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Modelling historical masonry aggregates using the equivalent frame approach

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Abstract

Many historical centres in Europe, including the city centre of Zagreb, feature masonry building aggregates, which developed as the building layout of the city was densified. Adjacent buildings in aggregates often share a structural wall and the building that was constructed second connects to the wall of the first building through a dry joint. When compared to the response of single free-standing buildings, several factors make the seismic response of masonry building aggregates more complex: It is not unusual for adjacent units to have different material properties, area and distribution of openings, roof and floor heights and orientations, and construction details.

Key words: historical masonry, masonry aggregates, equivalent frame models, epistemic uncertainty, incremental dynamic analysis, non-linear connections

Many historical centres in Europe, including the city centre of Zagreb, feature masonry building aggregates, which developed as the building layout of the city was densified. Adjacent buildings in aggregates often share a structural wall and the building that was constructed second connects to the wall of the first building through a dry joint. When compared to the response of single free-standing buildings, several factors make the seismic response of masonry building aggregates more complex: It is not unusual for adjacent units to have different material properties, area and distribution of openings, roof and floor heights and orientations, and construction details. All these factors can result in an out-of-phase behaviour of adjacent units and potential separation and pounding of the units. The interface behaviour which needs to account for this interaction adds another level of uncertainty to the already complex behaviour.

The advances in the modelling of unreinforced masonry aggregates were impeded by the scarce experimental data. A stone masonry aggregate was designed in the EUCENTRE laboratory in Pavia, Italy to reproduce the features typical for existing unreinforced masonry aggregates in Basel, Switzerland. It was subjected to a unidirectional seismic excitation in both the original and strengthened configuration [1, 2]. Senaldi et al. [3, 4], Formisano et al. [5-7], and Maio [8] modelled unreinforced masonry aggregates with equivalent frame approach, using non-linear macroelements [9] implemented in TREMURI software [10]. Even with some disagreements on the demands imposed on the units of an aggregate, overall, the studies found the influence of adjacent units to be important for the evaluation of the seismic behaviour of masonry aggregates. However, all the models featured a perfect connection between the units of an aggregate. Modelling the adjacent units as isolated or fully connected can result in conservative approximations regarding the PGA at failure, but ignores the complex response stemming from adjacent unit interaction. Interaction includes relative displacements in the longitudinal and transversal direction and potential pounding. To account for this, a new nD interface material model was developed and implemented into OpenSEES software [11].

To study the effect of interface modelling on the seismic response of a building aggregate, a case study aggregate was modelled using the Equivalent Frame Approach and a newly developed macroelement for modelling the in-plane and out-of-plane response of masonry walls [12]. The model was subjected to a bi-directional non-linear time history analysis using different modelling approaches regarding the interface: fully connected units, isolated units, 1D non-linear interface, and a newly developed nD non-linear interface material model. Uncertainty of the masonry and interface parameters is taken into account to give a stochastic response.

The results are reported in terms of the force-displacement response of the aggregate and failure mechanisms with regards to the interface model. Special attention is paid to the aggregate behaviour in relation to the interface separation. The results show that the PGA leading to failure is the least sensitive of the investigated response parameters. A simplification in the representation of the interface behaviour can, however, lead to a different failure mode and failure location in the building. This becomes especially relevant when the analysis serves as input for the design of retrofit interventions.

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