THE EFFECTS OF IMPLEMENTING DIFFERENT GROUND-MOTION LOGIC-TREE FRAMEWORKS ON SEISMIC RISK ASSESSMENT

Bekir Özer AY1, Özkan KALE2

ABSTRACT

This study investigates the link between probabilistic seismic hazard assessment and corresponding loss estimations by using different ground-motion logic-tree frameworks from reliable large scale seismic hazard projects as well as the logic-tree framework established in this study. The predictive models selected for these logic trees are expected to represent the center, body and range of ground-motion intensity measure estimates. Regarding with the hazard component of risk assessment, the ground motion intensities obtained by alternative logic-tree frameworks showed considerable dispersion. To scrutinize the effect of this dispersion on seismic risk and loss assessment, fragility curves derived for low and mid-rise reinforced concrete and masonry structures in Istanbul are used. The comparisons of loss estimations indicate the importance of the uncertainty in ground motion intensity calculations and the decision making process of hazard calculation for seismic risk and loss estimations studies.

Keywords: Seismic hazard and risk assessment; ground-motion logic-tree framework

1. INTRODUCTION

Earthquake loss estimation of large building stocks are of prime importance for risk assessment and mitigation studies. The reliability of seismic risk and developing strategies for disaster mitigation are primarily based on the link between engineering seismology and earthquake engineering. The main components of loss calculations are the level of seismic hazard and the vulnerability of the building stock in the region being studied. In recent years, the developments in engineering seismology increase the number of ground motion prediction equations (GMPEs) which significantly affect the former component of risk assessment because different considerations of GMPEs in ground-motion logic trees result in variabilities of the hazard results for the same region.

This study investigates the effects of different logic-tree frameworks on the results of loss estimations in urban areas. The logic-tree application which is established by considering the data-driven testing methods of likelihood - LH (Scherbaum et al., 2004), log-likelihood - LLH (Scherbaum et al., 2009), and Euclidean distance based ranking - EDR (Kale and Akkar, 2013) are used together with the logic-tree applications established in the projects of the SHARE (Seismic Hazard Harmonization in Europe; Delavaud et al. (2012)), EMME (Earthquake Model of the Middle East; Danciu et al., 2016) and T-SHM (Revision of Turkish Seismic Hazard Map; Akkar et al., 2017) projects. Likely damage for a given hazard is regarded by utilizing fragility curves derived for buildings in Turkey. Low and mid-rise reinforced concrete and masonry buildings that constitute more than 95% of the entire building stock in Istanbul are utilized in this study. The results of this study indicate the importance of connection between seismic hazard assessment and loss estimation of large portfolios.

1Assistant Professor, Department of Architecture, Middle East Technical University, Ankara, Turkey, ozer@metu.edu.tr
2Assistant Professor, Department of Civil Engineering, TED University, Ankara, Turkey, ozkan.kale@tedu.edu.tr
2. METHODOLOGY

2.1 Ground-motion logic-tree framework

Implementation of ground-motion logic-tree framework in probabilistic seismic hazard assessment (PSHA) is a common and inevitable approach to take into account the epistemic uncertainty in ground motion intensity measure (GMIM) estimates. In the current applications, there are two alternative routes to capture the epistemic uncertainty in ground motion characterization: a) implementation of multiple GMPEs with logic-tree branch weights (Kulkarni et al., 1984), and b) implementation of representative suit or backbone curve of GMPEs (Bommer, 2012; Atkinson and Adams, 2013). Both alternatives have some advantages and disadvantages over the other one as discussed by the study of Atkinson et al. (2014); however, both of them commonly aim at addressing the center, body and range (CBR) of GMIMs as described in the U.S. Nuclear Regulatory Commission (2012).

In this level, selection of the suitable set of GMPEs considering the seismological features of the site or region being studied and their classification into the CBR behavior is being a challenging task for the experts. To overcome these issues, some statistical tools are considered to select the most appropriate GMPEs (e.g. Scherbaum et al., 2004; Scherbaum et al., 2009; Kale and Akkar, 2013) and to facilitate less subjective decisions while defining the CBR trends of the predictive models and assigning logic-tree branch weights to the models (Kale and Akkar, 2015; Kale and Akkar, 2017) in PSHA. However, application of these methods cannot provide removing the expert judgement in the decision making process. Therefore, there would be some alternative ground-motion logic-tree frameworks that satisfy the above requirements but yields somewhat dissimilar spectral amplitudes for seismic hazard component of the seismic risk analysis.

2.2 Evaluation of loss for a given hazard

Site specific loss estimation for a given hazard level is a stochastic approach that contains uncertainties on likely earthquake scenarios of the region and structural response to that ground-motion intensity. An efficient and quite common tool for the latter part of this problem is to employ fragility curves derived for or representative of the buildings on the site under consideration. This way, the analyst can evaluate the probability of exceeding a performance level (i.e. limit state) of a building class for the given intensity. Thereafter, this information can be easily converted to the damage state probabilities. A major issue in this approach is the selection of suitable fragility set. One way of considering the uncertainty arisen from the fragility information is using sets of curves with a logic-tree approach similar to the methodology used in hazard estimation. Nevertheless, this study used a single fragility curve set to particularly scrutinize alternative hazard calculation approaches for loss assessment studies. Once the likely damage state of each building on a site has been assessed, the next step is to calculate the mean damage ratio (MDR), a single measure that synthesize the expected damage states (Crowley et al., 2005) of a building class. The final step to obtain the total loss is to aggregate the loss estimation of each building in the portfolio.

3. LOSS ASSESSMENT OF ISTANBUL - A COMPARATIVE CASE STUDY

3.1 Alternative ground-motion logic trees and corresponding hazard for Istanbul

Implementation of multiple GMPEs is considered within the context of this study as this alternative is still well known and widely used by the analysts and proposes some reliable logic-tree alternatives, rendering the application of the hazard results to the seismic risk analysis more feasible. The logic-tree frameworks proposed as the byproducts of the large scale seismic hazard projects of SHARE (Delavaud et al., 2012), EMME (Danciu et al., 2016) and T-SHM (Akkar et al., 2017) are employed. In addition, the logic-tree framework that is developed by combining the GMPE evaluations in the study of Kale (2017) and logic-tree method proposed by Kale and Akkar (2015; 2017) is implemented as well. In Kale (2017) study, the candidate GMPEs are selected by considering the non-data-driven
method (Bommer et al., 2010) and tested under the Turkish ground-motion database by implementing the data-driven testing methods of LH (Scherbaum et al., 2004), LLH (Scherbaum et al., 2009) and EDR (Kale and Akkar, 2013). The most appropriate predictive models for Turkey are extracted from this study and classified into the CBR behavior with respect to the study of Kale and Akkar (2017). The final logic-tree framework is decided by considering the sensitivity analysis proposed by the studies of Kale and Akkar (2015; 2017). Table 1 lists the GMPEs (Zh06 (Zhao et al., 2006), CF08: (Cauzzi and Faccioli, 2008), CY08 (Chiou and Youngs, 2008), AB10 (Akkar and Bommer 2010), AC10 (Akkar and Çağnan, 2010), ASB14 (Akkar et al., 2014), BSSA14 (Boore et al., 2014), CY14: (Chiou and Youngs, 2014); KAAH15: (Kale et al., 2015)) and their branch weights in the final logic-tree frameworks.

Table 1. GMPEs and their logic-tree branch weights in the ground-motion logic-tree frameworks considered in this study

<table>
<thead>
<tr>
<th>Logic-tree</th>
<th>Zh06</th>
<th>CF08</th>
<th>CY08</th>
<th>AB10</th>
<th>AC10</th>
<th>ASB14</th>
<th>BSSA14</th>
<th>CY14</th>
<th>KAAH15</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHARE</td>
<td>0.10</td>
<td>0.35</td>
<td>0.20</td>
<td>0.35</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EMME</td>
<td>0.10</td>
<td>-</td>
<td>0.35</td>
<td>-</td>
<td>0.20</td>
<td>0.35</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T-SHM</td>
<td>0.10</td>
<td>-</td>
<td>0.30</td>
<td>-</td>
<td>0.30</td>
<td>0.30</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>This study</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.10</td>
<td>0.30</td>
<td>0.30</td>
<td>-</td>
</tr>
</tbody>
</table>

The PSHA analyses are obtained for the centers of the districts of İstanbul, resulting in a total number of 39 sites. The area and fault + gridded background seismic sources for the study region are extracted from the studies of Şeşetyan et al. (2016) and Demircioğlu et al. (2017), respectively. The EZ-FRisk software is used in the probabilistic seismic hazard computations. The PGA values calculated from the logic-tree framework of the T-SHM project are normalized with respect to the resultant PGA values obtained from the logic-tree frameworks of SHARE, EMME and this study. The PGA ratios obtained by alternative logic-tree frameworks for return period of 72-year (top row), 475-year (middle row) and 2475-year (bottom row) are given in Figure 1. In general, T-SHM and EMME logic trees produce same levels of GMIMs, whereas consistently higher and lower GMIMs with respect to the T-SHM logic tree are observed for the logic-tree frameworks of the SHARE and this study, respectively.

3.2 Building Stock and Calculation of Loss

Seismic risk and loss assessment studies require detailed information on building stock on the subject site under consideration. The validity of available portfolio information and its spatial resolution is a function of the aim of the study as well as the size of the site under investigation. Considering the aim of this study, the building inventory that divides the city center of İstanbul into 0.005x0.005 degree size geocells and provides the number of buildings belonging to a certain class for each geocell (İstanbul Metropolitan Municipality, 2009) has been used in this study. The buildings have been classified into 57 types in this portfolio (İstanbul Metropolitan Municipality, 2009) depending on the load bearing material/system, construction year and number of story as these parameters strongly influence seismic performance of buildings (Erdik et al., 2003; Erberik, 2008). The main challenge of using such an extensive portfolio with numerous building types is assigning a fragility curve for each building class. Although previous studies like ATC-13 (Applied Technology Council, 1985) and HAZUS (National Institute of Building Sciences, 1999) have provided fragility curve sets for numerous types of structures, previous studies (e.g., Ay and Erberik, 2008; Erberik, 2010; Karimzadeh et al., 2017, etc.) highlighted the importance of using fragility curves considering the local building characteristics. Thus, this study employed a fragility set (Karimzadeh, 2016) that has been derived by considering Turkish building stock characteristics. Less than 2 percent of the whole building stock in İstanbul have been excluded from loss calculations since some building types have not been considered in fragility study of Karimzadeh (2016).
4. RESULTS AND COMPARISON

Earthquake loss estimation of Istanbul has been calculated for the given hazard information derived by alternative logic-tree frameworks. Figure 2 compares these loss estimations by taking the ratio of T-SHM outcomes (reference) to the results of SHARE (first column), EMME (second column) and this study (third column) for return period of 72-year (top row), 475-year (middle row) and 2475-year (bottom row). The plots showed that similar to the GMIM results, SHARE and this study consistently yield higher and lower losses, respectively, compared to T-SHM results. For larger return periods (i.e. rare events), the difference between loss assessments amplifies for all alternative logic-tree frameworks including EMME which gave ratios relatively close to unity. Although the trends on loss are similar to those on GMIMs, the estimations of loss varies ±0.25 units with respect to alternative logic-tree approaches.
5. DISCUSSION AND CONCLUSION

This study investigates the effect of alternative logic-tree frameworks on seismic risk assessment through loss estimations of Istanbul. Fragility curves derived for Turkish low- and mid-rise reinforced concrete and masonry buildings have been used to estimate the likely damage. The comparisons on normalized results indicate that the loss estimations show a considerable dispersion. The uncertainty on loss estimations are fairly comparable to the uncertainty on ground motion intensities which highlights the importance of logic-tree framework approach on hazard calculation for loss estimation studies of large building stocks.
6. ACKNOWLEDGMENTS

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7. REFERENCES


Cauzzi, C., and Faccioli, E., Broadband (0.05 to 20 s) prediction of displacement response spectra based on worldwide digital records, Journal of Seismology 12 (2008) 453-475.

Chiou B.S-J., Youngs R.R., Update of the Chiou and Youngs NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra, Earthquake Spectra 30 (2014) 1117-1153.


Karimzadeh, S, Use of Simulated Strong Ground Motion Records in Earthquake Engineering Applications. MSc. Thesis, Middle East Technical University, Ankara, Turkey, 2016.


