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THE USE OF SEISMIC RISK MAPS IN THE DEVELOPMENT OF SEISMIC RISK REDUCTION PROGRAMS

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Abstract

Mapping seismic risk at the territorial scale is a key process in earthquake-prone countries since it allows to understand the spatial distribution of risk and its quantification in economic terms. Seismic risk maps can be used by governments to outline short-, mid- or long-terms risk mitigation and/or transfer actions. The present contribution aims to show how the seismic risk mapping framework detailed by the authors in a companion paper can be used to investigate the financial sustainability of national seismic risk reduction programs, focusing the attention on the specific case of the national residential building stock of Italy.

Keywords: Seismic risk map, Italy, Seismic risk reduction programs, risk mitigation, cost-benefit analysis

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1 INTRODUCTION

For practitioners and authorities, seismic risk computation and mapping are fundamental knowledge tools for understanding and managing the risk at which communities are exposed. For these reasons, reliable seismic risk indicators are needed for quantitatively approach the problem of reducing and/or transferring the risk at with an extended territory is exposed. The Expected Annual Loss (EAL) is a widely adopted synthetic risk indicator, considering and weighing all possible loss scenario than can occur in a specific point. Furthermore, it allows quantifying benefits associated to a retrofit intervention and also provides a reasonable estimate the insurance premium that can be expected based on the design or strengthening decision taken [1].

In last years, many applications adopted the EAL for the evaluation of the best seismic strategy to be adopted, but mostly related to specific structures and addressing specific problems, most of time at punctual level and not at regional level. In [2], Beigi et al. performed a cost-benefit analysis for buildings retrofitted using a gapped-inclined brace system (GIB), while [3] discussed the possible criteria for the mitigation of seismic risk and for the structural strengthening in case of reinforced concrete structures [3]. In 2018, Hofer et al. [4] proposed a methodology for determining the most profitable seismic retrofit strategy to be adopted in an industrial productive plant. In this context, seismic risk evaluations have been extended to spatially distributed assets, for assessing seismic risk at regional level. Map of losses, conditioned on a specific return period, have thus been developed with the OpenQuake engine [5] for Portugal [6], Nepal [7], and Turkey [8]. In 2013, Asprone et al. [9] computed a possible seismic insurance premium for five different types of building categories within all the Italian territory, while in 2018 Zanini et al. developed the first seismic risk map in terms of EAL, for the Italian territory [10]. In particular, he performed the calculation for three different level of granularity according to the Italian administrative subdivision, obtaining in this way the Municipal Expected Annual Loss map (*MEAL*), the Provincial Expected Annual Loss map (*PEAL*), and the Regional Expected Annual Loss map (*REAL*). In addition, [10] showed the effect of different granularity levels on the EAL referred to 1 m^2 of build area (€/m^2), highlighting the averaging effect of assuming a less refined granularity.

This work wants to propose a possible seismic retrofit scenario for the entire Italian residential building stock, and accordingly compute the seismic risk maps for the retrofitted assets. From the difference between the two maps, it is thus possible to quantify the benefit associated to the retrofit interventions. Furthermore, this paper provides an insight on the problem of evaluating the profitability of retrofit interventions at national scale when a significant number of vulnerable structures is involved, and thus scale-effects may happen on the cost-benefit analysis. The paper thus proposes a possible sustainable risk reduction program for the Italian residential building stock and shows some possible applications of it. More details, and the complete procedure description can be found in [10, 11].

2 A RETROFIT SCENARIO FOR REDUCING THE CURRENT SEISMIC RISK

2.1 The current seismic risk map of Italy

Zanini et al. [12], showed the construction of the seismic risk map for Italy, computing the Expected Annual Loss for every Italian municipality, province and region. For the hazard representation, [10] adopted the seismogenic model of [13], jointly with the Gutenberg-Parameter of [14], the Ground Motions Prediction Equations of [15], and the soil map of [16].

A suitable building taxonomy have been adopted for representing the seismic vulnerability of the Italian residential building stock, which has been subdivided in eight Taxonomy Classes TCs. Masonry buildings have been subdivided in two TCs, masonry buildings built before and after 1919, respectively TC1 and TC2. Reinforced concrete structures have been subdivided in two main classes, depending if gravity-load design, or seismic-load design. Each one of these two classes have been furtherly subdivided in two classes, on the base of the number of storeys (1-2, or 3+), respectively TC3 and TC4 for the gravity-load design, and Tc5 and TC6 for the seismic-load design. Finally, two more TCs (again Other – gravity design TC7, and Other – seismic design TC8) have been adopted for describing structures other than masonry and RC, mainly combined RC-masonry structures. All parameters of the adopted fragilities can be found in [10].

About exposure data, they have been retrieved from the 15th census database of the National Institute of Statistics [17]. Figure 1 shows the seismic risk maps in terms of *MEAL*, *PEAL* and *REAL*, that are representations of the seismic risk in the so-called *as-built* condition.

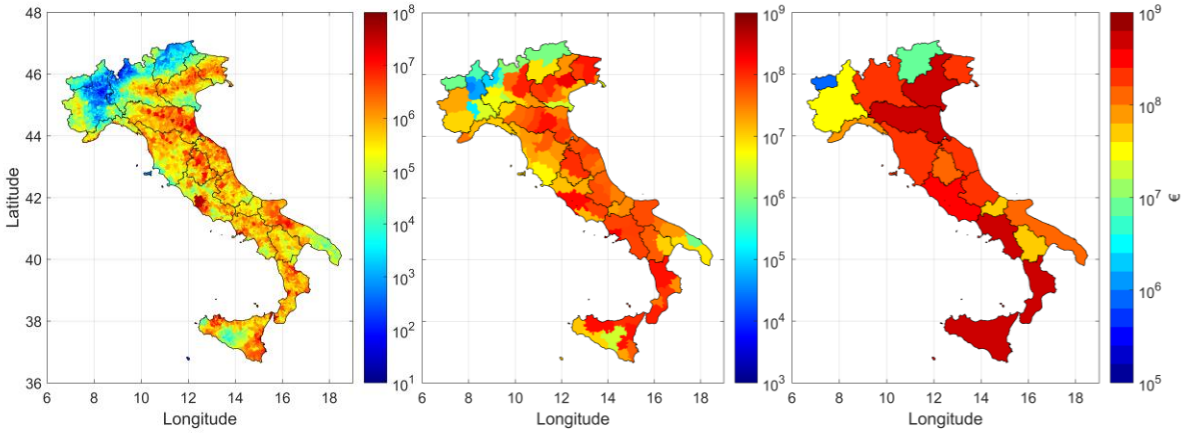

Figure 1: The seismic risk map of Italy in terms of MEAL (left), PEAL (center), REAL (right).

2.2 The seismic risk map of Italy after the retrofit of the building stock

This work investigates benefits of implementing a full seismic retrofit of the Italian residential building stock. For this scope, a seismic retrofit scenario for the entire building asset at national scale, has to be determined, and improved suitable fragilities have to be assumed.

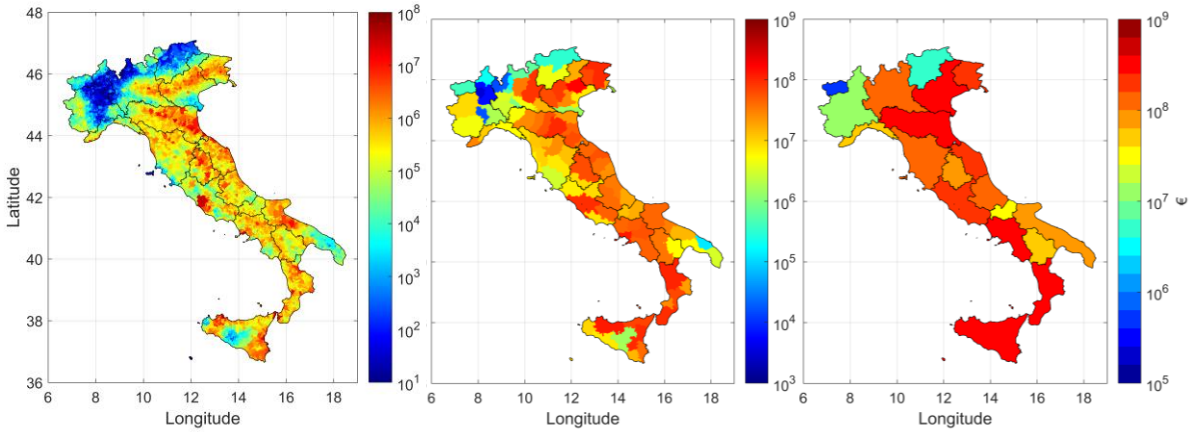

Figure 2: The seismic risk map in terms of MEAL (left), PEAL (center), REAL (right), for the retrofitted asset.

In particular, this paper assumes to improve the structural behavior or masonry buildings (TC1 and TC2), RC gravity load-designed structures (TC3 and TC4), and “Other” gravity load-designed structures (TC7). Retrofitting implies a change of the fragilities for the above-mentioned TCs: in particular it has been assumed that in the retrofitted configuration they behave like the respective seismic-designed classes, i.e. TC1, TC2, TC3 change in TC5, TC4 is modified as TC6, and TC7 is characterized as TC8.Under these assumptions, seismic risk maps have been recomputed for the three level of granularity. Figure 2 shows results in terms of *MEAL*, *PEAL* and *REAL*.

2.3 Assessing the retrofit convenience

For assessing the financial sustainability of the proposed seismic retrofit program, a cost-benefit analysis (CBA) is needed [18]. The main aim of CBA is to assess the profitability of a retrofit intervention, usually performed by computing the break-even time t_{BE}, i.e. the temporal point at which total cost and total revenue are equal. The $t_{BE,x}$ for each x^{th} municipality can thus be computed as:

$$t_{BE,x} = \frac{C_x}{B_x} \tag{1}$$

where C_x represents the cost to be sustained by the x^{th} municipality for retrofitting TC1, TC2, TC3, TC4 and TC7, and B_x is the benefits in terms of EAL provided by the all the retrofit interventions in the x^{th} municipality. B_x can be computed as the different between the *MEAL* in the as-built condition, and the *MEAL* after the structural improvement interventions as

$$B_x = MEAL_{x,as-built} - MEAL_{x,retrofit} \tag{2}$$

Similarly, the benefit due to seismic retrofit can be computed at provincial and regional level. Figure 3 shows the three benefit maps, highlighting how higher benefits are expected in the area of higher Annual Expected Losses.

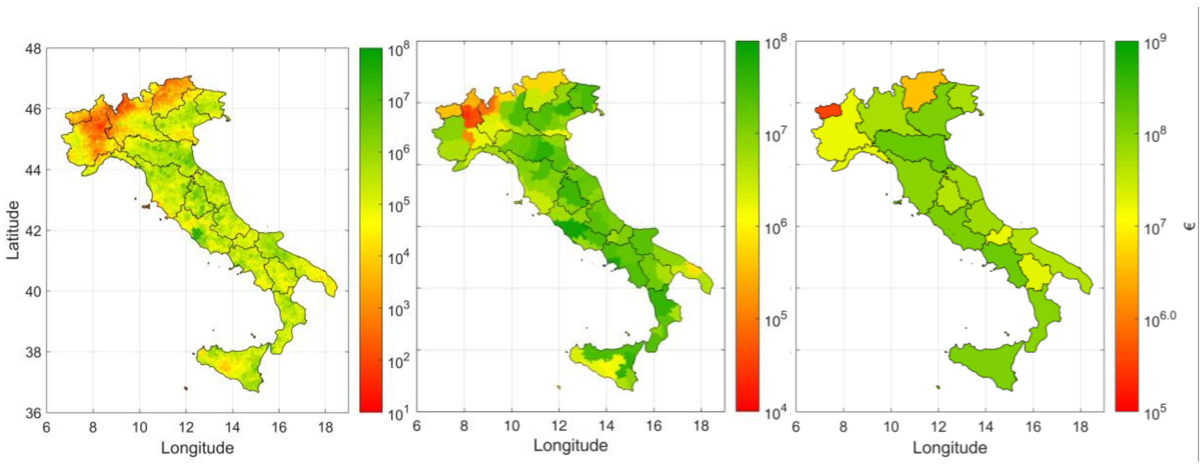

Figure 3: Benefit map at municipal (left), provincial (center), and regional (right) level.

Cost at municipal level C_x in Eq. (1) strictly depends on the planned seismic retrofit interventions for p = 5 TCs that need a structural improvement, and can be computed as

$$C_x = \sum_{y=1}^{p} A_{y,x} \cdot SRC_y \quad (3)$$

where $A_{y,x}$ is the built area of the y^{th} TC that needs seismic retrofit, and SRC_y is the unitary seismic retrofit cost for the y^{th} TC. The SRC_y values have been assumed equal to 68 €/m^2 for TC1, TC2, TC7 structures (i.e. retrofit schemes consisting in the insertion of tie-roads [19] and reinforced plaster) and 34 €/m^2 to for TC3, TC4 buildings (i.e. interventions based in FRP wrapping [20] or reinforced concrete jacketing of RC frame elements) in accordance to Prota [21]. Figure 4 shows the break-even time map, computed at municipal, provincial and regional level. Basing on this indicator, the Italian territory is mainly divided into two parts: in the first zone, coinciding with the Appennini area and northeastern Italy, seismic retrofit is recommended and t_{BE} ranges between few decades till about one hundred years. In the second case, for northwestern Italy, Puglia and the Tyrrhenian coast, retrofit interventions seem not to be convenient, since the break-even time is hundreds of years. Even in this case, the calculation at provincial and regional level, has an averaging effect, increasing the lower t_{BE} values at municipal level, and reducing the higher t_{BE} values.

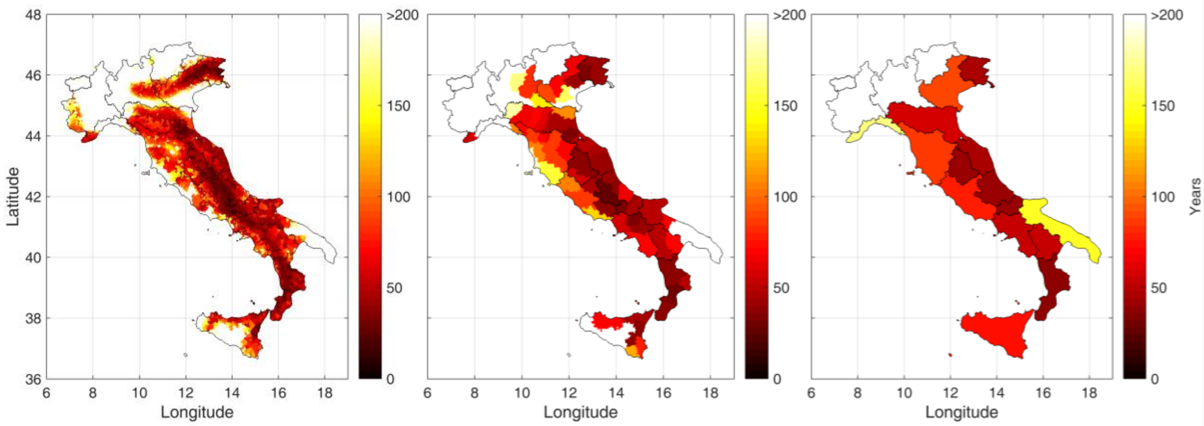

Figure 4: Break-even time map at municipal (left), provincial (center), and regional (right) level.

In general, for the entire national territory, structural retrofit implies gains in a medium-long term, and, except for some municipalities and provinces where it is highly recommended, seems not to be a convenient strategy for reducing seismic risk. However, the safety of citizens and the national risk reduction, cannot be neglected basing on cost-effectiveness analysis. For this reason, a financially sustainable seismic risk reduction program is proposed in the next section.

3 DEVELOPMENT OF SUSTAINABLE RISK REDUCTION PROGRAMS

The financial sustainability of implementing a nationwide retrofit program, has to be investigated in order to guarantee reasonable break-even times. The idea is that the implementation of the national seismic risk reduction program, should be managed by the Italian Government, or, better, by an *ad hoc* national public agency, which have to support the seismic retrofit at municipal level (or provincial and regional). The cost-effectives of the initial investment, and thus a reasonable financial return time, should be guaranteed by increasing benefits due to the seismic retrofit. This can be obtained by introducing for each x^{th} municipality (or Province and Region) a property tax PT_x, that can be seen as an additional income to be summed to the benefit B_x, thus reducing the break-even time:

$$t_{BE,x} = \frac{C_x}{B_x + PT_x} \tag{4}$$

In each x^{th} municipality, PT_x can be computed as a fraction PTR_x (property tax rate) of the total municipal cadastral income

$$PT_x = PTR_x \cdot CI_x \cdot A_x \tag{5}$$

where A_x is the total built area in the x^{th} municipality, and CI_x is the municipal cadastral income in €/m^2: in this application CI has been assumed constant and equal to 484 €/m^2 [22]. From Eq. (4) and Eq. (5) it is thus possible to compute the PTR_x, given a specific t_{BE}, and, on the contrary, compute the break-even time corresponding to a specific PTR_x. Figure 5 shows the map of the break-even time for PTR_x = 1 ‰ while Figure 6 shows the map for PTR_x = 2 ‰. Further examples for PTR_x = 0.5 ‰ and PTR_x = 3 ‰, and the calculation of PTR_x for a specific payback period can be found in [10].

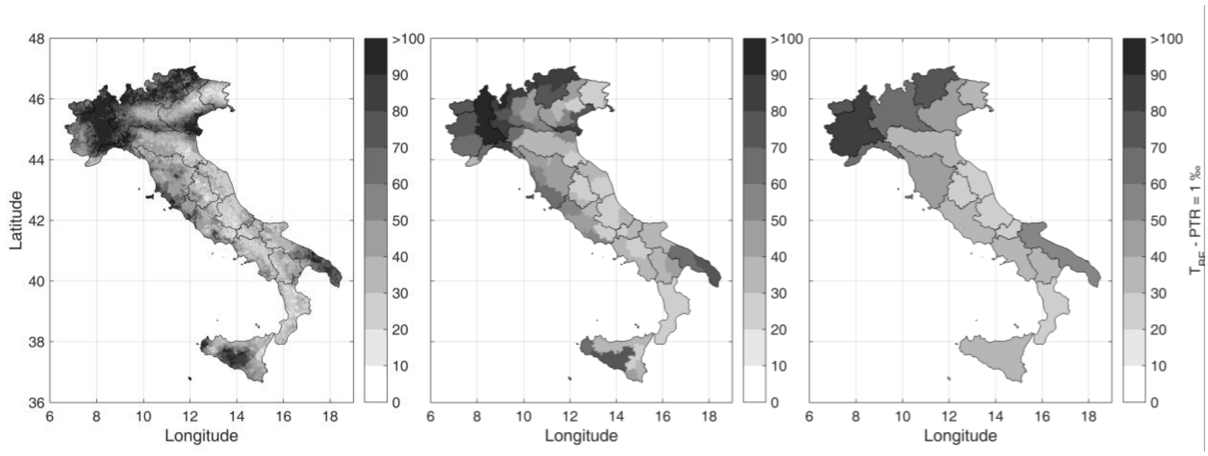

Figure 5: Break-even time map with *PTR* = 1 ‰ at municipal (left), provincial (center), and regional (right) level.

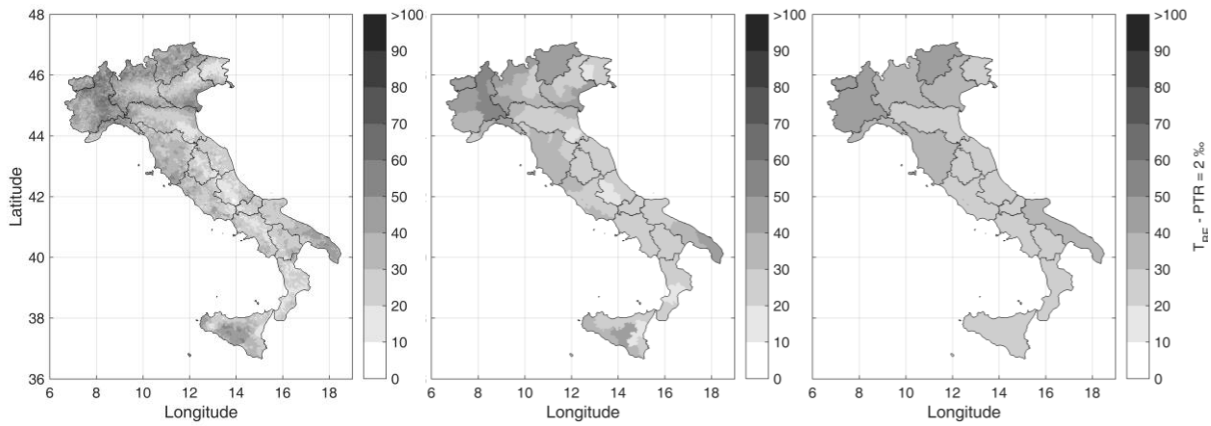

Figure 6: Break-even time map with *PTR* = 2 ‰ at municipal (left), provincial (center), and regional (right) level.

Figure 5 and Figure 6 clearly show the benefit of introducing this contribution. In particular, with PTR_x = 2 ‰ almost the entire national territory has a payback period lower than 30 years. Even in this case, considering less refined granularity has an averaging effect on t_{BE}, increasing the lower values, and reducing the higher ones.

4 CONCLUSIONS

In earthquake-prone countries, the development of financially sustainable risk reduction programs, is a key issue that has to be addressed starting from a deep knowledge of the risk at which the national territory is exposed. For this scope, suitable hazard, vulnerability and exposure models have to be defined, and then combined for computing the seismic risk map of the area of interest. The seismic risk map is the representation of the current *as-built* condition, from which the benefit due to seismic retrofit has to be computed. It is thus possible to compute the seismic risk map for the *retrofitted* configuration, and by subtraction the map of the expected benefit. The cost-benefits analysis performed for the Italian territory, showed a wide range of variability for the payback period, highlighting Italian regions in which seismic retrofit is highly recommended, and others in which it has a lower impact with high break-even times. For this reason, this work proposed a financially sustainable risk reduction strategy, based on the introduction of a property tax to be paid by citizen for achieving in a shorter time the financial break-even. The Italian Government, or, better, an *ad hoc* national public agency, has thus to support the seismic retrofit, whose cost-effectives is guaranteed by the introduction of this additional contribution. The flexibility of the proposed strategy allows computing the expected payback period corresponding to a given level of property tax rate, or vice versa, the property tax rate to be applied for re-entering the investment in a specific number of years. Results shows as a property tax rate of 2 ‰ assures for almost the entire national territory a payback period lower than 30 years. In this paper, all calculations are performed at three granularity levels, i.e. municipal, provincial and regional level, according to the Italian administrative subdivision. In particular, a less refined granularity has an averaging effect on the final break-even time, increasing the lower values, and reducing the higher ones. The use of different granularity levels is highly informative and, together with the developed maps, allows national authorities to take rational decisions for reducing the impact of future earthquakes that can occur in the Italian peninsula.

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