Seismic Risk Assessment for the Prioritization of High Seismic Risk Provinces in Turkey

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SUMMARY:
The aim of the present study is the assessment of the earthquake risk in Turkey to constitute the basis for the risk prioritization of provinces. Such prioritizations are important tools for the appropriate allocation of resources towards the mitigation of the seismic risk in a country. Risk is quantified in terms of building damage, annualized earthquake loss and the annualized earthquake loss ratio. The technical approach and the methodology used for the assessment of seismic risk in Turkey essentially follows the methodology developed for the estimation of earthquake losses in the Euro-Mediterranean region the JRA-3 component of the EU FP6 Project NERIES, which has been coded into the software ELER©. For the purposes of provincial earthquake risk prioritization in Turkey, the "Hazard" part of this modular routine is replaced with the probabilistic hazard maps, which are obtained as combination of time-dependent seismic hazard for the Marmara region and Poissonian hazard for the remaining regions of Turkey.

Keywords: Seismic Risk, Turkey, Prioritization

1. METHODOLOGY FOR THE ASSESSMENT OF PHYSICAL RISK

The aim of the present study is to develop a methodology for the assessment of earthquake risk for prioritization of high seismic risk provinces in Turkey. The following ingredients form the basis for the assessment of the physical risk:

- A comprehensive and most up-to-date assessment of the seismic hazard in the country using state-of-the-art methodologies,
- Compilation of the building inventory in Turkey using appropriate building taxonomy. A grid based compilation will be suitable for GIS based applications to assess the geographic distribution of the expected damages,
- Assessment of the structural vulnerability relationships for the prominent building classes in Turkey,
- Computation of the seismic risk (structural damage) as a combination of the hazard, inventory of elements at risk and associated vulnerabilities

Ranking (with prioritization) of the provinces and sub-provinces in Turkey with respect to risk indicators selected for the analysis. For the assessment of building damages, the use of both analytical and empirical methods is possible. The analytical methods, i.e. the spectral displacement based theoretical approaches, require detailed characteristics for the building inventory and may need to be validated in comparison with hard data. For regional or national scale damage assessments, the use of region-specific intensity based vulnerability models based on empirical data for generalized building classes are more rational and suitable. This is indeed the approach preferred by insurance and re-insurance companies in their loss models for portfolio risk evaluation and premium assessment. The earthquake loss estimation methodology used in this study can be defined as in the following steps:

1. The earthquake ground motion parameters for respective return periods obtained from the seismic hazard analysis are assigned to cells of a grid sized 0.05° x 0.05°.

2. A regional geologic map of Turkey including the geological age information as Quaternary, Tertiary and Mesozoic (QTM) is used for site correction. Vs,30 values of 589 m/s, 406 m/s and 333 m/s have been assigned to Mesozoic, Tertiary and Quaternary sediments respectively (Park and Elrick, 1998).
3. The grid-based ground motion data (spectral accelerations at 0.2 sec and 1.0 sec) are amplified with respect to the regional geological map splits. Maximum values of each piece are assigned to the related grid-cell.
4. Site dependent peak ground acceleration (PGA) and peak ground velocities (PGV) for each return period (72, 475 and 2475 years) are calculated using the site dependent spectral accelerations for T=0.2 sec and T=1.0 sec obtained in step 3 .
5. Considering the standard response spectrum provided in NEHRP (2003) Provisions, the site dependent PGA is defined as 40% of the SA at short period. Therefore the site dependent PGA values have been calculated by taking 40% of site dependent SA at T=0.2.
6. Based on HAZUS99 (FEMA, 366) recommendations site dependent PGV can be calculated from site-dependent spectral accelerations at T=1.0 s with the following equation

$$PGV = ((386.4/2\pi \cdot Sa(T = 1.0s))/1.65 \quad unit(inches\ per\ second) \qquad (1)$$

7. Based on the Wald et al. (1999a and 1999b) methodology, the intensity distributions corresponding to 50%, 10% and 2% probabilities of exceedence in 50 years (return period of 72, 475, and 2475 years) have been obtained from both the site dependent PGA and PGV values. The maximum intensity value obtained from PGA and PGV pertaining to the cell for each return period has been taken as the value to be assigned to that cell.
8. Intensity based vulnerability relationships obtained from the study of Erdik et al., (2002) and the grid-based building inventory for Turkey have been utilized to estimate the building damage, and loss distributions.
9. ELER V3.1 code (http://www.koeri.boun.edu.tr/depremmuh/ELER) has been used to estimate the grid based building damages for the return periods considered in the study.
10. The grid based numbers of damaged buildings in each damage state were aggregated in sub-province and province levels.
11. The damaged buildings in each damage state were divided by the total number of buildings, and multiplied by the corresponding repair-cost ratios to obtain the loss ratios for each return period in each sub-province and province.
12. The average annual loss ratio (AALR) is computed as the area under the best-fit logarithmic curve for the points corresponding to the loss-probability pairs. By integrating the logarithmic curve between annual rate of exceedence limit of 0.0001 and 0.015, province and sub-province based average annualized building loss ratios are computed for all settlements.

The components of the above methodology are elaborated in detail in the following chapters.

2. EARTHQUAKE HAZARD

2.1. Seismic hazard assessment methodology used in this study

Two different methodologies have been used to compute the probabilistic hazard in Turkey. These are:

1. Time-dependent approach for the Marmara region
2. Poisson approach for the remaining regions of the Turkish territory

The study of Erdik et al. (2004) forms the basis of the time dependent hazard model for the Marmara region. Earthquake occurrence and fault segmentation data in the Marmara region are adequate to constrain a time dependent characteristic model for the region. The results of the study indicate a lower future hazard for the region of the 1999 earthquake and a higher hazard for the Central Marmara Sea region corresponding to the unruptured segments of the Main Marmara Fault in the Marmara Sea, when compared to Poisson, so-called memory-less models. This finding is also in accordance with (Parsons et al., 2000) indicating heightened probabilities for a major earthquake in the Marmara Sea region based on stress transfer approach. The earthquake recurrence parameters for each fault segment given in Figure 1. The time-independent probabilistic (simple Homogeneous Poissonian) model was used to assess the seismic hazard in the remaining regions of the Turkish territory. The seismic zonation model developed in accordance with the Poisson approach (DLH, 2007) is given in Error! Reference source not found..

Owing to the geological and geo-tectonic similarity of Anatolia to California (strike slip faults similar to North, Northeast and East Anatolian Faults), the average of Boore et al. (1997), Sadigh et.al. (1997) and Campbell et al.(2003) ground motion prediction models for Peak Ground Acceleration (PGA) and the average of Boore et al. (1997) and Sadigh et al. (1997) ground motion prediction models for Spectral accelerations at 0.2 sec. and 1.0 sec. periods used for the assessment of earthquake hazard.

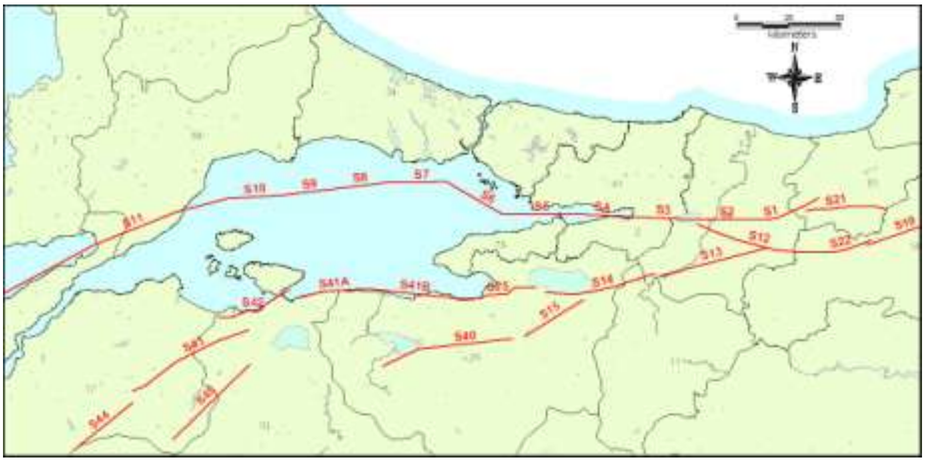

Figure 1. Fault segmentation model used in the time-dependent Marmara model.

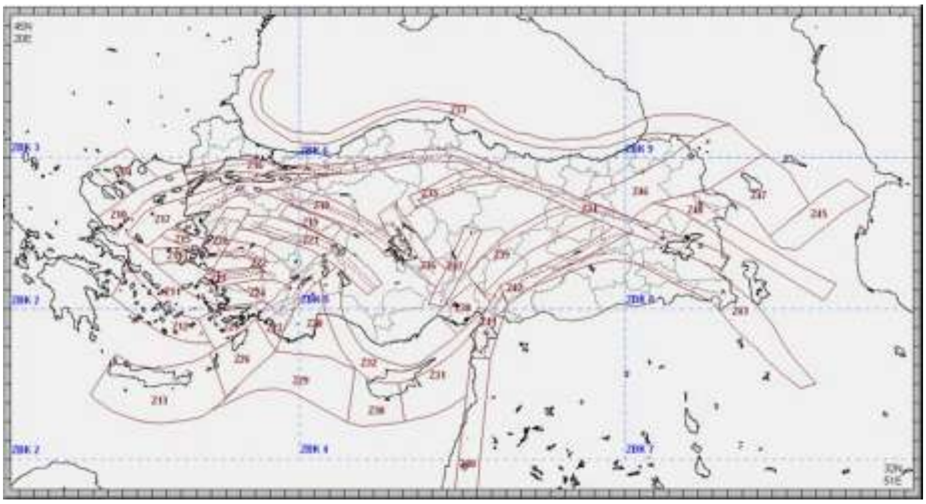

Figure 2. Source zonation model developed in accordance with the Poisson approach

2.2. Incorporation of local soil conditions

The 1/500,000 scale geologic map of Turkey produced by General Directorate of Mineral Research and Exploration (MTA) has been digitized and classified in terms of geological age as Quaternary, Tertiary and Mesozoic (QTM) by KOERI. The resulting QTM map given in Figure 3 has been utilized to reflect the effect of local sites. The approach used for the inclusion of site effects involves using QTM classification for the assigment of Vs30 (the average shear wave velocity of the upper 30 m) values. For southern California, Park and Elrick (1998) assigned Vs30 values of 589 m/s, 406 m/s and 333 m/s to Mesozoic, Tertiary and Quaternary sediments respectively. Site correction according to these values is applied by Wald et al. (1999) in the TriNet ShakeMap alghoritm. The average shear-wave velocity in the upper 30 meters (VS30) is mostly used to classify the local site conditions. The same QTM vs. Vs30 values, together with the site correction methodology of Borcherdt (1978) were used to obtain site corrected ground motion distributions from the assigned Vs30 values for Turkey.

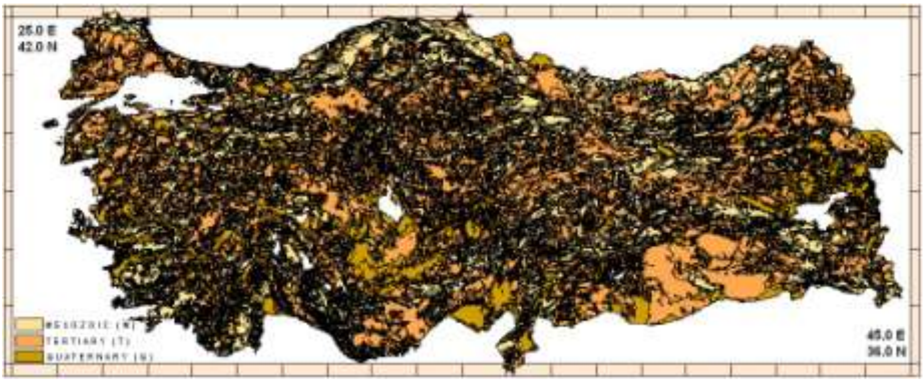

Figure 3. QTM based geologic age classification for Turkey

2.3. Conversion to intensity units

Regression relationships between Modified Mercalli Intensity (MMI, considered essentially similar to EMS'98) and ground motion parameters PGA and PGV developed by Wald et al., (1999a and 1999b) are used to estimate intensity distribution. These relationships were developed based on data from eight significant California earthquakes with magnitudes ranging between 5.8 -7.3. Site dependent PGA and PGV values inferred from site dependent short and medium period spectral accelerations SMS and SM1 are used to calculate the so-called instrumental intensity distributions corresponding to 50, 10 and 2% probabilities of exceedence in 50 years.

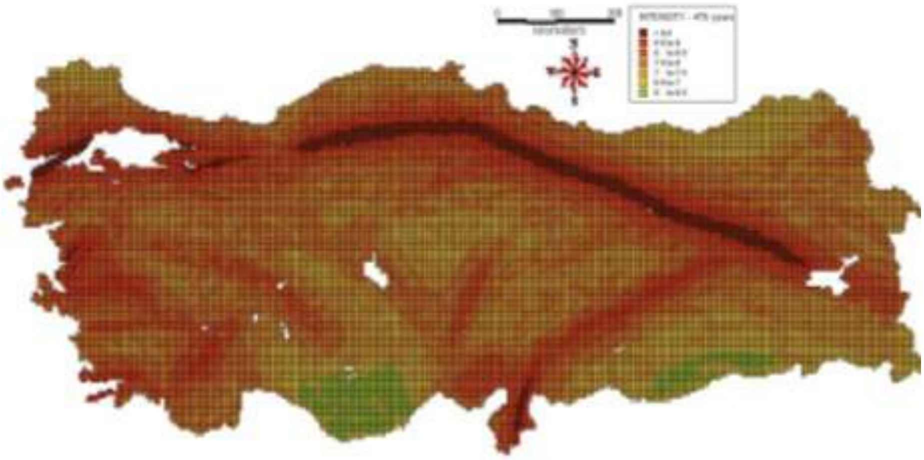

Figure 4. The grid based intensity distribution for 475 years return period.

3. BUILDING INVENTORY EXPOSED TO EARTHQUAKE HAZARD

The grid based building inventory for Turkey has been prepared in the study of Demircioglu et al., (2010). The TUIK building census data contained information in excel, the grid based Landscan population data, building inventory census at villages, population census of TUIK, Administrative boundaries of Turkey, and grid based Landscan population (2005) datasets were utilized to compose the grid based building inventory dataset for Turkey. According to the European Building Taxonomy, the building classification has been determined in the four catagories: Construction type, number of stories, construction date, and use of building. The Landscan population and the total number of building distributions are provided in Figure 5 and Figure 6 respectively. To provide a closer view to the database the mid-rise RC building distribution for the Marmara region in Turkey is given in Figure 7.

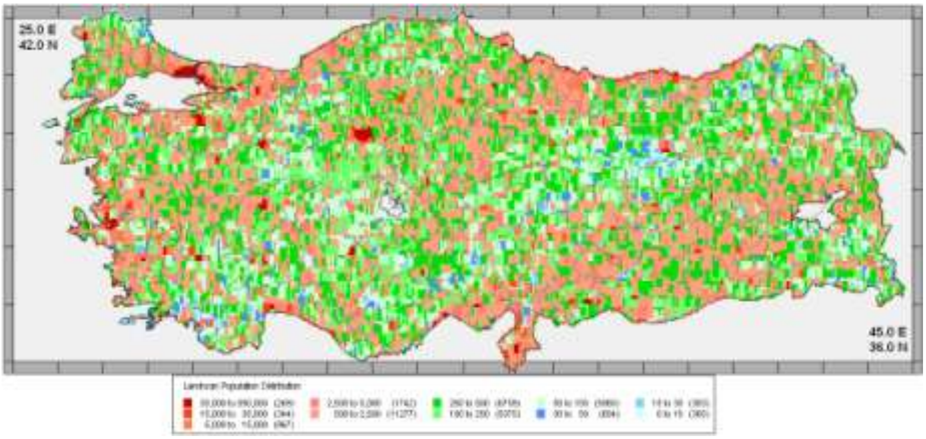

Figure 5. Distribution of population in Turkey on the basis of Landscan data

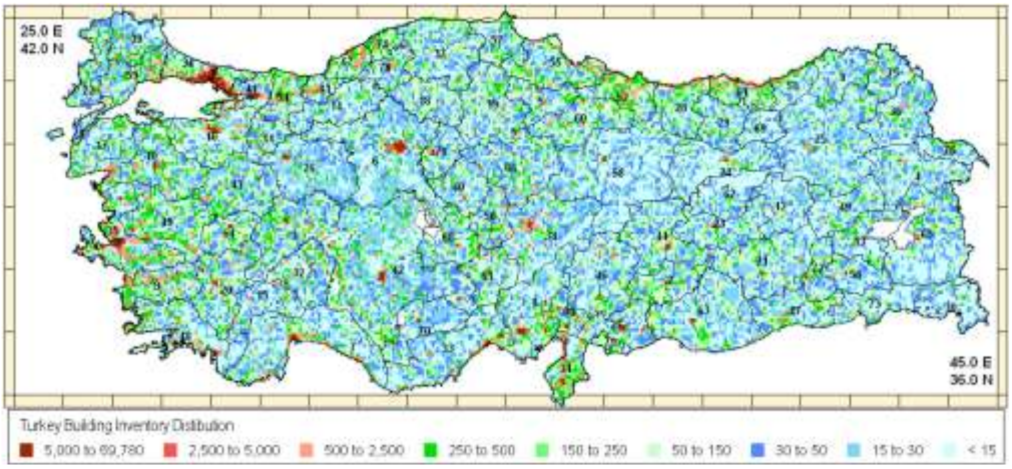

Figure 6. Building Inventory Distribution for Turkey

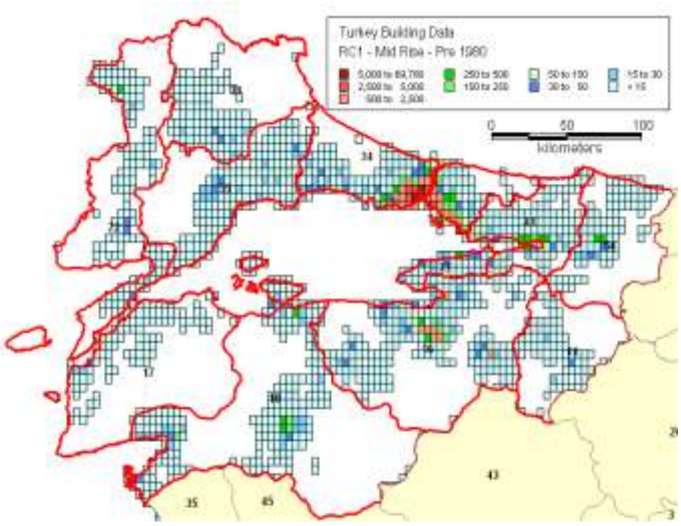

Figure 7. The mid-rise RC building distribution in the Marmara Region, Turkey

4. EARTHQUAKE RISK

4.1 Intensity Based Building Vulnerabilities

Based on available empirical data, compilations from referenced works and engineering interpretations, the vulnerability curves for the general medium-rise (4-8 storey) R/C Frame type buildings in Turkey are provided in Figure 8. The horizontal axis indicates the range (uncertainty) of MSK intensities and the vertical scale indicates the percentage loss for the five different damage grades, D1 through D5, as described in EMS (1998). Considering the damage level relations between low, medium and high rise R/C frame structures, the vulnerability curves for low-rise and high-rise R/C frame type buildings are obtained by half a unit left shifting of the intensity scale in the horizontal axis of the vulnerability curves of the medium rise R/C frame buildings. The resulting vulnerability curves are also illustrated in Figure 8. The damage levels obtained for high-rise structures compare well with the respective ATC-13 damage factor estimates. The vulnerability curves for masonry structures are assumed to be similar to the vulnerability curves of low-rise R/C structures.

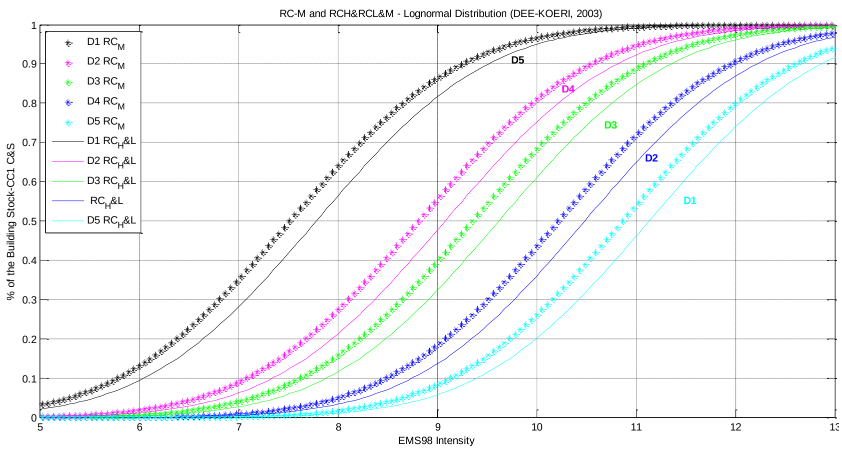

Figure 8. Intensity based vulnerability curves for the general mid rise (bold dashed lines) and high-, and low-rise R/C frame type and masonry buildings (thin solid lines) in Turkey

Damage data from seven earthquakes (Denizli-1976; Bingol-1971; Erzincan-1992; Dinar-1995;

Adana-1998; Kocaeli-1999; Bingol-2003) occurred in Turkey since 1975 were also used for the validation of the proposed vulnerability relationships. It should be noted that a lognormal distribution was used in the DEE-KOERI (2003) model. Figure 9 shows a good correlation between the damage surveys and empirical models.

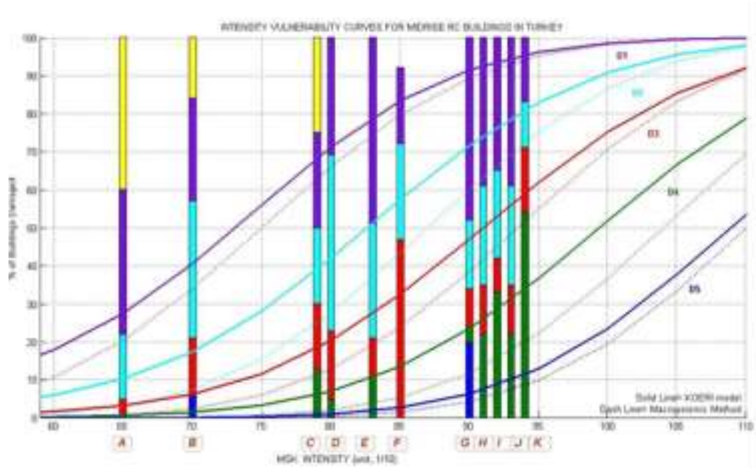

Figure 9. Intensity based vulnerability curves for mid rise RC building for Turkey (Demircioglu et al., 2010) (dashed and solid lines represent macroseismic and KOERI methods (DEE-KOERI, 2003), respectively) (A: 1976 Denizli; B:1971 Bingol, C: 1992 Erzincan; D: 1998 Adana, E: 2003 Bingol, F: 1995 Dinar, G:1999 Kocaeli, H: 1999 Kocaeli-Cumhuriyet, I: 1999 Kocaeli-Semercilar, J: 1999 Kocaeli-Orta, K: 1999 Kocaeli-Tiğcılar

5. PROVINCE BASED BUILDING DAMAGE DISTRIBUTION

The grid based building damage distribution corresponding to 72, 475, and 2475 years have been aggregated at province and sub-province levels. The province level results are presented in Figure 9 and Figure 10 in the form of pie charts indicating 1) the distribution of various damages states in the total of damaged buildings and 2) the ratio of Damage States D3+D4+D5 to the total number of buildings in the province.

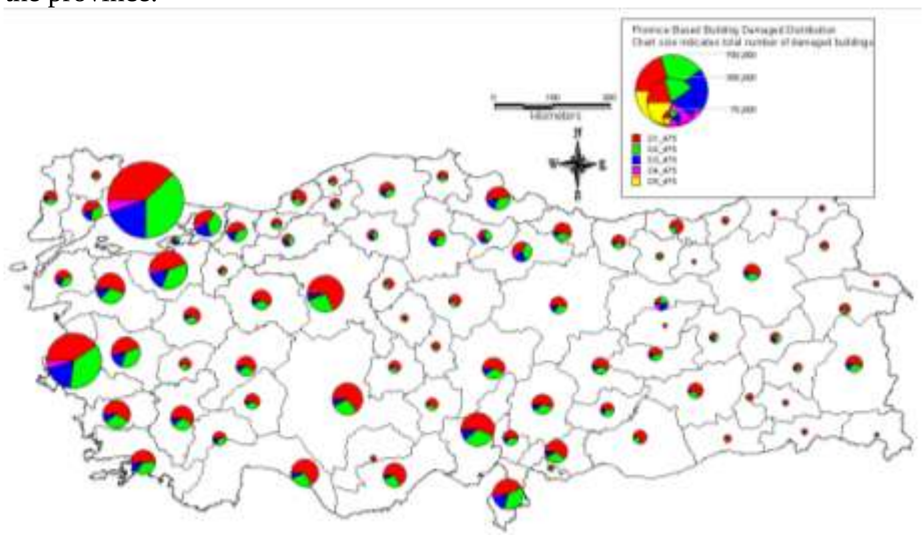

Figure 10. Province based building damage distribution corresponding to 475 years return period. Chart size indicates total number of damaged buildings.

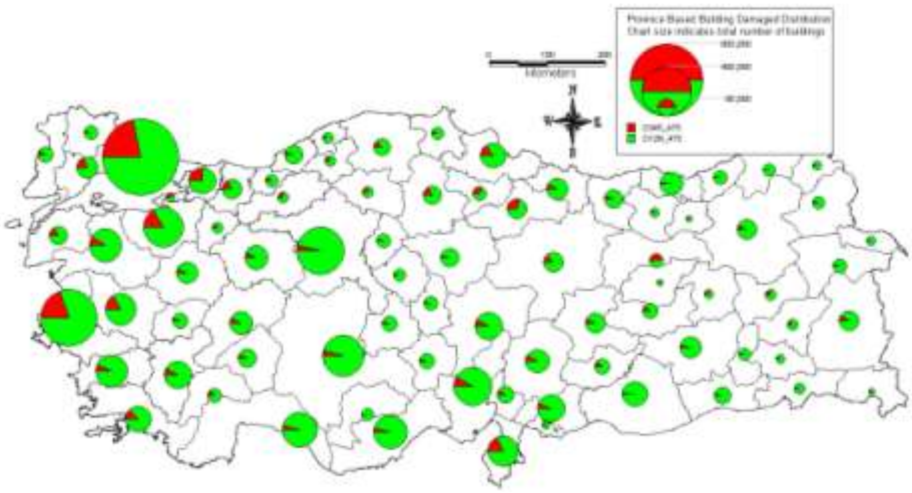

Figure 11. Province based building damage distribution (Damage states D3+D4+D5) corresponding to 475 years return period. Chart size indicates total number of buildings**.**

5.1. Parameters used in the quantification of seismic risk

HAZUS-MH (FEMA 366) uses two inter-related metrics to characterize earthquake risk: Annualized Earthquake Loss (AEL) and the Annualized Earthquake Loss Ratio (AELR). HAZUS computes Annual Losses for eight probabilistic return periods. The Annual Probability of the occurrence of the event is 1/RP. The Differential Probabilities is obtained by subtracting the Annual Occurrence Probabilities. Next the Average Loss is computed by averaging the Annual Losses associated to various return periods as shown in the column Average Losses. Once average loss is computed, the Average Annualized Loss is the summation of the product of the Average Loss and Differential Probability of experiencing this loss. The loss curve for a settlement is obtained by plotting 1/Return Period – Loss Ratio pairs. Similar to the HAZUS – MH (FEMA 366) definition, the area under the loss curve gives the Average Annual Loss Ratio (AALR) which can be used in the comparative evaluation of the earthquake risk in different settlements. The LR and the AALR are selected as the parameters to be used in the ranking of high risk settlements, as they are not a function of the actual cost of buildings, but a function of the ratio of repair cost to replacement cost of a building (the so-called repair cost ratio) for different damage states. There are several studies proposing repair cost ratio models for Turkey, associated with intensity based damage assessments. Table 1 summarizes the models of Durukal et al. (2006), and DEE-KOERI (2003) for the Damage States D1 to D5 of EMS-98. For the present study the DEE-KOERI (2003) is adopted as the repair cost ratio corresponding to damage level D1 proposed by Durukal et al. (2006) also includes the non-structural losses from an insurance point of view.

Table 1. Intensity based repair cost ratio models for Turkey

Repair cost ratio	D1	D2	D3	D4	D5
Durukal et al. (2006)	0.1	0.2	0.4	0.9	1
DEE-KOERI (2003)	0.05	0.2	0.5	1	1

The grid based building damage distributions corresponding to 72, 475, and 2475 years, aggregated at province and sub-province levels have been used for the computation of province and sub-province level loss ratios (LR) and average annual loss ratios (AALR) with the help of the methodology described above. The AALR for Istanbul, Ankara and Kocaeli provinces are 0.2%, 0.06% and 0.22% respectively. For entire Turkey the AALR is found to be 0.12%. This value is in good agreement with the AALR values provided by different international risk management companies for Turkish Insurance Industry, such as 0.09% provided by RMS, 0.14% provided by AIR and 0.06% provided by Willis and EQECAT. For the State of California, with a hazard exposure similar to Turkey, the estimated AELR is 0.14% (FEMA 366, 2003) and the AELR given for San Francisco Bay Area is 0.20%. The California and San Francisco Bay Area AELR are comparable to those estimated for Turkey and Istanbul, respectively. However, the repair-cost ratios used in FEMA 366 include costs for both the structural and non-structural components, such as piping, mechanical and electrical systems and the computation of building costs are different that what we have considered in this study. As such, a direct comparison of these AELR values is not straight forward. The sub-province level loss ratios corresponding to 475 years return periods and the average annual loss ratios are presented in Figure 11 and Figure 12. The results obtained in this study are intended for the ranking of the risk on the basis of the computed risk indicators.

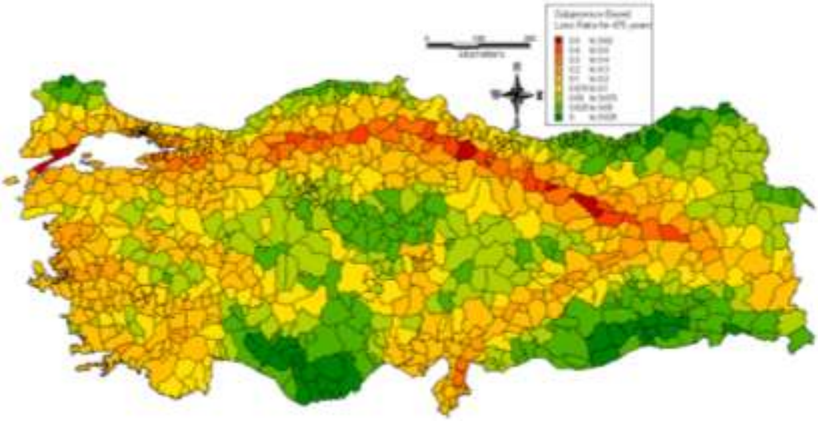

Figure 12. Sub-province based loss ratio corresponding to 475 years return period

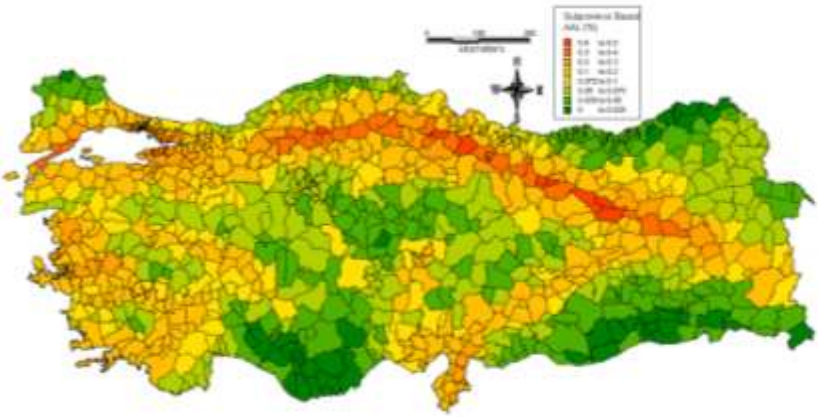

Figure 13. Sub-province based average annualized loss ratio (AALR) distribution for Turkey

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