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A simulation model to estimate human loss for occupants of collapsed buildings in an earthquake

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ABSTRACT: Process of human loss occurring in collapsed buildings are examined and a simulation model is developed based on event tree model. Probability of fatality can be estimated knowing occupancy pattern, regional building stock, their vulnerability, and lethality of collapse. Application of the model to the 1988 Spitak, Armenia earthquake shows good agreement of estimated and observed numbers of fatalities, and interesting distribution of human loss by location and structural types.

1. INTRODUCTION

Reduction of human casualty in earthquakes has long been one of the major goals of disaster prevention and accordingly of earthquake engineering research. Despite collapse of buildings is often accused, we do not understand mechanism of collapse, human entrapment, and conditions for survival. Furthermore field reports and casualty statistics tend to be too few and inaccurate to make proper estimation possible.

This study adopts Event Tree Model developed in the field of safety engineering for this casualty problem and tries to evaluate various factors affecting the process of human fatality occurrence. The simulation model is then applied to the 1988 Spitak, Armenia earthquake to estimate fatality distribution among towns and building types. Reliability and limit of the estimation is discussed.

2. EVENT TREE MODEL

2.1 Framework of Model

This study proposes a simulation model based on Event Tree Model to describe the processof human fatality occurrence due to different types of buildings. Event Tree Model developed in the field of safety engineering illustrates the flow from an initiating event to possible consequences (Ang and Tang 1975). Probability numbers at each branch point are given so that sum of those become 1.0. Probability can be calculated for different flow of consequences.

Framework of the model is depicted in Fig. 1. Here,

Ph: Residence (home) occupancy ratio
Pw: Work place & school occupancy ratio
Phj: Ratio of residential building type j
$$\sum_j Phj=1$$
Pwk: Ratio of work/school building type k
$$\sum_k Pwk=1$$
Pcj(I): Collapse ratio of building type j at intensity I
Ptj: Entrapment ratio of building type j when collapsed
Pfj: Fatality ratio under entrapment in building type j

Thus, local average of death ratio, Pd at intensity I can be expressed as;

$$Pd(I) = Ph \sum_j [Phj \cdot Pcj(I) \cdot Ptj \cdot Pfj] + Pw \sum_k [Pwk \cdot Pck(I) \cdot Ptk \cdot Pfk] \quad \ldots(1)$$

For simplicity, this model assumes that people located outside or inside buildings not collapsed in an earthquake do not die.

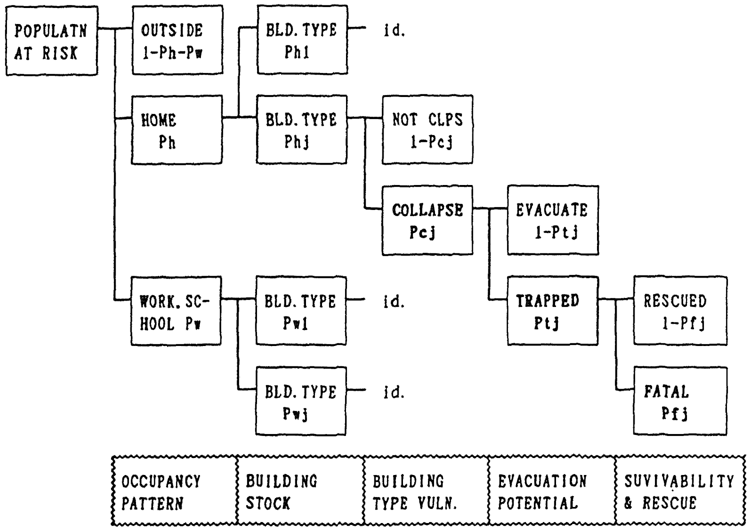

Figure 1. Event Tree Model of human fatality caused by building collapse.

2.2 Lethality Ratio

Probability parameters shown in Fig. 1 are not readily available for estimating fatality pattern or for explaining fatality distribution due to past earthquakes. Especially, entrapment ratio, Ptj and fatality ratio under entrapment, Pfj are the most difficult ones to obtain.

In order to avoid such an obstacle, we may introduce lethality ratio, defined as death ratio of occupants located in collapsed buildings (Coburn et al. 1987). Lethality ratio of building type j, Plj can replace the two parameters by;

$$Plj = Ptj \cdot Pfj \qquad \dots (2)$$

3. APPLICATION TO THE SCENARIO OF THE 1988 SPITAK-ARMENIA EARTHQUAKE

3.1 The Spitak Earthquake

The Spitak earthquake occurred in December 1988, in the northern part of Armenian republic (Table 1). It caused major damage to precast concrete frame and masonry buildings in Spitak, Leninakan, Stepanavan and rural part of the region. Number of fatality reached 25 thousand, which is the worst among disastrous earthquakes in Soviet Union in the 20th century. Isoseismal map is shown in Fig. 2 with dwelling damage ratio calculated by number of the temporally

Table 1. Parameters of the Spitak earthquake.

Local time:	December 7, 1988 11hr 41m
Magnitude:	Ms=6.8 (USGS)
Affected population:	589,000
Dwelling damage:	514,000 homeless
Fatality:	24,542 official

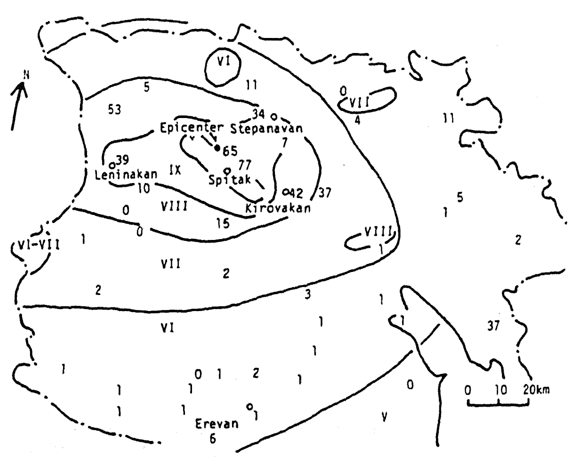

Figure 2. Dwelling damage ratio and isoseismal map of the Spitak earthquake.

Table 2. EERI damage statistics of multistory residential buildings in the 1988 Spitak earthquake. (I-MSK >= 8)

City or	Epic	I	Resist.	No.of	PC Panel		PC Frame				Composite Stone				Stone			
town	Dist	MSK	pop 1989	Death	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Spitak	9	10	14246	9733	-	1	-	-	-	-	43	9	7	-	20	2	3	-
Leninakan	32	9	178251	9974	-	16	72	55	6	-	27	115	67	20	24	160	154	150
Stepanavan	21	9	14273	198	-	-	-	-	-	-	8	13	33	2	10	-	9	16
Akhourian	27	9	41163	286	-	-	-	-	-	-	18	4	17	2	1	2	5	3
Artik	37	8	24774	44	-	-	-	-	-	-	-	2	47	25	-	14	2	-
Ghoukasian	33	8	10773	-	-	-	-	-	-	-	-	4	4	1	-	5	2	4
Pemzashen	37	8	33267	-	-	-	-	-	-	-	-	3	-	3	-	12	4	4
Googark	31	8	24930	65	-	-	-	-	-	-	-	-	-	-	3	2	9	1
Kirovakan	27	8	128207	1047	-	4	-	-	88	20	41	89	414	27	46	53	145	-
Amasia	38	8	11548	-	-	-	-	-	-	-	-	4	1	1	-	1	2	4

A=Collapsed. B=Heavily damaged, to be demolished. C=Damaged, to be repaired or strengthened.
D=No significant damage, habitable. (Wyllie & Lew, 1989)

absent population divided by the number of permanently registered population in 1989 census.

The author visited Armenia in summer of 1990 and tried to collect various reports and damage statistics. Though available data of building damage and fatality counts are still very limited, various probability parameters in Fig. 1 can be estimated to apply the event tree model of human fatality occurrence to this earthquake.

3.2 Evaluation of Probability Parameters

A table of damage statistics of multistory residential buildings for the 26 affected cities and towns is given by Wyllie and Lew (1989) in the EERI Report. Table 2 indicates a part of this statistics for I-MSK greater or equal to 8. Because this table does not fully count buildings with no damage, especially in smaller intensity zones, damage ratios calculated here tend to be larger than reality. Still this is the most comprehensive building damage statistics available so far and is used for the case study as an initial condition.

Average size of household:
According to Shimamura (1985), average size of household in Armenian republic in 1979 is 4.6 persons excluding one person family. Considering that 11.4% of USSR population is one person household, adjusted size becomes 4.2 persons /household.

Age group population:
Table 3 shows estimate of the age group population in Armenia. Since earthquake happened weekday daytime in winter, outside population (1-Ph-Pw) is assumed to be small and 5%; school age children at school to be 17%; residence population to be 16+10+57/4 = 40%; and working place such as factories and offices to be the residual of 38%.

Table 3. Age group population of Armenian Republic, estimate for the year 1985.

Age group	Male	Female	All	%
<0-6>	279	268	547	16
<7-16>	307	292	599	17
Working	<16-59>	<16-54>		
	1018	925	1943	57
Retirement	<60+>	<55+>		
	96	241	337	10
Total		3426		

After Shimamura (1985)

Average occupancy by building type:
Pre-earthquake population is calculated adding number of fatalities to the permanently registered population in 1989 census. Population ratio of single family dwellings, Rsh would depend on the size of population, P and is estimated by the following equation:

$$Rsh = -25 \log P + 150 \qquad \text{... (3)}$$

According to the Armenian government report, composite stone apartment buildings are 4-5 story high and stone masonry apartments are 1-5 story high in Leninakan and Kirovakan. Thus, the following is assumed:

$$Ocs : Osm = 4.5^2 : 3^2 = 9:4 \qquad \text{... (4)}$$

where Ocs: average occupancy per composite stone apartment and Osm: average occupancy per stone masonry apartment. Calculating Ocs by

Table 4. Building types and estimated damage ratio vs. MSK intensity.

	Story	Estimated Occupancy prsn/build	Collapse Ratio % I-MSK 8	9	10	Collapse+Heavy % I-MSK 8	9	10
Residential								
Apartment			(EERI Damage Statistics)					
PC panel	9	554	0	0		0	0	
PC frame	9	554	0	54		0	95	
Comp. stone	4-5	95	1	23	73	37	51	88
Stone masonry	1-5	42	4	14	80	50	31	88
House: stone *)								
Type A: rural	1	4.2		81	100			
Type b	1-2	4.2		33	87			
Type B	2	4.2		16	76			
School & Public			(Comparable to residential)					
Comp. stone	1-4						27	
PC frame								
Industrial & Workplace			(Comparable to residential)					
Comp.stone:prior to 1970								
PC frame: after 1970								

*) Grade 5 (Total Collapse) and grade 4 (Destruction) of MSK scale included

Ocs=4.5 story/build.* 5 unit/story
 * 4.2 person/unit = 95 person/build.
Osm = 42 person/building ... (5)

Precast concrete frame and precast concrete panel buildings are both 9 story high and seem to have similar occupancy pattern. Average occupancy (Opf) is obtained by by the Least Squares Method, and the result seems reasonable;

Opf = Opp = 554 persons/building ... (6)

Building type vulnerability:
Table 4 shows major use and structural types of buildings in the affected region. Average damage ratio for the residential apartments are calculated from the EERI table. No precast panel buildings were heavily damaged nor collapsed. PC frame buildings are most vulnerable and composite stone and stone masonry follow.

Types of stone masonry houses and their damage are reported by Grigorian (1990). Types A and B correspond to those defined in MSK Intensity scale and type b is in-between.

There are few reports on the types and damage of schools and work places. Old buildings prior to 1970 tend to be composite stone masonry type and newer buildings after 1970 to be precast concrete frame. Both types seem to have behaved more or less similar to the residential apartments.

Lethality:
Noji et al. (1990) investigated death rate by building types in Nalband village located near epicenter (Table 5). Intensity there is close to 10 and most of the buildings collapsed. Death rate in the Table 5 almost indicates lethality ratio Plj, that is, percentage of people killed among occupants of collapsed buildings.

Table 6 shows numbers of people extricated and dead reported by Klain et al. (1989). Dead/Extricated here corresponds to fatality ratio under entrapment Pf, though building types are not specified. Still, we know that majority of collapse in Spitak and Stepanavan are those of composite stone or stone masonry buildings, and most of entrapment in Leninakan occurred in PC frame buildings.

Comparing Tables 5 and 6, very preliminary estimates of lethality, entrapment, and fatality ratio are made (Table 7). Reliability of these figures are rather low and only relative comparison is possible. Entrapment ratios of 9 story PC panel and PC frame buildings seem to be much higher than those of medium rise masonry buildings, which may result in higher lethality of PC buildings.

Table 5. Effect of building type on survival in Nalband village for the Spitak earthquake.

Build. Type	Number	Occupants	Death rate%
Stone masonry	38	415	12.8
PC panel	2	40	47.5
PC frame	8	577	87.0
Total	48	1032	55.6

After Noji et al. (1990)

Table 6. Numbers of persons affected in selected cities and regions in Armenia.

Cities & Regions	Initial Population (thousand)	Extri-cated	Dead	D/E %
Leninakan	232.0	16959	9974	59
Kirovakan	171.0	4317	420	10
Spitak	18.5	13990	9733	70
Stepanavan	21.0	108	63	58
Rural Areas	146.5	4421	4532	103
Total	589.0	39795	24542	62

After Klain et al. (1989)

Table 7. Preliminary estimate of lethality ratio, entrapment ratio and fatality ratio under entrapment.

Building Type	Lethality Plj %	Entrapment Ptj %	Fatality Pfj %
PC panel	48	(100)	(48)
PC frame	73	(100)	73
Comp. stone, stone masonry	16	(25)	64
Masonry house (20)		-	-

3.3 Results

Using the probability parameters evaluated, number of fatality for each town and city in Table 2 are counted. Combination of school buildings is arbitrary assumed as composite stone / PC frame = 9:1 and that of work places as 6:4, because enough document is not available for any better judgement.

Reported and estimated number of fatalities are compared in Fig. 3 showing a very good agreement. Correlation coefficient is 0.94.

Fig. 4 depicts histogram of fatality by use of buildings and type of structures according to estimation. This estimate is valuable, since field reports tend to be only case study of few towns or of few buildings. Majority of victims seem to happen in apartment buildings and especially PC frame buildings.

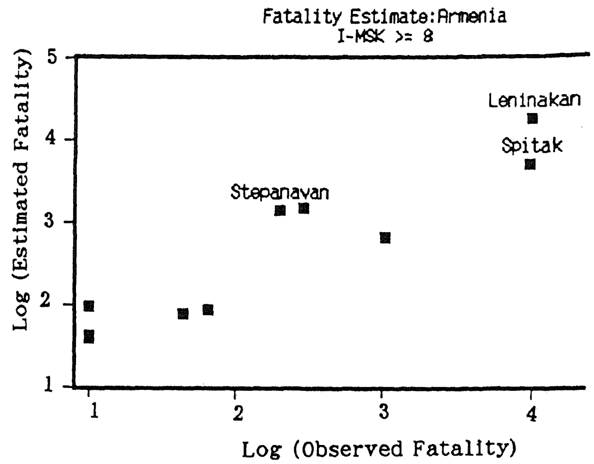

Figure 3. Correlation of observed and estimated number of fatalities in the 1988 Spitak earthquake.

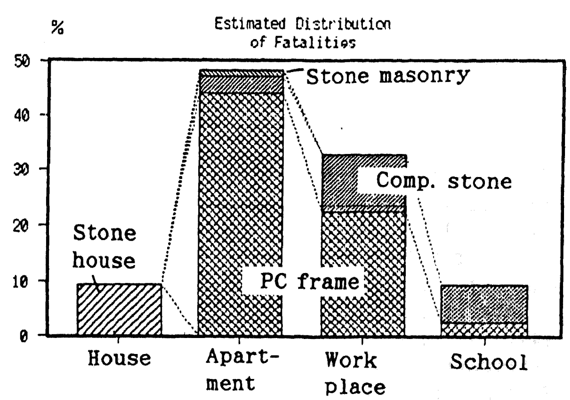

Figure 4. Estimated fatality distribution by location and structural types in the 1988 Spitak earthquake.

4. CONCLUDING REMARKS

A model to estimate probability of fatalities occuring in collapsed buildings in an earthquake is developed by applying Event Tree Model. Various factors involved are occupancy pattern, building stock, building type vulnerability, and lethality of collapse. The model is applied to the 1988 Spitak, Armenia earthquake by evaluating necessary parameters. Estimation agrees well with observation and shows interesting distribution of fatality by use and structural types.

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