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# AN ANALYTICAL METHOD FOR SEISMIC VULNERABILITY ANALYSIS OF UNREINFORCED MASONRY BUILDINGS

Hamed AZIZI-BONDARABADI
*Assistance Professor, Department of Civil Engineering, Yazd University, Yazd, Iran*
*hamed.azizi@yazd.ac.ir*

Nuno MENDES
*Post-doc Researcher, ISISE, Department of Civil Engineering, University of Minho, Guimaraes, Portugal*
*nunomnds@civil.uminho.pt*

Paulo B. LOURENÇO
*Professor, ISISE, Department of Civil Engineering, University of Minho, Guimaraes, Portugal*
*pble@civil.uminho.pt*

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The damage caused by past earthquakes in Iran indicates that school facilities, in particular masonry schools, are an important part of the built infrastructure that is vulnerable to earthquakes. However, researches focused on seismic loss assessment of masonry buildings in Iran is scarce in the literature (see e.g. Omidvar et al., 2012). As the supplement of a study performed by Azizi-Bondarabadi et al. (2016) to generate empirical fragility curves for Iranian unreinforced masonry (URM) school buildings, the objective of the present paper is to develop a new analytical method for providing validated fragility curves and subsequently performing an economic-based vulnerability assessment. Using the available database of schools in Iran, the empirical method has been developed for four building types from URM schools located in the province of Yazd, Iran. Within the empirical method, the indices of the GNDT II level method (Benedetti & Petrini, 1984) and an index-based method developed in Iran were first evaluated for 25 schools from the four typologies. The results were then correlated to calibrate the GNDT II level method. Then, a procedure was proposed for combining the GNDT II level method and the Macroseismic method (Giovinazzi, 2005) correlating macroseismic intensity I and PGA as well as the physical damage and the damage factor. Finally and using this combination procedure, the calibrated results were employed to derive a relationship for the school typologies that is able to calculate the index $V$ of the Macroseismic method with respect to a simple index $R_i$ of the Iranian method.

Among different building types introduced in the empirical method, the analytical method proposed in this paper focuses on the building type M2s (brick walls, horizontal RC ties and RC slabs), which presents a box-type seismic behavior. 25 typical buildings were sampled as representative of the M2s population in terms of building dimensions, structural details and geometric configuration. In the case of mechanical properties, one index building was selected, meaning that the considered buildings has a typical quality class of material with three levels of central, upper bound and lower bound. The structural component model implemented in the TREMURI software (Lagomarsino et al., 2012) was adopted to simulate the 25 school buildings. Pushover analysis was performed to obtain bilinear capacity curves of each of the sampled buildings.

The method uses the damage states definition implemented in the Macroseismic method, which are consistence with the EMS-98 damage grades. The HAZUS methodology (FEMA, 2003) was used to define the median displacement capacities on each bilinear capacity curve (damage state thresholds) and to derive their equivalent median acceleration capacities in terms of PGA. To this end, combination of the basic N2 method and its extended version (Fajfar et al., 2005), proposed and validated for URM buildings by Azizi-Bondarabadi, Mendes, and Lourenço (2019) were used to determine target displacements considering higher mode effects. Based on the concept of the FaMIVE procedure (D'Ayala & Speranza, 2002), the EDPs damage state thresholds and their dispersion at each damage state were derived from the cloud of the bilinear capacity curves assuming a lognormal distribution. Modeling (capacity) dispersion due to geometric configuration, mechanical characteristics and analytical models assumptions and the record-to-record (demand) dispersion were calculated and combined. Finally, analytical fragility functions were generated in terms of intensity measure (PGA) and the inelastic spectral displacement demand for three levels of typical quality class of mechanical properties, assuming a lognormal distribution to the building generic response. A procedure was also developed to correlate the analytical and empirical fragility analysis methods. Within this procedure, the analytical method was validated with respect to the empirical method comparing an analytical-based vulnerability index with a reference index obtained empirically. Moreover, the $V$-$R_i$ relationship developed empirically for the type M2s was calibrated with respect to the analytical results. Figure 1-a shows the comparison between the two methods. From the correlation procedure, two vulnerability modifiers were also derived by which the empirical fragility functions can be extended for different material quality levels. Finally, the vulnerability analysis was done using the probabilities resulting from the analytical fragility functions and the monetary-based damage factors obtained within the empirical method (see Figure 1-b).

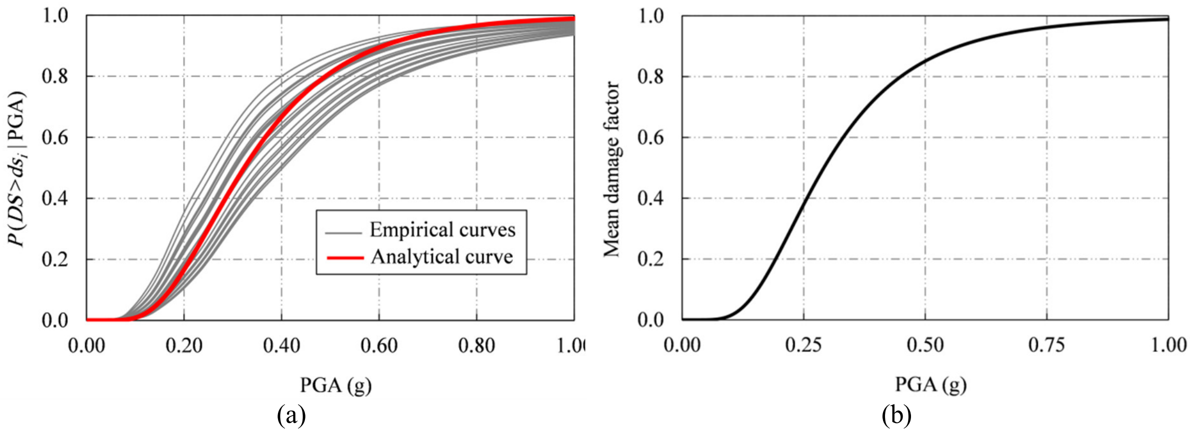


*Figure 1. Final results of the analytical vulnerability analysis for the type M2s (a) Comparison between the analytical fragility curve of very heavy damage and the empirical curves obtained for 25 sampled buildings; (b) Mean vulnerability curve obtained with typical class of material quality.*

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