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SUSTAINABLE RETROFITTING TECHNIQUES FOR SEISMIC PROTECTION OF MASONRY STRUCTURES

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Abstract

Nepal is subjected to frequent devastating earthquakes, causing dramatic human life and economic losses. The predominant construction typology in that region is represented by brick masonry buildings with cement-mortar or mud-mortar joints. Most of these buildings have been built using poor materials without a proper seismic design, and, as a result, they are highly vulnerable to seismic loading, as demonstrated by recent events like the 2015 Gorkha earthquake. Different retrofitting methods have been developed and applied to increase the seismic resilience of buildings in Nepal. However, most of them are based on the use of expensive materials, like cement and steel, often making the interventions unaffordable for low-income rural communities.

This paper presents the results of a comprehensive experimental campaign conducted at the Institute of Engineering of Tribhuvan University on small assemblages and full-scale weak brick-mud mortar masonry panels subjected to in-plane loadings before and after being reinforced by external plastering made of locally available material and reinforced by natural fibers. Numerical simulations are conducted employing the finite element methods at the level of the masonry material -- to evaluate the mesoscale parameters of bricks and mortar joints --, the structural element (panel) level – to evaluate the benefit of the intervention to increase the in-plane response of typical mud mortar-joints brickwork masonry panels built in Nepal. Even though the analyses are performed explicitly on Nepalese materials and structural layouts, the explored methodologies can answer the need for sustainable and economically affordable retrofitting methodologies for developing seismic countries with limited environmental impact and respect to the local construction culture.

Keywords: Seismic risk, Organic materials, Natural fibres, Jute fibres, Mud mortar, low-cost retrofitting, Diagonal tests, mesoscale models, finite element analyses, Abaqus software.

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1 INTRODUCTION

Unreinforced masonry (URM) is the most common construction typology in Nepal. Masonry buildings in that region are typically constructed without formal engineering input, often by local masons, and do not adhere to code-recommended practices. As a result, URM buildings in Nepal have exhibited poor seismic performance, suffering severe damage or collapse during moderate to strong seismic shaking, as seen during the [1] resulting in significant life and economic losses due to building failure.

A deep understanding of the seismic response of existing masonry structures and the most appropriate retrofitting technologies still needs to be gained. Bothara et al. [2] rated qualitatively different retrofitting (strengthening) methods such as jacketing of walls, “splint and bandage”, bolting of walls, steel beam-column cage and reinforced concrete beam-column cage. The splint and bandage retrofitting scheme -- consisting of creating external vertical (strips) and horizontal (bandages) layers of cementitious mortar reinforced by steel bars surrounding the wall edges and openings -- was found to be the optimal strengthening method; hence, it was implemented in the construction technical guidelines released by the Nepalese government after the Gorkha 2015 earthquake and was adopted to retrofit public school buildings the Kathmandu valley [3]. However, using concrete and steel for a massive reconstruction stage brings significant sustainability issues since these materials require high energy demand and CO_2 emissions (app. 10% of the CO_2 emissions worldwide are associated with cement and steel production [4]). In addition, the high stiffness introduced by the reinforcing system can lead to phenomena of mechanical incompatibility with highly deformable Nepalese masonry (mainly those made of mud mortar joints), generating premature delamination of the reinforcing system from the masonry support or reduction of the global structural ductility.

Several researchers have contributed to understanding the mechanical and seismic behavior of unreinforced masonry (URM) Nepalese structures. Endo et al. [5] conducted experiments on bricks and earthen mortar from historical structures in Bhaktapur. Parajuli [6] investigated a two-storey heritage building in Patan Durbar Square, analyzing the properties of brick, mud mortar, and masonry walls. Mishra et al. [7] assessed the mechanical properties of brick and mud mortar through uniaxial and diagonal compression tests. Jaishi et al. [8] focused on the dynamic performance of traditional temples built with brick in mud mortar. Finally, Kuinkel et al. [9] studied traditional “Ma-appa” bricks from Bhaktapur and Meimaroglou and Mouzakis [10] evaluated masonry materials constructed with natural stones and clay mortar.

On the other hand, environmental awareness has recently shifted attention worldwide towards new low environmental impact, eco-friendly and natural materials for construction and repair. As a result, reinforcing textiles from natural fibres are now under the spotlight. The use of natural fibers and their recyclability could help construct safer and more sustainable buildings. However, the literature shows limited experimental results on applying jute fibres to masonry walls. Natural fibers, such as jute, are increasingly being explored as sustainable alternatives to synthetic fibers in fiber-reinforced cementitious composites (FRCC). Additionally, recent research [11], [12] has focused on Textile Reinforced Mortars (TRMs) for retrofitting masonry structures using materials such as basalt, steel, and potentially natural fiber systems through both experimental and numerical investigations involving diagonal compression tests. Recent studies [13], [14]on jute fibers reveal a promising path toward eco-friendly and low-cost reinforcement solutions that can enhance the mechanical strength of concrete materials while minimizing environmental impact, demonstrating that natural fibers like jute (widely available from Nepalese local manufacture tradition) can are favored over polymer-based fibers thanks to their biodegradability, cost-effectiveness, and reduced health hazards [15]. Finally, Majumder et al. [16] demonstrated the effectiveness of using recycled jute fiber nets for retrofitting masonry walls, highlighting the material's potential in structural strengthening.

Further studies on jute-reinforced lime mortars [17] also demonstrated improvements in ductility and post-cracking behavior. These findings suggest that due to its availability, low environmental footprint, and improving mechanical performance, jute fiber holds considerable potential for use in seismic retrofitting and sustainable construction, especially in developing contexts like Nepal.

Despite the studies already performed in the literature, extensive experimental and numerical investigations are still needed to fill the knowledge gap in analysing the mechanical performance of natural fibre-reinforced masonry buildings, also in the presence of cyclic and dynamic excitations. Toward this over-hierarchical target, this paper presents the first results of an extensive, still ongoing experimental campaign performed at the Institute of Engineering, Pulchowk Campus, to characterise the mechanical properties of typical Nepalese bricks, mud mortar, and jute fibres. Tests are conducted to evaluate the compressive, flexural, and shear-sliding behaviour of masonry joints and the in-plane shear-diagonal behaviour of full-scale masonry panels with and without the presence of jute fibre mud-mortar reinforcing external plaster. The results of the experimental investigation are used to calibrate numerical models applying a mesoscale masonry description to investigate the role of reinforcement further and test the capability of numerical models to describe and predict the response of reinforced masonry. To model the masonry panels retrofitted with externally bonded layers, several refined FE approaches have been proposed [18], [19]. However, limited studies are available on modeling the retrofitted masonry using jute fibre. The presented experimental campaign can be used to expand this modelling strategy further to investigate a full-scale building retrofitted with proposed techniques and study its efficiency in reducing the seismic demand of existing Nepalese building stock.

2 EXPERIMENTAL CAMPAIGN

The first part of this section describes the mechanical tests on the masonry wall system to characterise the material parameters (compressive and flexural strengths) of brick and the mud mortar used for the joint and as reinforcing plaster. The second part of the section reports the experimental results of masonry triplets tested in compression and shear. Finally, the results of diagonal compression tests conducted on full-scale masonry panels are presented.

2.1 Brick and mud-mortar mechanical characterisation

In this study, locally available fired clay solid bricks with average dimensions of 215 × 140 × 55 mm^3 were selected and tested through three-point bending tests (6 specimens) to estimate the flexural strength and uniaxial compression tests in horizontal and vertical orientations (6 specimens for each orientation) to evaluate the compression strengths. Both tests were performed by applying a displacement rate of 0.5 mm/min. The brick compression strength (f_f) was evaluated according to EN 1015-11 [20] as follows:

$$f_f = \frac{3}{2}\frac{R_f l}{bh^2} \tag{1}$$

Where R_f is the failure load, l (100mm) is the length between the two supports while testing, b and h are the width and height of the tested specimen cross-section, respectively. The fracture energy in tension (G_f) is estimated using Equation (2).

$$G_f = 0.025(2f_f)^{0.5} \tag{2}$$

The mud mortar, used for the mortar joints and the reinforcing render, was prepared with a variable water/soil ratio to ensure easy workability. The moisture content of the mud (soil) was estimated to be 28.92%. The soil mix was designed according to the Nepalese Building Code (NBC) [21] and the recommendations released by the Department of Urban Development and Building Construction (DUDBC) [22], by which the sand content in earthen mortar should be less than 30% to achieve proper cohesiveness. More specifically, the identified proportions (sand, clay, silt) are 20.8%, 10%, 69.2% by weight, as indicated in the particle distribution curve shown in Figure 1.

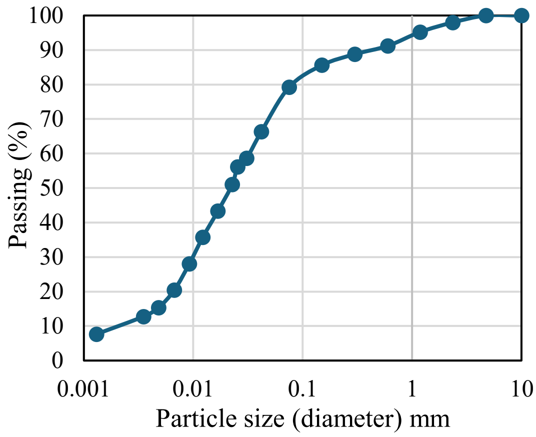


Figure 1. Particle size distribution curve of the earthen mortar.

Unreinforced (UR) and fibre-reinforced (FR) mud-mortar samples were prepared. In the latter case, 40 mm long jute fibres were added, considering a constant quantity of 1% of mud weight. Three-point bending moment (flexural) tests were conducted on 40 × 40 × 160 mm^3 beams prepared without (Figure 2a) and with jute fibres (Figure 3a) to evaluate the tensile strength and the fracture energy of the mortar by applying Eq. (1) and Eq. (2), respectively.

Cubes of size 50 × 50 × 50 mm^3 were cast for mortar joints and renders, without (Figure 2b) and with fibres (Figure 3b), respectively, and tested under uniaxial compression at a constant displacement rate of 0.5 mm/min. Figure 2c and Figure 3c show the load-displacement curves obtained in the flexural tests for the beam specimens without and with jute fibre, respectively. The mechanical parameters of bricks and mud-mortar specimens estimated experimentally are available in Table 1.

(a) (b) (c)

Figure 2. (a) Three-point bending tests; (b) compressive strength tests, (c) load-displacement response under flexure for mud-mortar without jute fibres.

(a) (b) (c)

Figure 3. (a) Three-point bending tests; (b) compressive strength tests, (c) load-displacement response under flexure for mud-mortar with jute fibres.

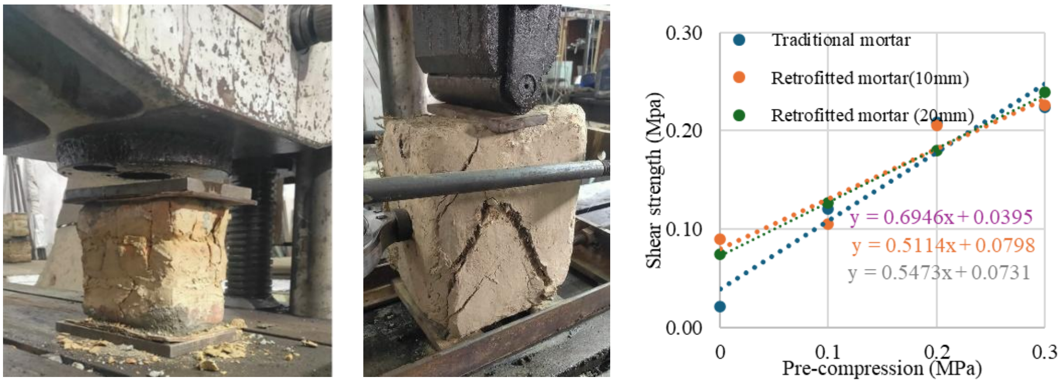
Mechanical properties	Brick	UR-Mortar	FR-Mortar
Density (kg/m^3)	1571	1409	1456
Young’s modulus, (MPa)	-	44	33
Compressive strength, (MPa)	6.52 (Horiz.) 7.80 (Vert.)	1.7	1.05
Flexural strength f_f , (MPa)	1.81	0.89	0.97
Fracture energy in tension G_f, (MPa·mm)	0.048	0.033	0.035

Table 1: Mechanical properties of masonry units and mortar (un-reinforced and reinforced).

2.2 Mechanical tests on masonry triplets

To evaluate the mechanical strength parameters of masonry in compression and shear sliding, 42 triplets were prepared, 15 of which were without reinforcing render and 27 with jute fibre-reinforced render on one face. Specifically, 6 samples (3 without and 3 with render) were tested under uniaxial compression force (Figure 4a), applied through a computer-controlled actuator with a maximum load capacity of 300 kN [23], [24]. In contrast, 36 triplets (12 without and 24 with render) were tested under a sliding-shear force (Figure 4b) with three different levels of pre-compression (0, 0.1MPa, 0.2MPa, 0.3MPa), considering 3 samples for each level of compression. Three triplet specimens tested under monotonic shear is catagorised into three groups: (a) triplets without render; (b) triplets with addition of jute fiber and mess of fiber mesh with 10 mm size grid; and (c) triplets reinforced with jute fiber and fiber mesh with a grid size of 20 mm. A constant downward displacement rate of 1.0 mm/min was applied to the central brick through the actuator with applied pre-compression in the horizontal direction. All the samples comprised 12 mm-thick mud-mortar joints. Three typologies of render were considered: unreinforced mud-mortar render, and mud-mortar render reinforced by 2D grids of jute fibres with respectively 10 mm and 20 mm mesh size and nominal diameter of the wires of 2 mm. The render was applied with an average thickness of 15 mm (the thickness was variable due to the geometrical irregularity of the masonry surface).

Figure 4 shows some results of the triplet tests available in Table 2. Namely, Figure 4a shows the failure mechanism of an unreinforced triplet sample in compression. The load-displacement curves obtained during the compression tests are used to evaluate the compression strength (f_c) and the Young's modulus (E), resulting in 3.48 MPa and 51 MPa, respectively. Figure 4b shows the failure mechanism of a triplet sample with fibre-reinforced render during a shear test. The results of the triplet tests are summarised in Figure 4c in terms of average peak shear strength (evaluated as the maximum force applied divided by double the brick transverse area 30,100 mm^2) and applied pre-compression stress. The linear regression lines, providing the parameters of the Mohr-Coulomb yield domain (namely the cohesion c and the friction coefficient μ), are also reported in the graph for each sample typology. It is possible to observe that the presence of the render provides a significant increase in shear strength at zero precompression (τ_0) from the value of 0.04 MPa in the case of unreinforced samples to 0.08 MPa and 0.07 MPa in the case of samples with render with 10mm and 20mm jute wire mesh, respectively. However, the presence of the render slightly reduces the friction coefficient, and the unreinforced and reinforced samples show approximately the same shear strength when the pre-compression level ranges from 0.2MPa to 0.3MPa.



(a) (b) (c)

Figure 4. (a) Compression test, (b) shear tests, (c) relationship between shear strength and pre-compression for masonry triplets.

Parameter	Unreinforced render	Reinforced render (10mm mesh)	Reinforced render (20mm mesh)
Young's modulus, E (MPa)	51	74	68
Compressive strength, f_c (MPa)	3.48	3.81	3.64
Friction coefficient, μ (-)	0.69	0.51	0.55

Table 2: Mechanical strength of masonry triplet specimens.

2.3 Diagonal compression tests on masonry walls

Nine wall panels of size (800mm × 800mm × 350mm) are prepared, including 3 walls without retrofitting and 6 retrofitted with jute fibre and fibre mesh (10mm and 20mm grid) integrated in the retrofitting render. The walls are retrofitted on both sides. A non-conventional test setup [25], [26], [27] is developed to perform a diagonal compression test on prepared URM wall panels (Figure 5a) and RM wall panels (Figure 5b). Figure 5c shows all prepared wall panels for testing. The prepared wall panels are subjected to constant diagonal loading until failure, and two LVDTs are attached at both sides of the specimens to record the displacements in both compression and tension zones. The masonry wall panels are retrofitted with two combinations: a) with jute fibre added (RM_FO) and b) with both jute fibre and jute fibre mesh added (RM_FM) in the mud-render. Figure 6a shows the failed URM and RM wall panel. It can be observed from Figure 6b,c, that the addition of jute fibre and fibre mesh significantly increases the shear capacity of the masonry system. RM_FO showed a 25% increase in shear capacity, whereas an increase of 35% in shear capacity is seen for RM_FM as compared to URM walls. It is worth noticing that the presence of the reinforced render produces a significant increase in the ultimate displacement capacity of the panels.

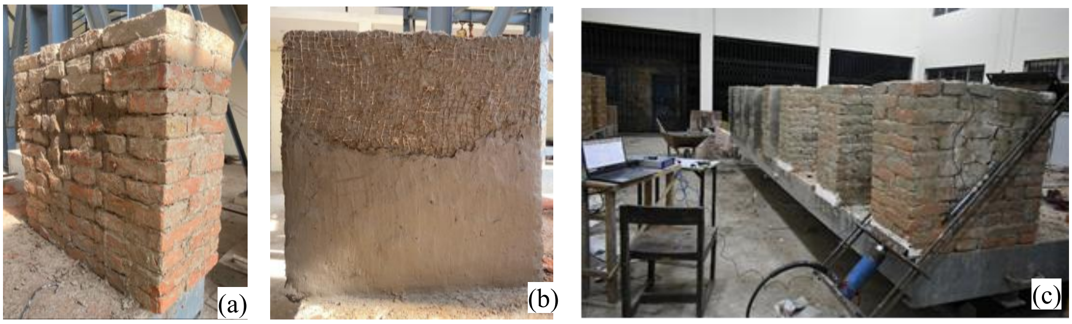
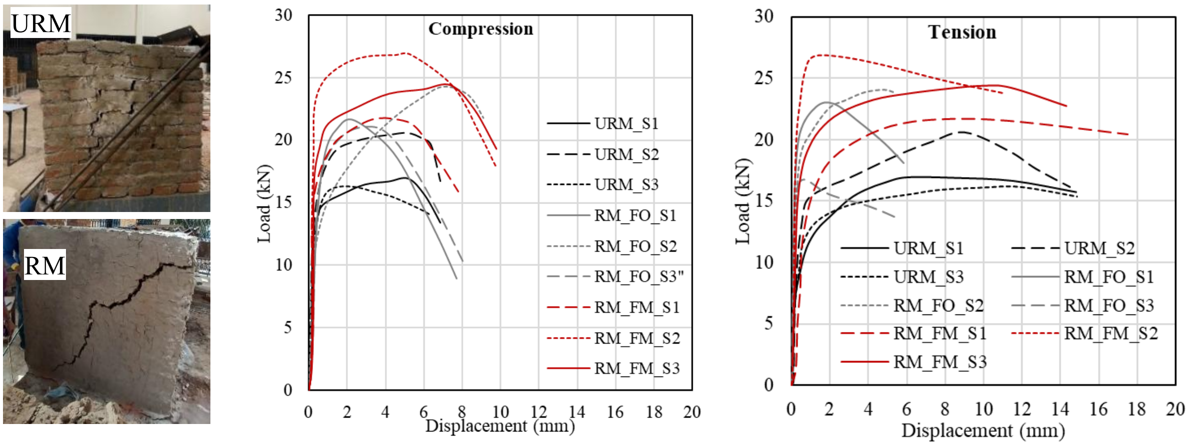


Figure 5. Prepared wall panels (a) without render (b) render with jute fibre and fibre mesh (c) test setup.



(a) (b) (c)

Figure 6. (a,b) Diagonal compression test of URM and RM wall, (b,c) Load-displacement response in compression and tension, respectively.

3 NUMERICAL SIMULATIONS

This section illustrates the simulation of the experimental tests described in Section 2 followed by a validation study on the experimental tests performed by Aminulai et al. [28] to predict the benefits of the proposed retrofitting system at a level of full-scale wall using a commercial finite element (FE) software Abaqus [29].

3.1 Modelling strategy

A 20-node quadratic element mesh discretisation (see Figure 7) is used with reduced integration (C3D20R) to model the masonry and the fibre reinforced mud-mortar. The behaviour of the masonry and render are described using a Concrete Damage Plasticity (CDP) model [30], [31]. The material parameters are taken from the in-situ tests (Table 1-3). Further details about the CDP model can be found in the Abaqus manual [32].

Surface-to-surface contact interfaces are used to simulate the bond between the masonry and render. The cohesive interfaces exhibit initially a linear elastic response, followed by a cracking behaviour that describes the most critical failure modes, namely, tensile cracking and shear sliding [33].

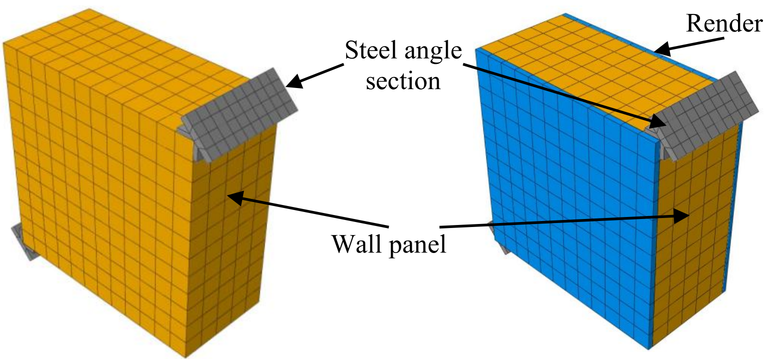


Figure 7. 3D mesh discretisation of (URM) and (b) RM wall.

3.2 Model calibration and validation

Tables 1 and 2 illustrate the main parameters describing the mechanical properties of the masonry and render. The masonry-render interface parameters are available in Table 3. It is noteworthy that these values have been taken from the characterisation tests carried out on the specimens of masonry triplets and mud-mortar. The stiffness parameters are estimated using empirical equations and the fracture energy parameters are chosen from the range suggested by [34]. In the absence of the flexural test, the cohesion (c_r) of the masonry-render interaction is calculated using the following expression

$$c_r = \Delta c \frac{t_m}{2t_r} \tag{3}$$

Where Δc is the difference between the cohesion value obtained experimentally for the unreinforced and reinforced triplets, t_m and t_r are the thickness of the triplets and the render, respectively.

Specific normal elastic stiffness, k_n (N/mm^3)	200 [34]
Specific tangential elastic stiffness, k_s (N/mm^3)	100 [34]
Cohesion, c_r (MPa)	0.09 (Eq. 3)
Coefficient of friction, μ (-)	0.5 (experimental tests)
Shear fracture energy, (MPa·mm)	0.02 [34]

Table 3. Properties of the contact interfaces describing the masonry-render interaction.

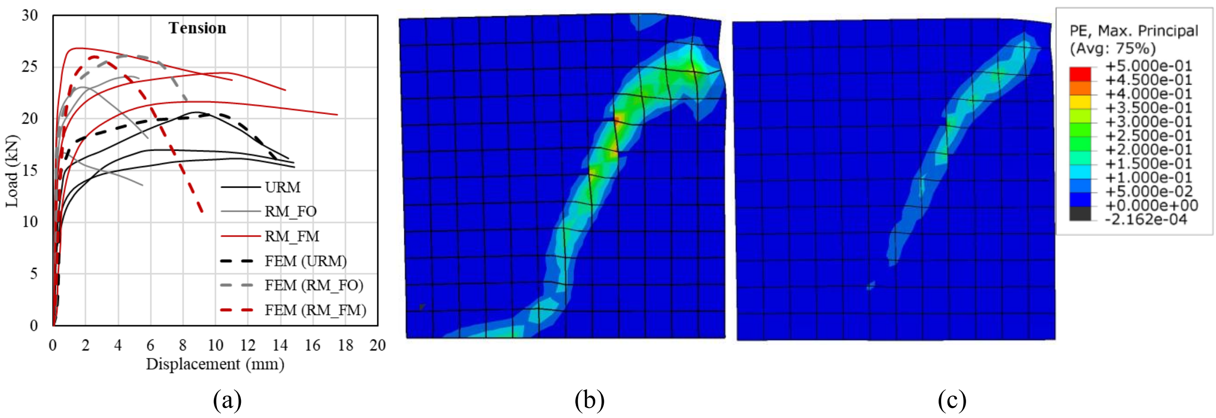


Figure 8. (a) Load-displacement response of URM wall, (b,c) plastic strain distribution for URM and RM wall, respectively.

Figure 8a compares the load-displacement responses from the FE analysis with the experimental outcomes for both URM and RM. The proposed model was able to calibrate the experimental results with reasonable accuracy (<10%) deviation. Figure 8b and Figure 8c shows the plastic strain distribution for URM and RM walls, respectively, at 1% drift level. Lower levels of plastic strain formation were seen for jute fibre reinforced masonry.

3.3 Numerical simulations of a full-scale masonry wall prototype

In this section, the macroscale model calibrated in section 3.2 is used to predict the seismic performance of a masonry wall strengthened using the natural fibre-reinforced mud-mortar render. The investigated wall has the geometrical layout tested in [28] as shown in Fig. 9a, while the thickness and the mechanical parameters are those already considered in Sec. 3.1 and 3.2

A vertical load of 6.05 tons is uniformly applied on the top surface of the wall, and a horizontal displacement is monotonically applied with a loading rate of 1mm/min to increase the numerical stability [32]. Finally, Figure.9b shows the schematic diagram of the retrofitted wall with 20mm jute fibre reinforced mortar on both sides of the wall. Figure.9c reports the capacity curves of the unreinforced and reinforced wall. Jute fibre reinforced masonry attained a peak capacity of 91.3 kN, approximately 1.4 times the capacity of the URM wall (62.8kN). Figure.9d shows the plastic strain distribution for jute fibre reinforced masonry wall. The addition of jute fibre reinforcement in RM minimise the tensile damage compared to the plastic stain visible for the URM wall (Figure.9d) for the same level of lateral drift.

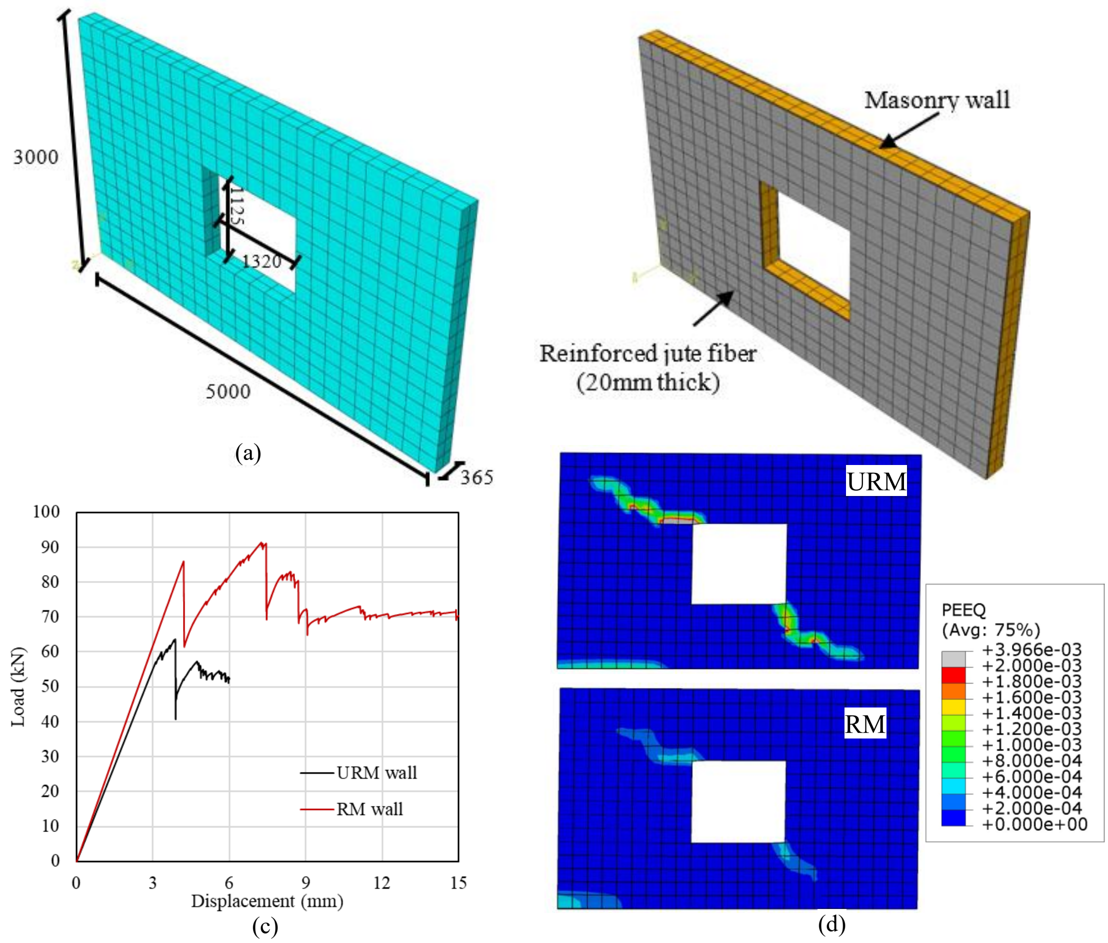


Figure.9. (a) geometrical layout of the URM wall (dim. in mm) and (b) numerical model of the RM wall, (c) capacity curve estimated, (d) plastic strain distribution for jute fibre URM and RM wall.

4 CONCLUSIONS

This paper investigates the in-plane response of typical Nepalese mud-mortar brickwork masonry panels reinforced by means of natural fibre-reinforced mud-mortar render with the main aim of providing insights into low-cost sustainable seismic retrofitting techniques suitable for seismic developing areas like Nepal.

The first part of the paper presents the results of an experimental campaign conducted on brick units and mud-mortar samples, followed by compression and shear tests performed on triplets. The results of these tests have been used to assess the main mesoscale parameters of masonry, which in turn have been used to evaluate a set of equivalent homogenized mechanical material parameters suitable to describe the macroscopic behaviour of masonry panels with and without reinforcing rendering. Subsequently, the paper presents the results of diagonal compression tests conducted on unreinforced and reinforced full-scale masonry panel prototypes subjected to. These results have then been replicated numerically by adopting a macroscale finite element approach. Finally, the calibrated finite element model is used to numerically predict the response of a masonry wall characterized by a typical Nepalese geometrical layout and adopting the material parameters evaluated in this study.

The presented experimental and numerical results demonstrated the effectiveness of the proposed retrofitting method in increasing strength and ductility at the material and structural levels, making it suitable for environmentally sustainable and economically affordable retrofitting interventions in Nepal or other similar seismic regions. However, further studies need to prove the benefits under cyclic and dynamic loading, considering more complex structural layouts.

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REFERENCES

[1] G. Chiaro, T. Kiyota, R. M. Pokhrel, K. Goda, T. Katagiri, K. Sharma. Reconnaissance report on geotechnical and structural damage caused by the 2015 Gorkha Earthquake, Nepal. *Soils and Foundations*, **55**(5), 1030-1043, 2015.

[2] J. K. Bothara, B. Pandey, R. Guragain, Seismic retrofitting of low strength unre-inforced masonry non-engineered school buildings, *Bulletin of the New Zealand Socie-ty for Earthquake Engineering*, **37**(1), 13–22, 2004.

[3] A. Adhikari, K. R. M. Rao, D. Gautam, H. Chaulagain, Seismic vulnerability and retrofitting scheme for low-to-medium rise reinforced concrete buildings in Nepal, *Journal of Building Engineering*, **21**, 186–199, 2019.

[4] A. Hasanbeigi, L. Price, E. Lin, Emerging energy-efficiency and CO2 emission-reduction technologies for cement and concrete production: A technical review, *Re-newable and Sustainable Energy Reviews*, **16**(8), 6220–6238, 2012.

[5] Y. Endo, K. Yamaguchi, T. Hanazato, C. Mishra, Characterisation of mechanical behaviour of masonry composed of fired bricks and earthen mortar, *Engineering Failure Analysis*, **109**, 104280, 2020.

[6] H. R. Parajuli, Determination of mechanical properties of the Kathmandu World Heritage brick masonry buildings, *15th World Conference of Earthquake Engineering (WCEE)*, 2012.

[7] C. Mishra, K. Yamaguchi, Y. Endo, T. Hanazato. Mechanical properties of components of Nepalese historical masonry buildings, 118-123, 2018.

[8] B. Jaishi, W.-X. Ren, Z.-H. Zong, P. N. Maskey, Dynamic and seismic perfor-mance of old multi-tiered temples in Nepal, Engineering Structures, **25**(14), 1827–1839, 2003.

[9] M. S. Kuinkel, S. Sukubhatu, R. Shrestha. Physical Performance of Traditional Brick Mud Masonry, *Khwopa Engineering College & Khwopa College of Engineering, 2019. Proceedings of the International Conference on Earthquake Engineering and Post Disaster Reconstruction Planning*, 25-27, April 2019.

[10] N. Meimaroglou, H. Mouzakis, Mechanical properties of three-leaf masonry walls constructed with natural stones and mud mortar, Engineering Structures, **172**, 869–876, 2018.

[11] L. Garcia-Ramonda, L. Pelá, P. Roca, G. Camata, In-plane shear behaviour by diagonal compression testing of brick masonry walls strengthened with basalt and steel textile reinforced mortars, *Construction and Building Materials*, **240**, 117905, 2020.

[12] P. Gulinelli, A. Aprile, R. Rizzoni, Y.H. Grunevald, F. Lebon, Multiscale Numer-ical Analysis of TRM-Reinforced Masonry under Diagonal Compression Tests, *Buildings*, **10**(11), 196, 2020.

[13] M. Zakaria, M. Ahmed, M. M. Hoque, S. Islam, Scope of using jute fiber for the reinforcement of concrete material, *Textiles and Clothing Sustainability*, **2**(1), 11, 2017.

[14] S.S. Ubayi, D.B.S.A. Esar Ahmad, S. Dulawat, M.N. Garko, A. Ahmad, U.S. Ibrahim, I.A. Ibrahim, A Re-view of the Impact of Jute Fiber Reinforcement on Mechanical Properties of Concrete, *International Journal in Engineering Sciences*, **2**(7), 2024.

[15] G. Ramakrishna, T. Sundararajan, Impact strength of a few natural fibre reinforced cement mortar slabs: a comparative study, *Cement and Concrete Composites*, **27**(5), 547–553, 2005.

[16] A. Majumder, F. Stochino, A. Frattolillo, M. Valdes, G. Gatto, E. Martinelli. Sus-tainable Retrofitting Solutions: Evaluating the Performance of Jute Fiber Nets and Composite Mortar in Natural Fiber Textile Reinforced Mortars, *Sustainability*, **16**(3), 1175, 2024.

[17] A. Formisano, G. Chiumiento, E. J. Dessì, Laboratory Tests on Hydraulic Lime Mortar Reinforced with Jute Fibres, *The Open Civil Engineering Journal*, **14**(1), 152–162, 2020.

[18] F. Ceroni, G. De Felice, E. Grande, M. Malena, C. Mazzotti, F. Murgo, E. Sacco, M.R. Valluzzi, Analytical and numerical modeling of composite-to-brick bond," *Materials and structures*, **47**(12), 1987–2003, 2014.

[19] N. Gattesco, I. Boem, Review of experimental tests and numerical study on ma-sonry vaults reinforced through fiber-reinforced mortar coating, *Bulletin of Earthquake Engineering*, **17**(7), 4027–4048, 2019.

[20] EN 1015-11, Methods of Test for Mortar for Masonry, Part 11: Flexural Compres-sive Strength Hardened Mortar," **3**(1), 2006.

[21] NBC, 203 Guidelines for Earthquake Resistant Building Construction: Low Strength Masonry, *Nepal National Building Code*, Department of Urban Development and Building Construction, Nepal, 2015.

[22] DUDBC, Design Catalogue for Reconstruction of Earthquake Resistant Houses, *Department of Urban Development and Building Construction (DUDBC)*, 2015.

[23] S. Barattucci, V. Sarhosis, A. W. Bruno, A. M. D'Altri, S. de Miranda, G. Castel-lazzi, An experimental and numerical study on masonry triplets subjected to monoton-ic and cyclic shear loadings, *Construction and Building Materials*, **254**, 119313, 2020.

[24] P. K. Dhir, E. Tubaldi, A. Orfeo, H. Ahmadi, Cyclic shear behaviour of masonry triplets with rubber joints, *Construction and Building Materials*, **351**, 2022.

[25] J. Segura, L. Pelà, S. Saloustros, P. Roca, Experimental and numerical insights on the diagonal compression test for the shear characterisation of masonry, *Construction and Building Materials*, **287**, 122964, 2021.

[26] M. Del Zoppo, M. Di Ludovico, A. Balsamo, A. Prota, Diagonal compression testing of masonry panels with irregular texture strengthened with inorganic composites, *Materials and Structures*, **53**(4), 107, 2020.

[27] H. Mahmood, J. M. Ingham, Diagonal Compression Testing of FRP-Retrofitted Unreinforced Clay Brick Masonry Wallettes, *Journal of Composites for Construction*, **15**(5), 810–820, 2011.

[28] H. O. Aminulai, M. Baiguera, D. A. Crump, A. Sextos, M. M. Kashani, Experi-mental qualification of seismic strengthening of URM buildings in Nepal, *Soil Dynamics and Earthquake Engineering*, **173**, 108130, 2023.

[29] Abaqus, "Abaqus," 2023, Dassault Systèmes. Accessed: Aug. 24, 2024. [Online]. Available: https://www.3ds.com/products/simulia/abaqus

[30] L. S. Rainone, V. Tateo, S. Casolo, G. Uva, About the Use of Concrete Damage Plasticity for Modeling Masonry Post-Elastic Behavior, *Buildings*, **13**(8), 1915, 2023.

[31] J. Lubliner, J. Oliver, S. Oller, E. Oñate, A plastic-damage model for concrete, *International Journal of Solids and Structures*, **25**(3), 299–326, 1989.

[32] Abaqus documentation, Abaqus user manual, Dassault Systèmes Simulia Corporation. Accessed: Aug. 24, 2024. [Online]. Available: https://www.3ds.com/support/documentation

[33] P. K. Dhir, E. Tubaldi, H. Ahmadi, J. Gough, Numerical modelling of reinforced concrete frames with masonry infills and rubber joints, *Engineering Structures*, **246**, 2021.

[34] P. J. B. B. Lourenço, Computational strategies for masonry structures, 1996.