TECHNIQUES AND PARAMETERS FOR EARTHQUAKE RISK ASSESSMENT

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SUMMARY

The principal elements of seismic risk assessment are outlined. An approach to seismic risk assessment is developed that provides quite satisfactory risk assessments on a scale of a single structure to regional assessments of risk. An example of a contemporary risk assessment is discussed and the development of a data base for routine risk assessments is advocated.

INTRODUCTION

The evaluation of earthquake risk is a complex problem involving the integration and evaluation of geological, seismological, engineering and economic data. The term earthquake risk is taken here in the engineering context to mean the likelihood of loss. This engineering definition of seismic risk can, however, be readily applied to the assessment of two important problems of earthquake insurance:

1. Average annual loss:
   What premium rate is required to cover the average expected loss?, and,
2. Catastrophe potential:
   What is the magnitude of a single loss (i.e. what reserve is necessary to cover a large single loss)?

The principal emphasis in this paper is to outline the geological and seismological aspects of the evaluation of earthquake risk, to comment on the engineering problems involved and to suggest how related research may be applied to the evaluation of average annual earthquake loss and catastrophe potential.

NATURE OF THE EARTHQUAKE RISK PROBLEM

The evaluation of earthquake risk depends, from a scientific and engineering point of view, on three principal elements: 1) the earthquake hazard; 2) vulnerability; and, 3) the inventory at risk (exposure - structures and people at risk). These elements are shown in figure 1 and will each be considered separately.

Earthquake Hazard

Earthquake hazard is taken to mean the effects of earthquakes that may (or may not) result in economic and/or life loss and injuries. It is important to realize that the principal earthquake hazard is ground shaking, since all earthquake-related geologic effects, with the exception of surface fault rupture associated with the mechanism of the earthquake, are caused by ground shaking. These geologic effects include ground-shaking induced landslides, liquefaction, lurching and other failure phenomena. In general, losses associated with surface fault rupture are small, relative to losses associated with ground shaking and geologic effects (Algermissen and others, 1972). Surface fault rupture can be important in catastrophe potential, but only rarely, since surface rupture is not associated with all earthquakes and major fault systems that produce surface ruptures during earthquakes are now generally recognised. Surface ruptures should not be important in evaluating average annual earthquake losses, since structures will not be rebuilt on the traces of known fault ruptures. There are, unfortunately, numerous known disastrous exceptions to this generalization.

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The ratios between damage from ground shaking to earthquake related landslides and liquefaction are highly variable and obviously depend upon the topography and liquefaction are highly variable and obviously depend upon the topography and the geotechnical properties of near-surface materials. Nevertheless, widespread losses related to landsliding and liquefaction tend to be rare events although they may be spectacular. Examples are the avalanche associated with the magnitude 7.3 Peru earthquake in 1970 that buried the village of Yungay, Peru, resulting in 15,000 fatalities and the extensive liquefaction associated with the great Alaska earthquake in 1964. As pointed out by Falck (1988), the discovery that an area may have a high liquefaction potential may appreciably change the estimate of single event losses. Thus, areas that are known to have large earthquakes, but only rarely (say, average recurrence times of 500 years or more) may have a considerable liquefaction and landslide potential that has not as yet been recognized.

An important generalizing principle in hazard assessment is that, at least in theory, if the characteristics of earthquake shaking (amplitude, frequency content, duration, etc.) can be estimated and something is known of the geotechnical properties of the surficial geologic materials (density, void ratios, layering, seismic wave velocities) and the topography, then estimates of the potential for liquefaction and landsliding are possible. Significant progress has been made on these problems in the U.S. Geological Survey program in the United States (see, for example, Youd and Perkins, 1987; and Wilson and Keefer, 1985).

Both deterministic (scenario) and probabilistic techniques are important in

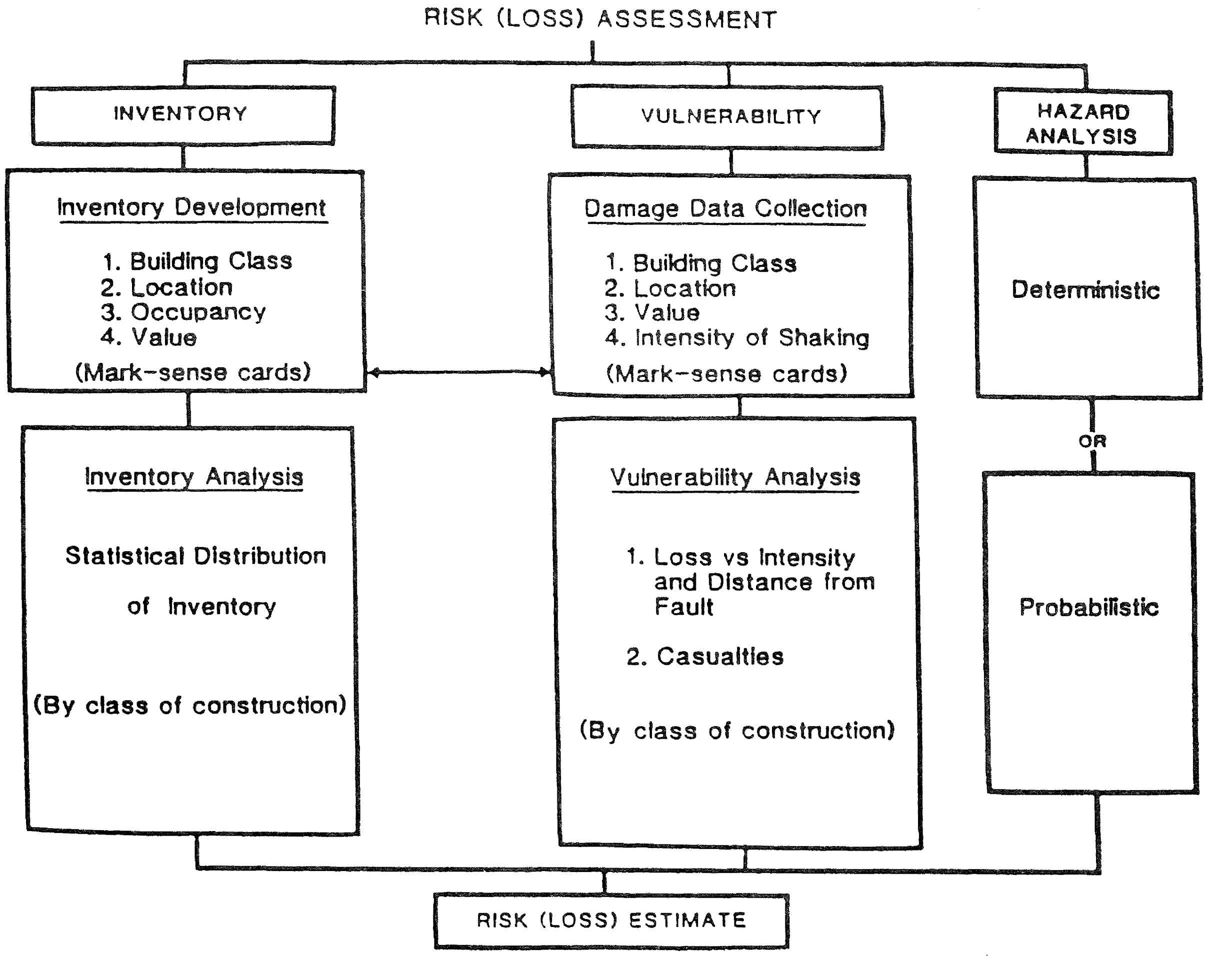


FIGURE 1. ELEMENTS IN SEISMIC RISK ASSESSMENT. The notation "mark-sense cards" indicates the manner in which earthquake damage data and building inventory are collected by the U.S. Geological Survey (also see figs. 4 and 5). Note that under Inventory Development, Building Class means an inventory of the building components critical to the estimation of damage (framing, number of floors, etc.) Building Class under Damage Data Collection means the inspection (for damage) of the same building Components that have been inventoried.

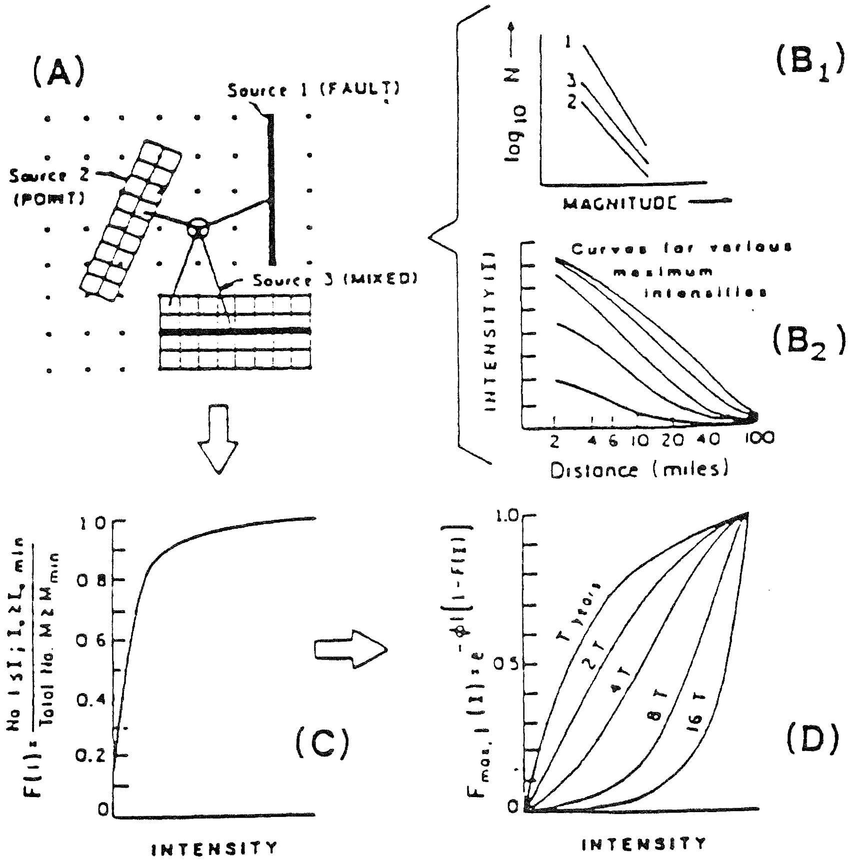


FIGURE 2. SCHEMATIC OF THE ELEMENTS OF PROBABILISTIC MODIFIED MERCALLI INTENSITY CALCULATION.

(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 from the site of interest 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 each of the seismic 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 source zone, earthquake recurrence and attenuation model.

(D) The probability (ordinate) of not exceeding any given intensity level (abscissa) for various time periods of interest. Any appropriate probability model can be used. The model illustrated is a Poisson model.

earthquake hazard assessment. In general, deterministic (scenario) type hazard evaluations are more useful in estimating catastrophe potential than for estimating average annual loss. Often scenario hazard studies of the largest possible earthquake believed likely to occur (on the basis of seismotectonic, paleoseismicity and seismicity studies) are coupled with an evaluation of the probability of occurrence of such a large shock (see, for example, Algermissen and others,1972; Algermissen and Hopper, 1984; and Hopper, ed., 1985). Generally, deterministic evaluations of average annual loss are difficult. They are, however, possible if the seismicity of the area considered is sufficiently high and is known for a reasonable span of time, say 200 years. Algermissen and Steinbrugge, 1978, for example, considered the known historical seismicity of California considered to be representative of future seismicity, the earthquake hazard and risk for each earthquake was simulated and the results annualised. The historical seismicity in three different historical time windows was computed and compared. An alternate technique for the estimation of both average annual loss and catastrophe potential is through probabilistic analyses of the earthquake hazard and risk. A schematic presentation of a general probabilistic technique for the estimation of Modified Mercalli intensity <taken from Algermissen, 1988) is shown in figure 2. The application of this type of analysis to risk assessment will be discussed later in this paper.

Vulnerability

Vulnerability is the susceptibility of a component of a structure or class of structures to damage. Vulnerability is often expressed as the percent of the total replacement cost of a structure required to repair it when it is subjected to some specified type and severity of earthquake hazard. The earthquake hazard may be ground shaking, landsliding, liquefaction, tsunami wave, etc. Vulnerability is essentially the linkage between hazard and loss and is obviously critical to risk assessment. Unfortunately, the data base for vulnerability is very poor. There are a number of reasons for this state of affairs. First, the characteristics of the building stock at risk have changed over the years and is constantly changing as new building and other structures are completed and older ones demolished. Thus, there is always little damage experience for new

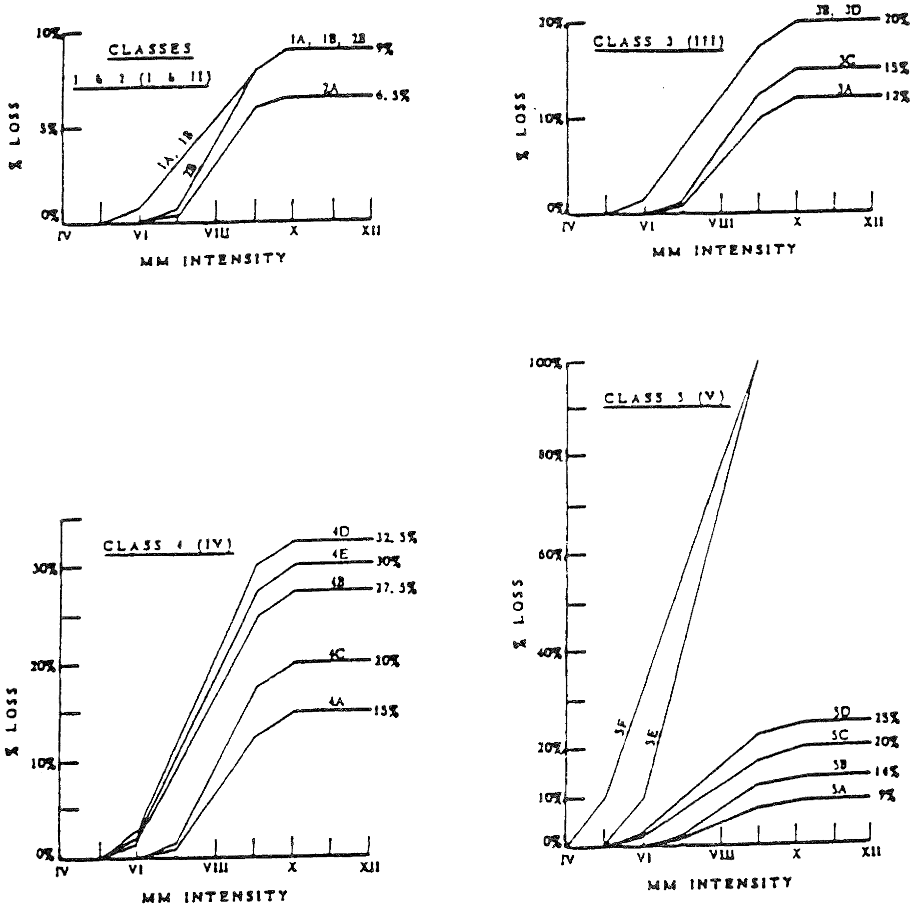
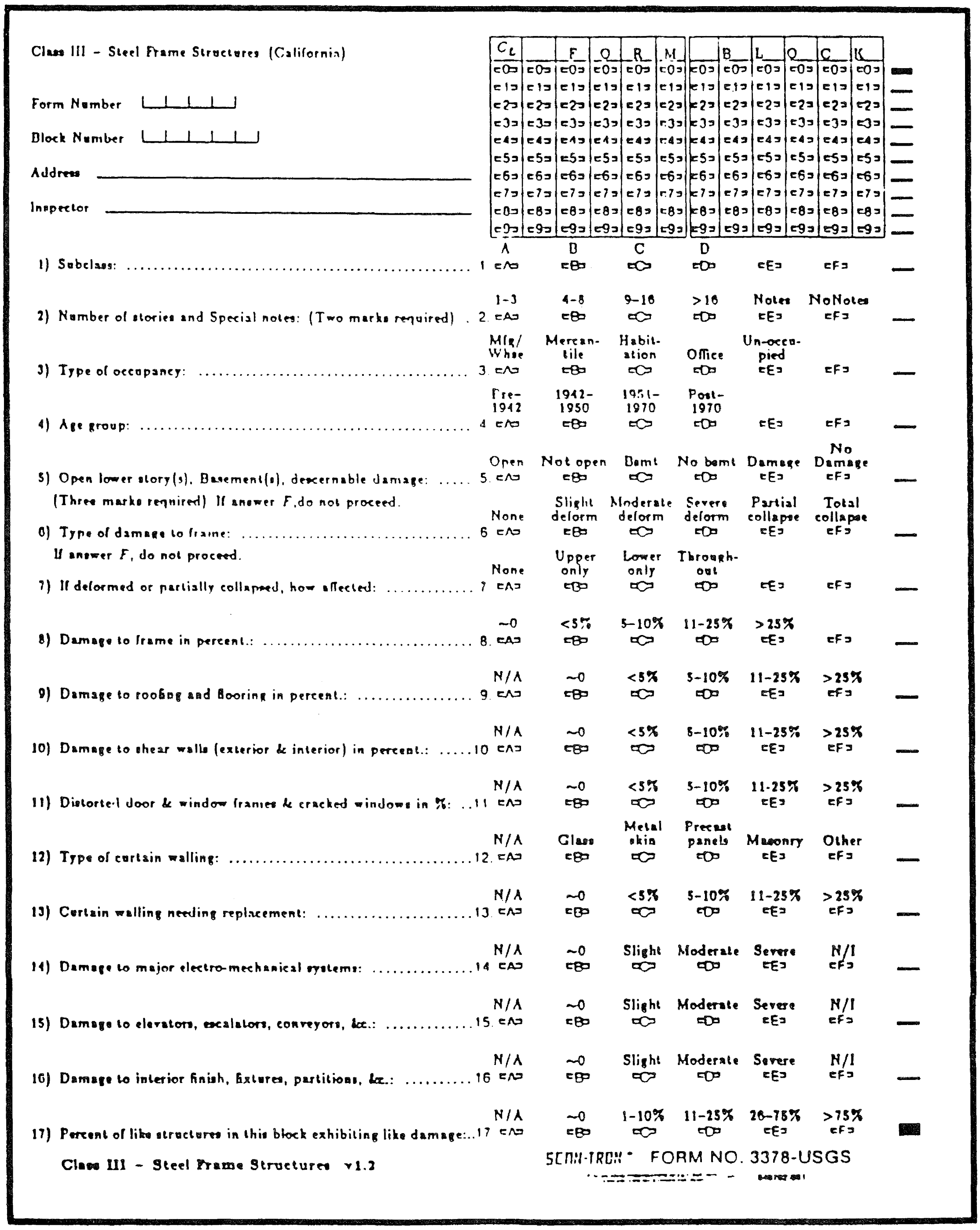


FIGURE 3. VULNERABILITY RELATIONSHIPS DEVELOPED BY K. V. STEINBRUGGE (SEE ALGERMISSEN AND STEINBRUGGE, 1984) AND THE DESCRIPTIONS OF THE CLASSES IN TABLE 1.

TABLE 1. NOTATION USED TO IDENTIFY BUILDING CLASSES AND BRIEF DESCRIPTION OF BUILDING CLASSES

Building Class	Brief description of building subclasses
1A	Wood frame and stuccoed frame dwellings regardless of area and height Wood fvrame and stuccoed frame buildings, other than dwellings, which do not exceed 3 stories in height and do not exceed 3,000 square feet in ground floor area Wood frame and stuccoed frame structures which do not exceed 3 stories in height regardless of area
1B	Wood frame and stuccoed frame buildings not qualifying under class 1A
2A	One storey all metal; floor area less than 20,000 ft^2
2B	All metal buildings not under 2A
3A	Steel frame, superior damage control features
3B	Steel frame, ordinary damage control features
3C	Steel frame, intermediate damage control features (between 3A and 3B)
3D	Steel frame, floors and roofs not concrete
4A	Reinforced concrete, superior damage control features
4B	Reinforced concrete, ordinary damage control features
4C	Reinforced concrete, intermediate damage control features (between 4A and 4B)
4D	Reinforced concrete, precast reinforced concrete, lift slab
4E	Reinforced concrete, floors and roofs not concrete
5A	Mixed construction, small buildings and dwellings
5B	Mixed construction, superior damage control features
5C	Mixed construction, orjdinary damage control features
5D	Mixed construction, intermediate damage control features
5E	Mixed construction, unreinforced masonry
5F	Mixed construction, load bearing walls of hollow tile or adobe
6	Buildings specifically designed to be earthquake resistant



Class III - Steel Frame Structures (California)

Form Number ☐☐☐☐☐

Block Number ☐☐☐☐☐☐

Address ______________________

Inspector ______________________

C_L		F	Q	R	M		B	L	Q	C	K
0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9	9	9	9

		A	B	C	D	E	F
1) Subclass:	1	A	B	C	D		
2) Number of stories and Special notes: (Two marks required)	2.	1-3	4-8	9-16	>16	Notes	NoNotes
3) Type of occupancy:	3.	Mfg/ Whse	Mercan-tile	Habit-ation	Office	Un-occu-pied	
4) Age group:	4	Pre-1942	1942-1950	1951-1970	Post-1970		
5) Open lower story(s), Basement(s), descernable damage: (Three marks required) If answer F, do not proceed.	5.	Open	Not open	Bsmt	No bsmt	Damage	No Damage
6) Type of damage to frame: If answer F, do not proceed.	6	None	Slight deform	Moderate deform	Severe deform	Partial collapse	Total collapse
7) If deformed or partially collapsed, how affected:	7	None	Upper only	Lower only	Through-out		
8) Damage to frame in percent.:	8.	~0	<5%	5-10%	11-25%	>25%	
9) Damage to roofing and flooring in percent.:	9.	N/A	~0	<5%	5-10%	11-25%	>25%
10) Damage to shear walls (exterior & interior) in percent.:	10	N/A	~0	<5%	5-10%	11-25%	>25%
11) Distorted door & window frames & cracked windows in %:	11	N/A	~0	<5%	5-10%	11-25%	>25%
12) Type of curtain walling:	12.	N/A	Glass	Metal skin	Precast panels	Masonry	Other
13) Certain walling needing replacement:	13.	N/A	~0	<5%	5-10%	11-25%	>25%
14) Damage to major electro-mechanical systems:	14	N/A	~0	Slight	Moderate	Severe	N/I
15) Damage to elevators, escalators, conveyors, &c.:	15.	N/A	~0	Slight	Moderate	Severe	N/I
16) Damage to interior finish, fixtures, partitions, &c.:	16	N/A	~0	Slight	Moderate	Severe	N/I
17) Percent of like structures in this block exhibiting like damage:	17	N/A	~0	1-10%	11-25%	26-75%	>75%

Class III - Steel Frame Structures v1.2

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FIGURE 4. MARK-SENSE CARD FOR CATALOGING INVENTORY AND DAMAGE. The cards are optically scanned for input to a microcomputer (see figure 5). Presently, a separate mark-sense card is used for each class of construction, but work is under way to reduce the number of cards. The card shown is for Class III - Steel Frame Structures.

building designs and materials. Second, there is the question of what actually is the loss when an older structure is damaged or destroyed. How should it be repaired or replaced? Third, damage information from many earthquakes is sketchy, only qualitative in nature and is rarely presented in the context of the total building stock at risk. In particular, it has been the practice in post earthquake damage surveys to intensively investigate a few structures of engineering interest while subtle damage to large numbers of structures is largely ignored. Only very recently have earthquake damage surveys attempted to be quantitative in context and statistically designed. Fourth, post earthquake damage surveys are expensive and time consuming if these surveys are to meet the needs of future damage (risk) assessment. Examples of vulnerability relationships for California are those developed by K. V. Steinbrugge for the Insurance Services Office (ISO). These are shown in figure 3 and explained in table 1 (Algermissen and Steinbrugge, 1984). Vulnerability relationships have also been published by the Applied Technology Council (1985) and a number of other groups. Note that in figure 3, percent damage is shown as a function of Modified Mercalli intensity. This has been the traditional way to present vulnerability information. A more direct and satisfactory method of assessing vulnerability (and loss) would be to analyze directly, the damage (for example, present replacement cost) by class of construction with distance from the macroseismic center of earthquake effects. 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 (i.e., a damage - attenuation) would require a reinvestigation of virtually all the damage data available for historical earthquakes. The idea of describing the distribution of damage by class of construction with distance from an earthquake, however, is greatly facilitated by a computer system for the compilation and analysis of earthquake damage data. Such a system, with accompanying software, has keen developed by the U.S. Geological Survey for surveys of damage after earthquakes and for the compilation of inventory. 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. Figure 4 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. 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.

Figure 5 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 has important implications. <u>This program should provide new statistical analyses of important earthquake damage sets not currently available for existing loss estimation techniques.</u>

<u>Inventory at Risk</u>

The third important parameter in risk assessment is the development of a Suitable inventory of structures and other facilities (such as lifelines) at risk (exposure). This is, in many ways, the most difficult aspect of risk assessment to resolve. The following general schemes have been used by the U.S. Geological Survey in risk assessments in the United States depending principally on the building class of construction (see Algermissen and Steinbrugge, 1984, for the building classes used here).

<u>Dwellings:</u> The Bureau of the Census provides adequate data for the distribution and numbers of residential housing in the United States but <u>not</u> framing system and construction materials. These later characteristics must be determined by statistical sampling.

<u>Buildings other than dwellings:</u> A number of techniques have been used to develop non-dwelling inventory, such as the following:

1. Zoning and land use classification maps.
2. Building permits and assessor's records.
3. Commercial building surveys (such as the now obsolete Sanborn maps, various commercial summaries of building statistics, etc.).
4. Local building departments.
5. Industry groups, regulatory agencies and owners (for lifelines).
6. Statistical sampling.

All of the above sources of inventory provide incomplete data that must be supplemented by sampling. The amount and detail of the sampling possible in any particular risk assessment depend on the amount of resources available for the assessment.

The personal computer Data Acquisition System developed by the U.S. Geological Survey described previously also can be used for the development of inventory. The advantage of the system for inventory development is that it is simple to apply and provides sufficient data for a reasonable risk assessment.

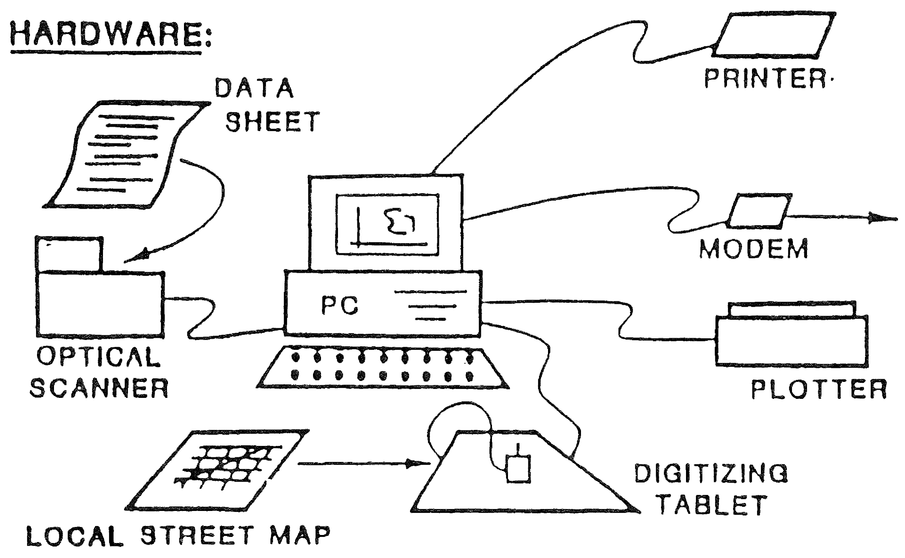

FIGURE 5. SCHEMATIC OF COMPUTER AND PERIPHERAL EQUIPMENT USED IN THE FIELD ACQUISITION OF EARTHQUAKE DAMAGE DATA AND FOR THE DEVELOPMENT OF INVENTORY. Mark-sense data sheets are scanned optically and entered into a personal computer. Street and area maps can be digitized and also entered into the computer. Statistical properties of the damage and/or inventory data can quickly be assembled and printed out or plotted with the geographical base already prepared. If the work is being done in the field, the data can be periodically stored on another computer remotely located.

A BASIC PROGRAM FOR RISK ASSESSMENT

Introduction

The purpose of this discussion is to outline an approach to risk assessment that has broad application for many countries and regions throughout the world, is realizable in most countries and will provide a reasonable assessment or earthquake risk for purposes of national economic policy, disaster planning and mitigation and insurance purposes.

Deterministic (Scenario) Risk Assessment

All risk assessments depend heavily on the hazard analyses available. Most countries have available seismic histories based on the Modified Mercalli scale or the MSK scale widely used in Europe. It is, therefore, a relatively simple matter to develop the distribution of intensity for scenario earthquakes that can be used to estimate the catastrophe potential (catastrophic risk potential) for an area. The risks (losses) are then obtained by convolving the intensity at a location of interest with suitable vulnerability curves (such as those shown in figure 3 to obtain the percent replacement cost or other measure of loss for any group of structures of interest.

The procedure outlined above is relatively simple and depends on only rudimentary seismological data. It does depend upon vulnerability relationships that have been developed with due regard to local variations in building codes, designs, and materials and upon a suitable inventory of structures at risk.

Probabilistic Risk Assessment

The elements of a simple probabilistic risk assessment are shown in figure 6. Figure 6 is identical with figure 2 with the exception of the portion labelled "B2". Here, intensity attenuation is replaced by convolving intensity attenuation relationships with vulnerability relationships, such as those shown in figures 3 and 4 or through a research program based on damage data from historical earthquakes where it is possible to determine the manner in which vulnerability changes with distance thus bypassing the use of intensity altogether.

The basic risk information obtained from figure 6, as shown in part D of the figure, is the maximum expected loss in various time periods of interest (T,2T,4T, etc.) at some level of probability of non-exceedance. For long time periods (or high probabilities of non-exceedance), the losses approach the catastrophe potential for a single structure, group of similar structures or total exposure in any particular region. Further examination of figure 6 shows that part C (the cumulative

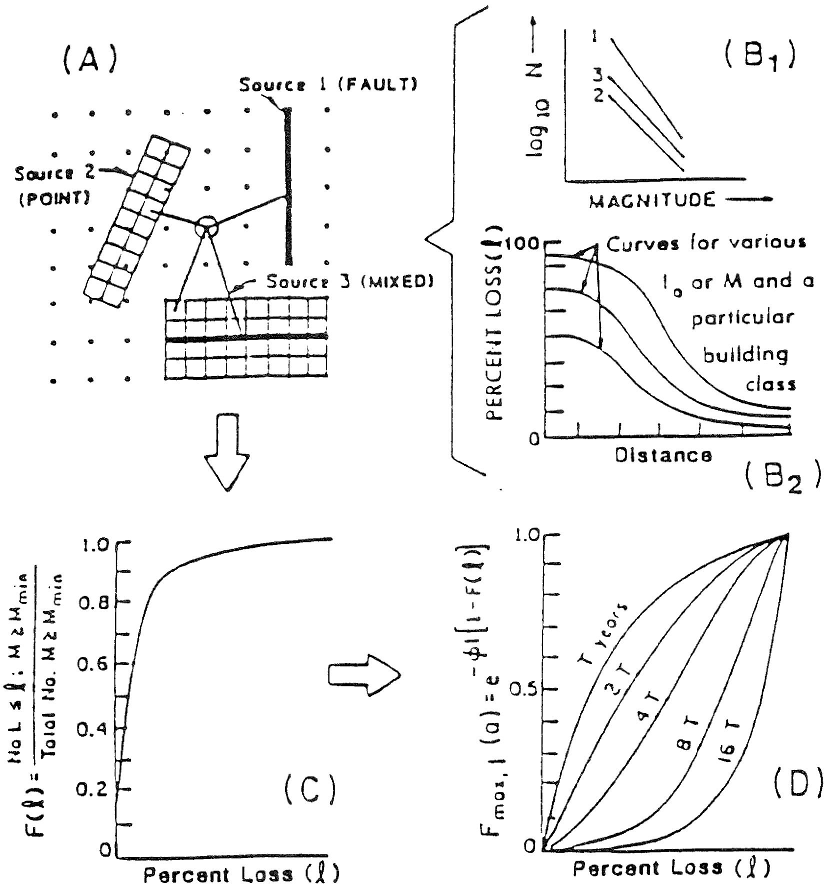

FIGURE 6. SCHEMATIC OF PROBABILISTIC SEISMIC RISK (LOSS) ASSESSMENT PROCESS. The model (and its description) is the same as shown in figure 2 for probabilistic hazard assessment with the exception that in this example of risk assessment the quantity mapped is "percent loss." Percent loss is obtained by substituting the attenuation of percent loss with distance for the attenuation of intensity with distance (as in fig. 2). Thus, the maximum expected loss in various time periods of interest (T, 2T, 4T. etc.) at some level of probability of nonexceedance is obtained (part D of figure).

conditional probability distribution of losses) contains all of the information for the assessment of average annual loss with only slight manipulation of data already in the computer program. Part D of figure 6 also contains additional information. By examining the losses for various time periods of interest for any constant level of probability (data along any horizontal line in part D), we see how losses change when various periods of time are considered. Additionally, if we consider a constant level of loss (data along any vertical line in part D of figure 6), the probability that such a loss will not be exceeded changes appreciably with time.

Thus in summary, a probabilistic risk assessment provides the following information, essentially in one computational process. These are:

1. Average annual loss.
2. Maximum probable loss at any probability level of not being exceeded in any particular time period considered. For long time periods, this loss approaches the catastrophe potential.
3. The loss (for a constant probability level of not being exceeded) for various time periods.
4. For any constant loss, the probability of this loss not being exceeded in various time periods of interest.

AN EXAMPLE OF A RISK STUDY: CENTRAL UTAH, USA

A study of possible future earthquake losses in central Utah has recently been completed (Algermissen and others, 1990, in press) which makes use of the general ideas for hazard and risk assessment already outlined. Only a summary of the study will be given here, since the report of the complete study will be available in six to nine months. Figure 7 shows the four-county study area and the general location of the Wasatch fault, the principal seismotectonic feature of the area. The Wasatch fault was selected as the loci of earthquakes of magnitude 5.5, 6.5, and 7.5 along segments of the Wasatch fault closest to Salt Lake City, Ogden and Provo, the three largest cities in Utah. In addition, one additional hypothetical fault west of Salt Lake City was considered and a probabilistic assessment of risk in the four-county area was made in terms of the maximum expected loss in a period of time of interest of 50 years with only a 10 percent chance that the maximum expected loss would be exceeded.

An innovation in the study is the inclusion of the so-called "site response" in the evaluation of loss. The site response is the contribution to the ground shaking associated with the materials beneath and adjacent to any site to depths of a few hundred meters. The U.S. Geological Survey has made an extensive instrumental study of the site response in the Central Utah area. Digital seismographs were placed on well-indurated rocks, as well as on rocks and soils of other types. The response at various sites was compared with the response on well-indurated rock sites for small earthquakes and blasts. The relative response was correlated with the various types of rock at many different sites. A conclusion of the study (Rogers and others, 1984) was the grouping of the shaking response of the various rock types into four general units: (1) rock; (2) rubble; (3) sand and gravel; and (4) silt and clay. The relative snaking in terms of Modified

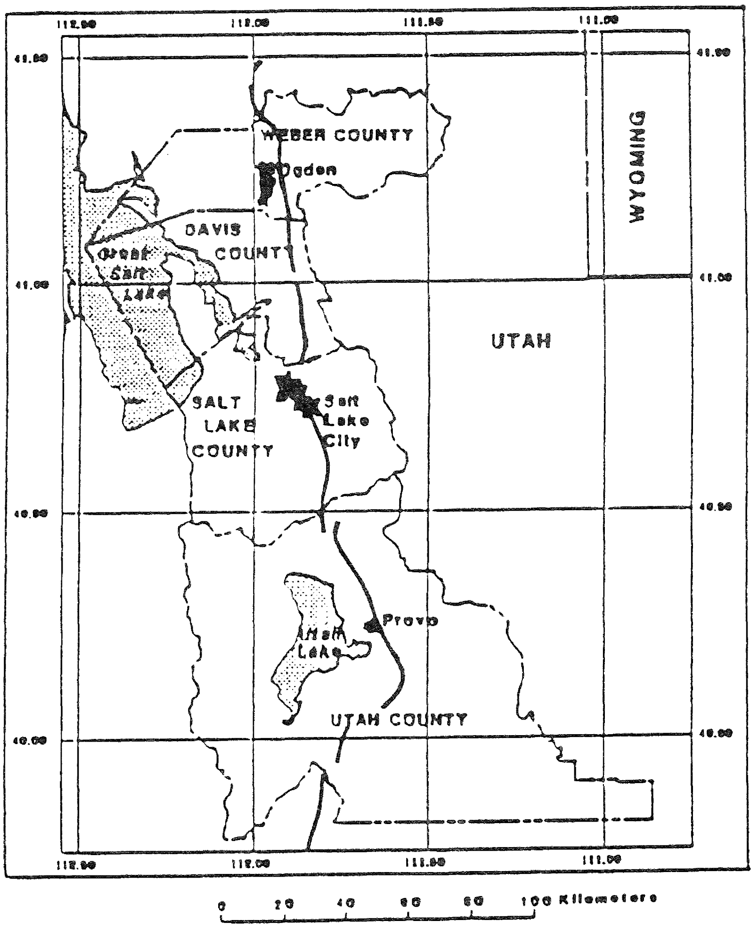

FIGURE 7. LOCATION MAP SHOWING THE FOUR-COUNTY STUDY AREA IN UTAH, THE WASATCH FAULT AND THE THREE PRINCIPAL CITIES: OGDEN, SALT LAKE CITY AND PROVO. About 77 percent of the population of Utah live in these four counties and over 90 percent of the buildings exceeding $1.0 million in original cost are located there.

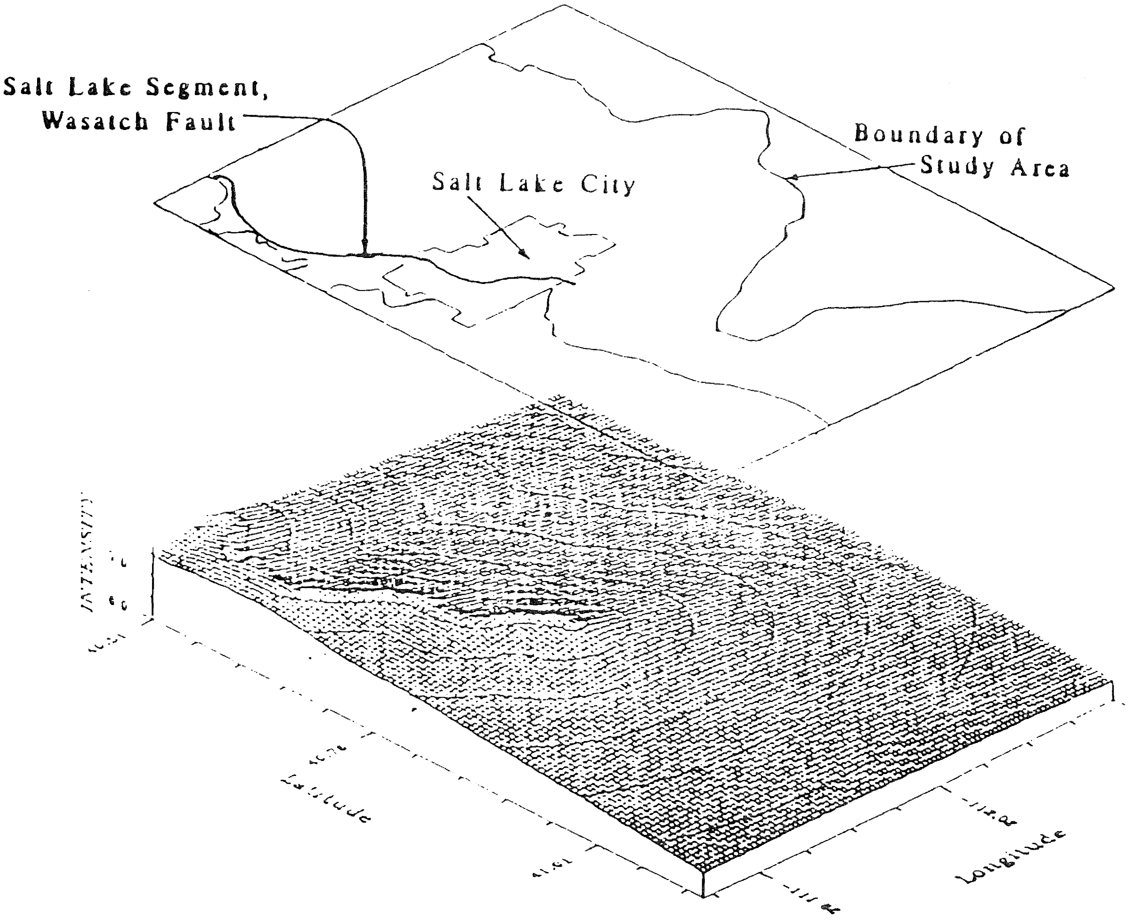

FIGURE 8. SIMULATED DISTRIBUTION OF MODIFIED MERCALLI INTENSITY (MMI) IN THE VICINITY OF SALT LAKE CITY, UTAH, AS A RESULT OF A MAGNITUDE 7.5 EARTHQUAKE ON THE WASATCH FAULT. THE SURFICIAL GEOLOGY IS ASSUMED TO BE "ROCK" AS DEFINED IN THE TEXT.

Mercalli intensity (MMI) of three of the units with respect to rock were determined to be: rubble, +1.4 intensity units; sand and gravel, +1.9 intensity units; and silt and clay, +2.6 units. The type of surficial geology of each U.S. Census tract in the StUdy area was determined and the site corrections in terms of MMI were applied to each Census tract and consequently were used in estimating loss. The effect of the site material on the attenuation of shaking in terms of MMI for a simulated magnitude 7.5 earthquake on the Wasatch fault is dramatically shown in figures 8 and 9. Table 2 summarizes the inventory and loss estimates. Figure 10 depicts graphically the estimated losses associated with the 10 earthquakes simulated as scenario events together with the expected 50 year maximum loss with a ten per cent chance of being exceeded. Figure 11 illustrates the results of a sensitivity study in which all intensities assigned to all Census tracts were increased one unit, the losses computed and then decreased one unit. Note that there is some saturation of losses for large earthquakes since the vulnerability relationships saturate for large ground motion. Figure 12 shows the distribution of losses by class of construction for a magnitude 7.5 earthquake near Salt Lake City. An important aspect of the distribution of losses by class of construction is the large loss sustained by brick dwellings. This is a major factor in loss estimation in much of the United States (except California). Since the central and eastern United States has the potential for large but infrequent earthquakes and much of the brick housing stock has not been tested by large earthquakes, a considerable risk appears to exist. Another important result of the Utah study is that where brick dwellings exist, it is important to sample sufficiently to establish the ratio of brick to non-brick dwellings because of the important difference in vulnerability between the two types of dwellings.

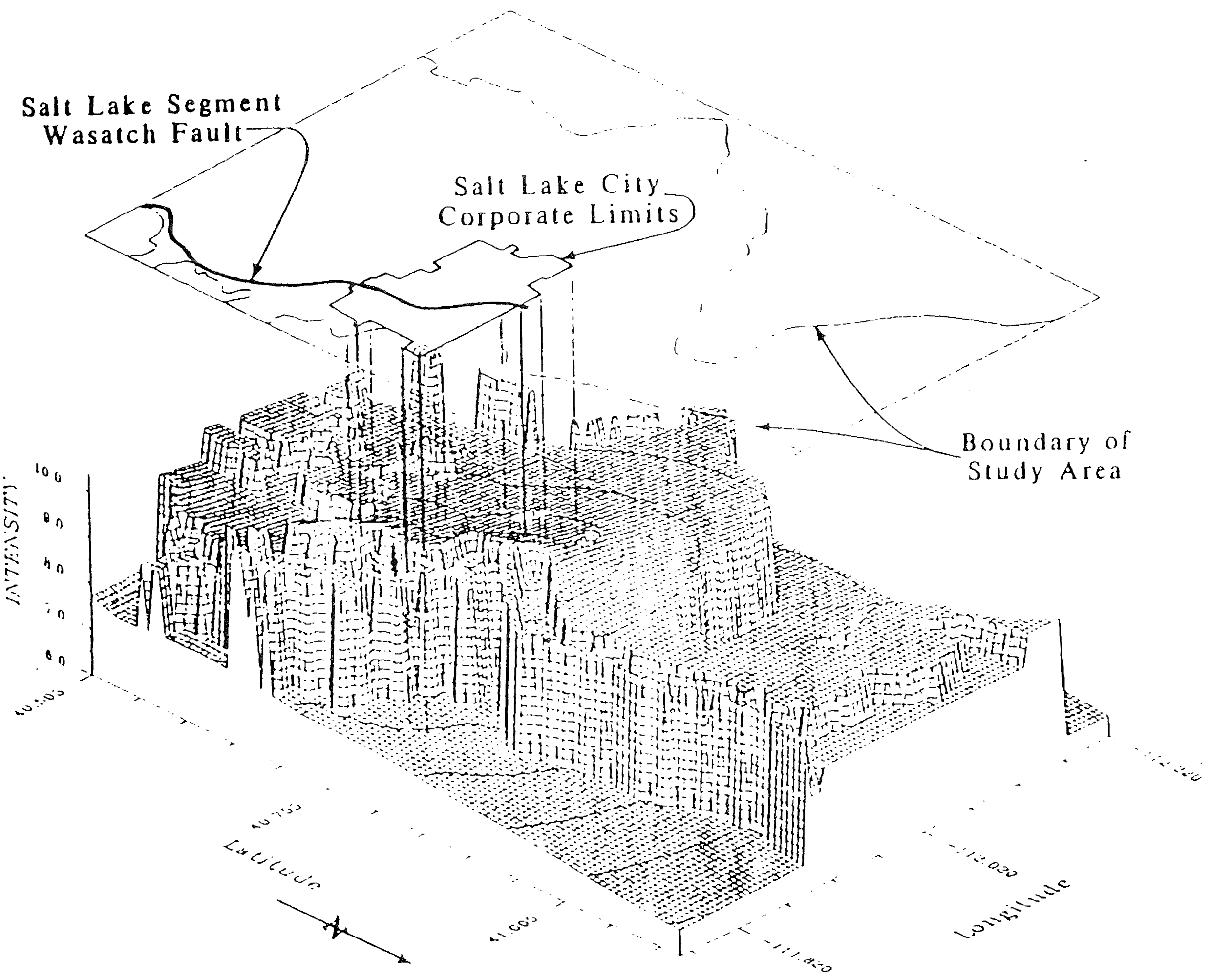

FIGURE 9. SIMULATED DISTRIBUTION OF MODIFIED MERCALLI INTENSITY (MMI) IN THE VICINITY OF SALT LAKE CITY, UTAH, AS A RESULT OF A MAGNITUDE 7.5 EARTHQUAKE ON THE WASATCH FAULT. The distribution of intensity has been estimated based on the actual distribution of surficial materials in the area (see text). Compare with figure 8, where a hypothetical, uniformly distributed "rock" has been assumed.

TABLE 2. INVENTORY AND LOSS STATISTICS
(UTAH, SALT LAKE, DAVIS AND WEBER COUNTIES)

	Value[1]	Range of Losses	Average % Losses
Dwellings	$18,871	$713 - 4,555	4 - 24
Non-Dwellings	4,868	118 - 923	2 - 20
Totals	$23,739	$831 - 5,478	3 - 23

[1] Millions of 1985 dollars

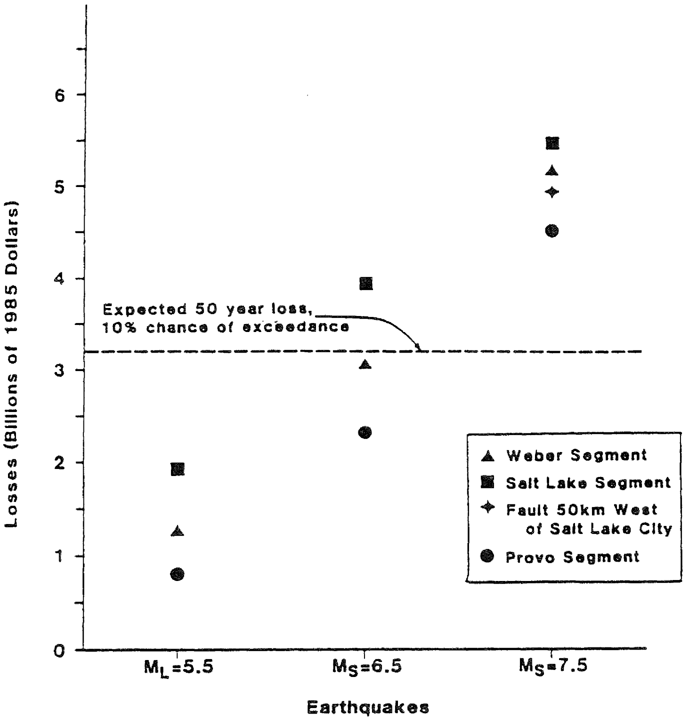

FIGURE 10. SUMMARY OF LOSSES TO ALL CLASSES OF CONSTRUCTION CONSIDERED IN CENTRAL UTAH (WEBER, DAVIS, SALT LAKE AND UTAH COUNTIES). Earthquakes of magnitude 5.5, 6.5 and 7.5 were considered at various locations for deterministic (scenario) loss simulation. A probabilistic estimate of maximum loss in 50 years with only a 10 percent chance of exceedance is also given. See figure 3 and table 1 for vulnerability relationships and building class descriptions.

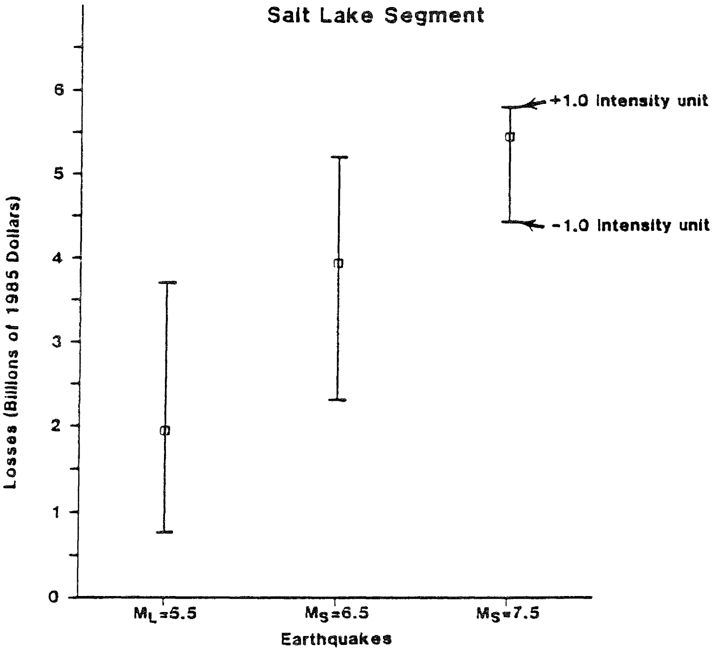

FIGURE 11. SENSITIVITY STUDY OF SCENARIO EARTHQUAKE LOSSES. The data points shown as squares are the actual results of the study. The higher values assume that the distribution of intensities are all 1.0 MM intensity unit higher and the lower bound values assume the distribution of all intensities are 1.0 MM unit lower. The cases shown are for earthquakes of magnitudes 5.5, 6.5 and 7.5 located close to Salt LaKe City on the Wasatch fault.

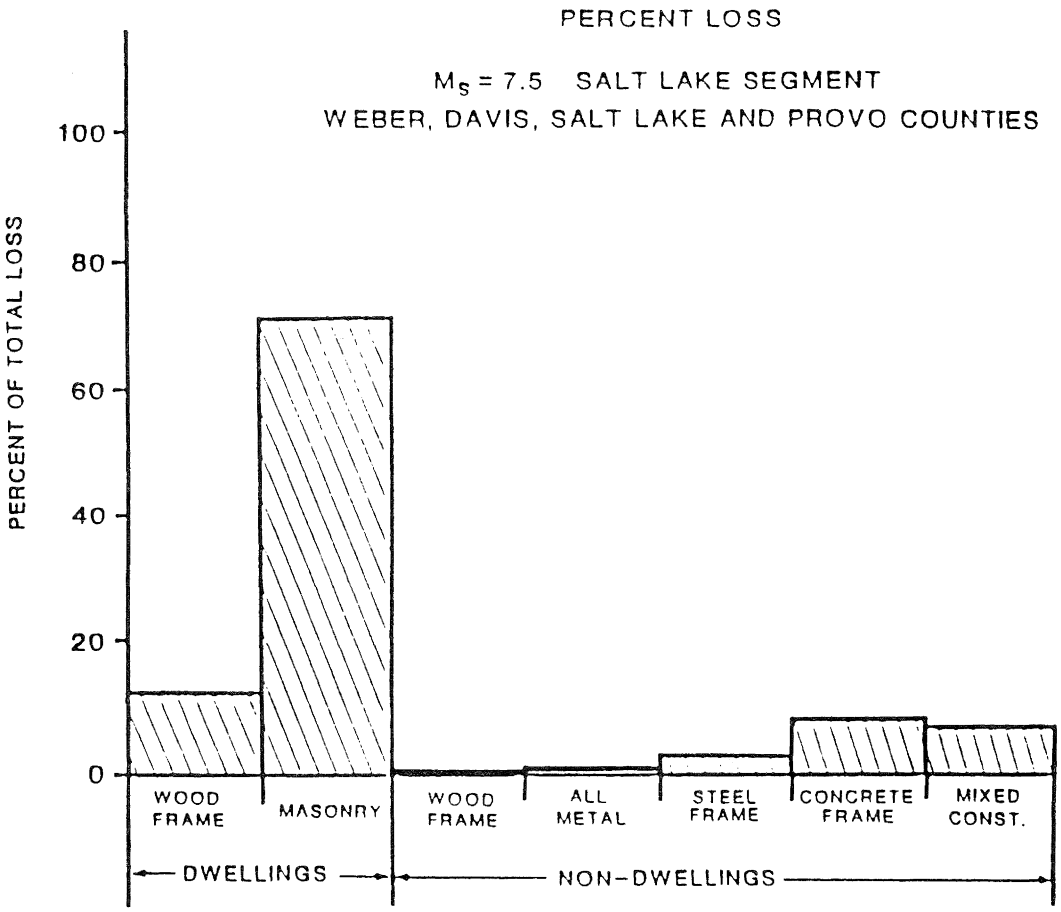

FIGURE 12. RELATIVE LOSS BY CLASS OF CONSTRUCTION FOR THE FOUR-COUNTY STUDY AREA IN CENTRAL UTAH FOR A MM = 7.5 EARTHQUAKE ON THE WASATCH FAULT NEAR SALT LAKE CITY. NOTE THE HIGH LOSSES ESTIMATED FOR MASONRY DWELLINGS.

DISCUSSION

An attempt has been made to outline the parameters and techniques of risk assessment that have wide application and that can be used in areas where only rudimentary geological and geophysical data are available but in areas where inventory and vulnerability can be developed commensurate with the accuracy of the required assessments. Risk assessment can be undertaken at various levels of sophistication, but it is important that all the important parameters of risk assessment can be estimated to the desired level of accuracy. Sufficient data are available for meaningful risk assessment in much of the world today. Figure 13 shows an estimate (Algermissen, 1988) of the quality of two important parameters in risk estimation - earthquake catalogs and seismotectonic data, for selected areas of the world. The estimates are very subjective, but they at least present a basis for discussion.

As already discussed, simple probabilistic earthquake hazard maps provide a basis for the comparison of the relative earthquake hazard in various areas. Figure 14 illustrates such a comparison for a number of cities in the United States based upon probabilistic ground acceleration maps generated for 10, 50 and 250 year periods of interest using a Poisson process for earthquake modelling (Algermissen and others, 1982). If probabilistic ground-motion maps, developed using a more or less standard, but simple, probabilistic approach, were available for much of the world, it would be possible to compare global earthquake hazard (and risk) on a somewhat objective basis. The U.S. Geological Survey has suggested this type of mapping on a worldwide basis as part of the International Decade for Natural Disaster Reduction (Peck, 1988).

The U.S. Geological Survey has proposed such an approach as part of the International Decade for Natural Disaster Reduction (Peck, 1988). It now appears that in FY90 the U.S. Geological Survey will undertake a limited number of earthquake hazard and risk demonstration projects of carefully selected areas worldwide.

QUALITY OF DATA

Area	Catalogs			Seismotectonics		
	E	G	F	E	G	F
North America	●			●		
Mexico		▲				■
Central America			■			■
Caribbean			■			■
South America	●				▲	
Southeast Asia (ASEAN countries)	●				▲	
North Africa			■			■
Middle East			■			■
Southern Europe - Balkans	●			●		
Eastern Europe	●				▲	
New Zealand, Australia	●			●		
China	●				▲	

FIGURE 13. SUBJECTIVE ESTIMATE OF ACCURACY AND COMPLETENESS OF EARTHQUAKE CATALOGS AND SEISMOTECTONIC DATA FOR SELECTED AREAS THROUGHOUT THE WORLD (ALGERMISSEN, 1988). THE RATINGS ARE EXCELLENT (E), GOOD (G) AND FAIR (F).

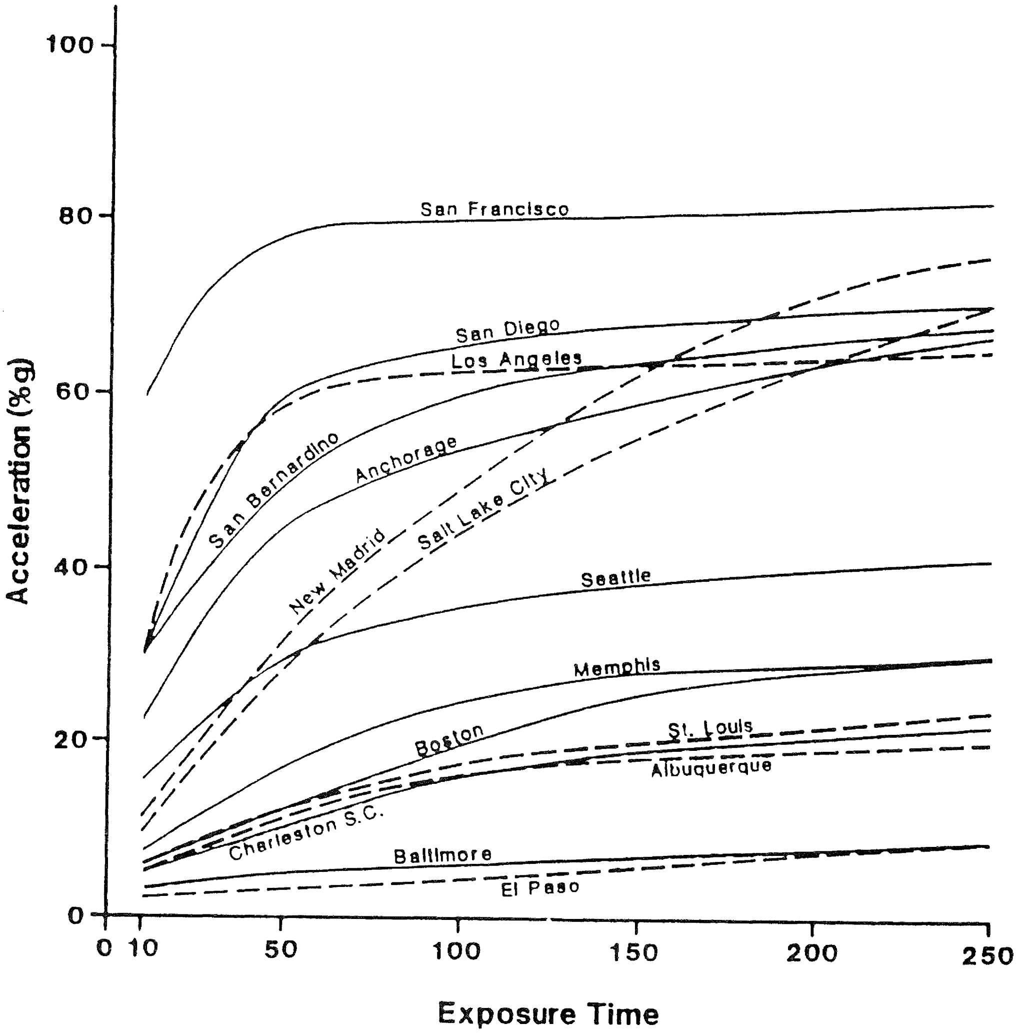

FIGURE 14 ASSESSMENT OF EARTHQUAKE HAZARD FOR A NUMBER OF CITIES IN THE UNITED STATES BASED UPON PROBABILISTIC GROUND ACCELERATION MAPS OF THE COUNTRY (ALGERMISSEN AND OTHERS, 1982). THIS TYPE OF PRESENTATION IS A USEFUL TOOL IN ESTIMATING THE RELATIONSHIPS BETWEEN THE EARTHQUAKE HAZARD IN A NUMBER OF AREAS.

An important question is the organization of data needed for risk assessment. One technique suggested by Algermissen (1988) is to organize all of the available earth science engineering and exposure information into a geographical database. For example, a geographical database could be set up on the basis of cells having areas of about 1 to 100 km^2. Within each geographical area, data of the following type could he accumulated as it became available for each cell.

1. Earthquakes known to have their epicenters in the cell.
2. MM or MSK intensities observed or estimated to have occurred using earthquake hazard simulations already discussed. This is the intensity history of the cell.
3. Estimated maximum magnitude earthquake likely to occur.
4. Maximum expected ground motion for various time periods of interest.
5. Known historical earthquake faulting or paleoseismic evidence of earthquake occurrence.
6. Description of the surficial geology and geology to depths of 100-500 meters.
7. Geotechnical properties of the materials itemized in (4) above (lithology depth to water table, depth to bedrock, layering, void ratios, densities, seismic wave velocities, etc.

8. Available inventory, type of construction, value occupancy, etc..

9. For insurance purposes--exposure.

Not all of the information suggested would be available for every cell but much of the data can be made readily available by properly organizing geological, seismological and engineering data routinely available. For example, item 1 above is available from the seismic history of the country or area. Item 2 is easily generated from item 1, etc. If information from available sources is organized into such a database, it is a simple matter to develop a computer program to estimate the risk in each cell. The lack of significant information in any cell would contribute to a measure of the uncertainty of the risk estimate.

A data base of the type described can be developed to any level of sophistication desired (or affordable). Even in a rudimentary form, such a data base provides a vehicle for the continuous updating of risk assessments and the routine application of these risk assessments to insurance problems, land-use planning and disaster mitigation studies.

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