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Recent Advances on the Mechanics of Masonry Structures

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Masonry, one of the oldest construction materials of mankind, consists of solid blocks such as stones or bricks that are laid in mortar or being held together by dry frictional contacts. The discrete built-up of masonry makes its behaviour non-linear and highly discontinuous. Although, masonry at low static stress levels it may still be modelled as a linearly elastic system, after the formation of first cracks the behaviour becomes increasingly non-linear until finally reaching collapse. The geometry of the individual stones and of the joints between them also significantly affects the behaviour of masonry, making it inhomogeneous and non-continuous.

While masonry is among the most important construction materials today, its importance is strengthened by the fact that historic structures mostly consist of masonry. Over the centuries or even millennia these structures have inevitably suffered different damages due to effects like earthquakes, soil settlements, material degradation, or improper intervention. Consequently, regular assessment of masonry structures is needed in order to check their load bearing capacity and safety levels. Structural engineers and architects often face the problem that a damaged masonry building and perhaps its different strengthening possibilities have to be analysed, in such a way that the response of the structure to future mechanical effects should be reliably modelled. Hence, suitable methods should be used for such calculations that can properly capture the most relevant features of the mechanical behaviour.

Seismic analysis of masonry structures deserves special emphasis due to the challenging contradiction that on one hand, masonry is vulnerable to earthquakes because of the possibility of the individual blocks to slide or move separately from their neighbours; on the other hand, masonry has a high energy dissipation capability, and in addition, even seriously damaged structures in which the blocks performed significant relative displacements can retain a high level of their load bearing capacity. No wonder that seismic analysis is the most actively studied field of masonry mechanics.

Calculation methods existing today embrace a wide variety of discrete element simulations, limit state analysis tools, nonlinear finite element modelling, different blocky models etc. These modern methods brought new insights into the understanding of issues like how the different structural types carry their loads; how the available strengthening techniques influence the behaviour by redistributing the internal forces or stiffening some parts of the structure while leaving others unaffected; how a specific structure will behave under usual effects throughout its expected lifetime or under an extreme effect like an explosion or an earthquake etc.

This special issue at the Journal of Engineering Mechanics focuses on recent advances in analysis and modelling of masonry structures. The special issue is part of 10 invited technical contributions from high profile international researchers in the area of computational modelling of masonry structures as well as on the authors presenting initially scheduled on the Mini-Symposium MS-72 at the 2020 ASCE International Conference, 5-8 April 2020, Durham, UK. A synopsis of each contribution is presented below.

Facades of masonry buildings are composed of piers and spandrels are vulnerable to in-plane action as a result of seismicity and soil subsidence. With the view to increase vulnerability and safety of masonry structures, Drougkas et al. 2021 presented the development of analytical models to determine the in-plane damage initiation and force capacity of masonry walls with openings. The model accounted for all potential damage and failure modes for in-plane loaded walls. Model results compared with numerous experimental cases and good accuracy achieved. The proposed model presents opportunities for future work related to the simulations of structural reinforcement such as in the form of embedded bars.

With an attempt to understand the response of masonry structure to explosions, Masi et al. 2021 presented scaling laws for the rigid body response of masonry structures under blast load. The proposed scaling laws have been validated against numerical and experimental tests. Then, the application to blocky masonry structures was investigated. As an example, multi-drum stone columns were considered. It was shown that the presence of complex behaviour such as wobbling, and impacts can be simulated. It should be highlighted that this work presents the first step towards the design of reduced scale experiments of masonry structures providing appropriate scaling laws which assure the similarity of both blast loading and structural dynamic response. All data, models and codes supporting this research are available by the authors.

In addition, Ferrante et al. 2021 presented the influence of stereotomy on discrete approaches applied to an ancient church in Muccia (Italy). a. The structure was modelled considering the actual stereotomy of blocks and other three hypothetical arrangements of blocks of the masonry walls, to adequately investigate the existing crack pattern and vulnerabilities of the church. Indeed, the findings presented in this work allowed a better understanding of the global and local behaviour of the structure, which leads to adequate restoration works of the Church.

An advanced nonlinear mechanical numerical model based on the micro-modelling approach to evaluate the evolution of damage on an already damaged structure strengthened with TRM material presented by Giordano et al. (2021). The model was first calibrated using modal analysis. The model presented a good compromise between computational efficiency and accuracy to evaluate the global capacity curve and damage patterns. The model was able to estimate the initial elastic phase, peak load, ductility, and failure mechanism scenario.

Aita and Sinopoli (2021) examined the collapse of non-symmetric masonry arches, modelled as assemblages of rigid voussoirs linked by unilateral constraints, and characterized by infinite compressive strength and finite coulombs friction. The alternative approach developed here allows solution finding that corresponds to both the limit equilibrium condition and the definition of a collapse mechanism with one degree of freedom, as thickness and friction coefficient vary.

Vlachakis et al. 2021 presented numerical block-based simulations of rocking structures using novel universal viscous damping models. In particular, the proposed viscous damping model made use of novel ready to use predictive equations that capture the dissipative phenomena during both one sided and two-sided planar rocking motions. Results compared with experimental findings and good agreement observed. Note that, even though the proposed numerical (viscous damping)
model was evaluated against the two most observed out-of-plane collapse mechanisms of unreinforced masonry structures, to further enhance its applicability, a more thorough investigation against additional collapse mechanisms (e.g., the vertical spanning strip wall, or the corner mechanism) is required. Such analyses, though, should be accompanied by extensive experimental campaigns, which are currently lacking in the literature and, thus, are topics of future research

The special issue focused on the behaviour of confined masonry and in particular the response of masonry infills. For example, Sirotti et al. 2021 presented the development and validation of new Bouc-Wen data-driven hysteresis model for masonry infilled RC frames. In this case, the infill panel was schematized as a single degree of freedom element, whose constitutive law was given by the proposed hysteresis model. The model combined a degrading Bouc-Wen element with a slip-lock element, which is introduced specifically to reproduce the pinching effect due to crack openings in the masonry panel. The model calibrated using a genetic algorithm-based optimization on single story, single bay RC infills subjected to cyclic loading. The potential of the model to simulate dynamic and stochastic simulations was also addressed.

In a similar topic, Pradhan et al. 2021 showed prediction equations for the out of plane capacity of unreinforced masonry infill walls based on a macro-element model using an extensive parametric analysis such as variation in geometrical and mechanical properties. From the results analysis it was shown that the out of plane strength of infills was largely influenced by compressive strength, slenderness ratio, aspect ratio and additionally by the level of in-plane damage. The reduction of the out of plane strength and stiffness due to in-plane damage was largely governed by the strength and the slenderness ratio of the unreinforced masonry infill wall. The reliability of the proposed model was also proved by comparisons with experimental results and some of the analytical models already available in the literature.

Grillanda et al. 2021 presented advanced modelling investigations into historical masonry umbrella vaults subjected to settlement and cracking development using NURBS kinematic analysis. The Principle of Virtual Works has been applied and a discontinuous displacement field deriving from an imposed settlement was obtained. Therefore, a meta-heuristic mesh adaptation procedure was applied to find the correct disposition of fracture lines. Different settlement typologies were adopted in the analyses to reproduce the crack pattern observed on the umbrella vault. Lastly, an inverse analysis was conducted to estimate the shape of the occurred settlements starting from the observed crack pattern.

Rios et al. 2021 presented statistical assessment of in-plane masonry panels using limit analysis with sliding mechanism. A discrete modelling approach based on a non-standard Limit Analysis approach adopted which was capable of reproducing sliding mechanisms. The parametric analysis presented allowed to objectively identify the effect that the panel ratio, block ration, bond type and friction ratio have in the collapse load and mechanism. All the analyses show the importance in the collapse behaviour of the size and the disposition of the bricks that determine the level of interlocking among bricks, and then the cohesion of the whole.

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