

Seismic Evaluation of Steel-Roofed Masonry Building Using FRP and FRCM.

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Abstract

Existing masonry buildings are vulnerable to earthquake-induced actions because of the limited tensile capacity and brittle behaviour of masonry. This study focuses on the seismic assessment and strengthening of an existing two-storey load-bearing masonry building located in Pune, Maharashtra. The building consists of masonry walls with reinforced concrete floor slabs and a steel truss roof system. The steel roof truss is analysed separately and its support actions are incorporated into the structural model to represent the actual load-transfer mechanism. A three-dimensional numerical model of the building is developed in SAP2000, and seismic behaviour is investigated using time-history analysis with the 2001 Bhuj earthquake ground motion. Three structural configurations are considered: the original unreinforced masonry (URM) building, URM strengthened with jute-fibre-based FRP, and URM strengthened with jute-fibre-based FRCM. The study focuses on assessing the seismic response of the existing structure and examining the applicability of natural-fibre-based composite systems as practical and sustainable strengthening techniques for existing masonry buildings. The comparative analytical framework provides a basis for evaluating suitable seismic retrofitting approaches for similar existing structures.

Keywords: Steel roof truss; Masonry building; Unreinforced masonry (URM); Seismic analysis; SAP2000; FRP; FRCM; Jute fibre; Bhuj Earthquake; Structural strengthening; Time history analysis; Natural fibre composites.

1. Introduction

Unreinforced masonry (URM) buildings are widely used due to their simplicity and cost-effectiveness, but their brittle behaviour and limited ductility make them vulnerable to earthquake loading. This study focuses on the seismic assessment of an existing two-storey masonry building with a steel truss roof. A numerical model is developed in SAP2000 and analysed using time-history analysis with the 2001 Bhuj earthquake ground motion. The study considers jute-fibre-based FRP and FRCM strengthening systems and compares the structural response of the original and strengthened configurations. The work also explores natural-fibre composites as a practical and sustainable approach for seismic retrofitting of existing masonry structures. [1].

2. Importance of URM Structures

Unreinforced masonry (URM) structures are important because they are widely used for residential and low-rise buildings due to their simple construction, availability of materials, and relatively low cost. However, URM buildings generally have limited ductility and brittle behaviour, making them vulnerable to earthquake-induced damage.

The major importance of studying URM structures is:

- **Widely used:** Commonly found in low-rise and non-engineered buildings.
- **Economical construction:** Masonry construction is relatively simple and cost-effective.
- **Seismic vulnerability:** URM structures can experience significant damage during earthquakes because of their brittle behaviour.
- **Life safety:** Understanding their seismic behaviour is important for reducing the risk to occupants.
- **Need for retrofitting:** Existing URM buildings may require strengthening to improve their earthquake resistance.
- **Sustainable strengthening:** Natural-fibre systems such as jute-based FRP and FRCM can be investigated as potential strengthening techniques.
- **Existing building assessment:** Seismic evaluation helps identify structural weaknesses and supports decisions regarding suitable retrofitting methods.

3. Strengthening of URM Structures Using FRP and FRCM –

FRP Strengthening

Fiber Reinforced Polymer (FRP) strengthening offers several advantages for URM structures:

- High strength-to-weight ratio – provides significant strengthening with low additional weight.
- Lightweight system – adds minimal dead load to the existing masonry.
- Easy and quick installation – can be applied as thin strengthening layers.
- Improves load-carrying capacity of masonry walls.
- Improves in-plane and out-of-plane behaviour of masonry.
- Good crack control and helps improve the integrity of masonry walls.
- Suitable for seismic retrofitting because it can improve the structural response without major changes to the existing building.
- Jute-based FRP can provide a more sustainable and locally available alternative to conventional synthetic-fibre systems.

2. FRCM Strengthening

Fiber Reinforced Cementitious Matrix (FRCM) strengthening has the following advantages:

- Cement-based matrix, making it suitable for masonry substrates.
- Good compatibility with masonry compared with some polymer-based systems.
- Improves ductility and energy absorption of strengthened masonry.
- Improves crack resistance and load transfer.

- Lightweight and relatively easy to apply.
- Jute fibre can be used as natural reinforcement in the cementitious matrix.
- Environmentally friendly compared with systems using synthetic fibres.
- Cost-effective and locally available, particularly where jute is readily sourced.

4. Review Methodology

The review followed a systematic, theme-based and critical approach. The starting point was the attached synopsis, which defines the research focus as seismic performance analysis of unreinforced masonry structure strengthened with FRP and FRCM. The synopsis provides the dissertation aim, research gap, objectives, methodology and expected outcomes, and these elements were transformed into a journal-style review framework. Systematic review methodology adopted in the present paper

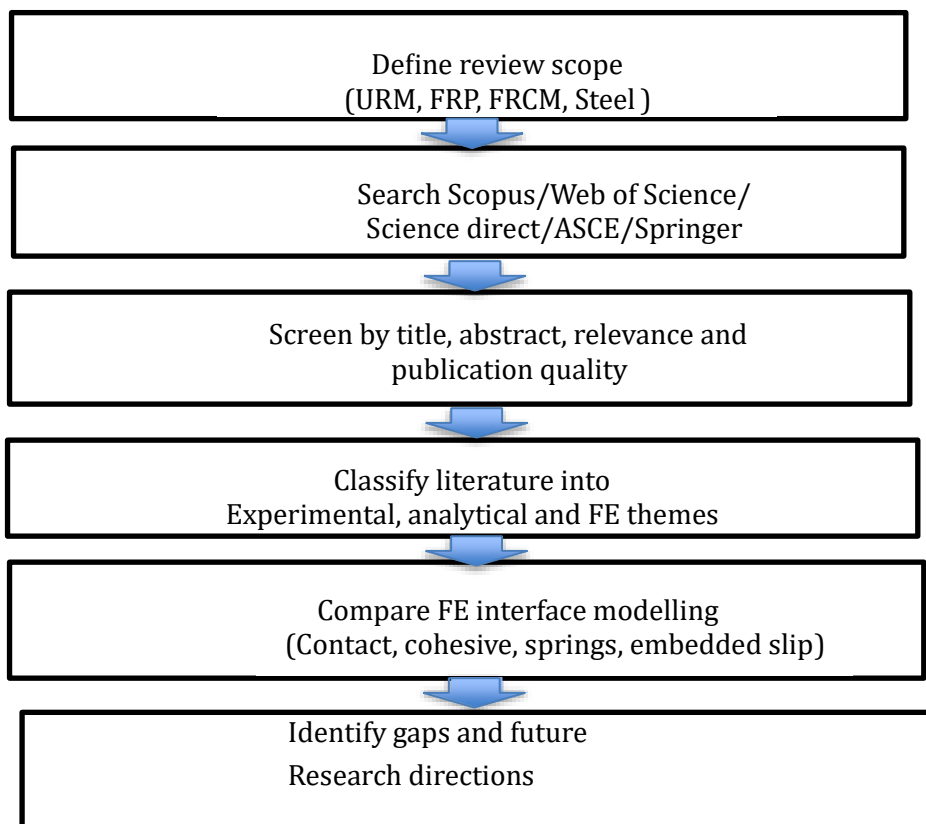


Figure 2. Systematic review methodology adopted for the present review paper. Source: Author synthesis based on review protocol and dissertation synopsis

The literature search focused on Scopus-indexed and high-impact journals, including Engineering Structures, Composite Structures, Construction and Building Materials, Case Studies in Construction Materials, Structures, Journal of Composites for Construction, Buildings, Materials and International Journal of Concrete Structures and Materials. Keywords included Unreinforced masonry (URM), Seismic analysis, SAP2000, FRP, FRCM, Jute fibre, Bhuj Earthquake, Structural strengthening, Time history analysis, Natural fibre composites.

After identification, studies were screened using title, abstract, methodology and relevance to URM modelling. Studies were then classified into experimental FRP and FRCM strengthened, numerical implementation, composite reinforcement, advanced cementitious matrices and design-oriented implications.

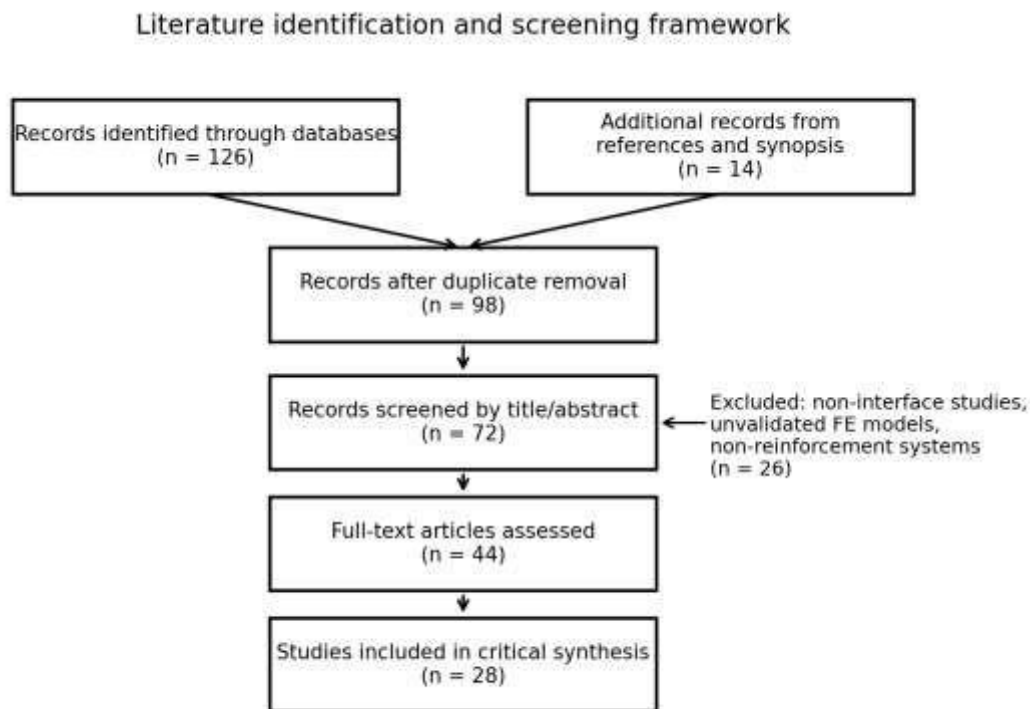


Figure 3. Literature identification and screening framework used for thematic synthesis. Source: Author synthesis based on Scopus-style review methodology.

5. Literature Selection Criteria

Inclusion criterion	Description
Reinforcement type	FRP, FRCM, Steel, Concrete, sand, TRM
Interface focus	Linear behavior, Non-linear behavior, Flexural bond strength of prism, Shear bond strength, lateral behavior.
Numerical relevance	Finite element analysis, contact modelling, nonlinear springs
Material system	FRP, FRCM, Brick, cement, sand, TRM
Publication quality	Peer-reviewed journal papers, Scopus-indexed papers, recent reviews, design guidelines and validated numerical studies

Table 1. Literature selection criteria adopted for the review.

6. Detailed Literature Review

6.1. Study of the seismic performance of damaged confined brick masonry walls reinforced with FRCM Masonry walls, the main load-bearing elements, are susceptible to shear damage due to seismic action. Currently, most masonry structures have various degrees of damage and must be strengthened in a timely manner to enhance their performance during earthquakes. This study presents pseudostatic test results for the use of FRCMs to strengthen damaged confined brick masonry walls. Tests were conducted on five walls, and performance indicators were compared for one unreinforced masonry wall and four masonry walls that were damaged and reinforced with various retrofit measures. Reinforcement by FRCM improved the integrity and increased the deformation of damaged walls. The study also examined the damage mechanism, hysteresis characteristics, deformation capacity, and energy dissipation. This study demonstrated the value of using FRCMs to repair damaged masonry walls to improve their seismic performance. The skeletal curves of the walls reinforced on both sides exhibited better postpeak behavior, and the seismic performance indices of the damaged walls strengthened by FRCM were better than those of the unreinforced wall. In accordance with the results of these experiments and previous studies by other scholars, the damage severity and limit state of the FRCM-strengthened walls were determined on the basis of displacement drift. Furthermore, the calculated shear capacities of the FRCM-reinforced walls agreed well with the experimental values. [1].

6.2. Advancements in fiber-reinforced polymer (FRP) retrofitting techniques for seismic resilience of reinforced concrete structures In recent years, civil engineering has increasingly focused on utilizing fiber-reinforced polymers (FRPs) to retrofit and strengthen reinforced concrete (RC) structures. This paper explores advancements in FRP retrofitting techniques, with a particular focus on their application to beam–column joints in RC structures. The introduction outlines the evolution of FRP materials and their optimization for seismic retrofitting applications. A critical review of existing research highlights the effectiveness of FRP reinforcement in improving seismic resilience. The study examines three distinct cases from post-earthquake assessments in Albania, addressing the impact of poor concrete quality and inadequate detailing on structural performance. To capture the behavior of FRP-strengthened RC structures comprehensively, nonlinear finite element analysis (NLFEA) was employed for localized analysis to observe the influence of FRP strengthening on critical joints, while finite element modeling (FEM) was used for global analysis to demonstrate the behavior at the structural level. The combined approach evaluates the effectiveness of FRP reinforcement in mitigating vulnerabilities, such as shear deficiencies and brittle failure modes, across varying scenarios of material quality and detailing. Key findings indicate that FRP retrofitting strategies result in a 25% increase in peak shear force and a 20% improvement in displacement capacity, showcasing enhanced ductility and seismic resilience. The finite element analysis demonstrated strong prediction accuracy, with error margins below 5% when compared to experimental results. These results emphasize the critical role of tailored FRP retrofitting strategies in enhancing seismic resilience, offering valuable insights for future retrofitting practices in seismic-prone regions. [2].

6.3. Evaluation of FRP and FRCM composites for the strengthening of reinforced masonry walls

Al-Jaberi et al. investigated the effectiveness of externally bonded Fiber Reinforced Polymer (FRP) and Fiber Reinforced Cementitious Matrix (FRCM) systems for strengthening reinforced masonry walls under out-of-plane cyclic loading. The experimental program included 12 masonry wall specimens, consisting of control specimens and walls strengthened using different types and amounts of FRP and FRCM reinforcement. The study examined flexural behaviour, stiffness, load–deflection response, crack development, and failure mechanisms. The results showed that both FRP and FRCM systems can enhance the flexural capacity and stiffness of masonry walls. The study also highlighted that strengthening performance is influenced by fiber type, reinforcement ratio, bonding characteristics, masonry bond pattern, and anchorage, while different failure mechanisms such as FRP rupture, debonding, and FRCM fiber slippage were observed [3].

6.4. Seismic behavior of heritage building with isotropic and orthotropic material properties: a comparative analysis

Restoration and retrofitting of heritage buildings is a complex analysis. In actual practice, building materials of heritage masonry buildings are anisotropic. However, in practice, these building materials had been considered isotropic to optimize the analysis. The present study is a comparative analysis of these two approaches. A heritage school building in northern India underlying seismic zone IV has been considered for the analysis. The seismic performance analysis of the buildings has been carried out through numerical modeling using the SAP2000. Analysis has been carried out for one set of isotropic and three sets of orthotropic material parameters. Normal and shear stresses had been observed and compared with stress calculated from the empirical relationships provided in the standard code of practice. [4].

6.5. An Experimental and Numerical Investigation of an Unreinforced Brick Masonry Structure Subjected to Base Excitation

Conducted an experimental and numerical study to examine the seismic response of unreinforced masonry (URM) structures subjected to base excitation. A scaled masonry model was tested on a shake table to simulate ground motion and observe structural behaviour such as displacement, cracking, and failure progression. Numerical modelling was carried out using SAP2000 software to replicate the experimental conditions and analyze dynamic response. The comparison showed a strong correlation between simulated and observed results, confirming the reliability of SAP2000 in capturing nonlinear seismic behaviour. The study provided key insights into failure mechanisms of URM structures and emphasized the importance of combined experimental and analytical approaches in seismic assessment [5].

6.6. Seismic performance-based assessment of urban cultural heritage assets through different macroelement approaches.

This paper aims at providing an insightful comparison between three of the most widely used commercially available macroelement models for assessing the global seismic performance of existing masonry structures: the equivalent frame model of 3Muri®, and the two- and three-dimensional discrete macroelements available in 3D-Macro®. To this aim, a stone masonry building, representative of the Urban Cultural Heritage (UCH) typology of the Azores archipelago (in

Portugal), was considered as a case study. Firstly, sensitivity analyses were performed to investigate the impact of a few modelling aspects on the seismic performance of the case study building, and ultimately to define the reference model. Secondly, this reference model was analysed both linearly and nonlinearly. Finally, the seismic performance was evaluated by applying the N2 Method. With this comparative study, the authors aim at discussing, from the user viewpoint, the features that these software codes and corresponding macroelement models have in common and those where they most diverge, as well as their main advantages and drawbacks. Results demonstrate that these models should be applied to UCH assets with due diligence, bearing in mind both the particularities of the case study as well as features and limitations associated with the chosen modelling strategy and software [8].

6.7. In-plane behavior of cavity masonry infills and strengthening with textile reinforced mortar.

The seismic vulnerability of masonry infilled reinforced concrete (rc) frames observed during past earthquakes in some south European countries resulted in losses of human lives and huge repair or reconstruction costs, justifies the need of deeper study of the seismic behaviour of masonry infills enclosed in rc frames. Therefore, the main goals of this study are related to: (1) better understanding of the cyclic in-plane behaviour of traditional brick infills built in the past decades as enclosures in rc buildings in Portugal; (2) analysis of a strengthening technique based on textile reinforced mortar (TRM) aiming at enhancing the in-plane behaviour. To accomplish the objectives, an extensive experimental campaign based on in-plane static cyclic tests on seven reduced scale rc frames with masonry infill walls was carried out. The performance of strengthening of masonry infill based on textile reinforced mortar was also evaluated experimentally.

Among the conclusions of this research, it should be stressed that: (1) the presence of infill inside the bare frame could significantly enhance the in-plane stiffness and resistance of bare frame; (2) TRM technique could enhance the in-plane behaviour of infilled frames by improving the lateral strength and by reducing significantly the damage of the brick infill walls [9].

6.8. Textile-reinforced mortar (TRM) versus FRP as strengthening material of URM walls: in-plane cyclic loading

In this study the application of a new structural material, namely textile-reinforced mortar (TRM), as a means of increasing the load carrying capacity and deformability of unreinforced masonry walls subjected to cyclic in-plane loading is experimentally investigated. The application of externally bonded TRM is considered in this work as an alternative method to the application of fiber-reinforced polymers (FRP). Hence, the effectiveness of TRM overlays is evaluated in comparison to the one provided by FRPs. Medium-scale tests were carried out on 22 masonry walls subjected to in-plane cyclic loading. Three types of specimens were used: (a) shear walls; (b) beam-columns; and (c) beams. The parameters under investigation included the matrix material (mortar versus resin), the number of textile layers and the compressive stress level applied to shear walls and beam-columns. Compared with their resin-impregnated counterparts, mortar-impregnated textiles may result in generally lower effectiveness in terms of strength, but in much higher in terms of deformability. From the results obtained in this study it is believed that TRMs hold strong promise as a solution for the structural upgrading of masonry structures under in-plane loading [10].

7. Comparative Analysis of Existing Studies

Study	System	Method	Major contribution	Key limitation
Fenghao. Et al. 2024	FRP & FRCM strengthen	Experimental analysis compares by different model	Summarized FRP & FRCM stiffness, influencing parameters	Natural jute fibrebased composite materials
Kabashi, Naser, et al. (2025)	SAP-2000	Numerical analysis	Developed understanding of bond beams effect in structure	Limited to bond beams and their contribution for lateral forces
Zuhair A. (2018)	Seismic retrofitting	finite element modelling in DIANA FEA	Pushover and modal analyses showed increased stiffness	CLT-based retrofitting
Kamaram et al. (2023)	Comparison between URM & CM	Experimental and numerical analysis	Strong correlation between simulated and observed results, confirming the reliability of SAP2000	Cracks determination limited to FRP only
Rehan A. Khan (2022)	Linear static and dynamic response spectra	Critical review + model evaluation	Tensile and shear stresses for different story	Limited to CM structure

Table 2. Comparative analysis of selected studies relevant to URM, FRP & FRCM modelling.

8. Research Trends

Seismic Retrofitting of Unreinforced Masonry (URM) Buildings: Seismic vulnerability of existing URM buildings, Performance-based seismic rehabilitation, Retrofit strategies for low-rise masonry buildings.

FRCM/TRM Strengthening Systems: Fabric-Reinforced Cementitious Matrix (FRCM), Textile-Reinforced Mortar (TRM), Durability and fire resistance compared with FRP, Compatibility with historic masonry.

Time History Analysis of Masonry Buildings: Linear vs nonlinear time history analysis, Selection and scaling of earthquake records, Dynamic response of retrofitted masonry structures.

Numerical Modelling of Masonry: shell element modelling, Macro-model vs micro-model, Interface modelling between masonry and retrofit materials, Finite element modelling in SAP2000, ABAQUS and DIANA.

Comparison of Different Retrofitting Techniques: FRP vs FRCM, FRP vs Steel Jacketing, FRP vs CRM (Composite Reinforced Mortar), Cost–performance comparison.

9. Research Gap

limited studies have evaluated the seismic behaviour of an actual existing two-storey URM building with a steel truss roof using jute-fibre-based FRP and FRCM strengthening systems within the same numerical framework. Previous studies have largely focused on individual masonry wall specimens, laboratory testing, or conventional synthetic-fibre strengthening materials. There is comparatively less work on real-building-scale numerical assessment using SAP2000 and earthquake time-history analysis, particularly for comparing unstrengthened URM, jute-based FRP, and jute-based FRCM under the same structural and seismic conditions.

10. Challenges and Limitations in Existing Studies

The main challenges of this research include accurately modelling the existing URM building and its material properties in SAP2000, representing the actual interaction between masonry, RCC slabs, and the steel truss roof, and selecting suitable properties for jute-based FRP and FRCM systems. The study is also limited by its reliance on numerical time-history analysis using the 2001 Bhuj earthquake record and published material properties. Since the strengthening systems are evaluated analytically, actual construction, bonding, workmanship, environmental effects, and long-term durability are not experimentally verified. Additionally, the study considers a specific two-storey building, so the findings may not be directly applicable to all types of masonry structures.

11. Practical, Industrial and Academic Implications

Practical implications: The findings of this study provide practical guidance for improving the seismic safety of existing unreinforced masonry buildings through FRP and FRCM retrofitting. The results help structural engineers select an appropriate strengthening technique based on seismic performance parameters such as displacement, story drift, base reaction, and acceleration. The study also demonstrates the application of SAP2000 for evaluating real masonry buildings under earthquake loading, making it useful for the rehabilitation of existing residential and institutional buildings in earthquake-prone regions.

Industrial implications: The study is beneficial for structural consultants, construction companies, and retrofitting contractors involved in seismic rehabilitation projects. It provides a comparative assessment of FRP and FRCM strengthening systems, enabling informed decisions regarding material selection, construction feasibility, and structural performance. The methodology can support engineers in designing safer retrofit solutions for existing masonry buildings while complying with modern seismic design practices.

Academic implications: The research contributes to the existing knowledge on seismic strengthening of masonry structures by comparing URM, FRP, and FRCM systems using Time History Analysis in SAP2000. It provides a useful reference for researchers and postgraduate students working in earthquake engineering, finite element modelling, and structural rehabilitation. The study also identifies research gaps and offers a foundation for future investigations involving nonlinear analysis, experimental validation, advanced retrofit materials, and performance-based seismic design.

12. Conclusion

This review confirms that Unreinforced masonry structure strengthen with FRP & FRCM is give impactful result as related to various seismic performance parameter. In that we analyze of stress contribution of bands.

Here we perform non-linear analysis of time history function by using real earthquake data of Bhuj earthquake. By numerical analysis we know load resistance by various retrofitting technique and stress distribution in structure.

From above research we got how many percentages of improvement in seismic performance of URM structure by using various retrofitting techniques.

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