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POST-EVENT RAPID ESTIMATION OF EARTHQUAKE FATALITIES FOR THE MANAGEMENT OF RESCUE ACTIVITY

by

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ABSTRACT

By integrating existing knowledge in seismology, earthquake engineering, and epidemiology, we developed a computer model applicable to the post-event, rapid estimation of expected fatalities for any given earthquake. Our design purpose for this model was to provide adequate information to simplify the post-event management of rescue activities. The model requires very few input variables making it a potentially useful tool in the early phase of rescue mobilization. Input data required in the estimation are earthquake magnitude, epicenter location, and three regional data as follows: population density, dominant building type, and seismic intensity increment due to local site effects. Once designed, we tested the model's performance accuracy using the data obtained from recent significant disasters.

Keywords: Earthquake Fatality, Rescue, Emergency Response, Response Planning, Rapid Estimation

1. INTRODUCTION

Effective search-and-rescue reduces fatalities. Since the occurrence of deaths in collapsed buildings is time-related (de Bruycker et al., 1983; Sheng, 1987; Krimgold, 1988), victims may be extricated alive when rescuers reach

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them quickly. Earlier arrival of rescue resources will result in higher possibility of live recovery of trapped victims.

An estimate of casualties is useful for the initiation of organized rescue activity conducted by professionals. Organized rescue efforts must be supported by two preparatory activities: first, the arrangement of rescue resources and, second, the reconnaissance of disaster situations. These two activities must take place immediately after the occurrence of an event and must be carried out simultaneously. Since very little actual data are available when these activities must be initiated, a plausible estimate is needed to substitute at that moment.

Despite the general agreement that the estimate of human casualties is crucial toward the effective mobilization of professional rescue power, such information has not up to this point been available to those in charge of the management of post-event activities. If decision makers are informed only that an earthquake of a particular magnitude occurred in a particular place, they have no concrete means to determine the extent of human casualty. Such seismological information must be transformed into a different kind of information that directly indicates the extent of disaster before given to decision makers.

Pre-event evaluation of disasters is available for some countries such as the United States and Japan. However, such estimates usually provide unsatisfactory information to support post-event activities. Pre-event estimates based on a hypothetical earthquake do not necessarily coincide with actual events.

Post-event estimation of human casualties is desired for improved mobilization of rescue resources. If seismic information of an actual earthquake is used in the estimation, a resultant estimate, expected casualties, can be more reasonable than that based on a hypothetical earthquake. It is quite possible to employ real seismic-information in the estimation as long as we use a very fundamental part of seismic data that can be collected even immediately after the occurrence of an event.

A considerable amount of knowledge for this purpose can be found in the fields of seismology, earthquake engineering, and epidemiology. By applying such existing knowledge, we can transform first-hand seismic information into an expected death toll.

In this study, we developed a computer model for the post-event estimation of fatalities in a given earthquake. A death toll is an efficient parameter applicable to the estimation of injuries and the trapped in the same event. Injury-to-death relationship is documented in numerous epidemiologic studies (Lechat, 1979; Alexander, 1985).

We laid the principal objective of this development on the realization of an actual model by the synthesis of existing knowledge. We avoided the analysis of crude data in this effort to realize a computer model. We also decided to use only a limited range of input data to enhance the applicability of the model to the real world. Included are magnitude, epicenter location, and the following three regional data of an affected area: population density, dominant construction types, and soil amplification characteristics.

2. METHODOLOGY

2.1 Structure of the Model

Figure 1 shows the general structure of the model developed in this study. The model is composed of four different kinds of element as follows:

1) Input Data
2) Knowledge, or Relationships
3) Transmitting Indicators
4) Result, that is, the Number of Fatalities.

2.2 Input Data

Input data for the model are composed of two parts:

1) Seismic Information
2) Regional Information.

2.2.1 Seismic Information

Seismic information includes:

1) Surface Wave Magnitude (Ms)
2) Epicentral Location.

This combination of data is available today for all significant earthquakes worldwide. Many countries have monitoring systems that can determine the location and magnitude of earthquakes. Also, there are several institutions that have coverage to determine the two data for any significant events worldwide. The data are released almost immediately after an event, generally, in less than a few hours.

2.2.2 Regional Information

Items included under this heading are:

1) Population Density
2) Dominant Construction Type
3) Site Effect in Terms of Increment in Seismic Intensity.

Geographical area in which the three regional data are assigned must be chosen to coincide with an affected area. The extent of affected area can be estimated based on magnitude of an earthquake and construction type dominant in an affected area.

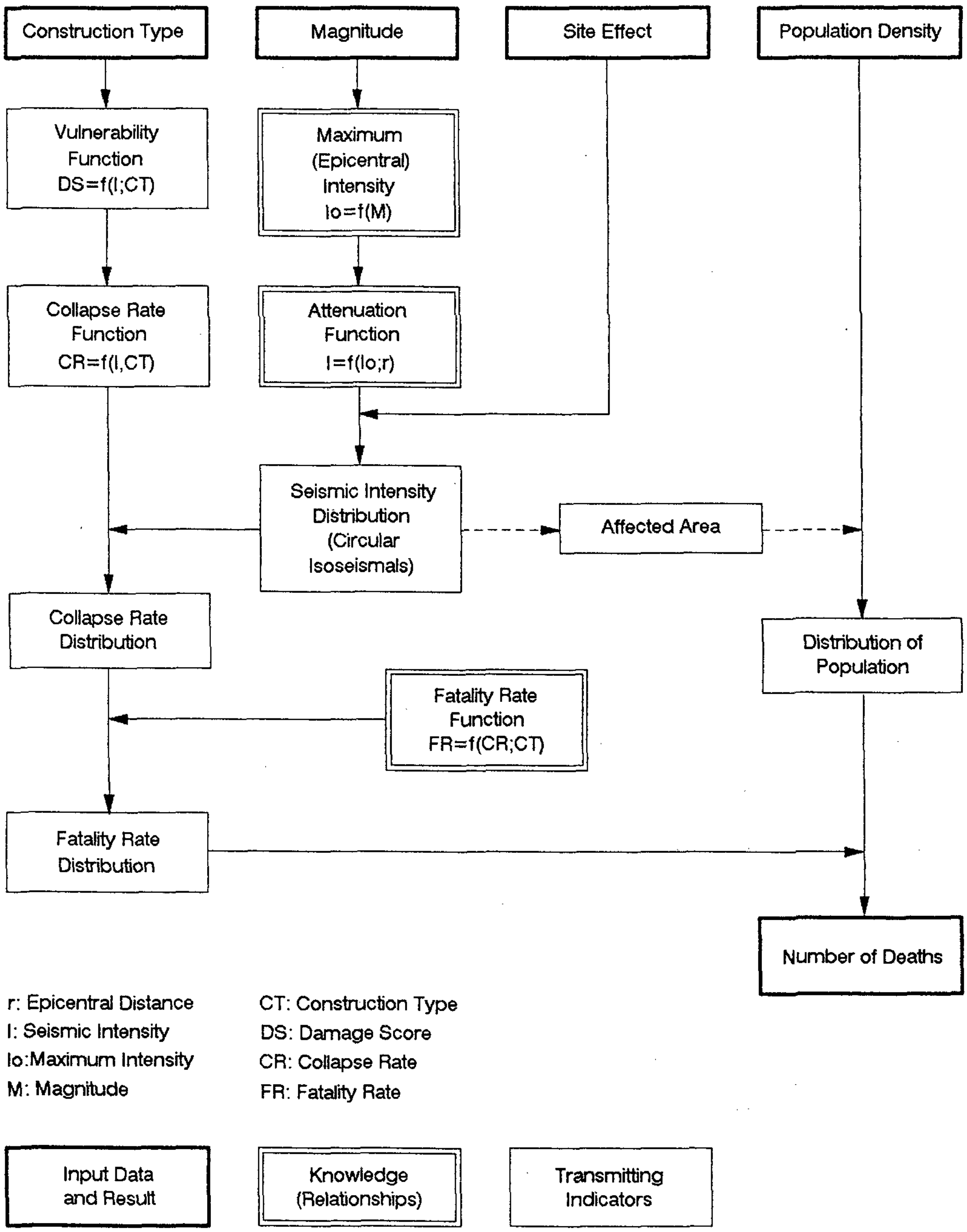


Figure 1. General structure of the model.

An eleven-category classification representing worldwide construction types consists of:

1) Rubble, or Weak Masonry
2) Adobe
3) Stone Masonry
4) Brick Masonry
5) Wood Frame with Poor Infill Walls
6) Wood Frame with Good Infill Walls
7) Wood Frame with Wood Panel Walls
8) Poor Quality Reinforced Concrete Frame with Infill Walls
9) Poor Quality Reinforced Concrete Frame with Shear Walls
10) Good Quality Reinforced Concrete Frame with Infill Walls
11) Good Quality Reinforced Concrete Frame with Shear Walls.

The classification of building type was done mainly based on wall material. Though other factors of a building such as size and roof material may affect the occurrence of human casualties, these are expected to have a primary relationship with wall material.

Where several building types are observed in an affected area, the rate of occupants in each building type is used to carry out the estimation. The rate of buildings in each construction category is not appropriate, because occupant size of a building is generally different among construction types.

2.3 Knowledge

Relationships used in the model are as follows:

1) Maximum Seismic Intensity versus Magnitude
2) Attenuation of Seismic Intensity with Distance (Attenuation Function)
3) Damage Degree of each Construction Type versus Seismic Intensity (Vulnerability Function)
4) Fatality Rate in Each Construction Type versus Collapse Rate.

2.3.1 Seismic Intensity

The distribution of seismic intensity was determined from: first, a magnitude versus maximum intensity relationship and, second, an attenuation function. As these relationships vary from area to area depending on seismological factors, they must be chosen to represent the observation for a particular country or region. Several currently available studies demonstrate these characteristics; for example: Karnik (1965) on maximum intensity; and Chandra (1979) on attenuation. Another way to determine the distribution of seismic intensity is seen in a study by Ohashi et al. (1983), where the attenuation function was derived for different levels of magnitude.

Figure 2 shows several examples of the relationships between seismic intensity and epicentral distance by country. The procedure to determine some of these curves is described later in this article.

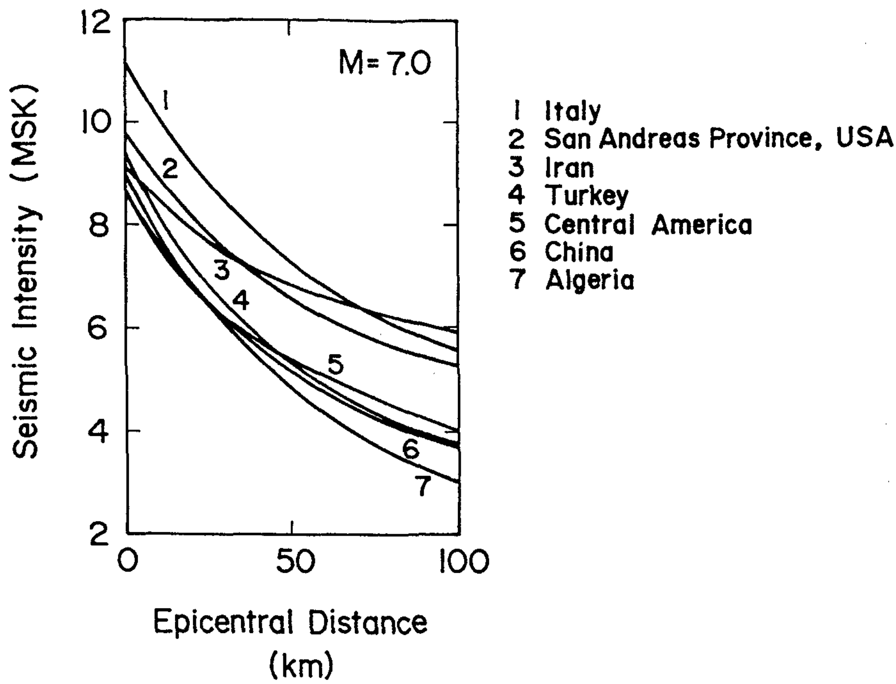


Figure 2. Attenuation of seismic intensity by country - Examples.

The distribution of seismic intensity, namely the shape of isoseismal curves, was represented by a set of circles that shears a center at the epicenter. Isoseismal curves are not generally circular because of the effects of fault configuration, site geology, etc. However, the set of circular isoseismals showed consistency with actual ones and was expected to be an acceptable approximation. Consistency was observed including a case for a fairly high magnitude of, for example, 7.5. Similar examples of good agreement are also seen in Chandra (1979) for several events in the United States.

Seismic intensity on the Medvedev-Sponheur-Karnik (MSK) scale was used in the calculation in this study. When a formula that is expressed in Modified Mercalli Intensity (MMI) was used, a conversion between the two scales was carried out as follows:

$$MSK=(9/8)MMI-(15/16) \quad \text{or} \quad MMI=(8/9)MSK+(5/6).$$

The equations were derived from a figurative indication appearing in Moriya (1989).

2.3.2 Structural Vulnerability and Collapse Rate

Structural vulnerability was defined as a relationship between the extent of damage to a single building and the severity of ground shaking affecting the building. A vulnerability function was defined for each construction type, and, therefore, a set of 11 vulnerability functions was generated to represent the total of construction types (Figure 3).

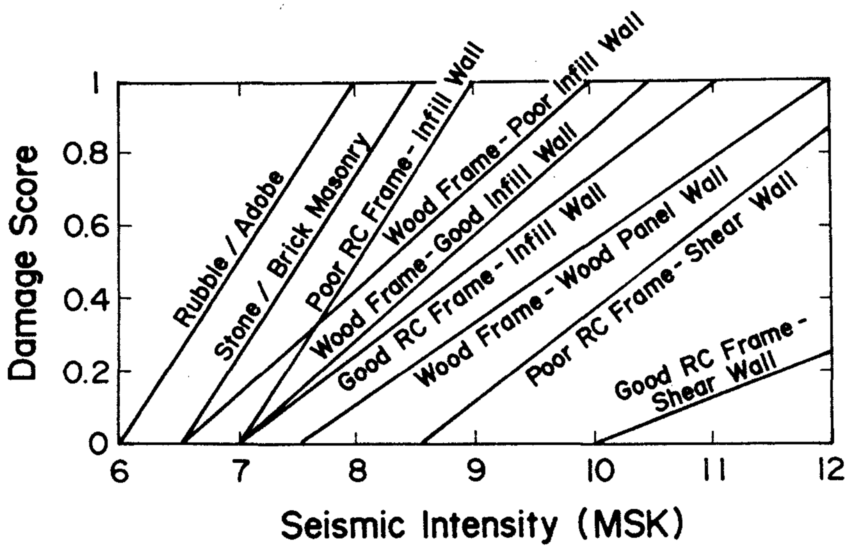


Figure 3. Vulnerability functions.

The extent of damage to a building was determined in terms of a scale named damage score. The scale ranges from 0 to 1; with a score of 0 corresponding to "no effect" to a building, and a score of 1 corresponding to "ultimate damage." Table 1 shows a possible correspondence between damage scores and the conventional definition of damage status.

Table 1
Relationship between the Conventional Definition of Damage Extent and Damage Degree Scores

Damage Score	Damage Status
0 - 0.1	Undamaged
0.1 - 0.3	Slight Damage
0.3 - 0.5	Moderate Damage
0.5 - 0.7	Heavy Damage
0.7 - 0.9	Partial Collapse
0.9 - 1	Collapse (Unrepairable)

A damage degree between 0 and 0.1 corresponds to very slight damage with no structural loss. Any damage score between 0.9 and 1 indicates the extreme damage status, collapse. There is wide variety within conventionally defined collapse, and the range of damage score between 0.9 and 1 corresponds to the variety.

In vulnerability functions, the score of damage degree for a building was assigned by two parameters, Im and Iu. "Im" corresponds to a seismic intensity at which the damage to a building shifts from moderate to heavy. In other words, it represents the lowest seismic intensity that brings heavy damage to a building. "Iu" corresponds to a seismic intensity at which the damage to a building reaches to the ultimate stage of collapse. These two parameters, based on damage survey reports (for example, Coburn et al., 1989) are shown for each construction type in Table 2.

Table 2
Parameters to Define Vulnerability Functions, Im and Iu

Construction Type	Im	Iu
Rubble	7.0	8.0
Adobe	7.0	8.0
Stone Masonry	7.5	8.5
Brick Masonry	7.5	8.5
Wood Frame with Poor Infill Walls	8.25	10.0
Wood Frame with Good Infill Walls	8.75	10.5
Wood Frame with Wood Panel Walls	9.75	12.0
Poor Quality RC Frame with Infill Walls	8.0	9.0
Poor Quality RC Frame with Shear Walls	10.0	12.5
Good Quality RC Frame with Infill Walls	9.0	11.0
Good Quality RC Frame with Shear Walls	14.0	18.0

In calculating collapse rates based on a vulnerability function, it was necessary to consider the dispersed structural characteristics among the buildings in a single construction category. The scattering of damage score among buildings in a construction type at given seismic intensity was represented by a normal distribution. The mean value of each normal distribution was set at the damage score as indicated by a vulnerability function; A standard deviation of 0.3 was used for all the construction types. A standard deviation of 0.3 was chosen because the calculated collapse rates agreed with the observed relationships such as seen in Coburn et al. (1989). Figure 4 represents a figured expression of collapse rate calculation. The relationships between seismic intensity and collapse rate by construction type are shown in Figure 5.

2.3.3 Fatality Rate

The fatality rate - the number of deaths divided by the total population - depends not only on the collapse rate but also on the building type. It is also affected by numerous factors such as the time of occurrence of an event (season; day or night), victims' characteristics (age, sex, health status), the effectiveness of rescue activities (voluntary or professional; search, extrication, medical care), etc. We used an assumption, in this development, that the most significant affecting factor is the extent of building damage observed with due consideration of construction type.

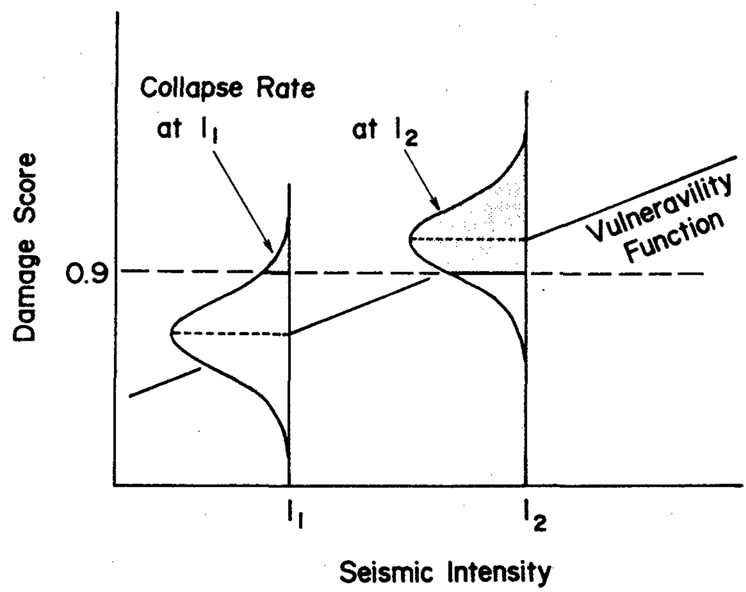


Figure 4. Procedure to calculate a collapse rate.

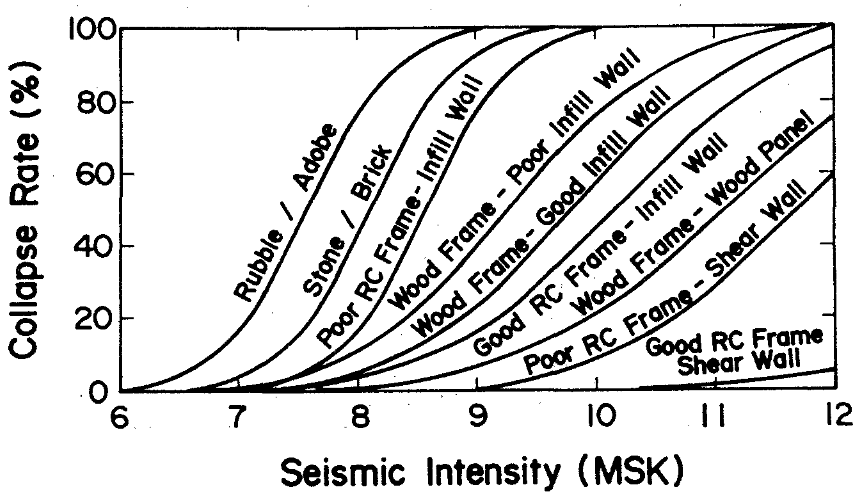


Figure 5. Collapse rate functions.

Coburn et al. (1989) summarized fatality rate as a function of the collapse rate for several types of construction. This work outlined the fatality by construction type for rubble, adobe, stone and brick masonry, and wood frame buildings.

Using inter- and extrapolation to the summary by Coburn et al. (1989), we derived a set of relationships between collapse rate and fatality rate for the 11 categories of construction type. In this determination, we paid considerable attention to the difference among construction types in the following two aspects: first, the weight of building materials and, second, the brittleness of buildings as a structural system.

The relationship between collapse rate and fatality rate for the 11 categories of construction type was given as a mathematical expression as follows:

$$FR(CT; CR)=FR100(CT)*(CR/100)^n$$

where

FR:	Fatality Rate (%)
CT:	Construction Type
FR100:	Fatality Rate at a Collapse Rate of 100 Percent
CR:	Collapse Rate (%)
n:	Coefficient which Account for the Non-Proportional Character between Collapse Rate and Fatality Rate.

Table 3 provides the values of FR100 for each construction type. Fatality rates for each of the construction types are given in Figure 6. A value of 1.6 for coefficient n was determined to obtain a consistency with the relationships compiled by Coburn et al. (1989).

Table 3
FR100: Fatality Rate at a Collapse Rate of 100 Percent

Construction Type	FR100 (%)
Rubble	30
Adobe	15
Stone Masonry	17.5
Brick Masonry	25
Wood Frame with Poor Infill Walls	15
Wood Frame with Good Infill Walls	10
Wood Frame with Wood Panel Walls	5
Poor Quality RC Frame with Infill Walls	15
Poor Quality RC Frame with Shear Walls	10
Good Quality RC Frame with Infill Walls	7.5
Good Quality RC Frame with Shear Walls	2.5

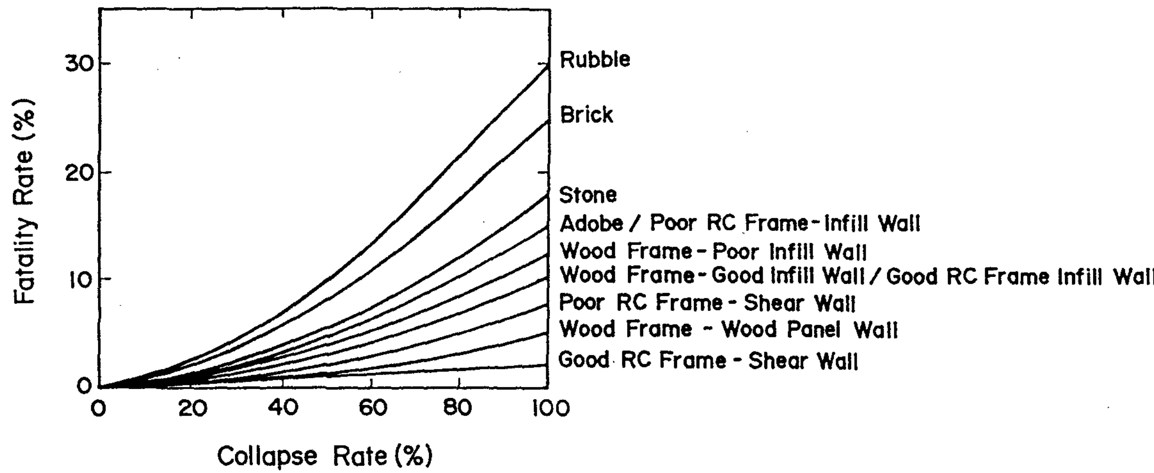


Figure 6. Fatality rate functions.

3. SENSITIVITY ANALYSIS

3.1 Fatalities

Fatalities calculated for a series of hypothetical input data are enumerated in Figure 7. The number of deaths was plotted against magnitude by construction type. Population density was fixed at 100 persons/sq-km. The distribution of seismic intensity was calculated based on the relationships for Turkey.

The number of deaths is essential information to decide the size of rescue power allocated to a disaster area. An estimate of fatalities suggests decision makers at emergency response how many rescuers they must send.

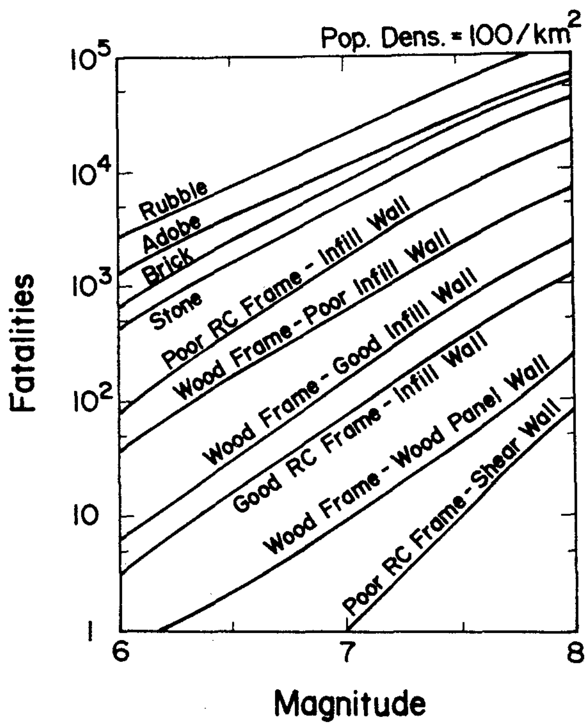


Figure 7. Deaths versus magnitude by construction type.

The number of deaths differs widely depending on construction type. For example, rubble and adobe buildings kill more than 1,000 times as many people as wood frame buildings with wood panel walls. Between adobe buildings and wood frame buildings with infill walls, the difference is more than 10 times. The mixture of these two construction types is observed in many seismic active locations including the majority of Middle Eastern and Latin American countries.

The death toll increases in proportion to population density. Therefore, population density must be considered as another significant factor affecting the result. It is realistic that population density varies on the order of 10 to 10,000 (persons/sq-km) over a factor of 1,000, depending upon the social situation of affected area such as urban/rural distinction.

3.2 Disaster Area

Similar calculation was conducted to relate the extent of damage area to seismic magnitude by construction type. Figure 8 shows the radii of equivalent circular area in which building collapse and, accordingly, fatality are expected. The size of affected area significantly depends on building type as well as seismic magnitude.

This type of information suggests the size of a reconnaissance area. Reconnaissance is one of the two preparatory activities required for professional rescue effort. The other is the arrangement of rescue resources, which can be decided base on the estimate of fatalities.

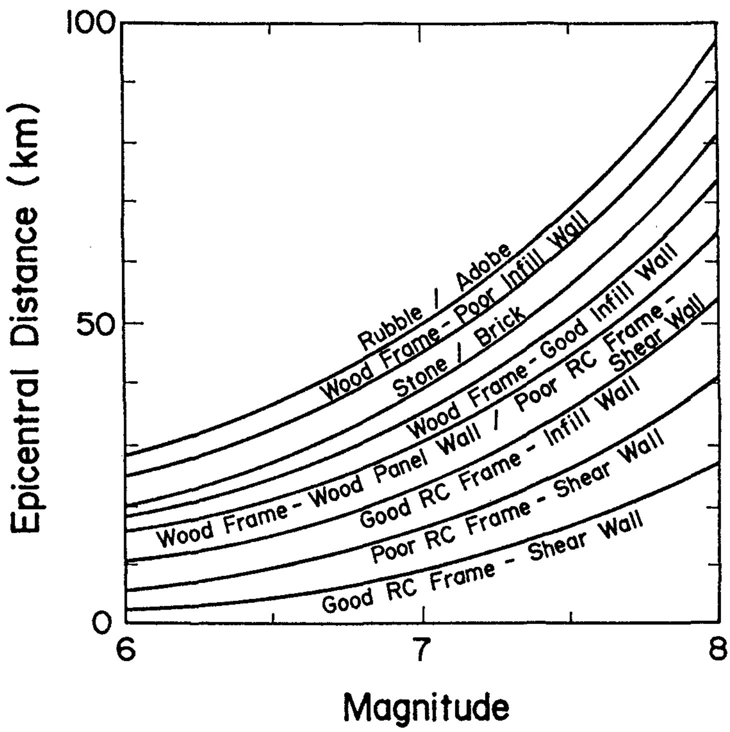


Figure 8. Epicentral distance within which building collapse and fatality are expected.

4. CASE STUDIES

4.1 General

Data from numerous past earthquakes exist to test performance of our model. We collected data from 17 earthquakes as listed in Table 4. In collecting data, we did not use any criteria to select events to analyze as many cases as possible. However, we did not analyze several earthquakes where damage was limited to sites distant from the epicentral region - such as the Rumanian earthquake of 1977 and the Mexican earthquake of 1985. For these events, a simplified approximation of the circular distribution of seismic intensity, which was used in our current development, is no longer appropriate.

Table 4
Earthquakes Examined in this Study

No.	Country	Year	Date	Time	M	Deaths
1	Iran	1962	09-01	10:52	7+1/4	12,000-15,000
2	Turkey	1966	08-19	14:22	6.5	2,394
3	Turkey	1967	07-22	18:56	7.5	89
4	Iran	1968	08-31	14:15	7.3	7,000-10,000
5	Turkey	1970	03-28	23:02	7.1	1,086
6	Turkey	1971	05-12	08:25	6.0	57
7	Turkey	1971	05-22	18:45	6.7	878
8	Iran	1972	04-10	05:37	7.1	5,000
9	Nicaragua	1972	12-23	00:28	6.6	5,000-11,000+
10	Turkey	1975	09-06	12:20	6.7	2,385
11	Guatemala	1976	02-04	03:05	7.5	22,778
12	China	1976	07-28	03:43	7.8	242,419
13	Turkey	1976	11-24	14-22	7.4	3,840
14	Algeria	1980	10-10	13:25	7.3	2,263
15	Italy	1980	11-23	19:34	6.8	2,735- 4,689
16	Chile	1985	03-03	19:50	7.8	180
17	El Salvador	1986	10-30	11:49	5.4	1,500

4.2 Iran

Three events in Iran, listed below, were analyzed.

Table 5
Three Iranian Earthquakes Analyzed in this Study

Area	Date	Magnitude
Buyin-Zara	Sep. 1, 1962	7+1/4
Dasht-Bayaz	Aug. 31, 1968	7.3
Ghir	Apr. 10, 1972	7.1

Seismic Intensity: The following relationship (Chandra et al., 1979) was employed to evaluate the distribution of seismic intensity:

$$I(r)=Io+6.453-0.00121r-4.960\log(r+20)$$

where

I: seismic intensity in MMI
r: epicentral distance in km
Io: maximum intensity given by Karnik (1965) as

$$Io=(M-1.78)/0.53$$

with M: surface wave magnitude.

Because any relationships between magnitude and maximum intensity were not available for Iranian earthquakes, a relationship for the northern next region, Armenia, in the classification by Karnik (1965), was employed to substitute.

Population density: The population densities for the 1968 and 1972 events were nine and five persons/sq-km, respectively (Amblaseys and Tchalenko, 1969; Abmblaseys et al., 1972). The average Iranian population density, 25 persons/sq-km, was assigned in the 1962 earthquake.

Construction Type: Adobe was the accepted building type in each event (Saidi, 1963; Ambraseys and Tchalenko, 1969; Ambraseys et al., 1972).

Site Effect: Increment in seismic intensity due to soil amplification was not included. The habitat situation in the affected area of the 1962 event was described as "small and medium-sized villages are scattered over dry plains and hills around isolated strips of cultivated land" (Saidi, 1963).

Calculation results for these events were:

Table 6
Reported and Calculated Fatalities in Iranian Earthquakes

Year	Reported Fatalities	Calculated Fatalities
1962	12,000-15,000	17,000
1968	7,000-12,000	6,700
1972	5,000	2,400

4.3 Nicaragua

Seismic Intensity: Shortly after the Managua, Nicaragua earthquake of December 23, 1973 (M=7.2), Hansen and Chavez (1973) conducted an intensive survey to develop isoseismal maps of Nicaragua. Two maps were derived; the first, for the urban area of Managua and, the second, for the entire country of Nicaragua.

In constructing our computer model for Nicaragua, we used these maps to determine the relationship between epicentral distance and seismic intensity. The areas enclosed by isoseismal curves were read from these maps, and the radii of equivalent circular isoseismal curves were calculated. An equivalent isoseismal curve was determined to enclose the area that agrees with the area enclosed by an observed isoseismal. The radii of equivalent circular isoseismals were plotted in Figure 9 to derive an attenuation function.

From Figure 9, it can be pointed out that the seismic intensity in and around the city of Managua - within the epicentral distance of 10 km - is high. That is significantly higher than was expected from the tendency of attenuation observed in the entire country of Nicaragua. This tendency coincides with the existence of soft alluvial deposits in Managua. Thus, it can be explained as a local soil effect, namely the amplification of earthquake ground motion in soft layers. The shear wave velocity in the surface layers at several sites in Managua was measured remarkably low, ranging between 200 and 300 m/sec (Faccioli et al., 1973).

We derived a seismic intensity versus epicentral distance relationship without the amplification in Managua using the attenuation data from Hansen and Chevez's (1973) isoseismal map for Nicaragua. To the original plots we added a 7.8 epicentral intensity in regression analysis. This epicentral intensity was calculated by the relationship of Gutenberg and Richter (1956).

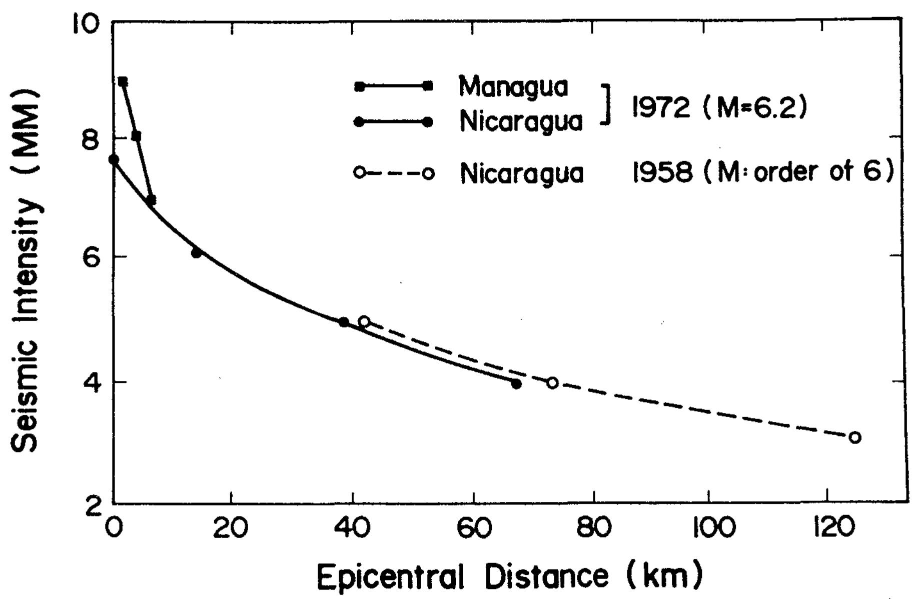


Figure 9. Relationship between epicentral distance and seismic intensity based on the isoseismal maps of the 1972 Managua, Nicaragua earthquake developed by Hansen and Chavez (1973).

This assumption of epicentral intensity was supported by the analysis of the acceleration records obtained in Managua (Facciori et al., 1973). The amplification of acceleration amplitude due to alluvial layers was determined in the range between 1.9 and 3.2. An amplification of acceleration amplitude by two-to-three corresponds to an increment in seismic intensity of 0.8 to 1.4 with the average of 1.2. A 1.2 increase in seismic intensity due to soil amplification was added to the estimated intensity of 7.8; resulting an observed maximum intensity of 9.

The relationship between epicentral distance and seismic intensity for Nicaragua was derived as follows:

$$I(r)=Io+0.41-0.018r-1.6\log(r+1.8)$$

where

I: seismic intensity in MMI
r: epicentral distance in km
Io: maximum intensity given by Gutenberg and Richter (1956) as

$$Io=1.5(M-1)$$

with M: surface wave magnitude.

Population Density: At the time of the 1972 earthquake, Managua's city boundaries (Knudson and Hansen, 1973) enclosed an area of 25 sq-km, and the city held an estimated population of approximately 450,000 (Duke, 1973). The population density was 17,000 persons/sq-km.

Construction Type: No suitable data could be located to provide the actual number of buildings by construction type in Managua at the time of the earthquake. Therefore, all buildings in the city were assumed to be wood frame with poor quality infill walls called "taquezal."

According to the national building survey in 1971 (Penalba, 1981), of the two types of earthen buildings - adobe and taquezal - taquezal was dominant in Managua. As of that survey, the urban areas of Managua had some 2,500 houses with adobe walls and some 7,500 houses with taquezal walls. Further, there were a considerable number of low- to lower middle-income houses made of light stuff including wood and some other scrap materials (Evaluation Technologies, 1981). These buildings had little life-threatening quality due to the light weight of their materials.

Site Effect: On the basis of the analysis mentioned above, seismic intensity was increased by 1.2 (MMI) to include the soil amplification in the alluvial structure in Managua.

Since human casualties were expected to occur most significantly in the most densely inhabited areas, we focused our calculation on the area within the urban boundary of Managua. We divided the area into several parts as shown in Figure 10 and calculated expected deaths on a segment-by-segment basis. The totals by segment were then summed to provide the resulting death toll for the city.

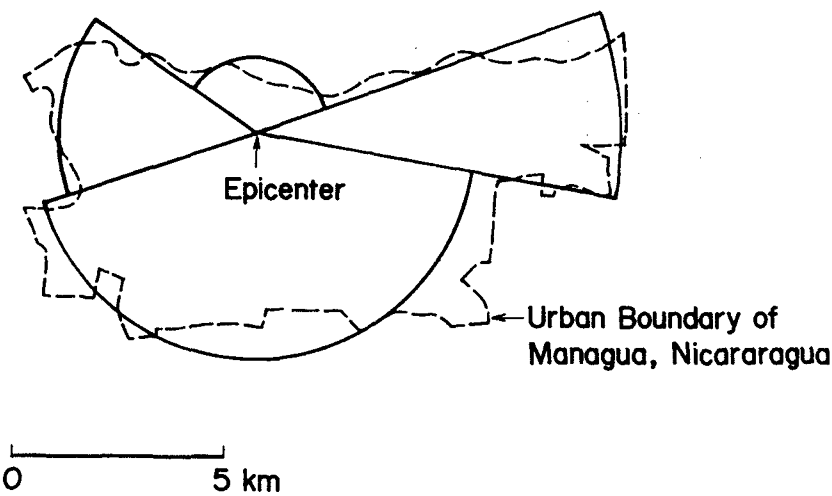


Figure 10. Segmentation of the affected area, Managua, Nicaragua for calculation.

Using the previously outlined formula, we calculated fatalities as totaling 9,800 persons. The government report estimated, in various ways, at 8,000-10,000, 6,000-10,000, and more than 11,000 (Pereira and Creegan, 1973).

4.4 Guatemala

Guatemala experienced an earthquake of magnitude 7.6 on February 4, 1976 (de Ville de Goyte et al., 1976).

Seismic Intensity: We evaluated the distribution of seismic intensity for this episode using the same relationship as those in Nicaragua:

$$I(r)=Io+0.41-0.018r-1.6\log(r+1.8)$$

where

- I: seismic intensity in MMI
- r: epicentral distance in km
- Io: maximum intensity given by Gutenberg and Richter (1956) as

$$Io=1.5(M-1)$$

with M: surface wave magnitude.

Population Density: Since the damage from this earthquake distributed over a large portion of the country, population density was given at the national average of 60 persons/sq-km.

Construction Type: Adobe was the predominant building material in the 1976 Guatemalan event. For a village in the most severely affected area, 85 percent of the houses were made of adobe (Glass et al., 1977). Further, Bates et al. (Undated) reported that 77.0 percent of houses in 17 communities were adobe construction with the remainder constructed of block, wood, and "bajaraque," or wood frame construction with poor infill walls. To carry out our calculation, then, we assigned dominant construction type as 80 percent adobe and 20 percent bajaraque.

Site Effect: Increment of seismic intensity due to site effect was not used in the calculation. The highlands constitute 50 percent of the total land area (Evaluation Technologies, 1982), and the major portion of population inhabit there.

Using these calculations, we arrived at a computation of 24,000 dead. Many reports adopted a death toll of 22,778.

4.5 China

The Tangshan earthquake, magnitude 7.8, occurred on July 28, 1976.

Seismic Intensity: Although several studies on the relationship between magnitude and maximum seismic intensity for Chinese events have been proposed (Karnik, 1965; Jennings, 1980), no attenuation function was available. We analyzed the isoseismal maps of the 1976 Tangshan earthquake (Jennings, 1980; Ye and Liu, 1980) to derive an attenuation function and obtained equivalent circular isoseismals (Figure 11). The procedure was the same with that used previously in the isoseismal maps of the 1973 Managua, Nicaragua event. The attenuation function was derived as follows:

$$I(r)=Io-3.38+0.001r-4.0\log(r+7.0)$$

where

- I: seismic intensity on MMI scale
- r: epicentral distance on km
- Io: maximum seismic intensity given by Lee (1958) as

$$Io=(M-1.5)/0.58$$

with M: surface wave magnitude.

Population Density: The population density of the affected area was given as 413 persons/sq-km. Tangshan District, which included the city of Tangshan and other 14 regions of a city and 13 counties, had a population of 5,569,000 and a surface area of 13,472 sq-km.

Construction Type: Brick masonry and wood-frame with good infill walls were the main construction types in the affected area. The relative number of buildings in each construction type was assumed 50%, respectively.

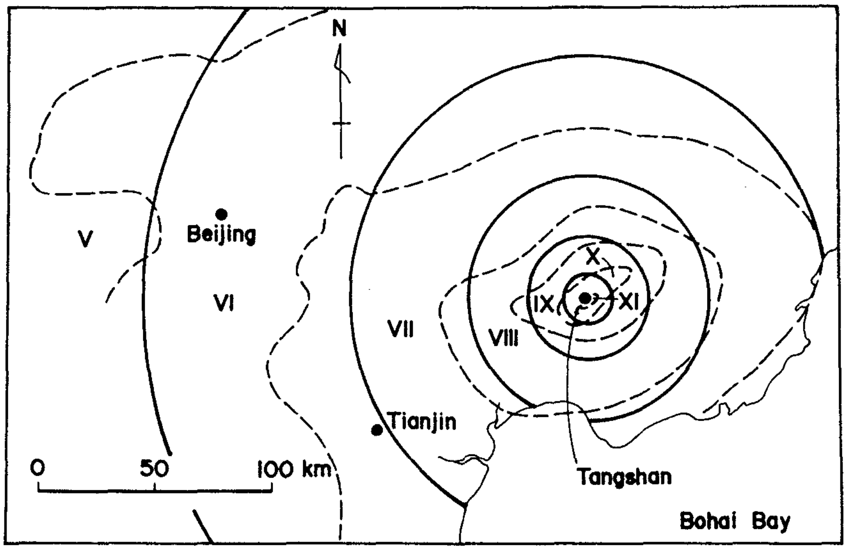


Figure 11. Isoseismal map of the 1976 Tangshan, China earthquake (After Ye and Liu, 1980). Equivalent circular isoseismals are shown by solid curved lines.

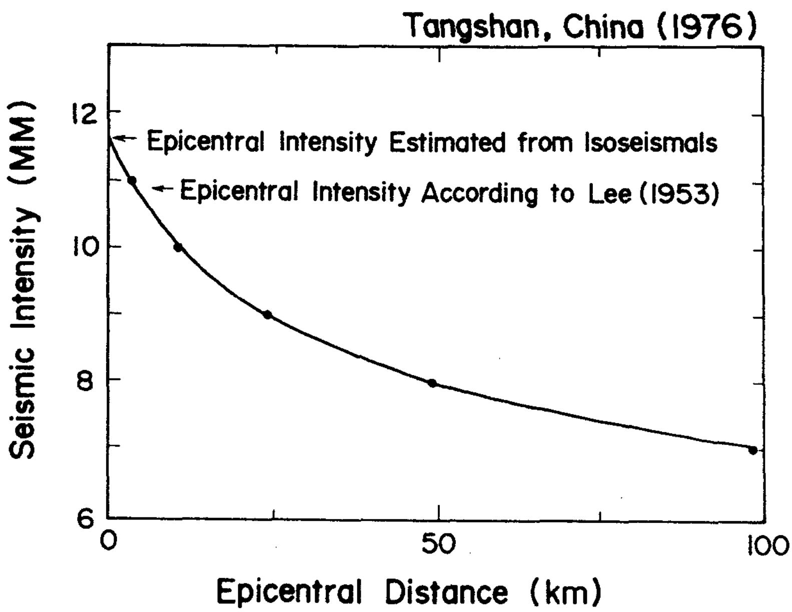


Figure 12. Relationship between epicentral distance and seismic intensity of the 1976 Tangshan, China earthquake.

Site Effect: Although an area of 27 sq-km in which seismic intensities were higher than 11 was observed (Jennings, 1980), the maximum intensity estimated according to Lee (1958) was less than 11 (10.9). As shown in Figure 12, the difference between the observed and estimated intensities was 0.7. Since Tangshan area is located in a large alluvial plain, it was interpreted that the increment in seismic intensity of 0.7 was attributed to soil amplification.

While a government estimate placed the earthquake death toll at 242,419, our computer model reached at 348,000 fatalities.

4.6 Algeria

The El-Asnam, Algeria earthquake of magnitude 7.3 occurred on October 10, 1980. The city of El-Asnam was formerly known as Owensville and is now called Ech-Cheliff.

The relationship between magnitude and maximum intensity was determined according to Karnik (1965). The relationship derived for northern Turkey was used with consideration of the similarity in seismological setting between Algeria and northern Turkey. Although a relationship for Algeria was shown in Karnik (1965), it was determined from moderate events and was not applicable to destructive ones. The formula in terms of MSK used in this study is:

$$I_o=(M-1.76)/0.54.$$

As no attenuation function for Algeria was available, we derived one based on an isoseismal map of the 1980 El-Asnam earthquake (Leeds, 1983).

Shown in Figure 13, the isoseismals are elongated east to west. This elongation corresponds with the direction along which the fault and sedimentary soils extend.

The relationship between epicentral distance and seismic intensity is shown in Figure 14 (a). Epicentral distance was measured in two directions; approximately east-west along the elongation of isoseismals and north-south perpendicular to the elongation.

The attenuation curve along the major axis shows a sudden change at the distance of 25 km. The curve along the minor axis shows a similar tendency at the distance of 15 km. These distances coincide approximately with the size of the valley in which El-Asnam is located. Therefore, the attenuation relation within the epicentral distance of 25 km along the east-west direction and 15 km along the north-south direction was interpreted as the amplification effect due to soil deposits in the valley.

An attenuation curve was derived from the relationship between average epicentral distance and seismic intensity, as shown by a broken line in Figure 14 (a). The three plots at seismic intensities of 6, 7 and 8, in addition to the maximum intensity at the epicenter, were used in the regression to eliminate the effect of soil amplification. In terms of MMI, the attenuation function was derived as:

$$I(r)=Io+4.11-0.010r-4.40\log(r+8.60)$$

where

I: seismic intensity in MMI
Io: maximum seismic intensity
r: epicentral distance in km.

Population Density: El-Asnam's population density when the earthquake struck was approximately 100 persons/sq-km. The "wilaya" (province) of El-Asnam supported 885,200 habitants within its surface area of 8,676 sq-km in January 1978 (Leeds, 1983).

Construction Type: Two dominant construction types, brick masonry and poor reinforced concrete frame with infill walls, contributed in the calculation of earthquake fatalities.

Site Effect: In the previous analysis of the isoseismal map we found the increment of seismic intensity in El-Asnam to be 0.7 in MMI.

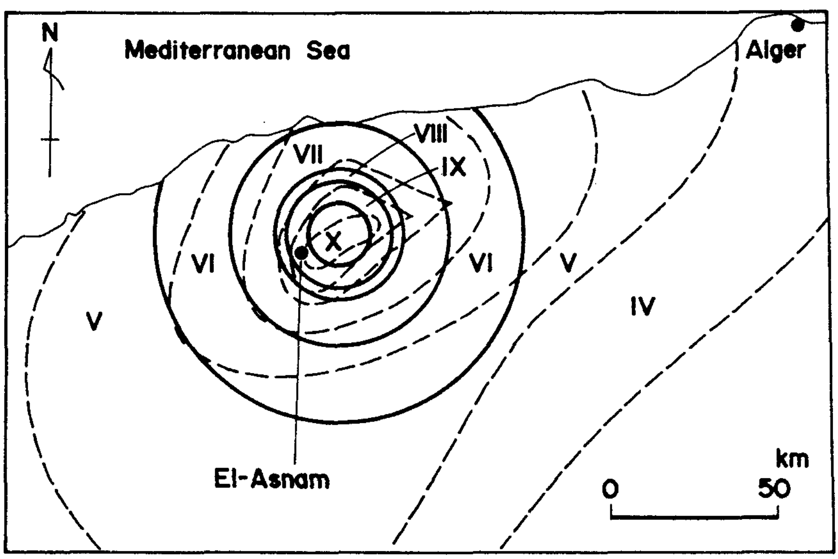
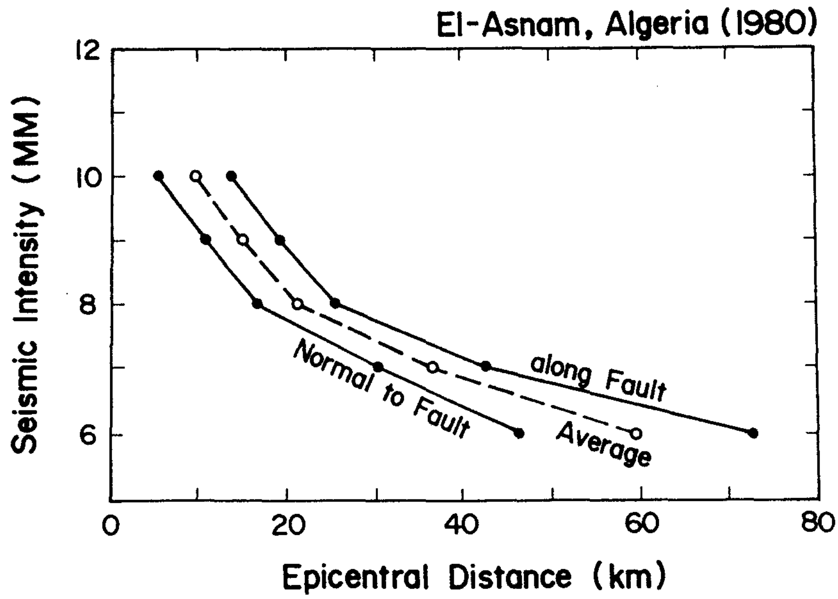
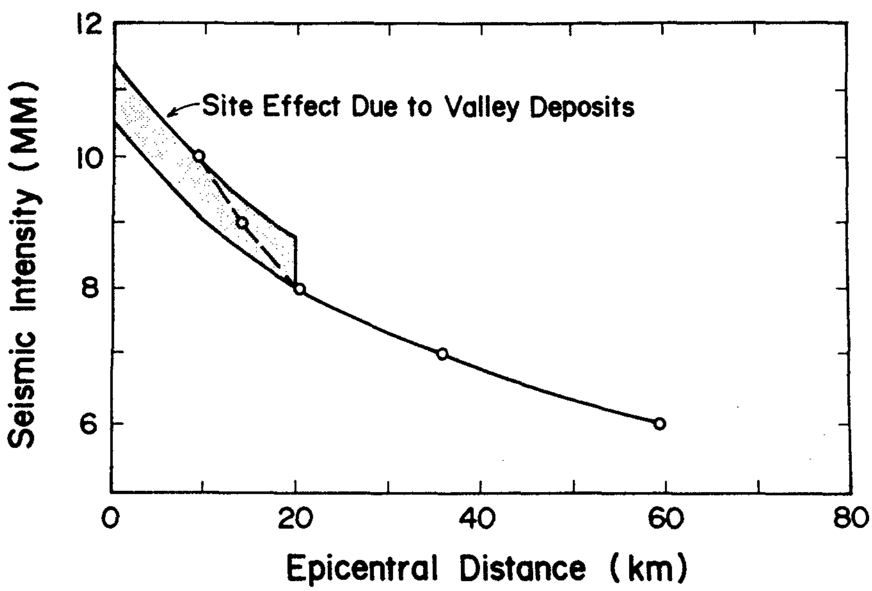


Figure 13. Isoseismal map of the 1980 El-Asnam, Algeria earthquake appearing in Leeds (1983). The map was developed by CTC, Organism de Controle Technicque de la Construction (1981). Seismic intensity in MMI. Equivalent circular isoseismals are shown by solid curved lines. Site effect is included in the equivalent isoseismals.



(a)



(b)

Figure 14. Attenuation of seismic intensity, the 1980 El-Asnam, Algeria earthquake. Seismic intensity in MMI. The relationships read from the isoseismals (Figure 13) are shown in (a), and that used in calculation is shown in (b).

Using the formula described earlier, we calculated expected fatalities in the 10,000 to 18,000 range. The result of 10,000 fatalities corresponds to an assumption that all buildings were of reinforced concrete; The result of 18,000 corresponds to an assumption that all buildings were of brick. Assuming that each construction type accounted for 50 percent of the buildings, a death toll of 14,000 was obtained. The reported death toll was 2,263.

4.7 Italy

The Campania-Basilicata earthquake, in southern Italy, occurred on November 23, 1980 with a magnitude of 6.8.

Seismic Intensity: Maximum intensity was determined according to the relationship for the regions of central Italy, Carpathia, and Bulgaria (Karnik, 1965). Although Karnik (1965) derived a relationship for southern Italy, he admitted that the formula did not fit severe events with intensities reaching 10 or 11. We used the formula considering the similarity in geologic and seismological setting between the affected area and the area for which the formula was derived. The formula used in this study is:

$$Io=(M-0.96)/0.53$$

where

Io: maximum intensity in MSK
M: surface wave magnitude.

In the determination of attenuation, we used a relationship developed for Turkey for the following two reasons; first, no relationships existed that were derived from the observations in Italy; second, the formula developed for Turkey sufficiently explained the isoseismal survey of the 1980 event (Stratta et al., 1981). The relationship used is:

$$I(r,M)=Io+a-br-c\log(d+r)$$

where

I: seismic intensity in MSK
r: epicentral distance in km
M: surface wave magnitude
Io: maximum intensity
a, b, c and d: coefficients defined as:

$$a=c\log(d)$$
$$b=0.005(M-6)$$
$$c=-0.335M^2+4.365M-7.28$$
$$d=13+2(M-6).$$

A detailed explanation of the procedure used to derive this formula is seen later in Section 4.10 on Turkish events.

Population Density: Supporting 20 persons/sq-km, the affected area of the 1980 Italian earthquake spanned portions of the three provinces of Avellino, Potenza, and Salerno. The total population of 1,800,000 and the surface area of 140 sq-km result a population density of 130 persons/sq-km. Reasoning of this disparity came from the fact the affected site lay in a rural, low density agriculture and forestry region. As the overall population in these two industries accounts for only 15 percent of the Italy's total population, we assumed that the same 15 percent could be applied to the portion in the affected provinces. The resultant density came to the 20 persons/sq-km figure used in the calculation.

Construction Type: Dominant construction types in this area were stone masonry and poor reinforced concrete frame with infill walls.

Site Effects: Because the affected area was in a mountainous region, we did not include any site effect in the calculation.

Applying these regional variables to our estimation model, we determined the number to be between 3,700 and 7,800 depending on construction type. The higher figure reflected the assumption that all buildings were made of stone, and the lower figure that all buildings were made of reinforced concrete.

The actual death toll was thought to be approximately 2,500 (Alexander, 1985) or 4,700; with the larger estimate including those missing eight days after the event (Stratta et al., 1983).

In this calculation, significant number of deaths was counted within an epicentral distance of 40 km for brick construction and 30 km for reinforced concrete. This was consistent with Alexander's (1985) observation, "The incidence of both death and injury was strongly concentrated on the epicenter area." The epicenter area can be regarded as the area within an epicentral distance of approximately 30 km including "the twelve villages that suffered most casualties."

4.8 Chile

The central Chile earthquake of March 3, 1985 had a magnitude of 7.8 with its epicenter located 20 km off the country's coast. The most significantly affected areas were in the following three regions: Region 5, the Metropolitan Region, and Region 6, from north to south.

To evaluate the distribution of seismic intensity, we employed the following relationships:

$$I(r)=Io+0.41-0.081r-1.6\log(r+1.8)$$

where

- I: seismic intensity in MMI
- r: epicentral distance in km
- Io: maximum intensity given by Gutenberg and Richter (1956) as

$$Io=1.5(M-1)$$

with M: surface wave magnitude.

We used the attenuation function derived from the isoseismal map of the 1973 Managua, Nicaragua earthquake, since the combination of it with Gutenberg and Richter's (1956) formula provided a considerable agreement with the observed seismic intensities of the 1985 Chilean earthquake (Booth, 1985; Astroza and Monge, 1988).

Population Density: Regional population densities (given as persons/sq-km) at the time of the disaster were 77 (Region 5), 285 (Metropolitan Region), and 39 (Region 6), respectively (Ortiz et al., 1986)

Construction Type: Adobe, brick masonry, and wood frame with wood panel walls were found out to be the dominant construction types. Significant area-to-area differences exist, however, regarding preferred construction materials. The only useful information obtained so far was the predominancy of adobe construction in Region 6; Ortiz et al. (1986) described that the building material in Region VI is, by and large, adobe.

Site Effect: We did not include any site effect in the calculation of fatalities, since the epicentral area was composed of a series of marine terraces (coastal plain) and the coastal range (Ortiz, 1986). It is necessary to include the effect of the river sediments to examine the damage in the intermediate depression, in which Santiago is located. However, we could not apply our model to this capital city because of the lack of information on construction type.

In the calculation, the regions were approximated with an assembly of segments as shown in Figure 15.

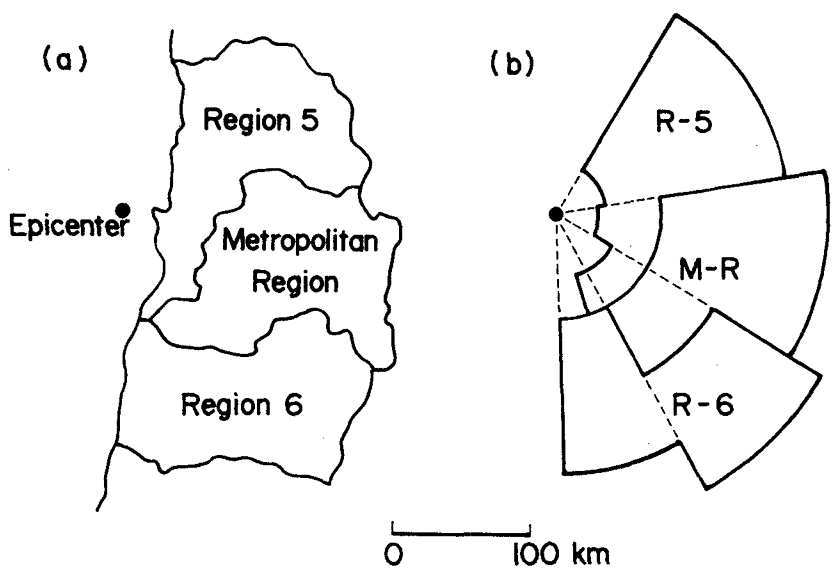


Figure 15. Affected area of the 1985 Central Chile earthquake (a) and segmentation of the affected area for calculation (b).

If an assumption was made that all buildings in the entire affected areas were of wood, the number of expected deaths would equal only 27. If adobe, the number could rise to as many as 62,000; or more than two thousand times those expected in wood frame construction.

The actual number of deaths by region amounted to 69 in Region 5, 80 in the Metropolitan Region, and 28 in Region 6. Totaling these figures, and another two from Region 7, one arrived at a final death toll of 180.

As long as only Region 6 was looked at, the result of calculation was fairly reasonable. The result for Region 6 was obtained at 141, if an assumption was made that all buildings were adobe according to the above mentioned description by Ortiz et al. (1986). Region 6 was situated far from the epicenter, extending 80 to 220 km in epicentral distance, and, therefore, the slight death toll was fundamentally attributed to this situation.

Many reports of this earthquake mentioned that the limited number of deaths was due to the time of occurrence, namely a sunny Sunday evening in the fall. Using the result for Region 6, we can evaluate the desirable effect of temporal occupancy at the difference between the calculated 140 deaths and the actual 28 deaths. In other words, the effect of temporal occupancy was fewer deaths of a factor of 5.

4.9 El Salvador

The 1986 San Salvador, El Salvador earthquake occurred on October 10 having a magnitude of 5.4.

Seismic Intensity: Like other cases in Central and South America, we used the following relationships to evaluate the distribution of seismic intensity:

$$I(r)=Io+0.41-0.081r-1.6\log(r+1.8)$$

where

- I: seismic intensity in MMI
- r: epicentral distance in km
- Io: maximum intensity given by Gutenberg and Richter (1956) as

$$Io=1.5(M-1)$$

with M: surface wave magnitude.

Site Effect: The geology of the city of San Salvador was characterized by thick, unconsolidated volcanic formations. The amplification of ground motion amplitude due to surface materials was estimated 4 to 5 (Rymer, 1987). This amplification of ground motion approximated the increment of seismic intensity by 2.

Population Density: Population density was given as 4,000 persons/sq-km. Although the estimated population of the city of San Salvador was 1,500,000, about 60 percent of them lived in marginal settlements (Evaluation

Technologies, 1984). Many of these marginal buildings were extremely poor as dwellings, but hardly had life threats to inhabitants. The population density was derived with 40 percent of the total population and the city's habitat area of 150 sq-km.

Construction Type: Construction type in San Salvador was surveyed by INTERTECT (1986), and the results were as shown in Table 7.

Table 7
Construction Types in San Salvador, El Salvador
(After INTERTECT, 1986)

Type	Buildings
Wood	about 15%
Block	about 10%
Brick	about 37%
Bajaraque	about 37%
Adobe	insignificant

As the survey was conducted only in the established residential areas, the extremely inferior dwellings mentioned above were not included. "Bajaraque" was a wall type classified into poor infill walls in this study.

The building type data used in our calculation was shown in Table 8 together with the number of estimated deaths in each building type. Calculation was carried out for the area shown in Figure 16.

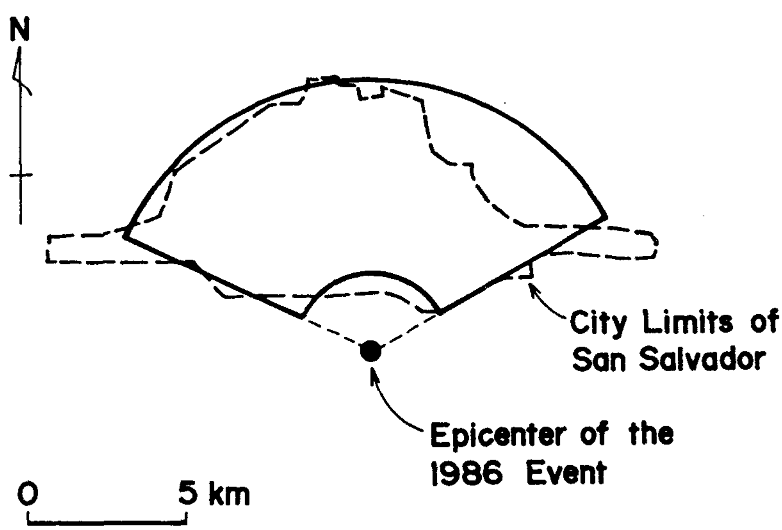


Figure 16. Affected area of the 1986 San Salvador, El Salvador earthquake.

Table 8
Construction Types and Associated Deaths in San Salvador, El Salvador Earthquake of 1986

Construction Type		Deaths
Adobe	1%	130
Stone (Block) Masonry	10%	380
Brick Masonry	37%	2,000
Wood Frame with Poor Infill Walls	37%	120
Wood Frame with Wood Panel Walls	15%	0
Total	100%	2,630

The total number of reported deaths was 1,500. Among these, 355 persons were killed in collapsed multi-story buildings (Durkin, 1986). Result of the current study did not include deaths in engineered buildings.

4.10 Turkey

Among the nine Turkish earthquakes 1966-1976 with a magnitude of 6.0 and greater, seven events listed below were examined. The other two were not examined because of the lack of regional data.

Table 9
Turkish Earthquakes Studied in this Study

Affected Area	Date	Magnitude
Varto	Aug. 19, 1966	6.5
Adapazari	Jul. 22, 1967	7.5
Gediz	Mar. 28, 1970	7.1
Burder	May 12, 1971	6.0
Bingol	May 22, 1971	6.7
Lice	Sep. 6, 1975	6.7
Chaldiran-Muradiye	Nov. 24, 1976	7.4

Seismic Intensity: The relationship between epicentral distance and seismic intensity was derived based on the study by Ohashi et al. (1983). They derived a function of magnitude that would indicate the area included within an isoseismal curve at a certain seismic intensity. For example, the area having intensities greater than 7 was expressed as:

$$\log(A7)=0.76M-1.81$$

where

A7: The area in which seismic intensity is higher than 7
M: Surface wave magnitude.

In this study, we represented the isoseismals by circles - equivalent circular isoseismals - having the area indicated by the relationships derived by Ohashi et al. (1983) and, then, calculated the radii of equivalent circular isoseismals. The results are shown in Figure 17 as the relationship between epicentral distance and seismic intensity by magnitude.

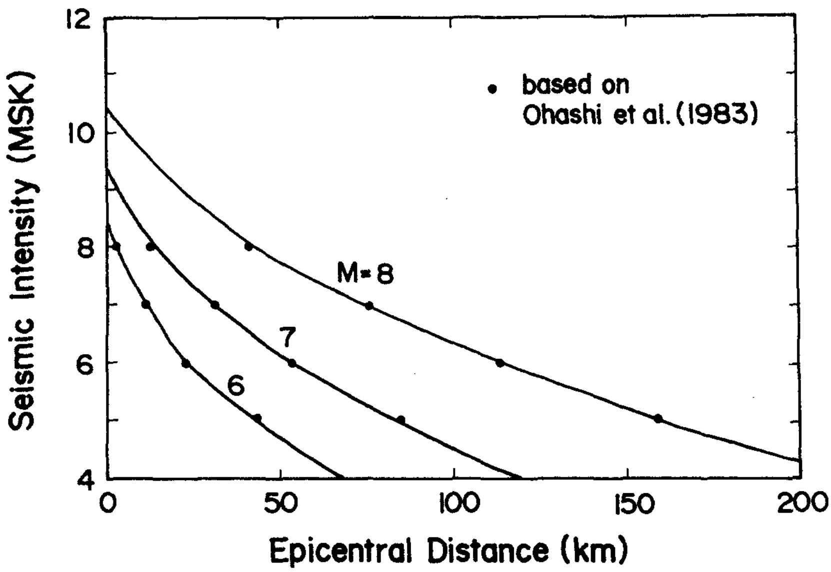


Figure 17. Attenuation curves of earthquakes in Turkey.

Attenuation relationships by magnitude were derived from the formula shown in Figure 17. The general form of attenuation function was given as follows:

$$I(r)=Io+a-br-c\log(r+d)$$

where

I: Seismic intensity in MSK
r: Epicentral distance in km
Io: Maximum intensity, or epicentral intensity
a: a coefficient given as a=clog(d)
b, c and d: coefficients determined through regression analysis.

The attenuation curves derived through regression analysis are shown using solid lines in Figure 17, while the coefficients of the attenuation functions are shown in Table 10.

Table 10
Coefficients in Attenuation Functions

	M		
	6	7	8
Io	8.5	9.5	10.6
a	6.13	5.88	4.92
b	0	0.005	0.010
c	13	15	17

Then, maximum intensity (Io) and the three coefficients (b, c and d) were expressed as functions of magnitude M. Resultant values follow:

$Io=0.05M^2+0.35M+4.6$
$b=0.005(M-6)$
$c=-0.35M^2+4.365M-7.28$
$d=13+2(M-6).$

Regional Data: Population density and dominant construction types, as obtained from population and building census reports, were assigned as shown in Table 11 (Ohta et al., 1983; Ohashi et al., 1983).

The other source of building type was found in Akkas and Erdik (1982). They conducted a field survey of predominant construction types found in the major damage areas. As applied to this study, their data were recorded in Table 12.

Table 11
Population Density and Dominant Construction Types in Seven Turkish Earthquakes

Earthquake	Population Density (Persons/sq-km)	Construction Type (%) *		
		Rubble	Adobe	Wood**
Varto, 1966	24.2	82	18	0
Adapazari, 1967	84.2	18	6	76
Gediz, 1970	37.0	28	12	60
Burder, 1971	30.5	34	47	19
Bingol, 1971	21.9	84	0	16
Lice, 1975	42.3	89	9	2
Caldiran, 1976	20.0	10	90	0

Note:
* Ohashi et al. (1983) included categories entitled "mix" and "other" in their designation, we distributed these proportionately in the above three categories.
** Wood frame with poor infill walls.

Table 12
Building Types in Seven Turkish Earthquakes:
(After Akkas and Erdik, 1982)

Earthquake	Construction Type (%) *		
	Rubble	Adobe	Wood**
Varto, 1966	89	11	0
Adapazari, 1967	0	6	94
Gediz, 1970	0	5	95
Burder, 1971	44	56	0
Bingol, 1971	84	16	0
Lice, 1975	90	10	0
Caldiran, 1976	80	20	0

Note: Although Akkas and Erdik (1982) classified 5 to 10 percent of the buildings as "other," we allotted these proportionately.

Table 13
Reported and Calculated Number of Deaths in
Seven Turkish Earthquakes
(Building Stock Data according to Building Census)

Earthquake	Deaths		C/R
	Reported (R)	Calculated (C)	
Varto, 1966	2,394	1,659	0.693
Adapazari, 1967	89	9,626	108
Gediz, 1970	1,086	3,113	2.87
Burder, 1971	57	441	7.74
Bingol, 1971	878	2,063	2.35
Lice, 1975	2,385	4,448	1.87
Caldiran, 1976	3,840	4,774	1.24

Table 14
Reported and Calculated Number of Deaths in
Seven Turkish Earthquakes
(Building Stock Data according to Field Survey)

Earthquake	Deaths		C/R
	Reported (R)	Calculated (C)	
Varto, 1966	2,394	1,732	0.723
Adapazari, 1967	89	1,744	19.6
Gediz, 1970	1,086	311	0.287
Burder, 1971	57	564	9.89
Bingol, 1971	878	2,278	2.59
Lice, 1975	2,385	4,525	1.90
Caldiran, 1976	3,840	7,722	2.01

The results of calculation are shown in Tables 13 and 14 in conjunction with the reported death tolls. We obtained the results in Table 13 from province-to-province regional data (Table 11) and the results in Table 14 from city-to-city regional data (Table 12).

5. STATISTICAL ANALYSIS

5.1 Turkish Earthquakes

In this study, we analyzed seven of the nine Turkish earthquakes that had a magnitude of 6.0 and greater and occurred in the period from 1966 and 1976. Turkey is the only country from which we could collect data for a considerable number of disasters having a specific criterion. Therefore, a set of results from Turkish events was the most appropriate data to examine the accuracy of our computer model.

The relationship between reported and calculated number of deaths is shown in Figure 18. The number of deaths calculated from province-to-province building data is shown in Figure 18 (a) and that from city-to-city building data is shown in Figure 18 (b).

The average and the standard deviation for the logarithmic ratio of calculated deaths (C) to reported deaths (R) were determined as follows:

Results from province-to-province data,

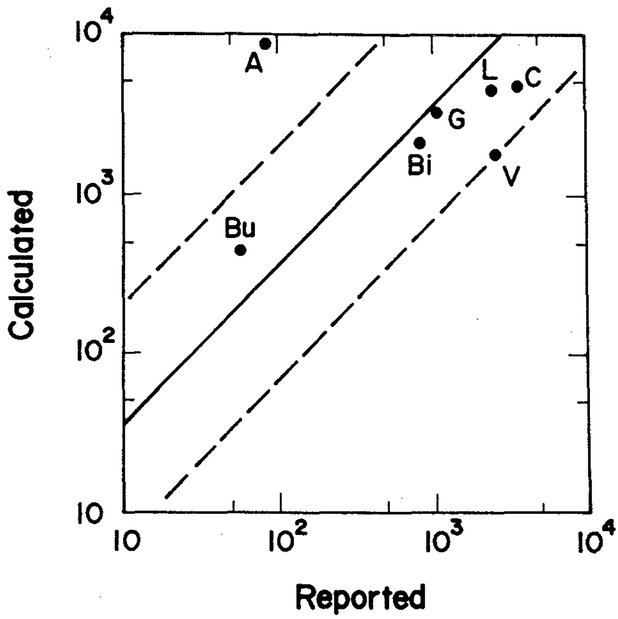
$$\text{Ave.}[\log(C/R)]=0.565 \quad (10^{0.565}=3.68)$$
$$\text{S.D.}[\log(C/R)]=0.742 \quad (10^{0.742}=5.30).$$

Results from city-to-city data,

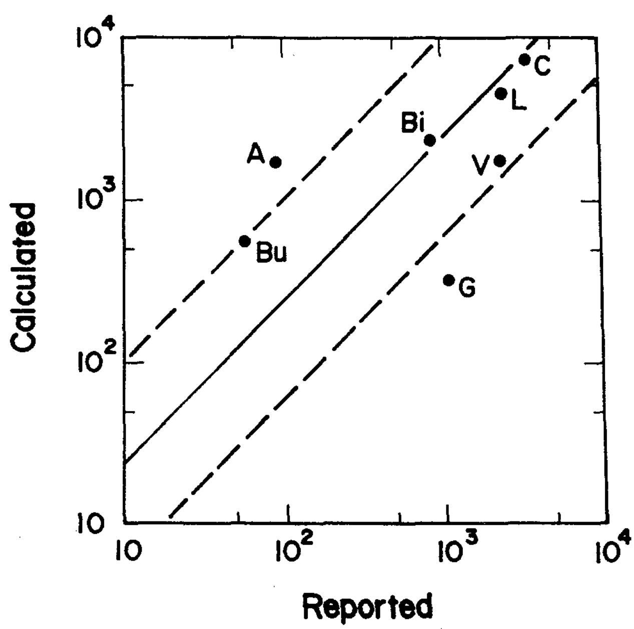
$$\text{Ave.}[\log(C/R)]=0.371 \quad (10^{0.371}=2.35)$$
$$\text{S.D.}[\log(C/R)]=0.626 \quad (10^{0.626}=4.23).$$

Both the average and the standard deviation of the ratio obtained from the city-to-city data were, as expected, smaller than those from the province-to-province data.

The ratio of the calculated to reported deaths can be understood as the error caused by the inaccuracy in input data and the inappropriateness of applied knowledge. However, it is difficult to identify the wrong part in the procedure from the limited experiences of applying the model. Also, in the model used here, we did not include the effects of several affecting factors, such as building size and temporal occupancy. These factors were repeatedly pointed out in related studies, but we still do not know specifically how these factors affect on fatalities.



(a)



(b)

Figure 18. Comparison between reported and calculated death tolls in Turkish earthquakes. Calculated fatalities based on the building census are shown in (a); Those based on the field data (Akkas and Erdik, 1982) are shown in (b).

In Figure 18, two broken lines are shown. These lines correspond to the deviation by "sigma" (standard deviation) of log(C/R) from the average. If the distribution of log(C/R) is assumed to be the normal distribution, approximately 70 percent (68.26%) of the estimates should be contained between the two values indicated by the broken lines. The estimates having 70 percent of the probability of occurrence are shown in Table 15.

Table 15
Fatality Estimates Having 70 Percent of the Probability of Occurrence

(a)
Estimates Derived from the Province-to-Province Data

Earthquake	Deaths		
	Data	Estimate	
		Low	High
Varto, 1966	2,394	85	2,390
Adapazari, 1967	89	495	13,872
Gediz, 1970	1,086	160	4,486
Burder, 1971	57	23	636
Bingol, 1971	878	106	2,973
Lice, 1975	2,385	229	6,410
Caldiran, 1976	3,840	245	6,880

(b)
Estimates Derived from the City-to-City Data

Earthquake	Deaths		
	Data	Estimate	
		Low	High
Varto, 1966	2,394	174	3,112
Adapazari, 1967	89	176	2,485
Gediz, 1970	1,086	31	559
Burder, 1971	57	57	1,013
Bingol, 1971	878	229	4,092
Lice, 1975	2,385	455	8,130
Caldiran, 1976	3,840	777	13,874

5.2 Earthquakes Worldwide

Death tolls calculated in this study were plotted in Figure 19 in comparison with reported fatalities. The calculated death tolls are shown in Table 16 with the high and low estimates at 70 percent of the probability of occurrence. The same statistical analysis with the case for Turkish events was applied.

For the 13 events having a death toll over 1,000, the average and the standard deviation for the logarithmic ratio of calculated deaths (C) to reported deaths (R) were determined as follows:

$$\text{Ave.}[\log(C/R)]=0.0467 \quad (10^{0.0467}=1.11)$$
$$\text{S.D.}[\log(C/R)]=0.314 \quad (10^{0.314}=2.06)$$

Although no criteria were applied in selecting earthquakes here, the events examined were among those regarded significant in the period approximately from 1960 to 1985. We collected data from such disasters virtually at random.

Table 16
Number of Deaths Calculated in the Computer Model

Earthquake			Deaths			
			Reported	Calculated	Estimates*	
No.	Country	Year			Low	High
1	Iran	1962	13,500	17,000	9,200	39,000
2	Turkey	1966	2,394	1,700	920	3,900
3	Turkey	1967	89	1,700	--	--
4	Iran	1968	10,000	6,700	3,600	15,000
5	Turkey	1970	1,086	310	170	710
6	Turkey**	1971	57	560	--	--
7	Turkey***	1971	878	2,300	--	--
8	Iran	1972	5,057	2,400	1,300	5,500
9	Nicaragua	1972	10,000	9,800	5,300	22,000
10	Turkey	1975	2,385	4,500	2,400	10,000
11	Guatemala	1976	23,000	24,000	13,000	55,000
12	China	1976	242,419	350,000	190,000	800,000
13	Turkey	1976	3,840	7,700	4,200	18,000
14	Algeria	1980	2,633	14,000	7,600	32,000
15	Italy	1980	4,689	5,800	3,100	13,000
16	Chile****	1985	28	140	--	--
17	El Salvador	1986	1,100	2,600	1,400	6,000

Note: * For events having more than 1,000 deaths.
** In Burder on May 12.
*** In Bingol on May 22.
**** Only Region 6 was examined.

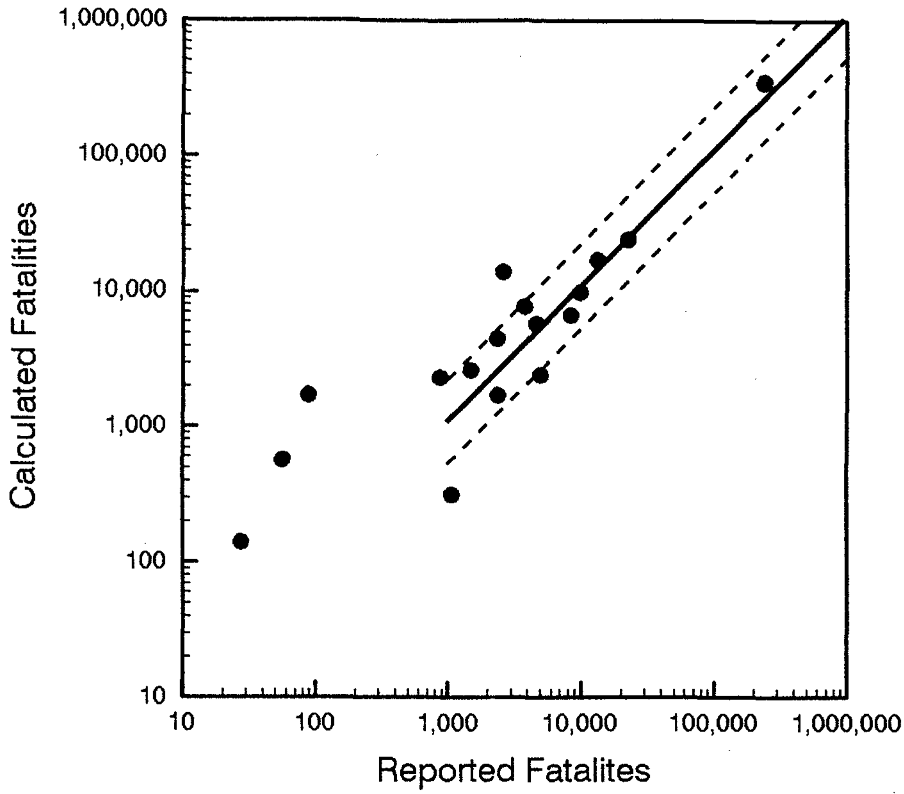


Figure 19. Comparison between reported and calculated death tolls.

6. DISCUSSION

6.1 Application of the Model

We developed a computer model to calculate earthquake fatalities using a personal computer. The calculation is carried out based on five input variables as follows:

Seismic Information:
1) Surface wave magnitude
2) Epicenter location

Regional Information:
3) Population density
4) Dominant construction type(s)
5) Increment in seismic intensity due to site effect.

Because seismic information listed above is available even immediately after the occurrence of an event, the model is applicable to post-event, rapid estimation. To carry out estimation quickly enough, regional information is desired before an event (regional database).

The number of fatalities estimated in the model can be used in the management of rescue activities. In the user interface of this computer model, decision makers are provided with information as follows:

1) Estimated number of deaths in each construction type, as well as total dead. The number of deaths suggests the requirement of rescue resources, while the information on construction type suggests effective types of rescue activities. The mobilization of highly professional rescue teams is suggested, for example, for casualties in large reinforced concrete buildings.

2) The location where deaths are expected to occur. The extent of an affected area suggests the area for reconnaissance.

The simultaneous practice of 1) the early stage arrangement of rescue resources and 2) adequate reconnaissance activities will contribute to the effective mobilization of professional rescuers. However, these two preparatory activities, which are required to take place immediately after an event, can themselves be supported only by estimates.

6.2 Performance of the Model

Our model was applied to 17 significant disasters between approximately 1960 and 1985 to demonstrate its performance. Good results were obtained particularly for the disasters having more than 1,000 deaths. Estimates for such 13 disasters were obtained within a range between 0.55 and 2.3 times of reported data for 70 percent of the probability of occurrence.

Errors in calculated fatalities are attributed to the affecting factors that we did not include in our current model. Some of these factors are:

1) Temporal occupancy
2) Victim characteristics (i.e., age, sex, health status, etc.)
3) Weather
4) Effectiveness of rescue activities (i.e., search, extrication, on- and off-site medical attention, and the transportation of injured persons.)

6.3 Evaluation of Site Effect

In a considerable number of the cases examined, soil amplification in the affected area had significant effects on fatalities. The effect was given in terms of increment in seismic intensity (Table 17).

These increments were evaluated in various ways rather than through a systematic development. In cases of Managua and San Salvador, however, the increments were consistent with the results of earthquake engineering studies analyzing seismic ground motion records.

Soils in the sites listed in Table 17 are alluvial deposits. Increments in seismic intensity roughly between one and two correspond with amplification factors that are often determined for alluvial sites. The difference in seismic intensity increment among these sites could be interpreted as the difference in the thickness of the sedimentary layers and the stiffness (i.e., seismic wave velocity) of layer material.

Table 17
Increment in Seismic Intensity Due to Site Effect

Area	Increment
Managua, Nicaragua	1.2
Tangshan, China	0.7
El-Asnam, Algeria	0.7
San Salvador, El Salvador	2.0

6.4 Limitation and Improvements

In some earthquakes, only areas distant from an epicentral region were affected. The damage was due to the resonance of buildings to the ground motions amplified in sedimentary layers. Such events, including the 1977 Rumanian earthquake and the 1985 Mexican earthquake, were not examined in this study. For these disasters, a simplified approximation with circular iso-seismals is no longer appropriate.

Difficulty in these earthquakes lies in that in the evaluation of their seismic intensities. In our current model, we used only magnitude, epicentral distance, and an increment in seismic intensity due to site effect to evaluate seismic intensities. To obtain an estimate of seismic intensity with appropriate accuracy, we would need more detailed information on source spectrum, attenuation characteristics along the path, and the response of sedimentary layers to ground shaking.

The other possible way to improve the estimation of seismic intensity is through on-site monitoring by means of instrumental observation. Because various procedures for evaluating seismic intensity based on an acceleration record were already proposed, we can choose one of those in accordance with our purpose.

6.5 Development of Regional Database

In this study, the collection of regional data was done only for past disasters. As a continuation of the study toward practical application, therefore, the collection of regional database is presently the most significant and urgent task for enhancing the applicability of the model to future disasters.

Two methods of database development are possible depending on the target areas where the estimation is done. First, if worldwide monitoring is intended, a database that covers all earthquake-prone areas is needed. A worldwide monitoring system will provide information applicable to the initial configuration of international response. Second, if national or local monitoring system is intended, only a database covering the specific area is required. In any case, required data include the population inhabiting each dominant construction type and the increment of seismic intensity due to site effects.

It is necessary to generate data for each unit less than several tens of square kilometers in surface area. Particularly in case of events having small to moderate magnitudes, most significant human casualties occur in an area having an epicentral distance of less than several km. An area of several tens of square kilometers usually coincides with that of cities, towns, and villages. The data for a province or its equivalents provide rather poor results; particularly cases where a major portion of the population concentrates in a few limited urbanized areas.

The instrumental measurement of soil amplification generally requires extensive effort. A possible and effective substitute is to assign the relation in terms of topography and/or surface geology. Topographical and geologic maps are widely available, and there is a considerable amount of interpretative knowledge (for example, Nakano et al., 1987). It is also possible to evaluate site effects by means of analyzing isoseismal maps as we did for several cases in this study.

6.6 Improvement of Algorithm

The model developed in this study can be improved in several aspects, as listed:

1) Elliptical equivalent isoseismals should be introduced to include the effects of fault dimensions. The effect is significant, particularly, in events having large magnitude.

2) Improved procedure to handle a space-related situation of population, soil condition, and/or construction type is introduced.

In case we are at some point able to use an on-site seismic monitoring system to improve the evaluation of seismic intensities, it is possible and appropriate to use more sophisticated estimation schemes. We can include the effect of, for example, building size, temporal occupancy, victim characteristics, weather, and the effectiveness of rescue activities.

7. CONCLUSIONS

We developed a computer model to estimate expected fatalities in any given earthquake immediately after the event applying the two first-hand seismic data of magnitude and epicenter location. We, then, confirmed the model's effectiveness through its application to a series of case studies.

In Chapter 1, we described the background of this development and defined the objective. The objective is to provide information to support the initiation of the following two post-event rescue activities: first, arrangement of professional rescue resources and, second, reconnaissance of human casualties. These two preparatory actions are crucial toward adequate mobilization of professional rescuers.

In Chapter 2, we described the composition of our computer model. We introduced existing applicable knowledge and gave it numerical expression. Such knowledge was found in seismology, earthquake engineering, and epidemiology.

In Chapter 3, we applied the model to a series of hypothetical earthquakes to analyze, first, expected fatalities and, second, the size of the affected area in relation to seismic magnitude, population density, and construction type.

In Chapter 4, we applied the model to 17 significant earthquakes between the dates 1962 and 1985. Through this series of case studies, we established estimation schemes for 9 different countries. Included were Iran, Nicaragua, Guatemala, China, Algeria, Italy, Chile, El Salvador, and Turkey.

In Chapter 5, the results obtained in Chapter 4 were analyzed statistically in comparison with reported death tolls to examine the accuracy of the calculation results. We observed that the estimation error was within the range between, approximately, one-half and twice at the confidential level of 70 percent.

In Chapter 6, we discussed the applicability of the model and the future development toward enhancing it. We mentioned its future development from the view point of, first, improvement of algorithm; second, development of regional database; third, introduction of an on-site monitoring system for ground shaking.

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REFERENCES

Alexander, D., 1985, Deaths and injury in earthquakes, Disasters, Vol.9, No.1, pp.57-60.

Ambraseys, N.N., A.A. Moinfar, and J.S. Tchalenko, 1972, Ghir earthquake of 10 April 1972, Serial No.2789/RMO.RD/SCE, UNESCO, Paris, France, 102pp.

Ambraseys, N.N. and J.S. Tchalenko, 1969, General Field Report, Dasht-e-Bayaz earthquake of 31 August 1968, Serial No.1214/BMS.RD/SCE, UNESCO, Paris, France, pp.1-37.

Anderson, R.W., 1987, The San Salvador earthquake of October 10, 1986 - Review of building damage, Earthquake Spectra, Vol.3, No.3, pp.497-541.

Astroza, M. and J. Monge, 1988, Effects of geology and soil on damage in central Chile earthquake of March 3, 1985, Proceedings of Ninth World Conference on Earthquake Engineering, August 2-9, 1988, Tokyo-Kyoto, Japan, Vol.VIII, pp.943-948.

Bates, F.L., W.T. Farrell, and J.K. Glittenberg, Undated, Changes in Housing Characteristics in Seventeen Guatemala Communities Following the Earthquake of 1976, Substantive Report #2, Guatemalan Earthquake Study, 93pp.

Bommer, J., 1987, The San Salvador earthquake of 10th October 1986, Disasters, Vol.11, No.2, pp.83-95.

Booth, E., 1985, The Chile earthquake of March 1985, Disasters, Vol.9, No.3, pp.190-196.

Chandra, U., 1979, Attenuation of intensities in the United States, Bulletin of the Seismological Society of America, Vol.69, No.6, pp.2003-2024.

Chandra, U., J.G. McWhorter, and A.A. Nowroozi, 1979, Attenuation of intensities in Iran, Bulletin of Seismological Society of America, Vol.69, No.1, 237-250.

Coburn, A.W., A. Pomonis, and S. Sakai, 1989, Assessing strategies to reduce fatalities in earthquakes, Proceedings of International Workshop on Earthquake Injury Epidemiology for Mitigation and Response, July 10-12, 1989, Baltimore, Maryland, pp.P107-P132.

Coultrip, R.L., 1974, Medical aspects of US disaster relief operations in Nicaragua, Military Medicine, November, 1974, pp.879-883.

de Bruycker, M., D. Greco, I. Annino, M.A. Stazi, N. de Ruggiero, M. Triassi, Y.P. Kettenis, and M.F. Lechat, 1983, The 1980 earthquake in southern Italy: Rescue of trapped victims and mortality, Bulletin of the World Health Organization, Vol.61, No.6, pp.1021-1025.

de Ville de Goyte and E. Jeannee, 1977, Earthquake in Guatemala: Epidemiological evaluation of the relief effort, Emergency Planning Digest, Vol.4, No.1, pp.2-8.

de Ville de Goyte, E. del Cid, A. Romero, E. Jeannee, and M. Lechat, 1976, Earthquake in Guatemala: Epidemiological evaluation of the relief effort, Bulletin of the Pan American Health Organization, Vol.X, No.2, pp.95-109.

Duke, C.M., 1973, Impact of Managua earthquake on earthquake engineering, Managua, Nicaragua Earthquake of December 23, 1972 (Earthquake Engineering Research Institute Conference Proceedings, November 29 and 30, 1973, San Francisco, California), Volume I, pp.1-7.

Durkin, M.E., 1987, The San Salvador earthquake of October 10, 1986 - Casualties, search and rescue, and response of the health care system, Earthquake Spectra, Vol.3, No.3, pp.621- 634.

Earthquake Engineering Research Institute, 1986, The Chile Earthquake of March 3, 1985, Earthquake Spectra, Vol.2, No.2, 513pp.

Evaluation Technologies, Inc., 1981, Nicaragua: A Country Profile (Prepared for the Office of U.S. Foreign Disaster Assistance, Agency for International Development, Department of State), Arlington, Virginia, 73pp.

Evaluation Technologies, Inc., 1981, Latin American Housing Survey for Disaster Relief and Preparedness, (Prepared for the Office of U.S. Foreign Disaster Assistance, Agency for International Development, Department of State), Arlington, Virginia, 141pp.

Evaluation Technologies, Inc., 1982, Guatemala: A Country Profile, (Prepared for the Office of U.S. Foreign Disaster Assistance, Agency for International Development, Department of State), Arlington, Virginia, 74pp.

Evaluation Technologies, Inc., 1984, El Salvador: A Country Profile, (Prepared for the Office of U.S. Foreign Disaster Assistance, Agency for International Development, Department of State), Arlington, Virginia, 62pp.

Evaluation Technologies, Inc., 1987, Chile: A Country Profile, (Prepared for the Office of U.S. Foreign Disaster Assistance, Agency for International Development, Department of State), Arlington, Virginia, 99pp.

Faccioli, E., E. Santoyo V., and J.L. Leon T., 1973, Microzonation criteria and seismic response studies, Managua, Nicaragua Earthquake of December 13, 1972 (Earthquake Engineering Research Institute Conference Proceedings, November 29 and 30, 1973, San Francisco, California), Vol.I, pp.271-291.

Glass, R.I., J.J. Urrutia, S. Sibony, H. Smith, B. Garcia, and L. Rizzo, 1977, Earthquake Injuries Related to Housing in Guatemalan Village, Science, Vol.197 pp.638-643.

Gutenberg, B. and C.F. Richter, 1956, Earthquake magnitude, intensity, energy and acceleration (Second paper), Bulletin of the Seismological Society of America, Vol.46, pp.105-145.

Hansen, A.F. and V.M. Chavez, 1973, Isoseismal maps of the Managua December 23, 1972 earthquake, Managua, Nicaragua Earthquake of December 23, 1972 (Earthquake Engineering Research Institute Conference Proceedings, November 29 and 30, 1973, San Francisco, California) Vol.1, pp.104-114.

INTERTECT, 1986, Assessment Report: Estimated Damage on the Housing Sector Caused by the October 1986 San Salvador Earthquake and Suggested Reconstruction Strategies (Prepared for the Office of U.S. Foreign Disaster Assistance, Agency for International Development, Department of State), Dallas, Texas, 26pp.

Jennings, P.C. (Editor), 1980, Report on the Tangshan earthquake, Earthquake Engineering and Hazard Reduction in China, CSCPRC Report No.8, National Academy of Science, Washington, D.C., pp.69-133.

Karnik, V., 1965, Magnitude-intensity relations for European and Mediterranean seismic regions, Studia Geoph. et Geod., Vol.9, pp.236-249.

Knudson, C.F. and A.F. Hansen, 1973, Accelerograph and seismoscope records from Managua, Nicaragua earthquake, Managua, Nicaragua Earthquake of December 23, 1972 (Earthquake Engineering Research Institute Conference Proceedings, November 29 and 30, 1973, San Francisco), Vol.I, 180-205.

Krimgold, F., 1988, Search and rescue in collapsed reinforced concrete buildings, Proceedings of Ninth World Conference on Earthquake Engineering, August 2-9, 1988, Tokyo-Kyoto, Japan, Vol.VII, pp.693-696.

Lala, M.A., 1987, The San Salvador earthquake of October 10, 1986 - Detailed evaluation of the performance of eight engineered structures, Earthquake Spectra, Vol.3, No.3, pp.543-562.

Lechat, M.F., 1979, Disasters and public health, Bulletin of the World Health Organization, Vol.57, No.1, 11-17.

Leeds, A. (Editor), 1983, El-Asnam, Algeria Earthquake, October 10, 1980, A Reconnaissance and Engineering Report, National Research Council and Earthquake Engineering Research Institute, 193pp.

Moriya, K., 1989, The Spitak Earthquake in Armenia <7 Dec. 1988>, Tokyo, Japan, 53pp.

Nakano, T., T. Mochizuki, and T. Mizutani, 1987, The application of research findings to disaster preparedness, planning and management, International Research and Training Seminar on Regional Development Planning for Disaster Prevention, October 13-23, 1987, Tokyo and Nagoya, Japan, United Nations Center for Regional Development, Paper No.2, 15pp.

Ohashi, H. and Y. Ohta, 1983, Distribution characteristics of structural damage and casualty at several recent earthquakes in Turkey and its factor analysis, A Comprehensive Study on Earthquake Disasters in Turkey in View of Seismic Risk Reduction, Hokkaido University, Sapporo, Japan, pp.131-166.

Ohashi, H., Y. Ohta, O. Ergunay, and A. Tabban, 1983, Empirical derivation of seismic intensity distribution laws based upon earthquake data in Turkey, A Comprehensive Study on Earthquake Disasters in Turkey in View of Seismic Risk Reduction, Hokkaido University, Sapporo, Japan, 167-202.

Ohta, Y., H. Ohashi, and A. Tabban, 1983, Macro statistical analysis on earthquake damage in Turkey, A Comprehensive Study on Earthquake Disasters in Turkey in View of Seismic Risk Reduction, Hokkaido University, Sapporo, Japan, 5-21.

Ortiz, M.R., M.R. Roman, A.V. Latorre, and J.Z. Soto, 1986, Brief description of the effects on health of the earthquake of 3rd March 1985 - Chile, Disasters. Vol.10, No.2, pp125-140.

Penalba, C.U., 1981, A review of the seismic behavior of earthen housing in Nicaragua, Proceedings of International Workshop: Earthen Buildings in Seismic Areas, May 24-28, 1981, Albuquerque, New Mexico, Vol.I, pp.312-333.

Pereira h., E. and P.J. Creegan, 1973, Statistical damage reports - Managua, Related to seismic events of 12/23/72, Managua, Nicaragua Earthquake of December 23, 1972 (Earthquake Engineering Research Institute Conference Proceedings, November 29 and 30, San Francisco, California), Vol.I, pp.733-745.

Rymer, M.J., 1987, The San Salvador earthquake of October 10, 1986 - Geologic aspects, Earthquake Spectra, Vol.3, No.3, pp.435-463.

Saidi, F., 1963, The 1962 earthquake in Iran, Some medical and social aspects, The New England Journal of Medicine, Vol.268, No.17, pp.929-932.

Sheng, Y-Z., 1987, Medical support in the Tangshan earthquake: A review of the management of mass casualties and certain major injuries, The Journal of Trauma, Vol.27, No.10, pp.1130-1135.

Shiono, K. and F. Krimgold, 1989, A computer model for the recovery of trapped people in a collapsed building: Development of a theoretical framework and direction for future data collection, Proceedings of International Workshop on Earthquake Injury Epidemiology for Mitigation and Response, July 10-12, 1989, Baltimore, Maryland, USA, pp.P260-P280.

Stratta, J.L., L.E. Escalante, E.L. Krintzsky, and U. Morelli, 1981, Earthquake in Campania-Basilicata, Italy, November 23, 1980, A Reconnaissance Report, National Academy Press, Washington, D.C., 100pp.

Teran, J.F., 1973, Historical context of building forms in Managua, Managua, Nicaragua Earthquake of December 23, 1972 (Earthquake Engineering Research Institute Conference Proceedings, November 29-30, 1973, San Francisco, California), Vol.I, pp.313-341.

White, R.A., D.H. Harlow, and S. Alvarez, 1987, The San Salvador earthquake of October 10, 1986 - Seismological aspects and other recent local seismicity, Earthquake Spectra, Vol.3, No.3, pp.419-434.

Whittaker, R., D. Fareed, P. Green, P. Barry, A. Borge, and R. Fletes-Barros, 1974, Earthquake disaster in Nicaragua: Reflections on the initial management of massive casualties, The Journal of Trauma, Vol.14, No.1, pp.37-43.

Ye, Y. and X. Liu, 1980, Experience in engineering from earthquake in Tangshan and urban control of earthquake disaster, The 1976 Tangshan, China Earthquake, Papers Presented at the 2nd U.S. National Conference on Earthquake Engineering Research Institute, Berkeley, California, pp.9-32.

震災時救急活動支援のための人的被害の即時推定

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要　約

地震の発生後、当該地震に関する2つの情報（マグニチュードと震央位置）を入力情報とし、被災域に関する3つの地域情報（人口密度、建物種別、地盤の増幅特性）を媒介として、死者の発生（数、分布）を即時的に推定する方法を開発した。この開発のねらいは、救急活動の初動時における被害情報の欠如を、確度の高い推定によって補い、被害調査の対象域や対策資源の投入量を決定するための補助手段を提供することにある。

推定のための地震情報には、発震後、ただちに掌握できるものだけを使うこととし、これによって推定の即時性を実現した。また、当該地震の地震情報を入力とすることにより、確度の高い推定を可能にした。被災域に関する地域情報には、比較的入手しやすいものだけを選び、方法の適用性を高めた。

この研究では、既存の知識を利用し、人的被害の震後即時推定手法をプロトタイプのレベルで実現することを目標とした。コンピュータ・モデルの構築には、以下のような既存の知識（関係式）を用いた：マグニチュードと震央震度の関係、震度の距離減衰式、建物の脆弱性関数、建物倒壊率と死者発生率の関係。

開発したコンピュータ・モデルを、1962年から1986年の間に発生した17の地震に適用し、推定精度を検討した。死者数の推定値と記録の対応は良好であり、推定値の範囲（70％の信頼区間）は、記録の1／2から2倍程度であることが明らかになった。

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