Available online at www.eccomasproceedia.org
Eccomas Proceedia COMPDYN (2017) 3225-3234

ECCOMAS Proceedia

COMPDYN 2017
6th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Rhodes Island, Greece, 15–17 June 2017

NEW SEISMIC RISK INDEX FOR EXISTING BUILDINGS

M. Mastroberti[1], M. Vona[1]

[1] School of Engineering – University of Basilicata
Potenza, Italy
{monica.mastroberti, marco.vona}@unibas.it

Keywords: Seismic Risk Mitigation; Existing RC buildings; Fragility Curves; Structural Performance; Seismic Risk Index.

Abstract. *The assessment of the seismic vulnerability of existing buildings (in particular for public or strategic) is frequently based on strongly simplified methods than those used for new or retrofitting design at least for the first evaluation. In particular, the seismic performances are often summarized by simple and poor indexes, incorrectly called seismic risk indexes. For example, the seismic risk index provided from several standard code or guidelines for practice are based on simplified and deterministic procedure. Moreover, the evaluation of the reference seismic intensity is generally based on simplified model. In this work, these limitations are highlighted and overcame. A new and probabilistic approach to define a more accurate Seismic Risk Index (SRI) for existing building is proposed. The novel SRI is based on reliable and analytical Fragility Curves.*

Peer-review under responsibility of the organizing committee of COMPDYN 2017.
doi: 10.7712/120117.5640.18246

1 INTRODUCTION

In last years, the priority ranking for the retrofit of existing buildings has become a key issue in the mitigation of seismic risk [1]. The ranking lists are generally based on seismic risk of the buildings, which is defined based on several analysis methods and procedures.

The seismic risk index (SRI) can be considered as the most important parameter in planning of seismic risk mitigation strategies and in prioritization of retrofitting interventions [2], [3], [4]. Moreover, the SRIs are also useful tools for monitoring the changes in seismic risk through time and space [5].

The SRIs should be able to investigate and summarize the building safety level. Nevertheless, they are needed in order to investigate about the economic impact of the existing buildings vulnerability.

Unfortunately, there is not a standard method and definition of seismic risk indexes. Consequently, the significant differences could be lead to significant discrepancies in term of seismic risk strategies. The SRI is affected from a high number of factors, such as simple procedure providing inappropriate results.

The SRI should be defined starting from one or more goals, which are generally called Rehabilitation Objectives (RO), for example [6]. RO is based on a Target Performance Level and a Seismic Hazard Level. The Target Performance Level (PL) must be defined in terms of safety of the buildings and their occupants during and after the event.

In the last years, several studies have been carried out and different approaches have been proposed and reported in guidelines, standards, and codes. These last applications have been defined in order to provide better and simple procedure for practice engineers and decision makers in order to reduce the seismic risk of the communities.

In this work, the new procedure to define the Seismic Risk Index for existing buildings is defined. New SRI definition has been applied to existing reinforced concrete with moment resisting frames (RC-MRF) building types.

On the first, several existing approaches have been reported and described in order to investigate the main existing procedures to SRI evaluation. Different safety assessment procedures and SRI definitions are reported in very much guidelines and codes in other part of the world. In Table 1, only some approaches have been reported, those are considered the most interesting in order to comparison with the new proposal.

The first definition has been widely used in the past years in order to define the prioritization for public or strategic Italian buildings [2], [3]. The second can be considered as the actual evolution of the first and it is defined Italian and European codes in force.

The classic SRI is based on the simple comparison (as ratio) between the building capacity and demand, where the building capacity is expressed in a deterministic way. In this ratio, the comparison between capacity and demand is expressed in terms of seismic intensity parameters.

The seismic capacity of the existing buildings is expressed in terms of seismic intensity that marks out the achievement of Performance Level. However, the demand level is defined as the seismic intensity threshold compatible with the hazard level accepted for each performance level.

The above SRI must be used according to a deterministic or semi probabilistic structural behavior assessment procedures. This approach is coherent with knowledge factor defined in the Italian and European codes [9], [10].

Then, the classic seismic risk index measures the level of non-compliance to PL requirement (different between capacity and demand).

Consequently, in some cases the SRI values could be not representative of real building seismic safety state. In fact, in most cases the factors considered in the deterministic approach could be no able to take into account the uncertain and variability of real seismic behavior of the existing buildings, and could be representative of a singular and low probable failure behavior.

It to be highlight that in more recent Italian regulations [7], [8], SRI is based on the same concept. It used for distribution of economic funding for seismic risk mitigation and post event reconstruction.

Code or Guidelines	SEISMIC RISK INDEX
O.P.C.M. 3274/2003 and subsequent guidelines	$$\alpha_{LSi} = \frac{PGA_{PLi}}{PGA_{PLi\|HL}}$$ PGA_{LSi}= seismic intensity that marks out the achievement of Performance Level (PL_i) compliance criteria. PGA_{LSi}= maximum seismic intensity threshold in accordance with the Hazard Level associated to PL.
NTC08 EC8	$$\alpha_{LSi} = min\left\{\frac{\theta_{PLi}}{\max(\theta_{PLi\|HI})}, \frac{Vr_{PLi}}{max(V_{PLi\|HI})}\right\}$$ $\max(\theta_{PLi\|HI})$ = maximum deformation of ductile elements achieved under a seismic intensity compatible with the Hazard Level associated to PL. θ_{PLi}= limit deformation for ductile elements required by Performance Level (PL_i). $\max(V_{PLi\|HI})$ = maximum force of brittle elements achieved under a seismic intensity compatible with the Hazard Level associated to PL. V_{rPLi}= limit force for brittle elements required by Performance Level (PL_i).

Table 1: Seismic Risk Index definitions.

An improvement in seismic risk evaluation should be obtained dealing the performance assessment problem in a probabilistic way; the uncertainties are directly considered. In this way, it is to be highlighted that the classic expressions of SRI definitions are unsuitable to synthetically handle the results of probabilistic assessment procedure, and then a new definition should be defined.

2 METHODOLOGY

New Seismic Risk Index is integrated in a probabilistic performance assessment procedure, which directly take into account all the uncertainty sources in building behavior. The new SRI quantifies the level of seismic risk in terms of probability that the building capacity no fulfill the demand required by each limit state. This is the main difference with the existing considered approach. In fact, the new SRI is based on Fragility Curves and accurate characterization of Hazard Level required for each PL.

The Fragility Curves (FCs) approaches allow a complete probabilistic characterization of building performances. However, the seismic intensity corresponding to the Hazard Level assigned at each PL allows identifying the range or the ordinate of FC to consider; taking into account that each performance criteria must be verified for given reference intensity.

In Figure 1, the amounts involved in new Seismic Risk Index definition in reference a generic Performance Level are highlighted.

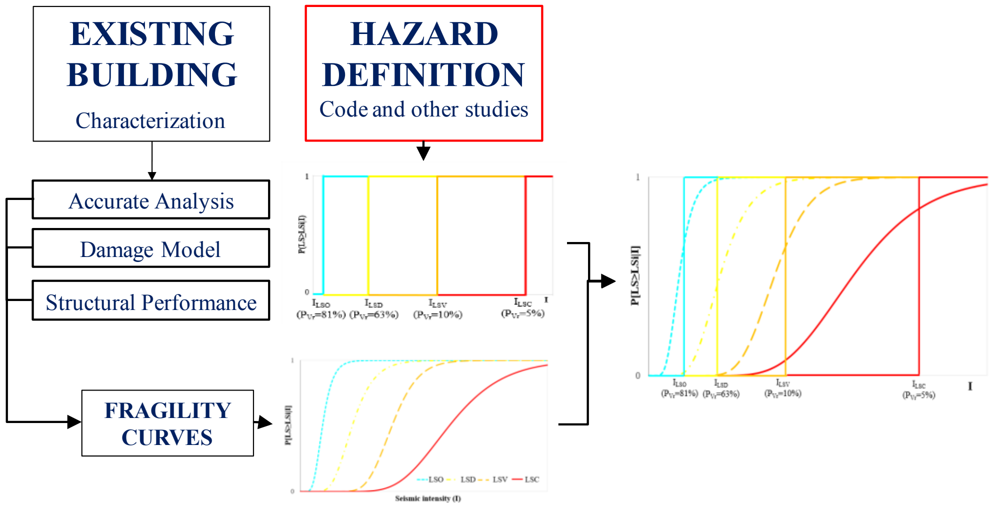

Figure 1. Framework to Seismic Risk Index definition.

New SRI definition is the follow:

$$\mathrm{SRI_{PLi}} = 1 - \frac{\int_{\mathrm{I_{PLi,i}}}^{\mathrm{I_{PLi,f}}} \mathrm{P[PL \geq PLi|I]dI}}{\int_{\mathrm{I_{PLi,i}}}^{\mathrm{I_{PLi,f}}} \mathrm{dI}} \tag{1}$$

In discrete way, the SRI become:

$$SRI_{PLi} = 1 - \frac{\sum_{I_{PLi,i}}^{I_{PLi,f}} P[PL \geq PLi|I]\Delta I}{\sum_{I_{PLi,i}}^{I_{PLi,f}} \Delta I} \tag{2}$$

SRI is equal or near to 1.0, if the considered building shows a good performances (or no achieves or exceeds the PL). For SRI less than 1.0, the considered building achieves or exceeds the PL requirements. The reliability of the new SRI strongly depends from accuracy of building fragility curves and hazard level characterization. In figure 2, a graphic representation of the formal definition of new SRI is reported.

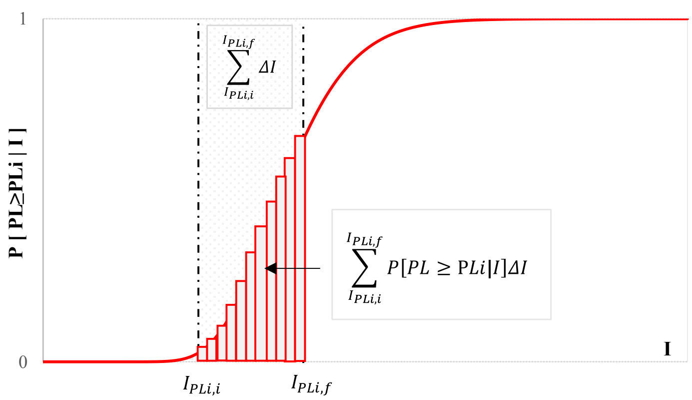

Figure 2: Graphic representation of new seismic risk index definition.

In the next section, a first application of new SRI is reported.

2.1 First application to existing RC-MRF buildings

As first application, in this work the proposed SRI definition has been applied to the most Italian and European widespread existing RC-MRF building types [11]. This application would provide a fast and reliable evaluation of the seismic safety level of considered building types with regard to the national Italian territorial scale. The application is based on previous studies [12], [13] and consequent Fragility Curves conditioned to Housener intensity.

On the first, it is to be highlighted that different approaches are available to FCs definition, base on different analysis methods, different damage models, different forms, and different intensity parameters; advantages and disadvantage have been discussed in other studies of the authors in order to define the optimal way [13], [14].

2.2 Seismic performance of investigated types

The considered types have been widely characterized in previous study [11]. The building types are low-mid-high rise (2-4-8 storey) and different infill panels distribution have been considered (frames without effective infills, BF; frames with regularly arranged of effective masonry infills IF; frames with effective masonry infills at the ground floor, PF). Based on the design code and construction age, other two different types have been considered. They can be considered as low-engineered buildings, designed with old codes and pre-modern seismic code typical of Southern Europe. The considered building types are briefly reported in Figure 3.

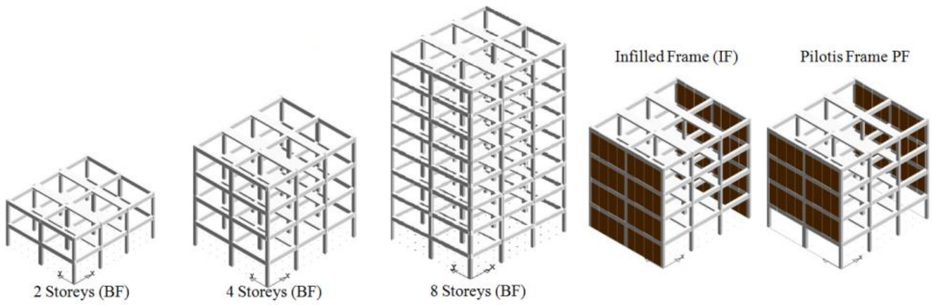

Figure 3. Considered building types: number of storey and infill distributions.

Structural performances have been evaluated using Non Linear Dynamic Analyses (NLDAs). More details about non linear models and analyses are reported in a previous study [11], [15].

The maximum performances have been summarized using global parameters (for example interstory drift ratio) and local ones (maximum, medium ductility ratio of beams and columns). These latter have been interpreted in terms of damage level based on a specific Damage Model [12], [13]. The considered damage levels are linked to four Performance Levels considered by Italian (NTC08) and European (EC8) code: Operatively PL, Light Damage PL, Life Safety PL and Collapse PL.

Each Damage Level (DL) has been characterized by a quantitative description addressed to section yield level of the more critical structural elements. In a synthetic way, the Figure 4 shows the structural elements flexural performance required by each Damage Level considered. Moreover, the Damage Level 0-1, is been linked also to interstorey drift ratio, that strongly influence the non-structural elements damage.

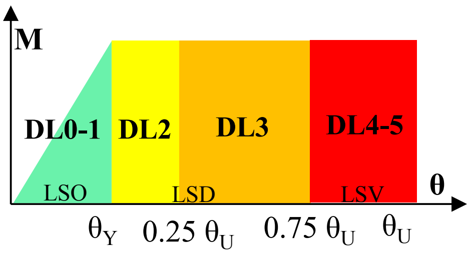

Figure 4: Structural element flexural performance required by each Damage Level.

According with Damage Model and the maximum damage distribution, base on the comparison between the achieved maximum structural performance by each primary structural element and non-structural element and the DL limit requirements, the achieved damage level has been identified.

2.3 Italian Life Safety Hazard level

With regard to methodology summarized in framework (Figure 1), seismic intensity range compatible with hazard levels required for each Performance Level have been identified. The Hazard Levels required by Italian seismic code in terms of probability of exceedance in a reference time interval of 50 years for each PL respectively have been considered.

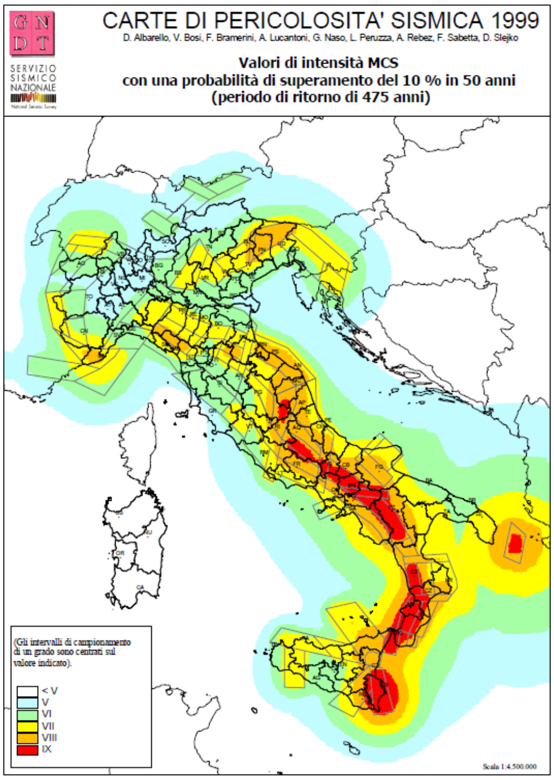

Figure 5: Italian Hazard map in MCS macro-intensity for an exceedance probability of 10% in 50 years.

In this study only the Life Safety Hazard Level has been characterized based on the Italian hazard map proposed in [16] in Mercalli-Cancani-Sieber macro-seismic intensity (MCS) for a return period of 475 years (Figure 5). The Figure 5 shows as the Italian territory could be splitted in six macro-seismic regions. Each of them is characterized by an expected macro-seismic intensity (MCS) with a return period of 475 years or probability of exceedance of 10% in 50 years.

The map has been chosen due to the strong correlation between MCS macro-seismic scale and EMS-98 one. As reported in previous study [17], about the macroseismic intensity scale, a substantial equality between Mercalli–Cancani–Sieberg scale (MCS; Sieberg 1930) and the European definition of macroseismic intensities (MSK-76, EMS-92 and EMS-98) has been considered.

3 RESULTS

New Seismic Risk Index values have been evaluated for considered RC-MRF building types. In this application, the EMS-98 intensity [18] has been considered as reference intensity thus, SRIs have been evaluated based on the discrete expression (2) in regarding to a range of seismic intensity. In this way, based on relationship between European macro-seismic scale EMS-98 and Housner intensity (I_H) proposed in [17] equivalence between I_H and EMS-98 has been defined. In Figure 6, the Fragility Curves for some building types considered have been reported. Moreover, the relation between I_H and EMS-98 has been highlighted.

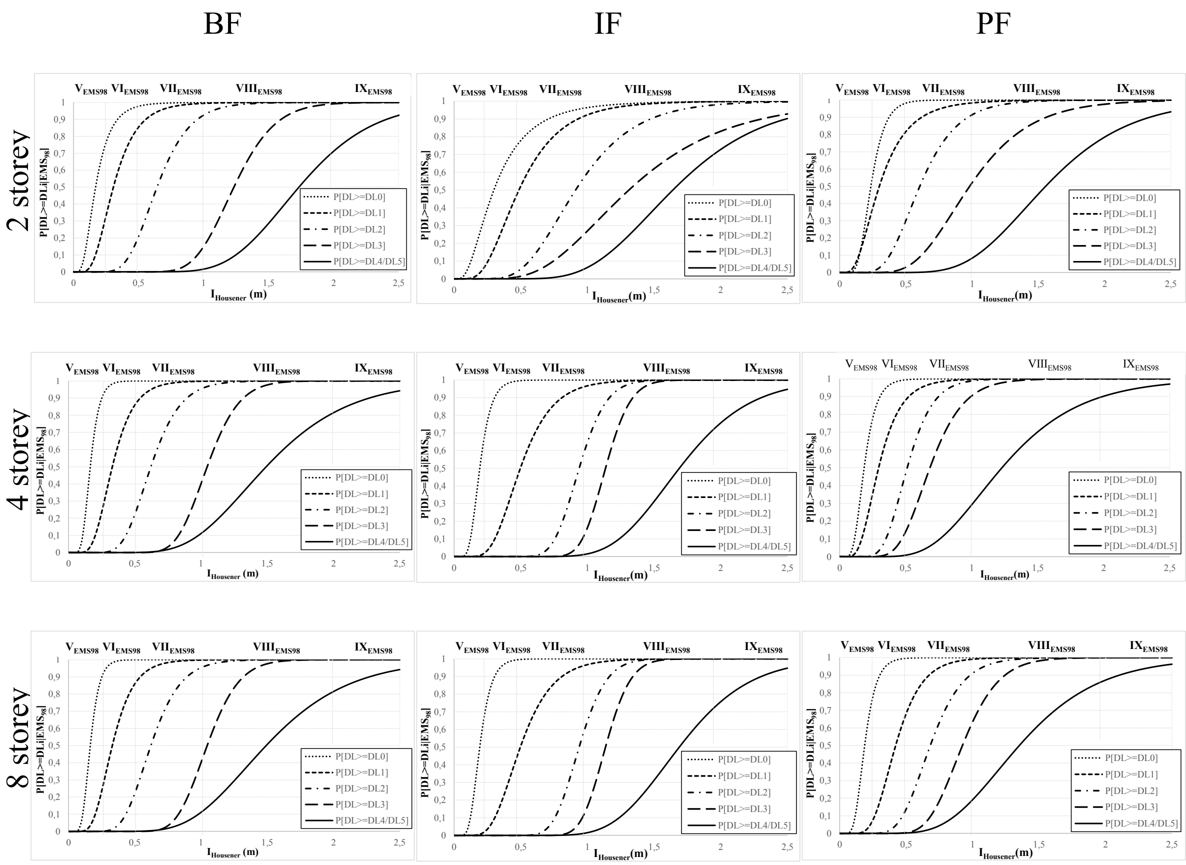

Figure 6: Fragility curves: Old Code for 2-4-8 storey types.

Different areas of fragility curve have been involved in SRIs quantification according with life safety hazard level intensity characterization. For each MCS Italian seismic area a different range of Fragility Curve has been considered. In order to clarify the application, in Figure 7 the areas of the fragility curve (for Life Safety LS) for each seismic region have been highlighted.

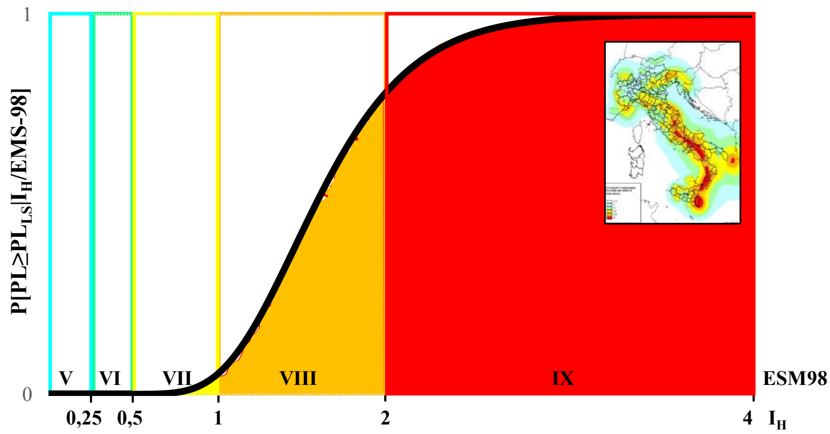

Figure 7: Fragility Curve and seismic intensity Hazard level characterization.

In Figure 8 are reported the SRIs values obtained for considered types for VII and VIII EMS98. SRIs have been classified in ascending order. For each Italian seismic region, types ranking lists for Life Safety PL have been obtained.

The Figure 8 (a) shows that the Old Code (OC) and PF types suffer the greater seismic risk level for I_{EMS98} = VII (0,8 < SRI < 1). However, the Figure 8 (b) shows that all types are characterized by a high seismic risk level for I_{EMS98} = VIII (0,3 < SRI < 0,63). Particularly, the typological ranking highlights as the Seismic Risk Index firstly depends by the infill panel distribution and effectiveness condition (PF-BF-IF). PF types are the most vulnerable types, following by BF and IF types.

For the same infill panel distribution and effectiveness condition, SRI is influenced by the design code. Building types designed in accordance with a no-seismic code (OC) are more vulnerable than those designed according to old seismic design code (PC). Finally, the Seismic Risk Index seems to be less influenced by the storey number.

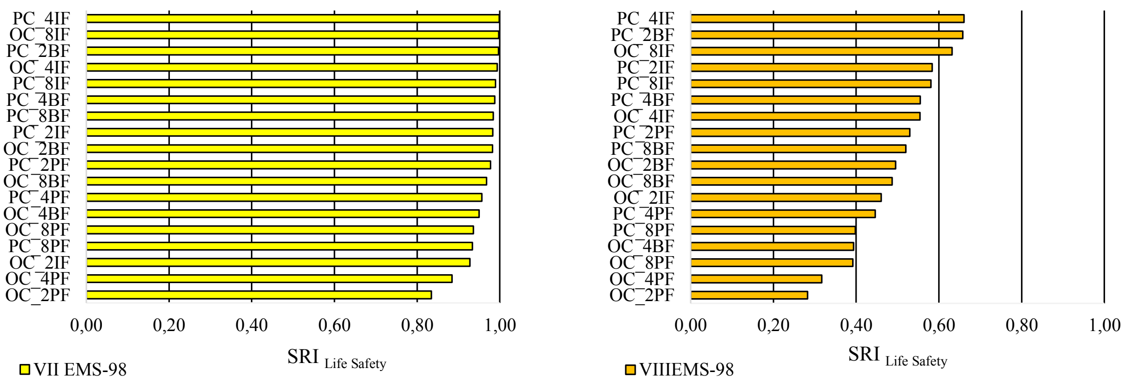

Figure 8: SRIs (for Life Safety PL) for each building types considered as situated in Italian seismic regions characterized by a reference macro-seismic intensity for Life Safety PL of VII, VIII EMS-98 intensity.

4 CONCLUSIONS

A new Seismic Risk Index based on the probabilistic approach has been defined in order to compare in a probabilistic way the performance of existing buildings with PL requirements. Specific Performance Level requirements have been proposed based on in force codes. It is considered a more accurate way to seismic risk evaluation, than the conventional approach based on the simple and deterministic comparison between building capacity and required demand. The new SRI definition, based on a totally probabilistic approach (both in building characterized that in performance assessment), seems to provide different seismic risk index estimation than the conventional one. Then, it could be considered a useful tool for a more accurate and realistic estimation of building seismic risk index, based on the probability that a PL could be exceeded.

The new SRI requires a more accurate probabilistic building characterization and the definition of building FCs, which are the best way to represent the building seismic vulnerability.

The new SRI for the MRF-RC building types considered in this first study could be a reference for practice applications but only for building types or single building similar to those examined. Therefore, a more extensive use of the obtained information could be possible relying on the expert judgment of the analysts, which may revise the results in accordance with the peculiarities of analyzed buildings.

In future works, the effectiveness of new SRI than classic one will be further tested, based on recent post-earthquake scenario, and specify cases study.

REFERENCES

[1] O.C. Zienkiewicz, R.C. Taylor, *The finite element method, Vol. I, 4th Edition*. McGraw Hill, 1989.

[2] J.T. Oden, T. Belytschko, I. Babuska, T.J.R. Hughes, Research directions in computational mechanics. *Computer Methods in Applied Mechanics and Engineering*, **192**, 913-922, 2003.

[3] J.H. Argyris, M. Papadrakakis, L. Karapitta, Elastoplastic analysis of shells with the triangular element TRIC. M. Papadrakakis, A. Samartin, E. Oñate eds. *4th International Colloquium on Computation of Shell and Spatial Structures (IASS-IACM 2000),* Chania, Crete, Greece, June 4-7, 2000.

[1] Vona M, Harabaglia P and Murgante B. Thinking about resilience cities studying Italian earthquake. *Urban Design and Planning*, **169**(4), 185-199, 2016.

[2] Vona M, Anelli A, Mastroberti M, Murgante B and Santa-Cruz S, Prioritization Strategies to reduce the Seismic Risk of the Public and Strategic Buildings. *Disaster Advances*, **10** (4), 2017

[3] Vona M. and Murgante B., Evaluation of retrofitting policies of strategic buildings based on different multi-criteria decision-making (MCDM) methods, *IALCCE 2014 - Fourth International Symposium on Life-Cycle Civil Engineering*, Tokyo, Japan, 2014

[4] Masi A., Santarsiero G., Chiaussi L., Vulnerability assessment and seismic risk reduction strategies of hospital in Basilicata region (Italy), *15 WCEE* , Lisboa, 2012.

[5] Parsons M, Glavac S, Hastings P, Marshall G, McGregor J, McNeill P, Morley P, Reeve I, Stayner R. Top-down assessment of disaster resilience: A conceptual framework using coping and adaptive capacities. *International Journal of Disaster Risk Reduction*, **191**(11), 2015

[6] FEMA356, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, 2000

[7] D.M. 28 febbraio 2017, n. 58 recante: *Sisma Bonus - Linee guida per la classificazione del rischio sismico delle costruzioni nonché le modalità per l'attestazione, da parte di professionisti abilitati, dell'efficacia degli interventi effettuati*. Ministero delle infrastrutture e dei trasporti (in Italian).

[8] DECRETO-LEGGE 17 ottobre 2016, n. 189. *Interventi urgenti in favore delle popolazioni colpite dal sisma del 24 agosto 2016*. (16G00205) GU Serie Generale n.244 del 18-10-2016. (in Italian).

[9] NTC 2008. *Norme Tecniche per le Costruzioni*. Decreto del Ministero delle infrastrutture, Supplemento Ordinario n.30 alla Gazzetta Ufficiale della Repubblica italiana, 29, 4/02/2008, Italy (in Italian).

[10] CEN Eurocode 8 2004, *Design Provisions for Earthquake Resistance of Structures*. European Prestandard ENV 1998, Brussels Belgium: ComitéEuropéen de Normalisation.

[11] Masi A. and Vona M., Vulnerability assessment of gravity-load designed RC buildings, evaluation of seismic capacity through nonlinear dynamic analyses. *Engineering Structures*, **45**, 257–269, 2012

[12] Vona M., Fragility Curves of Existing RC Buildings Based on Specific Structural Performance Levels, *Open Journal of Civil Engineering*, **4**. 120-134, 2014.

[13] Vona M., Mastroberti M, A critical review of fragility curves for existing RC buildings. ECCOMAS Congress 2016. *VII European Congress on Computational Methods in Applied Sciences and Engineering*. Crete Island, Greece, 5-10 June 2016

[14] Borzi B, Vona M, Masi A, Pinho R, Pola D. Seismic demand estimation of RC frame buildings based on simplified and nonlinear dynamic analyses, *Earthquakes and Structures*, **4**(2), 2013.

[15] Masi A, Vona M and Mucciarelli M., Selection of Natural and Synthetic Accelerograms for Seismic Vulnerability Studies on Reinforced Concrete Frames. *Journal of Structural Engineering*. 367, 2011.

[16] Albarello D, Bosi V, Bramerini F, Lucantoni A, Naso G, Peruzza L, Rebez A, Sabetta F, Slejko D. *Pericolosità sismica del territorio nazionale: carte di consenso GNDT e SSN*; 1999.

[17] Chiauzzi L, Masi A, Mucciarelli M, Vona M, Pacor F, Cultrera G, Gallovič F, Emolo A. Building damage scenarios based on exploitation of Housner intensity derived from finite faults ground motion simulations. *Bulletin of Earthquake Engineering*, **10**(2), 517-545, 2012

[18] Grunthal G. (editor). European Macroseismic Scale 1998 (EMS-98). European Seismological Commission, sub commission on Engineering Seismology, working Group Macroseismic Scales. Conseil de l'Europe, *Cahiers du Centre Europeen de Geodynamique et de Seismologie*, vol. 15. Luxembourg; 1998.