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A Distinct Element Method Comparison of Retrofit Systems for a Two-storey Unreinforced Masonry Building

Yopi Prabowo Oktiovan, Nicolò Damiani, Francesco Messali

Keywords: Unreinforced masonry, Distinct Element Method, Timber strong-backs, Oriented strand board panels, Steel retrofit system, In-plane pushover response

This study compares, through high-fidelity numerical simulations, two lightweight, sustainable, reversible, and minimally intrusive retrofit strategies for unreinforced masonry (URM) buildings: a modular steel braced system (Resisto 5.9) and a timber strong-back system combined with oriented strand board (OSB) sheathing. Both interventions are conceived to improve wall-to-wall and wall-to-floor connectivity, thereby mitigating premature local mechanisms and promoting a more global building response with increased lateral strength and deformation capacity of the masonry piers. The study uses a full-scale, two-storey URM terraced-house specimen tested at the Delft University of Technology. The experimental results provide the benchmark for the numerical model and reflect a common building type where response is sensitive to connection detailing and failure-mode transitions. The retrofit layout are summarised in Figure 1, which reports the elevation and wall views for the two solutions.

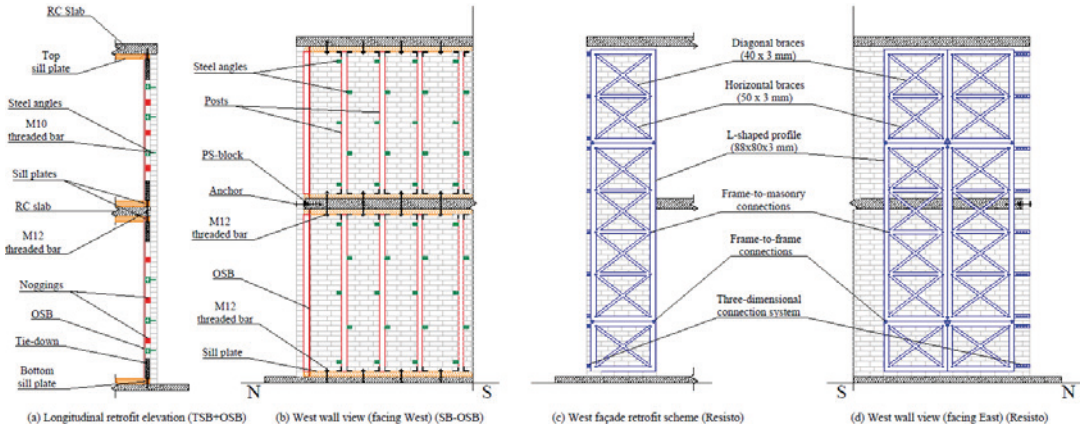


Figure 1: Retrofit configurations for the west masonry wall: (a–b) timber strong-back with OSB sheathing (TSB+OSB) and (c–d) steel braced Resisto 5.9 system, shown in elevation and west wall views (facing East/West).

The timber-based retrofit consists of vertical posts, acting as strong-backs, coupled with OSB sheathing and connected to the masonry through mechanical anchors and tie-downs at floor levels and at the foundation. The system provides a lightweight and reversible alternative load path, improves wall–diaphragm compatibility, and reduces deformation concentration in individual piers. The modular steel retrofit (Resisto 5.9) is an exterior braced frame with vertical, horizontal and diagonal members anchored to the masonry at predefined locations, including connection elements to couple orthogonal walls. It is intended to enhance global stability, redistribute in-plane forces, and increase ductility through improved restraint and continuity at critical interfaces.

Masonry is simulated with the Distinct Element Method (DEM) using a contact constitutive model that concentrates nonlinear behaviour at block interfaces for efficient building-scale analysis. The timber posts are modelled as beam elements, while sill plates (elastic) and OSB panels (elastic–perfectly plastic) are modelled as solid elements; timber-to-masonry connections are represented by nonlinear links, and sill plates are assumed perfectly connected to floors and base. For Resisto 5.9, the steel members are modelled as beam elements with nonlinear frame-to-masonry anchors, while frame-to-frame connections between modules are taken as rigid.

For simplicity, the study is limited to monotonic pushover analyses and models only half of the terraced house. The as-built and retrofitted configurations are compared in terms of the global force–displacement response and the end-state deformed shape at a target displacement of 80 mm (Fig. 2).

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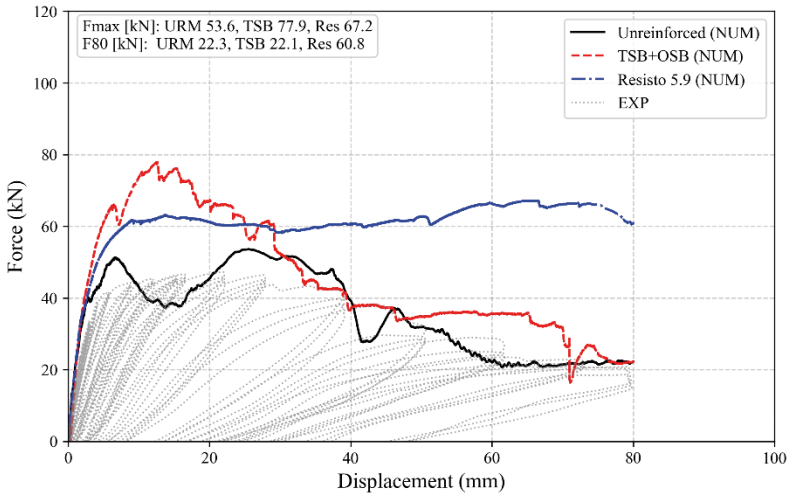


Figure 2: Force-displacement comparison

The pushover comparison shows that both retrofit strategies increase peak strength relative to the unreinforced model, but they differ markedly in post-peak stability. The unreinforced configuration reaches $F_{max} = 53.6$kN, while TSB+OSB increases the peak capacity to 77.9kN (≈+45%). Resisto 5.9 provides the largest increase, reaching 98.6kN (≈+84%). At the target end displacement of 80 mm, the response diverges: the unreinforced and TSB+OSB curves degrade to a similar residual level ($F_{80} \approx 22.3$ kN and 22.1kN, respectively), indicating pronounced post-peak softening and limited strength retention for TSB+OSB despite the higher peak. In contrast, Resisto 5.9 retains near-peak capacity at large displacement ($F_{80} = 96.0$ kN, ≈97% of F_{max}), evidencing a stable, ductile response once the braced-frame mechanism is fully mobilised.

This behaviour is consistent with the deformed configurations at 80 mm (Figure 3): Resisto 5.9 promotes a global drift mechanism with clear engagement of the steel system and more distributed deformation, whereas TSB+OSB provides earlier strength enhancement but the global deformation demand is accommodated through progressive masonry degradation and redistribution within the building system.

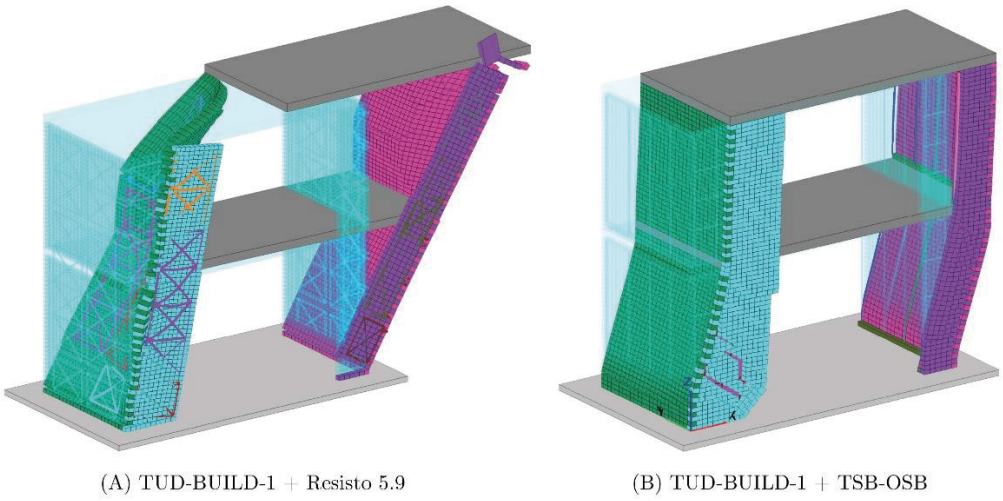


Figure 3: Deformed shape of the retrofitted building (Magnified 30x)

Overall, the comparisons show that both retrofits increase lateral capacity relative to the as-built structure, while Resisto 5.9 provides the most stable, high-capacity response at large displacement through effective mobilisation of the braced-frame load path. In contrast, the timber strong-back system achieves a clear strength gain but exhibits more pronounced post-peak degradation, indicating that its performance is governed by progressive masonry damage and connection compliance once peak resistance is reached.