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SHORT COMMUNICATION

Fatality rates implied by the Italian building code

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Abstract

The project *Rischio Implicito – Norme Tecniche per le Costruzioni* (RINTC) assessed the seismic structural reliability, in terms of the annual rate of earthquakes causing failure, of a large set of code-conforming buildings, designed to be located in three different sites, representative of low, mid, and high seismic hazard in Italy. It was found that seismic reliability tends to decrease significantly as the site's hazard increases, despite the design actions having the same return period at all sites. Because this is a consequence of the code's approach, the simple study presented in this paper aims to contribute to the discussion on whether the code-implied safety is yet acceptable. To this end, the annual fatality rates due to the seismic failure of the buildings from the mentioned project are computed, in a simplified manner, and compared with the annual risk from other common causes of death in Italy; the latter obtained based on data from the Italian Statistical Institute. The results, although subjected to the conventionality of the working assumptions, seem to indicate that seismic fatality risk is generally lower than that of other causes of death, by one or more orders of magnitude at the lower hazard sites. This can contribute to the discussion on seismic structural safety due to the characteristics of the Italian code that are common to state-of-the-art codes internationally.

KEYWORDS
structures, earthquakes, reliability, risk, safety

1 | INTRODUCTION

The Italian building code[1] is based on *capacity design* and has design seismic actions determined via *probabilistic seismic hazard analysis* (PSHA).[2] It has its roots in Eurocode 8[3] (EC8) and can be generally considered to be of state-of-the-art level, even if it does not entail quantification of the reliability implied by design, whose absence is commonplace in modern seismic codes (an advancement to this approach is the so-called *risk-targeted* design, which, however, yet has to find its way in building codes).

An extensive research program in Italy, *Rischio Implicito – Norme Tecniche per le Costruzioni* or RINTC[4] (2015–2017) evaluated the seismic structural reliability of several code-conforming, residential and industrial, buildings located at three sites that can be considered as representative of low, mid, and high hazard in Italy. Hundreds of buildings from these typologies, with various configurations, were designed, modeled, and analyzed. The seismic reliability metric adopted is the expected number of earthquakes that, in 1 year, cause a certain seismic performance that identifies failure, that is, the *failure rate*. Two performances were considered, they are related to impeded usability and life-threatening failure. The computation of the failure rates, followed the *performance-based earthquake engineering* (PBEE) paradigm,[5] that entails integrating the structural *fragility* with the site's *hazard curves*.

The most relevant result of the project was that the reliability systematically tends to decrease as the hazard of the site can be considered more severe.[4] Further research attributed that to the effect of code-prescribed minima and gravity-load design in low, and possibly mid hazard sites, as well as the impact on the reliability of ground motions with return periods larger than those considered in design.[6] This may spark concerns, as the law rationally postulates homogeneous safety measured, for example, via *fatality rates* for similar buildings designed across the country. On the other hand, it may be argued that even spatially variable safety is still acceptable if compared to other risks. To contribute to this debate, in the simple study presented in the following, the fatality risk caused by the structural failure of code-conforming buildings is computed in a simplified manner and compared to other risks that building residents may be exposed to; for example, some diseases or fatal accidents. Because the assessment of the fatality risk for code-conforming buildings requires significant working assumptions and a degree of conventionality, the rates were computed following two alternative approaches. To evaluate the other risks for the comparison, the death rates due to common causes were derived from national and local data of the *Istituto Nazionale di Statistica* (ISTAT).

The remainder of this note is structured so that in the next section the RINTC project is briefly recalled, followed by a description of the approaches adopted to evaluate the fatality rates. Subsequently, the risk related to some other death causes in Italy is computed and compared to the seismic fatality risk. Some conclusions end the short paper.

2 | THE SEISMIC RELIABILITY OF CODE-CONFORMING STRUCTURES IN ITALY

As mentioned above, in the RITNC project a large set of buildings was designed according to the current Italian building code, and their seismic reliability was evaluated. More specifically, five structural typologies were considered to represent as much as possible residential and industrial standard contemporary Italian constructions. As these structures were extensively discussed in dedicated literature,[7] only a brief summary is given here.

- Unreinforced masonry structures (URM): Two- and three-story residential buildings made of perforated clay units with mortar joints, with varying architectural configurations and wall thickness, comprising both regular and irregular structures, according to the definition provided by the code.
- Reinforced concrete (RC): Three-, six-, and nine-story moment-resisting frame buildings (MRF), regular in plan and elevation, under different configurations (bare-frame or BF, infilled-frame or IF, and *pilotis*-frame or PF) with or without shear walls (SW).
- Steel (S): Single-story rectangular industrial buildings featuring MRFs in the transverse direction and concentrically braced frames placed in the outer spans of the frame in the longitudinal direction; four different configurations were considered, with varying transverse and longitudinal bay widths.
- Precast reinforced concrete (PRC): Single-story industrial buildings with fixed-base columns fixed and connected, at the top, to prestressed beams via dowel connections; four different configurations were considered varying transverse and longitudinal bay widths and the story height.
- Base-isolated reinforced-concrete buildings (BI): Six-story infilled MRF building isolated considering three isolation systems, that is, double-curvature friction pendulums (FPS), high damping rubber bearings (HDRB), and a hybrid system made of HDRB's and sliders (SLDR).

These structures were designed in three Italian sites characterized by low, mid, and high hazard, that is, Milan (MI), Naples (NA), and L'Aquila (AQ), respectively (Figure 1, left) and for two different soil site conditions (i.e., soil A and soil C according to the EC8 classification). (Note that the Italian code allows design URM of buildings even in high seismicity areas; however, simplified design methods for URM cannot be used for buildings with the number of story larger than three when the PGA with 475-year return period is larger than 0.35g.)

Design referred to code's *damage* and *life-safety* limit states, which correspond to ground motion intensity with 50- and 475-year exceedance return period (Tr), respectively; Table 1 summarizes the structures analyzed (note that for some RC structures soil–structure interaction [SSI] and model uncertainty [MU] was also considered, although it was found that both have a relatively minor impact on the reliability).

The seismic reliability of these structures was assessed considering the two performance levels, or damage states, defined in the project: *usability-preventing damage* (UPD) and *global collapse* (GC). The onset of UPD is based on whether one of the following conditions occurs: (i) light damage in 50% of main nonstructural elements (e.g., infills); (ii) severe

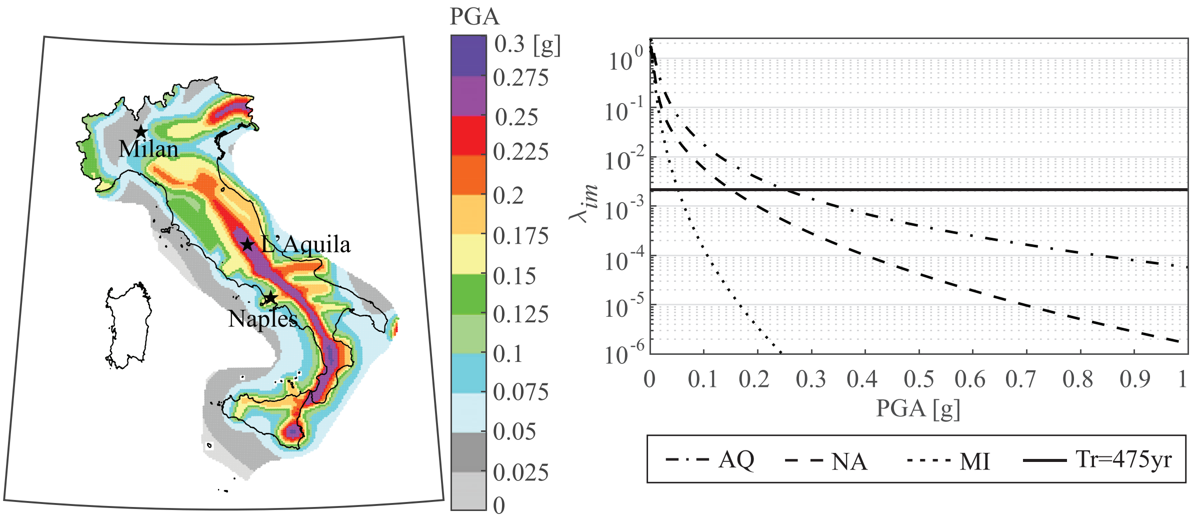

FIGURE 1 Left: Italian map of the seismic peak ground acceleration (PGA) on rock, which is exceeded at any site on average every 475years (used by the code). Right: PGA (rock) hazard curves for the three sites at which the structures are designed

TABLE 1 Structures for which seismic structural reliability has been evaluated in RINTC project

	AQ – soil A	AQ – soil C	NA – soil A	NA – soil C	MI – soil A	MI C – soil C
URM 2-st.	4 – Configs	6 – Configs	3 – Configs	4 – Configs	4 – Configs	3 – Configs
URM 3-st.	3 – Configs	–	4 – Configs	6 – Configs	4 – Configs	4 – Configs
RC 3-st. MRF	–	IF, BF, PF	–	IF, BF, PF	–	IF, BF, PF
RC 6-st. MRF	–	IF, BF, PF	–	IF, BF, PF, IF-MU, BF-MU, PF-MU	–	IF, BF, PF
RC 9-st. MRF	IF, BF, PF	–	–	IF, BF, PF	–	IF, BF, PF
RC 9-st. SW	IF-SSI, BF-SSI, PF-SSI	IF, BF, PF	IF, BF, PF	IF, BF, PF	–	IF, BF, PF
S	4 – Configs	4 – Configs	4 – Configs	4 – Configs	4 – Configs	4 – Configs
S w/cladding	4 – Configs	4 – Configs	4 – Configs	4 – Configs	4 – Configs	4 – Configs
PRC	4 – Configs	4 – Configs	4 – Configs	4 – Configs	4 – Configs	4 – Configs
BI	–	HRDB, FPS, HDRB+SLDRS	–	HRDB, FPS, HDRB+SLDRS	–	–

damage level in at least one of the nonstructural elements; (iii) first attainment of 95% of the maximum base-shear of the structure. The GC criterion is based on the deformation capacity (the roof displacement or the inter-story drift ratio) corresponding to 50% strength decay from the static nonlinear capacity curve of the structural model.

The seismic structural reliability was quantified via the failure rate, $\lambda_{f,\mathrm{DS}}$, computed as

$$\lambda_{f,\mathrm{DS}} = \nu \cdot \int_{0}^{+\infty} P\left[F_{\mathrm{DS}} \left| \mathrm{IM} = x \right.\right] \cdot f_{\mathrm{IM}}(x) \cdot dx, \tag{1}$$

where, $P[F_{\mathrm{DS}}|\mathrm{IM} = x]$ is the probability of failure corresponding to a certain damage state (DS), when DS ≡ GC or DS ≡ UPD, given the value of a (nonnegative) ground motion intensity measure (IM), that is, the seismic fragility of the structure; ν is the rate of earthquakes above a minimum magnitude of interest affecting the construction site; $f_{\mathrm{IM}}(x)$ is the probability density function of the IM at the site, given the occurrence of an earthquake among those the ν rate refers to. It is useful for the following to acknowledge that the integral in Equation (1) is just the failure probability (i.e., reaching or exceeding the damage state DS), given an earthquake among those the ν rate refers to. Indicating such a probability as $P[F_{\mathrm{DS}}|E]$, the equation can be written as $\lambda_{f,\mathrm{DS}} = \nu \cdot P[F_{\mathrm{DS}}|E]$. It is also noted that the product $\nu \cdot f_{\mathrm{IM}}(x)$ is the absolute value of the derivative – yet multiplied by dx – of the hazard curve for the site, computed via PSHA. The hazard curve provides, for any value of IM, say im=x, its annual rate of exceedance, which will be indicated as λ_{im}.[9]

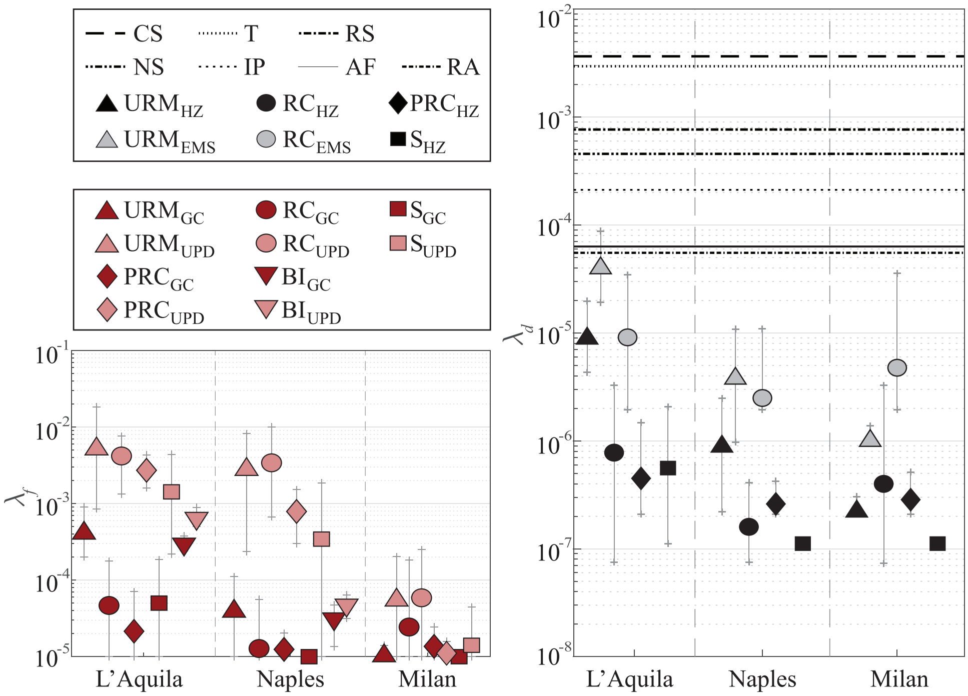

FIGURE 2 Left: Average seismic failure rates for the considered code-conforming buildings as resulting from the RINTC project. Right: Annual seismic fatality rates, computed with the HAZUS (HZ)- and the Zuccaro–Cacace (EMS)-based methods, in comparison with other risks in Italy. (vertical bars provide the range of rates for each typology)

The seismic structural response was evaluated via nonlinear dynamic analyses on three-dimensional nonlinear models, selecting the input seismic records via a hazard-consistent approach. In the analyses, the domain of the chosen IM (i.e., pseudo-spectral acceleration at a period close to the one fundamental of each structure) was discretized considering the IM values corresponding to 10 exceedance return periods (from 10^1 to 10^5 years) at the site.

In the RINTC project, the fragility curves were evaluated by means of the Shome and Cornell approach,[10] and discretizing the integral in Equation (1) at the 10 IM values at which dynamic analysis was performed. However, for the sake of the study presented herein (i.e., to improve with respect to the described integration procedure), the failure rates were recomputed by fitting lognormal fragility functions against the MSA results via the R2R-EU software.[11] Consequently, the hazard curves for the three sites were also recomputed via the REASSES software,[12] implementing branch 921 of the official Italian hazard model (i.e., that shown in Figure 1).[8]

The resulting failure rates are given in Figure 2 (left) for both considered performances. For representation purposes, for each typology, the rates are shown in terms of average taken across the failure rates of the analyzed buildings belonging to that typology. (In the figure, rates below 10^{-5} were set equal to 10^{-5}, as low failure rates are based on significant extrapolation of seismic hazard models.) One can see from the figure that the rates tend to decrease with the decreasing hazard for the site. The reason is two-fold: first, the code-prescribed minimum design requirements and gravity-load design tend to dominate in low and possibly mid hazard sites (i.e., Milan and Naples) ensuring larger seismic reliability in comparison to the design for L'Aquila. The second reason is that the structures were designed against seismic actions with maximum return period of exceedance equal to 475 years. However, it has been established that ground motions intensity beyond 475 years is disproportionally larger at L'Aquila with respect to Naples and Milan; that is, the so-called *peak-over-threshold*[13] that can lead to lower seismic reliability in the high hazard site. This can be seen in Figure 1 (right), where the PGA (on rock) hazard curves show a significant difference in shape for return periods beyond 475 years.

3 | SEISMIC FATALITY RATES

The fatality rates, λ_d, for the structures discussed above can be interpreted as the expected number of earthquakes (above the minimum magnitude of interest) to cause fatality, and can be seen as the product of the probability of dying given the occurrence of the seismic event, $P[D|E]$, and the rate of earthquake occurrence at the construction site. Applying the total probability theorem, the fatality rate can be computed as

$$\lambda_d = \nu \cdot P\left[D\left|E\right.\right] = \nu \cdot \sum_{i=1}^{n} P\left[D\left|\mathrm{DS}_i\right.\right] \cdot P\left[\mathrm{DS}_i\left|E\right.\right] = \nu \cdot \sum_{i=1}^{n} P\left[D\left|\mathrm{DS}_i\right.\right] \cdot \left(P\left[F_{\mathrm{DS}_i}\left|E\right.\right] - P\left[F_{\mathrm{DS}_{i+1}}\left|E\right.\right]\right)$$
$$= \sum_{i=1}^{n} P\left[D\left|\mathrm{DS}_i\right.\right] \cdot \left(\lambda_{f,\mathrm{DS}_i} - \lambda_{f,\mathrm{DS}_{i+1}}\right) = P\left[D\left|\mathrm{UPD}\right.\right] \cdot \left(\lambda_{f,\mathrm{UPD}} - \lambda_{f,\mathrm{GC}}\right) + P\left[D\left|\mathrm{GC}\right.\right] \cdot \lambda_{f,\mathrm{GC}}, \quad (2)$$

where n is the number of the considered damage states, $P[D|\mathrm{DS}_i]$ is the probability of death given the reaching of the i-th damage state, and $P[\mathrm{DS}_i|E]$ is the probability that the structure is in the i-th DS given earthquake occurrence, which can be computed as the difference of the failure probability related to the DS_i and DS_{i+1} states. The last equality in Equation (2) shows what the computation is reduced to, by only considering the UPD and GC damage states and with $P[D|\mathrm{DS}]$ left to be determined. Herein, $P[D|\mathrm{DS}]$ has been calculated following two alternative methods.

3.1 | Method 1

The first method is based on Tsang and Wenzel,[14] where $P[D|\mathrm{DS}]$ is equal to the fatality rate, given structural damage, from HAZUS.[15] In particular, $P[D|\mathrm{GC}]$ is computed considering that GC corresponds to *complete structural damage* (CSD), as per the HAZUS terminology, and distinguishing between *indoor* (in) or *outdoor* (out) probability of death:

$$P\left[D\left|\mathrm{GC}\right.\right] = P\left[D\left|\mathrm{GC,in}\right.\right] \cdot P\left[\mathrm{in}\left|\mathrm{GC}\right.\right] + P\left[D\left|\mathrm{GC,out}\right.\right] \cdot \left\{1 - P\left[\mathrm{in}\left|\mathrm{GC}\right.\right]\right\}. \quad (3)$$

In the equation, $P[\mathrm{in}|\mathrm{GC}]$ is the probability of being indoor at the time of failure, and it is assumed to be equal to 0.9. The probability of death occurring indoors is computed by further distinguishing whether GC leads to *collapse* (note that *collapse* as per the HAZUS terminology does not coincide with the GC according to the RINTC project):

$$P\left[D\left|\mathrm{GC,in}\right.\right] = P\left[D\left|\mathrm{GC,in,collapse}\right.\right] \cdot P\left[\mathrm{collapse}\left|\mathrm{GC}\right.\right] + P\left[D\left|\mathrm{GC,in,nocollapse}\right.\right] \cdot \left\{1 - P\left[\mathrm{collapse}\left|\mathrm{GC}\right.\right]\right\}. \quad (4)$$

$P[\mathrm{collapse}|\mathrm{GC}]$ is taken from HAZUS for each structural typology. (In fact, the fatality rates for the BI could not be computed because this typology is not covered in terms of required fatality model.)

HAZUS considers fatality for different injury severity levels; herein, *severity 3*, that is injury that poses an immediate life-threatening condition if not treated adequately and expeditiously, and *severity 4*, that is *instantaneously killed* or *mortally injured*, were considered. Therefore,

$$P\left[D\left|\mathrm{GC,in,collapse}\right.\right] = P\left[severity3\left|\mathrm{GC,in,collapse}\right.\right] + P\left[severity4\left|\mathrm{GC,in,collapse}\right.\right]. \quad (5)$$

The same applies for $P[D|\mathrm{GC,in,nocollapse}]$ and $P[D|\mathrm{GC,out}]$. Finally, for $P[D|\mathrm{UPD}]$, the same approach is followed, with UPD corresponding to *moderate structural damage* in HAZUS; in this case $P[\mathrm{collapse}|\mathrm{UPD}] = 0$.

3.2 | Method 2

The other method used to compute the fatality risk is based on the work of Zuccaro and Cacace,[16] as adopted by Iervolino et al.[17] in the context of *operational earthquake loss forecasting*. In this model, the casualty probability given a DS is provided based on the *vulnerability class* the building belongs to in accordance with the *European Macroseismic Scale*[18] (EMS). In this context, vulnerability classes C and D were assigned to the URM and RC structures, respectively. Moreover, it is also needed to let UPD and GC performances correspond to EMS; in this case, UPD was associated to DS3 and GC to DS5. (Because no industrial buildings or base-isolated structures are considered by EMS, it was not possible to apply this approach to S, PRC, and BI structures.) Because, according to this model, zero fatality probability is associated with damage levels equal to or lower than DS3, Equation (2) can be further simplified as

$$\lambda_d = P\left[D\,|\mathrm{GC}\right] \cdot \lambda_{f,\mathrm{GC}}, \tag{6}$$

where $P[D|\mathrm{GC}]$ can be expressed by Equation (3) assuming $P[\mathrm{in}|\mathrm{GC}] = 0.65$ and $P[D|\mathrm{GC}, \mathrm{out}] = 0$.

The fatality rates computed with these two methods are interpreted herein as about equal to the annual probability of an individual continuously exposed to failure of a building of a given typology at a specific site (the legitimacy of such an assumption depends on the way the conditional probabilities are formulated and computed in the two methods considered and could benefit from a refined modeling of exposure of individuals to building failure).

4 | OTHER RISKS IN ITALY

For comparison, the annual fatality rates associated with different causes of death in Italy were also computed. To this aim, ISTAT data for the 2012–2016 period were retrieved and analyzed. The considered causes of death are:

- (IP) infectious and parasitic diseases (tuberculosis, HIV, viral hepatitis, others);
- (T) tumors;
- (NS) diseases of the nervous system and sense organs (Parkinson's disease, Alzheimer's disease, others);
- (CS) diseases of the circulatory system (ischemic heart diseases, cerebrovascular diseases, others);
- (RS) diseases of the respiratory system (flu, pneumonia, chronic diseases of the lower respiratory tract, others);
- (AF) accidental falls;
- (RA) road accidents (in which car occupants or pedestrians died).

The fatality rates were obtained by dividing the number of deaths in Italy for a specific cause and year by the size of the resident population on January 1 of the year in question. Because the results among the considered years of analysis vary only mildly, only those referring to 2016 are considered in the following. These rates can be interpreted as the annual probability that a random member of the population dies for the considered cause. (In fact, the analysis was also carried out at a local scale referring to the provinces of Milan, Naples, and L'Aquila, but the results were similar to those at the national level.)

The comparison of the seismic safety and the risk due to other causes is given in Figure 2 (right). In the figure, the seismic fatality rates provided are simply the arithmetic averages for the considered buildings, without any relative weighting of the various configurations and possible occupancies. The comparison is carried out in the hypothesis that a generic (random) individual is continuously exposed to the causes of death the lines refer to in the very same way the same individual is continuously exposed to the seismic risk, measured by the seismic fatality rate for the (code-conforming) building typology corresponding to a specific mark. Although this may be considered simplified and conventional, it can be argued that the seismic risk is generally lower than the other considered risks. This holds even if the fatality rates for the URM buildings at L'Aquila from the Zuccaro and Cacace approach, which provides larger rates than those based on Tsang and Wenzel, are comparable to the lowest rates from the other considered causes.

5 | CONCLUSIONS

This study compared the seismic safety of Italian code-conforming buildings at three different sites, by transforming the failure rates into fatality rates according to two different methods. Because computed fatality rates depend on the two performance levels for which reliability was available, the evaluation of the fatality rates must be considered simplified, if not conventional, and subject to the working assumptions; nevertheless, it could be of interest, given the bulk of the results from the RINTC project, about the reliability assessment of code-conforming structures. Moreover, the Italian code has large similarities with the Eurocode 8 and can be considered of state-of-the-art level. The results show that the seismic structural safety of buildings tends to decrease as the seismic hazard for the site increases. Therefore, the seismic risk tends not to be uniform across the country.

This is a consequence of the minimum design requirements dominating at the low and mid hazard sites, as well as the fact that the ground motion with intensity larger than that considered in design is disproportionately larger at the most hazardous sites with respect to mid and low hazard sites. Nevertheless, the rough comparison with the fatality rates for some common causes building occupants are also exposed to, shows that the seismic risk tends to be, for most of the cases, lower than the others even at the most seismically hazardous sites considered.

Although the comparison between fatality risk due to structural failure and those health-related must be done carefully, these results may contribute to the discussion on whether the seismic safety achieved by current standards can be considered acceptable and on the vision of the future of seismic codes, which is going toward risk-targeted design.

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REFERENCES

1. Ministero delle Infrastrutture e dei Trasporti. D.M 17 Gennaio 2018: "Aggiornamento delle Norme tecniche per le Costruzioni." *Suppl Ordin alla Gazzetta Uff n 42 Del 20 Febbraio 2018- Ser Gen*. 2018;42:1-198. (In Italian)
2. Stucchi M, Meletti C, Montaldo V, Crowley H, Calvi GM, Boschi E. Seismic hazard assessment (2003–2009) for the Italian building code. *Bull Seismol Soc Am*. 2011;101(4):1885-1911.
3. EN 1998-1-1. *Design of Structures for Earthquake Resistance—Part 1: General Rules, Seismic Actions and Rules for Buildings*. CEN, Bruxelles, Belgium; 2005.
4. Iervolino I, Spillatura A, Bazzurro P. Seismic reliability of code-conforming Italian buildings. *J Earthq Eng*. 2018;22(sup2):5-27.
5. Cornell CA, Krawinkler H. Progress and challenges in seismic performance assessment. *PEER Cent News*. 2000;3. https://apps.peer.berkeley.edu/news/2000spring/performance.html. Accessed January 2021.
6. Cito P, Iervolino I. Peak-over-threshold: quantifying ground motion beyond design. *Earthq Eng Struct Dyn*. 2020;49(5):458-478.
7. Iervolino I, Dolce M. Foreword to the special issue for the RINTC (the implicit seismic risk of code-conforming structures) project. *J Earthq Eng*. 2018;22(sup2):1-4.
8. Stucchi M, Meletti C, Montaldo V, Crowley H, Calvi GM, Boschi E. Seismic hazard assessment (2003–2009) for the Italian building code. *Bull Seismol Soc Am*. 2011;101(4):1885-1911.
9. McGuire RK. *Seismic Hazard and Risk Analysis*. Oakland, CA: Earthquake Engineering Research Institute; 2004.
10. Shome N, Cornell CA. Structural Seismic Demand Analysis : Consideration of "Collapse." PMC2000 - 8th ASCE Specialty Conference on Probabilistic Mechanics and Structural Reliability. University of Notre Dame, South Bend, Indiana, 24–26 July, 2000.
11. Baraschino R, Baltzopoulos G, Iervolino I. R2R-EU: software for fragility fitting and evaluation of estimation uncertainty in seismic risk analysis. *Soil Dyn Earthq Eng*. 2020;132:106093.
12. Chioccarelli E, Cito P, Iervolino I, Giorgio M. REASSESS V2.0: software for single- and multi-site probabilistic seismic hazard analysis. *Bull Earthq Eng*. 2019;17(4):1769-1793.
13. Iervolino I, Giorgio M, Cito P. The peak over the design threshold in strong earthquakes. *Bull Earthq Eng*. 2019;17(3):1145-1161.
14. Tsang HH, Wenzel F. Setting structural safety requirement for controlling earthquake mortality risk. *Saf Sci*. 2016;86:174-183.
15. Kircher CA, Whitman RV, Holmes WT. HAZUS earthquake loss estimation methods. *Nat Hazards Rev*. 2006;7(2):45-59.
16. Zuccaro G, Cacace F. Seismic casualty evaluation: the Italian model, an application to the L'Aquila 2009 event. In: Spence R, So E, Scawthorn C, eds. *Human Casualties in Earthquakes: Progress in Modelling and Mitigation*. London, United Kingdom: Springer; 2011.
17. Iervolino I, Chioccarelli E, Giorgio M, et al. Operational (short-term) earthquake loss forecasting in Italy. *Bull Seismol Soc Am*. 2015;105(4):2286-2298.
18. Grünthal G. *European Macroseismic Scale 1998 (EMS-98)*. Vol 15. ESC; 1998.

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