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*Editorial*

# Editorial of the Special Issue "Seismic Vulnerability and Strengthening of Unreinforced Masonry Buildings"

**Antonio Formisano [1], Luigi Sorrentino [2] and Maria Zucconi [3,*]**

[1] Department of Structures for Engineering and Architecture, University of Naples "Federico II", Piazzale Tecchio 80, 80125 Naples, Italy
[2] Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Via Antonio Gramsci 53, 00197 Roma, Italy
[3] Department of Engineering, University Niccolò Cusano, Via Don Carlo Gnocchi 3, 00166 Roma, Italy
* Correspondence: maria.zucconi@unicusano.it

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Historical structures represent a significant percentage of existing constructions in numerous seismic-prone regions, and some of these are iconic monuments of their countries. These structures deserve special care because of their individual historical and/or architectural meaning and are important evidence of earlier traditions of construction. Most extant European historical structures are made of unreinforced masonry. Earthquakes often cause either massive damage to or the destruction of these structures, whose seismic behavior evaluation is a challenge for scientific research. The seismic vulnerability assessment of such structures is generally based on observed post-earthquake data and/or on reliable numerical simulations. The empirical vulnerability methods require damage data, representing the statistical base for the derivation of fragility curves. These methods are affected by a significant variability due to the selection of a uniform and statistically relevant building and damage sample. Conversely, the numerical modeling of the seismic behavior of masonry structures represents a very complex problem due to the constitutive law of this structural material and its highly nonlinear behavior. Starting from this basis, the target of this Special Issue is to investigate different empirical and numerical modeling methods for the structural analysis of historical constructions and monuments in seismic-prone areas.

Ferrante et al. [1] focused on the dynamics and failure mechanisms of the masonry "Apennine church" of Santissimo Crocifisso in Pretare in the municipality of Arquata del Tronto (Marche region, Italy). Such a peculiar structural type traditionally characterizes the intense seismicity area of Central Italy but was unfortunately almost totally destroyed by the recent shock sequence of 2016. Advanced numerical modeling by means of discontinuous and continuous approaches was used to obtain the dynamic behavior under strong excitations. The non-smooth contact dynamic method was applied in the discrete element approach, adopting a full 3D detailed discretization. The church was schematized as an arrangement of rigid blocks, subjected to sliding by friction and perfect plastic collisions, with a null restitution coefficient. In the finite element (FE) approach, the concrete damage plasticity model was utilized. This model allowed the reproduction of tensile cracking, compressive crushing, and the degradation of the material under cyclic loads. Finally, numerical analyses provided the reasonable reproduction of the actual behavior of the church, thus giving helpful hints for future strengthening interventions.

Guerrini et al. [2] presented an experimental and numerical study on different strengthening solutions for stone masonry buildings with timber diaphragms, aimed at enhancing wall-to-diaphragm connections, diaphragm stiffness, and masonry properties. The experimental results of incremental dynamic shake-table tests on three full-scale two-story buildings, complemented by material and component characterization tests, were initially summarized. The first building was unstrengthened. The second building was retrofitted at the floor and roof levels with improved wall-to-diaphragm connections and a moderate increase in diaphragm stiffness. Connections were also improved in the third building, together with a significant enhancement in diaphragm stiffness. The calibration of two numerical models versus the experimental response of the retrofitted buildings was then presented. The models were further modified and reanalyzed to assess the effects of masonry mechanical upgrades, which were achieved by means of deep joint repointing or various types of jacketing. These solutions were simulated by applying correction coefficients to the masonry mechanical properties, as suggested by the Italian building code. Finally, the effectiveness of the experimentally implemented and numerically simulated interventions were discussed in terms of strength enhancement and failure modes.

Chieffo et al. [3] investigated the vibration period of the structural units (SUs) of a typical masonry building aggregate located in the historical center of Mirandola, a municipality in the Emilia-Romagna region, Italy. The cluster of buildings consisted of eighteen SUs mutually interconnected with each other and characterized by solid brick walls and deformable floors. First, nonlinear static analyses were performed by adopting an equivalent-frame software and considering the analyzed SUs in isolated and clustered configurations. The contribution in terms of stiffness and mass from adjacent buildings necessary to obtain the reliable seismic response of the SUs arranged in aggregated conditions was defined. The analysis results were represented in terms of risk factor, stiffness, and ductility. Secondly, the eigenvalue analysis was faithfully developed to identify the main vibration modes of the investigated SUs by proposing an empirical formulation that predicts the vibration period of SUs placed in an aggregated configuration starting from the corresponding isolated units. Finally, fragility functions were derived for both the end-of-row and internal SUs to determine the expected damage during earthquakes with different intensities.

Addessi et al. [4] studied the nonlinear dynamic response of the masonry bridge 'Ponte delle Torri' in Spoleto, Italy, to assess the seismic performance of the structure and evaluate the occurring damage mechanisms. A 3D FE macromechanical procedure was adopted to model the bridge. An isotropic damage model was used to reproduce the typical nonlinear microcracking process that occurs in masonry material when subjected to external loads. The model was based on a scalar damage variable introduced with the stress–strain constitutive law. A nonlocal integral definition of the damage-associated variable was adopted in order to overcome the mesh dependency problems of the FE solution typically occurring in the presence of strain softening behavior. A single equivalent pier was analyzed, whose geometry and boundary conditions were selected, so that its response could provide useful information on the out-of-plane dynamic behavior of the overall bridge. A set of accelerograms recorded on stiff soil between 1980 and 2016, displaying the same magnitudes, distances and fault styles of historical events dating back as far as 1246, was selected to simulate the seismic history of the site. The nonlinear dynamic response of the structure was evaluated and monitored in terms of the top displacement time history, the evolution of the global damage index, and the distribution of the damage variable. A set of analyses was performed by imposing the selected ground motions first independently and then in sequence in order to analyze the influence of accumulated damage on the response. The interaction between the dynamic response of the damaged structure and the signal characteristics was also highlighted.

Zucconi and Sorrentino [5] focused on large-scale seismic risk assessment for the optimal management of economic resources allocated to mitigation. In particular, the study aimed at developing new empirical damage fragility curves for census-based typological unreinforced masonry buildings. Damage data observed after the 2009 L'Aquila earthquake, Italy, related to almost 57,000 residential buildings, were used to calibrate the fragility functions. These data were complemented with the census data with the aim of obtaining an accurate estimation of the number of undamaged buildings. Damage fragility curves were identified for typological building classes, defined by considering parameters present in both post-earthquake observations and census data with the aim of extending the results to the whole national territory. Six typological classes were defined with consideration for the categories of the construction timespan and of the state of repair parameters. Then, a further distinction of the typological classes, which considered the number of stories parameter, was included where relevant. The fragility curves were defined as a function of peak ground acceleration for five damage states, defined according to the European macroseismic scale. The results confirmed that older buildings are more vulnerable than newer ones and highlighted the crucial role of the state of repair on the damage fragility curves. Finally, the new set of damage fragility functions was uploaded into the Italian Risk Maps information technology platform, used by the Civil Protection Department for risk evaluation, as an example of the potential application of the fragility curves.

Ferracuti et al. [6] focused on the seismic damage to 36 masonry churches observed after the 2016 Central Italy earthquakes. Recurrent architectural and structural features were identified and accurately described in the sample. In order to classify the churches in the sample based on their safety level, their seismic vulnerability was assessed by adopting the simplified procedure proposed in the current Italian guidelines for cultural heritage. The observed damage, directly surveyed during the post-earthquake inspections, was presented and carefully described, highlighting the accumulation of the damage throughout the seismic sequence. An analysis of the damage suffered by the inspected churches highlighted the most frequent local mechanisms and the most vulnerable macroelements. Particular attention was devoted to the computation of a damage index based on the observed damage, as well as on the macroelements present in the surveyed churches. Moreover, the usability assessment, i.e., the suitability of a church to be utilized after a seismic event without increased risk to human life, was made using the official survey form and related to both the seismic intensity experienced and the observed damage index. An analysis of the collected data enabled the consideration of the usability assessment with respect to the damage index values, computed according to Italian practice.

Unreinforced masonry constructions frequently present ineffective internal connections that increase their earthquake vulnerability. A similar deficiency can be observed in precast buildings, such as those studied by Quaglini et al. [7], who focused on the seismic behavior of prefabricated industrial sheds typical of past Italian building practices, which typically exhibited rigid collapse mechanisms due to the absence of rigid links between columns, beams, and roof elements. This study presented the experimental and numerical assessment of a novel dissipative connection system (DCS) designed to improve the seismic performance of prefabricated sheds. The device, which is placed on the tops of columns, exploits the movement of a rigid slider on a sloped surface to dissipate seismic energy, control the lateral displacement of the beam, and provide a recentering effect at the end of the earthquake. The backbone curve of the DCS and the effect of vertical load, sliding velocity, and the number of cycles was assessed in experimental tests conducted on a scaled prototype in accordance with a test protocol designed to account for similarity requirements. In the second part of the study, nonlinear dynamic analyses were performed on a FE model of a portal frame, implementing, at beam-column joints, either the DCS or a pure friction connection. The results highlighted the effectiveness of the DCS in controlling beam-to-column displacements, reducing shear forces on the top of columns, and limiting residual displacements that can accrue during ground motion sequences.

**Data Availability Statement:** No new data were created or analyzed in this study. Data sharing is not applicable to this article.

**Conflicts of Interest:** The authors declare no conflict of interest.

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