LOSS ESTIMATION FROM EARTHQUAKE
SHAKING IN CALIFORNIA

by

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SUMMARY

This paper summarizes a study in which the potential economic effect of earthquake on various categories of structures was evaluated for California. Annualized loss estimates were computed by multiplying the building value at risk for California by the probability of experiencing various states of damage. Results show that the two largest metropolitan areas in the state i.e., the Los Angeles basin and the San Francisco Bay area, account for 82 percent of the total annualized loss. Other areas of high losses include San Diego, El Centro and Bakersfield in southern California, and Eureka and Sacramento in northern California. The present analyses, completed under a U.S. Geological Survey-sponsored project, were part of an overall Bayesian seismic risk analysis of California.

INTRODUCTION

A better understanding of the scale and distribution of disasters in future earthquakes is necessary to minimize losses due to these events. If areas vulnerable to earthquakes are identified in advance, it becomes possible to apply pre-disaster counter-measures, such as upgrading "low-quality" structures. In addition, post-disaster activities, such as surveying damage or distributing financial assistance, may be more effectively organized.

Loss, as it is defined in this study, is used to represent the economic loss (in dollars) to exposed building wealth from an earthquake environment. More specifically, it is the total cash value required to fully repair damaged buildings in earthquakes. This definition does not include losses to building contents, losses in income, or increased transportation costs due to supplier losses. It also does not reflect "social" losses (i.e., loss of life, homelessness, and unemployment).

There are at least two basic reasons why building losses should be evaluated: (1) they represent the most predominant dimension of damage from natural events, in general, and (2) they provide a basis for estimating other damages or losses through the use of an overall socio-economic assessment model. (Ref. 1)

This study utilizes an expected annual or "annualized" loss approach in representing the above losses. Over a long period of time, the sum of these annualized losses should reflect the total loss from actual earthquake events. This approach also provides a convenient basis for comparing alternative mitigatory measures on the basis of benefit/risk/cost.

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EXPOSURE MODEL

A critical step in assessing losses due to ground shaking is the quantification of exposed building wealth. An exposure model for California was developed using as a basis county income data published by the Bureau of Economic Analysis (Ref. 2). Two structure categories were defined: (a) residential, and (b) commercial and industrial.

Building values for residential structures were computed based on areal estimates of personal income per capita, population, and nationally-derived ratios of structure value to earnings. A grid of one-half degree by one-half degree squares was selected to be consistent with the discrete seismic source model defined in the study.

Populations per grid unit and estimates of income per capita were derived from Reference 2. These data were extrapolated to 1978 to reflect increases due to economic growth and inflation (Ref. 3). Residential building wealth (RBW) for each grid was computed using the following relationship:

$$RBW = K_{RES} \times (IN/C) \times (POPG) \tag{1}$$

where K_{RES} represents the building wealth-income coefficient for residential structures (Ref. 3), IN/C represents the income per capita per grid point, and POPG represents the population per grid point. The K_{RES} coefficient for the U.S. is given in Table 1.

Building values for commercial/industrial structures were evaluated in a similar manner. The income per economic sector (a total of ten) for each county was obtained from Reference 2 and projected to reflect 1978 dollars. The commercial/industrial building wealth (CIBW) was computed using the following algorithm:

$$CIBW = (CIBW_c/POPC) \times POPG \tag{2}$$

where $CIBW_c$ represents the commercial/industrial building wealth per county and POPC is the population per county. $CIBW_c$ was computed by summing the individual building wealths from each economic sector. The building wealth income coefficients used for each sector appear in Table 1.

Building code specifications were updated in California after the 1933 Long Beach earthquake in order to increase the requirements for lateral force resistance. For this reason, housing units built prior to 1934 were assumed not to be earthquake resistant (Quality 1); those built more recently were classified as another more resistant specification (Quality 3).

Based on the age distribution of buildings in California the following results were derived: 18 and 20 percent of all residential and commercial/industrial construction, respectively, were built prior to 1934.

DAMAGE ALGORITHMS

Expected annual building loss can be computed by evaluating the amount of damage sustained by various types of structures. The Modified Mercalli Intensity (MMI) scale was used to quantify ground motion. The lower limit of intensity which may produce damage was selected to be MMI = 6. The

upper limit was chosen to be MMI = 12; at this level, damage is essentially total.

The damage algorithm used in this study has the following form:

$$\log_{10} D = c + dI \tag{3}$$

where D is percent of damage, I is Modified Mercalli Intensity, and c and d are constants which are determined for different intensity ranges.

Damage algorithms were derived for two types of construction (i.e., residential and commercial/industrial), and for four subcategories of quality. Figures 1 and 2 show damage algorithms for residential and commercial/industrial construction, respectively. The data used to develop these relationships were derived from California earthquake data. In the derivation of the commercial/industrial algorithms, a linear regression analysis of observed data was performed for Quality factors 1 and 3. The curves for Q = 2 and Q = 4 were obtained by linear interpolation between the Q = 1 and Q = 3 curves, and extrapolation beyond the Q = 3 curve, respectively.

LOSS MODEL

After evaluating the earthquake hazard and building exposure as a function of geographic location, it is possible to determine the expected annual building loss using the following relationship:

$$E\langle \text{LOSS} \rangle = \sum_{h=1}^{2} \sum_{i=VI}^{XII} \alpha_i D_{ih} V_h \tag{4}$$

where h is the construction type index (1, residential; 2, commercial/industrial), i is an index for intensity level, α_i is the mean rate per year of earthquakes of intensity i, D_{ih} is the ratio of repair cost to total market value of the building, and V_h is the market value of the structure.

To compute the mean rate of occurrence α_i, the well-known earthquake frequency-magnitude relationship was used:

$$\log N = a - bM \tag{5}$$

where N denotes the cumulative annual frequency of occurrence of an earthquake of Richter magnitude M or greater, and a and b are the seismicity constants. Attenuation relationships developed in Reference 3 were used in this study to estimate ground motion intensities. That is,

$$\log X = C_1 + C_2 M - C_3 \log R \tag{6}$$

where X represents either peak ground acceleration, velocity or displacement, M is Richter magnitude, and R is hypocentral distance in kilometers. The constants C_1, C_2 and C_3 will, of course, be different for each of the three ground motions. The regional seismicity parameters for each site include the total seismicity, a, and the "effective hypocentral distance", $\bar{R}$. $\bar{R}$ represents the distance giving the same distribution of ground motion as if all point sources within the radius of search were replaced by one "equivalent" point source (Ref. 3). Using Equations 5 and 6, a frequency distribution for ground motion can be derived, of the form

$$\log N = a_X - b_X \log X \tag{7}$$

where

$$a_X = a + b_X C_1 - b_X C_3 \log \overline{R} \tag{8}$$

$$b_X = b/C_2 \tag{9}$$

It follows that

$$N = 10^{a_X - b_X \log X} = 10^{a_X} X^{-b_X} \tag{10}$$

Since the damage algorithms are based on Modified Mercalli Intensity (MMI), a transformation was necessary to convert the instrumental ground motion parameter to MMI. The logarithmic relationship developed in Reference 5 was used to relate MMI to peak ground velocity. The number of events within an interval of MMI (i.e., k to k+1) is given by the following relationship:

$$N_k - N_{k+1} = 10^{a_X} \left[10^{-b_X(-0.63 + 0.25 I_k)} - 10^{-b_X(-0.63 + 0.25 I_{k+1})} \right] \tag{11}$$

EXPOSURE AND LOSS MAP FOR CALIFORNIA

The total building wealth-at-risk in California is estimated to be 415,688 million dollars (in 1978 dollars). This wealth is distributed geographically to 187 grid points in California with the Los Angeles basin and the San Francisco bay area accounting for approximately 66 percent of the total. Figure 3 displays the distribution of building wealth geographically for California. Seven different wealth ranges are defined on that figure, ranging from less than 1 million dollars to greater than 50,000 million dollars; denser patterns represent the more wealthy areas. The numbers on the map are grid numbers. Of the total building wealth exposed, 55 percent is represented by residential construction and 45 percent by commercial and industrial.

The total annualized loss in California due to earthquakes is estimated to be 816 million dollars (in 1978 dollars). This number represents approximately 0.2 percent of the total structure value exposed in California. The estimated losses for the Los Angeles basin and the San Francisco bay area are 514 and 158 million dollars, respectively, the sum accounting for 82 percent of the total annualized loss. The geographical-distribution of the expected losses for the state are shown in Figure 4. Seven loss ranges are displayed, ranging from 0 to 0.001 million dollars to greater than 100 million dollars. The areas with the greatest loss are represented by the densest pattern. Other vulnerable areas include San Diego, El Centro and Bakersfield in southern California and Eureka and Sacramento in northern California.

CONCLUSIONS

An annualized loss map is provided for California. The two largest metropolitan areas in the state (i.e., Los Angeles and San Francisco) account for 82 percent of the total annualized loss. The loss estimates, however,

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may be low because of the historically-poor damage estimates on which portions of the model are based. Further study is needed to gain a better understanding of the relationship between expected damage and ground motion intensity. Using a ground motion parameter such as peak acceleration or velocity may provide a better indication of damage (Ref. 6).

ACKNOWLEDGEMENTS

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Table 1. Conversion Coefficients Used to Obtain Building Wealth from Income, by Economic Sector and Residential Type.

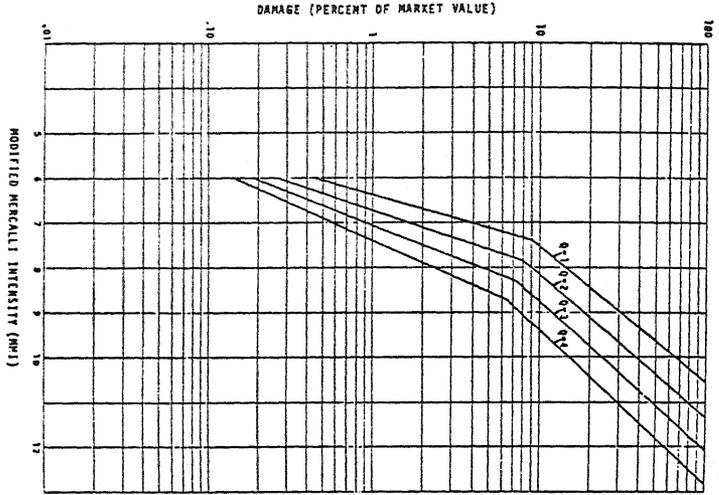|	ECONOMIC SECTOR	BUILDING WEALTH-INCOME COEFFICIENT, K^1
COMMERCIAL & INDUSTRIAL	FARM	0.34
	MANUFACTURING	0.66
	MINING	3.20
	CONSTRUCTION	0.61
	WHOLE SALE	0.74
	FINANCE	2.75
	TRANSPORTATION	5.30
	SERVICE	0.78
	FEDERAL GOVERNMENT	4.50
	STATE LOCAL	2.00
	RESIDENTIAL	1.30

1 Base Year 1978

Figure 1. Damage Algorithms for Residential Construction
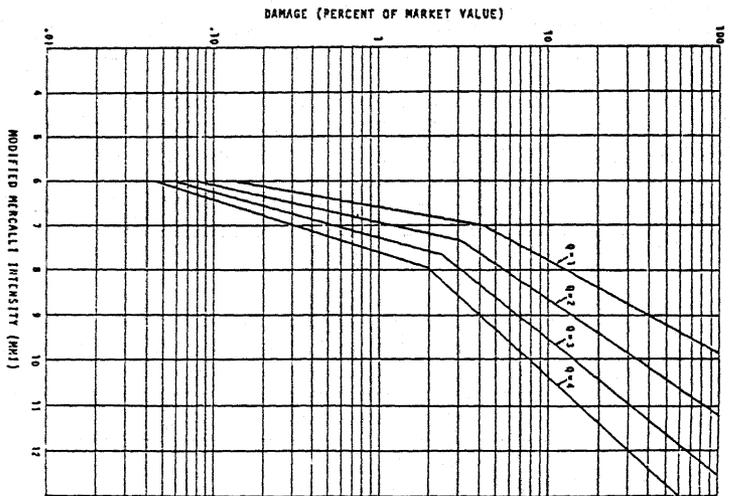

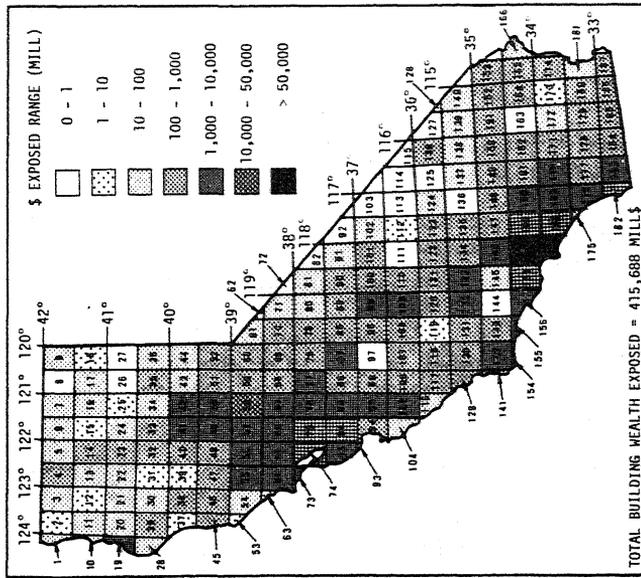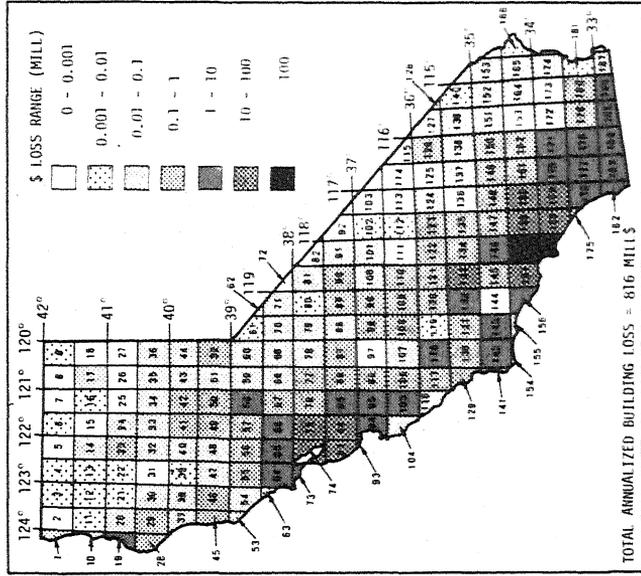Figure 2. Damage Algorithms for Commercial-Industrial Construction.

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Figure 4. Annualized Loss Map of California
(Millions of 1978 $)

Figure 3. Building Wealth Map of California
(Millions of 1978 $)