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Out-of-plane response of URM gable walls: from experimental testing to modeling and assessment tools

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Keywords: Gable walls, Roof stiffness, Seismic vulnerability assessment, Shake-table tests, Out-of-plane response, Unreinforced Masonry.

Low-rise masonry buildings in Europe and worldwide are predominantly characterised by unreinforced masonry (URM) walls combined with pitched timber roof systems, often supported by masonry gables. These structures constitute a significant portion of the existing building stock in seismic-prone regions, including areas exposed to both natural and induced seismicity. Among their components, masonry gables are frequently identified as the most seismically vulnerable elements with respect to out-of-plane (OOP) response. Post-earthquake damage surveys worldwide provide extensive evidence of this vulnerability, which arises from their pronounced slenderness, weak connections to roof structures, minimal vertical overburden, and their position at the building apex. In addition, the interaction between gable walls and flexible roof diaphragms can further increase seismic vulnerability. Rather than providing effective restraint, timber roof systems may amplify seismic motion and transfer increased OOP demands to the gables. Despite the recurrent observation of gable failures in past earthquakes, dedicated experimental investigations on their seismic response remain limited in the literature [1]. Most available insights are derived from tests on masonry walls with rectangular geometries [2,3], leaving a substantial gap in the understanding of the dynamic behaviour of triangular gable walls and their interaction with roof structures under seismic loading. To address this gap, this study presents an experimental campaign on the dynamic OOP seismic response of full-scale URM gable walls tested up to collapse.

Three identical full-scale URM gable specimens were constructed and tested. The gables were triangular in shape, with a base length of 6.0 m and a height of 3.0 m, and were built on a composite steel–concrete foundation. Solid clay bricks with average dimensions of 230 × 105 × 55 mm were used, resulting in a wall thickness of 105 mm, while 10-mm-thick mortar joints were adopted. The masonry materials were representative of existing construction practice, with weak mortar relative to brick strength. Each gable wall incorporated five joist pockets accommodating timber beams with a cross-section of 100 × 200 mm, representative of roof joists. These beams were used to apply vertical pre-compression and to transmit lateral inertial forces along the height of the gable. Timber-to-masonry connections relied solely on friction. A vertical load corresponding to half the weight of a typical timber roof, consistent with the gable geometry, was applied through the timber beams, resulting in a total vertical load of 22.5 kN on the gable wall.

Incremental dynamic shake-table tests were carried out at the EUCENTRE laboratory in Pavia, Italy, using the 9D LAB facility. This advanced seismic testing system features a dual shake-table configuration, allowing different input motions to be imposed at the base and at the top of the gable walls [4]. The influence of roof stiffness on the OOP response of the gables was reproduced by varying the motion applied to the top shake table. Three roof–gable interaction configurations were considered within the same campaign: (i) Gable1-STIFF, representing a stiff roof diaphragm, where the top motion replicated the base motion; (ii) Gable2-SEMIFLEX, representing an intermediate case, where the top motion was linearly amplified relative to the base motion; and (iii) Gable3-FLEX, simulating a flexible roof leading to amplification and phase shift at the gable top.

The applied input motions considered two alternative seismic scenarios, representative of both induced and tectonic seismicity. For the induced seismicity scenario, numerical analyses were performed on a finite element model of a typical URM building from the Groningen region of The Netherlands, and the resulting roof-level motions were used as input. For the tectonic seismicity scenario, recorded accelerations from the 2016 Central Italy earthquake were adopted, obtained from a monitored masonry building at the attic floor level. In this case, the gable–roof interaction was modelled using a representative elastic single-degree-of-freedom system. Further details on the selection and processing of the input signals can be found in [5]. Each gable specimen was subjected to an incremental testing sequence including both seismic scenarios.

Under the adopted testing sequence, all three gable specimens exhibited a one-way bending failure mechanism. Complete collapse was preceded by the development of a three-body rocking mechanism, associated with the

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formation of two horizontal flexural cracks spanning the full length of the gable at the locations of the two sets of timber joists (Figure 1). The seismic capacity of the gables and the influence of roof flexibility are evident from the incremental dynamic testing curves provided in Figure 1 for the three configurations. These curves are derived by plotting the peak bottom table acceleration (*PBA*) against the corresponding maximum gable displacement (i.e., max(d_{ctrl})) for each testing run. The comparison of the three capacity curves highlights the detrimental effect of roof flexibility, with the Gable3-FLEX configuration exhibiting significantly lower seismic capacity and markedly higher flexibility.

Overall, the experimental campaign provides unique insight into the dynamic out-of-plane response, damage evolution, and collapse mechanisms of URM gable walls under different interaction scenarios with the roof diaphragm. The generated open-access dataset (*https://doi.org/10.60756/euc-1avy7q49*), is currently being used to calibrate advanced discontinuum numerical models. These will support parametric studies on geometry, material properties, roof stiffness, and connection details not considered in this campaign, with the objective of improving simplified few-degrees-of-freedom assessment tools for large-scale vulnerability and risk analyses. The findings contribute to a more realistic representation of gable-roof interaction and provide experimental benchmarks to support the development of retrofit strategies and future code-oriented assessment procedures for URM gable walls.

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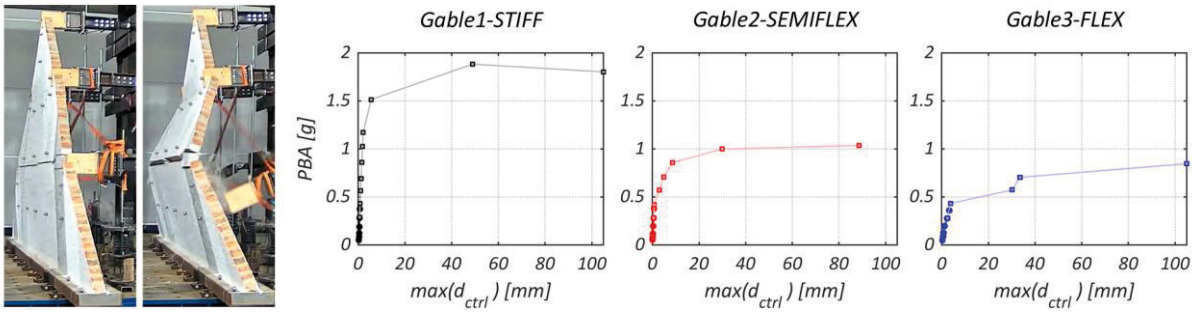


Figure 1: Failure mechanism (left) and capacity curves of Gable1-STIFF, Gable2-SEMIFLEX and Gable3-FLEX (right)

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