Cumulative damage to masonry structures due to repeated earthquakes and effectiveness of strengthening provisions

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The quantification of the response of buildings to consecutive shaking from strong motions occurring at the same site in relatively rapid succession, and before repairs can be implemented, is not a recent problem. Examples are documented from at least the late 1990's. However, after major swarms of earthquakes at the beginning of this decade, the Maule Chile earthquake, 2010, Christchurch, New Zealand earthquake, 2011, and the Tohoku, Japan earthquake, 2011, the scientific and technical community has been paying more attention to this issue with a significant number of studies devoted to this problem with the intent of providing design guidance for structures exposed to repeated shaking.

Such studies rely on:

- *more accurate documentation and reliable records of seismic sequences, thanks to denser and more sensitive arrays of sensors,*
- *better understanding and modelling of fault ruptures and relationship among consecutive strong motions;*
- *more detailed post elastic modelling of structures, with improved characterization of degrading capacity phenomena.*

Designing for multiple earthquakes is a logical extension of the performance-based design, responding to the necessity of minimizing damage, so as to reduce recovery times and costs, improve resilience and render the building stock more sustainable.

The paper summarizes key developments in this field within the framework of probabilistic risk assessment and illustrates the fundamental elements of such analyses with reference to the case of the 2016 Central Italy earthquake sequence, with particular attention to masonry structures. Using accurate data collected in situ for building affected by the earthquake in Norcia and in Amatrice, the mechanics approach coded in FaMIVE is used to determine initial and residual capacities of a large number of buildings under repeated shaking. Cloud of performance points are generated for each event to be used to determine fragility curves, representative of the percentage of buildings undergoing certain damage levels under the specific seismic scenario. A discussion on the obtained results and the capability of the method to represent the observed damage extents concludes the paper.