ASSESSMENT MODELS FOR EARTHQUAKE FATALITIES AND AN INTERPRETATION OF THE DEATHS IN THE 1999 KOCAELI, TURKEY, EARTHQUAKE[1]

by

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ABSTRACT

Two models for estimating earthquake fatalities were developed on the basis of existing knowledge in seismology, earthquake engineering, and natural disaster sciences. Those were designed so that disasters in the wide range of built environment are coherently examined with a limited range of input information. The performance accuracy of the models was examined and confirmed acceptable. One of the two models was applied to the discussion on the nature of the fatalities in the Kocaeli earthquake. It was pointed out that the enhancement of structural quality of multi-story apartment buildings is crucial toward the reduction of human losses in future earthquakes.

KEY WORDS: Earthquake Disaster
Damage Estimation
Mortality
Kocaeli Earthquake

1. INTRODUCTION

It is easy to understand that earthquake casualties depend on: 1) earthquake, 2) building collapse, and 3) affected population. Even non-professional people can tell that more victims are killed if an earthquake is more violent; if more buildings collapse; and if more people stay in a building.

Quantitative evaluation of earthquake fatalities, however, has seldom been attempted despite its significance in discussion toward the reduction of human casualties. Though not a few methods for correlating building damage to human losses were developed, those applicability was rather limited. Those were useful only in areas having the same built environment, which is characterized mainly by the construction type of local buildings.

Mass casualty in earthquakes is a serious issue from the viewpoint of global disaster management. With relation to the issue, it is crucial to have an estimation model that can coherently handle disasters in areas with different built environment.

In the first half of this paper, two models for estimating earthquake fatalities, which require only a limited range of input information, but applicable to disasters in the wide range of built environment were developed. In the last half, one of the two models was applied to the discussion on the nature of the fatality in the M7.4 Kocaeli, Turkey, earthquake of August 17, 1999.

2. TWO MODELS

Two models as follows were developed in this study:

1) Distribution model
2) Point model.

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The most significant difference between the two models is found in the method for giving seismic information. It was given by the spatial distribution of seismic intensity in the distribution model, while it was given by a single parameter of the earthquake magnitude in the point model. The point model did not include the spatial variation of seismic intensity in an explicit manner, but one of the relationships used in the model included the attenuation of seismic intensity.

In the point model, population density was given as that for the entire affected area. Building information was given as dominant construction types chosen from a nine-category classification. The classification was done based on the type of principal load-bearing elements and wall material. Detailed explanation is seen in the following section.

The point model is simple, because it was given as a single formula. Only substitution of three independent variables into the formula is required for deriving an estimate. A flaw in the point model lies in the exclusion of spatial relationship, or distance, between an epicenter and affected areas. However, this does not reduce the model's applicability, because most earthquake disasters are attributed to earthquake faults located near affected areas.

In the distribution model, earthquake information was given by the spatial distribution of seismic intensity. The spatial distribution of population density can be included if necessary. Building types were assigned from the nine-category classification, as was done in the point model, and their spatial distribution can be included if necessary. Numerical procedure in the distribution model is more precise in comparison with that in the point model. The numerical procedure in the distribution model, which requires a small computer program, is a little more complicated than that in the point model.

Characteristics of the two estimation models are compared in Table 1.

Only the general ideas for constructing the models and the performance accuracy of the models are described in this paper. Results of case studies for verifying the models are seen in Shiono et al. (1991).

3. DISTRIBUTION MODEL

(1) Structure

Figure 1 shows the flow of calculation in the distribution model. Figure 2 is schematic presentation of the numerical procedure in the distribution model.

Input information was composed of two parts:

1) Earthquake information
2) Regional information.

Earthquake information includes:

1) Surface wave magnitude
2) Epicentral location.

Regional information consists of:

1) Population density
2) Building type (s)
3) Site condition in terms of increment in seismic intensity.

Geographical area in which the three regional data assigned must be coincide with an affected area. Spatial distribution of regional data and a combination of dominant construction types can be included if necessary.

A nine-category classification representing worldwide construction types consists of:

1) Field stone
2) Adobe
3) Cut stone
4) Brick
5) Wood frame with thin infill walls
6) Wood frame with thick infill walls
7) Wood
8) Poor-quality reinforced concrete
9) Good-quality reinforced concrete.

Buildings of field stone and adobe correspond to structures classified in Category A of the MSK seismic intensity scale. Buildings of cut stone, brick, and wood frame with infill walls, or half timbered structures, are in Category B. Buildings of wood and good-quality reinforced concrete are in Category C. Buildings of poor-quality reinforced concrete need further discussion to be classified in an appropriate category.

Relationships, or knowledge, used in the distribution model were as follows:

1) Epicentral seismic intensity versus magnitude
2) Attenuation of seismic intensity with distance (Attenuation function)
3) Structural vulnerability of each construction type versus seismic intensity
4) Fatality rate (deaths/population) in each construction type versus collapse rate.

Distribution of seismic intensity was determined from: 1) magnitude versus epicentral intensity relationship, such as Karnik (1965), and 2) an attenuation function, such as Chandra (1979). A simplified approximation of the circular distribution of seismic intensity was employed in this study.

A vulnerability function, which is given as a relationship between seismic intensity and damage extent sustained by a single building, was defined for each construction type, and a set of nine collapse rate functions was generated to represent the total of construction types (Figure 3). Detailed explanation of the procedure for deriving collapse rate functions from vulnerability functions is found in Shiono et al. (1991).

Fatality rare functions were determined based on published survey results, such as Coburn et al. (1989). A set of three functions shown in Figure 4 was used in this study.

(2) Performance

Data from numerous past earthquakes exist to examine performance accuracy of the estimation model. Data were collected from 16 earthquakes (1962-1986) listed in Table 3. In collecting data, any criteria for selecting events was used, so that a performance test can be done with as many data as possible. However, several earthquakes in which damage was limited to sites distant from the epicentral regions, such as the Rumanian earthquake of 1977 and the Mexican earthquake of 1985 were excluded. For these disasters, a simplified approximation of the circular distribution of seismic intensity, which was used in this development, is no longer appropriate.

Death tolls calculated in the distributed model were plotted in Figure 5 in comparison with reported fatalities. A correlation coefficient of 0.84 was obtained between the estimated and reported death tolls for the entire (16) events, and that of 0.90 was obtained for the 13 events in which more than 1,000 lives were lost.

4. POINT MODEL

A simplified method, where spatial variation of seismic intensity was not explicitly included, was constructed and named the point model. A relationship derived from the distribution model, which implicitly includes the attenuation of seismic intensity, was used in the point model. In handling of the point model, programming in computers was not required. Only substitution of three variables, which respectively represent earthquake, building, and demographic characteristics of a disaster, into a single formula was necessary.

Input data to the point model were:

1) Surface wave magnitude
2) Dominant construction type (s) of local buildings
3) Population density (whole disaster area).

Among the three variables, magnitude was chosen as the principal variable, and the relationships between magnitude and fatalities was analyzed. Other two variables representing buildings and population were used as correction factors.

Figure 6 shows the relationship between magnitude and crude death tolls for the earthquake disasters listed in Table 3. Positive correlation between the two variables are seen, but the plots considerably scattered with a correlation coefficient of 0.46. Logarithms of death toll were used in the calculation of correlation coefficients.

Figure 7 illustrates how magnitude correlates with death tolls when death tolls were adjusted on an assumption that population densities of disaster areas are identical at 38 persons per sq-km. A population density of 38 persons per sq-km was given as the global average of population density. Scattering of the plots reduced, and the correlation coefficient increased up to 0.68.

The relationship between magnitude and deaths calculated in the distribution model is shown in Figure 8. In the calculation for deriving this chart, population density was given at 100 persons per sq-km. Relationships were essentially straight lines, and the lines were nearly parallel to each other. In view of these characteristics, ratios among the fatality rates in various construction types can be admitted constant irrespective of earthquake magnitude. The ratios were determined in Figure 8, and the results are shown in Table 3.

Figure 9 shows how magnitude correlates with fatalities when those were normalized by population density and corrected by construction type. The ratios shown in Table 3 were used for including the difference in vulnerability and lethality among the construction types. Scattering of the plots further reduced, and a correlation coefficient as high as 0.79 was obtained. A correlation coefficient of 0.48 was obtained when only correction by construction type took place, suggesting the significance of simultaneous inclusion of population and building characteristics.

From the regression line derived in Figure 9 with the ratios shown Table 3, the following formula was obtained:

$$D=(2.57 \text{ X } 10^{-6}) \text{ X } \exp(2.93M) \text{ X } (p/38)$$

$$\text{X} \left(\begin{array}{ll} 2.2 & \text{(Field stone, Adobe)} \\ 1.0 & \text{(Brick, Cut stone)} \\ 0.33 & \text{(Low-quality reinforced} \\ & \qquad \text{concrete)} \\ 0.12 & \text{(Wood frame with thick} \\ & \qquad \text{infill masonry walls)} \\ 0.026 & \text{(Wood frame with thin} \\ & \qquad \text{infill masonry walls)} \\ 0.0017 & \text{(Wood)} \end{array} \right) \qquad \cdot\cdot\cdot (1)$$

where,

D: deaths
M: magnitude (Ms)
p: population density of an affected area.

This equation can be applied to disaster areas having two or more dominant construction types. In that case, population density is given for each construction type, as total occupancies in residential buildings of each construction type.

Death tolls calculated in the two models were plotted in Figure 10 in comparison with reported tolls. Relative accuracy of the estimates obtained in the two models can be compared. Correlation coefficients between reported and estimated death tolls were obtained at 0.73 in the point model and at 0.84 in the distribution model, respectively. In the regard of performance accuracy, the point model is almost equal to the distribution model.

5. DEATHS IN THE KOCAELI EARTHQUAKE

The Kocaeli earthquake (M7.4) occurred on August 17, 1999 in the northwestern part of Turkey, and the death toll announced on September 13 was 15,480.

Post-event fatality estimation was done with the point model (Eq. (1)).

Following assumptions were made in the estimation:

1) Brick, half-timber (wood frame with thick infill walls), and poor-quality reinforced concrete were the dominant construction types in the affected area.
2) Brick and half-timber were structural types for single-family houses, while reinforced concrete was that for multi-story apartment buildings.
3) Ten families reside in an apartment building.

With assumed regional data shown in Figure 11 and Table 4, Equation (1) gave an estimated death toll of 15,380. The estimate was acceptable, though further investigation on the regional characteristics is indispensable.

A few additional cases were examined with equation (1), and the result is shown in Figure 12.

The cases represent a probable scenario of future transition in building type accompanying with regional development. The scenario includes, first, the rapid influx of population into industrializing areas, among which is the Kocaeli area severely damaged in the 1999 earthquake, and, second, increased demand for high-occupancy residential buildings, which are supplied as multi-story apartment buildings of reinforced concrete.

In comparison with a population density of 227 persons per sq-km on Stage 0, which represents the 1999 situation, that on Stage 3 is as high as 454 persons per sq-km. The increase in population results in that in the number of multi-story apartment buildings from 30% on Stage 0 to 60% on Stage 3. Increased death tolls on the later stages are attributed to the structural vulnerability in high-occupancy residential buildings of reinforced concrete.

6. CONCLUSIONS

Two models for estimating deaths in the wide range of built environment affected by any given earthquake were constructed. Those are simple and useful requiring a limited range of input information consisting of earthquake, building, and demographic data. Among the two models, one was named the distribution model, and the other the point model. The distribution model includes the spatial variation of input data, while the point model does not. Their performance accuracy was examined and proved acceptable, though the point model was sightly less accurate than the distribution model.

The point model was employed in the post-event estimation of the deaths in the 1999 Kocaeli earthquake. Remarkable agreement between the estimate and the official announcement was obtained, though the building information, or predominant construction types, was rather intuitive.

Death tolls in probable future circumstances of the Kocaeli area due to hypothetical recurrences of the 1999 earthquake were estimated in the point model. Estimated death tolls increase with the progress of regional development accompanied by population influx and increased demand for high-occupancy residential buildings. Structural quality management of high-occupancy residential buildings, or multi-story apartment buildings of reinforced concrete, is crucial toward life safety in future earthquakes.

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Table 1: Comparison of input data between fatality estimation models

Model	Category of Data			Procedure
	Earthquake	Building Type	Population Density	
Point Model	Magnitude	Predominant Types*	Average for the Whole Disaster Area	Formula
Distribution Model	Seismic Intensity Distribution**	Predominant Types*	Spatial Distribution	Small Program for Personal Computers

* Assigned from a nine-category classification (see the following section).

** Intensity distribution is given based on earthquake magnitude, epicentral distance, and site amplification.

Table 2: Earthquake disasters of which data were used in the verification of the model

	Affected Country	Year	M	Fatalities
1	Iran	1962	7+1/4	12,000 - 15,000
2	Turkey	1966	6.5	2,394
3	Turkey	1967	7.5	89
4	Iran	1968	7.3	7,000 - 10,000
5	Turkey	1970	7.1	1,086
6	Turkey	1971	6.0	57
7	Turkey	1971	6.7	878
8	Iran	1972	7.1	5,000
9	Nicaragua	1972	6.6	5,000 - 11,000+
10	Turkey	1975	6.7	2,385
11	Guatemala	1976	7.5	22,778
12	China	1976	7.8	242,419
13	Turkey	1976	7.4	3,840
14	Algeria	1980	7.3	2,263
15	Italy	1980	6.8	2,735 - 4,689
16	El Salvador	1986	5.4	1,500

Table 3: Ratio of fatality rate in various construction types to that in brick buildings

Building Type	Ratio of Fatality Rate*
Field stone, Adobe	2.2
Brick, Cut stone	1.0
Poor-quality reinforced concrete	0.33
Wood frame with thick infill walls	0.12
Wood frame with thin infill walls	0.026
Wood	0.0017

* Fatality rate in brick building is used as the standard.

Table 4: Assumed built and demographic environment of the Kocaeli area

Construction Type	Relative Number of Buildings	Relative Number of Occupants*	Population Density
Brick	40%	10.1%	24.5
Half-Timber	30%	8.1%	18.4
Poor-Quality RC	30%	81.8%	184.1
Total	100%	100%	227**

* Ten (10) was assumed as the number of families residing in a reinforced concrete apartment building.

** The population density of the affected area was given at 227 persons per sq-km, which is the population density of Kocaeli Province.

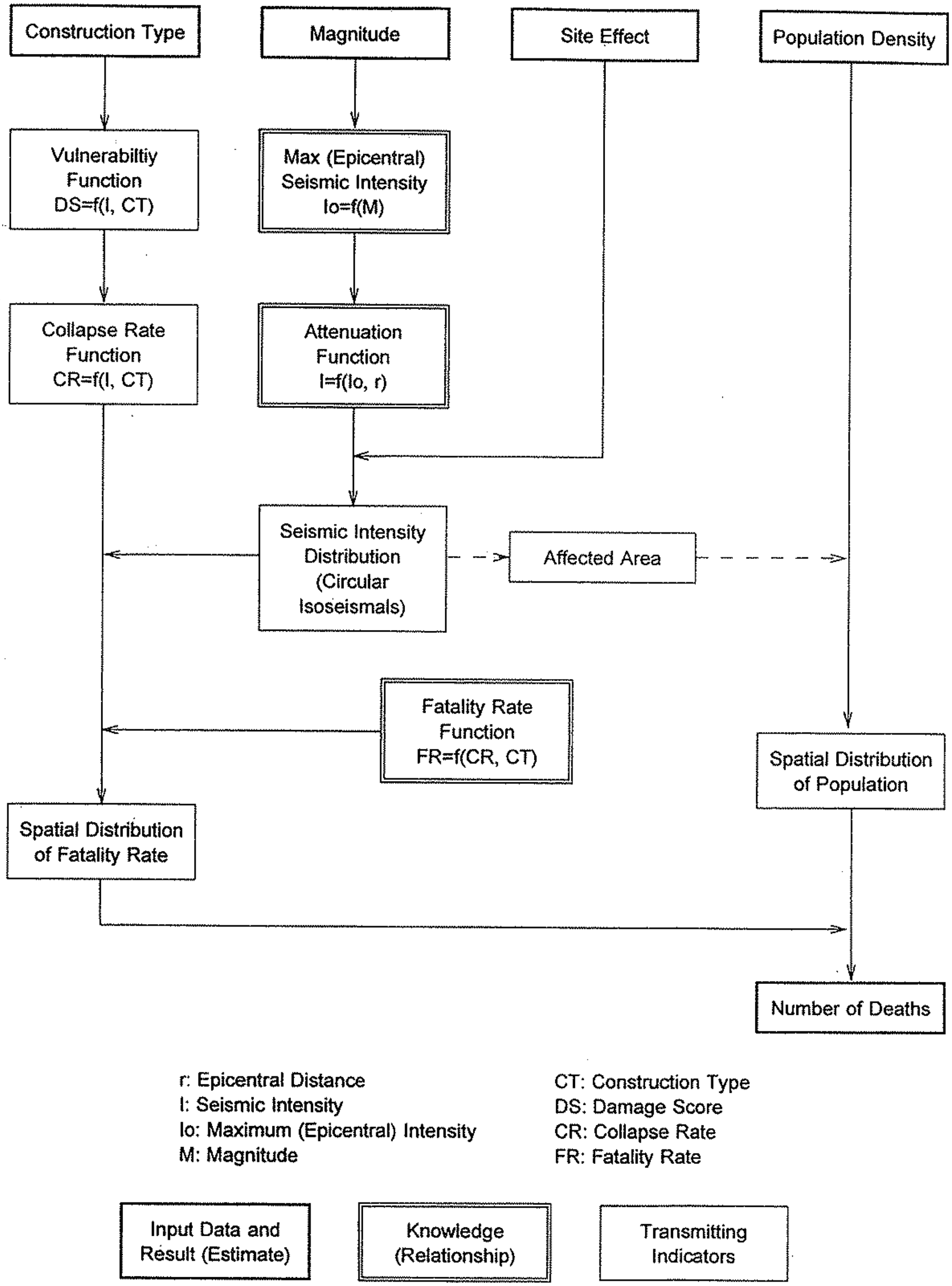

Figure 1: Flow of fatality estimation in the distribution model.

$$D=\int_{\theta}\int_{r} f(\rho\cdot V(I))\,d\,r\,d\,\theta$$

D : Total deaths
f : Deaths / sq-km
I : Seismic intensity
V : Collapse rate of buildings
ρ : Population density

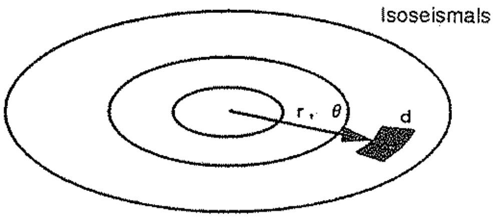

Figure 2: Schematic presentation of fatality estimation in the distribution model.

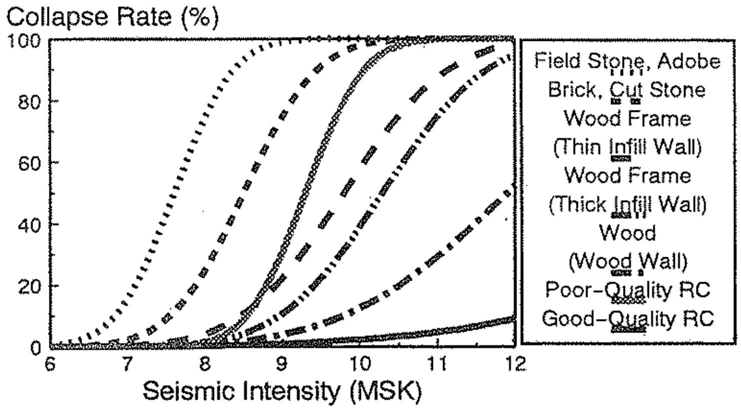

Figure 3: Collapse rate functions.

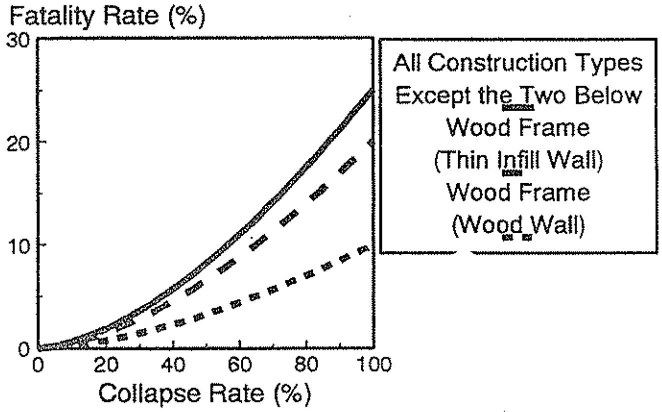

Figure 4: Fatality rate functions.

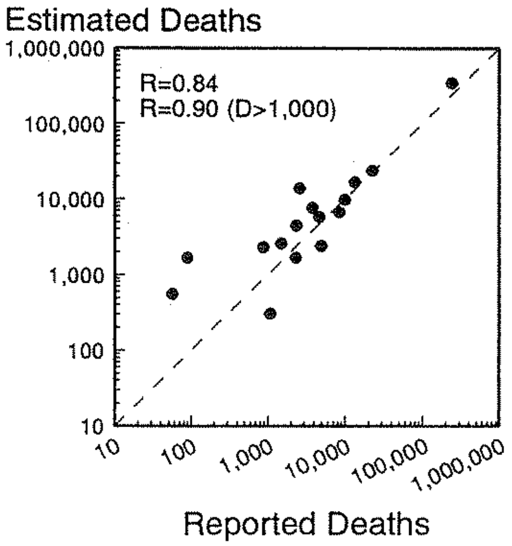

Figure 5: Comparison between reported and estimated death tolls.

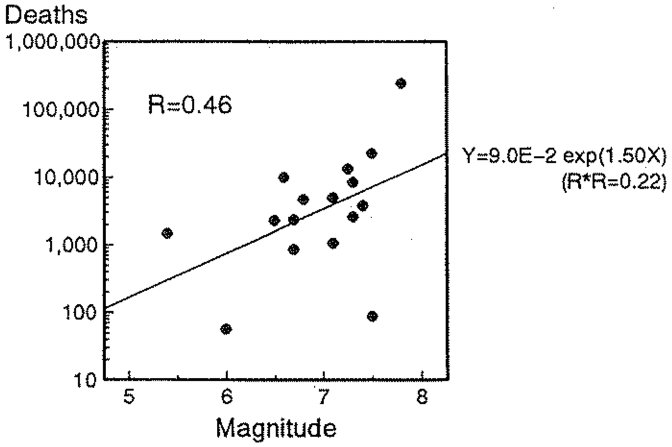

Figure 6: Relationship between earthquake magnitude and fatalities; Crude death tolls are plotted.

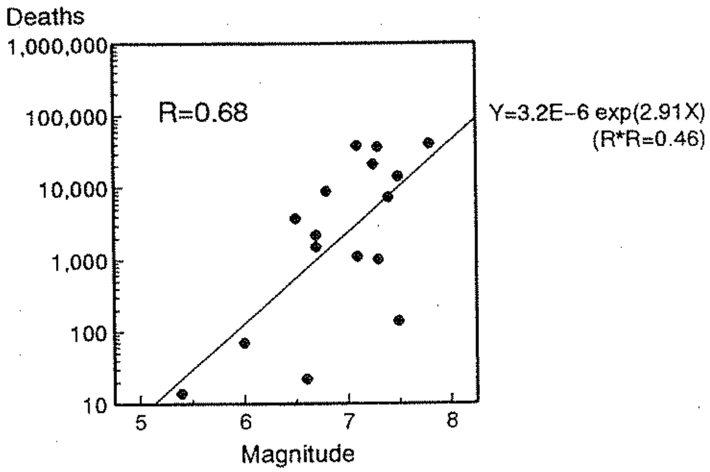

Figure 7: Relationship between earthquake magnitude and fatalities; Death tolls are normalized by the global population density.

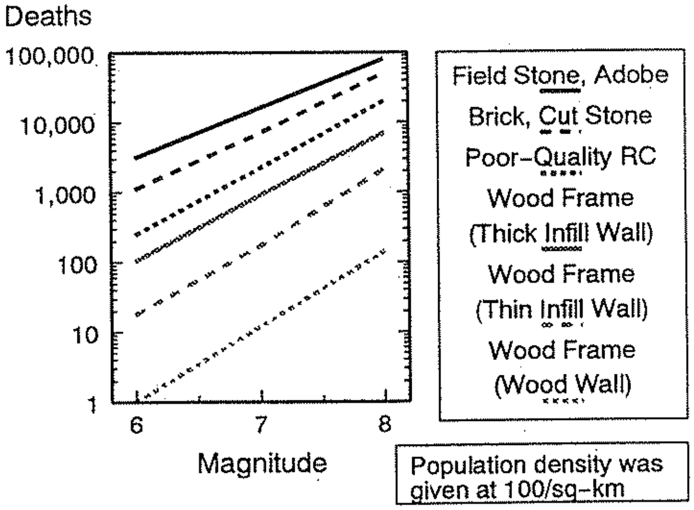

Figure 8: Relationship between earthquake magnitude and fatalities; Population density is normalized at 100 persons per sq-km.

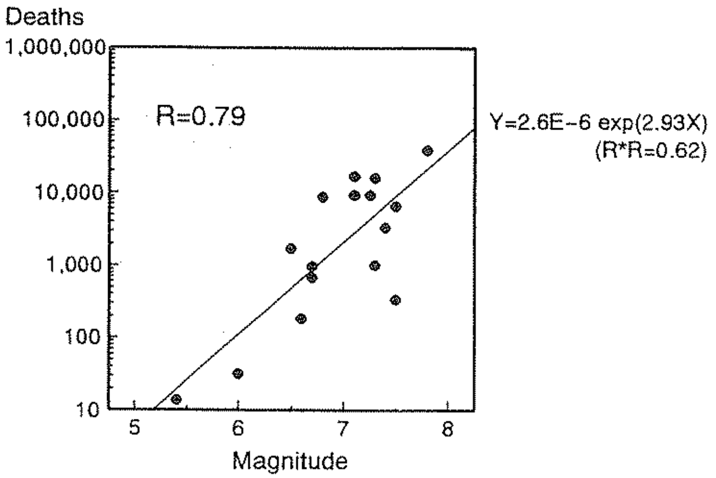

Figure 9: Relationship between earthquake magnitude and fatalities;
Death tolls were normalized by population density and corrected by building type.

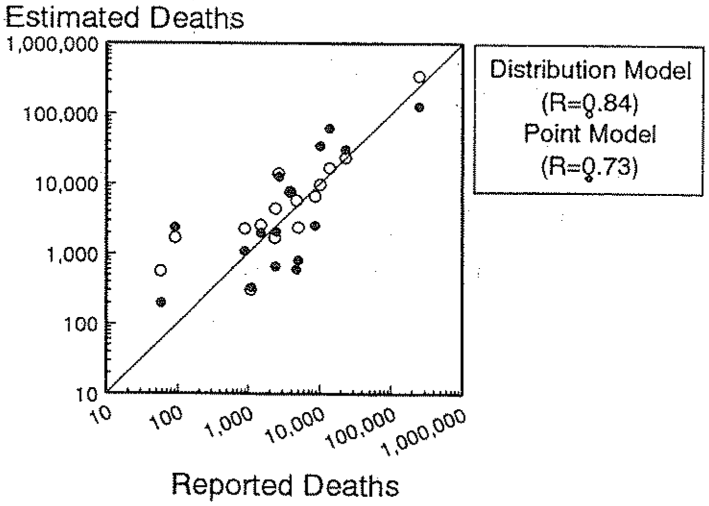

Figure 10: Comparison between recorded and estimated death tolls;
Death tolls estimated in the two models can be compared.

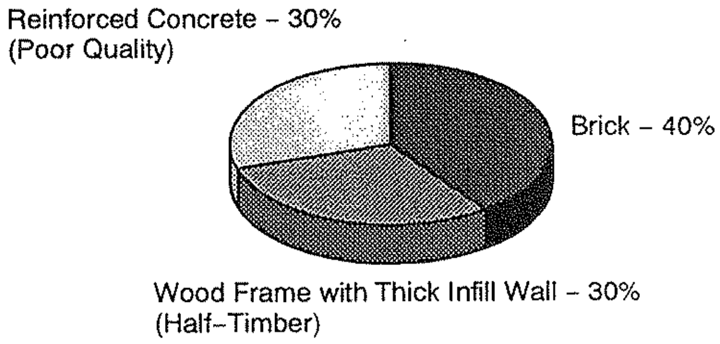

Figure 11: Relative number of buildings by construction type in the affected area of the Kocaeli earthquake.

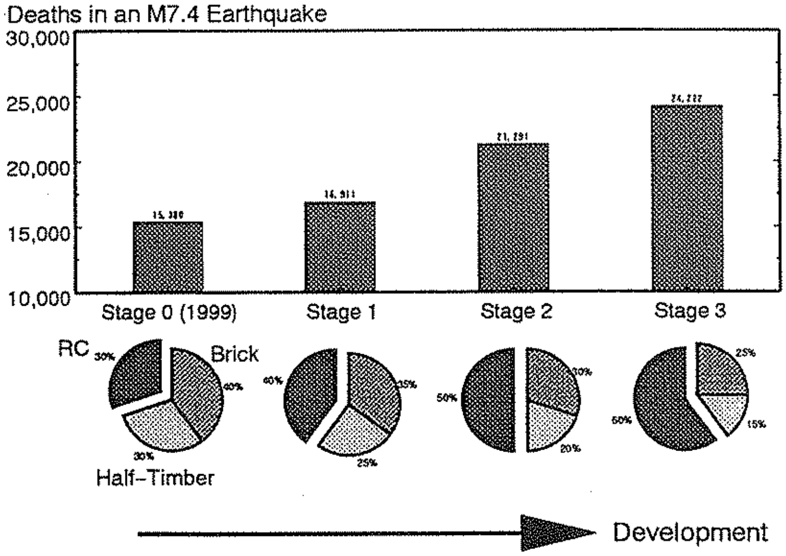

Figure 12: Increase in expected deaths with the progress of regional development.