Assessment of Earthquake Insurance Rates for the Turkish Catastrophe Insurance Pool

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ABSTRACT: The probabilistic model of earthquake insurance analysis, which was developed earlier, is applied using effective data processing methods and recent data, to obtain realistic estimates of the earthquake insurance premium rates applicable for reinforced concrete and masonry buildings in Turkey. While doing this, the information on future earthquake threat is integrated with the information on expected earthquake damage to buildings.

1 INTRODUCTION

The first study of earthquake insurance in Turkey dates back to 1978 with the consideration of obligatory earthquake insurance feasibility (Gürpinar et al. 1978). But only after the 1999 earthquakes could the obligatory insurance system be put into regulation, and for only residential units. In the year 2000, with the formation of the Turkish Catastrophe Insurance Pool (TCIP) as a part of the Turkish Emergency Flood and Earthquake Recovery Program (TEFER), earthquake insurance was made compulsory. However, the scheme covers only earthquake losses currently.

The insurance system has five tariff zones and also charges different premium rates depending on the construction type (steel, reinforced concrete, masonry and others). The rates charged by the insurance companies, as specified by TCIP, range from 5.50 to 0.44 per 1000 units of insured property. TCIP also requires compliance with building standards. Coverage is not offered for buildings constructed after September 27, 1999 without construction license. The scheme has a deductible of 2 % of the insured value for each property.

The obligatory earthquake insurance system established in Turkey is highly rated by national and international insurance authorities and currently holds the second largest number of policies in the world. The total amount of insured property throughout the country reached approximately to 2.5 million as of February 2007.

However, the validity of the present insurance premium rates (tariff) continues to be a subject of discussion among academicians as well as in the insurance sector. It is the aim of this study to improve the comprehensive probabilistic model of earthquake insurance analysis and obtain realistic estimates of the earthquake insurance premium rates by integrating information on future earthquake threat with information on expected earthquake damage to buildings.

2 EARTHQUAKE INSURANCE MODEL AND ITS APPLICATION

Earthquake insurance premium rates should be calculated based on (i) the frequency and (ii) the severity of earthquakes. This corresponds to a conditional probability of damage given a range of earthquake hazard levels. The frequency of earthquakes at a site will be the same for all structures. However the severity of damage will change depending on the structural system type, age, configuration and other features. Hence, severity of damage to different facility classes should be considered separately.

The future earthquake threat at a selected site is quantified by making use of probabilistic seismic hazard analysis techniques, which are based on input data containing uncertainties, because of the lack of understanding of the earthquake phenomenon by the mankind as well as the randomness in its occurrence. As the input information, past earthquake data, earthquake generating mechanisms and attenuation modeling are required. The magnitude, location and occurrence time of future earthquakes are not known. For all components, probability distributions have been used. The magnitude distribution of earthquakes is assumed to exhibit an exponential distribution as stated by Gutenberg & Richter (1949). The location randomness is modeled by establishing virtual seismotectonic provinces displaying the so called "uniform" seismic activity within each province. Finally, the temporal distribution is considered to follow a Poisson distribution in our study. The effect of a given earthquake at a specified location is estimated by ground motion prediction (attenuation) relationships.

The earthquake damage component of insurance considerations is quantified, on the other hand, by assessing the seismic vulnerability of buildings. Due to underlying uncertainties earthquake damage to buildings has to be treated also in a probabilistic manner. The most reliable data source for earthquake damage estimation is the observed damage data, provided that personal biases in the damage evaluation are eliminated. In our study, empirical damage data is used, which is supplemented by expert opinion. The qualitative descriptions of damage are correlated with quantitative size measures to end up with monetary values for insurance considerations.

The earthquake damage can be presented in various ways. Because of consistency with the previous studies on probabilistic earthquake damage evaluation in Turkey, a relatively old presentation proposed by Whitman (1973), which is the damage probability matrix (DPM), is utilized herein. A DPM is composed of probabilities that a certain damage state (DS) is observed when a certain type of structure (say, k) is exposed to a known earthquake intensity (say, I). The ratio of the cost of repairing the earthquake damage to the replacement cost of the building (excluding the value of land on which the building is constructed) is defined as the damage (or loss) ratio (DR). For computational convenience, a single DR, called the central damage ratio (CDR), is assigned to each DS to represent the best estimate DR of buildings in that DS. The General Directorate of Disaster Affairs of the Ministry of Public Works and Settlement in Turkey have been using the following damage states since 1994: no damage, N (CDR=0%); light damage, L (CDR=5%); moderate damage, M (CDR=30%) and heavy damage/collapse, H/C (CDR=85%). Prior to 1994, H and C states were distinct.

With the available post-earthquake damage data, each element of a DPM (the probability that DS is observed in k-type buildings when exposed to a given earthquake intensity, I, $P_k(DS,I)$) is obtained as the ratio of the number of k-type buildings in damage state DS to the total number of k-type buildings subjected to earthquake intensity I. The sum of the probabilities in each column of a DPM equals to 1.0. For insurance considerations, a $P_k(DS,I)$ does not provide much sense. Instead, the weighted average damage ratio of a building stock for a selected building type-earthquake size pair should be obtained. This is called as the mean damage ratio (MDR) and is obtained as the summation of the product of $P_k(DS,I)$ and the CDR at each DS.

Multiplying the seismic hazard (SH) by the MDR and superposing the results for a full range of SH's, represents the expected annual damage ratio for k-type buildings ($EADR_k$). $EADR_k$ is a unitless quantity and corresponds to the insurance rate for a unit property replacement cost. Finally, the pure risk premium (PRP_k) of a property is calculated proportional to the corresponding property's value. Certainly, the total insurance premium (TP_k) that will be charged by an insurance company should be determined to allow for recovery of expenses and profit. For this purpose, in classical studies the PRP_k is increased by some margin. In previous studies for Turkey, the corresponding factor is taken as 1.67 (Bulak 1997, Yücemen 2005). The same factor is adopted here. However, one should bear in mind that the insurance rate charged by a company is a function of its capital and the demand from the public and also reinsurance rates which are generally controlled by the foreign reinsurance firms and market conditions.

2.1 *Probabilistic seismic hazard assessment*

In this study, every effort was made to compile a complete and accurate earthquake catalogue as much as possible. For this purpose, the earthquake catalogues of the Earthquake Research Department of General Directorate of Disaster Affairs (Inan et al. 1996, GDDA-ERD 2004), Kandilli Observatory and Earthquake Research Institute of the Bogazici University (KOERI 2004), International Seismological Centre (ISC 2004a, b) and United States Geological Survey (USGS 2004a, b) are utilized.

The minimum earthquake magnitude in the moment magnitude scale (M_w) is accepted to be 4.5. The data in the body wave magnitude (M_b), duration magnitude (M_d), local magnitude (M_L) and surface magnitude (M_s) scales are converted to M_w scale by regression analyses, unifying the available earthquake catalogues of Turkey. During the earthquake magnitude conversion, the orthogonal regression is used to account for the effects of measurement error in predictors. The component earthquake data bases and the unified Turkish earthquake catalogue are available in Deniz (2006).

The Poisson model assumes independence between the occurrences of earthquakes. Main shocks are differentiated from foreshocks and aftershocks and alternative seismic hazard analyses are performed by considering only the main shocks. All the earthquakes that fall inside a given space and time window around another larger magnitude event are classified to be foreshocks or aftershocks (secondary events). The spatial aftershock zone sizes are determined as the enveloping space windows of Gardner & Knopoff (1974), Savage & Rupp (2000) and Kagan (2002). For the time windows, on the other hand, average of the windows specified by Gardner & Knopoff (1974) and Savage & Rupp (2000) are utilized. Spatial and temporal aftershock zone sizes are based on the magnitude of the main shock. Foreshock identification is achieved by using magnitude dependent spatio-temporal windows also.

Virtual seismotectonic provinces, within each of which seismicity is homogenized, are delineated at regions of epicenter clustering, based on subjective judgment of experts. The configuration given by Bommer et al. (2002) is adopted with some local modifications (Kocyigit 2005). For the earthquakes that can not be related to any of these seismogenic provinces, background seismicity regions are defined and no geographical region, throughout Turkey, is left out of a seismic source zone. The resulting seismic source zones and their geographical coordinates are available in Deniz (2006).

For the temporal distribution of earthquakes, the earthquake occurrence within a seismic source zone is assumed to follow the Poisson distribution, whereas the probability distribution of earthquake magnitude is described by the Gutenberg & Richter (1949) recurrence relationship. The source specific constants of the Gutenberg-Richter recurrence relationship are estimated both by carrying out regression analysis and applying the maximum likelihood method to the observed data. The results are combined together at the end.

Since smaller magnitude earthquakes are incomplete by the nature of the problem, the rates of small magnitude earthquakes are underestimated if the earthquake catalogue is used as it is. In our study, Stepp's (1973) method is utilized with separate consideration of each seismic source zone and the available earthquake catalogue is completed. The seismicity parameters of each seismic source zone are obtained after completeness analyses, again by using both the standard least squares regression and the maximum likelihood methods.

The effect of a given earthquake with respect to the desired ground motion parameter at a certain distance is modelled by using the ground motion attenuation relationship of Musson (2000) as given in Eq. (1).

$$I = 1.063 + 1.522 \times M_S - 1.102 \times \ln R - 0.0043 \times R \qquad (1)$$

Here, I is the intensity, M_s is the earthquake magnitude (which can be converted to M_w scale with no systematic error through the inverse of the orthogonal conversion relationship that we developed between M_s and M_w) and R is the hypocentral distance in *kms*. The standard deviation of Eq. (1) is specified to be σ_I = 0.486. Three different uncertainty levels around the mean attenuation curve are assumed in the computations. The attenuation analysis of Musson (2000) is based on the earthquake catalogue of Ambraseys (1988), which is a very comprehensive 100-year catalogue of the shallow Turkish earthquakes. Since intensity is by definition related to damage, the attenuation relationship selected in terms of an earthquake intensity scale provides convenience while integrating the hazard and the earthquake damage which is known with respect to different intensity levels. Besides, it predicts the intensity as a function of the earthquake magnitude and connects a link between the earthquake catalogue in magnitude scales and the seismic hazard in intensity units. Since, neither Musson (2000) nor Ambraseys (1988) made a discrimination among the earthquakes of the catalogue with respect to the soil conditions of the locations where damage occurred, the results of our seismic hazard analysis is expected to yield results compatible with "average" local soil conditions.

In the study, 21 pilot locations (cities) are selected for the determination of the insurance premium rates. The site group is established such that comparisons are possible with respect to cities in different seismic zones (according to the seismic zoning map accompanying the Specifications for Structures to be Built in Disaster Areas, 1997), and with respect to cities in the same seismic zone.

Different seismic hazard combinations are formed under the consideration of either the whole earthquake catalogue or the main shocks only, either incomplete or complete catalogues, using either the standard least squares regression or the maximum likelihood method while obtaining the recurrence relationships, different forms of the selected attenuation relationship and different levels of attenuation uncertainty. Finally, the best estimate hazard curves are obtained to be the combination of 2^4x3=48 different cases. While combining the results of these cases, logic tree and Bayesian approaches are utilized and subjective weights are assigned to each alternative case. These weights, which are shown in Table 1, represent the probability of each assumption being valid as compared to the alternative ones.

2.2 *Estimation of earthquake damage through DPM's*

Most of the building stock in Turkey under earthquake hazard is low to medium-rise buildings. High-rise buildings are usually designed and constructed with special care and comply highly with superior earthquake-resistant design principles. For this reason, the attention is turned on to the low and medium-rise buildings. However, a basic discrimination is made depending on the construction material so that reinforced concrete and masonry buildings are treated in different categories as their earthquake responses are quite different.

Table 1. Subjective probabilities of alternative assumptions

Alternative assumptions	Subjective probability
All earthquakes	0.5
Main shocks only	0.5
Incomplete catalogues	0.4
Artificially completed catalogues	0.6
Standard least squares regression in the computation of the recurrence relationships	0.4
Maximum likelihood method in the computation of the recurrence relationships	0.6
Attenuation relationship of Musson (2000) in its original form	0.5
Attenuation relationship of Musson (2000) converted to M_w scale	0.5
Attenuation uncertainty is equal to $\sigma_{\ln I} = 0.01$	0.15
Attenuation uncertainty is equal to $\sigma_{\ln I} = 0.06$	0.60
Attenuation uncertainty is equal to $\sigma_{\ln I} = 0.10$	0.25

In the conventional way of expressing the expected earthquake damage distribution via DPM's, separate matrices have been formed for different seismic zones. The reason for this is pointed out to be the different levels of expected earthquake excitation considered during the design and construction of buildings in different seismic zones. Gürpinar et al. (1978) separated the expected damage of structures depending on their compliance with earthquake resistant design provisions and established two groups as buildings constructed according to the Code (AC) and buildings constructed not in accordance with the requirements of the Code (NAC). "Code" referred to the Specifications for Structures to be Built in Disaster Areas, put into regulation in 1975. The initial observed damage data was considered to fall into the NAC class.

Gürpinar et al. (1978) established a set of DPM's based on the opinion of a working group. They assumed that the response of the structures is the same if they are in the NAC class, irrespective of the seismic zone they are located in, when subjected to the same level of earthquake intensity. For this reason, they specified only a single DPM for NAC class buildings. In our study, DPM's based on the opinion of Gürpinar et al. (1978) are considered as the expert opinion DPM's (for reinforced concrete buildings).

The empirical data available so far was poor because of several reasons. All empirical damage distribution studies considered the available data bases to correspond to reinforced concrete buildings only, although their DPM's were actually displaying the aggregated damage probability distributions of reinforced concrete and masonry buildings. But the resultant earthquake insurance premium rates were considered to belong to reinforced concrete buildings only. Consequently, the noise caused by the masonry buildings was completely ignored in these studies.

Finally, the past damage data bases do not discriminate the damaged buildings according to the degree of compliance with the existing codes and regulations. For this reason, buildings in AC and NAC classes are considered in the same category. Note that licensed buildings also went through high levels of damage in the past earthquakes, showing that their design and construction were also improper. Hence, even if discrimination was made, not much difference in the damage distribution would be expected.

2.2.1 *DPM's of recent earthquakes*

The available DPM's are complemented with more empirical data using the damage data bases starting with the devastating 1999 Marmara and 1999 Düzce earthquakes. Later, 2002 Bolvadin–Cay–Sultandagi, 2003 Izmir–Urla–Seferihisar, 2003 Bingöl, 2003 Malatya–Pütürge–Doganyol, 2003 Denizli–Buldan, 2004 Elazig–Sivrice–Maden, 2005 Hakkari and 2005 Cat–Karliova earthquakes, have occurred causing significant damage. The overall damage data refers to intensity levels of VI, VII, VIII, IX and X for Zone I; V, VI and VII for Zone II and V and VI for Zone III. The new empirical data is based on the damage assessment reports of the above mentioned earthquakes, from the archives of the General Directorate of Disaster Affairs. Damage statistics of approximately 120,000 buildings are compiled and processed as a part of this study.

Corresponding earthquake intensities are obtained from either available intensity mapping studies or estimated at each settlement, where damage occurred, using the relationship of Musson (2000) (for the earthquakes, intensity distribution of which are lacking). In using the intensity attenuation relationship of Musson (2000), the original equation and the converted equation as a function of M_w scale are used together and weighed equally.

The previous studies on the estimation of earthquake insurance premium rates focused on coming up with a single insurance premium rate for reinforced concrete buildings, by combining the estimates due to buildings in AC and NAC classes, based on subjective weights assigned to the two groups. For this reason, AC and NAC class buildings of the empirical part are not discriminated and all buildings are treated in the same category in our study, provided that their load carrying systems are differentiated.

The benefits of the availability of empirical damage data are restricted by the lack of information on (i) the damage distribution differences of different structural system types and (ii) the damage distribution differences of different story buildings within the same type. Within a selected building type, the assumption of uniform distribution of damage (in terms of the probabilities of observing each damage state) is maintained for different story buildings in further analyses. In order to separate the contribution of reinforced concrete and masonry buildings to the overall DPM's, the approximate relative vulnerability of masonry buildings with respect to reinforced concrete buildings is determined.

2.2.2 *MDR's of reinforced concrete and masonry buildings*

The percentage of masonry buildings in a building stock is expressed in terms of the "masonry ratio", as an auxiliary parameter to be used while separating the MDR's of reinforced concrete and masonry buildings. The masonry ratios of building stocks in different cities are compiled using the building census reports of the State Statistics Institute (2000).

With the availability of damage probability distribution of each earthquake, the overall empirical MDR's of all buildings (i.e., reinforced concrete and masonry combined) are calculated. Overall masonry ratios are obtained as the weighted average superpositions of the masonry ratios of component data bases. This procedure is repeated considering the seismic zoning maps accompanying both the 1997 Code and the 1975 Code.

While discriminating the MDR's of reinforced concrete and masonry buildings, a ratio is calculated for convenience, for a given intensity level-seismic zone pair, as the ratio of the MDR of masonry buildings to the MDR of reinforced concrete buildings. This ratio is called as the relative vulnerability coefficient and is applied constantly regardless of intensity levels and earthquake zones. Although MDR is actually a function of a set of DS probabilities and CDR's, the proposed solution is based on a simple definition of a single ratio representing the relative vulnerabilities of the two building types, so that the problem of determining the damage distributions of reinforced concrete and masonry buildings explicitly is bypassed, which is not possible to solve with the available information (i.e. aggregated MDR's and masonry ratios).

In Turkey, since shear wall structures are not very common, the reinforced concrete building stock can be considered to correspond to the moment resisting concrete frames according to the classification at the international level (for example, ATC-13 1985). On the other hand, the masonry building stock consists mostly of low-rise buildings. At the point of determining the relative vulnerability of masonry and reinforced concrete buildings with respect to the MDR's, DPM's of ATC-13 (1985) for low-rise and medium-rise non-ductile reinforced concrete buildings, the MDR's of different type of buildings in Turkey as given by Musson (2000) and DPM's of Bayülke (2005) are employed. The average of the ratios at each intensity level is calculated as 1.83, indicating that the vulnerability of masonry buildings to be 1.83 times greater than that of reinforced concrete buildings. Using the corresponding relative vulnerability coefficient, empirical MDR's of reinforced concrete and masonry buildings are separated.

The empirical damage distribution data is not adequate to establish a full set of MDR's for all intensity levels. Besides, the available observed damage statistics have some shortcomings such as MDR's for some intensity levels being very close or even larger than those of subsequent greater intensity levels. For some of the seismic zone-intensity level pairs, the number of buildings in the assessment of MDR's is very small. This also yields to somewhat unreliable results.

For these reasons, expert opinion DPM's given by Gürpinar et al. (1978) for reinforced concrete buildings are utilized to complement the empirical data. Initially, all buildings included in the damage evaluation of the earthquakes taken into consideration, were assumed to be in the NAC category by previous researchers. The weight assigned to the empirical data was 75 %, wherever the empirical data was available. Hence the empirical data was combined with the expert opinion DPM's of NAC category buildings with weights of 75 % and 25 %, respectively. Then the overall DPM's of NAC class buildings were superposed with the DPM's of AC class buildings with equal weights. However, previous studies assumed a constant and equal percentage of AC and NAC class buildings in all seismic zones. It is obvious that as the seismic provisions require less earthquake resistance, the buildings will display more similarities to buildings constructed against no earthquake or even to buildings in the NAC class. For this reason, as one moves from Zone I (zone with the highest seismicity) to Zone IV the percentage of AC class buildings should increase. The increased percentage may represent the actual percentage of AC class buildings as well as a virtual percentage indicating the average degree of compliance of the buildings under consideration with respect to the code requirements. Hence, AC class buildings in seismic zones I to IV are assumed to be 40 %, 55 %, 70 % and 85 %, of the whole building stock, respectively. These percentages are selected based on subjective judgment, but the fact that a weighted average of these percentages should be equal to approximately 50 % is maintained. The resultant MDR's of reinforced concrete buildings are given in Table 2 and show a satisfactory array from internal consistency point of view. For masonry buildings, there are no expert opinion DPM's. However, scaling the MDR's of reinforced concrete buildings up with a factor of 1.83, MDR's can also be estimated for the masonry buildings.

Table 2. Best estimate MDR's of reinforced concrete buildings

Seismic zone	Intensity (EMS-98)				
	V	VI	VII	VIII	IX
Zone I	0.15	4.67	7.98	15.77	24.00
Zone II	0.11	2.19	8.97	14.31	24.06
Zone III	0.15	2.50	10.56	21.08	32.08
Zone IV	0.04	4.16	14.64	22.78	33.40

2.3 *Insurance premium rates for different seismic zones of Turkey for reinforced concrete and masonry buildings*

The DPM's obtained in the previous section gives the damage probability distributions explicitly for each discrete earthquake intensity level. Accordingly the annual earthquake occurrence rates of each intensity level (intensity levels of V, VI, VII, VIII and IX) are obtained by conducting a probabilistic seismic hazard analysis as described in Section 2.1.

Matrix multiplication of the hazard component and the damage component yields the $EADR_k$'s, PRP_k's and TP_k's. While calculating the $EADR_k$'s, the contributions of the intensity level V are not taken into account since in the current earthquake insurance application, damage corresponding to at most 2 % of the replacement cost of buildings are considered to be deductible and are not covered by earthquake insurance.

The best estimate total premium rates for reinforced concrete buildings are computed and given in Table 3 for different seismic zones of Turkey. In the same table, the total premium rates for masonry buildings, which are obtained simply by scaling up the rates for reinforced concrete buildings by 1.83, are shown as well as the currently charged earthquake insurance premium rates.

Table 3. The best estimate total insurance premium rates and the currently charged insurance premium rates for reinforced concrete/masonry buildings

Seismic zone	Best estimate total insurance premium rates (1/1000)	Currently charged insurance premium rates (1/1000)
I	10.21/18.68	2.20/3.85
II	6.81/12.46	1.55/2.75
III	4.50/8.24	0.83/1.43
IV	3.32/6.08	0.55/0.60
V	1.55/2.84	0.44/0.50

The total insurance premium rates given in Table 3 consist of the contributions of the expected annual damages of different levels of earthquake hazard. Small intensity earthquakes produce less damage but occur more frequently and large intensity earthquakes result in major damage although they occur rarely. The ratios of the contribution of each intensity level to the insurance premium rates are computed and presented in Table 4.

Table 4. Ratio of the contribution of each intensity level to the total insurance premium rates

Seismic zone	Intensity IX	VIII	VII	VI
I	0.08	0.17	0.28	0.47
II	0.10	0.18	0.41	0.31
III	0.09	0.22	0.40	0.29
IV	0.03	0.13	0.42	0.42
V	0	0.04	0.32	0.64

As observed in Table 4, the majority of the insurance premium rates are due to small to moderate intensity earthquakes. This reveals that the accurate determination of the occurrence probabilities of small and moderate magnitude earthquakes deserves special attention in insurance considerations. Seismic hazard studies usually focus on the occurrence rates of large magnitude earthquakes.

The total insurance premium rates for AC and NAC class buildings are calculated and displayed in Table 5 for both reinforced concrete and masonry buildings. This aims at determining the sensitivity of results to the assumptions made while combining the DPM's and showing a set of total insurance premium rates ranging from a minimum (corresponding to a building fully complying with seismic design provisions) to a maximum (fully failing to comply with seismic design provisions). The earthquake insurance premium rate of a building is expected to remain between these two bounds.

Table 5. Variation of total insurance premium rates for reinforced concrete/masonry buildings with respect to the degree of compliance with the seismic resistant design provisions

Seismic zone	Total insurance premium rates (1/1000)		
	AC	Best estimate	NAC
I	5.22 / 9.55	10.21 / 18.68	14.17 / 25.93
II	4.23 / 7.74	6.81 / 12.46	8.68 / 15.88
III	3.87 / 7.08	4.50 / 8.24	5.45 / 9.97
IV	2.99 / 5.47	3.32 / 6.08	4.47 / 8.18
V	1.36 / 2.49	1.55 / 2.84	2.58 / 4.72

3 FINAL REMARKS

The best estimate insurance premium rates obtained in our study show differences with respect to both what previous researchers have determined and what is being applied currently in the international earthquake insurance implementation. At the international level, the maximum total premium rates are 5.25 for California, 4.30 for Japan and 7.27 for Mexico per 1000 units of insured value. For other countries, the maximum earthquake insurance premium rates are significantly smaller. However a typical deductible rate of 10-15 % is being applied in most of the countries. This rate is 2 % in Turkey. If a deductible rate of 10 % is also applied in Turkey, the $EADR_k$ of intensity VI earthquakes for both reinforced concrete and masonry buildings (in all seismic zones) and the $EADR_k$ of intensity VII earthquakes for reinforced concrete buildings in seismic zones I and II will no more contribute to the insurance premium rates (refer to Table 2). The contribution of only the intensity VI earthquakes to the expected annual damage ratios is 47 %, 31 %, 29 %, 42 % and 64 % for seismic zones from I to V, respectively (refer to Table 4). By disregarding this contribution, the earthquake insurance rates will reduce to the level of the ones implemented in other countries.

Besides, approximately half of our building stock has been considered not to comply with seismic resistant design specifications. Buildings in other countries are all considered to be designed and constructed in accordance with the appropriate building codes and regulations, which decreases the MDR's. If only the AC class buildings in Turkey are considered, the total premium rate in seismic zone I is calculated to be 5.22 ‰ for reinforced concrete buildings, which is consistent with the maximum total premium rates charged in other countries.

While calculating the total (commercially charged) premium rates using PRP_k's, a factor of 1.67 has been applied in the previous earthquake insurance studies in Turkey. However, it was emphasized that the insurance rate to be charged by an insurance company is a function of its capital and the demand from the public as well as reinsurance rates which are generally controlled by the foreign reinsurance firms and market conditions. Reduction of this factor will also result in a decrease in the total earthquake insurance premium rates computed in this study.

4 CONCLUSIONS

The main conclusions of the study are:

(i) Assessment of the earthquake insurance premium rates requires the integration of information on future earthquake hazard and seismic vulnerability of buildings. Consequently, the earthquake insurance rates are observed to be sensitive to the assumptions on seismic hazard analysis and damage probability matrices.

(ii) Estimation of earthquake damage depends mostly on the observed damage statistics compiled from past earthquakes. However, the observed damage data is generally not sufficient and should be supplemented with expert opinion.

(iii) The discrimination of the damage distributions of reinforced concrete and masonry buildings is poor in the available damage data bases. From the available domestic and international studies, the vulnerability of masonry buildings is determined on the average to be 1.83 times greater than that of reinforced concrete buildings.

(iv) Since earthquake response of reinforced concrete and masonry buildings are different, different insurance premium rates should be assigned to these two classes of buildings.

(v) The total earthquake insurance premium rates obtained in the study (per policy basis) are significantly greater than what is currently being charged by the insurance companies. This is partly attributed to the fact that, as the number of policies increases the uncertainty in the expected loss of an insured building stock decreases due to the law of large numbers, reducing the insurance premium rates requested by the insurer.

(vi) Major portion of the earthquake insurance premium rates results from the expected annual damage contribution of small and moderate magnitude earthquakes. Therefore special attention should be paid to the accurate computation of the seismic hazard resulting from small and moderate magnitude earthquakes.

(vii) The current deductible rate of 2 % in the Turkish earthquake insurance implementation is much less than what is currently being applied in other countries. At the international level, the deductible rate is on the order of 10-15 %. Considering the fact that small to moderate magnitude earthquakes occur very frequently but result in minor damage, the percentage of the deductible might be increased in the tariff specified by TCIP so that the insurance premium rates decrease.

(viii) Significantly higher (two to three 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 while determining the earthquake insurance rates. In other words, significantly different rates should be charged for buildings depending on their 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 also create a control mechanism.

(ix) Seismic vulnerability of structures is presented through fragility curves instead of damage probability matrices in recent studies. Multiplication of the elements of hazard curves by the elements of fragility curves would provide a more accurate set of expected annual damage estimates, due to the continuous format of these two components. Accordingly, it will be more appropriate to utilize fragility curves in future studies concerning the quantification of earthquake insurance rates.

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