DETERMINATION OF DAMAGE RATIOS AND INSURANCE RISKS FOR SEISMIC REGIONS

By

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ABSTRACT

Developing a rational method to estimate insurance risk for seismic regions of the world has been a major task for researchers for many years. In 1978 December, the United Nations through UNESCO had convened a special meeting of experts in Mexico to discuss this problem and suggest possible methods of estimating damage potential for various types of buildings as well as to help develop a method for estimating earthquake insurance rate structure. This paper will present a methodology to develop such a rate structure. Expected values of global losses for various classes of structures can be determined by the method presented in this paper. Convolution of all types of building construction together with the seismic hazard would provide the global loss estimates for a given region.

Damage ratio-MMI relations are presented for various structure types. Their functions are for data on structures in the United States, Central and South America, collected from various sources. For a given structure type the following relation can be used to determine the expected value on damage,

$$E(dr) = \sum_{\text{all } I} f(dr/I=i)P(I=i)$$

where E( ) is the expected value, F(dr/I=i) is the empirically derived function of damage ratio for a given intensity I, and P(I=i) is the probability of at least one occurrence of intensity i in a given year. The above damage ratio is modified to include the quality factors such as redundancy, symmetry, regularity, applicable code and quality control.

This methodology has bearing on two aspects of earthquake risk. One being the need to develop a standard to determine insurance premiums, and another is the problem of real estate investment risk analysis. Each being a separate problem, but requiring some means of predicting future damage.

INTRODUCTION

During the last decade, considerable work has been conducted by seismologists, geologists and engineers to estimate seismic hazard and risk.

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Most of this work has been directed towards the formulation of design criteria for important facilities or for the development of "seismic hazard (or risk or zone)" maps for building codes. The same level and quality of effort has not been directed at developing rational methods to estimate insurance risk. The Intergovernmental Conference on the Assessment and Mitigation of Earthquake Risk, held at UNESCO Headquarters in 1976 passed the following resolution:

"That UNESCO, in cooperation with other United Nations bodies and relevant international organizations, gather experts from all countries with earthquake insurance programs, together with interested experts from countries without such insurance programs and from major insurance and reinsurance companies, seismologists, earthquake engineers, economists and social scientists, to consider the possibility of developing a workable general framework for the implementation of earthquake insurance and of initiating a long-term program of studies on earthquake insurance problems".

Based on the above recommendation, an International Seminar on Earthquake Hazard and Insurance was convened in Mexico by UNESCO on Dec. 4-7, 1978. Two authors of this paper were invited to this seminar with the specific task of discussing the theme of Loss Assessment and Prognosis-Vulnerability Analysis. Based on the detailed discussions at the subject seminar, it was concluded that considerable research is needed in developing reliable and practical methods for estimating damages for various types of facilities and for developing decision alternatives to reduce future expected losses.

The purpose of this paper is to achieve the following objectives.

1. Development of procedures for assessing losses.
   a. Representation of seismic hazard in a form which would facilitate procedures for correlating risk of occurrence, level of hazard (loading) and the damage ratio for the type of structure under consideration.
   b. Damage estimation procedures for different types and qualities of structures.
2. Development of simplified algorithms for assessing seismic risk for insurance or investment purposes and to develop procedures for evaluating insurance risk.

The results of this paper should be of interest not only to the private sector but also to government and the public sector. It is important to recognize here the need to estimate the future damage potential in a region by the government and public officials. Such an input will facilitate the damage mitigation measures a community or a region could take. Thus, the title of "insurance risk" is not only in the context of insurance companies and insurance underwriting but also in a general context of risk.

PROCEDURES FOR ASSESSING LOSSES

Considerable work is available in the literature on damage estimation and loss prediction. See for example, Culver et al (1975), Sauter and Shah (1978), Steinbrugge (1968, 1971), Scholl (1972, 1973), Whitman, Biggs et al (1974), Whitman, Hong and Reed (1973), Whitman et al (1973). Most of the available information relates the earthquake loading - represented usually by the Modified Mercalli Intensity - with the damage ratio for a specific type and quality of a structure.

The use of PGA-MMI relations in any procedure is at best questionable. A review of the data shows tremendous scatter about any derived regression curve, unless of course an upper bound is derived, Krinitzsky and Chang (1977). However state-of-the-art methods for damage estimation call for such a relation if results from standard seismic hazard analyses are to be used, Shah et al. (1975). The relationship proposed here was originally developed for data from Central and South America.

The form of the equation is taken as a quadratic, shown in equation 1 where the A_i's are derived constants and I is Modified Mercalli Intensity.

$$\log_{10}(PGA) = A_0 + A_1 I + A_2 I^2 \qquad (1)$$

$$A_0 = 0.679 \qquad A_1 = 0.595 \qquad A_2 = 0.024$$

An equation of this form has certain advantages over linear relations that have been proposed in the past. It offers more versatility and is less restricted in the accelerations predicted at the extreme ends of the intensity scale. PGA in Figure 1 is in cm/sec^2
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An example for data from Central and South America, using equation 1 is shown in Figure 1.

Most seismic hazard analyses provide probabilistic information on peak ground acceleration, typically in the form of return period and/or the cumulative distribution function for a future time period, Shah et al. (1975). In this section a method will be outlined to develop the future expected damage ratio for a structure. This procedure will employ a PGA-MMI relation such as the one presented in Figure 1. The model is presented as a method for developing global earthquake loss-predications, as opposed to detailed structure specific estimations. It is based on empirical relationships between the loading parameter, MMI, and the damage ratio (defined as the ratio of the cost of repair to the overall replacement cost).

The damage incurred by a structure is a function of its dynamic characteristics, and of the properties of the ground motion. Some of the important structure properties are the type of lateral load resisting system, structure geometry, workmanship, etc. The important characteristics of ground shaking, include the intensity, duration, and frequency content. The availability of data, however, to take each of these variables into account, for all practical purposes is nonexistent. This has led to the use of the data base that is available, which relates Modified Mercalli Intensity to damage ratio. From this data set empirical relationships, such as the ones shown in Figure 2, can be developed for different structure types.

In order to obtain the expected damage ratio per year using relationships such as those in Figure 2, it is necessary to have the yearly probability mass function for Modified Mercalli Intensity. A change of variable makes the determination of the expected damage ratio a simple task. This concept is shown in equation 2.

$$E(dr) = \sum_{\text{all } I} f(dr/I=i)\ P(I=i) \quad (2)$$

where: E( ) = expected value
f(dr/I=i) = a function relating damage ratio to Modified Mercalli Intensity (I)
P(I=i) = probability of at least 1 occurrence of Modified Mercalli Intensity (I) equal to i

The uncertainty in damage ratio for a given intensity can also be considered, and is discussed in detail in Sauter et al. (1980).

ROLE OF STRUCTURAL QUALITY FACTORS IN LOSS ASSESSMENT

To take into account the construction and structural qualities for damage estimation, the expected values or the probabilistic estimates on damage ratios should be modified. The effect and significance of the following quality factors in the damage potential of structures is presented below.

1. frame line redundancy, 2. plan redundancy, 3. plan symmetry, 4. elevation regularity, 5. construction quality control and 6. applicable code under which the structure was designed. (If one is dealing with an existing structure). Suggested definitions of the above quality factors are listed below:

1. Frame Line Redundancy. Individual frame and/or wall lines in the direction of the applied lateral load shall have the following measures of redundancy in all stories:

<u>Frame System:</u> At least three bays having a relative width ratio of not more than 1.5. Frame bays may contain shear walls.

<u>Wall System:</u> At least one wall pier with story height to width ratio equal or less than 0.67, or at least two piers with a story height to width ratio equal or less than 1.0. These piers must extend over the full story height and must not contain openings or perforations that can significantly reduce the strength or stiffness of a pier.

2. Plan Redundancy. The plan of each story shall have at least four lines of frames and/or walls in the direction of the applied lateral load. These lines of bracing elements shall be spaced with reasonable symmetry and with a ratio of maximum to minimum spacing not exceeding 1.5.

3. Plan Symmetry. The eccentricity between the center of mass supported by any story and the center of rigidity at that story level shall not exceed fifteen percent of the effective building width measured normal to the direction of the applied lateral load.

4. Elevation Regularity. In any story, the total translational stiffness in line with the applied lateral load, and the total rotational stiffness against plan torsion must not change by more than fifteen percent from these stiffness values for the adjacent upper and lower stories. Also, these stiffness values must remain constant or generally decrease as the story levels increase.

5. Construction Quality Control. Provision within the contract documents for the performance of inspection at the important stages of construction. This inspection must be under direct supervision of the responsible design engineer of record. Inspection shall include material

Table 1

WEIGHT FACTORS

q_i	Criterion	Weight Factors: Meets Criterion	Weight Factors: Does not meet Criterion
1.	Frame Line Redundancy	0	0.1
2.	Plan Redundancy	0	0.1
3.	Plan Symmetry	0	0.1
4.	Elevation Regularity	0	0.1
5.	Construction Quality Control	0	0.2
6.	Applicable Code Used		
	1973 or later		0
	1956 to 1972		0.1
	pre-1956		0.2

In determining the expected damage ratio, the failure to meet any or all of these criteria implies greater "damageability" of the structure, resulting in an upgrading of the expected damage ratio. If all of the criteria are met, the expected damage ratio for the particular structure is not increased, thus the expected value on damage would be at its mean value. Failure to meet these criteria is to modify the expected damage from its mean value upwards to a new level of expected damage.

Considerations of the above quality factors can be represented analytically by equation 3.

$$E'[DR] = E[DR] \left\{ 1 + \sum_{i=1}^{6} q_i \right\} \qquad (3)$$

where

$\sum_{i=1}^{6} q_i$ = the summation of the weight factors for the six criteria as applied to a particular structure

$E[DR]$ = Expected damage ratio as defined by equation 2

$E'[DR]$ = Expected damage ratio with consideration of the structure quality

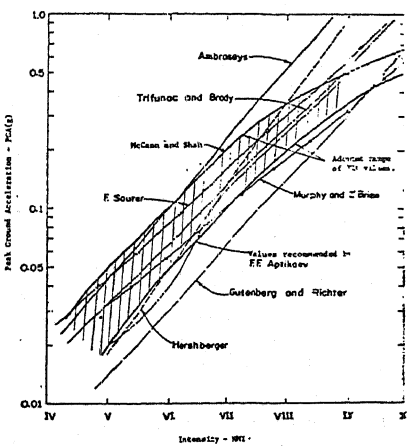
DEVELOPMENT OF SIMPLIFIED ALGORITHMS FOR ASSESSING SEISMIC RISK

All the information developed in the previous sections will be synthesized in the form of an algorithm. This algorithm or flow chart should help the user to assess the seismic loss potential (seismic risk) for a given region or for a given class of structures. However for important and unique specific facilities, a detailed "one of a kind" type of analysis for loss and damage estimation should be used. Figure 3 shows the algorithm for a simplified damage analyis. The following paragraphs explain the contents of Figure 3.

I. Input Information. This part of the algorithm is necessary to outline the problem at hand and the data provides the necessary input to evaluate seismic hazard and risk. Any and all structural, geotechnical and seismological information about the problem should be made available. The quality and quantity of information available in this step is important.
II. Analysis of Information. Based on the site location, determine the potential geologic hazards such as landslide, active fault, liquefaction, seiche, tsunami and subsidence. Ground shaking hazard should also be evaluated from one of the many probabilistic seismic hazard models available in the literature (Mortgat and Shah, 1979). Based on damage ratio curves of the previous section and the probabilistic loading information on PGA or MMI, the expected damage ratio can be calculated. This information should be modified with the structural quality factors of Section 3.
III. Synthesis. In this step, all the analyzed information is synthesized to obtain the convolved seismic risk at a site.

NUMERICAL EXAMPLE

A numerical example is presented here to demonstrate the applicability of the method developed in this paper. A moment resisting steel space frame is designed and built in San Francisco. The structure has more than 3 bays in x and y direction. There are at least four lines of frames in both directions. However, the spacing of the frames is such that the ratio of the maximum to minimum spacing at the 4th floor level is greater than 1.50. The plan is not symmetrical. From the 33rd floor to the 36th floor, there is a sudden change in stiffness and elevation regularity. Construction inspection and quality control are good. The applicable building code was 1973 UBC. The structure is located on waterfront fill and thus has high liquefaction and subsidence potential. The economic life of the structure is assumed to be 20 years. The available geologic, structural and soil information is compiled as per Step I of the previous section. Based on the available seismic hazard analysis model and using the transformation of PGA to MMI of Figure 1, Table 2 is obtained.



Existing Relationships and Proposed Ranges

Figure 1

Table 2

	1 year	20 years
V	1.000	1.0
VI	0.8233	1.0
VII	0.1455	.9570
VIII	.0218	.3570
IX	.0067	.1260
X	.0011	.0224
XI	.0010	.0202
XII	.0005	.0090
	≃ 0	≃ 0

Expected damage ratios for one and twenty years are obtained as follows: See Figure 2 for moment resisting frames.

$$E[dr]_1 = (0)(1) + (.0015)(.8233) + (.013)(.1455) + (.065)(.0218) + (.20)(.0067) + (.40)(.0011) + (.75)(.001) + (1)(.0005) \simeq 0.757\%$$

$$E[dr]_{20} = (0)(1) + (.0015)(1.95) + (.013)(.9570) + (.065)(.3570) + (.20)(.1260) + (.40)(.0224) + (.75)(.0202) + (1)(.0090) \simeq 9.55\%$$

Taking into account the quality factors;

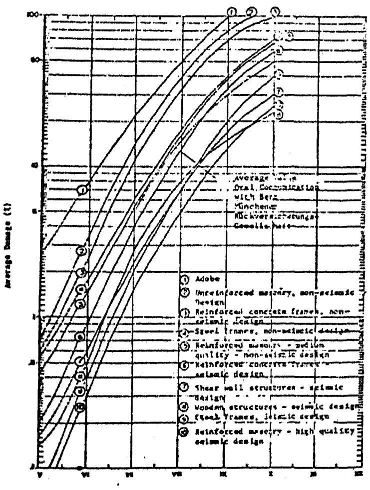
$$q_1 = 0;\ q_2 = 0.1;\ q_3 = 0.1;\ q_4 = 0.1;\ q_5 = 0;\ q_6 = 0$$

$$E'(dr)_1 = (.757)(1.3) = 0.985\%$$

$$E'(dr)_{20} = (9.55)(1.3) = 12.40\%$$

SUMMARY AND CONCLUSIONS

From the methodology presented in this paper, it can be seen that for insurance purposes, there is reasonably simple empirical approach available to estimate damage in the form of damage ratios. It should be pointed out that more research is needed before one can understand the confidence bounds on the results. In the meantime the method presented here can be used as a first approximation in damage estimation due to seismic events.



Modified Mercalli Intensity (M.M.I.)

Figure 2

(Ref.: Sauter & Shah, 1978)

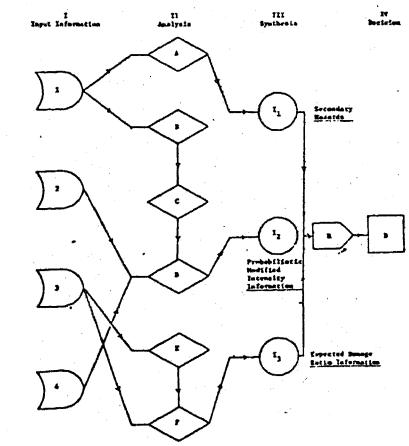


Figure 3

FLOW CHART - SEISMIC RISK ANALYSIS

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