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SEISMIC RISK ASSESSMENT OF EXISTING MASONRY BUILDINGS: A COMPARISON BETWEEN DIFFERENT METHODS

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Abstract

As evidenced by many earthquakes occurred from the past to more recent ones, Italy is a country strongly affected by seismic risk. Consequently, the scientific community has always focused its efforts in understanding how to reduce seismic risk and how to prioritize the required interventions. To this, it should be added that, due to limited economic resources, nowadays a new design strategy is pursued, consisting in reducing the seismic risk for as many existing buildings as possible, rather than allocating all the available economic resources for few buildings for increasing their safety level up to the new buildings one.
In this paper, the seismic risk assessment of a case study, an existing masonry building, is performed according to two methods: the conventional method reported in the Italian M.D. 65/2017 for seismic risk classification of existing buildings, requiring the pushover curves of the building investigated; a probabilistic approach based instead on the fragility curves, derived from a macro-seismic analysis of masonry buildings stocks available in Da.D.O. database. Finally, the study also shows the results in terms of EALs obtained with parametric fragility curves by varying some buildings characteristics.

Keywords: Expected Annual Losses, Fragility Curves, Nonlinear Static Analysis, Seismic Risk Assessment.

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1 INTRODUCTION

Among all the existing building typologies, certainly those of masonry constitute a substantial part of them.

As a consequence of this, the scientific community over time has spent many efforts in developing methodologies for properly assessing the seismic vulnerability and the related risk of these constructions. For instance, among the others, many studies have been addressed to numerical model masonry buildings [1, 2, 3], also having a historical value [4, 5, 6]. How the resulting seismic risk may vary considering some interventions has been investigated in [7, 8, 9].

In this paper, the seismic risk assessment on a case study is carried out. The Expected Annual Losses (EALs) are determined, considering both the conventional method reported in the Italian M.D. 65/2017 for seismic risk classification of existing buildings [10], and a probabilistic approach starting from fragility curves [11] derived with a macro-seismic analysis based on damage data available in Da.D.O. [12, 13, 14]. Lastly, parametric fragility curves are derived from a macro-seismic analysis starting from damage data related to some existing masonry buildings stocks, permitting a comparison in terms of EALs.

2 CASE STUDY DESCRIPTION

The case study examined is an Italian existing masonry building, having an L-shaped configuration in plan and four levels. The masonry is made by irregular soft stone with the recursive presence of two rows of regular brick layers. Locally, under the windows it has been found that masonry is made by solid brick masonry. To the solid brick masonry with lime mortar and irregular soft stone masonry, the self-weight of 18 kN/m³ and 16 kN/m³ have been assigned respectively [15]. Floors are made of hollowed bricks with a concrete slab. According to the Italian standards [15, 16], in this study it is assumed: a reference period V_R = 75 years, corresponding to a minimum level of seismic protection, with a Nominal Life V_N = 50 years and a Class of Use III [16]; a category B for the subsoil [16]; a Knowledge Level (KL) KL2, with a Confidence Factor (CF) equal to 1.2 [15]. Finally, the building is considered located in Rome.

A 3D view of the case study, modeled using the software 3Muri Professional [17], is shown in Figure 1.

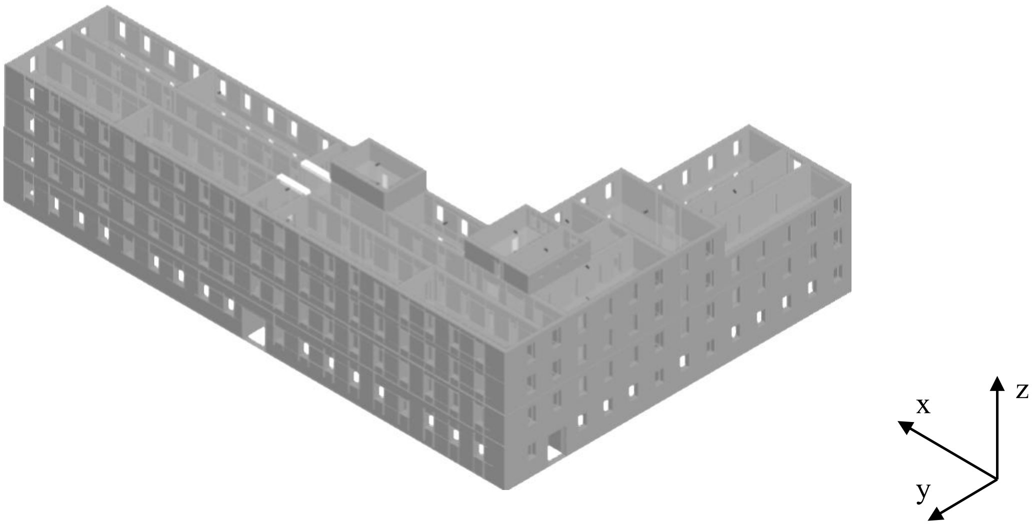


Figure 1: The existing masonry building considered. View of the 3D model made in [17].

3 SEISMIC RISK ASSESSMENT

This section reports the analyses performed on the case study previously described, aimed at assessing seismic risk in terms of EALs. Firstly, pushover analyses are conducted [15] to derive the structure capacity curve. Particularly, as already stated, the software 3Muri Professional [17] is used, involving the application of the Equivalent Frame Model.

At first, the seismic risk is assessed according to the conventional method proposed in [10], where a Risk Class is estimated, that is based on pushover curve of the considered structure. Then, a probabilistic approach is applied for evaluating the resulting EALs [11, 18, 19, 20, 21]. In this case fragility curves are required. In this study they are derived from damage data of existing buildings stocks stroke by the recent earthquake of "L'Aquila 2009", "Emilia 2012" and "Centro Italia 2016-2017" [9, 22], and archived within the Database of Observed Damage Da.D.O. [12, 13, 14]. Finally, a comparison in terms of EALs obtained with the two methods is made. Also, the results obtained from the derivation of parametric empirical fragility curves are illustrated.

3.1 Seismic risk assessment according to M.D. 65/2017

In total, 24 nonlinear pushover analyses are carried out, along +X, -X, +Y and -Y directions, using two force distributions (i.e., uniform and proportional to the first mode), and also taking into account accidental eccentricity at each floor. Figure 2 plots all the pushover curves, along X direction (Figure 2a) and along Y direction (Figure 2b). In the same figures, it is also highlighted the pushover curve considered in this study for evaluating the seismic risk. It is based on the search for the lowest value of the seismic vulnerability parameter (i.e., the safey index IS-V [10]).

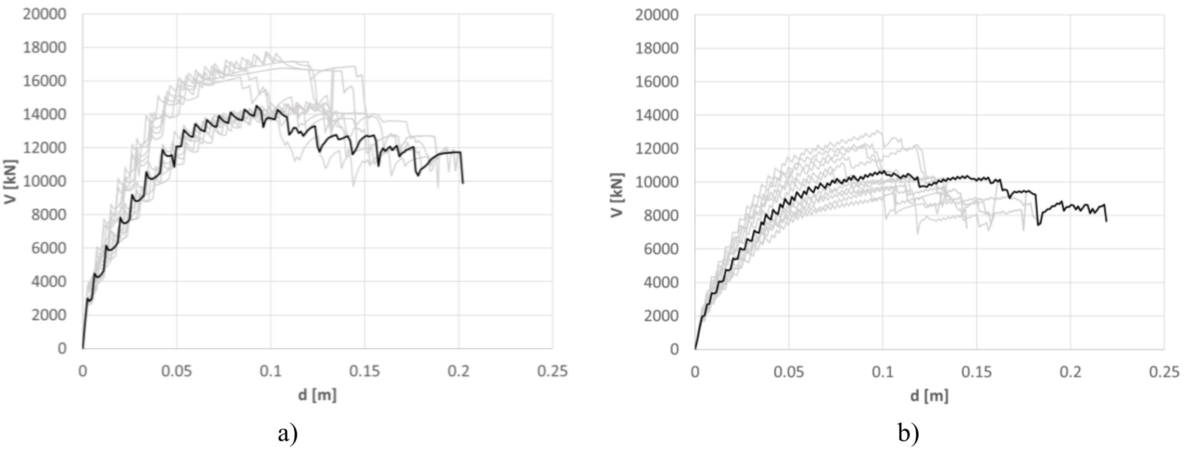


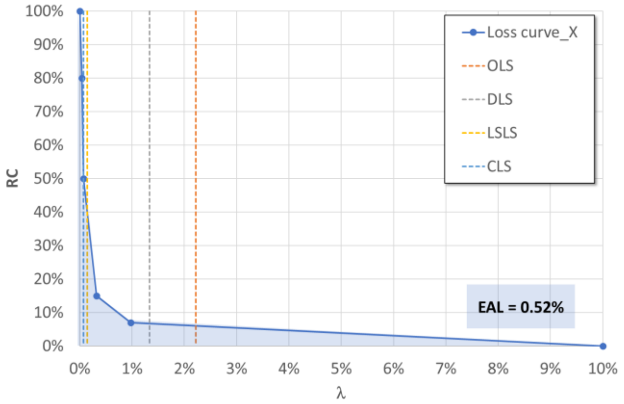
Figure 2: Pushover curves obtained along a) X and b) Y directions provided by [17].

Then, loss curves may be derived. They correlate the mean annual frequency of exceedance, indicated as λ, of the seismic action corresponding to the achievement of the Limit States to the related Reconstruction Cost (RC) [10]. Figure 3a and Figure 3b report the loss curves obtained for X and Y directions. In addition, the safey index IS-V is required, representing the ratio between the Peak Ground Acceleration (PGA) measuring the structure capacity and the expected PGA, calculated by referring to V_R = 75 years. Both PGAs are referred to the Life-Safety Limit State (LSLS).

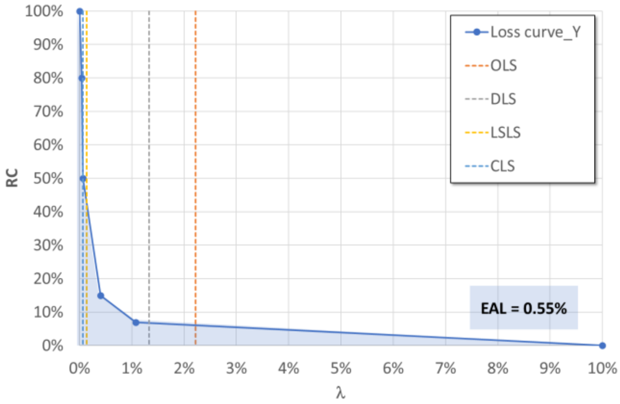
Finally, for the existing building considered the corresponding EAL is the maximum value obtained between the two directions considered, while, on the contrary, the corresponding value of IS-V is the minimum one. In this case, the following values are obtained:

- EAL = 0.55%, i.e., EAL Class A (0.50% < EAL ≤ 1% [10]);
- IS-V = 121%, i.e., IS-V Class A^{+} (100% < IS-V [10]).

The Risk Class is the worst class between EAL Class and IS-V Class, hence in this case it corresponds to Class A. The low-risk class in this case is given to the fact the building under consideration is located in an area with a low seismic hazard.



a)



b)

Figure 3: Loss curves for a) X and b) Y directions (OLS: Operativity Limit State; DLS: Damage Limit State; LSLS: Life-Safety Limit State; CLS: Collapse prevention Limit State).

3.2 Seismic risk assessment according to a probabilistic approach

According to this method [11], fragility curves are derived performing, as previously introduced, macro-seismic analyses starting from damage data after surveying existing buildings suffering some recent Italian earthquakes, such as “L'Aquila 2009”, “Emilia 2012” and “Centro Italia 2016-2017” earthquakes. These damage data are to date available within Da.D.O. database [12, 13, 14].

In particular, seismic fragility curves are derived by considering sample of buildings having the following characteristics:

- Floors number: 4;
- Underground floors: 0;
- Location: isolated;
- Masonry having a regular-texture and a good-quality, both without and with tie-rods or reinforced concrete ring beams, and with horizontal structures consisting of beams with rigid slab;
- Heavy and not-pushing roofing.

The fragility curves are obtained by following the procedure adopted in [23], including the database completion. They are shown in Figure 4.

Then the EAL is calculated as follows [19]: the damage probability curves are derived from the fragility curves; the typological economic loss curves, independent on a specific site seismic hazard, are obtained using the consequence correlations expressed in terms of Reconstruction Cost percentage for each Limit State [10]; the EAL is derived from the economic loss curves for each damage level, considering a law $\lambda = \lambda(IM)$ specific for the reference site (IM represents the Intensity Measure); finally, the EAL is determined as the area subtended by the loss curve.

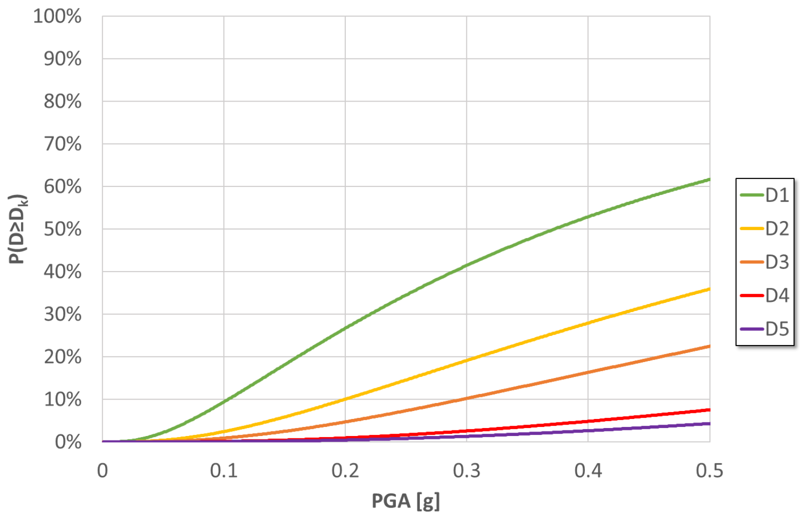


Figure 4: Empirical fragility curves.

According to the probabilistic method adopted, Figure 5 depicts, in logarithmic scale, the seismic hazard values available for the city of Rome, by considering the Peak Ground Acceleration (PGA) as Intensity Measure (IM). Moreover, in the same graph the closed form of the seismic hazard curve, as proposed in [18], is reported.

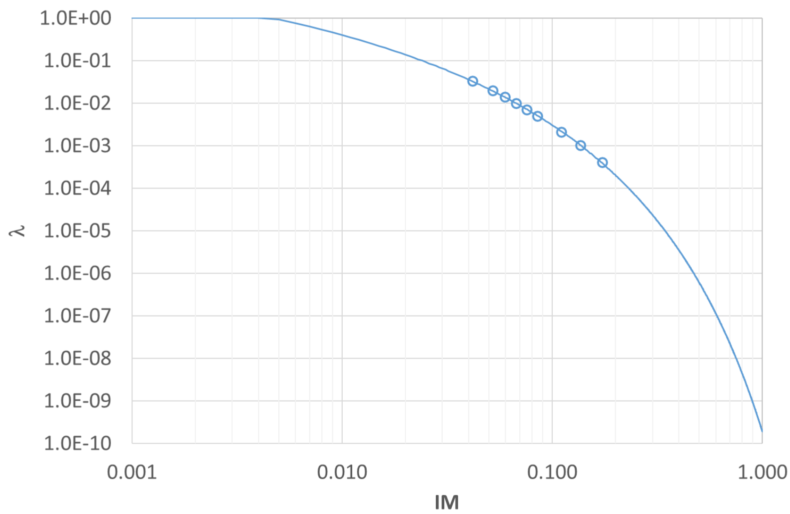
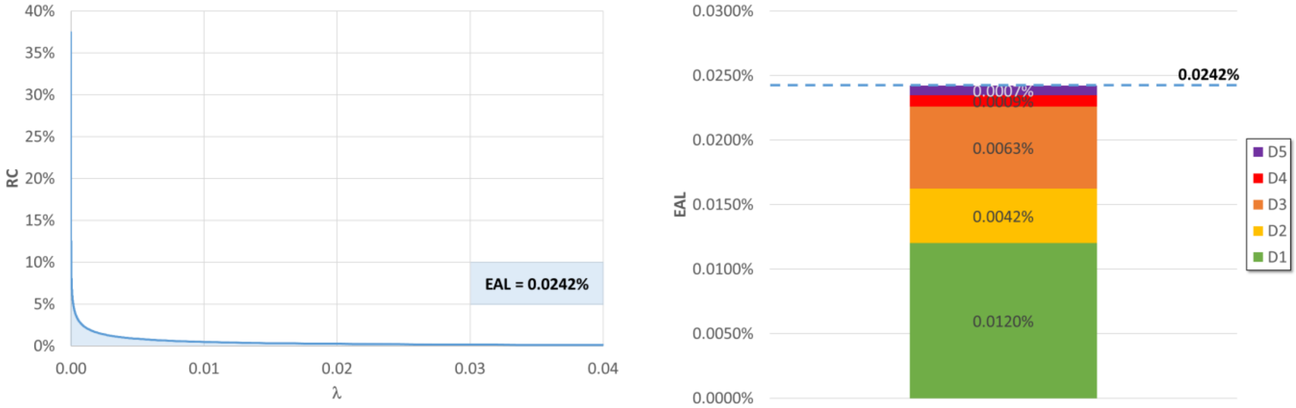


Figure 5: Seismic hazard curve according to [18].

The loss curve obtained is plotted in Figure 6a, providing a EAL of 0.0242%. This value, coherently with the conventional method proposed in [10], would correspond to an EAL Class A^+ [10].

The EAL found with this method is significantly lower than the one found with the conventional method. Figure 6b shows how the "partial EAL" given to each damage state contributes to the resulting EAL. It is interesting to note as, in the case analyzed, the first three damage states (i.e., D1, D2 and D3) significantly contributes to the resulting EAL. These damage states refer to the serviceability Limit States.



a) b)

Figure 6: a) Loss curve and b) EAL from the empirical fragility curves.

3.3 Parametric seismic risk assessment from empirical fragility curves

In this study also a parametric seismic risk assessment is conducted, with the aim of investigating how some buildings details may affect the related fragility curves and the resulting EAL.

To this scope, from Da.D.O. database the sample of masonry buildings having four stories, no underground floors and heavy and not-pushing roofing is considered, while two characteristics are varied, that are: the masonry texture and the slab type. Again, damage data related to "L'Aquila 2009", "Emilia 2012" and "Centro Italia 2016-2017" earthquakes are analyzed. From this buildings stock, six sub-samples are extracted and analyzed for deriving fragility curves. The procedure proposed in [23] is adopted, with a completion criterion.

Table 1 summarizes all the sub-samples chosen, indicating the variable characteristics and also reporting the acronym assigned.

Acronym	Masonry texture	Slab
IF	Irregular	Flexible
ISR	Irregular	Semi-Rigid
IR	Irregular	Rigid
RF	Regular	Flexible
RSR	Regular	Semi-Rigid
RR	Regular	Rigid

Table 1: Sub-samples considered.

Figure 7 reports the empirical fragility curves obtained, and the resulting EALs are plotted into Figure 8, calculated with the probabilistic approach. As it was easy to expect, one may note that if the slab type is the same, the irregular masonry texture provides a resulting EAL higher than the one obtained in the case of regular texture. Moreover, within the same texture quality, if the slab stiffness increases the resulting EAL reduces. The EALs values obtained are ranging from 0.03% for RR to 0.39% for IF.

It should be noted that, for each sub-sample considered, the EAL is always lower than 0.50% (as mentioned above, the minimum EAL is 0.03% for RR, while the maximum is 0.39% for IF). All the examined sub-samples would provide, according to the conventional method, a Risk Class A^+.

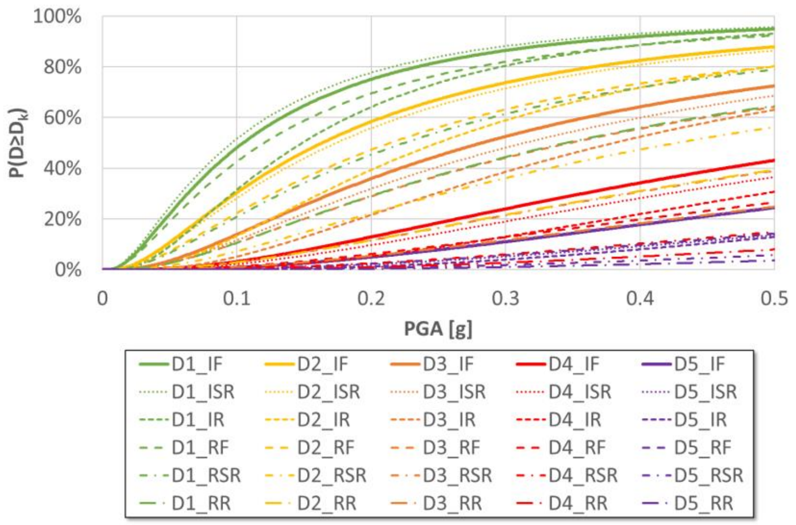


Figure 7: Empirical fragility curves for the sub-samples considered.

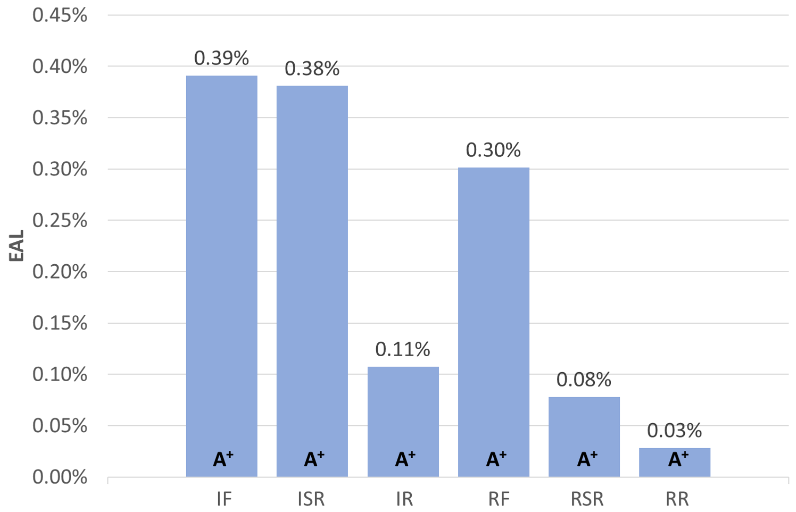


Figure 8: Sub-samples EALs from empirical fragility curves.

4 CONCLUSIONS

The study presented focused on the seismic risk assessment of existing masonry buildings. In particular, at first a case study is investigated for estimating the seismic risk in terms of EAL according to two different methods: the conventional method proposed by the Italian M.D. 65/2017; and the probabilistic one [11] based on the fragility curves, derived with a macro-seismic analysis of seismic damage data collected within the Da.D.O. database. In the case analyzed, a higher EAL with the conventional method is obtained than the one estimated with the probabilistic approach.

In addition, a parametric seismic risk analysis has been performed, by considering several fragility curves typologies. The results obtained, in terms of EALs, demonstrate that the seismic risk assessment is significantly influenced by buildings details, such as the masonry texture and the slab stiffness. This highlights the importance of having typological fragility curves to be implemented within the seismic risk framework, capable of better reflecting the characteristics of the sample investigated.

In future, further developments may involve the comparison in terms of EALs by varying the building Knowledge Level and including also the interventions.

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