ON HUMAN LOSS PREDICTION IN BUILDINGS DURING EARTHQUAKES

by

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SYNOPSIS

The problem of human loss prediction in buildings during earthquakes is discussed and a methodology for such predictions is proposed. Also a building classification scheme that accounts for performance and hazard potential necessary for this methodology is presented. Due to lack of sufficient data, several assumptions are made in an illustrative example, showing the application of the method. This methodology can form the framework for future data collection which need to relate human losses to damage and damage to intensity.

INTRODUCTION

Human loss prediction during an earthquake is as difficult a task as the prediction of the earthquake occurrence itself. Given that an earthquake of certain magnitude occurs, there are several major factors directly affecting the number of casualties that will be caused in a populated area. Some of them are: great variety of construction types, material and quality, time of earthquake occurrence and occupancy distribution, functioning of critical facilities immediately after the earthquake, geological characteristics of the ground, distribution of shaking intensities etc. All of them are important and influence each in its own way, whatever is reported as final casualty count.

The best effort so far for human loss prediction is to average losses due to past earthquakes in populated areas with building types having similar general characteristics and estimate with a number of deaths per 100,000 people. This method has been used in recent studies (2), in which further assumptions were made concerning occupancy ratios and time of earthquake occurrence.

The main problem of the above method is the range of its applicability, clearly limited to those areas inwhich the type of construction is similar to those from which the past experience comes. Thus experience from the Agadir earthquake (death ratio 30%) cannot be applied anywhere in the United States because the majority of the building types that collapsed in Agadir will not be found in this country. Reference (1) also gives estimates of deaths and serious injuries associated with various degrees of damage. These estimates are based on judgement formed from death and injury counts reported from U.S. earthquakes

In this paper a methodology to make more qualified statements about

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human losses in buildings during an earhtquake is presented, together with an appropriate building classification scheme. It is used in an example for which, due to lack of sufficient data, some guesses are made. Therefore, the results should be viewed as an illustration of how to make predictions when more relevant data become available. For simplification and in order to avoid definition problems, bodily injuries have not been considered.

HISTORICAL INFORMATION

Available information on human losses from selected earthquakes in the U.S. as well as from some others is summarized in Table 1. The top part of this Table has been taken from reference (2). The large numbers of the lower part indicate that U.S. (West Coast) construction practices offer a much better life protection than practices elsewhere in the world. It also points out the strong dependence of human life losses on the type and quality of construction, which in all the cases of the bottom part in the Table, is considerably poorer than on the West Coast. It becomes clear then that one should be careful about similarity of conditions, before using past experience to predict losses in other earthquake prone areas.

In reference (2), a death ratio of 12 per 100,000 people has been assumed for areas with single family wooden houses, MMI 9, and occurrence of the earthquake at night. It has been recognized that this low number, reflecting high safety of well constructed one story individual single houses, must be increased often substantially to reflect other less favorable situations. If the earthquake occurs during the day, when a significant percentage of people will be at work, in structures not as safe as their wooden residences, many of them in the streets where falling debris make them equally hazardous, then the expected death ratio could be as high as 500/100,000. This number has been postulated in (2) for the 1964 Anchorage earthquake if it had occurred earlier in the day and if the buildings under construction had been completed. A similar figure (480/100,000) can also be derived for the highly populated area of the 1967 Caracas earthquake (2). In order to arrive at this number, however, a series of assumptions and speculations had to be made for both the Anchorage and the Caracas events. This implies that ever what is considered as historical information or "data" is also based upon assumptions, adding therefore one more dimension to the uncertainty of the problem.

All this makes one skeptical as to the usefulness of any type of analysis and the reliability of its results. Much judgement and speculation needs to be combined with information about population distribution at various times of the day or at night, in order to arrive at a number whose reliability can never be very high. On the other hand such a number is needed for predisaster planning and mitigation purposes.

PROPOSED METHODOLOGY

The basic idea of the proposed methodology is to estimate human losses indirectly relating them to damage. The objective is to capitalize on existing damage information on one hand and set the framework for future data collection on the other. The reasons for using damage to buildings as an intermediate step, rather than going directly to human losses, are two. First is the physical dependence of losses to damage and second is the fact that damage prediction seems to be a much easier task than direct human loss prediction. Especially if one is interested in one particular building, its performance during some specific level of shaking can be predicted reasonably well, through the use of sophisticated computer analyses, tests, etc., while direct life loss prediction goes a step further and involves greater uncertainties. Such theoretical studies of building performance cannot be carried out for all the buildings in a city, but they could be applied to typical cases representing a whole class of similar units. In what follows, we limit the problem to human loss prediction in an individual building. This should be the first step in predicting losses in sets of buildings or populated areas in general.

If we define a random variable x ($0 \leq x \leq 1$) as the percentage of occupants in a building killed during an earthquake, we can express the cumulative distribution of x for a specified level of intensity as follows:

$$F(x) = \sum_{i} F[x|_{DS=i}] \cdot P[DS = i] \quad i = L,M,H,T,C \tag{1}$$

In this expression DS stands for Damage State and the letters L,M,H,T,C for Low,Medium, Heavy, Total, Collapse as defined in reference (1). The first factor in the summation terms is the conditional probability of x, given the occurrence of a Damage State. It describes the hazard potential of the building when it suffers a certain degree of Damage. The second factor is the probability of occurrence of the Damage State for the specified intensity level as measured by the MMI or MSK scales. This is related to performance criteria and can be obtained from Damage Probability Matrices such as those developed in (1). These matices were formed using Damage data collected from past earthquakes, several theoretical analyses and engineering judgement. The building classification scheme used in (1), however, is only based on performance criteria as expressed by lateral resistances corresponding to the UBC zones 0, 1, 2, 3. A more appropriate scheme for buildings commonly found in the U.S. that accounts for both performance and hazard potential is given in Table 2. Factors influencing the hazard potential of a building for a given Damage State are the number of occupants, weight of construction materials, modes of failure, etc. Also the use of the highly subjective MMI or MSK scales should be replaced with more quantitative measures of intensity, but such a measure is not available in most cases of existing building damage statistics.

Probability distributions for the percentages of people killed inside buildings could be derived for the categories of Table 3, if there existed sufficient data from past earthquakes. Unfortunately such data are very limited and often non-existent. Therefore, at this point, only guesses can be made about the shape and the parameters of the conditional distributions of x. Clearly for all Damage States except Collapse there is a finite probability that no one will be killed and practically zero probability that everyone will be killed, For Collapse, x can take any value in the interval $0 \leq x \leq 1$ with finite probabilities at the two ends. To avoid problems with tails of the distribution or mathematical inconsistensies, one should interpret $p_1 = P[x = 1]$ as probability of <u>nearly</u> everybody being killed, may be as $P\ [x \geq 0.9]$. Similarly $p_o = P[\overline{x = 0}]$ should be interpreted as Probability of x being close to zero, may be $P[x \leq 0.01]$. Also one must assume that expected values of x are independent of the total number of occupants. The shape of the distributions as well as p_o and p_1 become functions of the building types and the Damage States.

As an example, the above methodology will be applied for the ordinary brick masonry buildings, with no earthquake provisions and sufficient number of occupants (greater than 10). An estimate of the damage probabilities for this particular class can be found through numerical interpretation of the Medvedev-Sponheuer-Karnik (or MSK) scale (3), which is considered roughly equivalent to the MMI scale. Also the damage grades of 1,2,3,4,5 in this scale can be taken equivalent to L,M,H,T,C of reference (1). These numbers are shown in Figure 1.

A 3rd degree parabola was assumed for the conditional distribution of x for Damage States M,H,T as shown in Figure 2, in which "credible" values of the two parameters p_o and x_{max}, are also given, together with the expected values of x. Figure 3 shows various distributions for the Collapse State and Table 3 gives the expected values of x, for a range of the parameters p_o and p_1. For a different type of building the values of p_o and p_1 could be quite different. For example, the experience from the Caracas earthquake indicates that for multistory concrete buildings that collapse, p_o=0 and p_1 is close to 1.

The relative importance of the various terms can be seen in Table 3, where the expected values of x have been summarized for intensities up to X and Damage States M,H,T,C. One immediate observation by looking at these numbers is that, whenever the probability of collapse is not zero, this State dominates all the others, even if its probability of occurrence is much smaller. This has actually been observed in destructive earthquakes (e.g. Caracas, San Fernando, Nicaragua, etc.), that is, most human casualties come from relatively few collapses and not from the much larger number of badly damaged, but still standing buildings.

CONCLUSIONS

The following conclusions should be viewed, keeping in mind the limitations and assumptions made earlier as well as the state of the art in the subject.

1. More appropriate data than what is currently available are required to form a sound statistical basis for human loss prediction in buildings during earthquakes.

2. It appears that in those intensities for which danger of collapses exist, these collapses are the major cause of deaths. They outweigh all Damage States, even at lower intensities, for which the number of buildings that collapse may be much smaller than the number of all other buildings that suffer any level of damage. This suggests that major emphasis should be given in collecting appropriate data for buildings that collapse. These data are: Number of people killed in the collapsed building, total number of occupants when the earthquake occurred, and total number of buildings of the same category which did not collapse.

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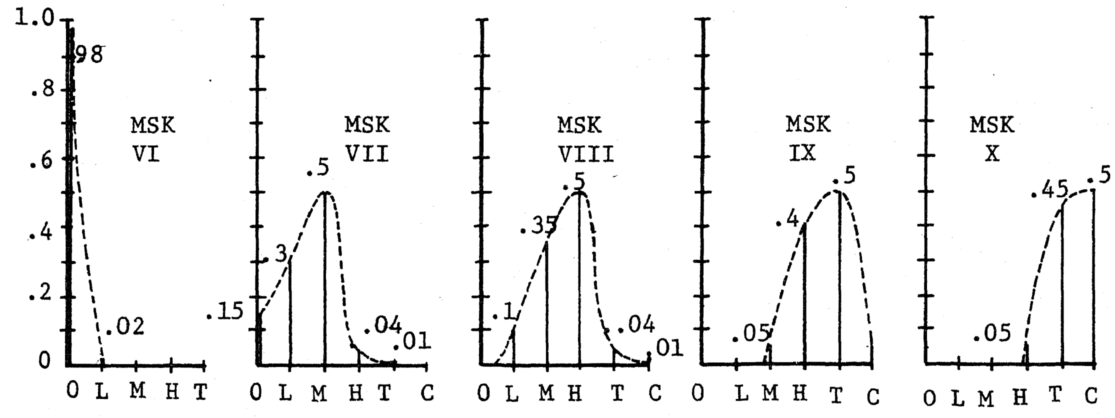
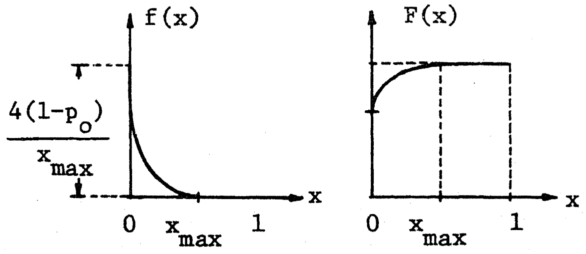


Figure 1

Damage Probabilities for Ordinary Brick Masonry



DAM. STATE	p_o	x_{max}	E[X]
M	.97	.03	.00018
H	.90	.10	.002
T	.70	.30	.018

$$f_{(x)} = \frac{4(1-p_o)}{x_{max}}\cdot\left(1-\frac{x}{x_{max}}\right)^3, \quad F_{(x)} = 1-(1-p_o)\cdot\left(1-\frac{x}{x_{max}}\right)^4, \quad 0 \le x \le x_{max}$$

Figure 2

Assumed Distribution of X for Damage States M,H,T

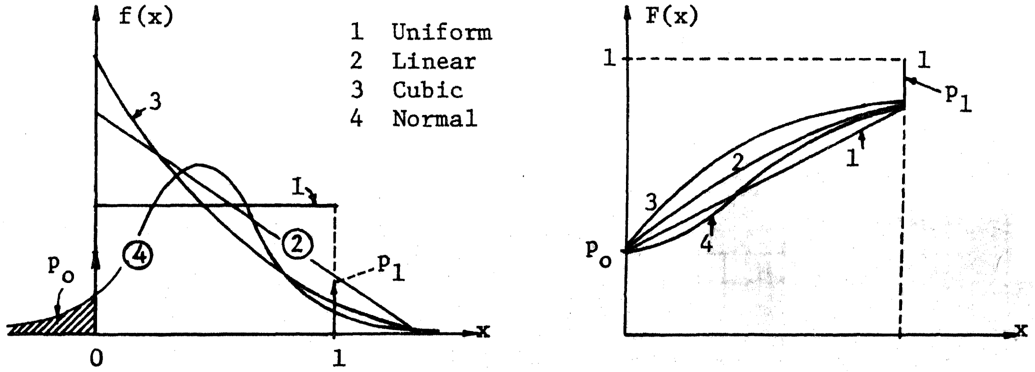


Figure 3

Various Distributions of X for Damage State C

EARTHQUAKE	RICHTER MAGNI-TUDE	MAX MMI	DATE	TIME OF OCCURRENCE	DEATHS PER 10^5 POPULATION
Charleston, S.C.	—	X	Aug. 31, 1886	9.51 pm	113
San Francisco, Cal.	8.3	XI	Apr. 18, 1906	5.12 am	124
Santa Rosa, Cal.	8.3	—	Apr. 18, 1906	5.12 am	116
San Jose, Cal.	8.3	—	Apr. 18, 1906	5.12 am	80
Santa Barbara, Cal.	6.3	VIII-IX	June 29, 1925	6.42 am	45
Long Beach, Cal.	6.3	IX	Mar. 10, 1933	5.54 pm	26
Imperial Valley, Cal.	7.1	X	May 18, 1940	8.37 pm	18
Olympia, Wash.	7.1	VIII	Apr. 13, 1949	11.56 am	1
Kern County, Cal.	7.7	XI	July 21, 1952	4.52 am	500
Bakersfield, Cal.	5.8	VIII	Aug. 22, 1952	3.41 pm	3
Anchorage, Ala.	8.4	—	Mar. 27, 1964	5.36 pm	9
Seattle-Tacoma, Wash.	6.5	VIII	Apr. 29, 1965	7.29 am	1.5
San Fernando, Cal.	6.6	VIII-IX	Feb. 9, 1971	6.01 am	64total
Agadir, Morocco	5.75	VIII-X	Feb. 29, 1960	11.41 pm	36000
Skopje, Yugoslavia	6.0	VIII	July 26, 1963	5.17 am	666
Caracas, Venequela	6.5	IX	July 29, 1967	8.00 pm	480
Managua, Nicaragua	5.6	VIII-X	Dec. 23, 1972	12.30 am	1200
Lice, Turkey	6.9	IX	Sep. 6, 1975	12.22 pm	15000
Guatemala, Guatemala	7.5-7.9	VII-VIII	Feb. 4, 1976	3.00 am	400

Table 1. Death Ratios for Selected Earthquakes

			PERFORMANCE CRITERIA		
			UBC ZONE 0,1	UBC ZONE 2	UBC ZONE 3
HAZARD POTENTIAL CRITERIA	1	Single Family Well Constructed Wooden Houses.			
	2	Multifamily, Old Wooden Houses up to 3 Stories.			
	3	1 or 2 Story Ordinary Brick Masonry Buildings.			
	4	3 to 5 Story Old Brick Masonry Buildings.			
	5	1 to 5 Story Steel Frame Buildings.			
	6	More than 5 Stories Steel Frame Buildings.			
	7	1 to 5 Story Reinforced Concrete Buildings.			
	8	More than 5 Stories Reinforced Concrete Buildings.			
	9	Prefabricated Concrete Buildings.			

Table 2 - Building Classification Scheme

P_o/P_1 f(x)	0/0	0/.1	0/.2	.1/0	.1/.1	.1/.2	.2/0	.2/.1	.2/.2	.5/0	.5/.1	.5/.2
Uniform	.50	.55	.60	.45	.50	.55	.40	.45	.50	.25	.30	.35
Linear	.33	.33	.38	.33	.30	.36	.27	.27	.33	.17	.19	.26
Cubic	.20	.43	.52	.18	.40	.49	.16	.36	.45	.10	.26	.33
Normal	.50	.65	.80	.23	.50	.56	.20	.42	.50	.10	.27	.34

Table 3. E[x] for Damage State Collapse and for various Distributions

	MMI or MSK				
DS	VI	VII	VIII	IX	X
M	0	9	6	1	0
H	0	8	100	80	10
T	0	18	72	900	810
C	0	0	200	1000	10000
Sum	0	35	378	1981	10820

Table 4. Expected Values of X ($x10^5$) for the Example Case.

DISCUSSION

Herbert Tiedemann (West Germany)

Slide 1 shows deaths per 10^5 population. Without any indication on area selected for comparison, population density and quality of buildings, to cite some factors, such indications are not of much use and may mislead those who are not well informed about details.

Author's Closure

The factors that Mr. Tiedemann cites, as well as others, are mentioned in the first paragraph of the introduction as directly affecting the number of casualties in a populated area. As far as the contents of Table 1 are concerned, most of them are for metropolitan areas for which population density was not available to the authors. The predominant type of construction which has been affected by the cited U.S. Earthquakes (top part of the table) is either small wooden houses or steel buildings, both with inherent seismic resistance, while in the lower part reinforced concrete, brick masonry or adobe seems to be the most common type. The first paragraph of the Historical Information section, although it does not specifically mention the types of construction, points out the differences and their importance.