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Natural fiber TRM systems for sustainable seismic retrofitting of masonry walls: an experimental study using jute fibers

Flavio Stochino[a]*, Arnas Majumder[a], Monica Valdes[a], Enzo Martinelli[b]

[a] *Department of Civil Environmental Engineering and Architecture, University of Cagliari, via Marengo 2, 09123 Cagliari, (CA), Italy*
[b] *Department of Civil Engineering, University of Salerno, via Giovanni Paolo II n.132, 84084, Fisciano, (SA), Italy*

Abstract

The increasing demand for sustainable and resilient construction practices in seismic areas calls for innovative retrofitting solutions utilizing renewable resources. This study presents an experimental investigation on the structural performance of masonry walls upgraded using a Natural Fiber Textile Reinforced Mortar (NFTRM) system based on jute fibers. Hollow brick masonry walls were strengthened through the application of jute fiber nets, jute-based diatons (transverse connectors), and a composite mortar incorporating 1% jute fibers by weight. In-plane cyclic shear tests were performed under constant vertical loads to evaluate the improvement in shear strength ultimate capacity. The results show that the NFTRM system significantly enhances the load-bearing performance compared to unreinforced walls, reaching an ultimate shear strength of approximately 2.7–2.9 MPa. The outcomes highlight the potential of bio-based reinforcement systems to provide an eco-friendly and effective alternative for masonry strengthening in seismic regions, promoting both sustainability and resilience.

Keywords: jute, fibers, masonry reotrifitting, sustanability

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1. Introduction

The structural upgrading of existing masonry buildings is a crucial challenge, especially in regions exposed to seismic hazards and characterized by a rich architectural heritage, see (P.D. Gkournelos et al., 2022) and (Zucca et al., 2024). A very interesting case study of an old masonry structures damaged by earthquakes is presented in (Zucca et al., 2022). An integrated seismic and energy retrofitting approach combining TRM overlays with thermal insulation (XPS or PCM-enhanced mortars) was experimentally validated on full-scale masonry-infilled RC frames under cyclic loading in (Christis Z et al., 2023).

Full-scale experimental testing has shown that TRM systems can effectively restore and nearly double the in-plane load-bearing capacity of damaged masonry walls under cyclic loading conditions (Torres et al., 2021). TRM

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strengthening techniques for masonry structures, including experimental approaches and modelling strategies for both in-plane and out-of-plane behaviour are well described in (Boem, 2022).

Actually, conventional retrofitting methods based on synthetic fiber composites (Trung Duc Pham et al., 2022), though effective, often raise concerns related to environmental impact and disposal (Fabbrocino et al., 2021). As an alternative, Textile Reinforced Mortar (TRM) systems employing natural fibers have gained growing interest for their lower embodied energy and reduced carbon footprint, see (Majumder et al., 2025), (Illampas et al., 2023), (Kohan et al., 2024), (Monaco et al., 2023). Indeed recent experimental studies have demonstrated that TRM systems using low-carbon mortars and natural fibers—such as flax textiles with lime or geopolymer matrices—can significantly enhance the structural performance of stone masonry walls while reducing environmental impact (P. D. Gkournelos et al., 2022).

For a comprehensive overview of sustainable seismic retrofitting strategies for historic masonry, including the use of natural fibers and minimally invasive techniques, see (Corradi et al., 2021). A specific review of retrofitting techniques for unreinforced masonry (URM) structures, with emphasis on their seismic performance, sustainability, and applicability to heritage buildings can be found in (Yavartanoo and Kang, 2022). The water effect of jute based TRM has been studied in (Majumder et al., 2024b) while a promising integrated masonry retrofitting approach with these materials is presented in (Stochino et al., 2025).

Despite the growing interest in natural fiber TRM systems, see for example (Ferrara et al., 2021), there is still a significant lack of full-scale experimental data on the structural performance of masonry walls strengthened with jute-based NFTRM (Natural Fiber Textile Reinforced Mortar) systems. Most studies to date have focused either on small-scale material testing or have addressed different types of fibers and matrix combinations, such as flax or hemp with lime mortars. While these works provide important insights, the structural contribution of jute fiber nets, diatons, and jute-reinforced mortars under cyclic in-plane loading remains underexplored.

Moreover, the specific interaction between the jute fiber components and hollow clay brick masonry units—commonly found in seismic-prone Mediterranean regions, see (Koutsoupakis et al., 2021) —has not been adequately studied. There is a critical need to quantify how different reinforcement configurations (nets, connectors, and fiber-modified mortar) affect shear strength and failure mechanisms under realistic loading conditions.

This paper addresses this gap by presenting a comprehensive experimental investigation on full-scale masonry wall specimens retrofitted with jute-based NFTRM systems, subjected to in-plane cyclic loading up to collapse. By doing so, it contributes new benchmark data on the mechanical performance and failure behavior of sustainable retrofitting solutions, thus offering a solid basis for future design, modeling, and code development.

2. Materials and methods

The experimental program involved strengthening hollow brick masonry panels using a Natural Fiber Textile Reinforced Mortar (NFTRM) system based on jute fiber products. The strengthening system included: (i) jute fiber nets with two mesh configurations (2.5 × 2.5 cm and 2.5 × 1.25 cm), (ii) jute diatons acting as transverse connectors, and (iii) a composite mortar incorporating 1% by weight of 30 mm long jute fibers.

Raw jute fibers were sourced directly from cultivators in West Bengal, India. The natural fibers used in this study were extracted from *Corchorus olitorius* (Bangla Tosha variety) cultivated in West Bengal, India. These raw jute fibers are 3–4 m long and were manually harvested and processed. Based on previous experimental studies, 30 mm fiber lengths were selected for incorporation into the composite mortar, ensuring an optimal balance between workability and performance. The fibers exhibit a tensile strength of approximately 215 MPa and can absorb water up to 200% of their dry mass, see (Majumder et al., 2022) for more details.

To enhance shear transfer and improve the connection between the two TRM layers, jute diatons—cross-wall connectors made of compacted jute—were fabricated in the lab. Their mechanical performance, as evaluated in prior tests, showed a tensile strength of 15.5 MPa and strain energy capacity of 14.2 kN·mm, (Majumder et al., 2022).

Two jute net types were produced using 1 mm class twisted yarns, selected for their superior mechanical characteristics. Nets were prepared with mesh sizes of 2.5 × 2.5 cm and 2.5 × 1.25 cm. Mechanical testing of the net with 2.5 × 2.5 cm mesh showed a maximum tensile load of 217 N, stiffness of 7.6 N/mm, and strain energy of 8.8 kN·mm, see Table 1 and (Majumder et al., 2024a) for more details.

Table 1 Mechanical properties of jute fiber nets.

Net Configuration	Stiffness [N/mm]	Strain Energy [kN·mm]	Max Load [N]	Max Displacement [mm]
2.5 × 2.5 cm	7.6 (C.o.V. 20.2%)	8.8 (C.o.V. 39.1%)	217.3	72.5
2.5 × 1.25 cm	10.3 (C.o.V. 11.9%)	14.1 (C.o.V. 21.0%)	337.2	82.9

The reference mortar was a cement-based M10 structural mix, with compressive strength ~10 MPa, shear strength ~0.15 MPa, and dry density ~1545 kg/m³. For the composite mortar, 1% by weight of 30 mm jute fibers was added to the mix, along with approximately 20% additional water (relative to total dry mass). This dosage was selected to optimize thermal insulation and strain energy without compromising workability.

The walls were constructed using semi-solid hollow clay bricks (300 × 250 × 250 mm), compliant with Italian technical standards (D.M. 17/01/2018., n.d.). The bricks had a specific gravity between 800–860 kg/m³, and satisfied the seismic performance criteria: vertical compressive strength FBk ≥ 5 N/mm² and orthogonal strength f'Bk ≥ 1.5 N/mm².

Retrofitting configurations included various combinations of nets, diatons, and composite mortar layers, a complete overview can be seen in Table 2.

The test setup and material combinations were designed to evaluate the contribution of each component (nets, diatons, fiber-modified mortar) to the overall shear capacity improvement, with a focus on practical applicability and sustainability.

Fig 1. Loading set-up.

All the walls were tested with the set-up shown in Fig. 1. The applied quasi-static loading protocol involved an initial application of a constant vertical load, equal to approximately 2% (80 kN) or 1% (40 kN) of the wall's estimated maximum capacity. Subsequently, in-plane cyclic horizontal loads of increasing amplitude were applied through three horizontal hydraulic jacks. After the completion of the cyclic sequence, a monotonic horizontal load was applied until the wall reached its ultimate failure condition.

In this paper, we focus exclusively on the evaluation of the ultimate load-bearing capacity. For a detailed discussion of the cyclic response and elastic behavior, the reader is referred to the full version of the study.

Table 2. Summary of maximum horizontal load and calculated shear strength.

Wall ID	**Configuration**	**Max Load [kN]**	**Displacement [mm]**
HBW1	Unreinforced	35.4	11.1
HBW2	Unreinforced	40.0	9.9
HBW3	Nets + Diatons	204.1	34.5
HBW4	Nets + Diatons	204.2	35.2
HBW5	Nets + Diatons + Composite Mortar	235.5	22.9
HBW6	Diatons Only	202.0	21.8
HBW7	Raw Fiber + Diatons	201.9	22.8

3. Results

All strengthened masonry panels showed a clear improvement in in-plane shear capacity compared to the unreinforced reference walls. Figure 1 illustrates the typical load–displacement curves for the unreinforced and NFTRM-strengthened walls. As shown, strengthened specimens sustained higher loads and larger displacements before failure.

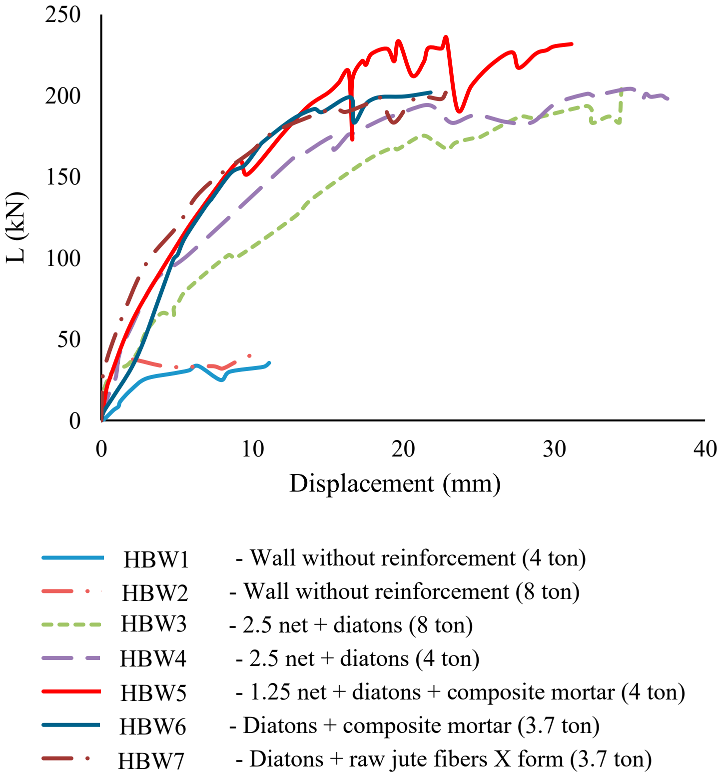

Fig 2. Load-displacement graphs for the whole walls.

Table 2 summarizes the maximum horizontal loads and corresponding displacements. Walls reinforced with the full NFTRM system (nets + diatons + composite mortar) reached the highest capacity.

Walls retrofitted with jute nets and diatons (HBW3 and HBW4) exhibited a significant increase in shear strength, with ultimate strengths around 2.7–2.8 MPa. The inclusion of the jute fiber-reinforced mortar layer (HBW5) further improved performance, achieving an ultimate shear strength of ~2.9 MPa, confirming the added benefit of fiber-modified mortar for integrated strength and ductility.

Failure modes were dominated by diagonal cracking across all specimens, consistent with strut-and-tie behavior typical of in-plane loaded masonry (Figure 3). In some strengthened panels, partial debonding at the TRM–substrate interface was observed but did not lead to premature failure, thanks to the bridging effect of the jute diatons.

Fig 3. Typical failure pattern of strengthened wall showing diagonal crack.

4. Discussions and conclusions

This study explored the structural performance of a jute-based Natural Fiber Textile Reinforced Mortar (NFTRM) system for the in-plane strengthening of hollow brick masonry walls. The retrofitting strategy combined jute fiber nets, jute diatons (transverse connectors), and a composite mortar incorporating 1% short jute fibers. All strengthened specimens were tested under constant vertical loads and subjected to cyclic in-plane shear to evaluate their ultimate load capacity.

The results confirmed a significant improvement in structural performance. The maximum horizontal load sustained by NFTRM-strengthened walls exceeded that of unreinforced counterparts by over 450%, with ultimate shear strength values consistently in the range of 2.7–2.9 MPa. The use of composite mortar slightly increased performance compared to configurations with nets and diatons only.

Key findings of this work include: the NFTRM system effectively enhances the in-plane shear resistance of masonry walls, transverse jute diatons contribute to better anchorage and reduced delamination, the presence of jute-reinforced mortar further improves load-bearing capacity, likely due to increased ductility and energy absorption.

Beyond mechanical performance, the use of jute—an abundant, low-cost, and biodegradable fiber—demonstrates strong potential for sustainable structural retrofitting. This makes the proposed solution particularly relevant for seismic-prone areas where both resilience and environmental impact are critical concerns. Indeed, compared to conventional synthetic fiber systems, the jute-based NFTRM solution offers clear environmental benefits due to the biodegradability and low embodied energy of natural fibers. The results demonstrate that bio-based reinforcement can deliver comparable structural gains, providing a viable pathway for sustainable retrofitting in seismic regions.

While this paper focused on ultimate strength, future developments will include optimization of TRM thickness, long-term durability, fire resistance , and the influence of multi-layer reinforcement. The promising results support further research toward the standardization and broader adoption of NFTRM systems in sustainable construction practice.

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