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# SEISMIC HAZARD AND RISK ASSESSMENT OF TURKEY

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## ABSTRACT

Turkey, being located in a highly seismically active region, has experienced several devastating earthquakes throughout its history. The recent $M_w$ 7.4 1999 Kocaeli and $M_w$ 7.2 2011 Van earthquakes caused a considerable amount of economical losses and physical damage, along with great numbers of casualties. This is due to not only to the high seismicity of the region but also due to the high physical vulnerability of the built environment. Therefore, developing an effective seismic hazard assessment along with a comprehensive seismic risk evaluation becomes an important matter for a sustainable development of the country. As both of these components involve uncertainties, a probabilistic scheme to calculate the seismic losses needs to be employed. This paper provides some important outcomes of a probabilistic seismic risk analysis for Turkey. The results of this comprehensive assessment are crucial to understand how the risk is distributed across Turkey and thus how this risk can be effectively managed.

## INTRODUCTION

The focus on seismic risk calculation has become an important topic in recent years in order to take action to decrease the human and economic losses due to earthquakes. The estimated risk profile then can be used to strengthen the current buildings, to propose design methods for new buildings and to establish an effective disaster management.

Three components are required for seismic risk assessment: seismic hazard, exposure and physical vulnerability. Considering the seismic hazard, probabilistic seismic hazard assessment (PSHA) is conducted in order to account for both epistemic and aleatory uncertainties in the source models and ground motion prediction equations (GMPEs). The required seismic sources for the PSHA used herein were obtained through the European FP7 Project SHARE (Seismic Hazard Harmonization in Europe, http://www.share-eu.org/) and were used together with a set of GMPEs applicable to Turkey.

In addition to the comprehensive seismic hazard analysis, an exposure data, which should sufficiently reflect the structural characteristics, value and spatial distribution of assets, is required. The 2000 Building Census Survey carried out by Turkish Statistical Institute (TUIK) contains information on buildings at the province-level. According to this source, the Turkish building stock is mainly composed of low- to mid-rise reinforced concrete (RC) infilled frames and unreinforced masonry (URM) structures.

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For what concerns the physical vulnerability, fragility functions, providing the probability of exceeding different damage states conditional on ground shaking intensity, derived by Erberik (2008) for the most common building typologies in Turkey were combined with a damage-to-loss model modified from DEE-KOERI (2003) and Bal et al. (2007) to obtain a set of vulnerability functions in terms of the loss ratio (i.e. ratio of cost of repair to cost of replacement).

The seismic risk calculation for Turkey was carried out using the OpenQuake-engine (Silva et al., 2013), the open-source software for seismic risk and hazard calculations developed by the Global Earthquake Model (GEM) initiative. Risk metrics in terms of the economic losses due to structural damage at different return periods have been investigated. These results were disaggregated according to the different building typologies, in order to assess which construction types are contributing the most to the aggregated loss. Although the economic losses are higher for the RC building stock, the ratio between the structure-specific average annual loss (AAL) and the respective economic value is estimated to be greater for masonry typologies.

## THE METHODOLOGY

The probabilistic seismic hazard assessment for Turkey has been carried out using source models, which were developed within the European FP7 Project SHARE. In the SHARE Hazard model, there are three seismic models to assess the occurrence of earthquake activity: a classic Area Source Model (see Figure 1 - this is a model that combines activity rates based on fully parameterized faults imbedded in large background seismicity zones), the Fault-Source and Background (FSBG) Model (Figure 2), and a kernel-smoothed model that generates earthquake rate forecasts based on fault slip and smoothed seismicity (SEIFA). These models use different assumptions to estimate earthquake activity rates in the European region (more information can be found on the project website: http://www.share-eu.org/ and portal: http://www.efehr.org).

Figure 1 SHARE Area (Active Crustal) Source Model v6.1 for Turkey

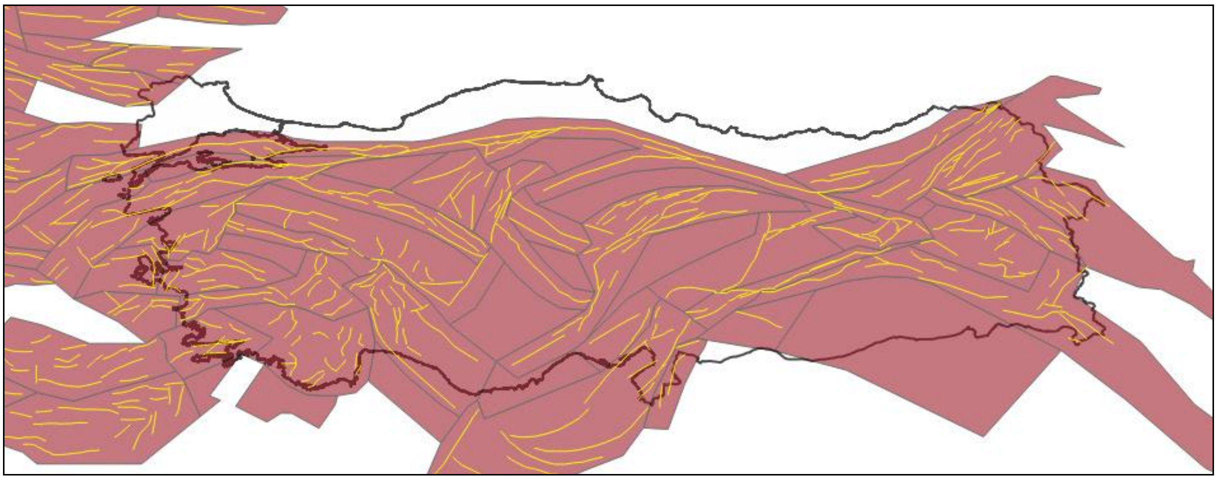

Figure 2 SHARE Fault-Source and Background v6.1 for Turkey

By using the OpenQuake hazard engine, the seismic source models together with GMPEs are combined within a classical PSHA framework using a logic tree approach to produce hazard curves at a range of fractiles. For this study, the GMPE proposed by Akkar and Bommer (2010) is used to calculate peak ground acceleration (PGA) and peak ground velocity (PGV). To account for site conditions in the hazard calculations, the shear wave velocity in the upper 30 meters of the soil (Vs30) is used to identify soil types in the region. For this purpose, as a simplified approach, Vs30 values are obtained by using the Global Vs30 Map Server developed by Wald and Allen (2007) and were included in the hazard calculations. The mean hazard map in terms of peak ground acceleration (PGA) for a probability of exceedance of 10% in 50 years is shown in Figure 3. It can be noted that the resulting hazard map is comparable with the current earthquake zoning map of Turkey (http://www.deprem.gov.tr/sarbis/Shared/haritaaciklama.aspx).

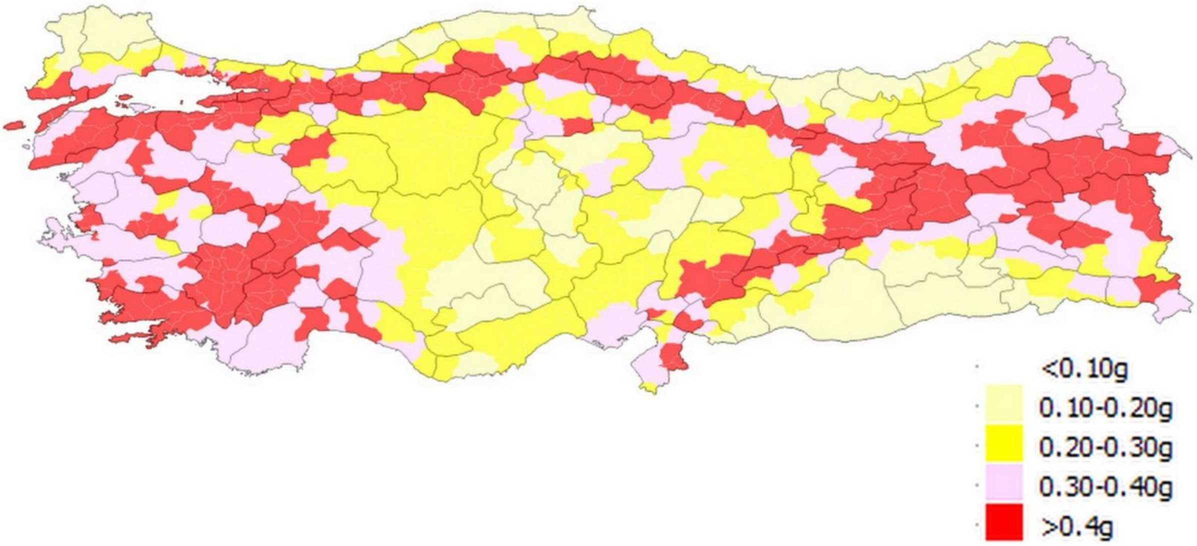

**Figure 3** Mean seismic hazard map in PGA (g) for a probability of exceedance of 10% in 50 years (475 years return period).

The 2000 Building Census carried out by Turkish Statistical Institute (TUIK) contains data at the province level on several attributes of buildings such as structural system and material, number of stories, date of construction etc. This information is very valuable to define building types in order to determine the vulnerability of the built environment. In the scope of this study, only residential building stock is taken into account by considering the height (low-rise: 1-3 stories, mid-rise 4-6 stories, high-rise: more than 6 stories) and the two most commonly applied structural systems, reinforced concrete frame with infill walls and unreinforced masonry structures with various materials (brick, concrete block, stone and adobe). Frequently, the date of construction is also used to determine building types in order to include the seismic code compliance; however, recent earthquakes In Turkey ($M_w$ 7.4 1999 Kocaeli and $M_w$ 7.2 2011 Van) have shown that previously enforced seismic design codes were not effectively applied to buildings.

Consequently, seven residential building types are obtained in three structural system groups:

(1) Reinforced Concrete; low-rise RC_LR, mid-rise RC_MR, high-rise RC_HR,
(2) Unreinforced Brick and Concrete Block Masonry; low-rise URM_LR, mid-rise URM_MR,
(3) Stone and Adobe Wall Masonry; low-rise SAM_LR, mid-rise SAM_MR

The fraction of these building types in each sub-province is shown in **Figure 4**. It can be seen that while masonry structures are dominated in the middle and eastern parts of Turkey, the reinforced concrete structures are mostly found in the western and northern regions, as well as in southeast sub-provinces. Considering the census results, in Turkey, the ratio of RC buildings in residential construction is around 47% and the stock value of this structure types constitutes 73% of the total stock value.

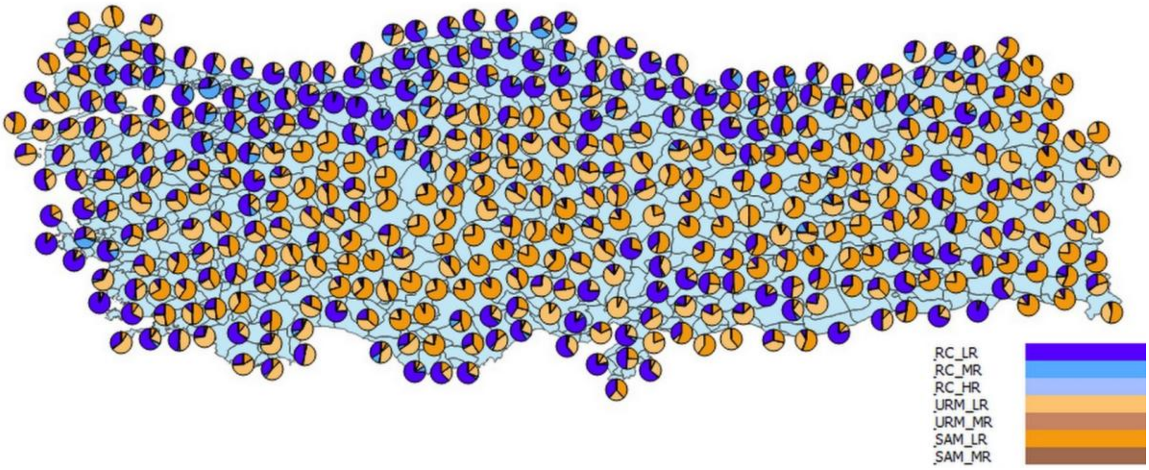

Figure 4 Distribution of RC and URM residential buildings at sub-province level

Fragility curves used in this paper is adopted from Erberik (2008a, 2008b) for both RC and masonry structures. For RC structures, three limit states are defined as LS-I (serviceability), LS-II (damage control), and LS-III (collapse prevention). In the reference, the RC buildings are also classified according to their level of degradation of structural components. Therefore, this has been also taken into account in the fragility curves of RC buildings (Figure 5). For what concerns the masonry structures, two limit states are defined as serviceability (corresponds to the point where the linear elastic behavior comes to an end by the visible cracks), and ultimate (maximum capacity after which there exists a severe degradation). This is consistent with the observations showing rapid shift from light to severe damage for masonry buildings due to their inherent deficiencies regarding in-plane and out-of-plane capacities of load bearing walls. Within this study, more focus is given to masonry structures in terms of settlement type (urban, rural) and design practices (engineered, non-engineered). The fragility curves given in Erberik (2008a) distinguish masonry building in this respect. Therefore, while adobe and stone structures are classified as non-engineered types, brick and concrete block masonry structures can be both engineered and non-engineered. The adopted fragility curves for masonry building can be seen in Figure 6 and Figure 7.

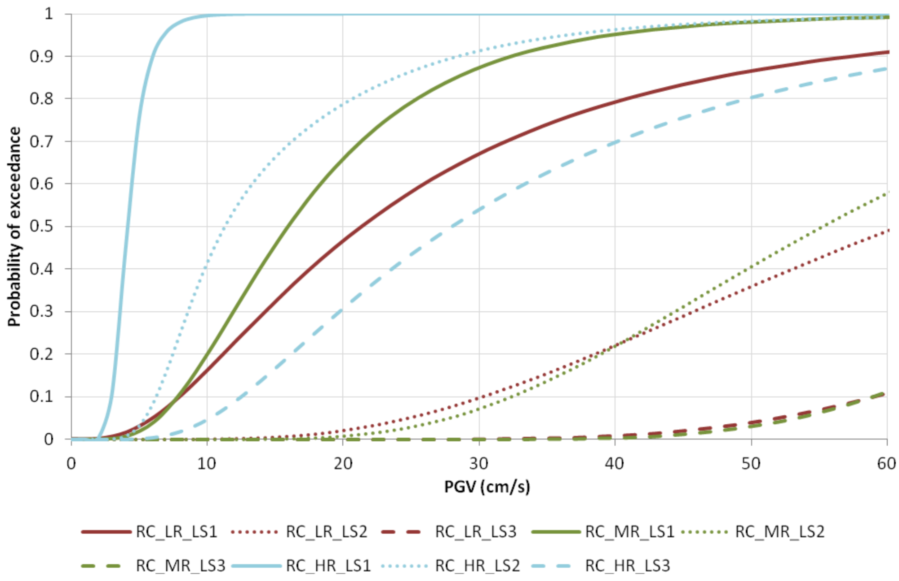

Figure 5 Fragility curves for Reinforced Concrete Frames

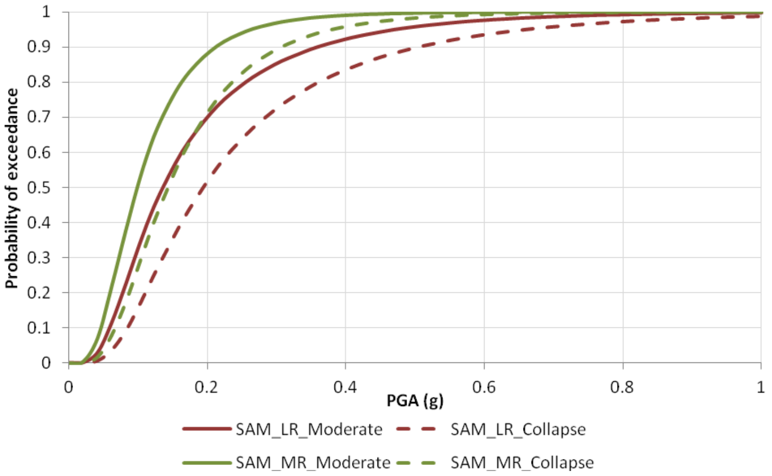

Figure 6 Fragility curves for Stone and Adobe Masonry Walls

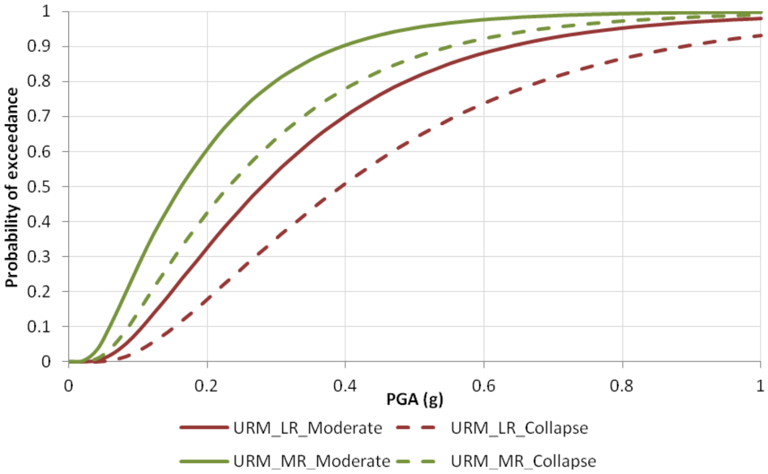

Figure 7 Fragility curves for Brick and Concrete Block Masonry Walls

By combining the fragility functions above with modified the damage-to-loss model proposed by DEE-KOERI (2003) and Bal et al. (2007) (Figure 8), a set of discrete vulnerability curves for the selected building types is obtained to calculate the seismic risk in Turkey. These vulnerability curves described for each building typology by a list of PGA and PGV values corresponding to loss ratio, which is the cost of repair to cost of replacement, and related coefficient of variation (Figure 9 and Figure 10). The coefficient of variation is considered such that it increases with low level of damage (low loss ratio) and decreases significantly as the level of damage approaches to collapse.

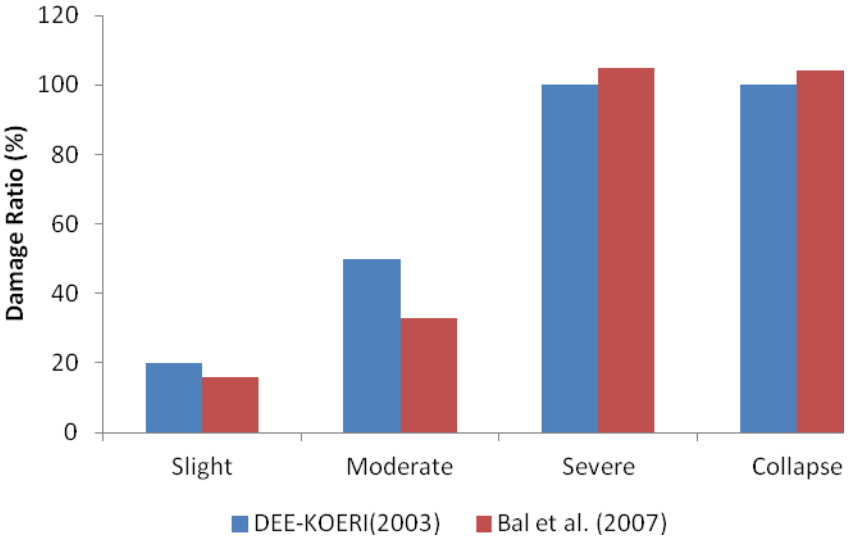

Figure 8 Damage ratios from DEE-KOERI (2003) and Bal et al. (2007)

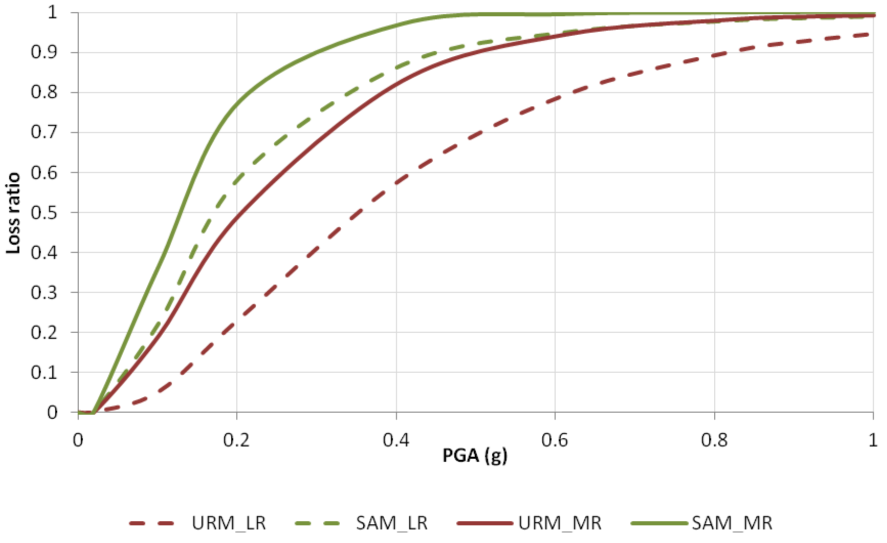

Figure 9 Vulnerability curves for URM and SAM structures

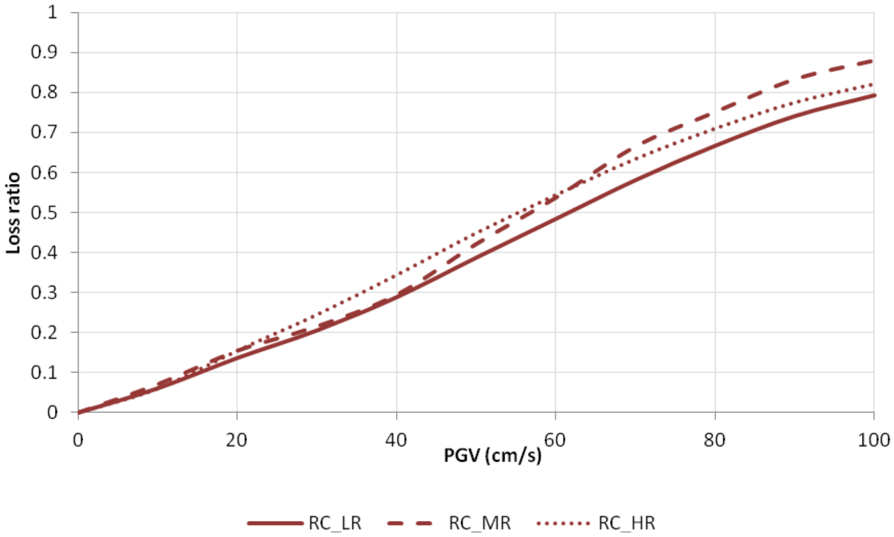

Figure 10 Vulnerability curves for RC structures

## RISK ASSESSMENT AND CLOSING REMARKS

Using this methodology, economic losses and the average annual loss ratio (AALR) are calculated for Turkey at the sub-province level (Figure 11). The AALR for Turkey is found to be 0.16% which is comparable with the values given by international risk management companies (0.14% by AIR and 0.09% by RMS) and that estimated by the previous study of Demircioglu (2010) (0.12%).

The highest AALR values are found to be in the eastern part of Turkey, namely in Erzincan (0.30%), Elazığ (0.27%) and Van (0.26%). This is clearly due to both high seismic hazard in the region and poor quality of structures, particularly resulting in a highly vulnerable physical environment.
Additionally, while AALR for Istanbul is around 0.18%, the average economic loss corresponding to the 475 years return period is the highest for this city which is due to a high concentration of building stock which includes a considerable amount of vulnerable buildings. Similarly, for entire Turkey the economic losses are higher for RC buildings since the cost of replacement is higher for these

structures. The results indicate that both the eastern part of Turkey and Istanbul (as well as the Marmara region) should be prioritised for future risk mitigation schemes.

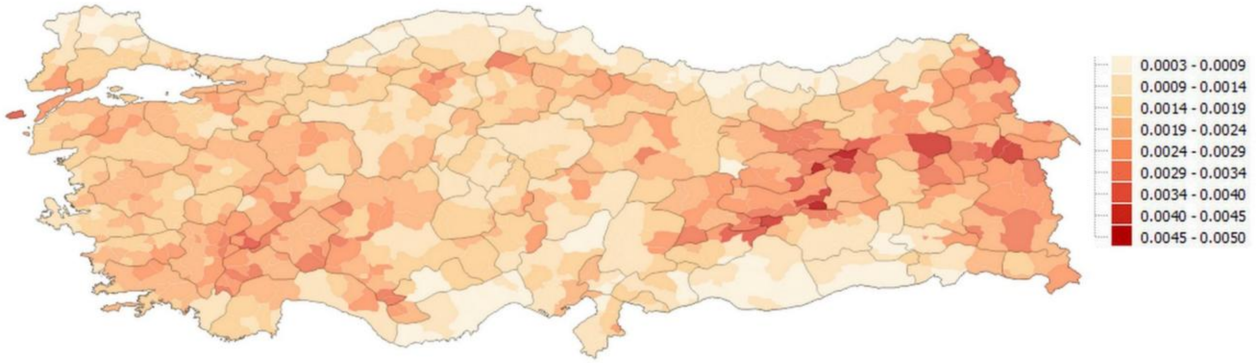

Figure 11 Average annualized loss ratio (AALR) at the sub-province level

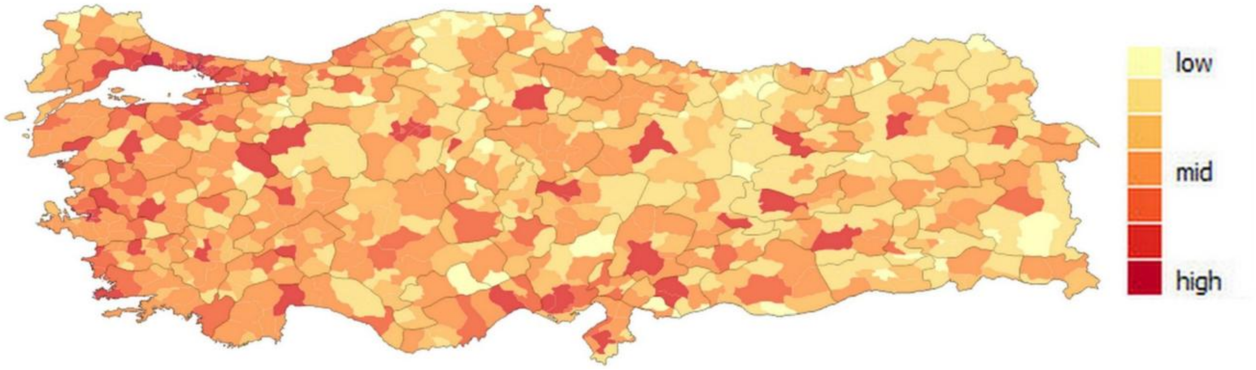

Figure 12 Average economic loss for 475 years return period

This work will be improved, firstly, in terms of exposure model such that: (1) extrapolating the building exposure up-to-date which will also help to understand the development of built environment in the long-term (2) investigating the effect of spatial distribution of the exposure data on risk calculations such as using aggregated administrative level or . Secondly, the hazard calculations will be enhanced by the use of site conditions that are outcome of microzonation studies.

Moreover, to fully understand and manage the complete picture of earthquake risk, the physical risk analysis of Turkey will be extended to include social vulnerability of the population. This is very essential in order to achieve an integrated and comprehensive estimate of risk by considering loss and damage as part of a dynamic system in between natural systems and societal factors.

## REFERENCES

Bal İ.E., H. Crowley, R. Pinho, F.G. Gülay (2007) , Structural Characteristics of Turkish RC Building Stock in Northern Marmara Region for Loss Assessment Applications, Istituto Universitario di Studi Superiori (IUSS) Press, Pavia

Turkish Statistical Institute, (2000), Building Census , Ankara, Turkey

DEE-KOERI, (2003), Earthquake Risk Assessment for the Istanbul Metropolitan Area, Report prepared by Department of Earthquake Engineering-Kandilli Observatory and Earthquake Research Institute, Bogazici University Press, ISBN 975-518-213-6, Istanbul

Demircioglu, M. B., (2010), Earthquake Hazards and Risk Assessment for Turkey, PhD Thesis, Bogazici University

Erberik M. A., (2008a), "Generation of fragility curves for Turkish masonry buildings considering in-plane failure modes", *Earthquake Engineering and Structural Dynamics*, 37:387-405

Erberik M. A., (2008b), "Fragility-based assessment of typical mid-rise and low-rise RC buildings in Turkey", *Engineering Structures* , 30:1360-137

Silva, V, Crowley, H, Pagani, M, Modelli, D, Pinho, R (2013b) "Development of the OpenQuake engine, the Global Earthquake Model's open-source software for seismic risk assessment" *Natural Hazards*

Wald, D. and Allen, T. (2007) "Topographic Slope as a Proxy For Seismic Site Conditions and Amplification" *Bulletin of the Seismological Society of America*, 97:5, 1379-1395