Available online at www.eccomasproceedia.org
Eccomas Proceedia COMPDYN (2025) 2456-2461

ECCOMAS
Proceedia

COMPDYN 2025
10th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Rhodes Island, Greece, 15-18 June 2025

PRELIMINARY RESULTS ON EXPERIMENTAL INVESTIGATION OF FUSE-BASED CROSS TIES USED IN OUT-OF-PLANE STABILIZATION OF MASONRY FACADES

Eugenia Verrigni Petrei Castelli[1], Giacomo Destro Bisol[2], and Luigi Sorrentino[1]

[1] Sapienza University of Rome
Piazzale Aldo Moro, 5, 00185 Roma RM
{eugenia.verrignipetrei,luigi.sorrentino}@uniroma1.it

[2] McGill University
a845 Rue Sherbrooke O, Montréal, QC H3A 0G4, Canada
giacomo.destrobisol@mail.mcgill.ca

Abstract

Vintage unreinforced masonry constructions often lack adequate connections between their facades and transverse structures, making them vulnerable to out-of-plane failures during earthquakes. Historically, cross ties have been used to prevent such failures and maintaining the box-like behavior of masonry structures, essential for their seismic stability. The strength and the brittle or ductile behavior of cross ties are highly influential on the response of masonry facades. Experiments available in the literature have shown that cross ties may develop limited ductility due to the threading necessary for their installation and tightening.
The research investigates a novel approach where a plastic fuse element is integrated into the cross-tie system to improve ductility and simplify repair by predetermining the failure location. A sacrifice element, made of a plastic material, is connected to carbon-steel rods by means of threaded turnbuckles. To investigate the behavior of these fuse-based cross ties tensile tests are performed. Preliminary experimental results show strength and elongation reduction due to threading, but the fuse-based cross ties have an elongation still significantly more ductile than standard threaded carbon-steel cross ties.

Keywords: URM, Tie Rods, Earthquake, Seismic, Strengthening, OOP.

Peer-review under responsibility of the organizing committee of COMPDYN 2025.
doi: 10.7712/120125.12580.25118

1 INTRODUCTION

Metallic cross ties are key structural components in vintage unreinforced masonry buildings, whose facades often lack adequate connections to transverse structures, making them prone to dangerous out-of-plane failures during earthquakes [1, 2]. Ensuring proper connections between structural elements is crucial to maintain the box-like response of masonry buildings [3, 4]. This behavior refers to the coordinated functioning of all structural components, which allows the in-plane response of the walls to be triggered and increases the building resistance to horizontal forces caused by an earthquake.

Cross ties are steel bars that connect the facade to transverse walls aligned with the earthquake direction, preventing the facade from overturning out of plane. Positioned parallel to the facade, they improve the in-plane load distribution and enhance the effectiveness of spandrels under load reversal. This technique is highly compatible and has become one of the most traditional methods frequently used in historical buildings [5].

Not all mechanical properties of steel cross ties significantly affect the response of masonry facades. For example, axial stiffness has a minimal role, while the yield strength and the type of material behavior (brittle or ductile) are the most influential parameters [6]. The steel bars currently used as cross ties differ from historical ones, as modern production processes ensure a high quality of material with well-defined mechanical properties. Installation typically involves threading the rod ends, but this detail unfortunately leads to a substantial reduction in ductility compared to the unprocessed material, with a 2% ultimate elongation reported for 12-mm diameter carbon steel cross ties [7-8].

To facilitate the repair process and predict the location of potential failures, a fuse-based solution is proposed hereinafter. This will make replacement easier while also being investigated as a way to improve ductility.

2 RESEARCH LAYOUT

To investigate the response of the proposed solution, different configurations are tested: one with each material considered independently (setup 0, S0) and another incorporating a plastic fuse (setup 3, S3). The experimentation is still in progress and when completed it will account for two diameters, 12 and 20 mm, and two lengths for the exposed threading, 1 mm and four diameters (i.e., 48 and 80 mm, correspondingly). To account for experimental scatter six tests are performed for each configuration.

To perform the axial force tests two vertical hydraulic universal machines, with maximum forces of 200 and 1000 kN, are used depending on material and configuration. The bar elongation is measured using a 500-mm-stroke LVDT instrument, while the force is measured by the machine incorporated system.

The experimental campaign is still ongoing, and the results discussed in this work should be considered partial, as the testing phase has not yet been completed. As previously highlighted [9], further experiments are currently underway and are expected to provide additional insights into the performance of the proposed configuration.

2.1 Smooth material (S0)

Tests on unthreaded bars (S0) are planned to deliver stress-elongation curves for each material. Hereinafter are presented the preliminary results on 12-mm-diameter carbon-steel and nylon bars. In Figure 1 the results of axial tests on S235JR steel grade, used for the cross ties sections, are shown. The average tensile strength was nearly 600 MPa, while the yield one was approximately 550 MPa, substantially higher than the declared characteristic strength. The non-dimensional elongations were approximately 12.0 and 1.5%, respectively.

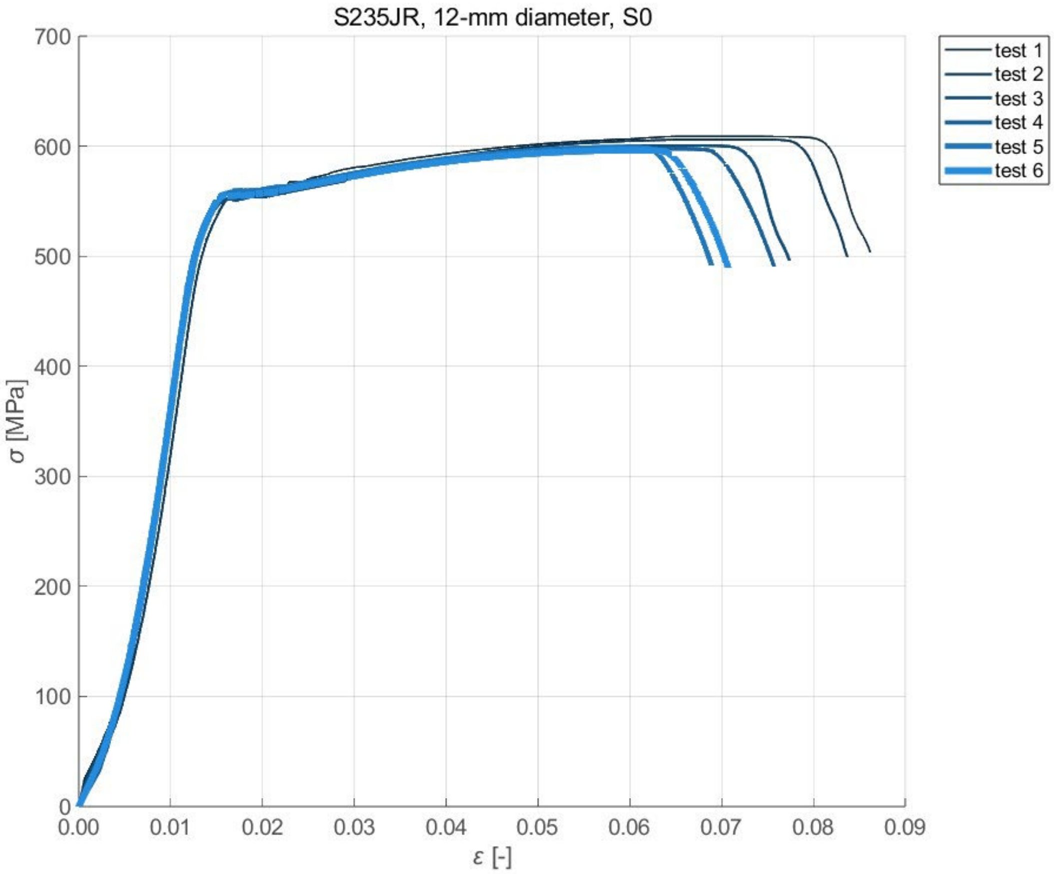

Figure 1: Stress-elongation diagram of six tests performed on 12-mm diameter carbon-S235JR-steel smooth bars.

The laboratory tests on nylon Figure 2, a thermoplastic, presented a response frequently so ductile that the machine stroke was reached. The average tensile strength of nylon was about 50 MPa, and it exhibited elongation values greater than 125%. The non-dimensional elongation of the single failed bar was approximately 105%.

Figure 2: Smooth nylon bar before the laboratory test.

2.2 Fuse-based cross ties (S3)

Setup 3 comprises two carbon steel bars, two carbon steel turnbuckles, and a single plastic fuse positioned at the center, resulting in a total length of 1 m. A total of 48 tests is planned for the fuse-based configuration (S3, Figure 3), with the 12 tests conducted on the 12-mm nylon fuse-based cross ties presented here.

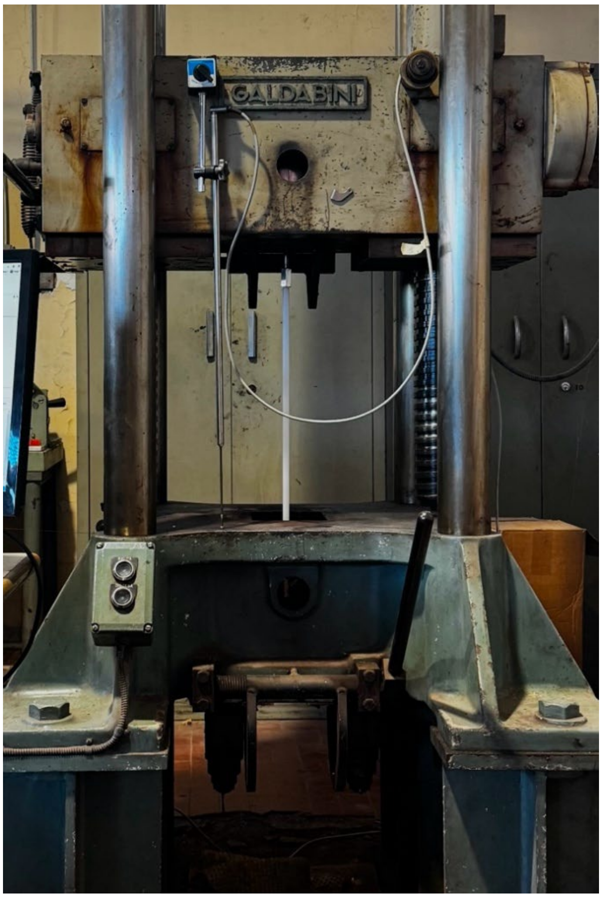

Figure 3: Twelve-mm diameter cross tie with nylon fuse in the vertical hydraulic universal machines during the laboratory test.

To examine the effect of the disengaged threaded length of the nylon fuse, two configurations are considered, and the following tests are performed: a) six tests with a 1-mm length (referred to as 0d in the legend of Figure 4); b) six tests with a 48-mm length (referred to as 4d). A fragile behavior was observed in this type of cross ties due to the failure of the nylon threading. As a result, the ductility of the thermoplastic material was not fully utilized, even with the longest turnbuckles readily available on the market. In this configuration, the carbon steel turnbuckles exhibited elastic behavior. Hence, tests on the S3 configuration revealed that the threading process significantly reduced both ductility and strength compared to the unthreaded nylon bars (S0). The average tensile strength for the S3 0d configuration was approximately 35 MPa (a reduction of about 35%), while for the 4d configuration, it dropped to nearly 25 MPa (a reduction of about 50%). The exposed thread did not introduce notable differences, as all cross ties failed consistently due to threading failure. The nondimensional elongation for both threading configurations (0d and 4d) was approximately 5%, representing an average reduction of 90%. Despite this substantial reduction, the 5% nondimensional elongation of the S3 setup remains more than twice that reported for threaded carbon steel tie rods [8].

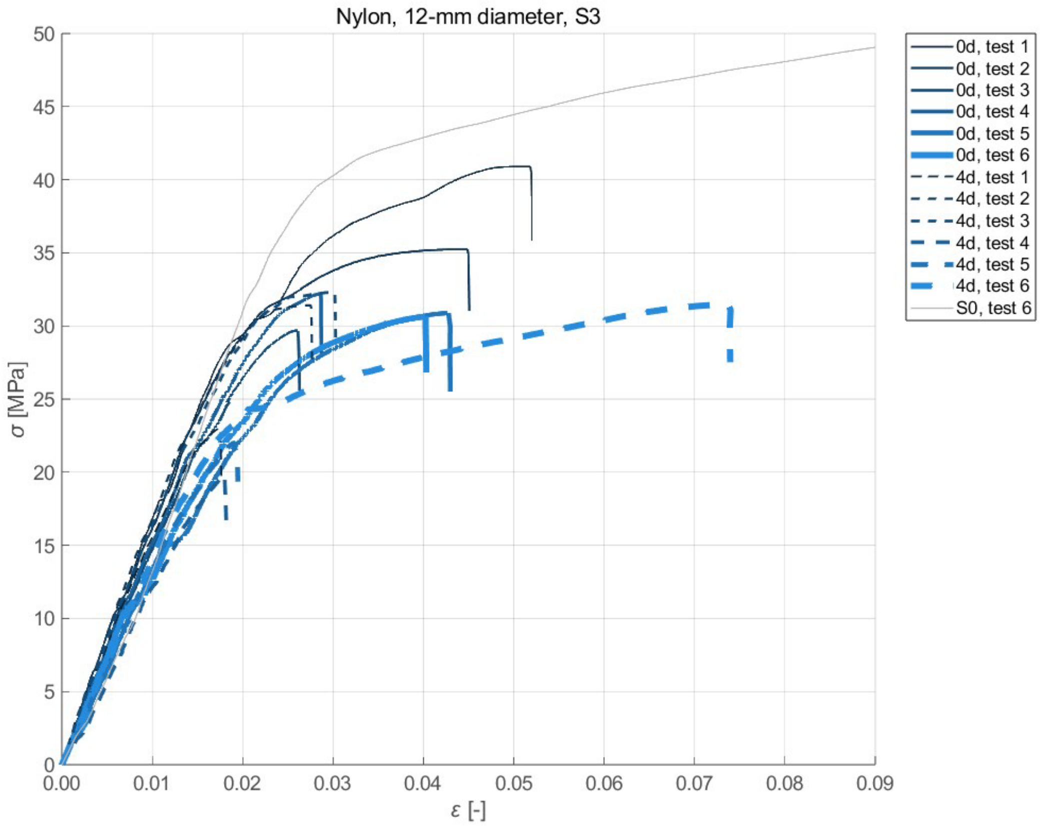

Figure 4: Stress-elongation diagram of tests performed on the 12-mm diameter fuse-based nylon configuration (S3). Solid lines are related to 1-mm (0d) exposed threading length, dashed lines are related to 48-mm (4d) length.

3 CONCLUSIONS

A cross tie configuration featuring a fuse was evaluated, utilizing a 12-mm nylon rod linked to two carbon steel rods via two carbon steel turnbuckles. When subjected to tension, the carbon steel components remain elastic, whereas the plastic rod threading fails. This specific failure mechanism led to a notable reduction in strength and a significant drop in non-dimensional elongation compared to the corresponding smooth nylon rod. Nevertheless, the setup normalized elongation remains more than twice that observed for same-diameter carbon steel threaded rods. Additionally, incorporating a fuse into this low-cost, low-impact retrofitting solution allows for an easily replaceable element. These initial findings require further validation for the planned larger diameters and alternative thermoplastic materials. Future research may also explore the use of a longer turnbuckle to mitigate threading failure.

ACKNOWLEDGEMENTS

This work was partially carried out under the research program SISTINA (SIStemi Tradizionali e INnovativi di tirantatura delle Architetture storiche) funded by Sapienza University of Rome and under the research program “Dipartimento di Protezione Civile – Consorzio RELUIS”. The opinions expressed in this publication are those of the authors and are not necessarily endorsed by the funding bodies.

REFERENCES

[1] O. AlShawa, D. Liberatore, L. Sorrentino, Dynamic One-Sided Out-Of-Plane Behavior of Unreinforced-Masonry Wall Restrained by Elasto-Plastic Tie-Rods, *International Journal of Architectural Heritage,* 13, 340–357, 2019.

[2] C. Calderini, P. Piccardo, R. Vecchiattini, Experimental Characterization of Ancient Metal Tie-Rods in Historic Masonry Buildings, *International Journal of Architectural Heritage*, 13, 425–437, 2019.

[3] G. Destro Bisol, S. Prajapati, L. Sorrentino, O. AlShawa, Vertical spanning wall elastically restrained at the top: validation and parametric dynamic analysis, *Bulletin of Earthquake Engineering*, 2024.

[4] V. Follador, P. Carpanese, M. Donà, F. da Porto, Effect of retrofit interventions on seismic fragility of Italian residential masonry buildings, *International Journal of Disaster Risk Reduction* 91, 103668, 2023.

[5] P.B. Lourenço, N. Mendes, L.F. Ramos, D. V. Oliveira, Analysis of Masonry Structures Without Box Behavior, *International Journal of Architectural Heritage,* 5, 369–382, 2011.

[6] S. Podestà, L. Scandolo, Earthquakes and Tie-Rods: Assessment, Design, and Ductility Issues, *International Journal of Architectural Heritage*, 13, 329–339, 2019.

[7] S. Prajapati, G. Destro Bisol, O. AlShawa, L. Sorrentino, Non-linear dynamic model of a two-bodies vertical spanning wall elastically restrained at the top, *Earthq Eng Struct Dyn*, 51, 2627–2647, 2022.

[8] F. Solarino, D. V. Oliveira, L. Giresini, Wall-to-horizontal diaphragm connections in historical buildings: A state-of-the-art review, *Eng Struct*, 199, 109559, 2019.

[9] E. Verrigni Petrei Castelli, G. Destro Bisol, L. Sorrentino, Tying facades of masonry buildings: preliminary experimental results on fuse-based solutions, *3rd International Conference on Resilience, Earthquake Engineering and Structural Health Monitoring (ICONREM)*, Torino-Ispra, Italy, June 24-27, 2024.