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Probabilistic Assessment of Earthquake Insurance Rates for Turkey

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Abstract. A probabilistic model is presented to obtain a realistic estimate of earthquake insurance rates for reinforced concrete buildings in Turkey. The model integrates information on seismic hazard and information on expected earthquake damage on engineering facilities in a systematic way, yielding to estimates of earthquake insurance premiums. In order to demonstrate the application of the proposed probabilistic method, earthquake insurance rates are computed for reinforced concrete buildings constructed in five cities located in different seismic zones of Turkey. The resulting rates are compared with the rates currently charged by the insurance companies. The earthquake insurance rates are observed to be sensitive to the assumptions on seismic hazard and damage probability matrices and to increase significantly with increasing violation of the code requirements.

Key words: seismic hazard, earthquake engineering, earthquake insurance, building damage, damage probability matrix, risk premium, insurance premium

1. Introduction

Turkey is located in one of the seismically most active regions of the world. Geological and seismological data indicate that in almost all parts of Turkey seismic hazard is significant: 95% of the population, 92% of the total area and 98% of the industry are under earthquake threat (Gencoglu *et al.*, 1996). To reduce the vulnerability of human settlements and industrial facilities, the engineered structures must be designed and constructed to resist the effects of earthquakes. However, due to poor control of construction in Turkey, a large degree of damage is expected if a major earthquake hits a large city, as observed during the recent earthquakes. Accordingly, different measures have to be considered to alleviate the post-disaster consequences of earthquakes as well as enforcement of the earthquake resistant provisions of the Code. The implementation of obligatory earthquake insurance is among such measures.

In Turkey, the State used to have a legal obligation to fund the costs of reconstructing buildings after an earthquake. This responsibility of the State naturally brought an unplanned burden on the national economy and on the already limited central budget in the case of catastrophic seismic events. The two recent major earthquakes in Turkey on 17 August and 12 November 1999 both occurred in or near urban settlements and caused widespread destruction of the building stock. This activated the idea of a nationwide obligatory earthquake insurance enforcement, which was first put forward in 1978 by the Ministry of Reconstruction and Settlement. At that time the Earthquake Engineering Research Institute, Middle East Technical University (EERI/METU), through a project sponsored by the same Ministry, investigated the feasibility of an obligatory insurance model (Gurpinar *et al.*, 1978; Gurpinar and Yucemen, 1980). The obligatory insurance model considered by EERI/METU aimed to serve for a number of purposes, which may be listed as: control and therefore improvement of construction practices in seismic regions, decrease of time loss due to the interruption of services, accumulation of funds for reconstruction and resettlement. The fact that the first purpose was included is due to the peculiar control mechanism in Turkey, which may to some extent be generalized to other developing countries. As control of construction is implemented unsatisfactorily, it is expected that the earthquake insurance may constitute a complementary control mechanism, based on the conflict of economic interests on the part of the insurer and the insured.

After the two major earthquakes in 1999, the Government of Turkey has decided to enforce the earthquake insurance on the nationwide basis with the sole purpose of privatizing the potential risk by offering insurance via the Turkish Catastrophic Insurance Pool (TCIP) and then exporting the major part of this risk to the international reinsurance and capital markets (Bommer *et al.*, 2002). Although the main aim was to reduce government's fiscal exposure, it was also intended to encourage risk mitigation and safer construction practices. To achieve these purposes all registered residential dwellings, the total number being about 13 million, are required to be in the compulsory earthquake insurance coverage. Initially funded by the World Bank, the TCIP program became effective as of March 2001. In spite of its compulsory nature, TCIP policy count was about two million as of September 2004, corresponding only to 15.3% of the total property owners. The highest insured percentage was observed in the Marmara region (24.80%), where the two major earthquakes in 1999 caused the highest damage (www.dask.gov.tr). Milli-Re (Turkish Reinsurance Company) is responsible for running the pool, which is protected by the World Bank and a whole host of reinsurers. TCIP has a potential to become one of the largest earthquake insurance companies in the world, provided that the penetration rate is increased significantly.

In the implementation of the obligatory insurance program, no reliable investigations were conducted for the assessment of earthquake insurance rates. As a matter of fact the rates are set by the Prime Ministry of the

Turkish Republic, the Under-secretariat of Treasury and charged by the insurance companies under the control and coordination of TCIP. Thus, this study aims at presenting a simple model for the assessment of earthquake insurance rates by considering the damage statistics and the potential seismic hazard. The proposed model is used for the assessment of the earthquake insurance premiums for reinforced concrete buildings constructed in different seismic zones of Turkey. The earthquake insurance premiums are computed by considering only the risk of damage due to earthquake shock and losses resulting from fire due to earthquake are omitted.

In most of the countries, earthquake insurance programs are implemented with the purpose of accumulating funds to cover the post-disaster expenditures. The practice and regulations of earthquake insurance vary from country to country. Below, a brief description for some countries, where the seismic hazard is significant is presented.

In Japan, earthquake insurance has been available since the 1950's (Kamei, 1976). Earthquake insurance covers damage from volcano eruptions and tsunamis also. The buildings are classified according to their earthquake resistance capacities and in this way constructions with poor quality and design are discouraged. The earthquake insurance for homes is an endorsement to fire coverage, and reinsurance is provided by the government (Brillinger, 1993, p. 16; Scawthorn *et al.*, 2003, chapter 32, pp. 24–25).

In California, a state-run earthquake insurance company, called the California Earthquake Authority (CEA), was formed in 1994 for providing coverage for homeowners. The all-residential CEA program was formed in order to overcome some of the difficulties encountered by the insurance companies after the 1994 Northridge earthquake (Scawthorn *et al.*, 2003, chapter 32, pp. 23–24).

In New Zealand, the earthquake insurance is a part of fire insurance. The Earthquake Commission (EQC), which was formed in 1993, handles the earthquake insurance nationwide. For homes there is a limit of 100,000 NZ dollars of coverage at a cost of 0.5 per 1,000 (Scawthorn *et al.*, 2003, chapter 32, p. 26). The New Zealand reinsurance program is one of the largest catastrophe coverages in the world (Steven, 1992).

Studies on the assessment of earthquake insurance premiums based on statistical methods and utilizing earthquake engineering concepts are limited in number. Gurpinar *et al.* (1978) and Gurpinar and Yucemen (1980) have considered the problems related to obligatory earthquake insurance implementation in Turkey and a pilot application was carried out for Denizli. Yucemen and Bulak (1997) have developed a statistical model for the assessment of earthquake insurance rates for the different seismic zones in Turkey. Smolka and Berz (1989, 1991) have developed a methodology for obtaining insurance premiums consistent with seismic risk and estimation of potential losses due to large earthquakes. Some of the other major studies conducted in the field of earthquake insurance are due to Straub (1973), Vere Jones (1973), Lockett (1980), Brillinger (1993), Kunreuther (1996), Walker (2000), Amendola *et al.* (2000) and Scawthorn *et al.* (2003).

2. Probabilistic Model for the Estimation of Earthquake Insurance Premiums

The assessment of earthquake insurance premiums requires two types of studies, namely: seismic hazard analysis (SHA) and estimation of potential earthquake damage to structures. In the following the models used for these two types of studies are presented.

2.1. SEISMIC HAZARD ANALYSIS (SHA)

In the probabilistic sense the seismic hazard can be defined as the probability of exceeding different levels of ground motion at a given place and within a given period of time due to expected seismic activity in the region.

Many models have been developed for seismic hazard analysis. Most of the earlier models of seismic hazard assessment were based on the assumption that earthquake occurrences are independent events in space and time, and utilized the Poisson model which is also known as the classical SHA model (Cornell, 1968) or the extreme value statistics. Later studies considered the temporal or spatial dependence of earthquakes only. Some models consistent with the "elastic rebound theory" considered the temporal dependence of earthquakes based on the processes with Markovian characteristics. Attempts were also made to model the spatial dependence of earthquakes. In recent studies, the occurrence of earthquakes is treated as a space-time process and the spatial and temporal correlations are taken into consideration (Yucemen, 1993; Akkaya and Yucemen, 2002). A detailed review and comparison of different stochastic models of earthquake occurrence is given in Yucemen and Akkaya (1996) and Akkaya and Yucemen (2002).

The probabilistic formulation adopted in this study is based on the classical SHA model. However, the classical model is improved by taking into account the uncertainties associated with the attenuation equation, geographical location of seismic sources and estimation of seismicity parameters. The SHA model used here involves the following stages:

(i) Determination of the probability distribution of earthquake magnitudes: The probability distribution of earthquake magnitudes is obtained from the linear magnitude-frequency relationship (Gutenberg and Richter, 1956) having a lower bound m_0 and an upper bound m_1 for earthquake magnitudes. The resulting exponential probability density function is as follows (Yucemen, 1992):

$$f_M(m) = k\beta \exp(-\beta(m - m_0)) \tag{1}$$

Here, k is the standardization coefficient which is needed to normalize the distribution function to unity at $m = m_1$ and obtained from the following formula:

$$k = [1 - \exp(-\beta(m_1 - m_0))]^{-1} \tag{2}$$

The parameter β, which is the slope of the magnitude-frequency relationship, is an indicator of the severity of seismic activity and is related to the tectonic structure of the region.

(ii) Determination of the probability distribution of earthquake occurrences: Earthquake occurrences are assumed to be independent events in the time domain and can be modeled as a Poisson process. Poisson model is preferred in this study since it is found to be in agreement with the observed seismic activity related to moderate or large magnitude earthquakes which affect engineering structures seriously (Cornell and Winterstein, 1998; Ferraes, 2003). According to the Poisson model, the probability of n earthquakes having intensity $m \geqslant m_0$ occurring during $[0, t]$ is:

$$P(N = n) = [\exp(-\nu t)(\nu t)^n]/n! \tag{3}$$

where, N = number of earthquakes ($m \geqslant m_0$) occurring in the time interval $[0, t]$ and ν = mean number of earthquakes having intensity $m \geqslant m_0$ per unit time (generally taken as 1 year).

(iii) Determination of an attenuation relationship: Attenuation relationships describe the decay of the "severity" of an earthquake of magnitude m with epicentral (or hypocentral) distance r. Due to the scarcity of local strong-motion data in Turkey, it was necessary to select an attenuation equation from a spectrum of such equations that appear in the literature. In this study the following widely used attenuation relationship given by Joyner and Boore (1981) is adopted.

$$\begin{aligned} \text{Log PGA} = {} & -1.02 + 0.249m - \log r - 0.00255r \\ & + 0.26p \quad \text{for } 5.0 \leq m \leq 7.7 \end{aligned} \tag{4}$$

Here, $r = (d^2 + 7.3^2)^{1/2}$ and $p = 0$ or 1, respectively, for 50 and 84% probability that the prediction will not exceed the real value. PGA denotes peak ground acceleration in terms of g and d is the closest distance in km to the surface projection of the fault rupture. The coefficient of p in the above equation represents the standard error of prediction, denoted by σ_{acc}. For this attenuation equation $\sigma_{acc} = 0.26$.

(iv) Determination of the error in the location of seismic sources: in this study, the location of seismic sources is taken to be random and the location of seismic source boundaries are assumed to exhibit a Gaussian distribution with mean zero and standard deviation, denoted by σ_{loc}. This standard deviation quantifies the expected error in the location of seismic sources. The details of this model are given in Yucemen and Gulkan (1994).

It is to be noted that the main source of uncertainty in SHA is the attenuation equation. Other sources of uncertainties are related to the seismicity parameters of the region (β, m_1, ν) and the geographical location of seismic zones.

2.2. ESTIMATION OF POTENTIAL DAMAGE TO STRUCTURES

The other component of the probabilistic model involves the assessment of the seismic vulnerability of buildings. Damage is commonly described by a loss ratio that varies with the strength of shaking and type of structure (Whitman, 1973; Blong, 2003a; Askan and Yucemen, 2003). Due to the uncertainties involved, the damage that may occur during future earthquakes has to be treated in a probabilistic manner. For this purpose damage probability matrices (DPM) are constructed from observational and estimated data. A DPM expresses what will happen to buildings, designed according to some particular set of requirements, during earthquakes of various intensities (Whitman, 1973, ATC-13, 1985). An element of this matrix P_k (DS, I) gives the probability that a particular damage state (DS) occurs when the structure of kth-type is subjected to an earthquake of intensity, I. The identification of damage states is achieved in two steps:

(i) The qualitative description of the degree of structural and non-structural damage by words: In the damage evaluation forms used by the General Directorate of Disaster Works prior to 1994, five levels of damage states were specified. These are: No damage (N), light damage (L), moderate damage (M), heavy damage (H), and collapse (C) states. This categorization of damage states is also used in this study.

(ii) The quantification of the damage described by words in terms of the damage ratio (DR), which is defined as the ratio of the cost of repairing the earthquake damage to the replacement cost of the building. For mathematical simplicity it is convenient to use a single DR for each DS (Blong, 2003b, p. 3; Gurpinar and Yucemen, 1980). This single DR is called the central damage ratio (CDR). Based on interviews with experts in charge of damage evaluation and based on similar studies, the damage ratios corresponding to the five damage states are estimated by Gurpinar *et al.* (1978) and are shown in Table I. In the present study only DPMs for conventional reinforced concrete frame buildings are considered, and the corresponding matrices are constructed from observational and estimated data available for Turkey.

Table I. Damage ratios and CDRs corresponding to different damage states.

Damage state (DS)	Damage ratio (DR) %	Central damage ratio (CDR) %
None	0–1	0
Light	1–10	5
Moderate	10–50	30
Heavy	50–90	70
Collapse	90–100	100

Using the post-event observational data on past earthquakes, $P_k(\mathrm{DS}, I)$ values can be calculated from:

$$P_k(\mathrm{DS}, I) = \mathrm{N}(\mathrm{DS}, I)/\mathrm{N}(I) \quad (5)$$

where, $\mathrm{N}(I)$ = number of kth-type of buildings in the region subjected to an earthquake of intensity I and $\mathrm{N}(\mathrm{DS}, I)$ = number of buildings which are in damage state DS, among the $\mathrm{N}(I)$ buildings.

DPMs can be obtained from past earthquake data and by using subjective judgment of experts. Techniques based on theoretical analyses for developing DPMs are also available (Whitman, 1973; Yucemen and Askan, 2003). In this study DPMs are obtained by using both empirical results and subjective judgment of experts. The form of a DPM is illustrated in Table II.

2.3. DETERMINATION OF THE PURE RISK PREMIUM

Expected annual damage ratio (EADR_k) is used as a measure of the magnitude of earthquake damage to a kth-type of structure that will be built in a certain seismic zone and is defined as:

$$\mathrm{EADR}_k = \sum_{\mathrm{I}} \mathrm{MDR}_k(I) \times \mathrm{SH}_I \quad (6)$$

Table II. Damage probability matrix.

Damage state (DS)	Central damage ratio (CDR) %	Modified Mercalli Intensity (MMI)				
		V	VI	VII	VIII	IX
None	0					
Light	5	Damage State Probabilities				
Moderate	30	$P(\mathrm{DS}, I)$				
Heavy	70					
Collapse	100					

where, $MDR_k(I)$ = average damage ratio for the kth-type of structures subjected to an earthquake of intensity I and SH_I = annual probability of an earthquake of intensity I occurring at the site.

The information contained in the damage probability matrix and in the damage ratios can be combined by defining the $MDR_k(I)$ as follows:

$$\mathrm{MDR}_k(I) = \sum_{\mathrm{DS}} P_k(\mathrm{DS}, I) \times \mathrm{CDR}_{\mathrm{DS}} \quad (7)$$

where, CDR_{DS} = central damage ratio corresponding to the damage state DS.

After calculating $EADR_k$, the pure risk premium (PRP_k) is computed based on the insured value of the building (INSV) under consideration from the following relationship:

$$\mathrm{PRP}_k = \mathrm{EADR}_k \times \mathrm{INSV} \quad (8)$$

2.4. DETERMINATION OF THE TOTAL EARTHQUAKE INSURANCE PREMIUM

The total earthquake insurance premium (TP_k) that will be charged by an insurance company for the kth-type of structure is found by increasing the PRP_k by some margin as follows:

$$\mathrm{TP}_k = (\mathrm{PRP}_k)/(1 - \mathrm{LF}) \quad (9)$$

where, LF = load factor which covers the hidden uncertainties, administration, business and taxation expenses and a reasonable profit allowance for the insurance firm. Here, LF is set equal to 0.4 (Gurpinar and Yucemen, 1980) and with this value of LF, the total insurance premium that will be charged by the insurance companies becomes:

$$\mathrm{TP}_k = 1.67 \times \mathrm{PRP}_k \quad (10)$$

A flowchart showing the algorithm for the computation of earthquake insurance premiums is given in Figure 1.

3. Application: Assessment of Earthquake Insurance Rates for Different Seismic Zones in Turkey

The implementation of the proposed probabilistic method is illustrated by computing the earthquake insurance rates for reinforced concrete buildings located in different seismic zones of Turkey. Cities are selected from the different zones according to the new seismic zonation map of Turkey (Gencoglu *et al.*, 1996). These cities and the corresponding seismic zones, (shown in parentheses) are as follows: Erzincan (Zone I), Denizli (Zone I), Istanbul/south (Zone I), Istanbul/north (Zone II), Ankara (Zone III) and Konya (Zone IV). In computing the earthquake insurance rates, compliance and non-compliance with the Code (1975) is also considered.

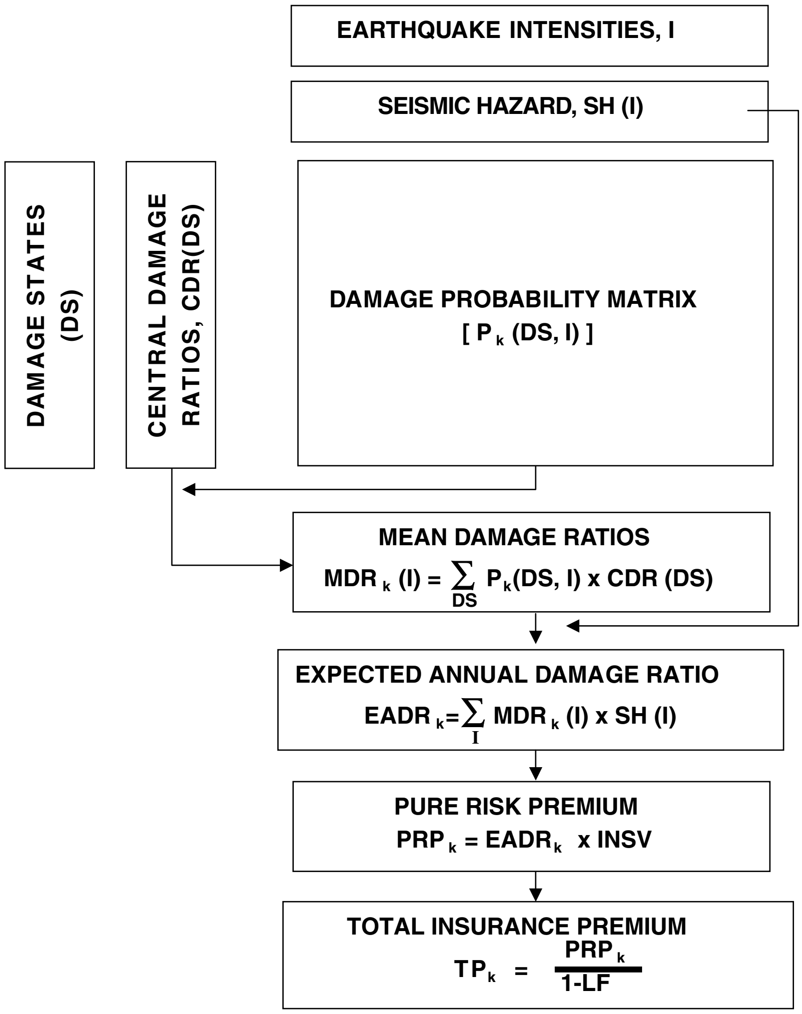

Figure 1. Algorithm for the computation of earthquake insurance premiums.

3.1. SEISMIC HAZARD ANALYSIS

In order to use the proposed model it is first necessary to carry out a SHA for these cities. For this purpose the comprehensive study carried out by Gulkan *et al.* (1993) for the assessment of seismic hazard in Turkey is utilized. The locations of the seismic sources are shown in Figure 2. These seismic sources are all modeled as area sources. The past seismic activity data with magnitude ≥4.5 are distributed to these sources according to their epicenteral locations and closeness to the sources. Earthquakes whose epicenters cannot

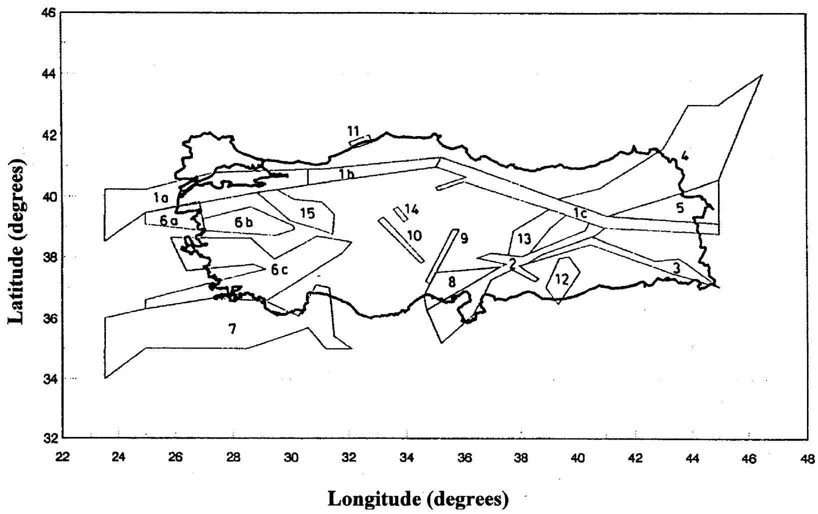

Figure 2. Seismic source zones for Turkey (Gulkan *et al.*, 1993).

be associated with anyone of these seismic sources are considered as "floating" earthquakes and assigned to "background" seismicity.

The values given in Table III are taken as the "best" estimates of the seismicity parameters and are used as the input to the computer program. The attenuation relationship given by Equation (4) is utilized as the attenuation model for PGA. The standard deviation σ_{acc} is assigned a value of 0.3, which is believed to be a good estimate of the uncertainty involved in the attenuation model adopted herein. The location uncertainty is assumed to be isotropic, and the corresponding standard deviation is taken as $\sigma_{loc} = 20$ km. With these input values the seismic hazard is computed for these five cities using the SEIS-HAZARD software package. A detailed description of this software is presented in Ozgur and Yucemen (1997).

Although intensity is not a very reliable and objective measure of the severity of ground shaking, it is used in this study mainly because earthquake damage to buildings is much better correlated with the modified Mercalli intensity (MMI). Accordingly, the seismic hazard values computed in terms of PGA are converted to MMI scale and for this conversion the empirical relationships given by Trifunac and Brady (1975) and Wald *et al.* (1999) are utilized. The resulting conversion curve is smoothed in the higher magnitude-intensity levels in order to achieve a better correlation. Based on the resulting seismic hazard values expressed in terms of MMI, the annual probabilities of observing different intensity levels are computed for each one of these cities. MMI scale provides 12 discrete levels of intensity with increasing severity. Consistent with the existing seismic activity, only levels

Table III. Values of the seismicity parameters for different seismic sources (Gulkan *et al.*, 1993).

Source no.	m_1	m_0	β	ν
1a	7.4	4.5	1.84	3.899
1b	7.2	4.6	1.60	1.164
1c	7.9	4.5	1.64	1.873
2	6.4	4.5	1.29	0.379
3	7.6	4.5	1.68	0.621
4	6.4	4.5	2.29	1.880
5	5.2	4.5	2.08	0.280
6a	7.0	4.5	1.62	0.663
6b	7.2	4.5	2.62	2.750
6c	7.4	4.5	1.92	4.254
7	7.7	4.5	2.25	8.567
8	6.0	4.5	1.99	0.100
9	6.3	4.7	0.73	4.000
10	6.3	4.7	0.73	0.010
11	6.3	5.0	0.73	0.030
12	6.4	4.5	3.47	0.020
13	6.5	4.8	1.39	0.070
14	6.3	4.7	1.02	0.070
15	5.8	4.5	1.85	0.162

V–IX are considered. The reader is referred to Gulkan *et al.* (1993) for further details of the SHA and the results concerning the variation of seismic hazard for each city.

3.2. DAMAGE PROBABILITY MATRICES

In order to compute EADR according to Equation (6), it is necessary to obtain the DPMs that are applicable for the seismic zones that these cities are located in. For this purpose the previous studies on the assessment of DPMs for reinforced concrete buildings located in different seismic zones of Turkey are examined and revised. The development of DPMs for Turkey was first considered by Gurpinar *et al.* (1978) and Gurpinar and Yucemen (1980). In these studies, based on the available damage evaluation records from the 1976 Denizli and 1971 Bingol earthquakes, it was only possible to estimate the damage probabilities in the MMI = VI and MMI = VIII columns of the DPM. Since the empirical data were inadequate for establishing a DPM completely, it was decided to estimate damage state probabilities by making use of the subjective judgment of experts. For this purpose a questionnaire was prepared and sent to thirty engineers experienced in the field of earthquake engineering. Only ten engineers responded and the responses of these ten engineers are averaged to obtain the subjective DPMs. The limited empirical data were combined with the DPMs obtained by the subjective method and DPMs for reinforced concrete buildings were proposed for the different seismic zones of Turkey. These DPMs give two sets of subjective damage probabilities for reinforced concrete frame buildings constructed in the different seismic zones of Turkey. The first set corresponds to buildings that are designed and constructed in conformance with the specifications designated in the Code (1975), and in the second set it was assumed that the earthquake resistant design provisions are violated. In the following sections these two conditions will be referred to as "According to the Code" (AC) and "Not According to the Code" (NAC), where "Code" refers to "Specifications for Structures to be Built in Disaster Areas" which was prepared and put into regulation in 1975. Here, because of space limitation only the DPM for seismic Zone I, where seismic hazard is the highest, is presented (Table IV).

Later, Yucemen and Bulak (1997, 2000) have obtained empirical DPMs by using the post-earthquake damage assessment reports compiled by the General Directorate of Disaster Affairs for the 1971 Bingol, 1976 Denizli, 1983 and 1992 Erzincan and 1986 Malatya earthquakes. In a series of studies conducted by Yucemen (2002) and Yucemen and Askan (2003), these DPMs are revised and updated in view of the additional information (Sucuoglu and Tokyay, 1992) assessed on these earthquakes. Also the damage assessment reports prepared by various institutions (Wasti and Sucuoglu, 1999; Elnashai, 2000; Ozmen and Bagci, 2000; www.seru.metu.edu.tr/archives/databases) concerning the recent earthquakes, namely: 1995 Dinar, 1999 Kocaeli (for the city of Adapazari) and 1999 Duzce are also utilized, especially for complementing the empirical DPM at higher intensity levels. The damage state probabilities are computed by using Equation (5). The resulting

Table IV. Subjective damage probability matrix for seismic Zone I (Gurpinar *et al.*, 1978).

Damage State (DS)	CDR (%)	MMI = V		MMI = VI		MMI = VII		MMI = VIII		MMI = IX	
		AC	NAC	AC	NAC	AC	NAC	AC	NAC	AC	NAC
None	0	1.00	0.95	0.95	0.70	0.70	0.50	0.50	0.20	0.30	0.05
Light	5	0	0.05	0.05	0.15	0.20	0.20	0.20	0.20	0.30	0.20
Moderate	30	0	0	0	0.10	0.10	0.15	0.20	0.40	0.20	0.40
Heavy	70	0	0	0	0.05	0	0.10	0.10	0.10	0.20	0.20
Collapse	100	0	0	0	0	0	0.05	0	0.10	0	0.15
MDR (%)		0	0.25	0.25	7.25	4.0	17.5	14.0	30.0	21.5	42.0

(AC: According to the Code; NAC: Not according to the Code).

empirical DPM is shown in Table V. In the sixth row of this table the number of buildings for which damage assessments were made is given.

The information on the date of construction of buildings was generally missing in the damage assessment reports compiled by the General Directorate of Disaster Affairs. Accordingly, it was not possible to classify the buildings as constructed before or after the 1975 Code, except for the 1976 Denizli and 1971 Bingol earthquakes. The building stock considered in these two earthquakes is assumed to be constructed not in accordance with the requirements of the Code (1975), since they were constructed before the 1975 Code became effective. For the buildings involved in the other three earthquakes, i.e. 1983, 1992 Erzincan and 1986 Malatya, it was difficult to decide. However, the general opinion of experts in charge of damage evaluation was that: most of the buildings did not comply with the requirements of the 1975 Code. A similar situation was valid for the 1999 Kocaeli and 1999 Duzce earthquake reports. However, for the 1995 Dinar earthquake, where only 39 buildings were examined, it was possible to decide for each building the degree of compliance with the Code. Accordingly, the empirical values given in Table V are assumed to be valid for reinforced concrete structures that are constructed not in accordance with the Code, except for the case of Dinar, where AC and NAC conditions are differentiated (Yucemen, 2002; Yucemen and Askan, 2003).

The values given in Table V are used to obtain the empirical damage state probabilities valid for different seismic zones by relating the cities with the seismic zones. Table VI gives the damage state statistics for Zone I with MMI = VI, VIII and IX and for Zone II with MMI = VII and VIII. For cases where more than one earthquake damage data are available for the same zone, weighted average damage state probabilities, based on the number of buildings, are computed. The empirical damage state probabilities given in this table correspond to the NAC case, as explained above.

3.3. BEST ESTIMATE DAMAGE PROBABILITY MATRICES

The DPMs will show differences from zone to zone. Therefore for each zone a DPM is needed. Besides, whether a building has been constructed according to the requirements of the code or not should be taken into consideration. In selecting these DPMs it is desirable to utilize all of the relevant information in a systematic way. In this respect, we note the following points concerning the information presented in the previous section.

(i) It seems that the most reliable method for constructing DPMs is the empirical method, which is based on the observed damage statistics, provided that personal biases in damage evaluation are controlled. However, due to lack of data it was only possible to quantify the empirical damage state probabilities for Zones I and II as given in Table VI.

Table V. Empirical damage state probabilities for reinforced concrete buildings.

Damage State (DS)	CDR (%)	19.8.1976 Denizli MMI = VI	18.11.1983 Erzincan MMI = VI	6.6.1986 Malatya MMI = VII	22.05.1971 Bingol MMI = VIII	13.3.1992 Erzincan MMI = VIII	1.10.1995 Dinar MMI = VIII		17.08.1999 Kocaeli MMI = IX	12.11.1999 Duzce MMI = IX
							AC	NAC		
None	0	0.49	0.74	0.45	0.12	0.31	0.23	0.24	0.04	0.17
Light	5	0.37	0.23	0.39	0.29	0.48	0.31	0.24	0.34	0.16
Moderate	30	0.13	0.03	0.12	0.31	0.09	0.38	0.41	0.27	0.28
Heavy	70	0.01	0.00	0.03	0.18	0.07	0.04	0.05	0.175	0.19
Collapse	100	0	0	0	0.10	0.05	0.04	0.06	0.175	0.20
Number of Buildings		378	112	89	46	415		39	13240	5420
MDR (%)		6.45	2.05	7.65	32.9	15	19.75	23	39.6	42.5

(AC: According to the Code; NAC: Not according to the Code).

Table VI. Empirical damage state probabilities for reinforced concrete buildings classified according to the seismic zones.

Damage State (DS)	CDR (%)	Zone I MMI = VI (NAC)	Zone II MMI = VII (NAC)	Zone II MMI = VIII (NAC)	Zone I MMI = VIII (NAC)	Zone I MMI = IX (NAC)
None	0	0.54	0.45	0.04	0.30	0.08
Light	5	0.34	0.39	0.43	0.45	0.29
Moderate	30	0.11	0.125	0.26	0.13	0.27
Heavy	70	0.01	0.035	0.135	0.07	0.18
Collapse	100	0	0	0.135	0.05	0.18
MDR (%)		5.7	8.15	32.9	16.1	40.15

(NAC: Not according to the Code).

(ii) The empirical damage state probabilities are supplemented by the information available from other sources. For this purpose the subjectively assessed DPMs given by Gurpinar *et al.* (1978) are utilized. Although this study was conducted long time ago, the experts answering the questionnaire were quite experienced and their responses were examined carefully, cross-checked and was rated very reliable at that time. Therefore, it is an important source of information which can not be ignored, especially if we consider the scarcity of the empirical damage data. However, this limitation of the DPMs based on subjective judgment of experts is taken into consideration by giving a smaller weight in computing the best estimate DPMs, as explained in the following paragraph (item iii).

(iii) The combination of the empirical DPM (Table VI) with the subjective DPMs is achieved by computing a set of weighted average DPMs. A subjective weight of 0.75 is assigned to empirical values whenever they are available and a weight of 0.25 is given to the subjective DPMs that are reflecting expert opinion.

(iv) A building that is not constructed according to the requirements of the code, is expected to experience the same degree of damage irrespective of the zone, when subjected to a given earthquake intensity. Therefore, the probabilities listed under the NAC columns of the DPMs for a given intensity level should be the same in all of the zones.

The resulting DPMs are called the "best estimate" DPMs and again due to space limitation only the DPM for seismic Zone I is given (Table VII). Modified Mercalli intensities of X–XII are not shown in the DPMs given in Tables IV and VII. This is due to the fact the seismic hazard corresponding to these high intensity levels are very small, and consequently their contribution to risk is negligible compared to that of smaller intensities. In Tables IV and VII the term MDR denotes the "mean damage ratio" and is to be computed from Equation (7). The variation of MDR with MMI for

Table VII. "Best estimate" damage probability matrix proposed for seismic Zone I.

Damage State (DS)	CDR (%)	MMI = V		MMI = VI		MMI = VII		MMI = VIII		MMI = IX	
		AC	NAC	AC	NAC	AC	NAC	AC	NAC	AC	NAC
None	0	1.00	0.95	0.95	0.58	0.70	0.46	0.50	0.28	0.30	0.07
Light	5	0	0.05	0.05	0.29	0.20	0.34	0.20	0.39	0.30	0.27
Moderate	30	0	0	0	0.11	0.10	0.14	0.20	0.20	0.20	0.30
Heavy	70	0	0	0	0.02	0	0.05	0.10	0.07	0.20	0.19
Collapse	100	0	0	0	0	0	0.01	0	0.06	0	0.17
MDR (%)		0	0.25	0.25	6.2	4	10.4	14	18.9	21.5	40.7

(AC: According to the Code; NAC: Not according to the Code).

different seismic zones and depending on the degree of conformance with the Code (1975) is shown in Figure 3. As observed in this figure, buildings not conforming with the requirements of the Code (1975) yield to significantly higher mean damage ratios, especially at lower intensity levels. As a matter of fact, the curve for the NAC case forms an upper bound envelope for the MDRs applicable to the different seismic zones.

3.4. COMPUTATION OF THE EARTHQUAKE INSURANCE RATES

In computing the earthquake insurance rates for the different cities the best estimate seismicity parameters and the best estimate attenuation equation (with uncertainty measure, $\sigma_{\text{acc}} = 0.3$) and the best estimate DPMs are used. Based on the seismic hazard results obtained for these cities, the EADRs corresponding to reinforced concrete buildings that are constructed in accordance and not in accordance with the requirements of the Code (1975) are computed and given in Table VIII. These EADR's can be interpreted as the pure risk premiums (PRP) to be charged for every 1,000 Turkish Lira (TL) of insured property. The corresponding total premium rates which are obtained by multiplying the PRPs by the load factor of 1.67 (Equations (9) and (10)) are also shown in Table VIII. Since the southern part of Istanbul falls into seismic Zone I and the northern part into Zone II, these regions are treated separately and for Istanbul two different rates are given. For seismic Zone I, where the seismic hazard is highest, three cities, Erzincan, Istanbul/ south and Denizli are considered. The earthquake insurance rates computed for these three cities are quite close to each other; therefore the average rates

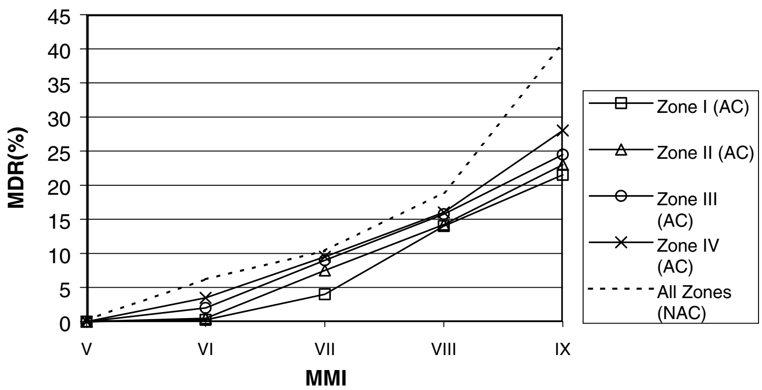

Figure 3. Variation of mean damage ratio with MMI for different seismic zones and degree of compliance with the Code (AC: According to the Code; NAC: Not according to the Code).

Table VIII. Pure risk premium (PRP) and total earthquake insurance premium (TP) rates for different cities.

City (seismic zone)	Pure risk premium rate PRP (1/1000)		Total earthquake insurance premium rate TP (1/1000)			
	AC	NAC	AC	NAC	Best estimate	Charged by the insurance firms
Erzincan (Zone I)	1.41	6.37	2.35	10.62	6.49	2.20
Istanbul/South (Zone I)	1.25	6.01	2.08	10.02	6.05	2.20
Denizli (Zone I)	1.07	6.08	1.78	10.13	5.96	2.20
Average for Zone I	1.24	6.15	2.07	10.25	6.16	2.20
Istanbul/North (Zone II)	1.05	3.31	1.75	5.52	3.64	1.55
Ankara (Zone III)	0.92	1.82	1.53	3.03	2.28	0.83
Konya (Zone IV)	0.73	1.22	1.22	2.03	1.63	0.55

(AC: According to the Code; NAC: Not according to the Code).

obtained based on the values assessed for these three cities can be used for seismic Zone I. These average rates are presented in Table VIII.

In order to come up with a single value for the total earthquake insurance premium rate, it is assumed that the reinforced concrete buildings in these cities are constructed on the average with 50% compliance with the code requirements. This leads to a rate, which is equal to the average of the rates computed for the cases of construction in accordance and not in accordance with the code. The resulting rates are called as the "best estimate" total earthquake insurance premium rates for these cities and are also shown in Table VIII.

Finally, the earthquake insurance premium rates obtained in this study under different assumptions are compared with the current practice of the insurance companies in Turkey which implement the tariff specified by TCIP. These premium rates cover only insurance against earthquake damage and are shown in Table VIII. It is to be noted that on the average the best estimate total insurance premium rate is about 2.7 times more than the rate that the insurance companies currently are charging against earthquake risk, making the purchase of earthquake insurance quite feasible. This difference results from the fact that, in this study the earthquake insurance rates are computed considering a single property, whereas the insurance firms have a portfolio of n policy holders, where n is generally a very large number. The ratemaking of insurance companies is based on the law of large numbers (central limit theorem) which implies that as n increases the uncertainty on the expected loss becomes less, because the standard deviation of the expected (mean) loss decreases inversely proportional to the square root of n. Since it is a more predictable risk and dispersed to a large number of households, it becomes a more manageable risk from the point of view of the insurance companies. This is the main reason for the difference between the rates estimated in this study based on a single household and the rates currently charged by the insurance companies in Turkey.

Within the context of the probabilistic approach it is also important to comment on the different types of uncertainties that contribute to the insurance rates and their variation with the degree of code compliance. The uncertainties can be categorized into two, namely: the aleatory (probabilistic) uncertainty that is inherent in earthquake occurrence and damage potential, and the epistemic (knowledge-based) uncertainty that is associated with the degree of code compliance. The aleatory uncertainty cannot be reduced by acquiring additional information (McGuire, 2004), whereas the epistemic uncertainty over the code compliance or violation could be reduced by implementing a systematic program of building inspection and rehabilitation.

4. Conclusions

In this paper, a probabilistic model is presented for the calculation of the earthquake insurance rates and its application is illustrated by computing the earthquake insurance rates for five cities located in different seismic zones of Turkey. The following main conclusions can be stated based on this study:

1. The computation of earthquake insurance rates requires information on future earthquake hazard and expected seismic vulnerability of engineering structures.
2. In this study all empirical data are utilized in the preparation of DPMs. However, since observed data were not sufficient for establishing DPMs for all of the seismic zones completely, other sources of information, including subjective judgment of experts, are utilized. It is to be emphasized that the determination of the appropriate DPMs is crucial as far as the validity of the resulting insurance rates are concerned.
3. For seismic Zone I, three cities, namely: Erzincan, Denizli and the southern part of Istanbul are considered. No significant difference is observed among these three cities with respect to the PRP and TP rates. Therefore the average value obtained from these three cities can be applied for seismic Zone I.

4. For reinforced concrete buildings constructed according to the Code (1975), the pure and total premium rates decrease gradually, but consistently as it is moved from Zone I to Zone IV (Table VIII). Actually TP rates for Zones I and II are quite close to each other (2.07‰ *versus* 1.75‰). Similarly Zones III and IV have almost the same TP rates (1.53‰ versus 1.22‰). This trend suggests that for reinforced concrete buildings constructed according to the requirements of the Code (1975), earthquake insurance premiums may be implemented by treating Zones I and II as one group and Zones III and IV as another group. The TP rates computed for buildings satisfying the code requirements in Zones I and II are observed to be slightly below and above, respectively, what has been currently charged by the insurance firms. On the other hand, for Zones III and IV this difference is rather high; 1.85 and 2.22 times more, respectively.
5. For the case where the requirements of the Code (1975) are violated, total premium rates are again observed to decrease consistently as it is moved from Zone I to Zone IV, but this time the differences are quite significant (Table VIII). In this case grouping is not possible. Besides the TP rates are much higher (3.6–4.7 times more) than the rates currently charged by the insurance companies.
6. As the final outcome of this study the best estimate total premium rates are computed for each zone based on the assumption that reinforced concrete buildings are constructed on the average with 50% compliance with the code requirements. The resulting best estimate TP rates are about 2.7 times more than the rates currently charged for insurance against earthquakes (Table VIII).
7. Much higher (up to five times more) insurance premium rates that result from the violation of the code requirements strongly suggest that compliance with the code should be an important factor in deciding on the earthquake insurance rates. In other words, significantly different rates should be charged for buildings depending on the degree of compliance with the code. It is also believed that enforcement of such a criterion, will not only encourage the implementation of the code requirements with respect to earthquake resistant design provisions, but it will also create a control mechanism.
8. It is to be emphasized that the earthquake insurance rates presented herein are based on the SHA carried out and DPMs assessed within the scope of this study. Both of these inputs are obtained based on the data currently available and are subject to revision as new data become available. It is also to be noted that the rates are valid for reinforced concrete buildings and 1975 Code is considered, throughout the study.
9. The earthquake insurance rates are observed to be sensitive to the assumptions on SHA and DPMs. Therefore more consideration should be given to the assessment of proper input parameters. Future studies

should also concentrate on the collection of earthquake damage data, which is essential for obtaining a realistic estimate of the damage state probabilities.

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