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EFFECT OF GROUND MOTION UNCERTAINTIES ON EMPIRICAL FRAGILITY CURVES FOR MASONRY BUILDINGS DERIVED FROM 2020 SIVRICE EARTHQUAKE

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Abstract: *In earthquake risk assessment studies, empirical fragility curves, which can be derivated from post-earthquake damage survey data, are of primary importance. The inventory of damaged and undamaged buildings and the ground motion intensity values at the locations of the buildings are the two inputs used in the construction of empirical fragility functions. Large scale post-earthquake damage surveys were carried out by the Turkish Ministry of Environment, Urbanization, and Climate Change following the January 24, 2020 Sivrice (Mw:6.8) earthquakes in Turkiye. While damage data are precise data, ground motion intensity values obtained by different GMPEs or shake maps may contain large uncertainties. These uncertainties can be listed as epistemic uncertainty in ground motion prediction, soil classification of the considered area. The aim of this study is to examine the effects of uncertainties on ground motion intensity on the fragility curves created for masonry structures. Ground motions are generated from ELER software by using 5 different ground motion prediction equations. The Vs30 maps based on the topographic slope from USGS and based on geological age information as Quaternary, Tertiary and Mesozoic (QTM) are used to define the soil class of the considered buildings' location. As a result, fragility curves from different ground motion models were compared for different damage levels. The results show that using different vs30 inputs does not cause a clear change in fragility curves, but the 5 different ground motion models used yield curves that are quite different from each other. For this reason, instead of choosing a ground motion model, it is recommended to use a ground motion model created with logic tree.*

Introduction

The prediction of buildings' potential performance in future events greatly relies on assessing their seismic vulnerability. One way to evaluate this vulnerability is by analyzing the observed damage data from earthquakes. By conducting post-earthquake surveys and collecting data on damage, empirical fragility functions can be generated based on statistical analysis. Taking into account the uncertainties arising from both structural capacity and soil-structure interaction, the most realistic approach to modelling fragility is through the utilization of observational data (Hancılar et al., 2013).

On January 24, 2020 (17:55 UTC), the Elazig earthquake transpired along the East Anatolian Fault Zone, measuring a moment magnitude (Mw) of 6.8. The epicenter of this earthquake (38.36° N- 39.06° E) was situated within the Sivrice district, with a depth of approximately 8 km. Numerous buildings were also affected by this event, resulting in the loss of 41 lives, injuries reported by 1607 individuals, and the collapse of 547 observed buildings (AFAD, 2020).

In this study, empirical fragility curves will be obtained by considering the ground motion uncertainty for 8835 masonry buildings constructed before 2000 for which a post-earthquake damage survey was conducted after the Sivrice earthquake. The aim of the study is to show the effect of using different ground motion models and different Vs30 inputs on fragility curves and to obtain more consistent curves by using the logic tree method for different ground motion models. Ground motions are generated from ELER software by using 5 different ground motion prediction equations. The Vs30 maps based on the topographic slope from USGS and based on geological

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age information as Quaternary, Tertiary and Mesozoic (QTM) are used to define the soil class of the considered buildings' location.

Data Set

After the Sivrice earthquakes in Turkiye on January 24, 2020, with a moment magnitude (Mw) of 6.8, extensive damage surveys were conducted by the Turkish Ministry of Environment, Urbanization, and Climate Change. As a result of the damage survey,19662 independent buildings were inspected and their damage state is determined. Of these structures, 11252 are masonry and 8410 are reinforced concrete. Figure 1 illustrates the distribution and cumulative percentage of the masonry buildings as a function of the year of construction and the number of storeys. Data contains some beneficial information about the buildings, such as year of construction, number of storeys and structural system type. To consider the effect of ground motion variability and uncertainty on the fragility curves, the 1 to 4 storeys masonry structures that were constructed before the year 2000 were selected. There are 8835 masonry buildings that are considered for this study.

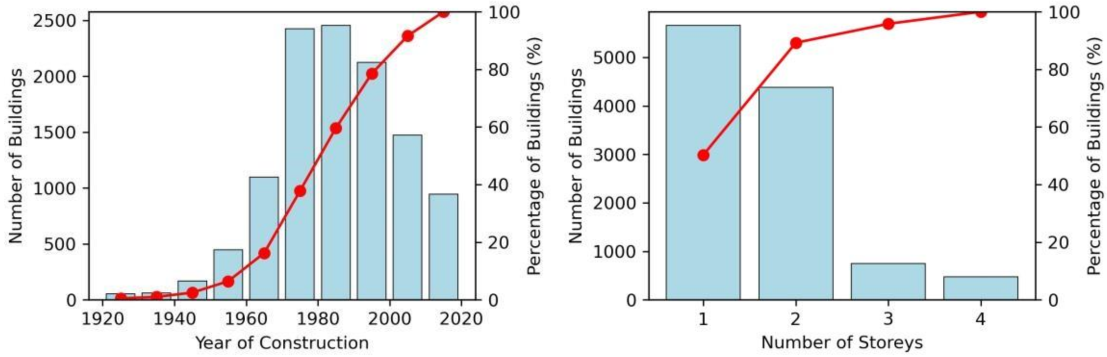

Figure 1. Distribution and cumulative percentage of the masonry buildings as a function of year of construction(left) and number of storeys (right)

Figure 2 shows the distribution of damage states of the considered buildings. When obtaining fragility curves, Rossetto et al. (2014) recommend utilizing a minimum of 100 buildings, with at least 30 of them having reached or exceeding a specified damage state. It is also important for the data points to cover a wide range of intensity measure (IM) values. What is striking in Figure 2 is that there are almost no buildings at moderate damage levels. This may be due to the fact that the buildings of interest were not designed with good engineering services or that the damage survey teams could not distinguish between moderate and extensive damage. This is one of the bad aspects of the available data. In Figure 3, the spatial distribution of the considered buildings, the epicenter of the earthquake and the ruptured fault can be seen.

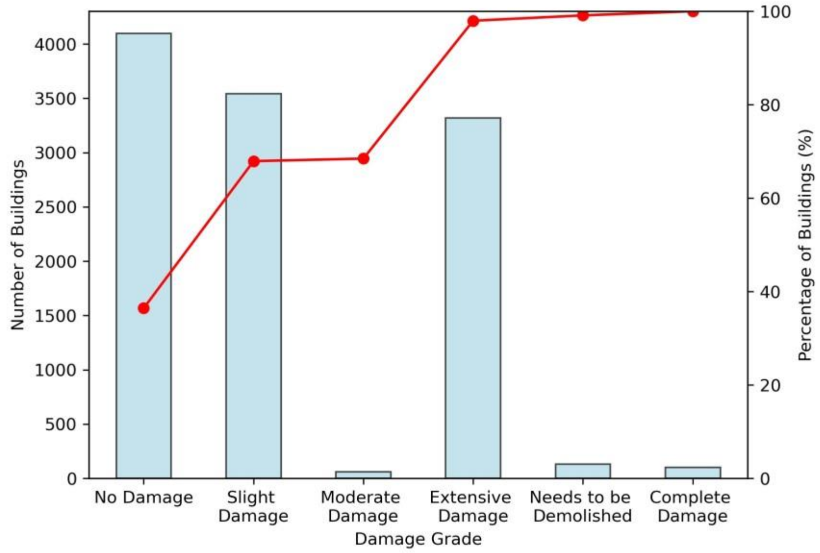

Figure 2. Distribution of damage states of the considered masonry buildings.

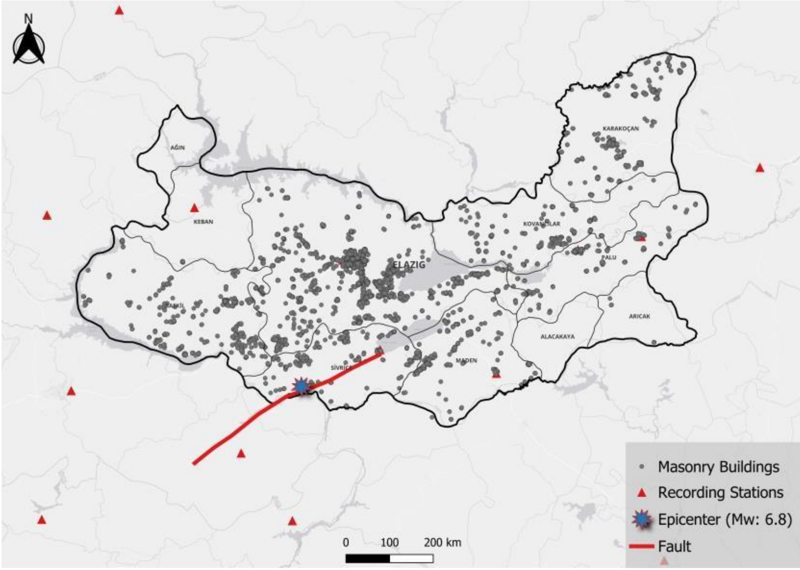

Figure 3. Spatial distribution of considered masonry buildings and epicenter of the event.

Figure 4 illustrates the damage level to buildings as a function of the year of construction and the number of stories. It is observed that there is a clear relationship between the year of construction and damage rates. As the year of construction of the building progresses, it has been observed that the buildings have been exposed to great damage. There is no such relationship between the number of floors and the damage. However, it may not be correct to comment because the rate of 3 and 4 storey buildings is very low (see Figure 1).

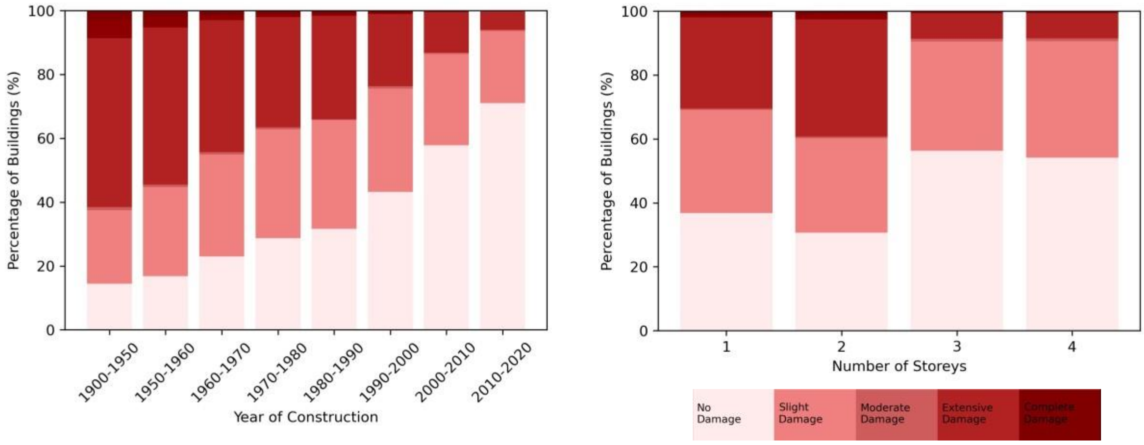

Figure 4. Damage level to buildings as a function of year of construction (left) and number of storeys (right)

Ground Motion Uncertainty

Vs30 Variability

Ground motion values are calculated by using ELER (Earthquake Loss Estimation Routine) software. In ELER software there is a default Vs30 map which comes from USGS based on the topographic slope.

In addition, a different Vs30 map based on geological age information as Quaternary, Tertiary and Mesozoic (QTM) was introduced as an input to the ELER program for use in this study. The QTM values come from the General Directorate of Mineral Research and Exploration (MTA) of Turkey. Within the QTM map, the Vs30 velocity values for the Quaternary (Q) sedimentary class are represented as 333 m/s, while the Tertiary (T) soft rock and Mesozoic (M) hard rock classes are represented as 406 m/s and 589 m/s, respectively. Figure 5 illustrates the distribution of Vs30 values around Elazig province.

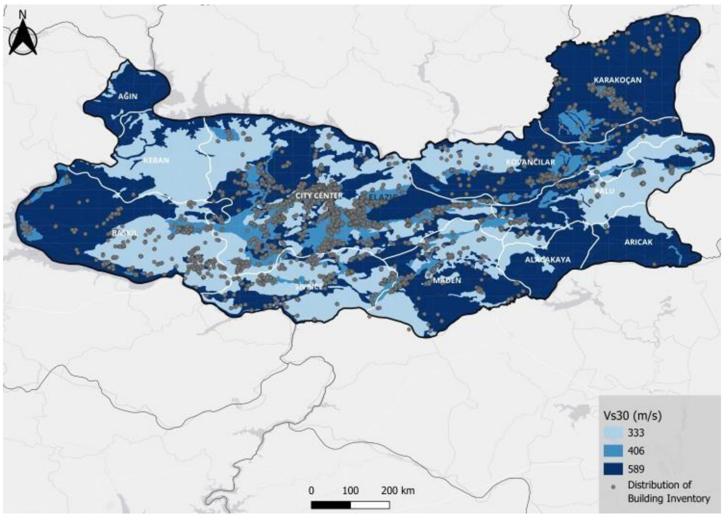

Figure 5. Vs30 values for Elazig city derived from QTM maps by the General Directorate of Mineral Research and Exploration (MTA) of Turkey

Ground Motion Models

The incorporation of uncertainty in IM is important for an accurate evaluation of the vulnerability and fragility functions as well as their confidence and prediction intervals (Ioannou et al., 2014). To minimize uncertainty and to find the optimum of the fragility curves which is the one that yields the fitted fragility curve with the smallest confidence bounds, several ground motion models were utilized in this study.

A recent study by Kale et al. (2019) has utilized several ranking methods for comparing the predictive performance of ground motion models (GMMs) for shallow crustal and active tectonic regions with the Turkish strong motion database. Analysis results indicated that the regional Kale et al. (2015) model, the Turkiye (TR)-adjusted version of the Boore and Atkinson (2008) model (Gulerce et al. 2016), and the global Chiou and Youngs (2014) model have better predictive performances when compared to other alternatives.

Çetin et al. (2021) inspect the geotechnical aspects of the 2020 January 24th, Sivrice-Elazig earthquake, and they assume that Abrahamson et al. (2014) model is satisfactory for RRUP > 10 km. Also, another recent study (Askan et al., 2021) has indicated that the global Next Generation Attenuation West 2 (NGA-W2) models developed by Abrahamson et al. (2014; ASK14), Boore et al. (2014; BSSA14), Campbell and Bozorgnia (2014; CB14), and Chiou and Youngs (2014; CY14), along with the most recent local Ground Motion Model (GMM) developed for Turkiye by Kale et al. (2015; KAAH15) have exhibited satisfactory performance on various subsets of the Turkish ground motion dataset.

As a result, five of the aforementioned models were selected and a logic tree was created with these models. Table 1 shows the selected ground motion models and logic tree ratio. For simplicity, the same weight is assigned to all five ground motion models (Akkar et al. 2014, Abrahamson et al. 2014, Boore et al. 2014, Chiou and Youngs 2014, Kale et al. 2015).

Ground Motion Model	**Abbreviation**	**Ratio**
Akkar et al. 2014	ASB14	0.2
Abrahamson et al. 2014	ASK14	0.2
Boore et al. 2014	BSSA14	0.2
Chiou and Youngs 2014	CY14	0.2
Kale et al. 2015	KAAH15	0.2
Logic Tree Model	LT	1

Table 1. Considered ground motion models and corresponding contributions of the logic three

Figure 6 shows the PGV distribution using a logic tree model with Vs30 coming from USGS and QTM values respectively. It can be seen that there is not much difference between the two maps. Figure 7 shows the distribution of masonry buildings in Elazig province for building classes and PGV bins. This figure clearly shows that the degree of damage increases as the PGV value increases.

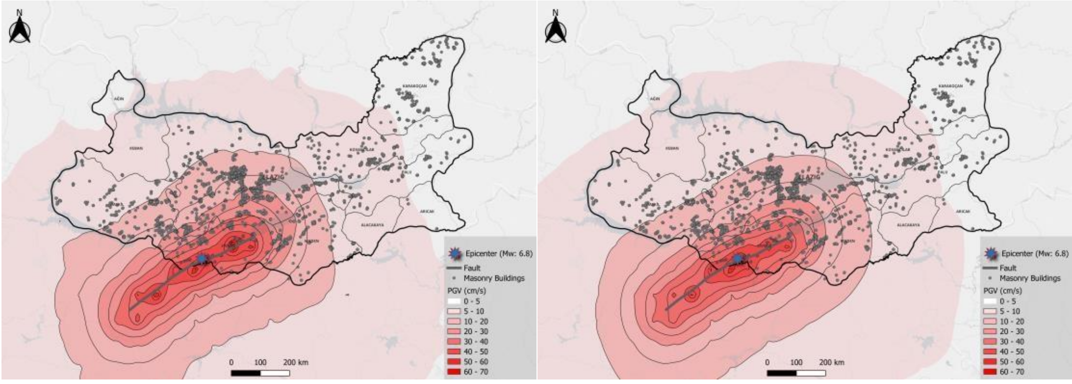

Figure 6. Distribution of PGV (cm/s) using Vs30 from USGS (left), Vs30 from QTM values (right)

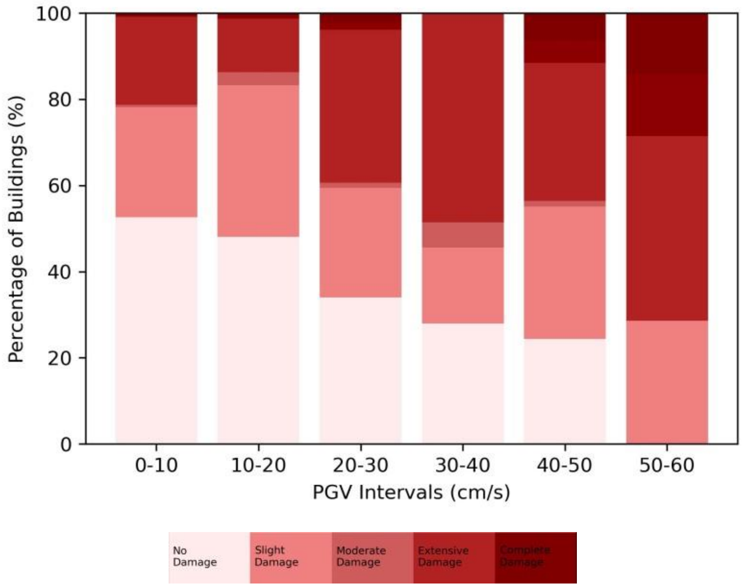

Figure 7. Distribution masonry buildings of Elazig province for building classes and PGV bins

Results

The calculation of fragility functions involved the utilization of the maximum likelihood estimation (MLE) method, as outlined by Shinozuka et al. (2000). The MLE method aims to identify the parameter vector value that maximizes the likelihood function, thereby determining the highest probability of generating the available data within a given dataset. In this study, the fragility function parameter was derived based on the assumption that the distribution of earthquake damage can be represented by the cumulative standard lognormal distribution function (Kircher et al., 1997).

Resulting fragility curves using 5 different ground motion models and logic tree models using Vs30 values from USGS and QTM maps for slight, extensive and complete damage can be seen in Figure 7, Figure 8 and Figure 9, respectively.

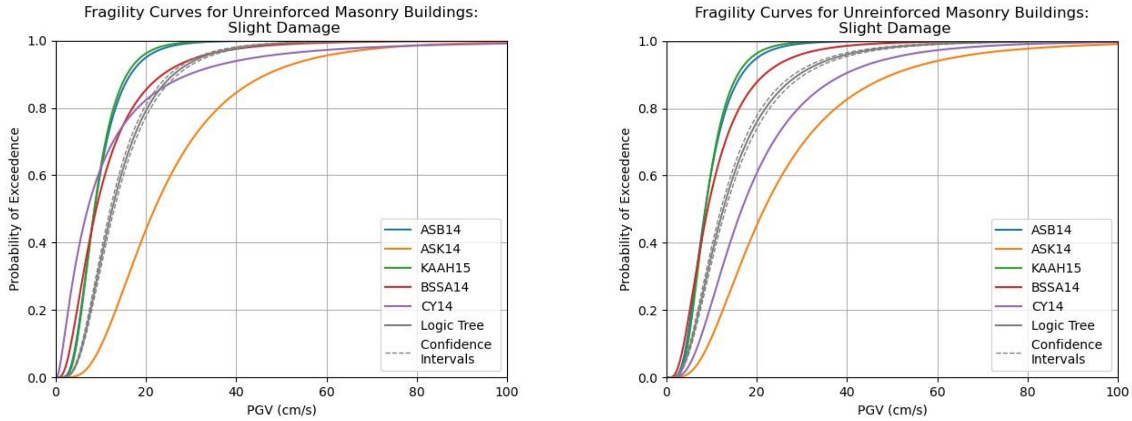

Figure 7. Slight damage fragility curves for masonry buildings using Vs30 from USGS (left) and QTM (right)

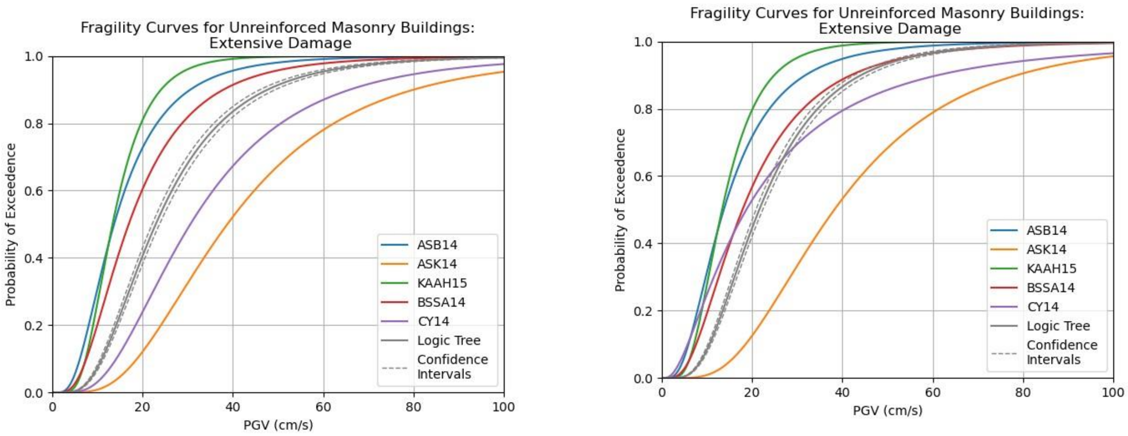

Figure 8. Extensive damage fragility curves for masonry buildings using Vs30 from USGS (left) and QTM maps (right)

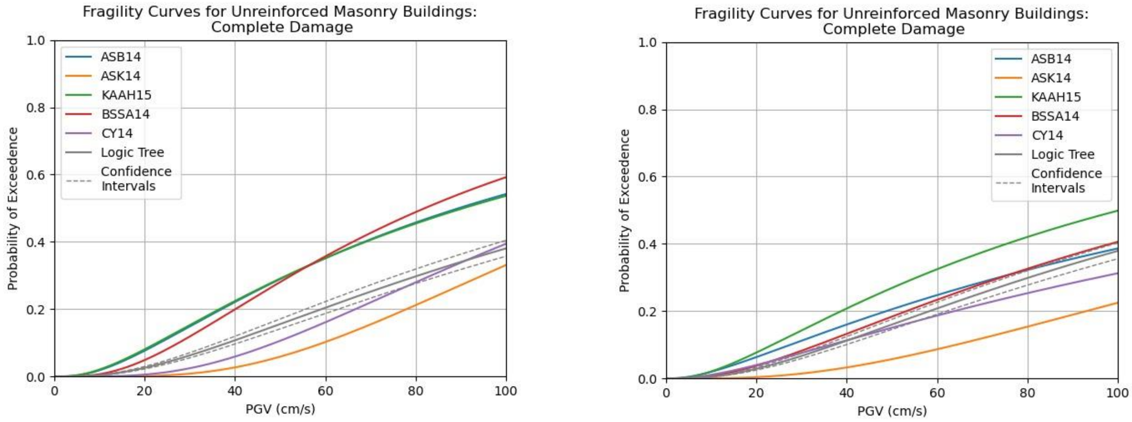

Figure 9. Complete damage fragility curves for masonry buildings using Vs30 from USGS (left) and QTM maps (right)

The resulting fragility curves derived from masonry buildings constructed before 2000 using logic tree ground motion model can be seen in Figure 9 and their parameters can be found in Table 2.

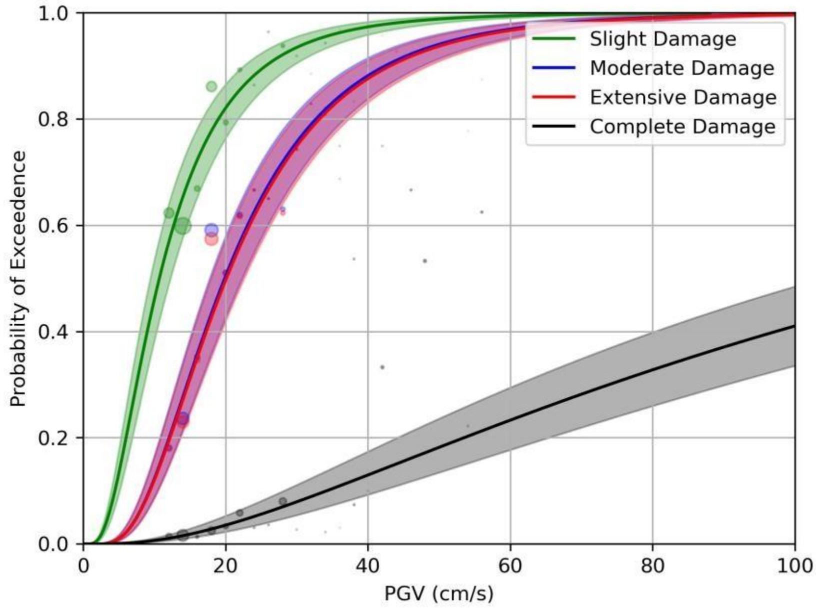

Figure 9. Fragility curves and their %95 confidence intervals for pre-2000 masonry buildings considering Vs30 from QTM maps

Damage State	**Mean**	**Standard Deviation**
Slight Damage	(9.43) 10.71 (12.27)	0.68
Moderate Damage	(17.81) 19.89 (22.38)	0.59
Extensive Damage	(18.01) 20.13 (22.67)	0.60
Complete Damage	(104.08) 125.93 (154.23)	1.01

Table 2. Fragility curve parameters for the masonry buildings (Values in parentheses indicate lower and upper confidence intervals)

Conclusions

In this study, it is aimed to assess the impact of uncertainties in ground motion intensity on empirical fragility curves for masonry structures. The study utilized data from large-scale postearthquake damage surveys conducted by the Turkish Ministry of Environment, Urbanization, and Climate Change following the Sivrice earthquakes in January 2020. Ground motions were generated using the ELER software, employing five different ground motion prediction equations (GMPEs). Also, to define the soil class of the building locations, Vs30 maps based on the topographic slope from the USGS and geological age information (QTM) by the General Directorate of Mineral Research and Exploration (MTA) of Turkey were utilized. Fragility curves were created for different damage levels and compared across the various ground motion models.

It was seen that the choice of Vs30 inputs did not significantly affect the fragility curves. This indicates that the QTM-based Vs30 values from the General Directorate of Mineral Research and Exploration (MTA) of Turkey can be used instead of USGS slope based Vs30 values.

Fragility curves for all damage states illustrate that the use of different ground motion models resulted in noticeably different curves. As a recommendation, the study proposed adopting a logic tree approach to develop a ground motion model, rather than relying on a single model, to account for the epistemic uncertainties associated with ground motion models.

Moderate and extensive damage levels are very close to each other. This could be attributed to two main factors: inadequate design with insufficient engineering services or challenges faced by damage survey teams in accurately discerning between moderate and extensive damage. This limitation represents a significant drawback of the available data.

References

Hancilar, Ufuk; Taucer, Fabio; Corbane, Christina (2013) "Empirical Fragility Functions based on Remote Sensing and Field Data after the 12 January 2010 Haiti Earthquake "Earthquake Spectra, Volume: 29, Issue: 4, Pages: 1275-1310.

Disaster and Emergency Management Presidency Situation Report on January 30th, 2020.https://en.afad.gov.tr/press-release-rehabilitation-efforts-in-elazig-and-malatya-quakezonescontinue

Rossetto, T., I. Ioannou, D.N. Grant and T. Maqsood (2014), Guidelines for empirical vulnerability assessment, GEM Technical Report 2014-08 V1.0.0, 140 pp., GEM Foundation, Pavia, Italy, doi:10.13117/GEM.VULN-MODTR2014.11

Ioanna Ioannou, John Douglas, Tiziana Rossetto, Assessing the impact of ground-motion variability and uncertainty on empirical fragility curves, Soil Dynamics and Earthquake Engineering, Volume 69, 2015, Pages 83-92, ISSN 0267-7261, https://doi.org/10.1016/j.soildyn.2014.10.024

Kale O (2019) Some discussions on data-driven testing of ground-motion prediction equations under the Turkish ground-motion database. J Earthquake Eng 23(1):160–181

Cetin, K.O., Cakir, E., Ilgac, M. et al. Geotechnical aspects of reconnaissance findings after 2020 January 24th, M6.8 Sivrice–Elazig–Turkiye earthquake. Bull Earthquake Eng 19, 3415–3459 (2021). https://doi.org/10.1007/s10518-021-01112-1

Abrahamson NA, Silva WJ, Kamai R (2014) Summary of the ASK14 ground motion relation for active crustal regions. Earthquake Spectra 30(3):1025-1055

Askan, A., Gülerce, Z., Roumelioti, Z. et al. The Samos Island (Aegean Sea) M7.0 earthquake: analysis and engineering implications of strong motion data. Bull Earthquake Eng 20, 7737–7762 (2022). https://doi.org/10.1007/s10518-021-01251-5

Boore DM, Stewart JP, Seyhan E, Atkinson GA (2014) NGA-West 2 equations for predicting PGA, PGV, and 5%-damped PSA for shallow crustal earthquakes. Earthq Spectra 30(3):1057–1087. https://doi.org/10.1193/070113EQS184M

Campbell KW, Bozorgnia Y (2014) NGA-West2 ground motion model for the average horizontal components of PGA, PGV, and 5%-damped linear acceleration response spectra. Earthq Spectra 30(3):1087–1117. https://doi.org/10.1193/062913EQS175M

Chiou BSJ, Youngs RR (2014) Update of the Chiou and Youngs NGA model for the average horizontal component of peak ground motion and response spectra. Earthq Spectra 30:11171153

Kale O, Akkar S, Ansari A, Hamzehloo H (2015) A ground-motion predictive model for Iran and Turkiye for horizontal PGA, PGV, and 5% damped response spectrum: investigation of possible regional effects. Bull Seismol Soc Am 105(2A):963–980. https://doi.org/10.1785/0120140134

Akkar, S., Sandıkkaya, M.A. & Bommer, J.J. Empirical ground-motion models for point- and extended-source crustal earthquake scenarios in Europe and the Middle East. Bull Earthquake Eng 12, 359–387 (2014). https://doi.org/10.1007/s10518-013-9461-4

Shinozuka, M., Feng, M. Q., Lee, J., and Naganuma, T., 2000. Statistical analysis of fragility curves, Journal of Engineering Mechanics (ASCE) 126, 1224–1231.

Kircher, C. A., Nassar, A. A., Kustu, O., and Holmes, W. T., 1997. Development of building damage functions for earthquake loss estimation, Earthquake Spectra 13, 663–682.