurance portfolio.

Results of the simulated interactions of thousands of combinations of these four factors suggest that the damage production of earthquakes and hurricanes is very sensitive to the relative positioning of the earthquake's geographical pattern of strong ground motion, or the spatial distribution of high wind accompanying the inland passage of a hurricane, upon the haphazard geographical array of the exposed elements-at-risk in the affected area. There are usually a very large number of possible overlappings of these ground motion or high wind patterns upon the computerized maps of the elements-at-risk. Each superposition produces a different overall loss potential. This potential can vary widely in size depending upon the positioning of the pattern even though the physical characteristics, such as intensity, of the event (earthquake or hurricane) are not changed. Probabilities of occurrence of each of these simulated overlappings must be consistent with the known seismological and climatological conditions in the hazard prone area.

Utilization of Available Natural Hazard Information

Each insurer, either implicitly or explicitly, takes account of the interaction of the four above-mentioned factors in managing the loss producing potentials of earthquakes and hurricanes to its books of business that are directly or indirectly vulnerable to these particular perils. There is a wide range in the depth of this analysis among insurers. It ranges from brief qualitative considerations or the use of outside consultants to the in-house utilization of mathematical modeling and computer simulation techniques for estimating the potential damage impact of each of the many possible overlappings of earthquake ground motions or hurricane wind patterns upon the geographical arrays of damage susceptible properties in the insurer's portfolio.

One company developed its computerized simulation modeling procedures for the earthquake and hurricane hazards in the mid-1960's. It has continuously updated these models over the past two decades by incorporating new research findings in the physical (seismology, meteorology, climatology) and engineering sciences that pertain to the damage-producing potential of these perils. The models provide the insurer with an analysis vehicle for translating this new information and knowledge into an appropriate context for determining its implications to the insurance and investment operations. For the California earthquake hazard, the original model of this insurer in the 1960's generated and superimposed the geographical patterns of Modified Mercalli intensity of simulated earthquakes upon a computerized mapping of the insured elements-at-risk. Subsequently, application of vulnerability relationships, based upon past claim experience, provided a means of estimating the damage potential of the simulated recurrence of past and hypothetical new earthquakes to the present property portfolios.

Currently, in addition to computing the Modified Mercalli pattern, the model has been expanded to calculate loss potential based upon the generation, mathematical superposition, and interaction of ground motion patterns on the insured portfolio in which ground motion is expressed in terms of spectral acceleration or spectral velocity of specified wave lengths depending upon the building type that is exposed. It incorporates a measure of the estimated effect of strong motion duration as a function of the earthquake's moment magnitude. Consideration also is given to additional increments of damage potential to the exposed portfolio that may be caused by possible differences in the direction and speed of faulting during an earthquake. The effect of the probable aftershock earthquakes that usually follow a moderate or major event is approximated using combinations of earthquake magnitude and location in areas adjacent to the fault rupture where these events are most likely to occur. Other insurers are now using numerical modeling techniques to study their event-orientated earthquake questions. Of course, a major question that remains unanswered at the present time is how much additional insight can be obtained using these complicated methods as compared with simpler ones about the damage potential of moderate or high magnitude events at locations where they have not occurred in historical times. This is another information need of some insurers.

The earthquake information needs of those insurers that do extensive in-house natural hazard risk analysis work are much more extensive than those who choose to make only a cursory qualitative evaluation. Consequently, there are no "standard" needs for earthquake information among insurers. A major reason for this difference is the size and content of an insurer's portfolio that may be susceptible to significant earthquake-caused losses and the insurer's preconceived ideas about the actual magnitude of the earthquake peril. No doubt, a few insurers completely ignore the potential earthquake threat because of the minimal insured loss experience of the insurance industry in the past four decades. During this period insured losses caused by earthquakes in the United States was a very small fraction (about one percent) of the aggregate loss attributed to the major atmospheric and geophysical perils that are covered by private insurance (wind, hail, earthquake ground motion, fire following earthquakes). Most of the effects of the flood peril are covered by the federally operated National Flood Insurance Program.

In the past, the scientific community has satisfied a number of the site-orientated information needs of those insurers who do not use outside earthquake consultants and who are interested in making quantitative evaluations of the earthquake perils. Examples of available information are ground motion intensities (expressed in Modified Mercalli units) that have been observed in past earthquakes at specific locations or estimated exceedance probabilities (or return periods) of physical measures of ground motion, such as velocity and acceleration at various sites. This information is of prime importance in earthquake engineering evaluations of specific buildings at given sites, or for an insurer's determination of the expected average annual loss for rating and underwriting purposes on a location-by-location basis.

Unfortunately, the scientific community has done much less work on putting its seismological knowledge into a form that can easily be utilized by those insurers who are interested in improving their event-orientated analysis procedures, especially for earthquake occurrences outside of California. A likely reason for this lack of emphasis is that the insurance industry and other potential users have not adequately expressed a need for this type of information. Examples of useful information that can be used for event-orientated analysis purposes include the computerized mapping of local ground conditions, on a detailed scale, for the metropolitan areas of San Francisco and Los Angeles which was prepared by J. Evernden of the U.S.G.S., and the discussion of the state-of-the-art findings of various researchers such as was reported in the U.S.G.S. Professional Paper 1360 (Reference 6).

For the earthquake hazard outside of California, most insurers who do in-house studies no doubt have extensive event-specific information needs in each of the four analysis categories: earthquake characteristics and their resultant effects upon the size and shape of the spatial pattern of strong ground motion, its frequency content, severity and duration; influences of local ground and water table conditions upon ground motion at given locations and local effects of large scale subsurface conditions on an area wide basis; vulnerability relationships between ground motion characteristics and resultant potential structural and non-structural damages to typical types of buildings; and representative inventories of buildings (insured and uninsured) by location, type, usage and other characteristics. These inventories are needed by an insurer to estimate the possible casualty and damage impact of the earthquake perils on other affected coverages such as fire-following-earthquake, worker's compensation, general liability, automobile, life and medical.

Maximum Catastrophe Potential and its Occurrence Probability

An important measure of natural hazard risk is the estimated maximum value of the catastrophe producing potential of individual storms and earthquakes on an insurers portfolio of business. To fully utilize this measure for the earthquake peril, there are two information needs from the scientific community: first, an event-orientated estimate of the geographical pattern of ground motion of the probable maximum loss (PML) event; secondly, an estimate of the probability of the event's occurrence.

A number of years ago, the scientific community constructed probable ground motion patterns resulting from the occurrence of several scenario earthquakes in California. These were great earthquakes (Richter magnitude 8+) on the main stem of the San Andreas fault near San Francisco (a repeat of the 1906 event) and near Los Angeles (a repeat of the 1857 event). In addition, a ground motion pattern was developed for a maximum likely earthquake (Richter magnitude 7.5) on an adjacent fault (Newport-Inglewood) directly under densely populated sections of metropolitan Los Angeles (References 7, 8). Updates have been made of the ground motion patterns for the Richter 8+ event near San Francisco (Reference 9) and near Los Angeles (References 6, 10). The probable ground motion pattern of a Richter 6+ quake on the Newport-Inglewood fault recently has become available (Reference 6).

For an insurer to be able to take full advantage of the implications of the damage potential of these ground motion patterns to its book of business, it is also necessary to have an estimate of the occurrence probabilities of the parent earthquakes. A recent U.S. Geological Survey report (Reference 11) satisfies this information need for the San Andreas events based upon currently available research results. Hopefully, similar type probability estimates soon will become available for moderate to major earthquakes on adjacent faults near or under highly urbanized areas of California, such as the Inglewood-Newport, Hayward and Rose Canyon fault systems and in other sections of the United States.

An insurer has event-orientated information needs beyond these individual worst-case-scenario high magnitude events which may have low occurrence probabilities and rupture locations which are not close to the main spatial arrays and densities of the portfolio properties. It is possible that other combinations of lower earthquake magnitude and closer rupture locations will produce ground motion patterns that cause somewhat lower catastrophe potentials, but have much higher occurrence probabilities. For some types of properties, a moderate magnitude earthquake centered under a highly urbanized area can have a much greater catastrophe producing potential than a high magnitude event with its fault rupture a considerable distance from populated areas.

Estimation of Large Catastrophe Potentials to an Insurance Portfolio

To graphically illustrate how large catastrophe potentials are produced by storms and earthquakes, results of the simulation of many thousands of possible overlappings of hurricane wind patterns upon the spatial array of insured properties along the Gulf and East Coast can be utilized. The results emphasize the need for event-specific information from the scientific community on other events, in addition to the "PML event". This information could assist the insurer in more adequately defining the probable range of large catastrophe potentials and their relative probabilities to the portfolios of insured properties rather than basing a risk assessment solely on a single PML event and its particular occurrence probability. Atlantic hurricanes, even though more frequent than moderate or high magnitude California earthquakes (240 landfalls on the U.S. Coastline since 1871), have similar damage producing characteristics. This involves the interaction among the four major contributing factors (natural hazard severity pattern, local exposure conditions, number and location of elements-at-risk, their vulnerabilities) which produces the large loss events common to both storms and earthquakes.

An illustration of how this interaction determines the frequency and severity of natural disasters can be had by simulating the potential damage impact of several recent severe intensity Atlantic hurricanes. Just before Hurricane Gilbert moved across the Yucatan Peninsula in mid-September of 1988, it had the lowest barometric pressure ever measured in an Atlantic Hurricane (26.13 inches of mercury). Resultant wind speeds in the eye wall were estimated at 175 miles per hour sustained, with gusts to 200 miles per hour. Also, it was a very large storm in geographical area. Physically, this hurricane had the largest damage-producing potential ever observed in the Atlantic. It produced about $2 billion dollars in insured damages in Jamaica and Mexico. The National Weather Service projected an eventual United States landfall near Galveston in the metropolitan Houston area (Exhibit 1). What would the catastrophe producing potential be to the insurance industry's portfolio of insured properties if the storm had actually followed this forecasted path? What was the climatological probability that this scenario would occur?

To attempt to answer these questions, it is necessary to describe the high wind speed severity patterns of hurricanes. The typical high wind pattern is bell-shaped after the hurricane makes landfall. Highest winds are in the area swept out by the eye wall of the storm near and to the right of its center (Exhibit 2). Computerized mappings can closely approximate the actual wind patterns and the spatial array of insured properties down to a zip-code area scale. Computerized numerical modeling techniques for superpositioning of these wind patterns on the spatial array of properties and for determining the resulting damage producing interactions provide a means of estimating the overall potential damage impact of each simulated storm. A close correspondence of simulated damage estimates with actual insurance losses caused by United States hurricanes in the past forty years suggests that numerical models can provide useful approximations of the catastrophe-producing mechanism (Exhibit 3).

The size of the catastrophe producing potential of a hurricane or an earthquake to an insured portfolio is dependent upon two factors. One is the inherent magnitude of the catastrophe potential which is dependent upon the physical properties of the geophysical or atmospheric event. Of particular importance is the event's intensity (Richter magnitude or lowest barometric pressure). The second factor is the percentage of this overall damage producing potential that is actually realized. This depends upon how the storm or earthquake severity pattern happens to overlay the spatial distribution and density of the elements-at-risk.


Houston
New Orleans
Mobile
Pensacola
Tampa
Corpus Christi
Brownsville

Exhibit 1

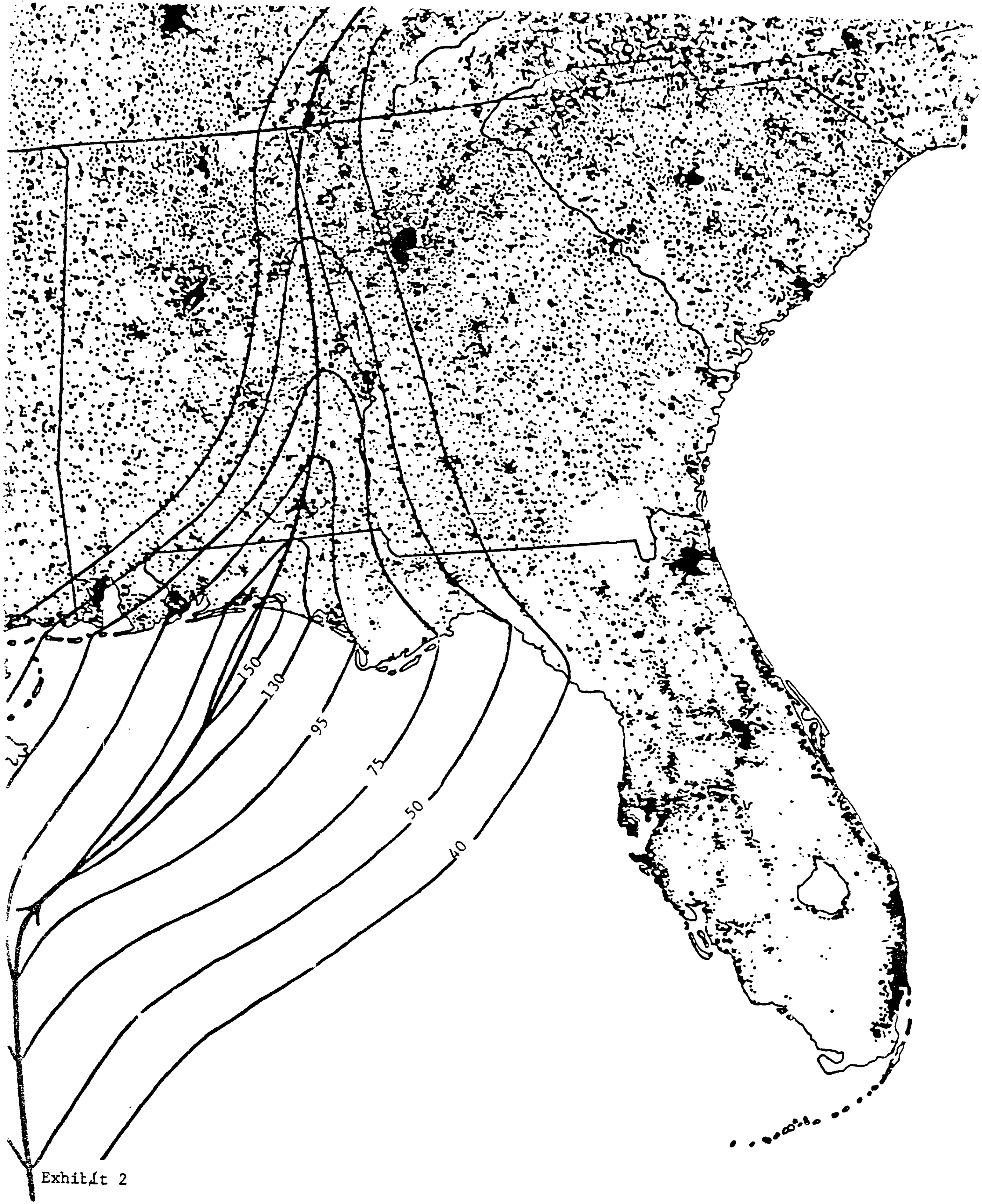
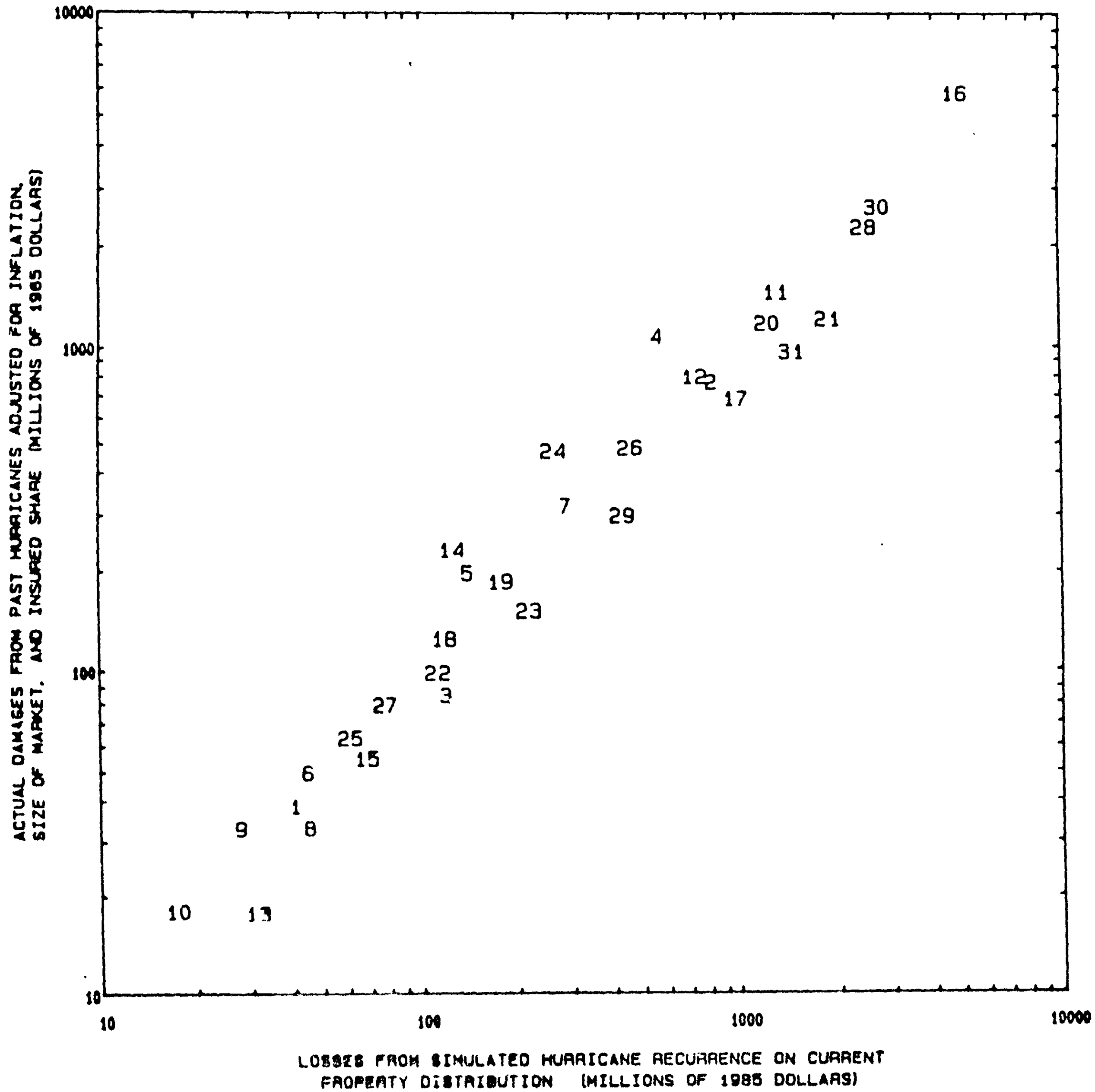


Exhibit 2



1	1984	Diana
2	1983	Alicia
3	1980	Allen
4	197?	Frederic
5	1979	David
6	1976	Belle
7	1975	Eloise
8	1974	Carmen
9	1972	Agnes
10	1971	Edith
11	1970	Celia
12	1969	Camille
13	1968	Gladys
14	1967	Beulah
15	1966	Alma
16	1965	Betsy
17	1964	Cleo
18	1964	Dora
19	1964	Hilda
20	1961	Carla
21	1960	Donna
22	1959	Debra
23	1959	Gracie
24	1957	Audrey
25	1956	Flossy
26	1955	Connie
27	1955	Ione
28	1954	Carol
29	1954	Edna
30	1954	Hazel
31	1950	King

Exhibit 3

Importance of the first factor can be shown by simulating the total damage-producing potentials of hurricanes of different intensities (lowest barometric pressure) to a uniform, maximum density, geographical distribution of a given type of building. When these calculated damage potentials are plotted against the storm's intensity using, say, the Saffir-Simpson 1-5 scale, the most severe intensity hurricanes (code 5) have a much greater damage-producing potential than the less severe ones (codes 1-4) as shown in Exhibit 4. These severe storms are rare, with a frequency of much less than 1 percent of the total number of hurricanes that affect the coastline. Hurricane Gilbert was classed at the top limit of the code 5 intensity category. It had the physical properties to produce an exceptionally large catastrophe. Fortunately, it weakened during its crossing of the Yucatan peninsula, took a westerly course, and crossed the Mexican coast 120 miles south of the U.S. border. Gilbert's inherent ability to produce a large catastrophe was markedly diminished at landfall because of its decreased intensity, which changed it from a code 5 to a code 3 storm.

Another example of potential ability to produce a large catastrophe was Hurricane Gloria which moved up the East Coast in the early fall of 1985. It was forecasted by the National Weather Service to make landfall on the western tip of Long Island accompanied by peak wind gusts in excess of 140 miles per hour; winds of 120 miles per hour in Hartford; and up to 100 miles per hour in southern Maine. This storm, if it had occurred as projected, could have produced multi-billion dollar insured damages.

The forecasted path and strength of Gloria represented the worst case scenario for a hurricane-caused catastrophe that could be anticipated anywhere on the Gulf or Atlantic coastline. The storm had maximum likely severity for a northward moving hurricane at that latitude and a projected optimal path across densely populated areas so that it could realize a large percentage of its inherent damage-producing potential (Exhibit 5). The probability of this particular combination of factors was less than 1 out of 500. Fortunately, the upper portion of the hurricane was separated from the lower part by strong winds aloft as it approached Long Island. As a result, the storm's strength dissipated rapidly before it struck land. Gloria was only a minor (code 1) storm at landfall on Long Island causing insured losses of $400 million. If Hurricanes Gilbert and Gloria had maintained their forecasted paths and intensities, each would have been among the great hurricane damage-producers because of an optimal combination of the two factors, namely, the inherent strength of these two storms due to their strong physical intensities and their forecasted paths that would have carried them across two highly urbanized sections of the U.S. coastline.

The difficulty in estimating catastrophe potential of a hurricane or earthquake is that the percent of the event's overall damage-producing potential which is actually realized depends upon how the ground motion or wind pattern happens to overlay the haphazard geographical distribution of exposed properties. A severe intensity storm that affects the Florida panhandle can produce much less damage impact than a moderate intensity storm moving directly across the highly urbanized strip from West Palm Beach to Miami (Exhibit 6). A moderate magnitude earthquake on the Hayward fault under Oakland could have a much larger realized catastrophe potential than a high magnitude earthquake centered on the Garlock fault in the Mojave Desert.

Holding a simulated storm's intensity constant at a particular level implies an inherent level of catastrophe producing potential. If its landfall is then shifted in increments along the Southeast coastline and the realized damage potential is calculated based on the interaction of the severity pattern with the geographical array of the elements-at-risk for each landfall, peaks and valleys are observed in these overall potentials as represented by the length of the arrows in Exhibit 7. The coastal metropolitan areas

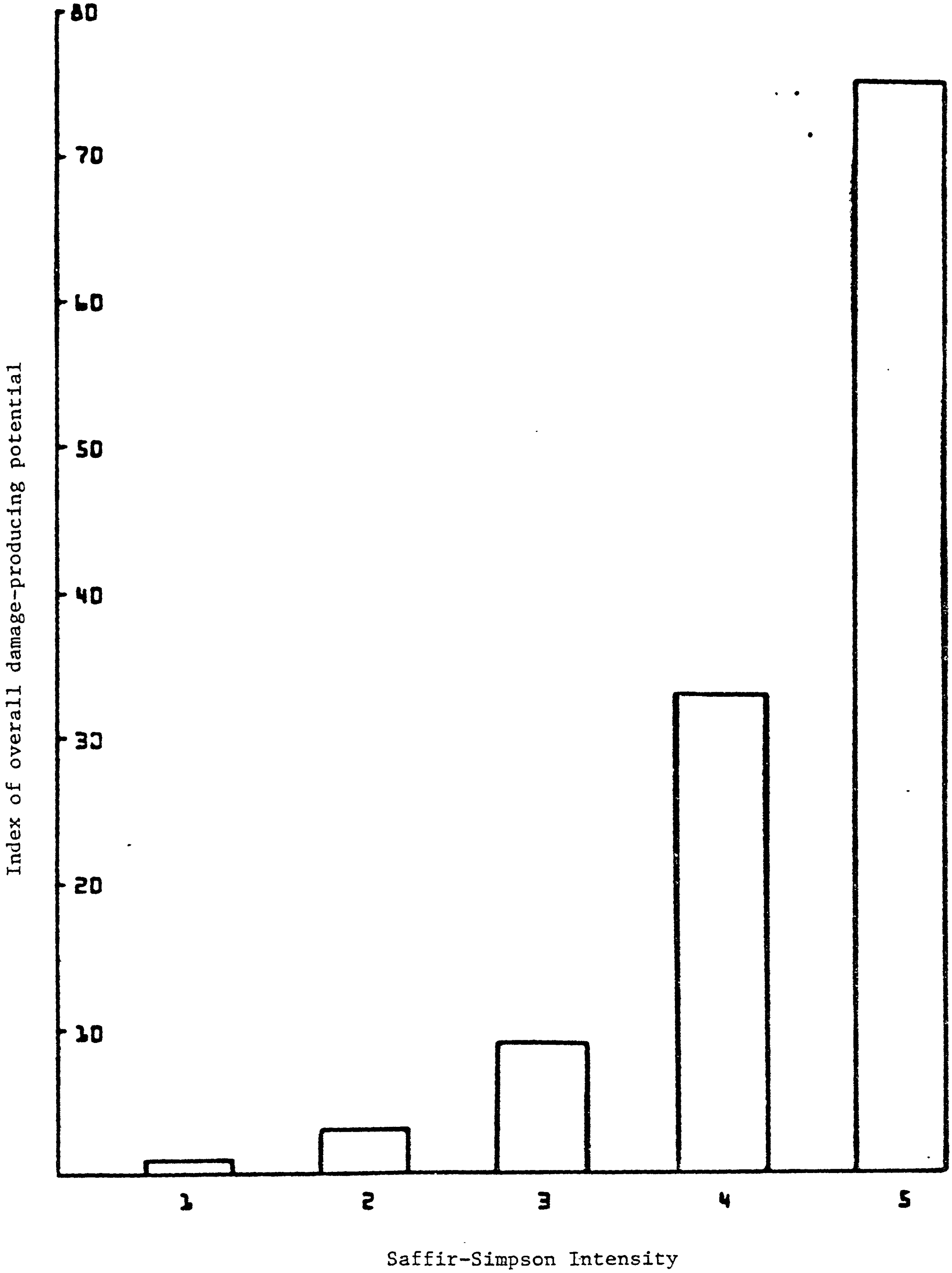

80
70
60
50
40
30
20
10
Index of overall damage-producing potential
1
2
3
4
5
Saffir-Simpson Intensity

Exhibit 4

Exhibit 5

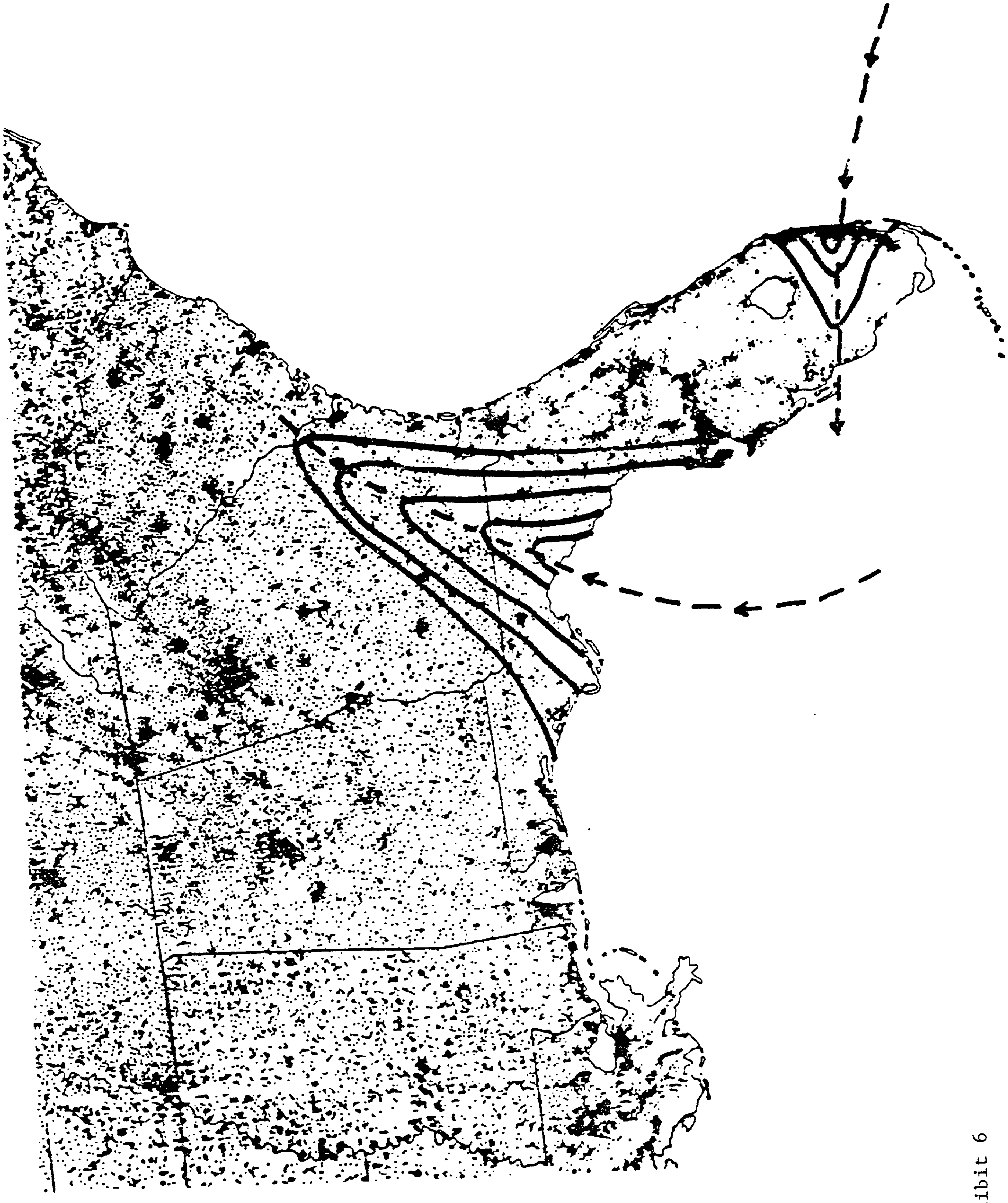


Exhibit 6

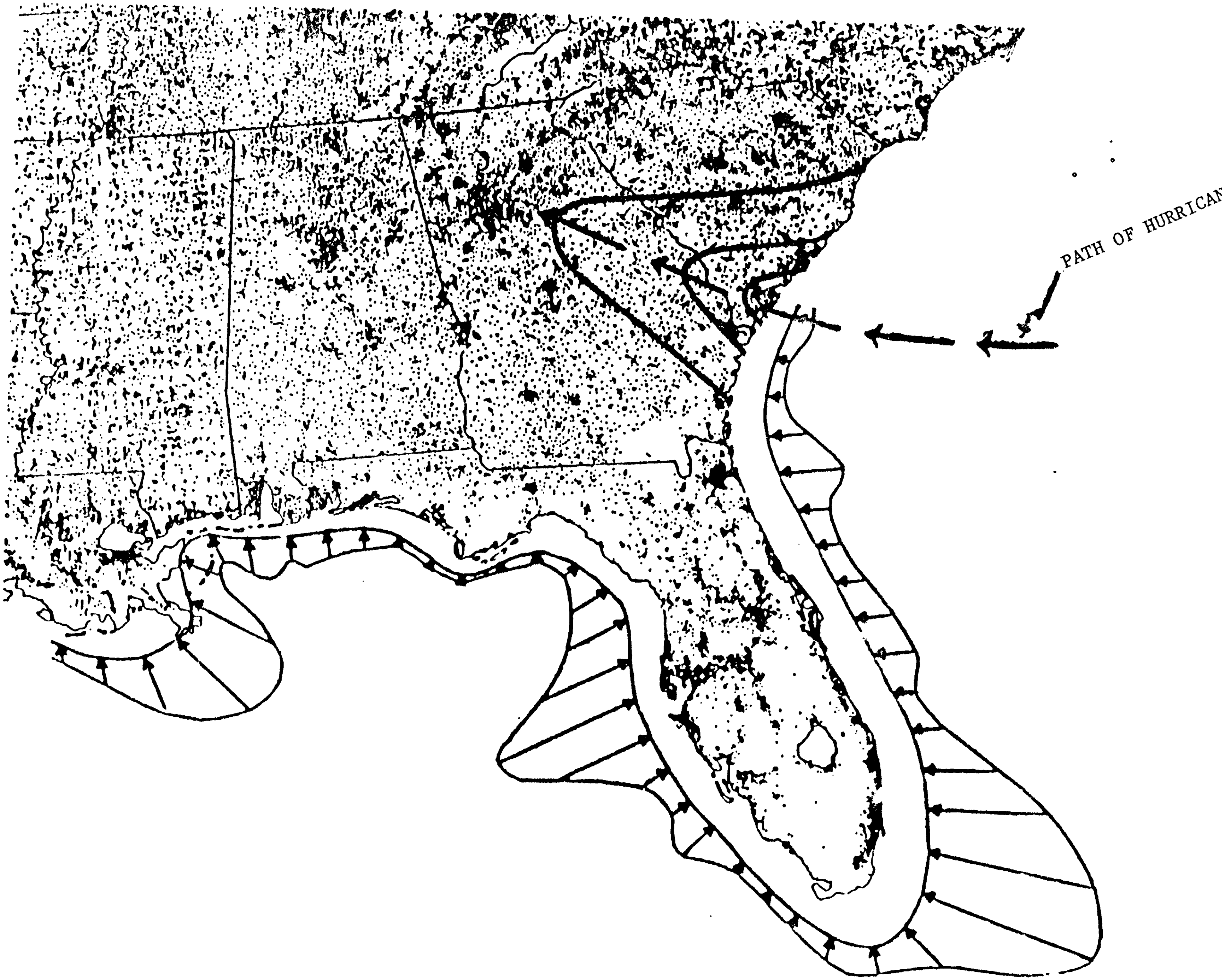


Exhibit 7

such as New Orleans, Tampa and Miami cause large increases in the simulated losses. When this process is continued up the East Coast; damage potentials increase to very large values for landfalls along coastal segments of the New York metropolitan area where the numbers of exposed properties approach maximum likely density. Realized damage potentials decrease rapidly when landfalls of the constant intensity storm are moved beyond New York and Boston to segments of the sparcely populated Maine coastline. This simulation analysis illustrates that there is not a one-to-one relationship between a hurricane's intensity and its realized catastrophe producing potential. The storm's path relative to coastal clusterings of insured properties also must be considered. The same is true for the earthquake peril: there is not a one-to-one relation between an earthquake's magnitude and its realized damage impact. For an individual catastrophe potential analysis, the probability of the occurrence of a hurricane of given intensity along various segments of the coastline has to be incorporated.

This illustration of how the frequency and severity of hurricane-caused natural disasters are affected by the interaction of the high wind pattern with the spatial array of the elements-at-risk can be applied to an estimate of the potential damage impact of Hurricane Gilbert at the time it was projected to make landfall on the Texas coast. As the hypothetical landfall of a storm is moved closer to the densely populated Houston area, the resultant simulated losses rise rapidly because a larger percentage of the storm's overall damage-producing potential is realized due to a larger number of properties that are adversely affected (Exhibit 8). For a hurricane of Gilbert's code 5 strength, the size of the calculated loss potential to the industry's current book of business varied by a factor of over 25 times depending upon the assumed landfall location. Simulated insured losses ranged from about $200 million if the storm had crossed the coast a few tens of miles north of the Mexican border to over $5.2 billion, if it had made a direct hit on the Galveston-Houston area. A simulated recurrence of the most severe storm to hit the Houston area in this century, the great 1900 Hurricane which drowned 6000 people, could currently cause about $2 billion in insured losses. Consequently, Gilbert would have had a devastating impact of a magnitude never before experienced on the Texas coast.

However, the climatological probability that Gilbert would be of code 5 strength at landfall before following the optimal damage producing track directly across the Houston metropolitan area was small as shown in the following example: given that a severe intensity hurricane will make landfall somewhere on the United States coastline, the probability is .19 (about 2 in 10) that it will be on the Texas coast (Exhibit 9). If it does hit somewhere on the Texas coast, the conditional probability that it will cross the coastline in the sector that would cause maximum damage to Houston is about 1 out of 25. It is a long coastline with an equally likely probability that the landfall would be in any one small coastal segment.

The product of 2 in 10 (to hit the Texas coast) and 1 in 25 (to have an optimal damage-producing landfall near Houston) gives a joint probability of 1 out of 125 for maximum damage production. The level of catastrophe potential drops off very rapidly when the landfall is to the right or left of the optimal track for maximum damage production. In addition, the probability that the severe intensity storm would still be of code 5 strength when it crossed the coastline also must be considered. It is about 1 in 4. Therefore, even though all of the ingredients for Gilbert to produce a monumental disaster were there, the probability that all of them would combine in such a way as to produce the extreme-impact event was small, as it was with Hurricane Gloria. The point is that size of the catastrophe producing potential of a hurricane is very sensitive to the combination of its intensity and path relative to coastal clusters of the insured properties-at-risk.

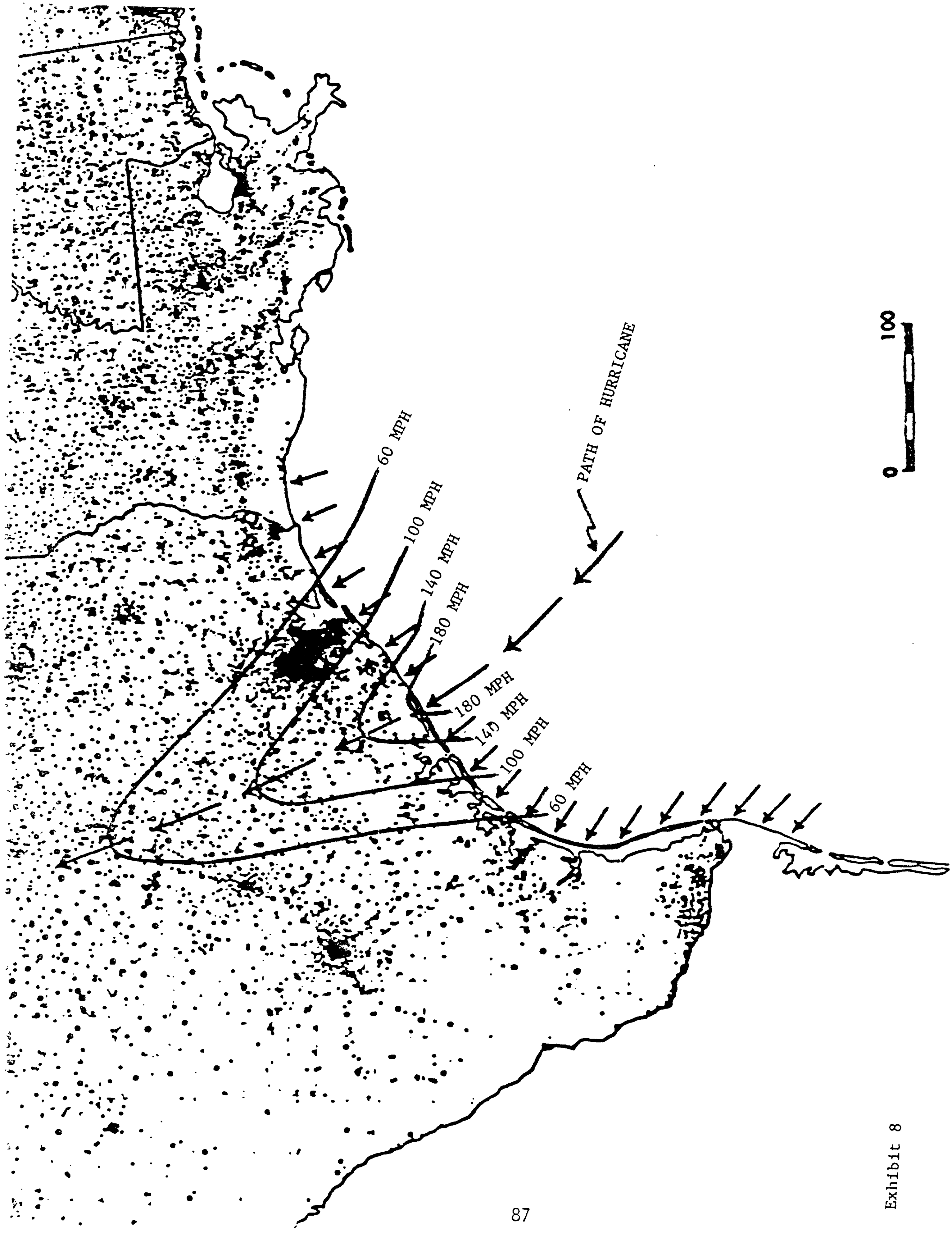

PATH OF HURRICANE
60 MPH
100 MPH
140 MPH
180 MPH
180 MPH
140 MPH
100 MPH
60 MPH
0
100

Exhibit 8

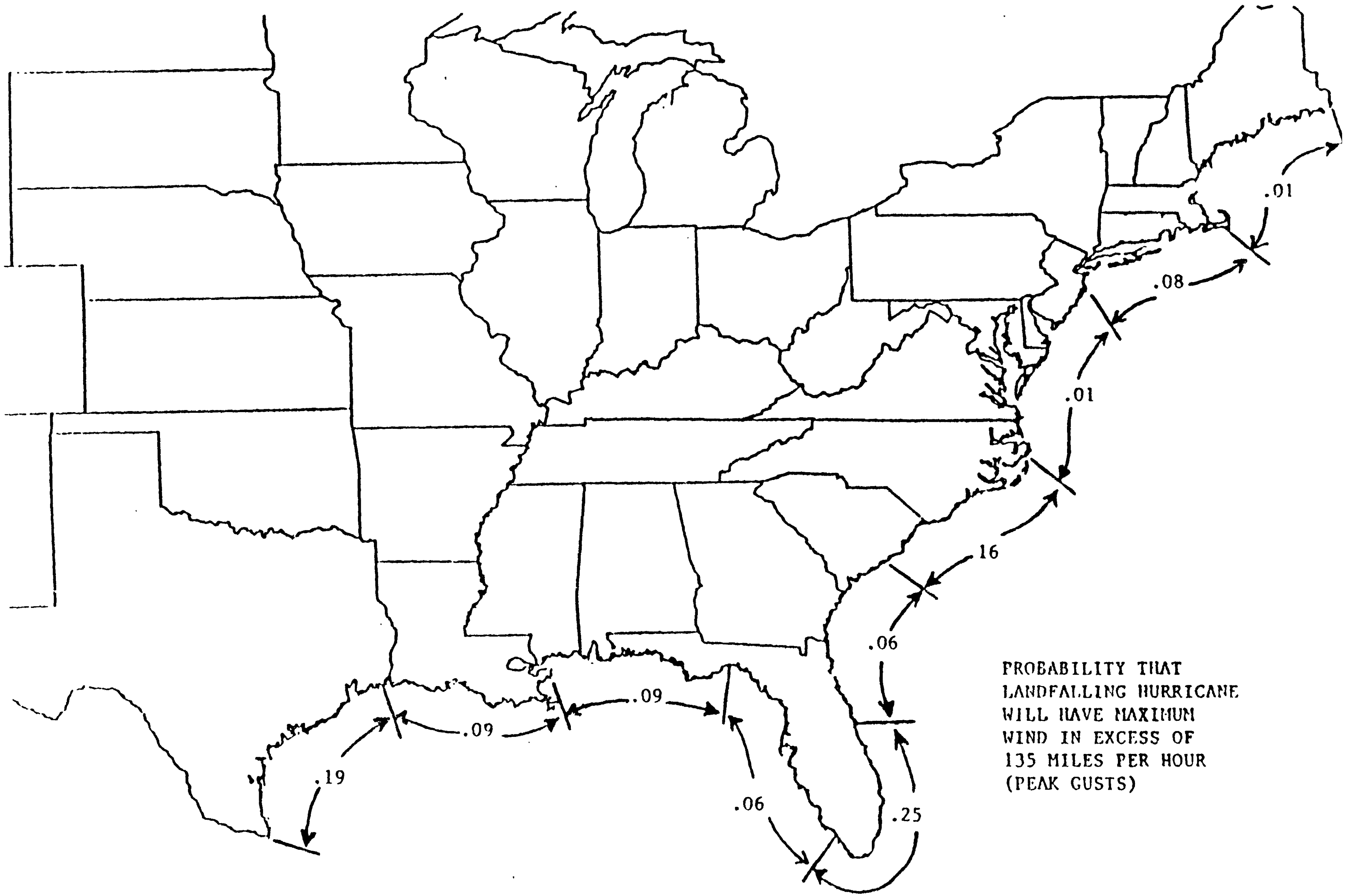

.01
.08
.01
16
.06
.25
.06
.09
.09
.19
PROBABILITY THAT LANDFALLING HURRICANE WILL HAVE MAXIMUM WIND IN EXCESS OF 135 MILES PER HOUR (PEAK GUSTS)

Exhibit 9

The hurricane model has been used to simulate maximum loss potentials of the many climatologically possible combinations of storm intensity and path of severe and extreme hurricanes that could occur along the Gulf and Atlantic coastlines of the United States with credible occurrence probabilities (Reference 12). The simulated interactions of these hypothetical storms with coastal concentrations of exposures produced five possible combinations of hurricane intensity and landfall which could produce a catastrophe potential of at least $7 billion to the insurance industry. Affected coastal metropolitan areas were: Miami, Houston, Miami-Houston (double landfall storm), Miami-Tampa-New York-New England (another double landfall storm with a track similar to the highly damaging Hurricane Donna in 1960), and New York-New England (Exhibit 10). The catastrophe producing potential of each scenario event is large, but the probability of the precise combination of extreme storm intensity and an optimal damage producing track across these coastal concentrations of population is small.

Note that the direction of the hurricane track at landfall and as the storm moves inland makes a significant difference in the resultant damage producing potential in the Houston area. An extreme intensity storm moving across the Gulf from the east-southeast starting near the southern tip of Florida can produce a catastrophe potential to the insurance industry in excess of $7+ billion. A storm that would follow the forecasted path of Hurricane Gilbert, from the south-southeast (Exhibit 1), has a lesser potential of $5+ billion. This is because the landfall location of the Gilbert-type storm, would be about 30 miles down the coastline in order for it to carry its highest winds directly across metropolitan Houston. This landfall has a much less dense concentration of coastal properties than the landfall position of the Florida type storm. It would be near the city of Galveston.

These numerical simulation studies of large catastrophe producing potentials associated with the hurricane peril suggests that the PML event is not a clear cut entity that can be easily delineated. Estimation of the magnitude of hurricane catastrophe potentials appears to be equivalent to sampling from a frequency distribution of possible potentials whose sizes are dependent upon the particular combinations of the storm's intensity and track relative to dense coastal clusters of the elements-at-risk. Even though the magnitude of the catastrophe potential resulting from these "draws" may be somewhat less than that of the maximum probable loss event, the probability of the physical combination of the storm's intensity and track may be much larger than that of the worst case scenario. Consequently, insurers have a need for information that would assist in defining the shape and size of this frequency distribution of large catastrophe potentials rather than relying solely upon one draw which represents the PML event.

Because the catastrophe producing potentials of earthquakes also depend upon the interaction of the severity (ground motion) pattern with an array of elements-at-risk, the above mentioned considerations for hurricanes also apply to PML earthquakes. Hence, there is a need for information from the scientific community not only about PML events but also other possible earthquake combinations of moderate or high magnitude and rupture location, and the resultant ground motion severity pattern, that could produce large catastrophe potentials and have higher occurrence probabilities than the PML event.

This particular need was highlighted recently in an All Industry Research Advisory Council (AIRAC) study of the probable losses to the insurance industry in the workers compensation and general liability coverages resulting from the occurrence of a "PML earthquake event" in the Los Angeles metropolitan area (Reference 3). The probable ground motion pattern that was constructed by a federal agency for a Richter

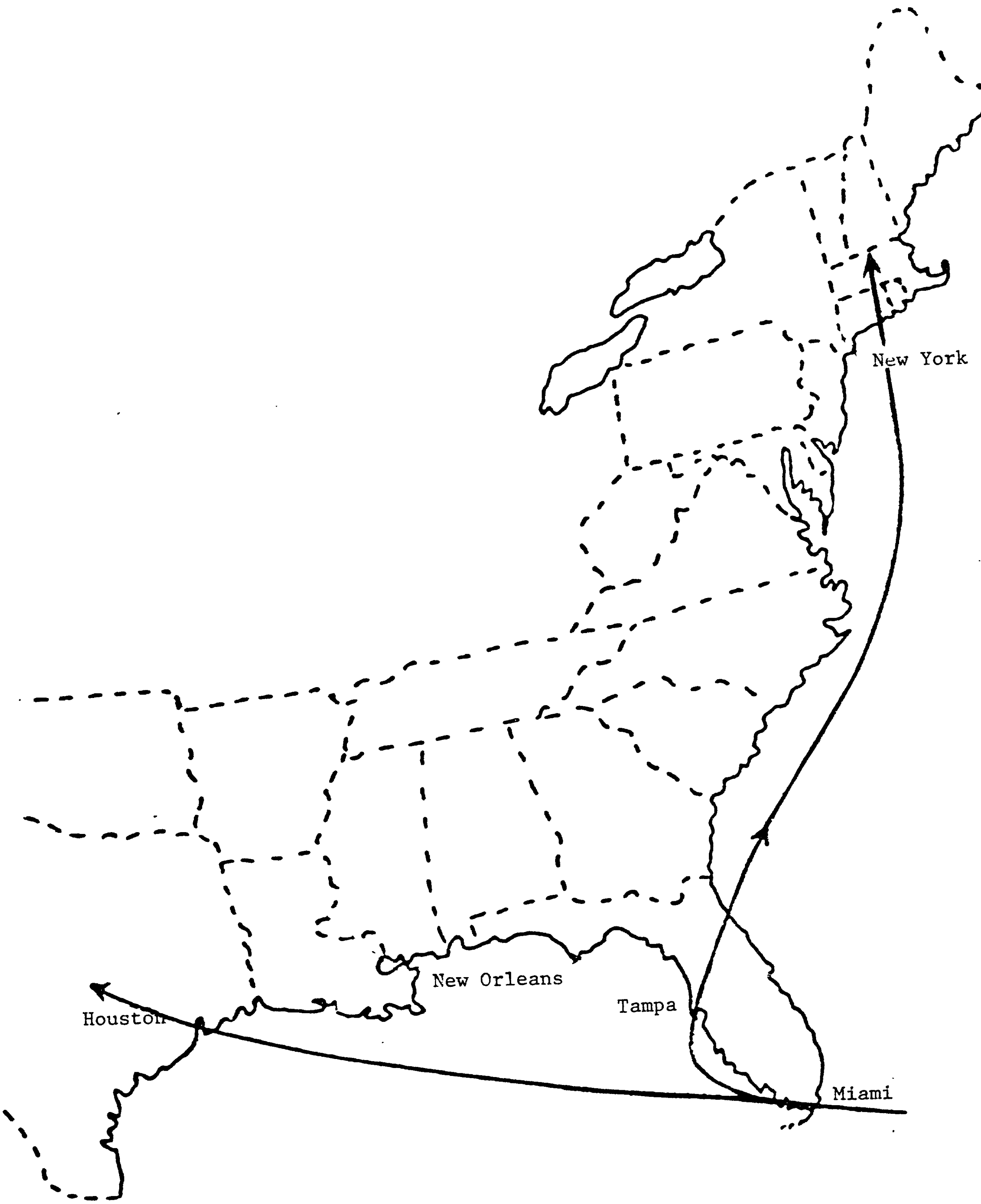


Exhibit 10

magnitude 7.5 event on the Newport-Inglewood fault (Reference 8) was used to determine these catastrophe potentials. However, there apparently is a current feeling among some seismologists that the occurrence probability of a magnitude 7.5 earthquake on this fault has a much lower probability of occurrence than was originally assumed in 1973 when it was selected as the PML event for faults that lie under Los Angeles. Therefore, attempts were made to estimate the catastrophe potential to these insurance lines when the physical combination of magnitude and location of the earthquake was changed. The location was held constant but the magnitude was changed, in turn, to Richter 6.0, 6.5, 7.0. Potential losses were estimated for the resultant hypothesized ground motion pattern of each of the three magnitude earthquakes. The probability of occurrence of each of these combinations was assumed to be larger than that of the Richter 7.5 event. Unfortunately, very little consistent information was available from the scientific community on the probable ground motion patterns of these lesser magnitude events or their probabilities of occurrence.

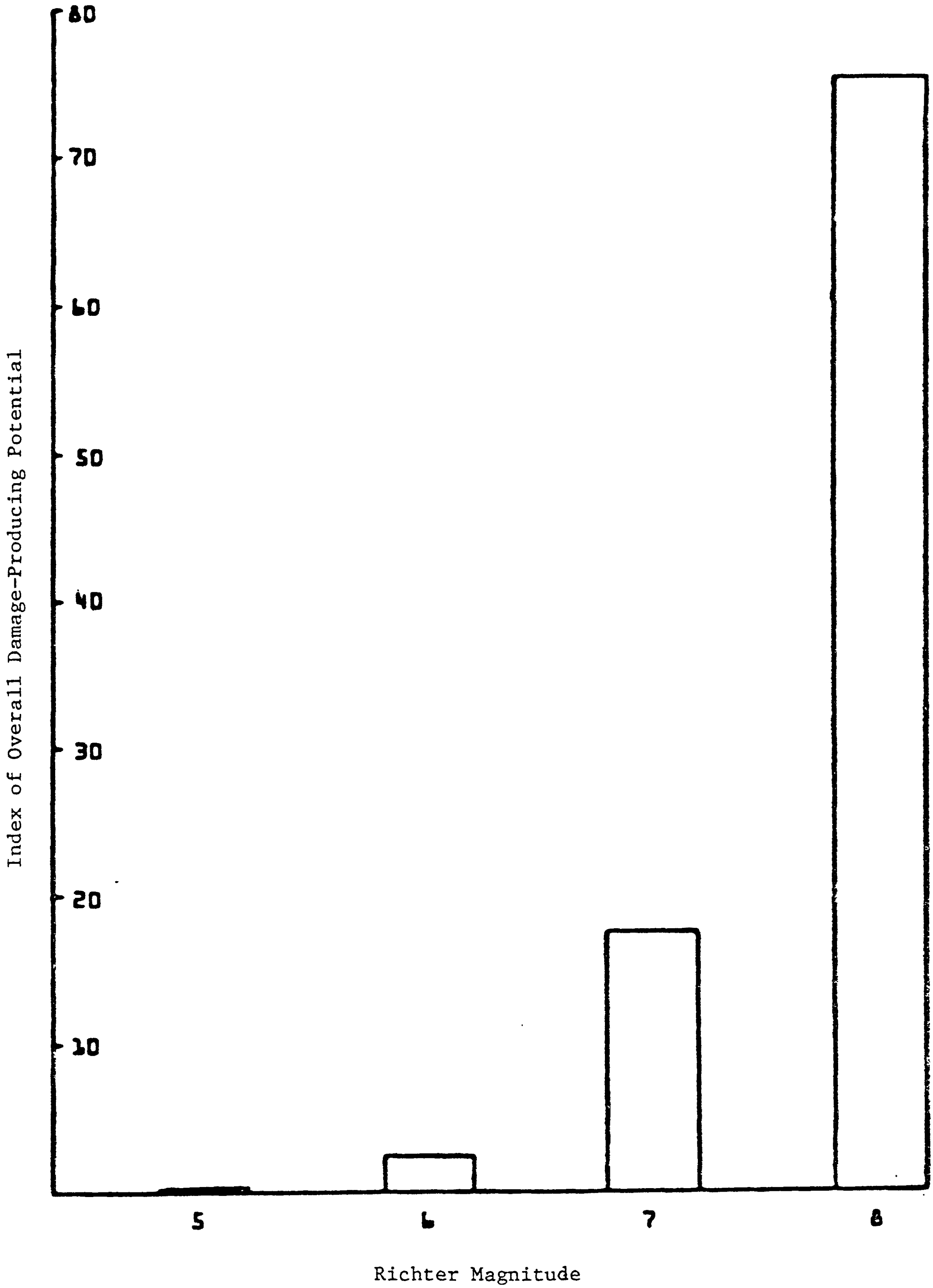
There are differences between the earthquake and hurricane perils with respect to possible physical combinations of the magnitude and locations of these events. For instance, the location of earthquakes with moderate or higher magnitude is usually restricted to relatively narrow fault zones whereas hurricanes can climatologically make landfall on nearly all segments of the Gulf and Atlantic coastlines of the United States. A second difference is that for those long sections of the San Andreas fault that rupture only infrequently (return periods of over 100 years), the range of magnitudes of probable earthquake events may be restricted to a narrow band of, say, magnitude 7.0 or above. In contrast, the possible range of intensities of landfalling hurricane is from minor (code 1) to extreme (code 5) on a large section of the United States coastline. A major similarity is the relationship between the magnitude of the geophysical event and its inherent damage producing potential. The simulated relationship for earthquakes is shown in Exhibit 11 which can be compared with the hurricane counterpart in Exhibit 4.

A rough comparison can be made of the occurrence probabilities of PML hurricane events, such as the forecasted tracks and intensities of Hurricane Gloria and Gilbert, with those of a high magnitude (7.5 to 8) earthquake on sections of the southern San Andreas (Table 2 of Reference 11) near the Los Angeles metropolitan area within the next 30 years:

		San Andreas Fault Segment		
	Hurricane Gloria or Gilbert	Carrizo Magnitude 8	Mojave Magnitude 7.5	San Bernardino Mts. Magnitude 7.5
Occurrence Probability (1988-2018)	0.06*	0.10	0.30	0.20

*1/500 per year times 30 years

The probability of a PML hurricane event is about 2 to 5 times less likely in the next 3 decades than a high magnitude PML earthquake on some section of the southern San Andreas.



80
70
60
50
40
30
20
10
5
6
7
8
Index of Overall Damage-Producing Potential
Richter Magnitude

Exhibit 11

The estimated catastrophe producing potential to insured properties of the PML hurricane is approximately 4 times less in size than the total insured and uninsured loss of a great earthquake on the San Andreas: PML hurricane $7+ billion versus PML earthquake $25+ billion (Table 3 of Reference 1). No estimate is currently available on the total insured damage potential of a high magnitude earthquake on the southern San Andreas. A recent Earthquake Project estimate of insured losses due to a Richter 7.5 earthquake on the Newport-Inglewood fault is $66 billion (Reference 13) but no indication is given on this PML event's probability of occurrence. The earthquake peril in California apparently has a much higher maximum catastrophe potential for a single event than the hurricane peril along the Gulf and East Coasts of the United States. The probability of occurrence of the PML earthquake event also is larger than for the PML hurricane event.

Discussion

The need of insurers for information from the scientific community depends, in part, upon the following considerations:

1. The earthquake peril is only one of the "natural hazard" perils covered by insurance.

2. A measure of the importance of each of these weather or geophysical perils as insured damage producers can be obtained by using the industry's coded catastrophe loss listings.

3. An atmospheric or geophysical event is coded as a catastrophe producer when industrywide losses exceed $5 million. Prior to 1982, the threshold loss was $1 million.

4. In recent years, the average annual loss due to these catastrophes has ranged between $1.0 billion and $1.5 billion.

5. There have been 820 coded catastrophes since the system was begun nearly 40 years ago in 1949.

6. An estimate of the aggregate industry loss resulting from a recurrence of each of the 820 events to the insurance industry's current portfolio of insured property is $67 billion (1988 dollars).

7. The hurricane wind peril caused 50 of these catastrophes which accounted for about 40% of the total losses.

8. The earthquake peril, which is not as covered as frequency as the hurricane peril, caused 9 catastrophes and accounted for 1% of the aggregate loss.

9. There are two insurance risk measures which require the use of earthquake information. These are the average annual loss per insured structure and the catastrophe producing potential of individual earthquake events to an insurer's portfolio of insured properties.

10. Past earthquake loss experience, even measured over a 40 year period, is not an adequate measure of present risk to the insurer's portfolio of business. The combination of a moderate or high magnitude earthquake located near or under a densely populated area is an infrequently occurring event even in seismically active areas of California. However, when one of these events do occur, the insured losses can be very large.

11. Catastrophe producing potential is an important risk measure of rarely occurring natural hazard events such as earthquakes in an insurance operation. To estimate catastrophe potential, an insurer needs event-orientated information such as an earthquake's geographical pattern of ground motion severity.

12. Site-orientated information, such as the long-term frequency of ground motion intensity at a particular location, is not very useful in estimating the magnitude of catastrophe producing potential of individual earthquakes.

13. Determination of catastrophe potential of earthquake events to a particular portfolio of insured properties depends upon the interaction of four major factors: characteristics of the earthquake's geographical pattern of ground motion, local effects that can alter the ground motion's dominant wave frequency, its severity, and duration at each affected location, the vulnerability of insured properties to damage when ground motion attains a specified severity and duration, and the geographical array of insured properties in the portfolio by number and type.

14. Each insurer, either implicitly or explicitly, must account for the damage impact of these interactions on its particular portfolio of insured properties in managing the earthquake peril.

15. Some insurers make only a cursory, qualitative risk assessment while, at the other extreme, some use numerical simulation techniques to estimate the catastrophe potential. Others have outside consultants make the evaluations. Therefore, those using the quantitative methods have extensive information needs as compared to minimal needs of those who make no formal examination. There apparently is no "standard" need for earthquake information among insurers.

16. It is possible that a few insurers completely discount the importance of the earthquake peril as a potentially large damage producer based on the insurance industry's earthquake loss experience in the past four decades. In these cases, there may be a need, from the scientific community, for educational information on the potential potency of earthquakes as large loss producers.

17. Some information is available from the scientific community on the probable maximum loss (PML) producing earthquakes in California and their probabilities of occurrence, at least along the San Andreas fault. Much more information is needed on other combinations of moderate or high magnitude and location of earthquakes that would assist the insurer to more adequately evaluate the catastrophe potential risk to the portfolios of exposed properties. A moderate magnitude earthquake, with a location under a densely populated area, could produce a larger catastrophe potential to certain types of property in an insurer's portfolio than a great earthquake which occurs some distance away. Also the probability of occurrence of the moderate magnitude earthquake could be much larger than for the high magnitude "PML event".

18. Coded catastrophes of the insurance industry which produce large numbers of industrywide losses were caused much more frequently by hurricanes than by earthquakes in the past 40 years. Hurricanes caused the equivalent of nearly half of the total losses attributed to the 820 natural hazard events during the period.

19. A rough comparison of the size of maximum catastrophe producing potential of a PML event caused by a hurricane and its probability of occurrence, with that of a PML earthquake event in California indicates that both the size of the earthquake loss potential and its current probability of occurrence are greater than for the maximum damage producing hurricane event.

20. A single high magnitude earthquake, if it occurs near or under a high populated area of California, could cause insured losses that equal or exceed one-half of the aggregate damage, $67 billion (1988 dollars), produced by a recurrence of each of the past 820 atmospheric or geophysical events and their resultant interactions with the insurance industry's current portfolio of insured properties.

It is concluded that many insurers currently have an urgent need for more communication with the scientific community, and more information from it, to assist them in managing the earthquake peril in California and in seismic areas of other states.

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EARTHQUAKE DAMAGE TO COMMERCIAL AND INDUSTRIAL BUILDINGS

By
Edgar V. Leyendecker
U.S. Geological Survey
Denver, Colorado

INTRODUCTION

It is clear, and perhaps sounds trivial to say, that the more we know about earthquake damage to structures and facilities the better job we can do in evaluating losses due to earthquakes. However, we must temper this simple statement with at least three questions:

(1) How much information would we actually need if we had access to an unlimited amount?
(2) Will the information ever be available in the depth we want it?
(3) What can we do with the data we have available to us today?

The answers to these questions greatly affect how we proceed in collecting data on earthquake damage and subsequent estimation of losses. The user of the data, in this case insurance or reinsurance companies, must provide answers to these questions in order to develop a more useful data base. The response will be different for different users. I will describe some of the work USGS is doing that will impact the availability or potential availability of damage data and provide some thoughts on the depth to which it might be desirable to collect data.

SOME USGS ACTIVITIES

The USGS is currently conducting studies of losses due to earthuakes in several geographic areas throughout the United States. Work in the Salt Lake Valley in Utah is nearing completion and work in the Puget Sound area is in its early stages. These studies are being done to develop more realistic estimates of what the losses will be due to earthquakes of various magnitudes and to estimate damages due to real earthquakes. It is intended to develop approaches and data which can be used by others in addition to the USGS.

The procedure includes:

(1) a simple system for classifying buildings,
(2) the census tract as the basic area for inventory and/or damage data collection, and
(3) machine read "mark-sense" sheets for compiling data into a computer data base.

Each of these factors is described below. The procedure was used in documenting damage following the October 1987 Whittier Narrows earthquake. This was a valuable experience in developing an improved approach to collecting data.

BUILDING CLASSIFICATION - The 1983 Insurance Services Offices (ISO) classification system is being used in loss estimate studies and was used in a survey of damage in selected census tracts following the Whittier Narrows Earthquake. This system was selected for its relative simplicity and ease of use by a lay person as well as for consistency with existing data. Use of the system in the Whittier Narrows study indicated that some modifications are desirable although major changes are not anticipated in the near term.

DATA COLLECTION AREAS - The census tract is being used as the primary data collection area in order to simplify the inventory of buildings. The Zip Code is popular with some, still others have suggested areas bounded by uniformly spaced latitude and longitude. Since census data provide a relatively accurate count of residential housing units, this is one component of an inventory that does not have to be compiled in detail. Other types of structures require inventory work. Unfortunately a detailed inventory is expensive to obtain.

DATA COLLECTION FORMS - Data will be collected on "mark-sense" sheets which describe building class (and type of damage in a damage survey). The mark-sense sheets are preprinted forms with multiple choice responses that are filled out with a soft lead pencil. The "marks" by the soft lead pencil can be "sensed" by an optical scanning device. Space is also provided for general comments and/or observations. The presence of this latter type of data can be "sensed" although it must be entered by hand. These forms are then read into a computer data base using an optical scanner. This procedure for data collection worked relatively well in Whittier although it was concluded that the specific data recorded on the forms, while adequate, should be simplified as much as possible for future use. A more general form of data collection which will allow data to be recompiled into other classification systems as well as ISO appears practical and desirable for future use.

NEED FOR EXPANSION OF DATA BASE

DAMAGE DATA - Damage data provide the most reliable source for development of *percent loss*, the average percentage of the total cash value required to fully repair or rebuild in kind any building of a particular class, and *vulnerability functions*, the relation of percent loss with Modified Mercalli intensity (MMI).

As would be expected the largest, albeit limited, data base for earthquake damage exists for California. These data have been cautiously extrapolated for use in other areas of the United States. Caution has been used since earthquake style and construction practices differ. Data from other geographical areas are needed.

Most data relate damage with MMI as the measure of ground motion. Although the limitations of intensity for this use are well recognized, it is also well recognized that there is little information on building damage as a function of some other measure of ground motion. Due in part to the lack of widespread instrumentation it is anticipated that the use of MMI will continue for some time.

BUILDING CLASSIFICATION - The current data base uses a rather simple building classification. This is due in part to limited data. If the system were too complex the amount of data in each classification would possibly be meaningless. Simplicity also leads to somewhat easier data collection. However, many buildings differ from the "average" building considered in classification systems. We know that building response and subsequent damages are dependent upon the complex interaction of many factors, some of which have a major impact on performance and damage. Failure to consider these in a classification system can mean a large statistical scatter in the data. A few of these factors are listed below:

Materials of construction
Structural load resisting system
Building irregularity (both plan and elevation)
Building height
Foundation type
Construction inspection
Quality control
Soil type

Explicit consideration of these factors in a classification system will reduce the range of error in vulnerability functions and percent loss data. At the same time we must remain prudent and guard against making a system overly complex. However we should begin collecting the data.

Quantitative influence of some of the factors is only now being included in building codes. This guidance is generally says how much deviation from the "norm" is allowed before one must begin taking explicit consideration of the factor. Part of our expanded data base should begin to include documention of these factors since they do affect damage, sometimes in a major way. As a consequence, they should be of more than passing interest to audiences such those attending this workshop, building code writers, etc.

OTHER DATA - Data collection should also begin to address important matters such as Loss of Contents and Loss of Function. Data on performance of structures that have been strengthened or repaired are also needed. We also need to better address lifeline losses.

WHEN TO INVESTIGATE EARTHQUAKE DAMAGE

We should investigate damage due to earthquakes of all sizes. If we wait only for the largest earthquakes we may wait a long time for data. In such an earthquake there are major areas affected in which the intensities are less than the maximum. We can learn a considerable amount about damage at these intensities from study from the smaller earthquakes. Such earthquakes also allow us to debug our data collection and analysis procedures, this is far better than being overwhelmed with flawed procedures during the "big one".

CENTRAL DATA BASE

Damage data are collected following every major earthquake. How the data are collected and when analysis become available are dependent upon individual investigators. Original data in a consistent form are difficult to obtain from such a variety of sources. It appears sensible to get the maximum use of the damage data from earthquakes by having a central collection point for data that would be available to all for their own individual analysis requirements. Individual investigators could do their own analysis but basic data in a common format should be readily available. Certainly this would be a big effort and would require resources in both money, manpower, facility, and a stable organization. However, only in this way can we begin to develop a consistent and enlarged data base by which we can get the information we need for a variety of purposes.

CLOSURE

Past USGS work has contributed in a major way to our ability to estimate earthquake losses. Current and future activities are planned to refine these contributions and develop our capabilities even further. A partnership among collectors and users of the results of loss studies offers the unique opportunity to make major strides.

INSURANCE NEEDS FOR EARTHQUAKE COVERAGE

By
Robert B. Holtom
Insurance Consultant
Whittier, California

The least sophisticated major type of insurance, from both a rating and underwriting standpoint, is earthquake insurance. Although written premiums exceed $200 million annually in California alone, many insurance companies know very little about their true exposures to loss.

Scientific information would be used by many insurers if it was available in a language which could be understood by insurance persons. (Most insurance people do not understand scientific terms and thus are not able to use the reports now being published.)

Information would be used in these two critical areas:

1. Rates. Although many insurance companies use the rates promulgated by the Insurance Services Office (ISO), some large companies, and a few smaller ones, use independent rate programs. Improved knowledge could lead to lower rates in some areas, and quite possibly higher, more realistic, rates in others. One caveat is needed: when the insuance market is "soft", some companies will lower their rates in order to "maintain market share"; earthquake rates may be the first to be reduced, because they are less objective than most other rates.

2. Underwriting. Each company determines its own practices as to which applicants it will accept. Insurers are guided by their own calculations of Probable Maximum Loss (PML). With improved data, better calculations could be made, permitting the writing of more coverage in some areas. While less coverage might then be written in other areas, this will help to assure that insurers will be able to pay the losses which occur. Also, improved knowledge can help underwriters to recommend improvements in individual properties, thus avoiding some losses and reducing the amount of loss when damage does occur.

The types of data which would help in the rating and underwriting of buildings, contents,and time element coverages are these:

1. Faults. Insurers now know, or can easily determine, the distance to known faults. They need to know three types of information about each fault or fault segment.

- Intensity projections. How strong will the shocks be? What types of shock waves can be anticipated?

- Frequency projections (return period). How soon is the next earthquake expected? How often will shocks occur?

- Aftershock expectations. How large an aftershock can be expected? What is the duration of expected damaging aftershocks? (This information is needed both to set a moratorium and to help in planning for the reinsuance to be purchased.)

2. Soil conditions. Insurers usually have little or no knowledge about the soil conditions which could affect the amount of loss to structures. They could make better decisions if they had good data on liquifaction, settling, and the expected transmission of shock waves through the soils.

3. Types of construction. Insurers have general knowledge about how different types of construction and materials will react to shocks. They need more information on these items, as well as the effects of the height of structures. Acceptable methods of retrofitting of older buildings will be helpful in selecting applicants and in making recommendations for improvements.

4. Resulting damages. Insurers generally have little knowledge about the types of damage which may result from an earthquake shock. They could plan better if they had data on expected flooding, collapse, contamination, and land deformation.

The above discussion concerns the peril of earthquake shock only. Related hazards would be of intense interest to many insurers, both in rating and underwriting, because so little is known about these exposures. Included would be such as:

- volcanic activity
- tsunami possibilities
- landslides
- bluffs, considering their effects on both shock waves and landslides

The insurance industry is concerned about much more than losses by earthquake shocks and their related effects as listed above. Almost all companies which write earthquake insurance also write coverage against the perils of fire and other types of property losses. Most of them also write other lines of insurance, such as liability, automobile, and theft. Some experts predict that these losses would exceed the shock loss in a major earthquake. Some of the most prominent of these exposures are:

- fire following an earthquake
- life and accident losses
- automobile
- worker's compensation
- time element losses, such as loss of earnings (Business Interruption) and extra expense

Additional scientific information might be used by insurance companies in either the rating or underwriting of these other lines. For example, the "fire following" loss exposure could cause some insurers to limit their exposures in certain zones. Companies are now aware of their PML because of their annual reports to the California Department of Insurance; some companies use more refined zones in determining their PML, and might well include chances of loss in addition to shock, if good information was available.

All of this additional information could lead to improved rating and underwriting programs. The availability of insurance would almost certainly improve. Insurance companies, many of which are now very uncomfortable with their earthquake exposures, could take steps to control their chances of loss, by internal programs and by purchasing reinsurance.

INDICES TO RELATIVE SEISMIC HAZARD FOR COMMERCIAL BUILDINGS

by
David M. Perkins
U.S. Geological Survey
Denver, Colorado

We believe it should be possible for USGS researchers and consultants to develop a check list leading to indices which would make it possible for insurors to better assess the likelihood of damaging levels of ground motion and the relative vulnerability of particular buildings at particular sites. The check list would include such items as recurrence of critical levels of ground motion, type of building material, system of resistance, height, geologic site condition, building period, and specific structural or architectural features (for example, age, horizontal configuration, vertical discontinuities, eccentricity of resistance, and soft story). The index numbers would be measures of both the relative hazard and relative vulnerability, and would be assigned to map locations and categories of structures and structural features in the check list.

Seismic recurrence is clearly the most important item of the check list. For the eastern United States, it is likely that recurrences of damaging levels of ground motion may vary with geography by factors of more than 500. Consideration of sites in the western United States may increase that variation by a factor of 4 or more. Because of this wide range, we would expect an index reflecting relative hazard according to geographic site location to have a broader range of values than any other index.

Building material, *system of earthquake resistance*, *height*, and *geologic site condition* are likely to be the next most important general items. The first three items would permit construction of a *building classification* index. This index and that of the site condition would each probably influence the relative damageability of a building by at least a factor of 2 increase or decrease from that of some reference standard building classification or site condition.

An estimate of *building period*, derived from *building height* and *system of earthquake resistance*, would be important in assessing what seismic ground motion parameter to use for a recurrence index.

The other check list items may lead to indices as important as those indicated above, but would be specific to the relative performance of an individual building compared to the average behavior of a building in the general classification to which that particular building would be assigned. We expect that the crude nature of present data would limit the accuracy of estimates of relative vulnerability factors to within a factor of 2.

The USGS, as a result of its work on national seismic hazard maps and its work in loss studies with its consultants, is in an excellent position to be able to provide such hazard and vulnerability indices. Considerable developmental work may remain in order to realize these indices. As an example of the complexities of the various aspects that need to be addressed in developing hazard indices, let us consider some of the issues involved in mapping indices for ground motion recurrence.

Current national ground motion hazard maps are not directly suitable for use in producing recurrence indices. On these maps, seismic hazard is displayed as ground motion having a constant annual probability of being exceeded. These maps are designed to be suitable for use in building codes, where a measure of relative required *resistance* to ground motion is desired, rather than an estimate of the relative *recurrence* of a given level of ground motion. As a general rule of thumb, when two points lie on two ground motion contours a factor of two apart, the recurrences of a given lower ground motion level at the two points differ by a factor of four or five. Thus the existing hazard maps usually fail to show the true relative contrast in recurrence between points.

In figure 1a, we see a portion of the acceleration hazard map of Algermissen and others (1982) showing the range of probabilistic peak acceleration values having about 1 chance in 2500 of being exceeded in a given year in the southeastern United States. In figure 1b we see contours of the index number for annual recurrence rate for the exceedance of acceleration values of 0.25 g. For direct use with other (hypothetical) index numbers of building vulnerability, which would be estimates to within a factor of two, these numbers are the logarithms to the base 2 of the exceedance rates (or, equivalently the negative logarithm of the return period of 0.25 g)—thus showing the relative recurrence also in terms of factors of 2. Note that the range of values depicted on the upper map is about a factor of 20, while the range on the lower map is 2^8 or about a factor of 250.

The ground motion parameter used to make one such index map is unlikely to be useful for all structures. Consider, for example, *peak acceleration* as such a parameter. Peak acceleration is a relatively high-frequency ground motion and is likely to be a good damage index for shorter, stiffer structures, which have short natural periods. However, because the predominate period of the peak acceleration lengthens with greater distance, as does the duration of shaking, a given value of peak acceleration may indicate a different degree of damageability near the epicenter than at greater distances, for a given class of structures. Alternatively put, the same degree of damage might occur with a given level of acceleration near the epicenter as occurs at a lower level of acceleration far from the epicenter, because of the damaging effect of the prolonged duration of shaking. We conclude that a ground motion parameter taking period into account and having some sensitivity to longer duration should be mapped—perhaps *response velocity* averaged over a particular period band would be a useful hazard parameter.

The appropriate level of the ground motion parameter to be used as an index needs to be considered. It is reasonable to expect that the greatest contribution to loss of function or of loss of contents comes from ground motions within a factor of two of the level corresponding to the threshold of damage. (Loss studies have suggested that the greatest annual loss takes place at modest intensity levels.) However, the threshold for damage for a highly resistant structure may be a ground motion level which would produce nearly total loss for another category of structure. Thus, the level of ground motion to be used as an index needs to be carefully chosen to preserve in the relative recurrence indices the relative vulnerability of the range of categories of structures. If a suitable single ground-motion level cannot be chosen, one may be forced to make recurrence maps for several different levels of ground motion. The ensuing complexity in using different recurrence index maps for different categories of buildings is very undesirable.

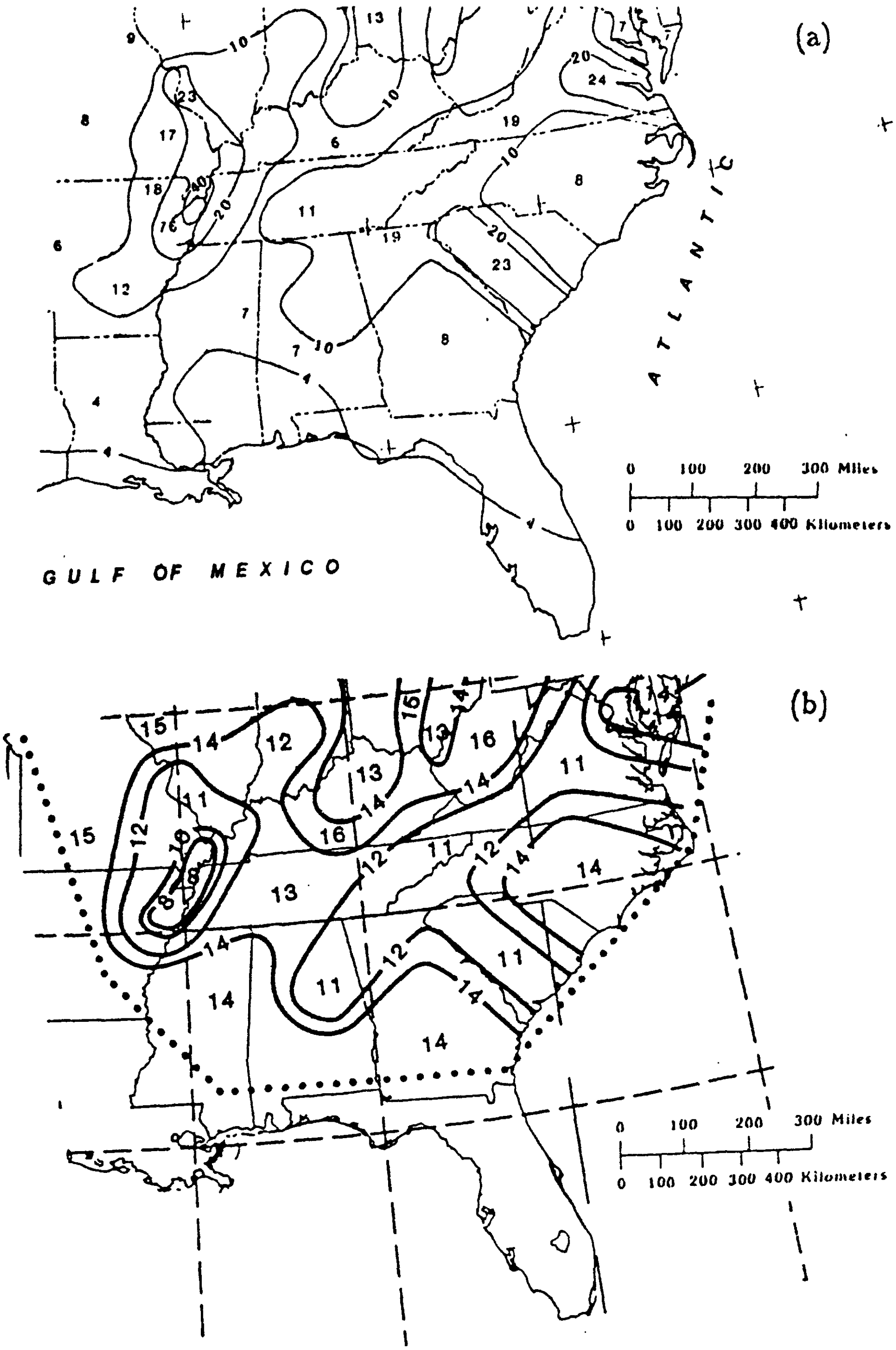


Figure 1 (a) Probabilistic peak acceleration values having about 1 chance in 2500 of being exceeded in a given year in the southeastern United States (Algermissen and others, 1982). (b) Preliminary map of index number for annual recurrence rate for the exceedance of acceleration values of 0.25 g. Index numbers values are the logarithms to the base 2 of the exceedance rates (or, equivalently the negative logarithm of the return period of 0.25 g). (Negative signs are omitted.)

Location of a site with respect to major faults may have minor importance for a damage-threshold level of ground motion. If this level of ground motion is sufficiently low, its recurrence may not be very sensitive to distance to active faults, *if the site is sufficiently close to the fault*, say within a few tens of kilometers. This is because for sites within several tens of kilometers of active faults, the hazard is dominated by the relatively likely occurrence of the largest events on these faults, and hence the probability of exceedance of a ground motion corresponding to a threshold for damage is likely to be relatively constant, for all such sites. Thus, once a site is within a certain distance of the fault, distance to the nearest fault is not likely to be important, *as an indicator of recurrence probability of damage-threshold levels of ground motion.*

The distance to active faults will remain important for indexing the recurrence of quite violent levels of ground motion. Current attenuation functions for ground motion indicate a dramatic increase of ground motion as a site nears a fault. Catastrophic collapse for earthquake-resistant structures may, in many cases, depend on a site being in the immediate vicinity of a fault. (A prominent exception is noted below.) Maps indicating this hazard are probably quite feasible in major metropolitan areas of California and Utah, but unlikely elsewhere.

The above two points are illustrated in figure 2. Figure 2a shows values of peak acceleration taken along a traverse running from a point offshore southwest of San Francisco running northeast toward Sacramento across the San Gregorio/Hosgri Fault, the San Andreas Fault, the Hayward Fault, and the Calaveras Fault. To facilitate comparison with the indexed recurrences in the figure 2b, below, the acceleration ordinates are also in log to the base 2. Figure 2b shows index values of annual recurrence rate of exceedances of 0.25 g. Notice four things.

1. The recurrence rates do not change greatly with respect to distance to the fault (once a site is within 20 km of the fault). The recurrence rate is dominated by the most active of the faults—the San Andreas. (This conclusion is weakened when considering higher levels of ground motion than 0.25 g.)
2. The peak acceleration depends strongly on distance to the faults, but is strongly, almost dominantly, affected by the fault with the greatest likelihood of recurrence (here, the San Andreas). Thus, even when considering collapse hazard, the role of fault recurrence rate is of equal importance as distance to the nearest active fault.
3. In the area dominated by the faults, the variation in recurrence of 0.25 g is comparable to the variation in peak accleration at a given return period—each is about a factor of 4. However, along the entire traverse, the range in recurrence is much greater than the range in peak acceleration—a factor of 64 vs a factor of 8.
4. Comparing the index numbers in figure 2b with those in figure 1b, we find that the total range across the U.S. is about 11 index numbers, or a factor of 2000, about that hypothesized earlier in the paper.

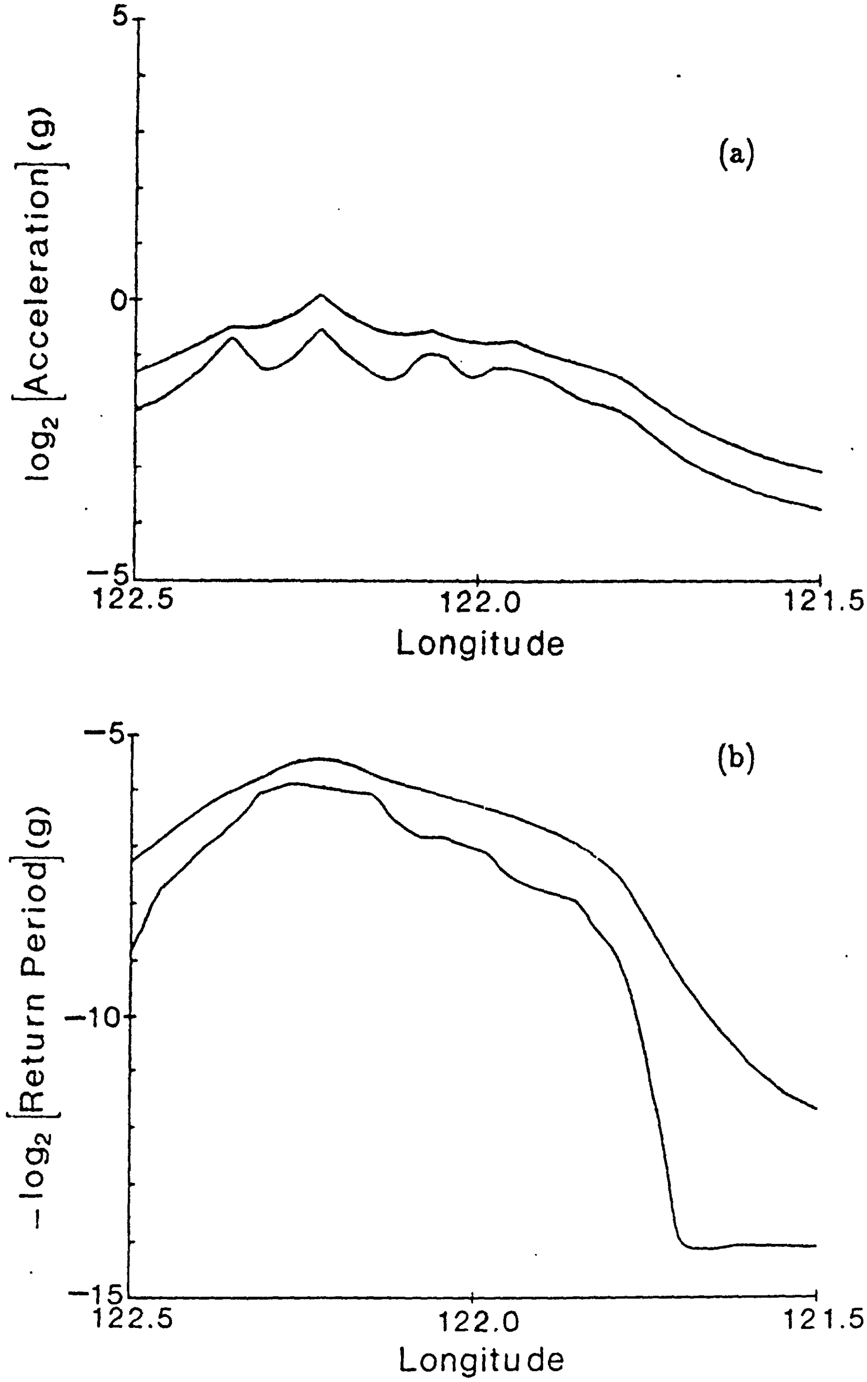


Figure 2 (a) Logarithm to the base 2 of probabilistic peak acceleration having about 1 chance in 10 of being exceeded in 50 years. Values are taken along a traverse running from a point offshore, southwest of San Francisco, running northeast toward Sacramento across the San Gregorio/Hosgri Fault, the San Andreas Fault, the Hayward Fault, and the Calaveras Fault. (b) Index values of annual recurrence rate of exceedances of 0.25 g. (Negative signs have been retained.) Seismicity model used in both (a) and (b) is that of Algermissen and others, 1982. Dual curves show results with (upper) and without (lower) attenuation variability taken into account.

Building collapse may occur other than in the immediate vicinity of a fault. The collapses seen in the Mexico earthquake are a potent illustration of the circumstances of collapse at sites distant from a fault. The correspondence between the natural period of a building and the natural period of the soil column beneath the building produced a very strong resonance effect, resulting in the collapse of many buildings. In major metropolitan areas, it may be feasible to map those locations where analogous behavior may be important. This mapping will depend on knowledge both of the site conditions and of the natural periods of typical buildings which may be located on those conditions.

The above considerations illustrate that ground motion recurrence indices are feasible, but that selection of the appropriate parameters and levels needs to be carefully assessed. We believe that hazard factors are feasible as well for the other indices proposed, under similar conditions of careful assessment, and with some limitation on the resolution possible.

References Cited

Algermissen, S.T. Perkins, D.M., Thenhaus, P.C., Hanson, S.L., and Bender, B.K., 1982, Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U.S. Geological Survey Open-File Report 82-1033, 99 pp.

EARTHQUAKE RISK--INFORMATION NEEDS OF INSURANCE INDUSTRY

By
E. A. Simner
Merrett Group, Lloyds of London
London, England

THE RE-INSURERS PERSPECTIVE OF THE EARTHQUAKE RISK

At the WWERM briefing in Washington in March, I was struck with the divergent backgrounds of the people attending.

To non-insurance people, re-insurance may seem an esoteric subject - and yet the re-insurance community plays a crucial role in the provision of catastrophe insurance throughout the world.

Therefore, as a prelude to the Panellist's contributions, it is perhaps worthwhile outlining a few basic features of what is actually a somewhat pragmatic industry.

Figures 1 & 2 are intended to convey the partnership and international nature of the total insurance picture - which for the most part is invisible to people outside the industry and even to may commercial insurance buyers.

This partnership between insurers and re-insurers is emphasised by figures which emerge from the annual PML evaluation by the Californian Insurance Department.

In the event of a major earthquake it is estimated that some 60/70% of the insured structural losses will be borne by re-insurers. If this applies to a large and mature insurance market such as the US, it is hardly likely to be less true for other quake prone countries throughout the world.

As re-insurers we are concerned with more than just structural damage - other areas to worry about in the event of a major earthquake are those shown in Figure 3.

Next, some of the conceptual factors which face an underwriter dealing with earthquake exposures - Figure 4.

For the most part insurance is a private enterprise industry, driven by the profit motive and subject to the normal, day-to-day commercial pressure and business motives.

Although earthquake premium income can be viewed as attractive income on a short term basis - you need to close your mind to the financial implications of a catastrophe.

Too often our instinctive perception of the earthquake risk (this year? - next year? - never?) leads us to ponder why expose our financial base to poorly understood, poorly presented risks with ill-understood catastrophe potentials when we can underwrite other, more predictable alternative risks?

We would be strange people if we gave preference to the relatively unknown over the relatively known risks. We do have a choice.

One of the questions facing this initiative is whether these factors and their components (figures 5 and 6) can be systematically quantified, assigned relative contribution values and used to produce self-consistent analyses at site specific, area and zonal levels.

If so, more sophisticated, computer generated, Probable Maximum Loss and Rating formulae than these (figures 7 & 8) can be applied to greater effect.

A more soundly based quantitive approach along these lines would help balance other, less substantive factors, which currently heavily influence underwriting attitudes.

As re-insurers, we are concerned with - how much? (so that we can align its impact to our financial strength)
- how often? (so that we can set the premium terms to match the recurrence periods)
- which areas? (so that we are aware of the areas/zones at risk without subsidising the catastrophe exposure by other insurance risks/premiums)

A final observation, whatever emerges from this meeting - and we are all committed to a positive outcome - the opportunities arising from this week's activities must include a commitment to co-ordination with existing earthquake initiatives such as:-

CRESTA - an international technical/re-insurers aiming at the promotion of efficient identification, assessment, management, control and financing of earthquake risks whose aims include co-operation in appropriate action to achieve these ends. Out of these endeavours, a pattern of standardised earthquake information has emerged - a typical example of which is shown in figure 9.

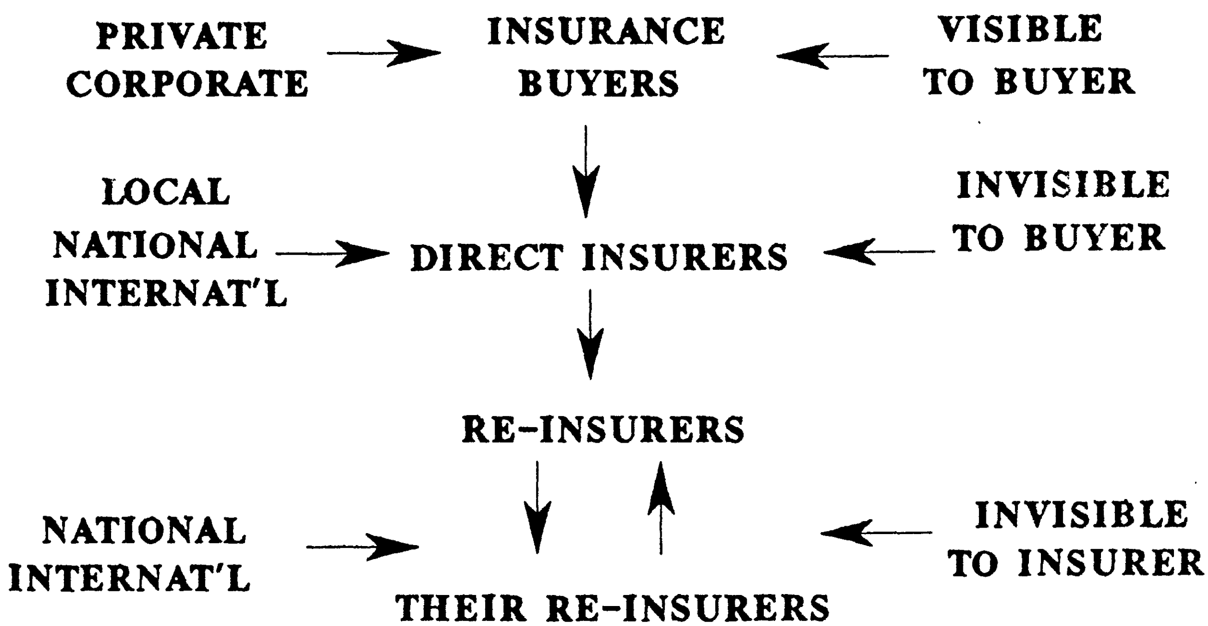
ROA - the Re-Insurance Offices Association 9a British based equivalent to the Re-Insurance Association of America) who publish studies of various territories.

Current US based insurance activity includes "The Earthquake Project" (a Federally supervised, industry directed programme), EMIC (a proposal for a "mutual" insurance company giving personal and commercial earthquake cover only on a long term , non-cancellable basis) and EPIC (a proposed joint stock company providing earthquake only cover for dwellings).

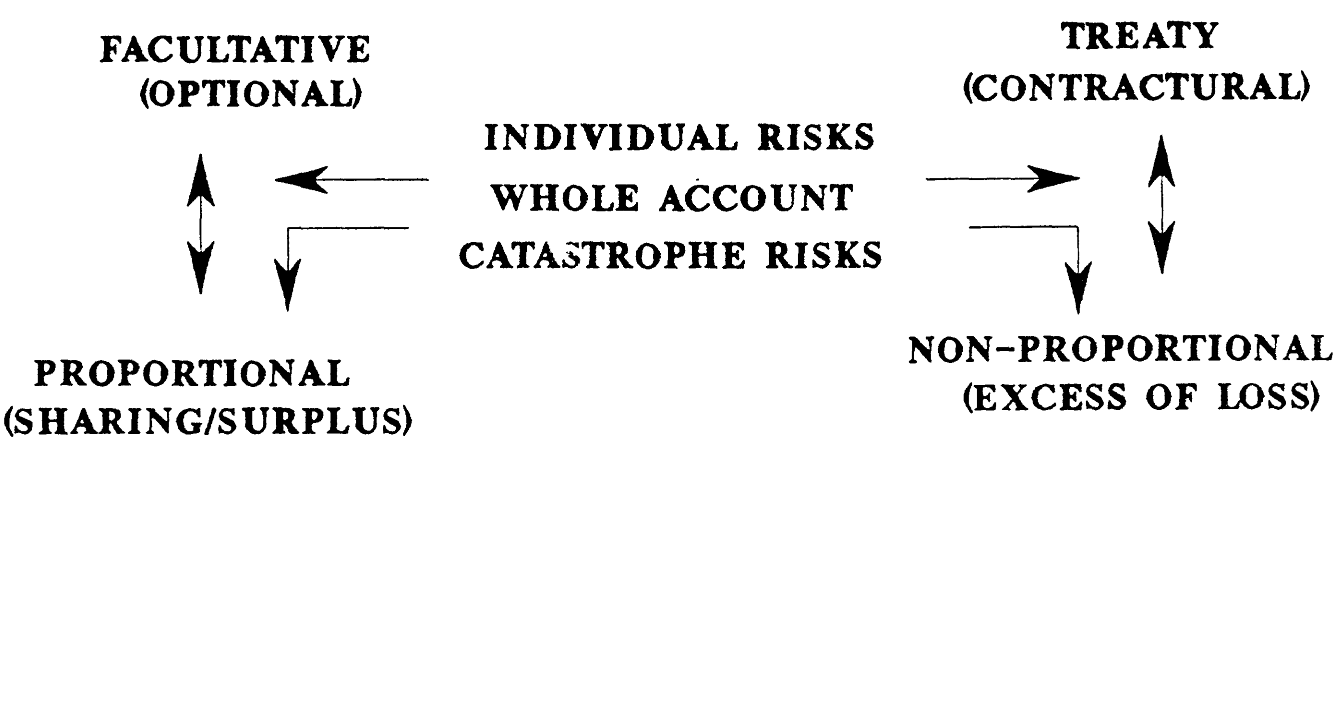
It is significant - and this highlights my basic point - the availability of adequate re-insurance capacity is fundamental to the viability of initiatives such as the Earthquake project, EMIC and EPIC.

After these preliminary remarks we should, I hope, be in a better position to put into context the contributions from our Panellists - the first of whom is Ted Algermissen of the US Geological Survey.

PARTNERSHIPS



MECHANISMS



RELATIONSHIPS

TREATY

- CORE CAPACITY
- LONG TERM
- PAY BACK
- BUSINESS KNOWLEDGE
- RETROCESSIONS

FACULTATIVE

- VOLATILE CAPACITY
- OPPORTUNISTIC

EXPOSURE ACCUMULATIONS

SHOCK DAMAGE – PROPERTY & BI

FIRE FOLLOWING – CONFLAGRATIONS

WCA – BUILDING COLLAPSE RISK

MORTGAGE IMPAIRMENT – DIC COVERS

OWNERS/LANDLORDS/TENANTS LIABILITY

- PARAPETS
- COLLAPSE

AUTO PA LIFE MARINE

MEDICAL MALPRACTICE – EMERGENCY TREATMENT

DAMAGED FACILITIES

UNDERWRITING CONCEPTS

BUILDING FACTORS

+

SITE FACTORS

+

DAMAGE POTENTIAL

↕

PREMIUM RATE

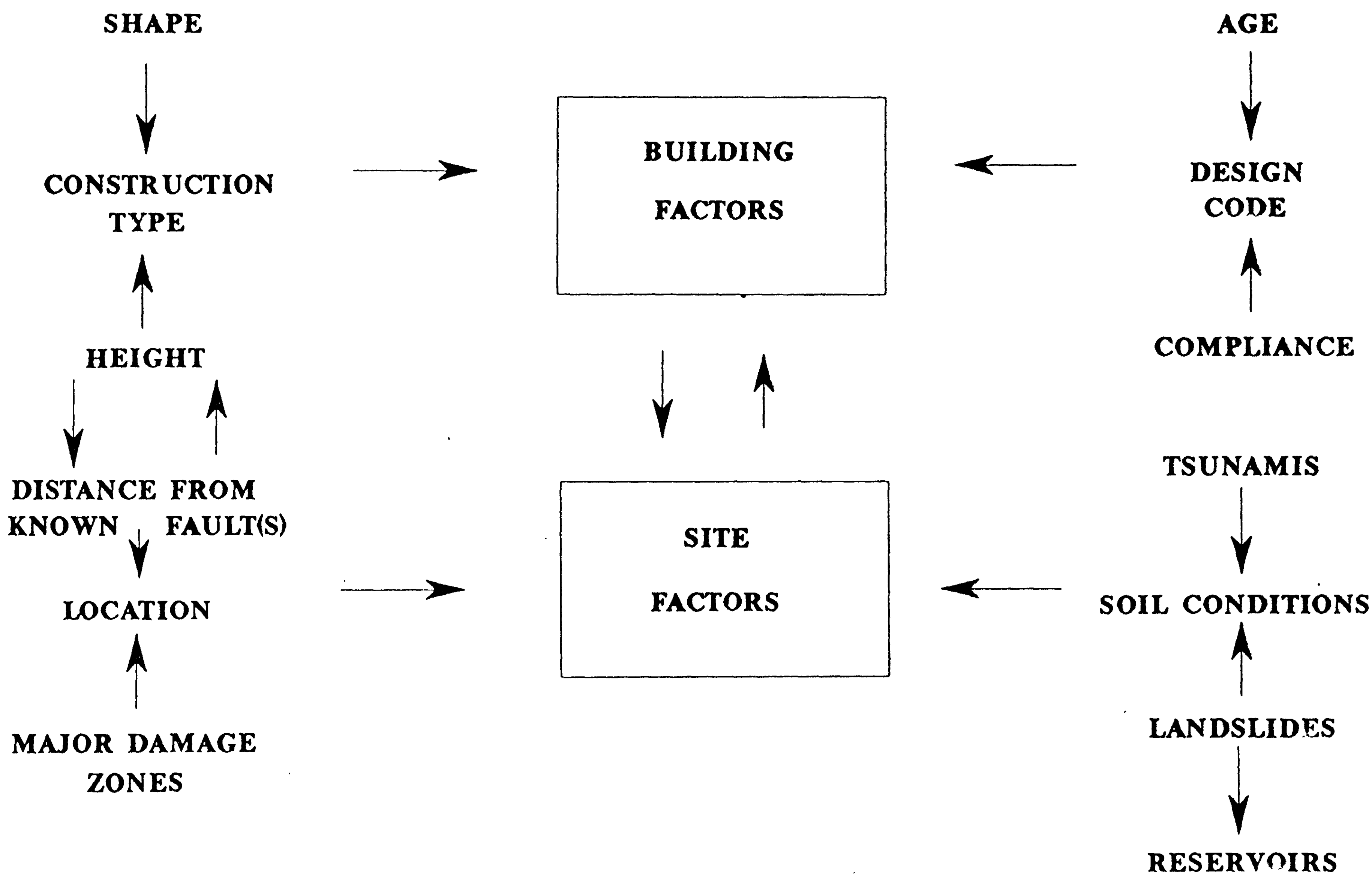
+

PROBABLE MAXIMUM LOSS

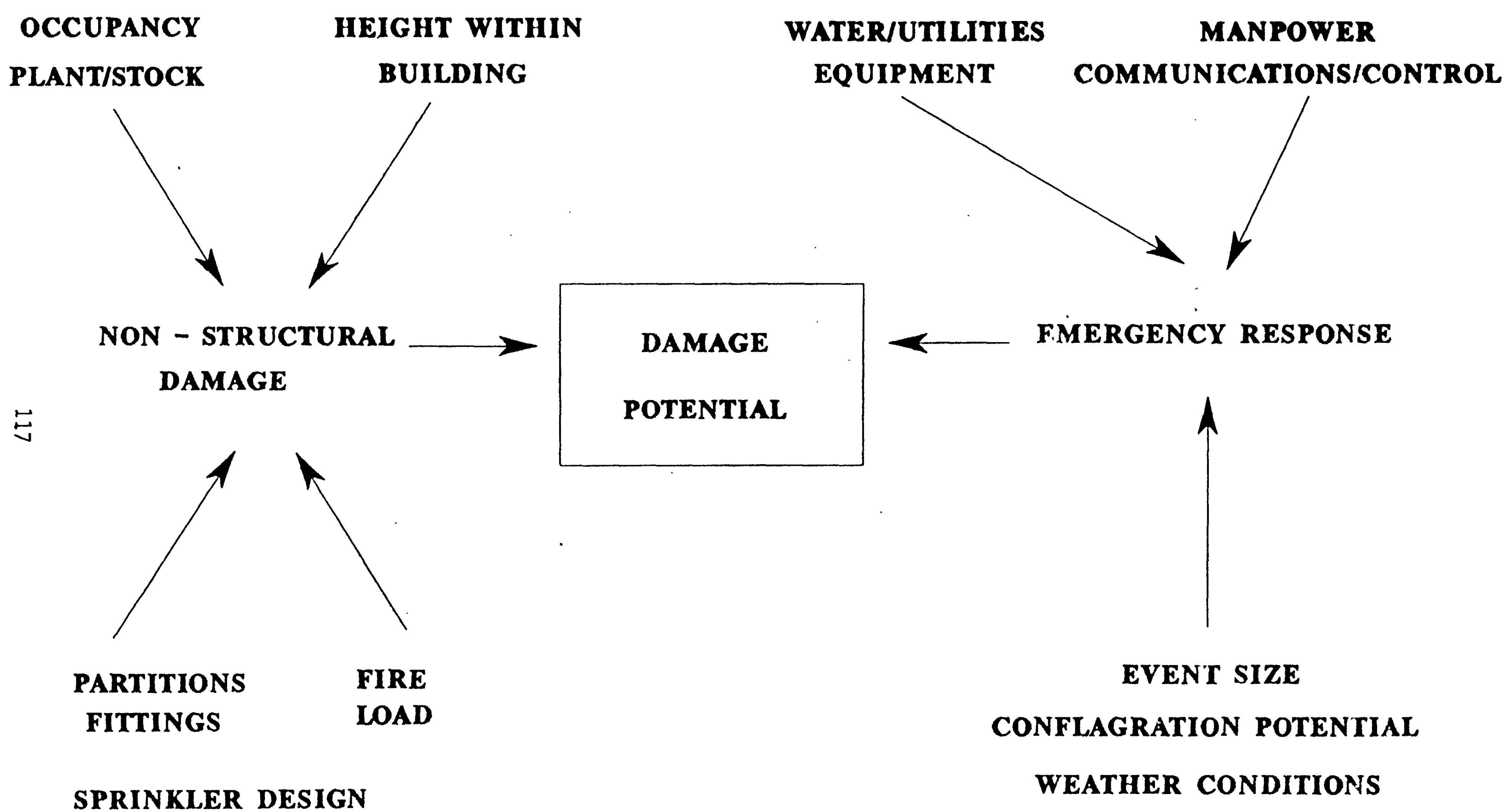
+

ZONAL AGGREGATES

CONCEPTS


SHAPE
CONSTRUCTION TYPE
HEIGHT
DISTANCE FROM KNOWN FAULT(S)
LOCATION
MAJOR DAMAGE ZONES
BUILDING FACTORS
SITE FACTORS
AGE
DESIGN CODE
COMPLIANCE
TSUNAMIS
SOIL CONDITIONS
LANDSLIDES
RESERVOIRS

CONCEPTS



OCCUPANCY
PLANT/STOCK
HEIGHT WITHIN
BUILDING
WATER/UTILITIES
EQUIPMENT
MANPOWER
COMMUNICATIONS/CONTROL
NON - STRUCTURAL
DAMAGE
DAMAGE
POTENTIAL
FMERGENCY RESPONSE
PARTITIONS
FITTINGS
FIRE
LOAD
SPRINKLER DESIGN
EVENT SIZE
CONFLAGRATION POTENTIAL
WEATHER CONDITIONS

INDIVIDUAL PROBABLE MAXIMUM LOSS

GROSS PML = TIV x BASIC PML x Q x L x S

TIV - Total Insurance Value

Basic PML - Building Construction Class

Quality of construction - age, shape, height vs type etc.

Location - distance from known faults

wave attenuation/height etc.

Fault maps Poor Ground Maps

Susceptibilty to non-structural damage

contents sensitivity/type

height within building

relative building vs contents vs B.I. values

NET PML = GROSS PML less DEDUCTIBLE

A RATING FORMULA

$$\text{RATE\%} = \frac{LE \times F \times V \times P \times 100}{SI \times R}$$

LE = Loss Expected from a single event corresponding corresponding to 'R' used.

F = factor reflecting costs, brokerage, profit

V= variance factor reflecting uncertainty in LE/R

P = Period of exposure eg P= 1 for annual policy

SI = Sum Insured

R = Return period of a single event liable to cause damage equivalent to LE

OR

Annual probability of event

CRESTA SUMMARY EQ INFORMATION

PUERTO RICO **JUNE 1984**

GEOLOGY: SURROUNDED BY HIGHLY SEISMIC ZONES TO E,N & WEST. ZONE OF TENSION BUILT UP BETWEEN N. AMERICAN & CARIBBEAN PLATES.
WHOLE ISLAND CONSIDERED ONED ZONE.

SUB SOIL: VERY BAD ALLUVIAL IN ZONES OF MAJOR CONCENTRATION (SAN JUAN).

HISTORY: 1946 - MM VI; 1906 - MM VIII (CATASTROPHIC); 1867 - MM VIII.

RETURN PERIODS: MM VII - 15/30 YEARS; MM VIII - 40/80 YEARS; MM IX - 160/320 YEARS.

BUILDING CODES: CODES OF 1954. "LESS RESTRICTIVE THAN CALIFORNIA ..... DESIGN ERRORS ...... POOR WORKMANSHIP" (ROA).

PLUS INSURANCE RELATED INFORMATION

CLAUSES	CO-INSURANCE
TARIFF RATES	DEDUCTIBLES
REPORTING REQUIREMENTS	COMMISSION
MAPS (FOR ACCUMULATIONS)	

ASSESSMENT OF EARTHQUAKE RISK
(For Purposes of Reinsurance)

By
S. T. Algermissen
U.S. Geological Survey
Denver, Colorado

From an earth science point of view and considering the general nature of reinsurance, it would seem that the most important information (listed in decreasing order of importance) for reinsurance companies might be the:

1. Potential for Catastrophe: The spatial distribution of ground motion and geological hazards (such as landsliding and liquefaction) associated with the larger earthquakes that might occur regionally and the probability of occurrence of such events. The characteristics of ground motion change with distance from an earthquake and consequently, the various types of structures are affected differently. For example, the 1985 earthquake that occurred near the west coast of Mexico severely affected high rise buildings in Mexico City but did very little damage to one story structures. Thus in considering the catastrophe potential for a single site or a number of sites, the ground shaking and geological hazards associated with an ensemble of earthquakes of varying distances from the site (or sites) must be considered and the associated losses (risks) for each earthquake evaluated.

   The catastrophe potential can be evaluated deterministically by the simulation of "scenario" earthquakes or probabilistically through the analyses of the maximum expected ground motion in some period of time for some level of probability. Regional probabilistic ground motion maps are also useful in establishing the relative hazard (and risk) among areas.

   Maps showing faults (or areas) where surface rupture may occur are important in special situations where critical facilities (dams, power plants, etc.) may be constructed close to or astride a fault and where failure of a facility might result in large losses.

2. Vulnerability: The spectra and duration of shaking associated with earthquakes change with increasing distance from earthquakes and are modified by the geotechnical properties of sites. It is therefore important to know what characteristics of earthquake ground motion are important in causing damage to a structure of a particular class (type of framing, construction materials, contents, etc.) Unfortunately, a great deal of additional research is needed to improve our understanding of vulnerability. Improved vulnerability information will become available through the dynamic analysis of structures and statistical surveys of damage to buildings after earthquakes.

3. Average Annual Loss: Average annual loss can be estimated both probabilistically and deterministically. This can be done by modeling earthquake sources, wave attenuation and site response using various hypotheses concerning the ground motion likely to affect a site or sites in some period of time of interest. For the United States, average annual loss for any area of interest could be derived from the basic data used by Algermissen and others, 1982, in the preparation of national probabilistic ground motion maps, provided appropriate inventory is available.

REFERENCE

Algermissen, S.T., Perkins, D.M., Thenhaus, P.C., Hanson, S.L., and Bender, B.L., 1982, Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U.S. Geological Survey Open-File Report 82-1033, 99 p., 6 pl.

INFORMATION NEEDS OF INSURANCE INDUSTRY (AS SEEN FROM A REINSURANCE COMPANY)

By

Bruno O. Porro
Swiss Reinsurance Company
Zurich, Switzerland

Two crucial questions have to be asked with regard to reinsuring the earthquake hazard:

1) Do I get enough premium to pay all the losses in the long run?

2) What amount of money might be due after a catastrophic event?

These questions can only be answered if information from different areas is combined in a meaningful way.

1) Seismology: frequency, magnitude-distribution, attenuation pattern of (MM) intensities, duration, geographical fault distribution with regard to insured values.

2) Vulnerability of insured items: building type, soil structure interaction design, building materials, contents, BI.

3) Insurance conditions: type of coverage (full value, first loss, layered policies), extent of coverage (shock, fire following, debris removal, earthquake induced material damage by landslides, settlement, liquefaction, etc.), type of deductible (amount, % of insurable value), indemnity limit, insured items (building, contents, loss of property inducing contingency coverage for supply/demand failure), loss adjustment (prices used in settlement of claims; post earthquake inflation). Beware of court decisions (concurrent causation).

4) Portfolio information: geographical distribution of (insurable) values with breakdown in buildings, contents, BI (CRESTA).

Information quality mentioned above has to be balanced, there is no sense in developing and applying very sophisticated seismological models if information about sensitivity of insured items and/or portfolio information is poor or wrong!

Areas where the U.S. Geological Survey could contribute to risk assessment:

-- Updating of earthquake catalogues (relocation of square hypocenter, new magnitude assignment).

-- Collection, assessment, interpretation (unification) and dissemination of pre-instrumental seismic information (isoseismal maps, estimated magnitudes).

-- Local geological conditions for areas with large value concentration (landslide/liquefaction/settlement potential, natural frequencies of subsoil).

-- Vulnerability of lifelines (roads, highways, bridges.)

-- Calculation/estimation of mean damage ratios for various building classes as a function of MM Intensity (or acceleration).

-- Building classification (vulnerability assessment) by investigation of buildings affected by damaging events.

EARTHQUAKE RISK:
INFORMATION NEEDS OF THE UNITED STATES INSURANCE INDUSTRY

FINAL COMMENTS ON SUGGESTIONS FOR BRAINSTORMING SESSION

by
William A. Hodges
American Sterling Insurance Company
El Torro, California

The comments and suggestions made by the group participants reflected a wide range of interests and needs for information about the earthquake risk in the context of the insurance industry. This diversity brought out clearly that all insurance companies are not uniform in the degree and kind of information they would like from the U S G S.

In attempting to satisfy some of those needs the U S G S would do well to learn about the different goals and objectives, the disparity of sizes of insurance companies, the resources that may already be available, and the differing degrees of progress that may have been made to date. In short, the industry is a diverse collection of thousands.

The comments made by the group seem to fall into four general categories:

1. Enhance the use and availability of existing materials and information.

   A great deal has already been done by the U S G S and others that would be useful to the industry if only it were in a different format or more knew about its existence.

2. Foster increased communication about the efforts and considerable accomplishments already achieved.

   This should be done in order to create additional interest and support in the area of earthquake research. As more people at the many levels within the industry and individual organizations become more aware of the progress in quantifying the EQ exposure, additional capital will be committed to writing insurance coverage and funding additional research.

3. Coordinate and integrate the various efforts of private and public sectors and international organizations which are involved.

   Some basic research work is being duplicated by the wide range of affiliated associations and individual organizations. At the same time many of the groups would probably welcome recommendations regarding work that still needs to be done.

4. Define and prioritize the remaining critical issues that need to be addressed.

   Since much research and analysis is still needed it is appropriate that the insurance industry participate in determining the priorities of that work.

Specific suggestions to accomplish the four general tasks were also forthcoming from the brainstorming session. There was some consensus that these projects are worth consideration.

1. Enhance use and availability.

   a. Translation service for users.
      This would be a Readers Digest of the literature on the subject. The digest would be two tiered to benefit users of differing backgrounds and needs, and would involve a degree of translation from scientific to user jargon.

   b. Usable maps.
      Such maps would be digitized for use with computers and would have the ability to locate by street address or nine digit zip code information pertaining to soil condition, ground motion, intensity zones and the like.

   c. Institutionalized database.
      All of the known underwriting data that presently exists in other public domain databases are consolidated and updated as additional information becomes available.

   d. Define generic earthquake probability and PML model.
      This computer model could be used by those insurance companies that lack the facilities to create their own. It could also become the basis of standardized format for capturing and transferring data between interested parties.

   e. Yellow pages.
      Publish a listing of the various organizations both public and private that have information and services useful to the earthquake research and insurance field and distribute widely.

2. Foster communication.

   a. Model Presentation.
      Create a model presentation consisting of visual materials and prepared script explaining the joint effort required to resolve the earthquake exposure. Speakers would communicate what is presently available to aid in the insurers underwriting analysis and solicit support for continued funding of basic earthquake research. This presentation would have an intended audience of senior insurance industry management and others that might be of influence in obtaining additional funding.

   b. Seminars.
      Continue to conduct interdisciplinary seminars to further the establishment of working relationships. Cross train scientists and insurers in needs, usage, and vocabulary.

3. Coordinate and integrate efforts.

   a. Clearing House.
      Conduct a campaign to identify the various associations dedicated to promoting earthquake research and promote the establishment of a communications clearing house.

   b. Publish a call for research.
      Publish an annual request for research that could be conducted by other associations or foreign governments. Cooperate in efforts by other foreign governmental agencies.

4. Define and prioritize remaining critical issues.

   a. Establish working groups.
      Call on industry members to participate in clarifying critical issues. Candidates for critical issues not already mentioned include: Recurrence, damage estimates, secondary loss estimates, vulnerability, obtaining insured inventories, and post earthquake investigations.

In summary, it became extremely clear that the participants saw the need to work together within the insurance industry and with the U S G S to enhance the knowledge about the earthquake risk. While there are some concerns about competitive advantage and proprietary information, most felt that the real problem to be addressed was how to increase the industry's capacity to insure the exposure. To that end, most participants seemed dedicated to improving the relationship between all parties involved.

EARTHQUAKE RISK: INFORMATION NEEDS OF THE INSURANCE INDUSTRY

by

Ake Munkhammar
Skandia International Insurance Corporation
Stockholm, Sweeden

Earthquake Risk: Information needs of the insurance industry.

Skandia International Insurance Corporation (SIIC) is a Swedish domiciled, international life and non-life insurer and reinsurer. In the the USA Skandia America operates as a reinsurer, but SIIC is active also as direct insurer in earthquake prone markets such as Colombia.

I would like to describe the information needs by firstly stating the ideal information situation and then discussing what in practice could be done to come as possible to the ideal situation.

1. Utopia. The ideal information situation in respect of earthquake risk

1.1 Potential loss information
Damage ratios on existing structures in a certain area for each probable EQ magnitude

This information should be split into:
- Shock damage on buildings and contents
- Fire following damage on buildings and contents
- Business interruption as a consequence of EQ

This information should in turn be grouped into:
- Losses to EQ shock insured structures
- Losses to Fire insured structures

In addition loss estimates are needed for non building risks such as Life, Personal Accident, Workers Compensation, Automobile Physical Damage and Marine Cargo policies.

1.2 Seismic hazard information

- The frequency of each probable damaging EQ magnitude
- The conditional probability for each EQ magnitude (considering the time lapsed since the last event)
- The attenuation pattern of Ground Motion

1.3 Tsunami (and volcanic eruption) hazard information

- The frequency of probable damaging tsunamis (and eruptions) affecting the area

With this information available the insurer would be able to set correct rates, encouraging clients with well designed buildings situated on firm ground at an appropriate distance from the faults.

Insurers with risks of a less satisfactory character would have to pay correspondingly higher rates.

Furthermore, the insurer would know the maximum loss he would have to face and, depending of his risk willingness, he could design a catastrophe protection program allowing him to optimize the use of his risk capital.

It would also give the insurer a chance to give his reinsurer correct risk information so the reinsurer in his turn does not overexpose himself, thereby making his claims paying ability questionable.

For the reinsurer this ideal information would permit correct pricing of the protection provided and a possibility to optimize his capacity in the same way as for the insurer above.

2. What can practically be achieved in the foreseeable future?

2.1 Potential loss information

- Shock damage to structure

  Today, the damage ratio estimates are often based on Mercalli intensities, for which return period are calculated.

  However, the Mercalli intensities, are seldom exactly defined geographically. Therefore also damageability curves such as the Sauter & Shah curves are difficult to apply on an inventory of risks.

  Would it be possible to map the expected (damaging) ground motion (acceleration and velocity) at specific locations (postal codes)? Both expected peak values and ranges of lower values should be presented with the expected frequency of recurrence.

  Furthermore one needs to translate the ground motions into damage ratios to structures.

  I understand that USGS after the Whittier EQ 1987 has started to collect information about damaged buildings in relation to the total inventory of buildings. Can we find a proper forum to collect the same information for losses on contents and for loss of profits?

- In respect of fire following EQ loss potential, the only systematic estimation approach I have seen is the AIRAC study. Can this very important element be further developed by collecting the insurance industry's experience?

2.2 Seismic hazard information

At least for interplate EQ's it would seem possible to estimate the expected frequency of various EQ magnitudes for each location. Can this information be transformed into expected frequency of recurrence of damaging ground motion taking the subsoil conditions into consideration?

For intraplate EQ's I suppose one just has to add a loading factor in the rating formula.

2.3 Tsunami (and volcanic eruption) hazard information

For tsunami exposed areas the probability could be estimated as done by Rikitake and Aida (see following reprint, "Tsunami Hazard Probability in Japan"). In addition one must of course calculate the insured damage resulting from the expected tsunamis.

Can any meaningful probability calculations be made for volcanic eruption?

If we can find good answers to these questions the EQ peril would become insurable!

Bulletin of the Seismological Society of America, Vol. 78, No. 3, pp. 1268–1278, June 1988

TSUNAMI HAZARD PROBABILITY IN JAPAN

BY T. RIKITAKE AND I. AIDA

ABSTRACT

An analysis of future tsunami hazard on the coast of the Japanese Islands is made in terms of probability for a coastal site being hit by a tsunami, of which the wave height exceeds a certain level during a period from 2000 to 2010. Tsunami wave height at a site on the Pacific coast is estimated mostly based on numerical experiment, in which a typical fault model of the tsunami-generating earthquake is assumed. Meanwhile, probability of the tsunami-generating earthquake occurring during 2000 to 2010 is evaluated either from historical data of earthquake occurrence or from near-shore crustal strain accumulation.

Combining the wave height estimate with the probability evaluation of tsunami occurrence, probabilities of a site being hit by a tsunami, of which the wave height exceeds certain levels, are evaluated on the Pacific coast. It seems that the probability for a violent tsunami, of which the wave height exceeds 5 m, is highest along the Pacific coast in central Japan, reaching a value of 41 per cent. On the other hand, a probability value as high as 69 per cent is found for a moderately large tsunami having a wave height of 1 m or so along the Shikoku and Kyushu coasts.

A crude probability evaluation is also made for tsunamis on the Japan Sea coast, where tsunami activity is substantially lower than that of the Pacific coast. The probability for a violent tsunami seems to amount to only 1 per cent or so for a 10-yr period. Similar probabilities for tsunamis excited by a distant source off Peru, Chile, Kamchatka, and Aleutian-Alaska are also evaluated. In this case, probabilities of tsunami wave height exceeding 1 and 3 m are, respectively, evaluated as 19 and 15 per cent on the Pacific coast, such probabilities being not quite negligible.

INTRODUCTION

In contrast to seismic zoning or earthquake hazard analysis, very few analyses of future tsunami hazard have been conducted in Japan. Probably, the work by Takahashi (1951) is the only quantitative estimate of future tsunami damage on the Pacific coast of the Japanese Islands. The degree of future hazard is defined by the sum of squares of tsunami wave amplitude expected at a site on the coast during a 100-yr period. Assuming that the period of tsunami wave is approximately constant, the aforementioned quantity is proportional to tsunami wave energy that reaches the site concerned. Since the estimate relies on the historical record, it can be applied to the future only on the condition that the tsunami activity in the past can be extended to the coming 100-yr period.

Aida (1969) conducted a numerical experiment on tsunami wave generation and propagation based on the sea-bottom deformation caused by an earthquake. By now, such computer simulation of tsunami waves has developed so markedly that highly plausible wave height and form on a 200 m depth contour can be obtained based on an earthquake fault model determined seismometrically.

Meanwhile, it has in recent years become possible to evaluate probability of a major offshore earthquake occurring in seismic areas adjacent to the Japanese Islands on the basis of recurrence time of earthquakes and/or accumulation of near-shore crustal strain (Wesnousky *et al.*, 1984). Although the accuracy of such evaluation is not always high, it is important that something can be said about future occurrence of major offshore earthquakes in terms of probability.

Combining numerical tsunami experiment and probability evaluation of offshore earthquake occurrence, it is possible to evaluate the probability of having a tsunami, of which the maximum water elevation exceeds a certain value, at a site on the coast provided various parameters of the earthquake fault model are given. As there are a number of potential tsunami sources, probabilities for all the sources are to be synthesized. The overall probability of tsunami hazard at any site on the coast will thus be evaluated.

The previously mentioned probability evaluation will here be applied to tsunami arising from sources off the Pacific coast of the Japanese Islands. Attention should be drawn to the fact, however, that a major tsunami sometimes occurs in the Japan Sea, although less frequently. Even a tsunami from very distant sources, such as from South America, Aleutian Islands, Kamchatka, and so on, sometimes hits Japan. A crude evaluation of hazard probability for tsunamis of these kinds will also be made in this paper.

Tsunami Waves Arising from a Typical Fault Model

Imminence of a great earthquake of magnitude 8 or so occurring in the Tokai (literally east sea) area off the Pacific coast of central Japan has become widely accepted not only by seismologists but also by the public at large in recent years. One of the most likely fault models of the anticipated earthquake, which is certainly associated with the subduction of the Philippine Sea plate, would be the one shown in Figure 1. The fault plane having a length of 130 km and a width of 60 km dips down to the west with an angle of 34° from the horizontal plane. The upward slip of the western side of the fault at the time of earthquake occurrence would amount to 3.8 m along the dipping plane, while a 1.3 m left-lateral slip would take place in the strike direction of the fault. The seismic

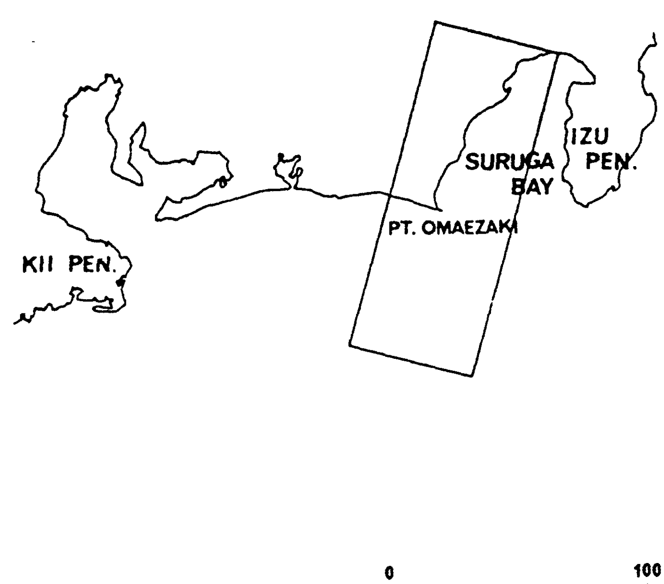


FIG. 1. Horizontal projection of the fault model for the hypothetical Tokai earthquake.

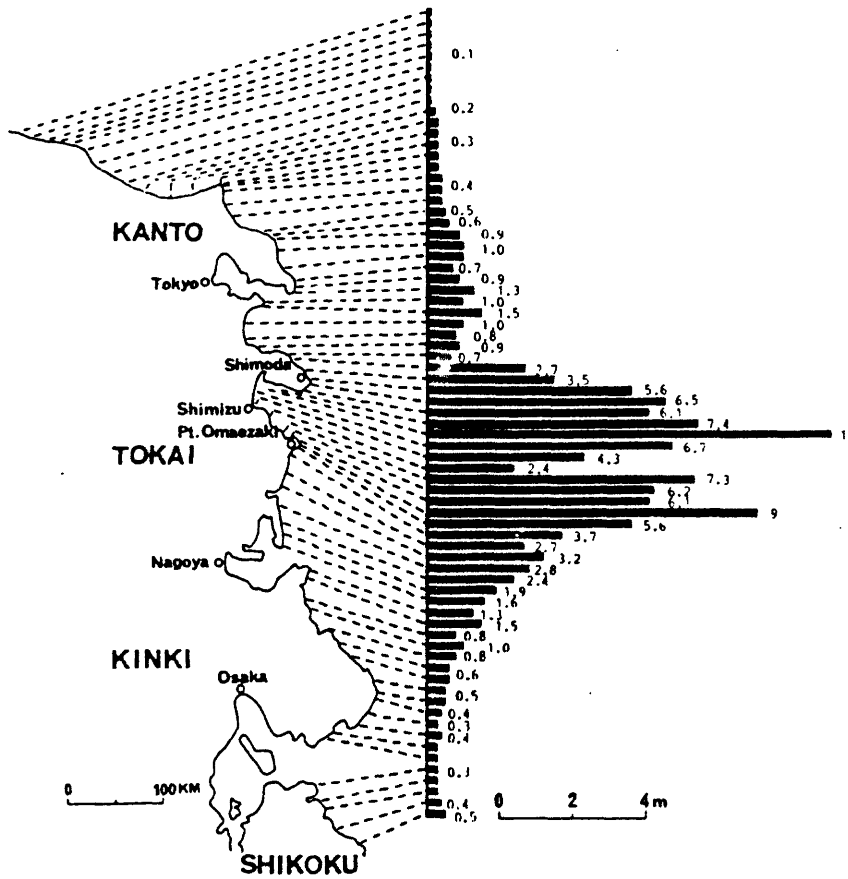


FIG. 2. Wave height distribution of the tsunami excited by the hypothetical Tokai earthquake of which the fault model is shown in Figure 1.

moment would amount to 1.56×10^{28} dyne-cm, which corresponds to a moment magnitude of 8.1. The model is a slightly modified version of the one proposed by Ishibashi (1981).

Aida (1984) estimated the behavior of tsunami wave on the 200 m depth contour based on the previously mentioned fault model. The wave height, which is defined by the total amplitude of the first wave, is then converted into the wave height at the nearest shore, taking into account the amplification factor during wave propagation over the continental shelf (Aida, 1977). In such a way, tsunami wave heights, that are likely to hit the Pacific coast in association with the hypothetical Tokai earthquake, can be estimated. In Figure 2 are shown the wave heights thus estimated at various seashore sites. Very large wave heights exceeding 5 m are to be observed at sites close to the fault assumed.

TSUNAMI-GENERATING EARTHQUAKES

Figure 3 shows the seismic zones from which major tsunamis on the Pacific coast are originated. The tsunami associated with the hypothetical Tokai earthquake is generated at the easternmost portion of zone VII. According to the existing studies on earthquake origin (Iida, 1983), typical fault models can be assigned to zones I, III, VI, VII, and VIII, although the details of those models are put aside here for the sake of brevity (Aida, 1984). Probable tsunami wave heights from these sources can then be estimated on the Pacific coast in a fashion similar to the last section. For other zones, no representative models of tsunami source are known. However, wave height on the coast can be approximately inferred from the actual data of typical tsunamis in the past. It is therefore possible to estimate tsunami wave height at various sites on the Pacific coast on the condition that a tsunami is generated from one of the zones shown in Figure 3.

We are in a position to see how often a tsunami-generating earthquake occurs from the cited zones. Probability of a major earthquake of $M = 7$ or over occurring in respective zones is evaluated primarily on the basis of historical records. When the number of historical earthquakes is sufficiently large, we make use of a Weibull distribution analysis for estimating mean recurrence period and thus occurrence probability. Meanwhile, we have to rely on a Poisson distribution in the cases of scarce data on the assumption that earthquake occurrence is stationary and random. Weibull distribution analysis is widely used in quality control engineering and was first introduced into the earthquake prediction study by Hagiwara (1974). The analysis is different from the Poisson distribution analysis because the probability increase after a particular earthquake can be evaluated.

Zone I, or the seismic area off Hokkaido-Kurile, can be divided into six subareas, each of which having been a seat of major earthquakes in the past. A Weibull distribution analysis of recurrence period is made for the data set as a whole, while a fault model that represents that of the 1952 Tokachi-Oki earthquake ($M = 8.1$) is chosen as the typical tsunami source. As major earthquakes have already occurred in the 1950's, 1960's, and 1970's in all of these subareas, the probabilities of having a major earthquake off Hokkaido-Kurile during a period from 2000 to 2010 are not high as can be seen in Table 1.

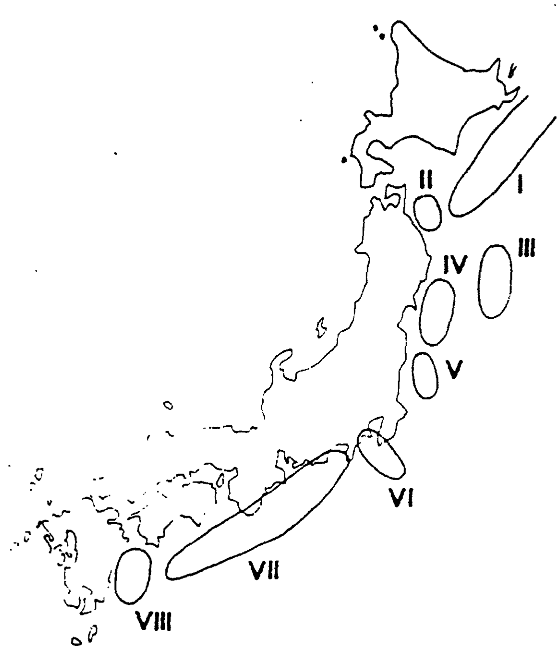


FIG. 3. Seismic zones for major tsunami-generating earthquakes off the Pacific coast of the Japanese Islands.

For zone III, from where the great 1896 Meiji Sanriku and 1933 Showa Sanriku tsunamis were originated, a fault model equivalent to that of the 1896 one is assumed, although the source location is somewhat shifted to the south because a conspicuous seismic gap exists there.

No historical data for evaluating occurrence probability of a major earthquake are available for zone VI. However, the crustal strain monitoring over the Sagami Bay area to the southwest of Tokyo is useful for probability evaluation. As for the fault model, the one for the 1923 Kanto earthquake ($M = 7.9$) is adopted.

For the easternmost portion of zone VII, both historical data and crustal strain are available. The fault model assumed is already shown in Figure 1. The probability of having a great earthquake there exceeds 40 per cent for the 10-yr period in question. As for the middle and southern parts of zone VII, the probabilities are small because the 1944 Tonankai ($M = 7.9$) and 1946 Nankai ($M = 8.1$) earthquakes have already occurred there, respectively. In view of the small probabilities, the height of the tsunami wave from these parts of the zone is estimated by means of interpolation of the 1944 and 1946 tsunami data.

Zone VIII is known for frequent occurrences of earthquakes having a magnitude around 7, so that a fairly high probability is obtained (Table 1). As for the fault model, the one for the 1968 Hyuganada earthquake ($M = 7.5$) is adopted.

No fault models are specified for zones II, IV, and V, but tsunami wave heights from these sources are estimated based on tsunami data in the past. Only a tsunami of 1 m or so in wave height is expected from these source areas.

Overall Tsunami Hazard Probability

The information presented in the previous two sections makes it possible to evaluate the probability of tsunami wave height exceeding a certain level at a seashore site during a period from 2000 to 2010, as will be shown in the following.

As an example, let us evaluate the tsunami probability at Shimoda near the extremity of Izu Peninsula (see Figure 2). According to Figure 2, the wave height due to the coming Tokai earthquake at Shimoda amounts to 5.6 m. On the other hand, the probability of the said earthquake occurring during the period in question is evaluated as 0.41 (Table 1). The probabilities for Shimoda being hit by a tsunami wave caused by the hypothetical Tokai earthquake are then evaluated for wave heights equal to or larger than 0.5, 1, 2, 5, 7, and 10 m as 0.41, 0.41, 0.41, 0.41, 0, and 0, respectively.

The respective probabilities at the same site due to the Kanto earthquake or the earthquake arising from zone VI are obtained as 0.22, 0.22, 0, 0, 0, and 0. Similarly, the respective probabilities for the middle portion earthquake of zone VII are evaluated as 0.05, 0.05, 0.05, 0, 0, and 0. Meanwhile, those for the southernmost portion earthquake of zone VII amount to 0.04, 0.04, 0.04, 0, 0, and 0. No tsunami wave height exceeding 0.5 m is expected at Shimoda from other tsunami-generating areas shown in Figure 3.

Denoting the probability of tsunami wave height exceeding a certain level due to a tsunami from the ith area by p_i, the synthetic probability p is estimated by

$$p = 1 - \prod_{i=1}^{n} (1 - p_i) \tag{1}$$

where n is the total number of tsunami-generating areas. Applying equation (1)

TABLE 1

PROBABILITIES OF A LARGE EARTHQUAKE OCCURRING FROM OFFSHORE EARTHQUAKE AREAS DURING 2000 TO 2010*

No.	Earthquake Area	Mean Latitude (°N)	Mean Longitude (°E)	Mean Magnitude	Year of Last Earthquake	Mean Return Period (yr)	Probability for 2000–2010	Remark
Ia	Off Hokkaido -Kurile	44.5	151.2	7.9	1963	85.3	0.037	W
Ib		44.0	149.0		1958		0.050	
Ic		43.3	147.6		1969		0.021	
Id		42.6	146.2		1973		0.017	
Ie		42.2	144.6		1952		0.070	
If		40.7	143.6		1968		0.026	
II	Off Aomori Prefecture	40.7	142.4	7.3	1945	69	0.14	P
III	Off Sanriku	39.4	144.4	7.9	1933	107	0.089	P
IV	Off Miyagi Prefecture	38.2	142.0	7.4	1978	34.9	0.28	W
V	Off Fukushima Prefecture	37.2	141.6	7.5	1938	146	0.066	P
VI	Sagami trough	34.7	139.8	8.0	1923	159	0.22	W
VIIa	Nankai trough	34.7	138.3	8.0	1854	117	0.41	W
VIIb		33.9	136.8		1944		0.045	
VIIc		32.9	134.4		1946		0.042	
VIII	Hyuganada Sea	32.1	132.1	7.0	1984	7.2	0.68	W

* P and W in the last column indicate that Poisson and Weibull distributions are used, respectively.

TABLE 2

SYNTHETIC PROBABILITIES OF TSUNAMI WAVE EXCEEDING THE KEY HEIGHTS AT SHIMODA

Tsunami Wave Height (m)	Probability
≧0.5	0.58
≧1	0.58
≦2	0.46
≧5	0.41
≧7	0
≧10	0

to the probabilities for Shimoda, the synthetic probabilities of tsunami wave exceeding respective heights are evaluated (Table 2).

Similar probability evaluations are made for key sites along the Pacific coast of the Japanese Islands as shown in Figures 4, 5, 6, and 7 for Hokkaido, Tohoku, Kanto-Chubu-Kinki-Shikoku, and Shikoku-Kyushu coasts, respectively.

It is observed from these figures that the highest probability of tsunami wave having a height of 5 m or larger is expected for the Pacific coast of central Japan. Most seashore sites in Shizuoka Prefecture are characterized by a probability higher than 40 per cent during the 10-yr period in question. Such a high probability is certainly brought about by the anticipated Tokai earthquake that is feared to occur in the near future. There are also a few sites, where a wave height exceeding 5 m is expected on the southernmost coast of Hokkaido and the Sanriku area in Tohoku of North Japan, although the probabilities are smaller than 10 per cent.

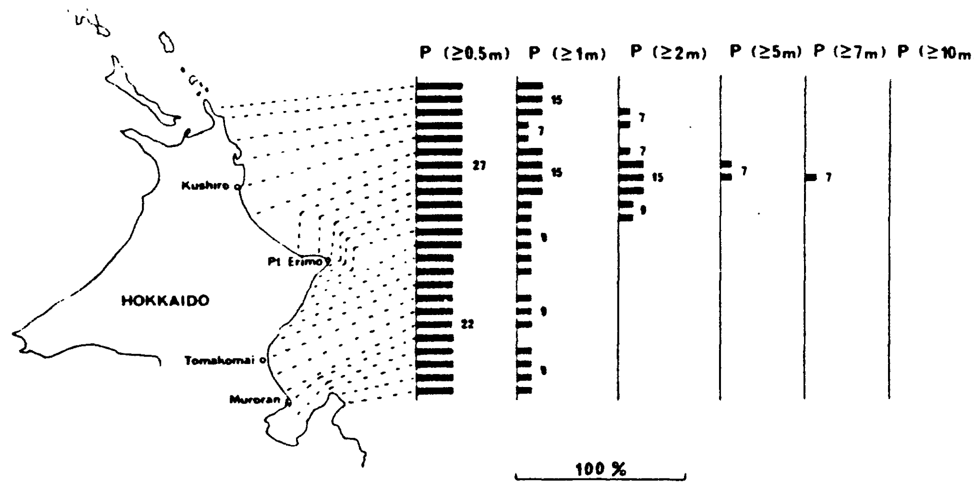


FIG. 4. Probabilities for the Pacific coast of Hokkaido being hit by a tsunami of which the wave height exceeds respectively 0.5, 1, 2, 5, 7, and 10 m during a period from 2000 to 2010.

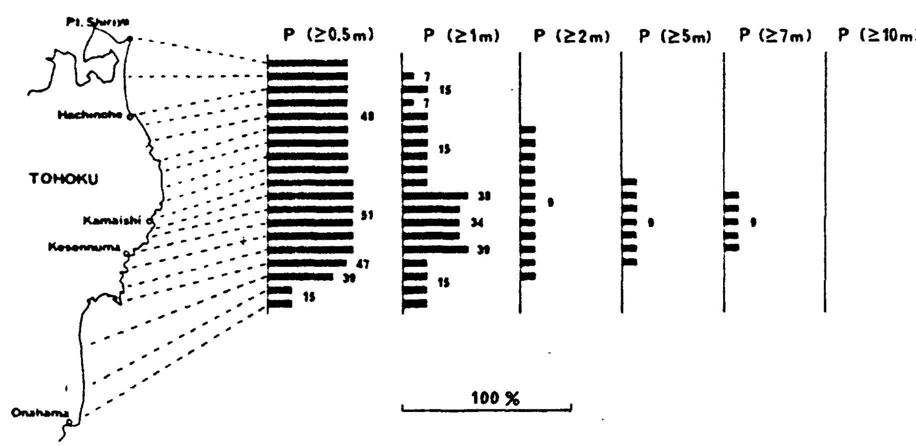


FIG. 5. Tsunami probabilities for the Pacific coast of Tohoku. Other legends are the same as those for Figure 4.

As for tsunami waves having a height of 1 m or thereabout, a high probability amounting to 69 per cent is assigned to the Pacific coast of Shikoku and Kyushu because of frequent Hyuganada earthquakes in zone VIII. It is therefore said that the worst sites for a highly dangerous tsunami are located on the Pacific coast of central Japan and that such sites for a moderately dangerous tsunami are found on the Shikoku and Kyushu coasts.

We also see that probabilities of being hit by a tsunami having a wave height of 0.5 to 1 m exceed 50 per cent at most seashore sites except Hokkaido. This means that the possibility of moderate tsunami hazard cannot be ignored along the whole Pacific coast of the Japanese Islands.

TSUNAMI HAZARD ON THE JAPAN SEA COAST

The tsunami associated with the 1983 Nihonkai Chubu earthquake (M = 7.7) that occurred underneath the Japan Sea off Akita Prefecture killed 100 people.

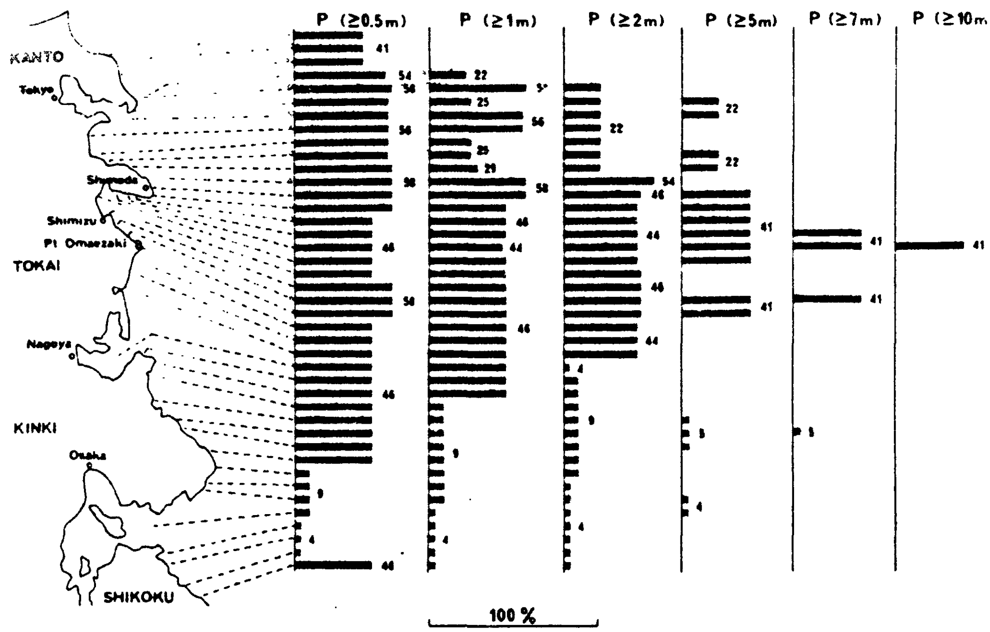


FIG. 6. Tsunami probabilities for the Pacific coast of Kanto-Tokai-Shikoku. Other legends are the same as those for Figure 4.

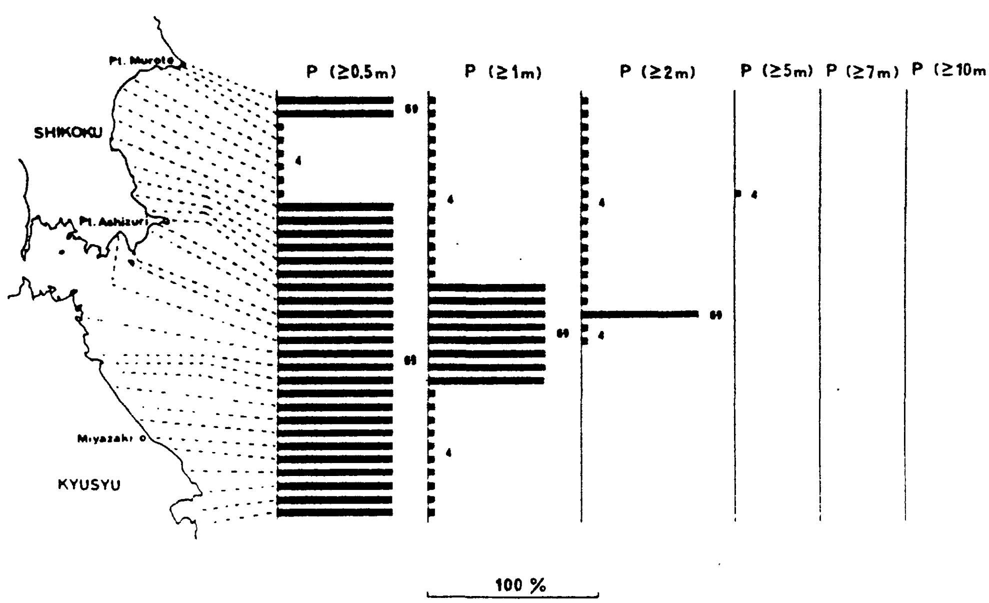


FIG. 7. Tsunami probabilities for the Pacific coast of Shikoku-Kyushu. Other legends are the same as those for Figure 4.

Maximum water height locally exceeded 10 m at some beaches. In view of this and a few violent tsunamis found in Japan's history, hazard analysis is also important for tsunamis occurring in the Japan Sea.

In contrast to offshore earthquakes on the Pacific side of the Japanese Islands, it is no easy matter to evaluate occurrence probability of tsunami-generating earthquakes located in the Japan Sea because occurrence frequency is extremely small. The available history is too short for discussing the recurrence period. Nevertheless, Shimazaki (1984) attempted to estimate recurrence periods based on the size of epicentral areas and historical records for the past 400 yr and concluded that an earthquake equivalent to the 1983 event probably recurs every 600 to 1200 yr.

Kanamori and Astiz (1985), who relied on the relation between age of subducting plate and aseismic slip, estimated a recurrence period of the 1983 earthquake as 600 to 1370 yr.

Let us assume that the mean recurrence period is 1000 yr. When a Poisson distribution is assumed, the probability of this class of earthquake occurring in the Japan Sea amounts to about 1 per cent for a 10-yr period. As the area occupied by the northern half of the Japan Sea may accommodate approximately four earthquakes of this class, the probability amounts to 4 per cent for the northern half of the Japan Sea. No great earthquakes occur in the southern half of the sea.

Wave height of the tsunami excited by an earthquake of the previously mentioned class exceeding several meters, the probability of a 100 to 200 km segment of Japan Sea coast being hit by a tsunami having a wave height of several meters, is evaluated as 1 per cent or so for a 10-yr period.

Tsunamis of somewhat smaller scale, which are characterized by a wave height of about 1 m or thereabout, occur approximately every 10 yr or so in the Japan Sea as inferred from the historical record. Assuming a Poisson distribution, the probability of having at least one tsunami of this class occurring in the Japan Sea amounts to 50 per cent for a 10-yr period, so that the probability of such a tsunami hitting a coastal segment of 100 km in length is about 3 per cent.

TSUNAMIS FROM DISTANT SOURCES

A tsunami caused by a great earthquake (M = 8.5, 1960) that occurred off Chile gave rise to much damage to Japan. The maximum tsunami height along the coast of Japan was reported as large as 4 m. The numbers of dead and missing people were 119 and 20, respectively. It is therefore important to estimate possible tsunami hazard due to an earthquake that occurs at an extremely distant locality.

According to an evaluation based on a Poisson distribution, great earthquakes that generate tsunamis that affect Japan occur off Peru and Chile, with a probability of 27 per cent for a 10-yr period. On the basis of such probability value, it is evaluated that the probabilities of a tsunami with a wave height that exceeds 0.5, 1, and 3 m, hitting the Pacific coast of Japan, amount to 26, 14, and 4 per cent, respectively.

Similar probabilities for a tsunami from Kamchatka and Aleutian-Alaska are evaluated as 15, 6, and 3 per cent, respectively. Combining the effects of the two sources, probabilities of tsunami wave height exceeding 0.5, 1, and 3 m are, respectively, evaluated as 37, 19, and 15 per cent on the Pacific coast of Japan for a 10-yr period. It should be stressed that the tsunami probabilities from distant earthquakes thus evaluated are not quite smaller than those from near offshore earthquakes as shown in Figures 4 to 7.

CONCLUSIONS

Combining occurrence probability of offshore earthquakes with tsunami wave height estimated at seashore sites, the probability of tsunami wave height exceeding a certain level is evaluated on the Pacific coast of the Japanese Islands. It seems that probability of a violent tsunami, of which the wave height exceeds 5 m, hitting the coast of the Tokai area in central Japan, amounts to about 40 per cent for a 10-yr period from 2000 to 2010. Such a high hazard probability is due to the earthquake that is expected to occur off the Tokai area sooner or later. The probability of the earthquake occurring within the 10-yr period from 1988 is evaluated as 30 to 35 per cent. As for the probability of a moderately large tsunami having a wave height of 1 m or so, the highest value around 70 per cent is found at some sites on the Shikoku and Kyushu coasts because of fairly frequent occurrence of moderately large earthquakes in the Hyuganada Sea.

It also should be borne in mind that a tsunami originated by a great earthquake that occurs in the north Pacific and off South America sometimes affects the Japanese Islands. According to a crude evaluation, probabilities of a tsunami from such a source hitting the Pacific coast of the Japanese Islands amount to 19 and 15 per cent for a 10-yr period, respectively, for wave heights exceeding 1 and 3 m. Such probabilities are not quite negligible in comparison with those for tsunamis from offshore earthquakes in the vicinity of Japan. It is therefore necessary to modify the graphs in Figures 4 to 7 in such a manner as to make all of the probability columns a little taller.

Tsunami probabilities on the Japan Sea coast are considerably lower than those on the Pacific coast because of low seismicity in the Japan Sea area. A tsunami having a wave height of several meters hits a seashore site on the northern half of Japan Sea coast with a probability of 1 per cent or so for a 10-yr period. For a moderately large tsunami, of which the wave height amounts to about 1 m, the probability is evaluated as 3 per cent. Tsunami probability is almost zero for the southern half of the Japan Sea coast.

The tsunami hazard probability evaluated in this paper may be used for planning public evacuation from a tsunami area, selecting coastal sites for construction purposes or estimating rates for tsunami insurance.

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Association for the Development of Earthquake Prediction
3, Kanda Mitoshiro-cho
Chiyoda-ku, Tokyo, Japan

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INFORMATION NEEDS OF THE INSURANCE INDUSTRY: PERSPECTIVE OF CORPORATE PLANNERS

By
Paul F. Lenzi
Continental Insurance
New York, New York

Corporate financial planners in the insurance industry tend to ask deceptively simple questions in seeking to quantify potential impact of natural catastrophe. Invariably, insurers look to their underwriters and actuaries for responses to: Where? When? How Big? and How Often? Regardless the difference in subject of inquiry (i.e. earthquake, hurricane, tornado, flood, wildfire, volcanic eruption, landslide, subsidence, etc.), the relative frame of reference remains the same - "policyholder surplus" (PHS) - a traditional insurance accounting phrase which describes, in essence, an insurer's net worth and its capital vitality.

Unlike more statistically predictable loss scenarios, the very elusiveness of catastrophe probability has caused standardized financial accounting practices to prohibit insurers from setting aside (reserving) portions of their premium income to fund potential catastrophe.

If a loss were to occur of a size exceeding the amounts routinely reserved from premium income for actuarially anticipated loss levels, PHS would have to be drained to satisfy claims. In theory, then, an underwriter assuming a single risk as large as his or her company's surplus would be "betting the corporation" on that decision. In fact, it wouldn't take nearly so large a risk to threaten company survival. There are various reasons for this, but chief among them is another financial accounting device known as the "premium-to-surplus ratio" (P:S). The greatest interests in an insurer's financial stability are vested in its policyholders, investors and government regulators. A series of financial tests have developed over time which are employed to ascertain and publicly proclaim that an insurer remains fit and capable of meeting its loss commitments, or not. P:S is a key element of such tests, albeit not the only one. Nonetheless, understanding it can serve to illustrate financial impact considerations.

Drawn from historic implications that each premium dollar supports a given multiple of exposed risk dollars, and the recognition that "spread of risk" is a natural element not only of fundamental underwriting concept but, as well, of a highly competitive marketplace where individual insurers rarely have more than several percent market shares - P:S criteria have been established as financial stability indicators. While it varies by type or line of insurance, an approximate cumulative standard ceiling for a typical Property & Casualty (P&C) insurer is a P:S of 3:1. Should its ratio rise higher, particularly if it does so alone and not in concert with some industrywide development, the insurer would draw consternation from its regulators and investors who'd presume it was probably taking in more risk than it might ultimately be able to bear.

The potential drain of PHS, then, to pay catastrophe claims and costs means that the insurer might have to drop as much as $3 in premium from its rolls for every $1 of drained surplus. By way of illustration, a simple example of a hypothetical mid-sized P & C company in this situation could look like this:

Assume - $500 Million Surplus Position
$1.5 Billion Annual Written Premium Volume
3:1 Premium: Surplus Ratio
Good Financial/Regulatory Standing
50 cents Avg. Premium Rate per $100 Risk Exposure

If a catastrophe loss surplus call were unexpectedly made for $250 Million, the insurer might face need to cancel $750 Million of its premiums, or half of its customers, in order to remain financially viable. The likelihood of general premium rate increases throughout the industry as a first step toward loss recoupment and a period of gradual surplus replenishment could exacerbate the situation. If the average increase were 20%, that insurer might have to further cancel 20% of its remaining customers. Despite its residual PHS and premium writing capacity, the reputation of our hypothetical insurer would hardly remain marketable.

From a pre-loss perspective, the 50 cent rate assumption implies this company has a total of $300 Billion in insured risk exposures. Here, the spread of risk concept becomes poignant. If it underwriters allow so much as .0008 of that exposure to accumulate at risk of a single loss occurrence, the illustrated $250 Million PHS threat becomes real and corporate survival becomes subject to nature's whim.

All of this makes pre-loss planning critical to the development of alternative responses which will be more responsible and effective than the wholesale cancellation of insurance protection. One such traditional alternative has been the reinsurance mechanism, which provides for a rudimentary version of "catastrophe reserving" through the transfer of risk and premium portions from insurers to reinsurers. However, the same financial considerations ultimately apply to each. If and when the potential size of catastrophic loss looms large enough to threaten the combined financial resources of insurers and reinsurers, both the "science" of risk evaluation and the "art" of risk assumption will have need of significant overhaul. The questions I put to the forum are, "Do we yet know enough to determine when that point may be reached?" and "If so, how best can we employ that knowledge in the form of more equitable and prudent business practices going forward?"

Now, I'd like to present for panel discussion an array of the specific considerations which any diversified multiple line insurer must address in seeking the answers to those simple financial questions. The process is complex, even for the least diversified insurers, and relies squarely upon the ability to accurately predict the scope of initiating damage.

In order to assist insurance and other financial sector underwriters evaluate these respective potential costs of an earthquake catastrophe, the scientific community should consider providing its analyses in the following ways:

1. Geographic definition of all seismic zones which carry measurable probability of sustaining a 6.0 or greater Richter magnitude earthquake, where that probability is at least 30% in the ensuing 50 years.

2. Range of probabilities those same events will occur in alternatively earlier time periods of 40, 30, 20 and 10 years.

3. Range of probabilities those same zones will sustain alternatively higher Richter magnitude events, regardless of time period; i.e., from 6.0 to 9.0 in increments of 0.5.

4. Something along the lines of a universal property damage index; perhaps in the form of matrices that would correlate construction and soiling characteristics with distance to faulting and ground motion/acceleration variables--for each Richter magnitude per #3 above.

5. A similar universal index for bodily injury estimation; perhaps also in the form of matrices that would correlate population densities and structural "landscape" characteristics with distance to faulting and ground motion/acceleration variables--for each of the Richter magnitudes in focus.

6. Site specific evaluations, as may be applicable to the zones defined in #1 above, of local exacerbating conditions that could significantly increase the loss of property and people beyond the universally modelled estimates in #4 and #5 above; i.e., coastal tsunami, inland flooding, dam break, landslide, etc.

I believe that information of this type, in this format, would help place those financial planners with their questions within reach of the answers.

PLANNING TO INCORPORATE KNOWLEDGE ON NATURAL HAZARDS

By
Walter W. Hays
U.S. Geological Survey
Reston, Virginia 22092

INTRODUCTION

Corporate planning to deal with natural hazards is essential because throughout history, naturally occurring event having a geologic-atmospheric-hydrologic origin have caused and are continuing to cause a heavy toll of death, destruction, and economic loss. Many of these events have a short duration, ranging from seconds to weeks, and the potential for causing great sudden loss. Other events have a duration ranging from weeks to years.

In the past 20 years, short-duration events such as, earthquakes, volcanic eruptions, floods, landslides, windstorms (hurricanes, cyclones, and tornadoes), tsunamis, and wildfires have claimed more than 2.8 million lives worldwide and adversely affected communities, industrial facilities, and dwellings of 820 million people (National Academy of Sciences, 1987). The United Nations Disaster Relief Organization (UNDRO) reported in a recent study (Zupka, 1988) that the worldwide economic losses in a 16 year period (1970-1985) from 657 major windstorms, floods, and earthquakes reached $109.6 billion--an average daily loss of $18.8 million.

PHYSICAL CHARACTERISTICS AND MITIGATION STRATEGIES

To plan effectively, one must identify the similar and dissimilar physical characteristics of natural hazards (Table 1) and implement the most effective mitigation strategies (Table 2). For earthquakes, volcanic eruptions, floods, landslides, windstorms, tsunamis, and wildfires, the most important physical characteristics and the key questions needing answers are as follows:

1) Affected Area - what is the size and shape of the area expected to be affected by the occurrence of an event?

2) Severity - how severe are the physical effects expected to be in both near-source and far-source regions?

3) Frequency - how often, on the average, is an event large enough to cause damage expected to occur?

4) Impact Time and Duration - how much lead time is expected between the first precursors of the event and its peak impacts? When the event strikes, how long is it expected to last?

5) Primary and Secondary Physical Effects - what kinds of damaging physical phenomena (hazards) are expected when an event occurs?

Each natural hazard generates its own ensemble of physical phenomena (hazards) and sometimes one natural hazard triggers the occurrence of another. The primary and secondary hazards of each natural hazard are summarized below:

1) Earthquakes - The primary hazards are: ground shaking and permanent ground failure (landslides and liquefaction). The secondary hazards are: surface fault rupture, regional tectonic deformation, tsunamis, seiches, fire, flooding from dam failure, and aftershocks. (Note: the potential for very large sudden losses is the feature that distinguishes earthquakes from all other natural hazards).

2) Volcanic Eruptions - The primary hazards are: pyroclastic flows and lahars, (i.e., mud flows generated by melting of snow and ice). Secondary hazards are: tephra, ash fall, lava flows, volcanic earthquakes, lightning, glacier bursts, floods, and sometimes tsunamis and famine.

3) Windstorms - The primary hazards are: storm surges, high winds, and floods.
The secondary hazards are: lightning, hail, erosion, and scouring.

4) Floods: The primary hazards are: inundation from riverine floods, flash floods, and storm surges along the coast. The secondary hazards are: high water velocity, high waver levels, overtopping, erosion, and scouring.

5) Landslides - The primary hazards are: falls, topples, slides, spreads, and flows of rock and soil. The secondary hazards are: debris dams, floods, and sometimes tsunamis.

6) Tsunami - The primary hazards are: inundation, and wave impacts on structures. The secondary hazards are coastal erosion and scouring.

7) Wildfires - The primary hazards are: Encroachment on the community. The secondary hazards are inceneration, smoke, winds, fire storms, and erosion.

Corporate planning is optimal on all scales--global, regional, national, and urban--when knowledge of the hazard (derived from hazard maps) and professional practices is integrated with economic and other considerations. Hazard maps are based on either deterministic or probabilistic methods and depict the spatial and temporal variation of a primary or hazard accompanying an event.

Flood-hazard maps are constructed to quantify the threat from the approximately 6 million miles of riverine watershed to the more than 6 million dwellings and nonresidential buildings located in flood plains. All States are at risk from flooding, precipitation, snow melt, thunderstorms, tornadoes, and the storm surges generated in hurricanes. Ground-shaking and ground-failure hazard maps are constructed to depict the primary hazards expected from earthquakes occurring in the approximately 150 seismogenic zones throughout the Nation. No State is free from these two earthquake hazards, although the frequency of damaging earthquakes is much greater in Alaska and California than in the remainder of the Nation. Landslides occur in all the States and Territories with California, Alaska, Utah, Kentucky, West Virginia, Tennessee, Puerto Rico, Ohio, Washington, and American Samoa having the most extensive landslide problem. In the case of volcanic eruptions, only parts of Alaska, Hawaii, Washington, Oregon, Idaho, California, Nevada, Utah, Arizona, and New Mexico are at risk from the effects of potential volcanic eruptions.

Damaging tsunamis in the past have struck Hawaii, Alaska, Washington, Oregon, California, Puerto Rico, and the Virgin Islands, but are absent in the historical record of the East Coast.

Hazard maps are an integral part of loss-reduction strategies implemented by State and local governments (Table 1). They contribute to a wide range of risk management strategies such as:

- Prevention - controlling the source of the event in a way that changes the physical characteristics of the physical phenomena generated in the event.
- Protection - building structures to withstand the physical phenomena generated in the event.
- Land-use Control - identifying and avoiding sites where an event is expected to have the greatest severity.
- Site Modification - modifying the physical characteristics at the site of man's works in order to increase the likelihood of survival in an event.
- Alert and Warning - providing advance notice to the affected populace on the location, severity, and time of an impending event.
- Short-term Protection - In response to an alert or warning, performing actions to strengthen existing structures and lifeline systems so that they will be able to withstand an impending event.
- Emergency Preparedness - Making comprehensive plans to deal with the entire spectrum of expected requirements from event.
- Indemnification - Spreading the potential economic losses from an event over a large population throughout insurance and other financial strategies.
- Recovery Planning - Making plans to accelerate the recovery process after a disaster-generating event.

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Table 1: Comparison of the characteristics of selected natural hazards

HAZARD	FREQUENCY	PREDICTABILITY			SUDDEN LOSS POTENTIAL
		LOCATION	TIME	IMPACTS	
Volcanoes	highly variable (14)	high	good (15)	moderate (16)	up to 5×10^8 USD high, casualties up to 10^5 (17)
Earthquakes	global, annual: log N=8.2-M (1)	high to moderate	impossible (2)	moderate (3)	up to 5×10^{10} USD casualties 5×10^5 (4)
Tsunamis	highly variable	good	high but only after a large tsunami generating earthquake	highly variable	decreases with distance from the source, casualties
Landslides	low to high (5)	low to moderate	associated with other hazards such as earthquakes, floods, volcanic eruptions	low to moderate (6)	low casualties
River floods	variable (7)	high	good (8)	good	very high casualties up to 10^5
Flash floods	seasonal (summertime)	high (not local thunderstorm prediction)	good (diurnal effects)	good (hazardous small basins)	locally high to severe casualties
Sea floods	poorly known (9)	moderate (10)	good to high (few days)	good	very high casualties up to 5×10^5
Windstorms a) extra tropical cyclones	seasonal (wintertime)	high, using numerical models	high (models)	high (both winds and assoc. rains)	high to severe casualties

Comparison of the characteristics of selected natural hazards

HAZARD	FREQUENCY	PREDICTABILITY			SUDDEN LOSS POTENTIAL
		LOCATION	TIME	IMPACTS	
b) tropical cyclones (hurricanes, typhoons)	seasonal (summer-time)	good, synoptic scale tracking (11)	good at short time range	high (12)	high to severe casualties (13)
c) tornadoes	seasonal (summer-	regional	low but diurnal	low	high to severe casualties
Droughts and Desertification	some recurrent factors (Sahel ?)	low moderate	low moderate	low moerate	very high casualties very high casualties
Wildfires	variable	good	seasonal	low	low to high

Characteristics of natural hazards - brief commentary

1. Generally valid relationship between the number N of events and their size M $\log N = a - bM$ is varying from region to region and with time interval

2. At research stage, successful only very exceptionnally.

3. Can be evaluated only if hazard and vulnerability are known.

4. Depends on density of population, concentration of industry, etc.

5. Depends on occurence of other natural hazards and man-made calamities.

6. Cumulative impacts over time and space may be high.

7. Can be assessed if information available from long term records or through relation with rainfall.

8. Lead time depends more on the size of the basin than on the lead time of the meteorological quantitative rain forecasting; the former from several days to several weeks.

9. Adequate information is rare, no long term records are available, recording stations not designed to withstand.

10. In temperate zones rather than in case of storm surges generated by tropical depressions.

11. Mesosynoptic uncertainties.

12. Both winds and associated rains, uncertainty for storm waves.

13. Severe especially on flat tropical islands.

14. About 50 per year. Major, very disastrous eruptions about 2/decade.

15. At research stage, excellent in well-monitored volcanoes.

16. Depends largely on a knowledge of previous history of a volcano and how it works.

17. Combination of eruptive force and mass and triggered mudflows, tsunamis, landslides, etc.

Table 2. Summary of Mitigation Strategies

SUMMARY OF MITIGATION STRATEGIES

MITIGATION TECHNIQUES	EARTHQUAKES	TSUNAMIS	LANDSLIDES	AVALANCHES	WINDSTORMS	STORM SURGES	RIVER FLOODS	VOLCANOES	WILD-FIRES
Prevention (Controlling the source)	(1) No	No	Small-scale only	Snow brakes	(2) No	No	Watershed Management	Lava/Lahar Diversion	No
Protection (Building to withstand)	(3) Earthquake resistant construction	Partial (trees, dikes)	No	?	Wind-resistant construction	Flood-proof buildings Houses on stilts	Flood control engineering works	Roof design for ash falls	Fire brakes
Land use control (4)	Hazard zoning	Hazard zoning	Hazard zoning	Hazard zoning	(5) No	Hazard zoning	Hazard zoning	Hazard zoning	-
Site Modification	-	-	Slope stabilizing	-	-	Refuge mounds Embankments	Embankments	-	-
Alert and Warning (6)	Not yet	(7) Yes	?	(8) Partial	Yes	Yes	Yes	Yes	Yes
Short-term Protection (In response to warning)	Various	Evacuation	?	Control of access	Storm shutters	Evacuation	Evacuation	(9) Evacuation	Evacuation
Rehabilitation (10)									

NOTES

1. The phenomena of induced seismicity has given rise to some speculation on the possibility of releasing seismic stress in a controlled manner by the injection of fluids into the earth's crust. It seems unlikely, however, to become a practical possibility in the foreseeable future.

2. Many attempts have been made to modify the intensity of tropical storms by cloud seeding, but without notable success.

3. Codes regulating the design of buildings to resist earthquake forces have been adopted in many countries. However, in only very few countries are these codes enforced by regular and strict inspection of buildings in course of construction.

4. The control of risk by hazard zoning and appropriate land use is feasible only in areas in which the population pressure can be contained.

5 Some areas are of course more subject to strong winds than others, but such areas are so large that wind hazard zoning is of little practical relevance to land-use planning.

6. Temporary protective action against natural hazards is always more effective if it can be planned as a series of responses to a progressively increasing hazard. Monitoring and prediction systems should preferably be capable of providing a graded series of alerts prior to any formal warning of a potentially disastrous event.

7. The problem of providing adequate tsunami warning to populations in the case of nearby offshore earthquakes has yet to be solved satisfactorily.

8. See the UNDRO/UNESCO Handbook on Volcanic Emergencies.

9. Evacuations of hazardous areas in cases of volcanic eruption are likely to last much longer (e.g. several weeks or months) than in the case of other natural hazards.

10. Whatever the nature of the disaster, the recovery/rehabilitation process, if it is to result in a reduction of risk in the future, will necessarily involve the measures of prevention, protection, land-use planning, warning and preparedness outlined in the above Table.

INFORMATION NEEDS OF THE INSURANCE INDUSTRY

By
James C. Smith
Fireman's Fund Insurance Company
Novato, California

The following is the type of scientific and engineering information the insurance industry needs to improve their capability to underwrite and price insurance coverages relating to the earthquake hazard:

- Distance from the earthquake epicenter, soil condition and intensity of shaking are major factors in determining damageability. It would be advantageous if the amount of damage could be developed within ranges of distance from the epicenter? As an example, what amount of damage would be expected for exposures 0 to 10 miles; 11 to 20 miles; and 21 or more miles from the epicenter. Then, can factors be developed to modify these damage estimates based on soil condition?

- Using the above information, a computer estimating model for earthquake damage should be developed. The model should estimate the total damage by state earthquake zone. The current approach assumes that large geographical areas (hundreds of square miles) will have the same damageability factor.

- Currently, damageability estimates concentrate on structures. Separate damageability estimates need to be developed for structures, contents and business interruption exposures.

- Deductibles are a major factor in earthquake insurance. The impact of deductibles in reducing or eliminating losses needs further analysis. Of particular importance is:

  - Damageability factors need to be developed for all exposures, based on varying deductible options.

  - As deductibles increase, their ability to substantially reduce or eliminate losses diminishes. At what point do high deductibles, by exposure, have diminishing returns?

- The ability of deductibles to reduce losses should increase with distance from the fault. Damageability factors should be developed based on deductible option and distance from the earthquake epicenter.

- Earthquake building codes have been used and improved upon for many years. The impact of the various key elements of the building codes should be studied to determine their actual performance during an earthquake and impact on reducing insured losses.

- Earthquakes, like other natural hazards, need to be quantified. What is the maximum anticipated magnitude for the known major faults in various tectonically active regions and what is the reasonably expected frequency of a major earthquake by major fault?

- Earthquake information is evaluated and presented using various techniques and parameters. It would be advantageous if a uniform method of analysis and format for presenting information can be developed for seismic data.

- Fire following an earthquake can be a major source of loss. However, the extent and probability of fire following is presently undetermined. Study is needed to determine the probability of a major fire following an earthquake and the expected amount of damage to industrial, commercial and residential exposures.

- Recognizing that fire following is a major exposure, additional study is needed to determine what engineering or risk management techniques can be used to reduce or prevent fire following. As an example, can or should automatic gas shut-off valves be installed on every structure?

- Evaluating the earthquake exposure of individual risks is difficult and expensive. A uniform method for economically evaluating the earthquake exposure of individual risks should be developed.

PUBLIC POLICY ISSUES OF EARTHQUAKE AND LANDSLIDE HAZARDS REDUCTION

by

Richard L. Bernknopf
U.S. Geological Survey
Reston, Virginia 22092

Earthquake and landslide events in the United States are facts. The occurrence of a great earthquake and/or several major damaging earthquakes in the U.S. during the next 50 years is very likely. Landslide damage of about $1-2 billion occurs annually. Federal Government post-disaster relief could be enormous without significant private sector financial incentives to participate in hazard protection. Some of the government financial burden could be reduced by an active insurance market. A private sector insurance market could function efficiently if supplied with accurate risk information. Unfortunately though, unlike other Federal disaster prevention programs such as the flood-hazard delineation programs, there is a lack of a coherent public policy for earthquake and landslide risk assessment and mitigation. Historically, hazard protection in the United States has taken a form that functions with a "free market" balance between insurance and mitigation, or one that functions as a consequence of a Government-imposed strategy that regulates land use to minimize exposure to hazardous events. In either of these alternative strategies, the probability of earthquake and landslide occurrence for life and property risk assessments should be an integral part in the formulation of a public policy.

Active participation by the private sector in insuring against earthquakes and landslides will occur when the risk information available is sufficient for financial evaluations and decisions. For example, interest in earthquake insurance by the private sector has been severely limited because of large uncertainties inherent in the current approaches to risk assessment. Currently, loss estimates are derived from a time-stationary, nonconditional probabilistic assessment based on proximity to prior events. No risk assessment information available from the USGS is based on the conditional probability of earthquake occurrence or allows for the time-dependent nature of the earthquake process. Probabilistic assessments that incorporate time variability would assist in better defining financial risks for private sector insurance markets, evaluating the finanacial impacts of mitigation rules for public sector decision making, and in forecasting needs for disaster relief response.

USGS research on how to minimize the impacts of damaging earthquakes bears directly on the issues associated with the health of national financial and insurance markets. The first issue is concerned with how these markets can incorporate USGS earth science information. Related to this issue is USGS assistance that can be provided to other Government agencies associated with hazard mitigation. The second issue is concerned with alternative technical approaches to estimating risk and potential losses.

Federal Government intervention into financial markets ideally occurs when there has been some form of market failure.

In the case of earthquakes and landslides, Government involvement can come either prior to an event in the form of (a) information for risk assessments, (b) federally backed insurance with land use restrictions, (c) preparedness assistance, and (d) mitigation requirements, or after the fact in the form of (a) systematic damage assessments, (b) federal disaster relief subsidies, and (c) long-term programs for rehabilitation and reconstruction. Knowledge of the distribution of earthquakes and landslides in location and size is essential for developing an actuarially sound approach to insurance. Insurers need hazards information for estimating the likelihood and extent of losses, in order to determine whether to offer coverage and to establish fair insurance rates.

Earthquake risk assessment is based on scientific data in addition to financial data. Some examples of the types of information that should be applied to risk assessment are: (a) site-specific geologic data, (b) earthquake resistance of specific structures, (c) seismicity of the region, and (d) ground motion studies. At present, there is no systematic way to apply these types of scientific information to forecasting changes in earthquake risk for insurance purposes.

Insurance decisions are guided by economic evaluations that estimate the expected loss of an asset. To be useful for economic evaluations, risk information must be conveyed with the statistical uncertainties of the probability of a damaging event. An estimate of the probability determined from scientific information can be combined with property value data to provide an accurate estimate of expected loss for insurance rate setting. The insurance market should be able to provide the systematic adjustments associated with changes in earthquake and landslide risk.

The specification and accuracy of probability estimates are a significant input into decisions regarding an insurance firm's portfolio, as well as the regional extent of coverage, the possibilities of reinsurance, and the plans for policy premiums. At present, insurance firms that are active in property markets in regions affected by various levels of earthquake and landslide hazards routinely make judgments about coverage and rates with only a vague knowledge of the underlying risk.

The perception of the accuracy of the probability can have a significant influence on the demand and supply for insurance services. Current estimates of the probability of earthquake recurrence and landslide occurrence are not explicit enough in statistical terms. Different perceptions of the risk by different insurance companies may lead to wide variations in insurance rates.

STATUS OF FLOOD STUDIES BY THE U.S. GEOLOGICAL SURVEY

By
Ernest D. Cobb
U.S. Geological Survey
Reston, Virginia

The U.S. Geological Survey (USGS) carries out an extensive program to collect and interpret hydrologic data to define flood hazards and flood characteristics. Flood studies are often conducted in coordination with other agencies. A wide variety of publications are used to report the results of these studies.

The USGS has prepared more than 13,000 flood-prone area maps on standard topographic quadrangles. The maps delineate the approximate areas that would be inundated by a 100-year flood (Flood with a 1 percent probability of occurring each year). These maps are available from USGS Water Resources Division (WRD) offices, located in most States.

The delineation of areas flooded during more than 200 major floods have been published as USGS Hydrologic Investigations Atlases. Flood profile and other information concerning the floods are included in these publications. Major floods have also been documented in a number of other reports describing in detail the characteristics of the flood.

The USGS has participated extensively in the mapping of hypothetical floods for the Federal Emergency Management Agency's (FEMA) flood-insurance program. This includes defining the flood profile and areas that would be inundated by the 100-year and other hypothetical floods. These maps and associated information are available from FEMA.

USGS reports that include methods to determine flood magnitudes for selected probabilities of occurrence for ungaged areas, have been published for the entire country These methods are based on extensive flood data. Reports are also available for estimating flood magnitudes for selected probabilities in urban areas.

Studies have been made of some areas that have been covered by debris flows. For example, past debris flows on Mt. Shasta have been mapped and reported in USGS Professional Paper 1396-C. The potential hazards that would accompany a dam break have been defined for some lakes. For example, downstream hazards for a failure of the blockage damming Carver Lake in the Three Sisters area of Oregon have been described in the USGS open-file report 87-41.

EARTHQUAKES

The resultant release of stress, usually occurring within a few cubic kilometers of the Earth's crust, is called an earthquake. The relatively small portion of the crust at which the stresses are relieved by movement is the focus of an earthquake. From this point, mechanical energy is propagated in the form of waves which radiate from the focus in all directions through the body of the Earth. When this energy arrives at the surface of the Earth, sometimes from as deep as 700 kilometers, it forms secondary surface waves of longer periods. The frequency and amplitude of the vibrations thus produce at points on the Earth's surface, and hence the severity of the earthquake depend on the amount of mechanical energy released at the focus, the distance and depth of the focus, and the structural properties of the rock or soil on or near the surface of the Earth at the point of observation.

Effects--A large earthquake is one of nature's most devastating phenomena. The energy released by a magnitude 8.5 earthquake on the Richter scale is equivalent to 12,000 times the energy released by the Hiroshima nuclear bomb. While these cataclysms have their foci well below the Earth surface, cities have been destroyed and thousands of lives lost in a few seconds as the result of great earthquakes of the past.

Primary Effects--The onset of a large earthquake is initially signaled by a deep rumbling or by disturbed air making a rushing sound, followed shortly by a series of violent motions in the ground. The surroundings seem to disintegrate. Often the ground fissures, and there can be large permanent displacements--21 feet horizontally in San Francisco in 1906 and 47 feet vertically at Yakutat Bay in 1899. Buildings, bridges, dams, tunnels, or other rigid structures are sheared in two or collapse when subjected to this movement. People standing have been knocked down and their legs broken by the sudden lateral accelerations.

As the vibrations continue, structures with different frequency-response characteristics are set in motion. Sometimes resonant motion results. This effect is particularly destructive, since the amplitude of the vibrations increases (theoretically without limits) and usually structural failure occurs. Adjacent buildings of different frequency response can vibrate out of phase and pound each other to pieces. In any event, if the elastic strength of the structure is exceeded, cracking, spalling, and--often--complete collapse results. Chimneys, high-rise buildings, water tanks, and bridges are especially vulnerable to vibrational motion. The walls of high-rise buildings without adequate lateral braking frequently fall outward, allowing the floors to cascade one on top of the other, crushing the occupants between them. In the poorer countries, where mud brick and above are used extensively in construction, collapse is often total even to the point of returning the bricks to dust.

Water in tanks, ponds, and rivers is frequently thrown from its confines. In lakes, an oscillation know as "seiching" occurs, in which the water surface from one end to the other, reaching great heights and overflowing the banks. As a result of the 1964 earthquake in Alaska, for example, water rose 6 feet at Memphis, Tennessee, 5,000 miles from the center, due to this type of action.

Secondary Effects--Often as destructive as the earthquake itself are the resulting secondary effects such as landslides, fires, tsunamis, and floods.

Landslides are especially damaging, and often account for the majority of the lives lost. The 1970 earthquake in Peru is a case in point. The total number of deaths was in excess of 70,000 with 50,000 injured. Of those killed, 40,000 were swept away from a landslide which fell 12,000 feet down the side of Mt. Huascaran. It roared through Yungay and Rauachirca at 200 miles per hour, leaving only a raw scar where the villages had been.

The fire damage frequently increase due to the loss of firefighting equipment destroyed by the quake and the breaking of the water mains essential to firefighting. Blocked access highways can hinder the arrival of outside help. This type of secondary effect is well illustrated by the San Francisco earthquake of 1906, in which, only approximately 20 percent of the half billion dollars in damage was estimated to have been due to the earthquake, while the remainder was caused by the fire, which was out of control for several days. One of the greatest disasters of all times, the Kwanto, Japan, earthquake in 1923, also results from large fire losses. Almost 40 percent of the dead perished in a firestorm which engulfed an open place where people had gathered in a futile attempts to escape the conflagration.

Other secondary effects include the disruption of electric power and gas service, which further contributed to fire damage. Also, highways and rail systems are frequently put out of service, presenting special difficulties to rescue and relief workers.

GLOSSARY

Accelerogram. The record from an accelerometer showing acceleration as a function of time. The peak acceleration is the largest value of acceleration on the accelerogram.

Acceptable Risk. A probability of occurrences of social or economic consequences due to earthquakes that is sufficiently low (for example in comparison to other natural or manmade risks) as to be judged by authorities to represent a realistic basis for determining design requirements for engineered structures, or for taking certain social or economic actions.

Active fault. A fault is active if, because of its present tectonic setting, it can undergo movement from time to time in the immediate geologic future. This active state exists independently of the geologists' ability to recognize it. Geologists have used a number of characteristics to identify active faults, such as historic seismicity or surface faulting, geologically recent displacement inferred from topography or stratigraphy, or physical connection with an active fault. However, not enough is known of the behavior of faults to assure identification of all active faults by such characteristics. Selection of the criteria used to identify active faults for a particular purpose must be influenced by the consequences of fault movement on the engineering structures involved.

Attenuation. A decrease in seismic signal strength with distance which depends on geometrical spreading and the physical characteristics of the transmitting medium that cause absorption and scattering.

Attenuation law. A description of the average behavior of one or more characteristics of earthquake ground motion as a function of distance from the source of energy.

b-value. A parameter indicating the relative frequency of earthquakes of different sizes derived from historical seismicity data.

Capable fault. A capable fault is a fault whose geological history is taken into account in evaluating the fault's potential for causing vibratory ground motion and/or surface faulting.

Design earthquake. A specification of the ground motion at a site based on integrated studies of historic seismicity and structural geology and used for the earthquake-resistant design of a structure.

Design spectra. Spectra used in earthquake-resistant design which correlate with design earthquake ground motion values. A design spectrum is typically a broad band specturm having broad frequency content. The design spectrum can be either site-independent or site-dependent. The site-dependent spectrum tends to be less broad band as it depends at least in part on local site conditions.

Design time history. One of a family of time histories used in earthquake-resistant design which produces a response spectrum enveloping the smooth design spectrum, for a selected value of damping.

Duration. A description of the length of time during which ground motion at a site exhibits certain characteristics such as being equal to or exceeding a specified level of acceleration such as 0.05g.

Earthquake hazards. Natural events accompanying an earthquake such as ground shaking, ground failure, surface faulting, tectonic deformation, and inundation which may cause damage and loss of life during a specified exposure time. See earthquake risk.

Earthquake risk. The probability that social or economic consequences of earthquakes, expressed in dollars or casualties, will equal or exceed specified values at a site during a specified exposure time.

Earthquake waves. Elastic waves (P, S, Love, Rayleigh) propagating in the Earth, set in motion by faulting of a portion of the Earth.

Effective peak acceleration. The value of peak ground acceleration considered to be of engineering significance. It can be used to scale design spectra and is often determined by filterng the ground-motion record to remove the very high frequencies that may have little or no influence upon structural response.

Epicenter. The point on the Earth's surface vertically above the point where the first fault rupture and the first earthquake motion occur.

Exceedence probability. The probability (for example, 10 percent) over some exposure time that an earthquake will generate a level of ground shaking greater than some specified level.

Exposure time. The period of time (for example, 50 years) that a structure or facility is exposed to earthquake hazards. The exposure time is sometimes related to the design lifetime of the structure and is used in seismic risk calculations.

Fault. A fracture or fracture zone in the Earth along which displacement of the two sides relative to one another has occurred parallel to the fracture. See Active and Capable faults.

Focal depth. The vertical distance between the earthquake hypocenter and the Earth's surface.

Ground motion. A general term including all aspects of motion; for example, particle acceleration, velocity, or displacement; stress and strain; duration; and spectral content generated by an earthquake, a nuclear explosion, or another energy source.

Intensity. A numerical index describing the effects of an earthquake on the Earth's surface, on man, and on structures built by him. The scale in common use in the United States today is the Modified Mercalli scale of 1931 with intensity values indicated by Roman numerals from I to XII. The narrative descriptions of each intensity value are summarized below.

I. Not felt--or, except rarely under specially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes birds and animals reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway--doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons. Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds and animals reported uneasy or disturbed; sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body of striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink or clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars noticeably.

V. Felt indoors by practially all, outdoors by many or most; outdoors direction estimated. Awakened many or most. Frightened few--slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes and glassware to some extent. Cracked windows--in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors and shutters abruptly. Pendulum clocks stopped, started or ran fast, or slow. Move small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees and bushes shaken slightly.

VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees and bushes shaken slightly to moderately. Liquid set in strong motion. Small bells rang--church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knickknacks, books, pictures. Overturned furniture in many instances. Move furnishings of moderately heavy kind.

VII. Frightened all--general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows and furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII. Fright general--alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly--branches and trunks broken off, especially palm trees. Ejected sand and mud in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse, racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls, cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX. Panic general. Cracked ground conspicuously. Damage considerable in (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changes level of water in wells. Threw water on banks of canals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipelines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments often for long distances. Few, if any (masonry) structures, remained standing. Destroyed large well-built bridges by the wrecking of supporting piers or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipelines buried in each completely out of service.

XII. Damage total--practically all works of construction damaged greatly or destroyed. Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.

Liquefaction. The primary factors used to judge the potential for liquefaction, the tranformation of unconsolidated materials into a fluid mass, are: grain size, soil density, soil structure, age of soil deposit, and depth to ground water. Fine sands tend to be more susceptible to liquefaction than silts and gravel. Behavior of soil deposits during historic earthquakes in many parts of the world show that, in general, liquefaction susceptibility of sandy soils decreases with increasing age of the soil deposit and increasing depth to ground water. Liquefaction has the potential of occurring when seismic shear waves having high acceleration and long duration pass through a saturated sandy soil, distorting its granular structure and causing some of the void spaces to collapse. The pressure of the pore water between and around the grains increases until it equals or exceeds the confining pressure. At this point, the water moves upward and may emerge at the surface. The liquefied soil then behaves like a fluid for a short time rather than as a soild.

Magnitude. A quantity characteristic of the total energy released by an earthquake, as contrasted to intensity that describes its effects at a particular place. Professor C. F. Richter devised the logarithmic scale for local magnitude (M_L) in 1935. Magnitude is expressed in terms of the motion that would be measured by a standard type of seismograph located 100 km from the epicenter of an earthquake. Several other magnitude scales in addition to M_L are in use; for example, body-wave magnitude (m_b) and surface-wave magnitude (M_S), which utilize body waves and surface waves, and local magnitude (M_L). The scale is theoretically open ended, but the largest known earthquakes have had M_S magnitudes near 8.9.

Region. A geographical area, surrounding and including the construction site, which is sufficiently large to contain all the geologic features related to the evaluation of earthquake hazards at the site.

Response spectrum. The peak response of a series of simple harmonic oscillators having different natural periods when subjected mathematically to a particular earthquake ground motion. The response spectrum may be plotted as a curve on tripartite logarithmic graph paper showing the variations of the peak spectral acceleration, displacement, and velocity of the oscillators as a function of vibration period and damping.

Return period. For ground shaking, return period denotes the average period of time or recurrence interval between events causing ground shaking that exceeds a particular level at a site; the reciprocal of annual probability of exceedance. A return period of 475 years means that, on the average, a particular level of ground motion will be exceeded once in 475 years.

Risk. See earthquake risk.

Rock. Any solid naturally occurring, hard, consolidated material, located either at the surface or underlying soil. Rocks have a shear-wave velocity of at least 2,500 ft/sec (765 m/s) at small (0.0001 percent) levels of strain.

Seismic Microzoning. The division of a region into geographic areas having a similar relative response to a particular earthquake hazard (for example, ground shaking, surface fault rupture, etc.). Microzoning requires an integrated study of: 1) the frequency of earthquake occurrence in the region, 2) the source parameters and mechanics of faulting for historical and recent earthquakes affecting the region, 3) the filtering characteristics of the crust and mantle along the regional paths along which the seismic waves travel, and 4) the filtering characteristics of the near-surface column of rock and soil.

Seismic zone. A generally large area within which seismic design requirements for structures are uniform.

Seismotectonic province. A geographic area characterized by similarity of geological structure and earthquake characteristics. The tectonic processes causing earthquakes are believed to be similar in a given seismotectonic province.

Source. The source of energy release causing an earthquake. The source is characterized by one or more variables, for example, magnitude, stress drop, seismic moment. Regions can be divided into areas having spatially homogeneous source characteristics.

Strong motion. Ground motion of sufficient amplitude to be of engineering interest in the evaluation of damage due to earthquakes or in earthquake-resistant design of structures.

IMPORTANT HISTORICAL EARTHQUAKES IN THE UNITED STATES

Northeastern Region

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

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

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

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

Southeastern Region

The southeastern United States is an area of diffuse low-level seismicity that has not experienced a MMI VII or greater earthquake in nearly 80 years. The largest and most destructive earthquake in the region was the 1886 Charleton earthquake, which caused 60 deaths and widespread damage to buildings. It had an epicentral intensity of X and a magnitude from surface waves (M_S) of approximately 7.7 (Bollinger, 1977). Important earthquakes of the southeastern region are listed in Table 2. The distribution of earthquakes through 1976 in the southeastern region is as follows:

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

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Feb 21, 1774	Eastern VA	VII	
Feb 10, 1874	McDowell County, NC	V-VII	
Dec 22, 1875	Arvonia, VA area	VII	
Aug 31, 1886	Near Charleston, SC	X	7.7
Oct 22, 1886	Near Charleston, SC	VII	
May 31, 1897	Giles County, VA	VIII	6.3
Jan 27, 1905	Gadsden, AL	VII-VIII	
Jun 12, 1912	Summerville, SC	VI-VII	
Jan 1, 1913	Union County, SC	VII-VIII	5.7-6.3
Mar 28, 1913	Near Knoxville, TN	VII	
Feb 21, 1916	Near Asheville, NC	VI-VII	
Oct 18, 1916	Northeastern, AL	VII	
Jul 8, 1926	Mitchell County, NC	VI-VII	
Nov 2, 1928	Western NC	VI-VII	

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

Central Region

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

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

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

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

Western Mountain Region

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

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

Date	Location	Maximum MMI (I_0)	Magnitude (Approx. M_S)
Nov 9, 1852	Near Ft. Yuma, Arizona	VIII	
Nov 10, 1884	Utah-Idaho border	VIII	
Nov 14, 1901	About 50 km east of Milford, Utah	VIII	
Nov 17, 1902	Pine Valley, Utah	VIII	
Jul 16, 1906	Socorro, New Mexico	VIII	
Sept 24, 1910	Northeastern Arizona	VIII	
Aug 18, 1912	Near Williams, Arizona	VIII	
Sept 29, 1921	Elsinore, Utah	VIII	
Sept 30, 1921	Elsinore, Utah	VIII	
Jun 28, 1925	Near Helena, Montana	VIII	6.7
Mar 12, 1934	Hansel Valley, Utah	VIII	6.6
Mar 12, 1934	Hansel Valley, Utah	VIII	6.0
Oct 19, 1935	Near Helena, Montana	VIII	6.2
Oct 31, 1935 (Aftershock)	Near Helena, Montana	VIII	6.0
Nov 23, 1947	Southwestern Montana	VIII	
Aug 18, 1959	West Yellowstone-Hebgen Lake	X	7.1
Aug 18, 1959 (Aftershock)	West Yellowstone-Hebgen Lake	VI	6.5
Aug 18, 1959 (Aftershock)	West Yellowstone-Hebgen Lake	VI	6.0
Aug 18, 1959 (Aftershock)	West Yellowstone-Hebgen Lake	VI	6.0
Aug 18, 1959	West Yellowstone-Hebgen Lake	VI	6.5
Mar 28, 1975	Pocatello Valley, Idaho	VIII	6.1
Jun 30, 1975	Yellowstone National Park	VIII	6.4
Oct 28, 1983	Borah Peak, Idaho	VII	7.3

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

California and Western Nevada Region

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

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

Date	Location	Maximum MMI (I_0)	Magnitude (Approx. M_S)
Dec 21, 1812	Santa Barbara Channel	X	
Jun 10, 1836	Hayward fault, east of San Francisco Bay	IX-X	
Jun 1838	San Andreas fault	X	
Jan 9, 1857	San Andreas fault, near Fort Tejon	X-XI	
Oct 21, 1868	Hayward fault, east of San Francisco Bay	IX-X	
Mar 26, 1872	Owens Valley	X-XI	
Apr 19, 1892	Vacaville, California	IX	
Apr 15, 1898	Mendocino County, California	VIII-IX	-
Dec 25, 1899	San Jacinto, California	IX	
Apr 18, 1906	San Francisco, California	XI	8.3
Oct 3, 1915	Pleasant Valley, Nevada	X	7.7
Apr 21, 1918	Riverside County, California	IX	6.8
Mar 10, 1922	Cholame Valley, California	IX	6.5
Jan 22, 1923	Off Cape Mendocino, California	(IX)	7.3
Jun 29, 1925	Santa Barbara Channel	VIII-IX	6.5
Nov 4, 1927	West of Point Arguello, Ca.	IX-X	7.3
Dec 21, 1932	Cedar Mountain, Nevada	X	7.3
Mar 11, 1933	Long Beach, California	IX	6.3
May 19, 1940	Southeast of El Centro, Ca.	X	7.1

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Jul 21, 1952	Kern County, California	XI	7.7
Jul 6, 1954	East of Fallon, Nevada	IX	6.6
Aug 24, 1954	East of Fallon, Nevada	IX	6.8
Dec 16, 1954	Dixie Valley, Nevada (2 shocks)	X	7.3
Feb 9, 1971	San Fernando, California	XI	6.4
Oct 15, 1979	Imperial Valley, California	IX	6.6
May 2, 1983	Coalinga, California	VIII	6.5

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

Washington and Oregon Region

This region is charcterized by a low to moderate level of seismicity independent of the active volcanism of the Cascade Range. With the exception of plate interaction between the North American and Pacific tectonic plates, no clear relation is known between seismicity and geologic structure. From the list of important earthquakes that occurred in the region (Table 6), the two most recent damaging earthquakes in the Puget Sound area (M_S = 6.5 in 1965; M_S = 7.1 in 1949) occurred at a depth of 60-70 kilometers. Currently, researchers are speculating that a great earthquake could occur as a consequence of the interaction of the Juan de Fuca and the North American tectonic plates. The distribution of earthquakes in the Washington and Oregon region is given below:

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

Date	Location	Maximum MMI (I_0)	Magnitude (Approx. M_S)
Dec 14, 1872	Near Lake Chelan, Washington	IX	(7.0)
Oct 12, 1877	Cascade Mountains, Oregon	VIII	
Mar 7, 1893	Umatilla, Oregon	VII	
Mar 17, 1904	About 60 km northwest of Seattle, Washington	VII	
Jan 11, 1909	North of Seattle, Washington near Washington-British Columbia	VII	
Dec 6, 1918	Vancouver Island, BC	(VIII)	7.0
Jan 24, 1920	Straits of Georgia	(VII)	
Jul 16, 1936	Northern Oregon, near Freewater	VII	(5.7)
Nov 13, 1939	Northwest of Olympia (Depth of focus about 40 km)	VII	(5.8)
Apr 29, 1945	About 50 km southeast of Seattle, Washington	VII	
Feb 15, 1946	About 35 km north northeast of Tacoma, Washington (Depth of focus 40-60 km)	VII	6.3
Jun 23, 1946	Vancouver Island	(VIII)	7.2
Apr 13, 1949	Between Olympia and Tacoma, Washington (Depth of focus about 70 km)	VIII	7.1
Apr 29, 1965	Between Tacoma and Seattle, Washington (Depth of focus about 59 km)	VIII	6.5

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

Alaska Region

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

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

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

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

Hawaiian Islands Region

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

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

Date	Location	Maximum MMI (I_o)	Magnitude (Approx, M_S)
Apr 2, 1868	Near south coast of Hawaii	X	
Nov 2, 1918	Mauna Loa, Hawaii	VII	
Sep 14, 1919	Kilauea, Hawaii	VII	
Sep 25, 1929	Kona, Hawaii	VII	
Sep 28, 1929	Hilo, Hawaii	VII	
Oct 5, 1929	Honualoa, Hawaii	VII	6.5
Jan 22, 1938	North of Maui	VIII	6.7
Sep 25, 1941	Mauna Loa, Hawaii	VII	6.0
Apr 22, 1951	Kilauea, Hawaii	VII	6.5
Aug 21, 1951	Kona, Hawaii	IX	6.9
Mar 30, 1954	Near Kalapana, Hawaii	VII	6.5
Mar 27, 1955	Kilauea, Hawaii	VII	
Apr 26, 1973	Near northeastern coast of Hawaii	VIII	6.3
Nov 29, 1975	Near northeastern coast of Hawaii	VIII	7.2
Nov 16, 1983	Near Mauna Loa, Hawaii		6.6

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

Puerto Rico and the Virgin Islands Region

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

TABLE 9

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

Date	Location	Maximum MMI (I_0)	Magnitude (Approx. M_S)
Apr 20, 1824	St. Thomas, Virgin Islands	(VII)	
Apr 16, 1844	Probable north of Puerto Rico	VII	
Nov 28, 1846	Probably Mona Passage	VII	
Nov 18, 1867	Virgin Islands	VIII (also tsunami)	
Mar 17, 1868	Location uncertain	(VIII)	
Dec 8, 1875	Near Arecebo, Puerto Rico	VII	
Sep 27, 1906	North of Puerto Rico	VI-VII	
Apr 24, 1916	Possibly Mona Passage	(VII)	
Oct 11, 1918	Mona Passage	VIII-IX (also tsunami)	7.5

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

BIOGRAPHIES

S. T. ALGERMISSEN is a Supervisory Geophysicist in the Branch of Geological and Risk Assessment of the U.S. Geological Survey. He is a specialist in earthquake hazard mapping and risk (loss) assessment research, both in the United States and internationally. Earthquake ground-shaking hazard maps developed by him have been used in building codes in the United States since 1970. He has participated in UNESCO and UNDP projects as a consultant and was principal investigator in a number of earthquake hazard assessment projects in Latin America, Southeast Asia, Europe, and the Near East. Formerly Director of the Seismological Society of America and the Earthquake Engineering Research Institute, Dr. Algermissen is currently Chairman of the Ground Motion Committee and a member of the Technical Management committee of the Building Seismic Safety Council. He has published widely on all aspects of earthquake hazards and risk.

EDOUARD P. ARNOLD is a Geophysicist in the Branch of Geological Risk Assessment, U.S. Geological Survey. He is a specialist in earthquake location determination and building loss estimation. He is well known both nationally and internationally and was for some years the Director of the International Seismological Centre. He has participated in and, in some cases, directed a number of USAID, UNESCO, and UNDP programs, mostly in Southeast Asia but also in Europe. He is currently working with Dr. Algermissen on the estimation of losses to domestic structures.

RICHARD L. BERNKNOPF is an Economist in the Office of the Chief Geologist with the U.S. Geological Survey. Ongoing research activities have focused on developing methods for estimating the value of scientific information. Research in natural hazards includes measuring the spatial and temporal risk of earthquakes and landslides including the estimation of the real estate and recreational costs of temporary hazard alerts in communities at risk. Past assignments in the U.S. Geological Survey (USGS) have included, Chief of the Plans and Programs Staff in the Office of the Director, USGS, and Chief Economist in the Office of the Director, USGS.

ERNEST D. COBB is a hydrologist with the Water Resources Division of the U.S. Geological Survey. His duties include the coordination of the Water Resource Division's volcano hazards program since 1986 and the flood insurance mapping program since 1985. He has worked in California, New Mexico, Puerto Rico, and Virginia.

JAMES F. DAVIS is Supervisory Geologist: Geologic Hazards in the California Department of Conservation's Division of Mines and Geology. In the past 15 years, he has served as the State Geologist of California and New York. Dr. Davis has provided leadership for earthquake loss estimation in California and contributed to reports describing comprehensive planning scenarios for earthquakes on the San Andreas and other active fault systems in California.

LLOYD BRIAN FALCK is Chief Executive and Deputy Chairman of the New Zealand Earthquake and War Damage Commission. This Commission specializes in the provision of insurance against earthquake and related perils on a nationwide basis. In addition, he is Deputy Chairman of the Works and Development Services Corporation (N2) Ltd., which as part of its research effort retains a team of specialized engineers whose function is to develop strategies to minimize loss in structures exposed to earthquake stress. His graduate background is in Mathematics, System Analysis, and Government Administration.

JOHN R. FILSON served as Chief, Office of Earthquakes, Volcanoes, and Engineering, from February 1980 to June 1988 in the U.S. Geological Survey. This office carries out activities and responsibilities of the USGS under the National Earthquake Hazards Reduction Program. He received an undergraduate degree in geology from Rice University and a Ph.D. degree in geophysics from the University of California, Berkeley. He has worked as a staff scientist at Lincoln Laboratory of the Massachusetts Institute of Technology and was Program Manager at the Defense Advanced Research Projects Agency. His research interests include earthquake loss estimation, digital seismicity networks, and seismic wave propagation.

DON G. FRIEDMAN is Director of National Hazards Research Service of Travelers Insurance Company. For more than 30 years, he has specialized in assessment of casualty and damage potentials of natural hazards (earthquakes, storms, floods) on the spatial array of population and buildings in affected areas. He pioneered the use of computer simulation techniques in making these evaluations beginning with their application during development of the National Flood Insurance Program in the mid 1960s. Since then, he has served a number of Federal agencies (NRC, NSF) expert groups for United Nations (UNESCO, UNDRO, UNEP, UNDP), and other agencies in Europe, Africa, Mexico, Australia, and Japan. He has presented results of his work on natural disasters at more than 70 conferences in 12 countries and has written over 2 dozen articles on the subject.

WALTER W. HAYS is Deputy Chief for Research Applications in the U.S. Geological Survey's Office of Earthquakes, Volcanoes, and Engineering (OEVE). Since 1977, and after 16 years as an educator and a research engineering seismologist, he has been responsible for fostering research applications and loss reduction throughout the United States. On behalf of UNESCO, he participated in earthquake engineering programs in Algeria and Jordan. Through USGS'S international activities, he contributed to scientific programs in Spain, Italy, Japan, China, Argentina, Switzerland, Austria, and the Soviet Union. He participated in the formative phases of the International Decade of Natural Disaster Reduction. A former Director of the Earthquake Engineering Research Institute, Dr. Hays chairs its Committee on Continuing Education, which has worldwide activities. He has published more than 100 papers, books and reports.

WILLIAM A. HODGES is Senior Vice President in charge of all underwriting activities for the American Sterling Group, Irvine, California. His 15 years of industry underwriting experience, both as an insurer and as a reinsurer, includes evaluating exposures to loss resulting from natural disasters such as earthquake, flood, and windstorm. He has managed aggregate accumulation surveys and PML studies of treaty reinsurance portfolios. Mr. Hodges has participated in fire investigations and earthquake studies of the Metropolitan Los Angeles area earthquake. His most recent activities are centered around the mortgage lending institutions' exposure to catastrophic losses in the areas of flood and earthquake.

ROBERT B. HOLTOM is an Insurance Consultant in Southern California. He is one of the founders of Earthquake Mutual Insurance Company, whose application for a license is pending, and will be its president when the company is in operation. His work experience included underwriting and product development in two major insurance companies, and he was Assistant Vice President in both. He was a Consultant to the California Department of Insurance for 1-1/2 years, and served on the Special Earthquake Study

Committee of the National Committee for Property Insurance for many years. Mr. Holtom is a CPCU, has an MBA and LLB, and has had several books on underwriting published. He is currently Editor of the Best's Underwriting Newsletter.

MARGARET HOPPER is a Geophysicist with the U.S. Geological Survey. Her work has primarily involved intensity information for historical and modern earthquakes in the United States. She has participated in post-earthquake damage surveys for many United States earthquakes in the last decade. Her work includes studies of potential damage from large hypothetical earthquakes in several urban areas. Ms. Hopper's most recent work has been in the New Madrid seismic zone, the Wasatch Front, and Puget Sound. Her interests include intensity attenuation, relation of intensity to other ground motion parameters, damage generated secondarily by ground effects produced by earthquakes, hypothetical intensities and loss estimation, and improved methods of gathering damage data.

LOWDEN JESSUP is Vice President of American Protection Insurance Company, Kemper Group, San Francisco, California. He is manager of the group of Highly Protected Risk (HPR) underwriters and Fire Protection Engineers. He is a licensed Fire Protection Engineer of the State of California. He has served twelve years with IRI and 22 year with Kemper, which during this time was heavily involved with earthquake risk evaluation (i.e., EQ PML's) and earthquake underwriting. Mr. Jessup is a member of National Committee on Property Insurance (NCPI) advisory group assisting California Department of Insurance on earthquake probable maximum loss.

PAUL L. LENZI is Assistant Vice President of Property and Casualty Operations headquarters in New York City. During his 20+ year career he has occupied a succession of underwriting positions. He has served on various insurance industry committee and is currently a member of the American Nuclear Insurers Board of Directors. As staff underwriting officer for Continental's $1.3 billion in worldwide property insurance premiums, his responsibilities include the development of corporate underwriting policy, strategy and guidelines. Within these responsibilities fall such specific tasks as catastrophe perils management, risk retention, and reinsurance strategies. Evaluation and analysis of maximum probable earthquake loss are among the important elements of his integrated activity.

EDGAR V. LEYENDECKER is a Research Civil Engineer with the U.S. Geological Survey. His current work includes studies in structural vulnerability and acquisition and analysis of damage distribution data. Prior to joining the USGS, Dr. Leyendecker was with the National Bureau of Standards (NBS) for over 17 years. At the NBS he was a supervisory structural engineer and head of the earthquake engineering group. He has been particularly active in improvement of seismic design criteria through his effort with the private sector's Building Seismic Safety Council and the Federal Government's Interagency Committee on Seismic Safety in Construction.

AKE MUNKHAMMAR is Vice President and Manager of the Underwriting Control Function of Skandia International Insurance Corporation, Stockholm, Sweden. He is responsible for the formulation of the Corporate underwriting policy, which expresses the risk willingness of the Group Management and guides the various insurance and reinsurance units within the Skandia International group of companies. He is also a member of the Board of Directors of the Swedish Atomic Pool.

ROBERT L. ODMAN is Assistant Vice President - Underwriting of State Farm Fire and Casualty Companies in Bloomington, Illinois. His responsibilities include development and administration of underwriting policy for a number of regional offices throughout the country. He has been a past member and is present chairman of the National Committee on Property Insurance, Special Earthquake Study Committee.

DAVID PERKINS is a research Geophysicist for the U.S. Geological Survey in Golden Colorado, in the Branch of Geological Risk Assessment. He received a B.A. in physics from George Washington University and a M.S. in engineering geoscience from the University of California (Berkeley). Since 1971 he has been involved in research on earthquake statistics and the development of techniques for assessing seismic risk in terms of probabilistic ground motion. Probabilistic ground motion hazard mapping techniques in use in the branch have been developed largely from his recent work or work conducted under his direction. He has served as a consultant for the Nuclear Regulatory Commission, the Bureau of Reclamation, the Department of Energy, and UNESCO. For several years he was a geophysicist for the U.S. Coast and Geodetic Survey, operating magnetic and seismographic observatories in Texas, California, and the Antarctic. He is author or coauthor of risk maps for the Balkan countries, the United States, and India, and has lectured in seismic hazard assessment in Italy, Indonesia, and Thailand.

BRUNO O. PORRO is Vice President and leads the Reinsurance Research and Development Department at Swiss Re in Zurich. He is responsible for the development of risk assessment methodologies for natural perils and their implementation. This includes estimation of loss potential, capacity assignment, and accumulation assessment and control. He has investigated earthquake losses caused by events in Yugoslavia, Italy, Mexico, Chile, and El Salvador with the goal to quantify loss determining factors. His memberships in several professional societies assist in linking seismological and engineering knowledge to insurance and reinsurance related matters.

RICHARD J. ROTH, JR. was appointed Assistant Insurance Commissioner and Chief Property/Casualty Actuary for the California Department of Insurance on July 1, 1984. Mr. Roth is responsible for issues relating to property and liability insurance, specifically reinsurance, workers' compensation, medical malpractice, mortgage guaranty, public liability, and the availability and affordability of automobile insurance. He is the author of the Department's annual report on earthquake insurance. Mr. Roth is a Fellow of the Casualty Actuarial Society and holds a B.S. (mathematics), M.A. (economics), and M.S. (statistics) degrees from Stanford. He also has a law degree and is a member of the Connecticut Bar.

EDWIN A. SIMNER is the Underwriter for Lloyds Syndicate 1104 and Managing Director of Merrett Insurance Services Limited. He has more than 20 years' experience including extensive travel to many part of the world, investigating, evaluating, and underwriting earthquakes and other natural hazards and large risk factors.

JAMES C. SMITH is Vice President of Fireman's Fund Insurance Company. Within the Corporate Affairs Department, he manages the Corporate Underwriting Department. Beginning his career in the property and casualty industry in 1963, he has held various positions with Fireman's Fund during his 25 year career. He has served on industry committees and is a member of the American Insurance Association and the California Workers' Compensation Institute.

KARL V. STEINBRUGGE is a Structural Engineer and Consultant on Earthquake Loss Estimation. He has served as past chairman of the California Seismic Safety Commission, past president of the Earthquake Engineering Research Institute, and past president of the Seismological Society of America. He has been a consultant to Federal and state governments on earthquake loss estimations for over 30 years and has authored or co-authored over 100 papers and studies on earthquakes, earthquake damage and losses, and earthquake loss estimation (monetary and casualties).

PAUL C. THENHAUS is a Research Geophysicist with the U.S. Geological Survey. During his 12 years with the USGS, primary investigations have concerned the interfacing of geological data and information with probabilistic ground-motion techniques. He is a member of the USGS Scientific Review Panel to the Nuclear Regulatory Commission rendering reviews on seismology aspects of siting critical facilities and has authored probabilistic ground-motion hazard maps for Western California, Alaska, and Western Saudi Arabia. Recent investigations have concerned the effect of multiple seismotectonic hypotheses on variability of regional ground-motion hazard estimates along the eastern seaboard of the United States and transverse structural zones that segment and terminate north-south belts of young faulting in Utah and Nevada.

RONALD W. WARDROP is a Actuarial Research Associate at the Allstate Research and Planning Center in Menlo Park, California (next door to the USGS). He is responsible for modeling earthquake losses for Allstate Insurance and AIRAC's "Earthquake Project."

ROBERT L. WESSON is Chief of the Office of Earthquakes, Volcanoes, and Engineering of the U.S. Geological Survey. This office is responsible for USGS's hazards and risk research programs associated with earthquakes, volcanoes, and landslides. He received his B.S. degree from Massachusetts Institute of Technology and his M.S. and Ph.D. degrees from Stanford University. His varied and multifaced career includes research on seismic and aseismic deformation in the earth, the eruption of Mt. St. Helens, and a year living and working at a geophysical camp of the Soviet Academy of Sciences in the seismically active mountains of Soviet Central Asia. Dr. Wesson's previous positions with the USGS include: Chief for the Office of Earthquake Studies, Assistant Director for Research, and Assistant Director for Energy and Minerals. In 1980, he was detailed to the Office of Science and Technology Policy, Executive Office of the President, to participate in a National Security Council study on the consequence and preparation for a major California earthquake.

APPENDIX C

WORKSHOP ON "EARTHQUAKE RISK: INFORMATION NEEDS OF THE INSURANCE INDUSTRY"
Sheraton Old Town Hotel, Albuquerque, New Mexico
September 13-15, 1988

Sponsored by the United States Geological Survey and the California Department of Insurance

PROGRAM

TUESDAY, SEPTEMBER 13, 1988

WORKSHOP FACILITATOR: Walter Hays, U.S. Geological Survey

8:30 a.m. **THEME I: BACKGROUND INFORMATION**

Welcome and introductions; goals of the workshop
-- John Filson, U.S. Geological Survey and Richard Roth, California Department of Insurance

Earthquake Risk: Information Needs of the Insurance Industry--from a Regulatory Perspective
-- Richard Roth, California Department of Insurance

9:30 Break

10:00 Mapping Earthquake Hazards and Assessing the Risk in Urban Areas
-- Ted Algermissen, U.S. Geological Survey

Experience in New Zealand Providing Guidance on the Scientific and Engineering Needs of the Insurance Industry
-- Lloyd Falck, New Zealand Earthquake and War Damage Commission

Discussion

Noon Lunch (restaurant of your choice)

2:00 **THEME II: INFORMATION NEEDS OF THE INSURANCE INDUSTRY**

PANEL 1: LONG RANGE EARTHQUAKE PROBABILITIES IN CALIFORNIA
(See background paper by Thenhaus and Algermissen)

Chairperson: Jim Davis, California Division of Mines & Geology

Panelists: Paul Thenhaus, U.S. Geological Survey
Ted Algermissen, U.S. Geological Survey

Discussion

3:00 Break

3:30 Discussion of Background Papers and Issues

PANEL 2: EARTHQUAKE HAZARDS AND RISK TO PERSONAL LINES (DWELLINGS) (See background papers by Odman, Hopper, Jessup, and Arnold)

Chairperson: Robert Odman, State Farm Fire and Casualty Company

Panelists: Margaret Hopper, U.S. Geological Survey
Lowden Jessup, American Protection Insurance Company, Kemper Group
Edouard Arnold, U.S. Geological Survey

5:00 Adjourn

WEDNESDAY, SEPTEMBER 14, 1988

8:30 a.m. **THEME II: INFORMATION NEEDS OF THE INSURANCE INDUSTRY (CONTINUED)**

PANEL 3: EARTHQUAKE HAZARDS AND RISK TO COMMERCIAL AND INDUSTRIAL PROPERTIES (See background papers by Friedman, Leyendecker, Holtom, and Perkins)

Chairperson: Don Friedman, Travelers Insurance Company

Panelists: Edgar V. Leyendecker, U.S. Geological Survey
Robert Holtom, Insurance Consultant
David Perkins, U.S. Geological Survey

Discussion of Background Papers and Issues

10:00 Break

PANEL 4: EARTHQUAKE HAZARDS AND RISK FROM THE PERSPECTIVE OF REINSURERS (See background papers by Simner, Algermissen, Porro, and Munkhammar)

Chairperson: Eddie Simner, Merrett Insurance Services Limited, Lloyds of Londons

Panelists: Ted Algermissen, U.S. Geological Survey
Bruno Porro, Swiss Reinsurance Company
Ake Munkhammar, Scandia International Insurance Corporation

Discussion of Background Papers and Issues

Noon Lunch (restaurant of your choice)

2:00 **THEME II: INFORMATION NEEDS OF THE INSURANCE INDUSTRY (CONTINUED)**

PANEL 5: PERSPECTIVES OF CORPORATE PLANNERS ON OTHER NATURAL HAZARDS IN ADDITION TO EARTHQUAKES (See background papers by Lenzi, Hays, Smith, Bernknopf, and Cobb)

Chairperson: Paul Lenzi, Continental Insurance Company

Panelists: Walter Hays, U.S. Geological Survey
James Smith, Fireman's Fund Insurance Company
Richard Bernknopf, U.S. Geological Survey
Ernest Cobb, U.S. Geological Survey

Discussion of Background Papers and Issues

3:30 Break

4:00 **THEME III: CLARIFICATION OF NEEDS AND ISSUES**

Group Discussion or Needs and Issues Raised by All Five Panels

Cochairpersons: Karl Steinbrugge, Consulting Engineer and
John Filson, U.S. Geological Survey

5:00 Adjourn

THURSDAY, SEPTEMBER 15, 1988

9:00 a.m. **THEME IV: THE NEXT STEPS**

Brainstorming session to identify possible opportunities for joint activities

Cochairpersons: Karl Steinbrugge and John Filson

Objective: To identify a wide range of possible joint activities which, if undertaken in the next 2 to 3 years, would: a) foster communication, b) help to resolve critical issues, and c) enhance the availability and use of the types of information on earthquake hazards and risk needed by the insurance industry. Topics for consideration include:

1) Formation of working groups on subjects like PML's, seismic cycles of seismogenic zones, vulnerability, seismic microzonation, etc.

2) Post earthquake investigations: what should be studied and how should relevant new knowledge be transferred?

3) Credibility of information: what mechanisms should be adopted to ensure that the information is credible and that it represents the consensus?

4) Pilot meetings, conferences, demonstration projects: what are the top priority activities?

10:30 Break

11:00 CLOSURE

<u>Chairperson:</u> Walter Hays, U.S. Geological Survey

I. Comments on suggestions made in the brainstorming session

<u>Panelists</u>

- -- William Hodges, American Sterling Group
- -- Ron Wardrop, Allstate Research and Planning Center
- -- Ted Algermissen, U.S. Geological Survey
- -- Richard Roth, California Department of Insurance

II. Closing Comments

- -- John Filson, U.S. Geological Survey
- -- Richard Roth, California Department of Insurance

Noon Adjourn

Appendix C

PARTICIPANTS LIST

WORKSHOPS ON "EARTHQUAKE RISK: INFORMATION NEEDS OF THE INSURANCE INDUSTRY,"
ALBUQUERQUE, NEW MEXICO
SEPTEMBER 13-15, 1988,

Dr. S. T. Algermissen
U.S. Geological Survey
Box 25046, Mail Stop 966
Denver Federal Center
Denver, Colorado 80225
Tel: (303) 236-1611

Dr. Edouard Arnold
U.S. Geological Survey
Box 25046, Mail Stop 966
Denver Federal Center
Denver, Colorado 80225
Tel: (303) 236-1579

Dr. Richard Bernknopf
U.S. Geological Survey
922 National Center
Reston, Virginia 22092
Tel: (703) 648-6726

Mr. Ernest Cobb
U.S. Geological Survey
Water Resources Division
415 National Center
Reston, Virginia 22092
Tel: (703) 648-5319

Dr. James F. Davis
Supervising Geologist:
Geologic Hazards
California Department of Conservation
California Division of Mines & Geology
1416 Ninth Street, Room 1314
Sacramento, California 95814
Tel: (916) 445 1923
Fax: (916) 324-0616

Mr. Lloyd Falck
New Zealand Earthquake and
War Damage Commission
133A Queen Street, LEVIN
New Zealand
Tel: 699-771
Fax: 04 697 015

Dr. John Filson
U.S. Geological Survey
922 National Center
Reston, Virginia 22092
Tel: (704) 648-6785

Dr. Don Friedman
Travelers Insurance Company
One Tower Square
Hartford, Connecticut 06183-7200
Tel: (203) 277-3488

Dr. Walter Hays
Office of Earthquakes, Volcanoes
and Engineering
U.S. Geological Survey
905 National Center
Reston, Virginia 22092
Tel: (703) 648-6711
Fax: (703) 648-6717

Mr. William A. Hodges
American Sterling Group
22481 Aspan Street
El Toro, California 92630
Tel: (714) 380-1900

Mr. Robert Holtom, CPCU
Insurance Consultant
P.O Box 390
Whittier, California 90608
Tel: (213) 696-1520

Ms. Margaret Hopper
U.S. Geological Survey
Box 25046, Mail Stop 966
Denver Federal Center
Denver, Colorado 80225
Tel: (303) 236-1606

Mr. Lowden Jessup
Kemper Insurance
180 Howard Street
San Francisco, California 94105
Tel: (415) 442-6514

Mr. Howard Leikin
Federal Insurance Administration
Federal Emergency Management Agency
500 C Street, S.W.
Washington, D.C. 20472

Mr. Paul F. Lenzi
Continental Insurance Company
180 Maiden Lane
New York, New York 10038
Tel: (212) 440-3882

Dr. E. V. Leyendecker
U.S. Geological Survey
Box 25046, Mail Stop 966
Denver Federal Center
Denver, Colorado 80225
Tel: (303) 236-1601

Mr. Ake Munkhammar
Skandia International
Insurance Corporation
Box 7693
Stockholm, Sweeden S-103-95
Tel: 46-8-788 46-21
Fax: 46-8-211206

Mr. Robert Odman
State Farm Fire and Casualty Company
112 East Washington
Bloomington, Illinois 61701
Tel: (309) 766-5906

Mr. David Perkins
U.S. Geological Survey
Box 25046, Mail Stop 966
Denver Federal Center
Denver, Colorado 80225
Tel: 303-236-1616

Dr. Bruno Porro
Swiss Reinsurance Company
P.O. Box Ch 8022 - Zurich
Switzerland

Mr. Richard J. Roth
Assistant Insurance Commissioner
California Department of Insurance
600 South Commonwealth Avenue
Los Angeles, California 90005
Tel: (213) 736-2538

Mr. Edwin A. Simner
Merrett Group, Lloyds of London
33 Creechurch Land
London, England EC3A 5AJ
Tel: 01 283 3434

Mr. James C. Smith
Fireman's Fund Insurance Company
777 San Marin Drive
Novato, California 94998
Tel: (415) 899-2435

Mr. Karl V. Steinbrugge
Consultant
6851 Cutting Boulevard
El Cerrito, California 94530
Tel: (415) 233-1060

Mr. Paul Thenhaus
U.S. Geological Survey
Box 25046, Mail Stop 966
Denver Federal Center
Denver, Colorado 80225
Tel: (303) 236-1610

Mr. Ron Wardrop
Allstate Research Planning Center
321 Middlefield Road
Menlo Park, California 94025
Tel: (415) 324-2721 x 375

APPENDIX D

CONFERENCES TO DATE

Conference I	Abnormal Animal Behavior Prior to Earthquakes, I Not Open-Filed
Conference II	Experimental Studies of Rock Friction with Application to Earthquake Prediction Not Open-Filed
Conference III	Fault Mechanics and Its Relation to Earthquake Prediction Open-File No. 78-380
Conference IV	Use of Volunteers in the Earthquake Hazards Reduction Program Open-File No. 78-336
Conference V	Communicating Earthquake Hazard Reduction Information Open-File No. 78-933
Conference VI	Methodology for Identifying Seismic Gaps and Soon-to-Break Gaps Open-File No. 78-943
Conference VII	Stress and Strain Measurements Related to Earthquake Prediction Open-File No. 79-370
Conference VIII	Analysis of Actual Fault Zones in Bedrock Open-File No. 79-1239
Conference IX	Magnitude of Deviatoric Stresses in the Earth's Crust and Upper Mantle Open-File No. 80-625
Conference X	Earthquake Hazards Along the Wasatch and Sierra-Nevada Frontal Fault Zones Open-File No. 80-801
Conference XI	Abnormal Animal Behavior Prior to Earthquakes, II Open-File No. 80-453
Conference XII	Earthquake Prediction Information Open-File No. 80-843
Conference XIII	Evaluation of Regional Seismic Hazards and Risk Open-File No. 81-437
Conference XIV	Earthquake Hazards of the Puget Sound Region, Washington Open-File No. 82-19
Conference XV	A Workshop on "Preparing for and Responding to a Damaging Earthquake in the Eastern United States" Open-File No. 82-220
Conference XVI	The Dynamic Characteristics of Faulting Inferred from Recording of Strong Ground Motion Open-File No. 82-591
Conference XVII	Hydraulic Fracturing Stress Measurements Open-File No. 82-1075
Conference XVIII	A Workshop on "Continuing Actions to Reduce Losses from Earthquakes in the Mississippi Valley Area Open-File No. 83-157
Conference XIX	Active Tectonic and Magmatic Processes Beneath Long Valley Open-File No. 84-939
Conference XX	A Workshop on "The 1886 Charleston, South Carolina, Earthquake and its Implications for Today" Open-File No. 83-843

Conference XXI	A Workshop on"Continuing Actions to Reduce Potential Losses from Future Earthquakes in the Northeastern United States" Open File No. 83-844
Conference XXII	A Workshop on "Site-Specific Effects of Soil and Rock on Ground Motion and the Implications for Earthquake-Resistant Design" Open-File No. 83-845
Conference XXIII	A Workshop on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in Arkansas and Nearby States" Open-File No. 83-846
Conference XXIV	A Workshop on "Geologic Hazards in Puerto Rico" Open-File No. 84-761
Conference XXV	A Workshop on "Earthquake Hazards in the Virgin Islands Region" Open-File No. 84-762
Conference XXVI	A Workshop on "Evaluation of the Regionald and Urban Earthquake Hazards in Utah" Open-File No. 84-763
Conference XXVII	Mechanics of the May 2, 1983 Coalinga Earthquake Open-File No. 85-44
Conference XXVIII	A Workshop on "The Borah Peak, Idaho, Earthquake" Open-File No. 85-290
Conference XXIX	A Workshop on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in New York and Nearby States" Open-File No. 85-386
Conference XXX	A Workshop on "Reducing Potential Losses From Earthquake Hazards in Puerto Rico Open File No. 85-731
Conference XXXI	A Workshop on "Evaluation of Regional and Urban Earthquake Hazards and Risk in Alaska" Open File No. 86-79
Conference XXXII	A Conference on "Future Directions in Evaluating Earthquake Hazards of Southern California" Open-File No. 86-401
Conference XXXIII	A Workshop on "Earthquake Hazards in the Puget Sound, Washington Area" Open-File No. 86-253
Conference XXXIV	A Workshop on "Probabilistic Earthquake-Hazards Assessments," Open-File 86-185
Conference XXXV	A Workshop on "Earth Science Considerations for Earthquake Hazards Reduction in the Central United States," Open-File Report No. 86-425
Conference XXXVI	A Workshop on "Assessment of Geologic Hazards and Risk in Puerto Rico" Open-File 87-007
Conference XXXVII	A Workshop on "Earthquake Hazards Along the Wasatch, Utah Open File 87-154 ,
Conference XXXVIII	A Workshop on "Physical & Observational Basis for Intermediate Term Earthquake Prediction Open-File 87- [in press]

Conference XXXIX	Directions in Paleoseismology Open File 87- [in press]
Conference XL	A Workshop on "The U.S. Geological Survey's Role in Hazards Warnings" Open-File Report 87-269
Conference XLI	A Review of the Earthquake Research Applications in the National Earthquake Hazard Reduction Program: 1977-1987 Open-File 88-13-A
Conference XLII	A Workshop on "Evaluation of Earthquake Hazards and Risk in the Puget Sound and Portland Areas" Open-File Report 88-541
Conference XLIII	A Workshop on "Earthquake Risk: Information Needs of the Insurance Industry" Open-File Report 88-669

For information on ordering the above publications, please contact:

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