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REVIEW

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Theoretical Framework for Experimental Research on Seismic Performance of Masonry-Infilled RC Frames

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Abstract

Fabric-reinforced cementitious matrix (FRCM) technology has emerged as a promising solution for the reinforcement of existing buildings, particularly in seismically active regions. This paper presents a comprehensive review of experimental research methods focusing on the seismic performance of masonry-infilled reinforced concrete (RC) frames retrofitted with FRCM. Drawing on a wealth of literature from various regions, this review synthesizes advancements in FRCM technology, experimental techniques, and theoretical frameworks. Key aspects explored include material properties testing, bond behaviour between fabric and matrix, and the seismic behaviour of masonry-infilled RC frames. Additionally, the significance of in-plane and out-of-plane behaviours is discussed, highlighting the importance of comprehensive testing methodologies. This paper also examines advancements in experimental equipment, such as shake tables, underscoring their pivotal role in simulating realistic seismic conditions. Overall, this review provides a systematic foundation for further research on the efficacy and potential of FRCM technology in structural reinforcement, contributing to the ongoing discourse in seismic engineering and retrofitting strategies.

Keywords Fabric-reinforced cementitious matrix, Masonry-infilled reinforced concrete frames, Experimental research methods, Seismic performance, Structural reinforcement, Retrofit strategies

1 Introduction

In accordance with prior scholarship by Wang, (2023); Wang et al., (2021), the core principle of fabric-reinforced cementitious matrix (FRCM) composites lies in embedding high-strength fabrics within a cement-based mortar, resulting in a mineral-based composite (MBC) material. When short polymeric fibres are incorporated into the mortar matrix, the resulting material is commonly referred to as an engineered cementitious composite (ECC). FRCM systems, also known as textile-reinforced mortars (TRM), have been widely applied to various substrates for structural strengthening purposes. These include applications such as textile-reinforced concrete (TRC) and TRC-strengthened masonry, particularly in the retrofitting of existing reinforced concrete (RC) structures.

Extensive experimental research has been conducted in both Europe and the United States comparing fibre-reinforced polymer (FRP) and FRCM reinforcement techniques. Nearly all studies that have undertaken direct comparisons have concluded that FRCM represents an evolution and, in many cases, a replacement for FRP technology. Compared to FRP sheets, FRCM stands out as a more advanced solution for infill wall strengthening, offering improved fire resistance, lower added mass, enhanced durability, and better compatibility with substrate materials. The method typically involves applying

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fibre fabrics embedded in mortar to masonry or concrete surfaces, using a variety of fibre types such as glass, carbon, aramid, basalt, and p-phenylene benzobisoxazole (PBO).

A multitude of factors influence building energy performance, including installed heating/cooling systems, climatic conditions, and the architectural envelope. Enhancing envelope insulation capacity serves to mitigate energy demand by improving thermal retention, while the integration of energy-efficient operational systems further contributes to conservation efforts. Consequently, energy-saving initiatives primarily target ageing facilities characterized by inadequate insulation, which results in elevated energy consumption rates.

Recent investigations underscore the necessity of integrating independent retrofit measures to comprehensively enhance overall performance. Efforts to merge seismic resilience with the ecological benefits of mitigating seismic-induced damage and/or avoiding demolition due to earthquakes have garnered considerable attention. Consequently, a multidisciplinary approach has emerged, emphasizing simultaneous enhancements in seismic and energy efficiencies.

This paper systematically consolidates and evaluates a substantial body of experimental inquiries concerning the retrofit of masonry-infilled frames utilizing FRCM systems. These collective endeavours establish a theoretical framework for experimental investigations into the seismic performance of masonry-infilled RC frames.

2 Test methods on material property

2.1 Matrix (Mortar)

The FRCM system relies on the reinforced mortar as an essential component to bear flexural and compressive loads and to provide bonding between the substrate and the outer thermal insulation and enhance the cooperative working mechanism with the fabric. To accomplish this, specialized moulds are used to create prismatic mortar matrix samples sized 160 × 40 × 40 mm. The flexural and compressive strength of these samples are tested in accordance with (EN1015-11, 2019), as shown in Fig. 1.

The longitudinal tensile test is significant as it closely aligns with the stress distribution characteristics of the mortar block within the FRCM system. However, previous testing methodologies have fallen short in adequately mitigating the impact of fixture deadweight. A novel approach is suggested wherein the sample is positioned horizontally on a smooth surface, or on a specialized test platform integrated with ball bearings to diminish friction resistance. Applying a horizontal load by affixing the load at both ends presents an opportunity to enhance the precision of tensile strength testing for the mortar block.

2.2 Fabric (Textile)

As the primary load-bearing element of the FRCM system for tensile force, fabrics have been developed to provide the required levels of tensile strength and elasticity. Direct tensile tests can be used to evaluate the tensile strength of dry fibres and/or a single bundle of fibres. Previous research by Wang et al., (2020) provides

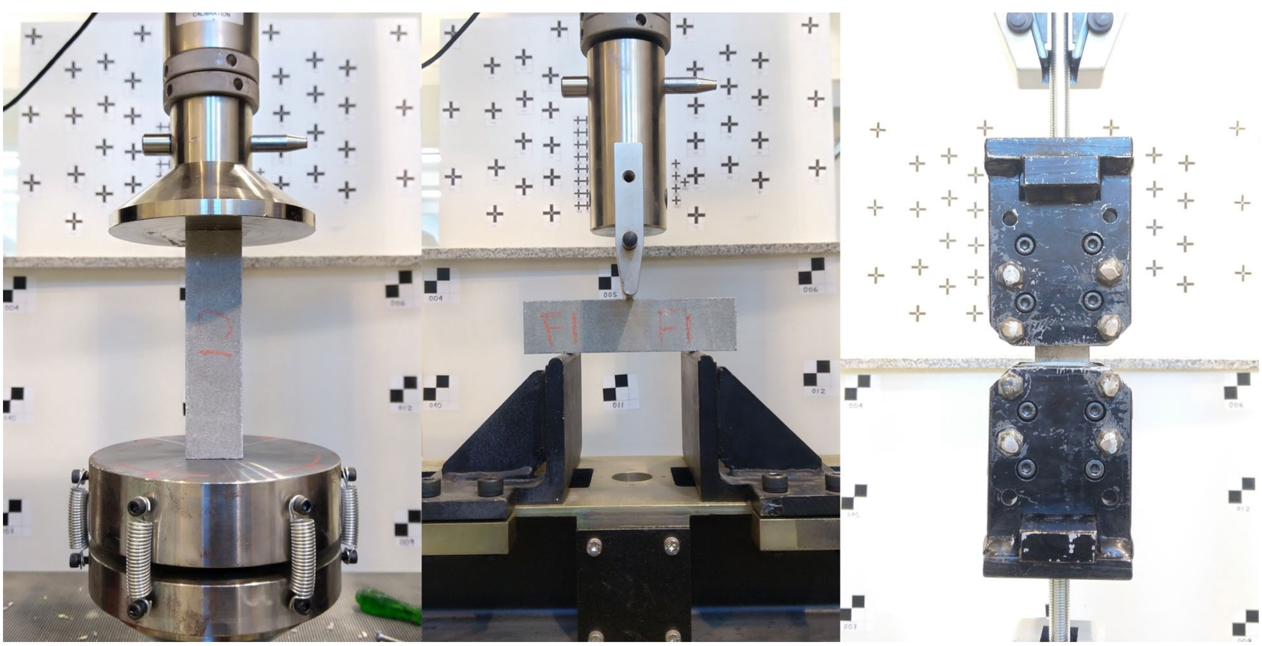


Fig. 1 Test method for compressive, flexural, and tensile strength of the mortar block. Reprinted from Wang et al., (2021)

valuable insights into these evaluations, as shown in Fig. 2.

3 Bond Behaviour

To achieve an effective combination of materials in the FRCM system, it is necessary to understand the bond-slip behaviours between the different components. There are two main test methods used to study the bonding mechanisms: fabric-to-matrix and matrix-to-substrate.

3.1 Tensile Bond Behaviour

The fibre-to-mortar bond mechanism consists of the chemical bond between the bare fibres and mortar blocks. This is originally determined as a load–slip response curve obtained by pull-out tests. The test setup is shown in Fig. 3, which is taken from the research of Dalalbashi et al., (2021); Pei et al., (2021).

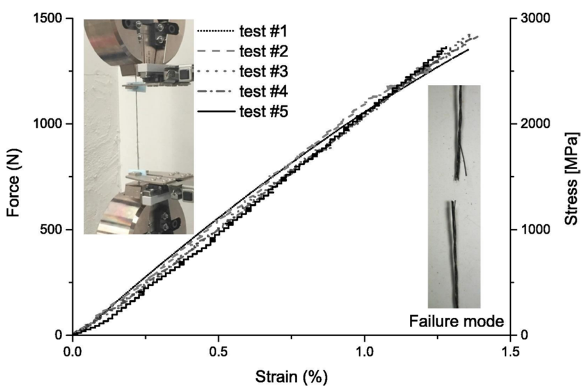


Fig. 2 Test method for tensile strength of single-bundle samples. Reprinted from Wang et al., (2020)

However, this method cannot measure finished fibre fabrics with cords and may cause measurement errors for coated fabrics. The fabric meshes are mechanically interlocked by shearing the matrix when the main bundle fibres are pulled out, which cannot be measured in pull-out tests on a single bundle of fibres. Additionally, the friction-increasing overcoat may cause debonding to occur between the fibres and the coating, rather than between the coating and the mortar, potentially hindering the accurate testing of the bond-slip behaviour of the fabric-to-matrix mechanism. Consequently, direct tensile tests on FRCM samples are now preferred for studying the bond-slip behaviour of various fibre fabrics embedded in different mortars.

The fabric-to-matrix bond mechanism is usually studied through the tensile bond behaviour of the FRCM composites. This behaviour is typically presented as a stress–strain response curve obtained by direct tensile tests.

Guidelines for performing direct tensile tests on FRCM composites in the United States are provided by (AC434, 2013) and (D3039/D3039M-17, 2017). While there are currently no specific norms for FRCM materials used for structural retrofitting in European countries, standardization committees are working to develop national and European guidelines. The test setups, as summarized by Caggegi et al., (2017), are shown in Fig. 4.

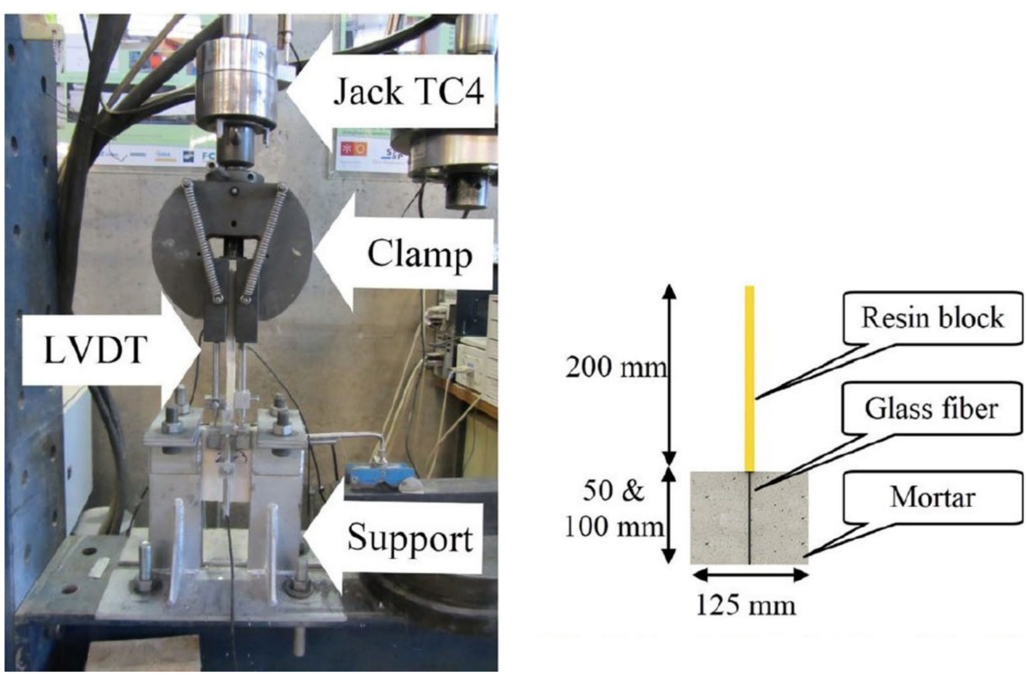


Fig. 3 Pull-out test method for fibre-to-mortar bond behaviour. Reprinted from Dalalbashi et al., (2021)

A comprehensive review of previous experimental studies by De Santis et al., (2017) has summarized the testing methods with operational details that can be fully emulated. It is noteworthy that test results from related studies may differ significantly, not only due to material properties but also because of specimen shapes and gripping methods.

The idealized stress–strain curves of dry fabric, clamped, and pinned FRCM composites, as drawn by Arboleda et al., (2016), are depicted in Fig. 5. Tensile specimens consist of one or more layers of fabric embedded in a mortar matrix, and the FRCM samples are also designed in different shapes. Such studies are summarized by Truong and Kim, (2021) in Fig. 6.

Rectangular-shaped specimens are long, flat prisms with gripping areas fixed by clamps and their surfaces treated to enhance friction, using materials such as aluminium plates, rubber plates, or sandpapers. Bone-shaped and dumbbell-shaped specimens have larger gripping areas with rounded or bevelled corners for wedging, while waist-shaped specimens are made of perforated steel plates embedded in the interior of two gripping areas without other outer inlays. Additionally, gripping regions in specimens can be reinforced with additional fibre fabrics or fibre-reinforced polymer (FRP) sheets, and their thickness may be increased as needed.

Direct tensile tests are used to determine the constitutive relationship of FRCM composites, as described by de Felice et al., (2020). The tensile bond behaviour typically follows three stages of response, as described by De Santis et al., (2017) and illustrated in Fig. 7.

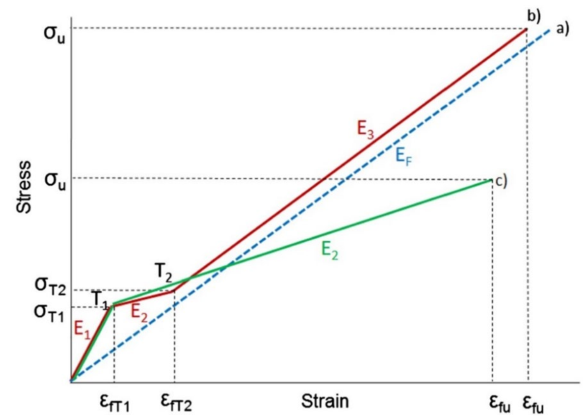


Fig. 5 Idealized stress–strain curves: **a** dry fabric; **b** clamped FRCM; **c** pinned FRCM. Reprinted from Arboleda et al., (2016)

In some cases, FRCM composites exhibit a higher Young's modulus and lower peak strain compared to dry textiles. This can be attributed to two main reasons. Firstly, the mortar matrix between subsequent cracks can contribute to the stiffness and allow for better stress distribution, increasing peak stress. Secondly, the uneven stress distribution between yarns or wires, or local damage in the clamping area during the test of dry textiles, may lead to the premature fracture of some of the yarns, resulting in an underestimation of the actual tensile strength of the textiles. The mismatch between the tensile behaviour of dry fabrics and FRCM composites depends on the bond or interlocking between the fabric and the

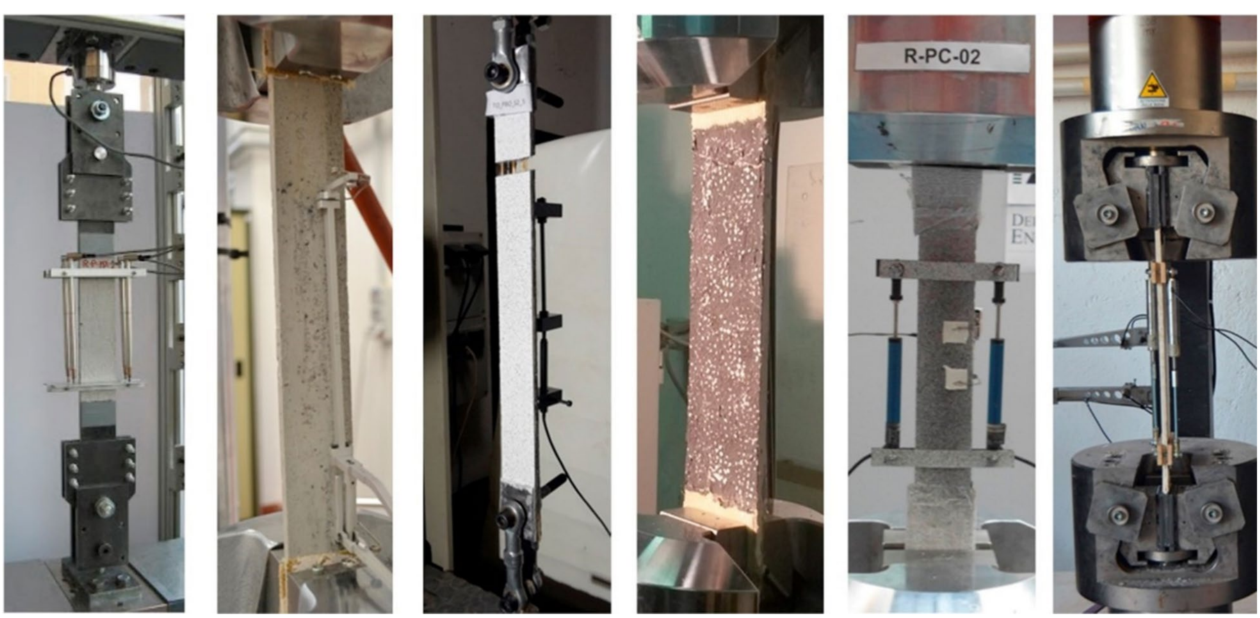


Fig. 4 Direct tensile test method on fabric-to-matrix bond behaviour. Reprinted from Caggegi et al., (2017)

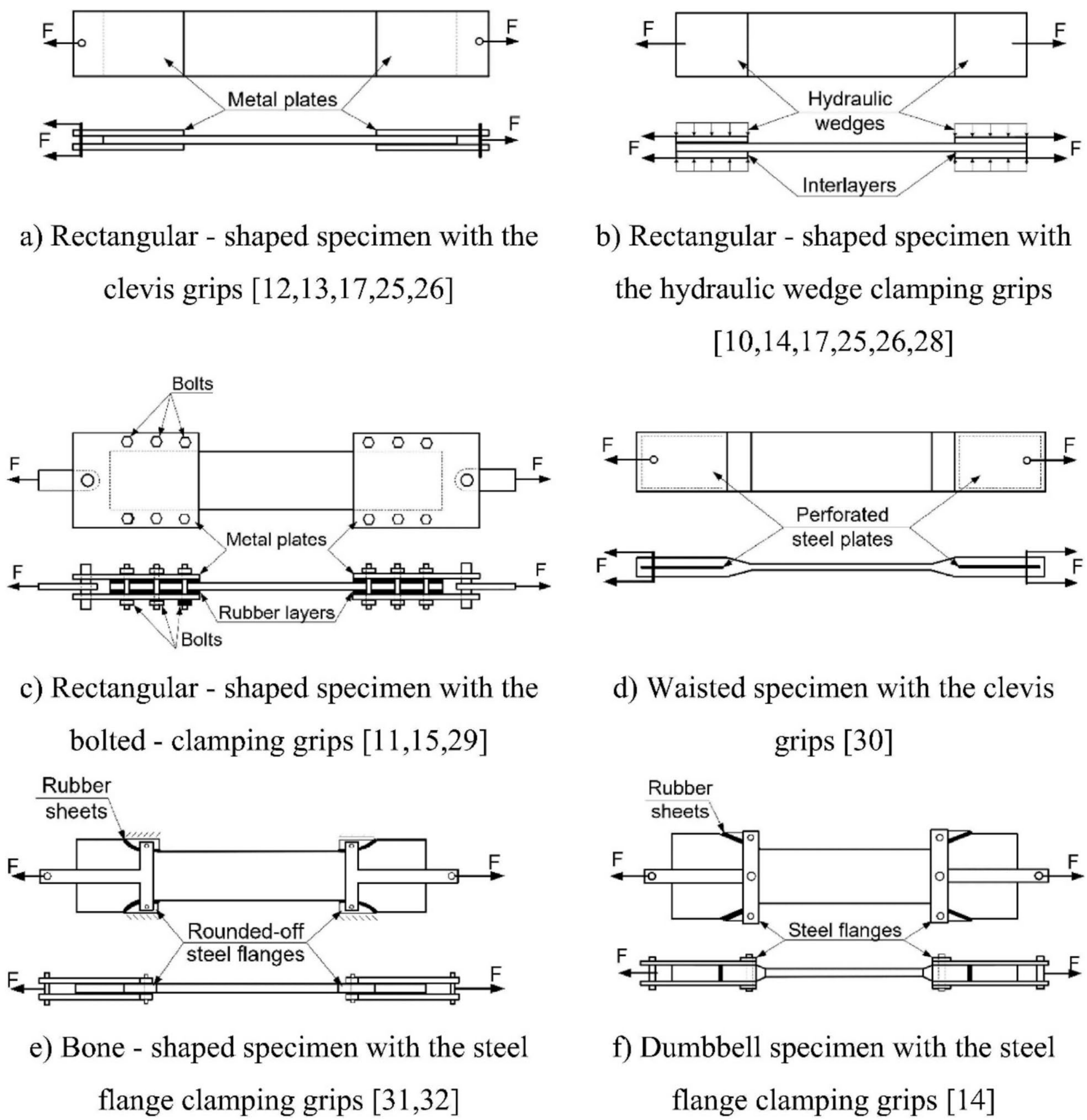


Fig. 6 Previous tensile specimens and direct tensile test setups. Reprinted from Truong and Kim, (2021)

matrix. This bond is higher for dry fabric made of several filaments and lower for pre-impregnated or coated fabric and steel fabric. Typically, there are four failure modes of FRCM composites in tensile tests, as presented in Fig. 8 from the research of Caggegi et al., (2017).

After reviewing the theory of direct tensile test methods, it is worth discussing tests related to the flexural bond behaviour of FRCM. The test method is shown in Fig. 9. These studies primarily investigate FRCM for reinforced concrete (RC) elements subjected to bending, or for walls subjected to out-of-plane loads.

3.2 Shear Bond Behaviour

The matrix-to-substrate bond mechanism is investigated through the shear bond behaviour between the FRCM layer and substrate, generally expressed as a shear force (or stress)–displacement response curve. This behaviour is evaluated using single-lap or double-lap shear tests

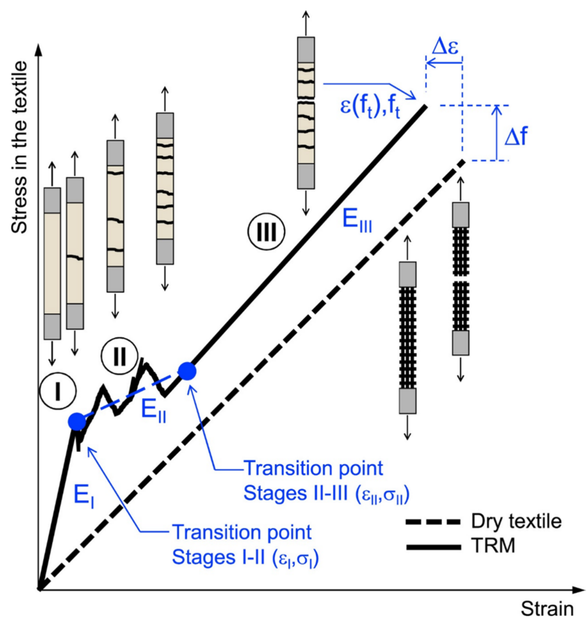


Fig. 7 Stages of tensile stress–strain response. Reprinted from De Santis et al., (2017)

on one prism, as well as double-lap double-prism shear tests. The setups of shear bond tests on masonry substrates by tension are shown in Fig. 10, as selected by De Santis et al., (2017).

Additionally, a type of shear bond test conducted by bending between two prisms is used to study the FRCM as reinforcement for flexural RC members or walls subjected to out-of-plane loads. An example of this test is depicted in Fig. 11, presented in a study by Calabrese et al., (2021). Likewise, the typical failure modes of the specimens in shear bond tests are also categorized by De Santis et al., (2017), as shown in Fig. 12.

Moreover, an insufficient embedded length of the fabric may alter the failure modes of the test specimens, resulting in a lower bond strength and different failure mechanisms. The bond-slip law of the interface between FRCM and RC substrate at various bond lengths was presented as response curves by Bencardino et al., (2017), shown in Fig. 13.

To account for the exponential nature of bond force along the bond length, it is crucial to place resistance strain gauges at different locations for measurement. The strain gauge configurations proposed by Napoli et al., (2016) for experimental research on the shear bond behaviour of the steel FRCM are particularly noteworthy. In their study, detailed distances from the gauges to the loaded end are marked, as shown in Fig. 14.

However, special considerations are necessary when conducting shear bond tests between FRCM and masonry substrates due to the surface characteristics and chemical bond strength differences between mortar

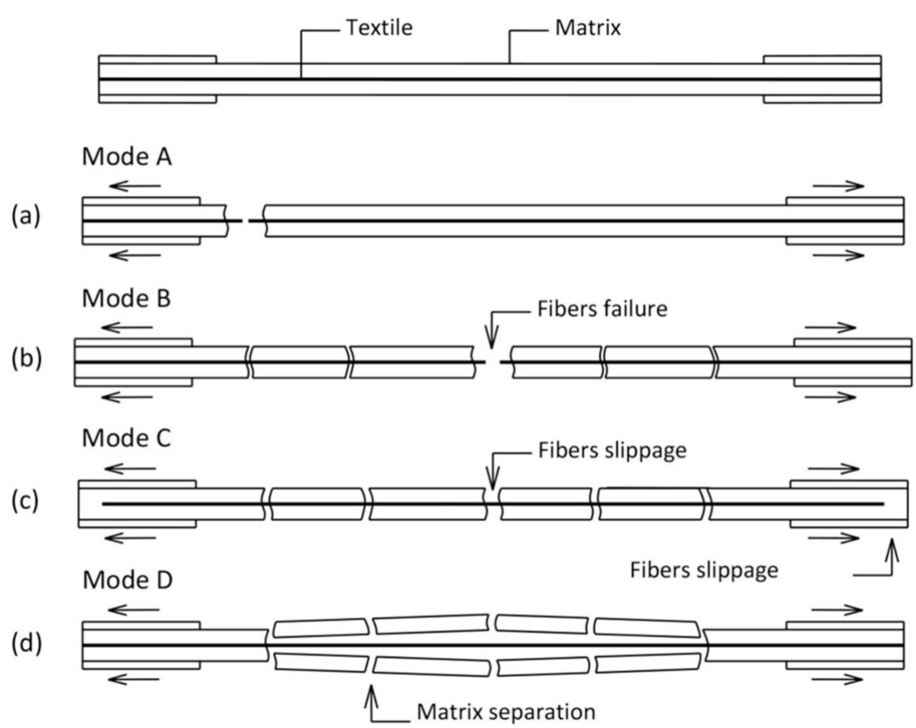


Fig. 8 Classification of failure modes of FRCM composites in tensile tests. Reprinted from Caggegi et al., (2017)

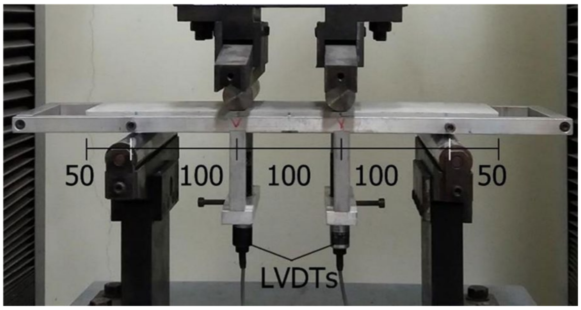


Fig. 9 Flexural test method for fabric-to-matrix bond behaviour. Reprinted from Kim et al., (2020)

joints and bricks. The anisotropy of bricks and the interlocking effect provided by the mortar joints create discontinuities in the stress distribution. This phenomenon was observed in shear bond tests between basalt FRP and masonry by de Felice et al., (2015), illustrated in Fig. 15.

Based on these results, it can be inferred that the distribution of bonding is discontinuous due to the influence of mortar joints in the masonry substrate, which may also affect the bond-slip law between FRCM and masonry. Furthermore, since there has been no separate investigation on the matrix-to-substrate bond when the FRCM is combined with a thermal insulation layer, specialized research on the fabric-to-matrix and matrix-to-substrate bond behaviour was conducted by Wang et al., (2021). Different arrangements of extruded polystyrene (XPS) plates were applied to the FRCM to test the shear bond capacity of this insulation system when used on a large-scale wall.

4 Seismic Behaviour

Masonry elements, including modern RC infill walls and unreinforced masonry (URM), are prone to collapse under bending or damage under shear forces. The deformation of the RC frame can also lead to the crushing of infill walls. To enhance seismic performance, numerous studies have investigated the use of FRCM strengthening, often utilizing wallettes or small-scale models for ornamental or experimental purposes. Test methods for different types of representative wall specimens typically include vertical compression (Fig. 16), diagonal compression (Fig. 17), and flexural bending (Fig. 18).

Conventionally, the seismic behaviour of planar elements is divided into out-of-plane (OOP) and in-plane (IP) behaviour, depending on the earthquake's direction. The load state of the masonry infill is illustrated in Fig. 19 by Gkournelos et al., (2020), showing that the infill wall is primarily subjected to flexure under out-of-plane loads and to diagonal compression under in-plane loads.

Although diagonal compression and flexural bending tests on wallettes are widely conducted to study masonry-infilled RC frames retrofitted with FRCM systems, it is still necessary to test the seismic performance of full-scale walls and infilled RC frames. The stress state of the masonry within the frame is more complex, and multiple failure modes often occur in different parts of the masonry. Relying solely on calculations of crushing, shearing, or flexural strength based on specifications is insufficiently accurate.

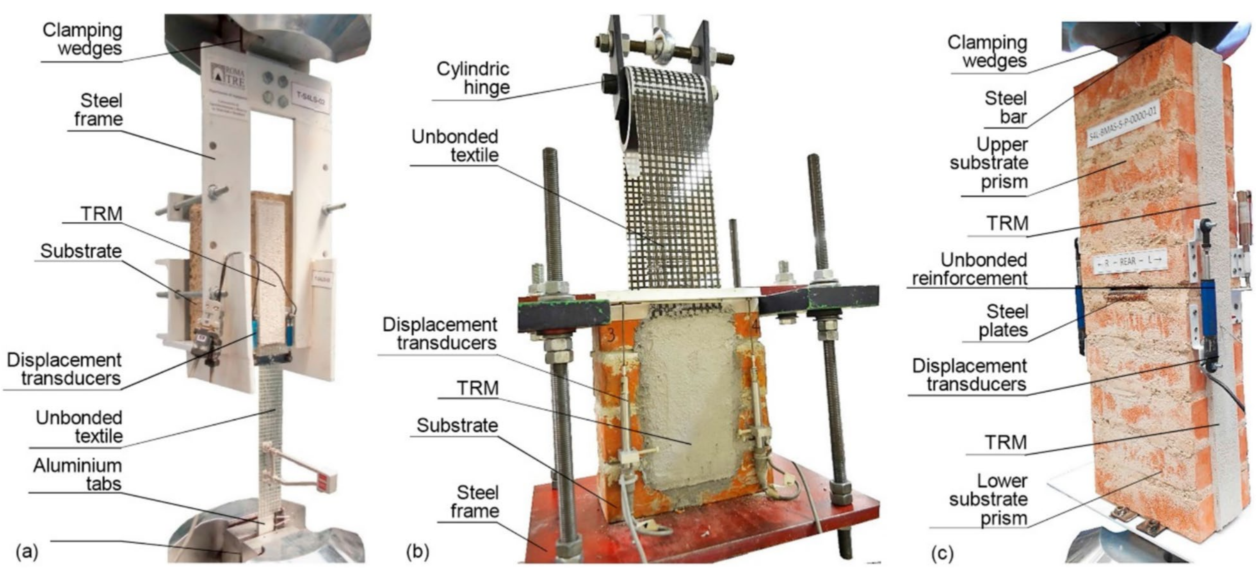


Fig. 10 Shear bond test methods for matrix-to-substrate bond behaviour by tension: **a** single-lap, **b** double-lap single-prism, **c** double-lap double-prism. Reprinted from De Santis et al., (2017)

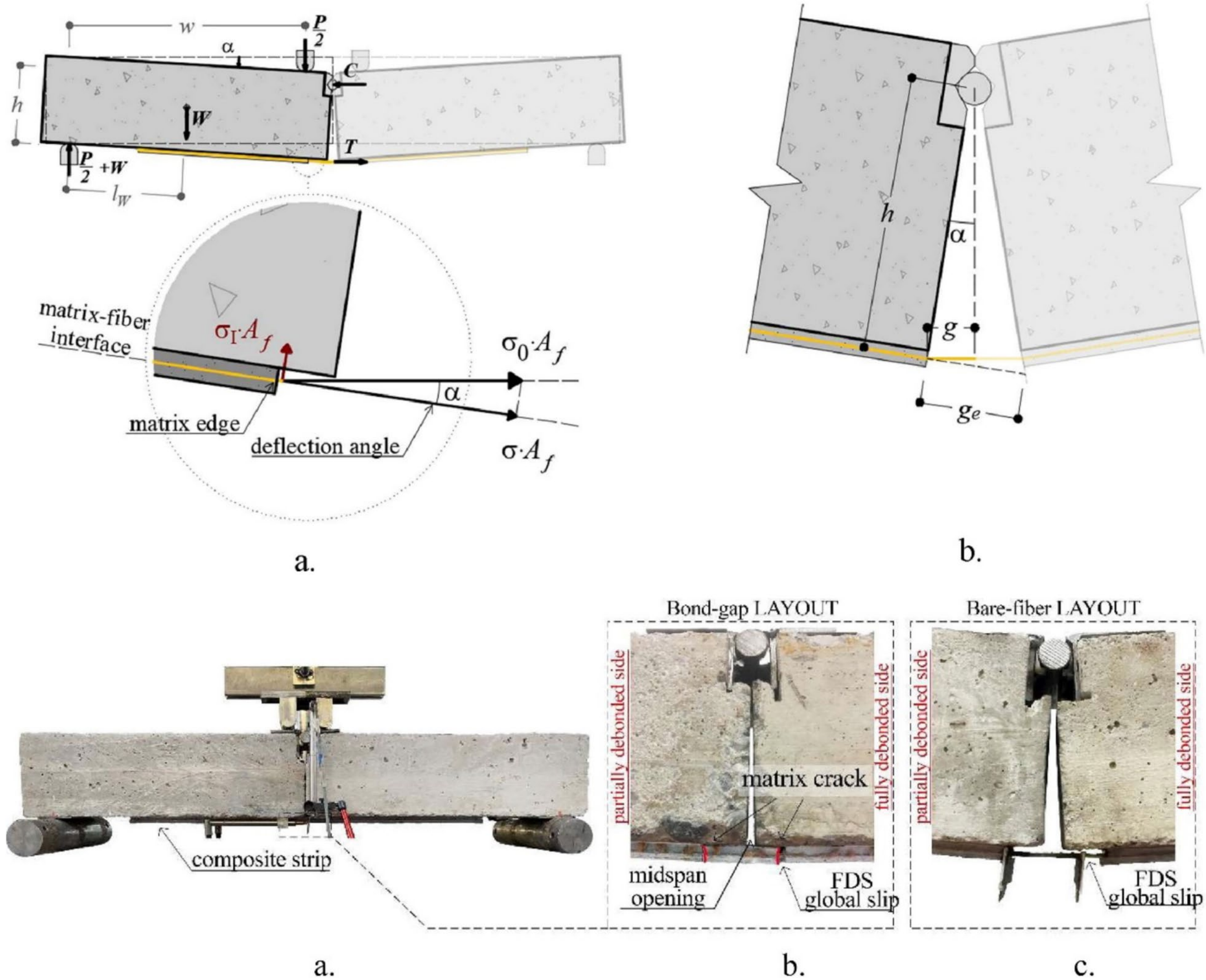


Fig. 11 Shear bond test method for matrix-to-substrate bond behaviour by bending. Reprinted from Calabrese et al., (2021)

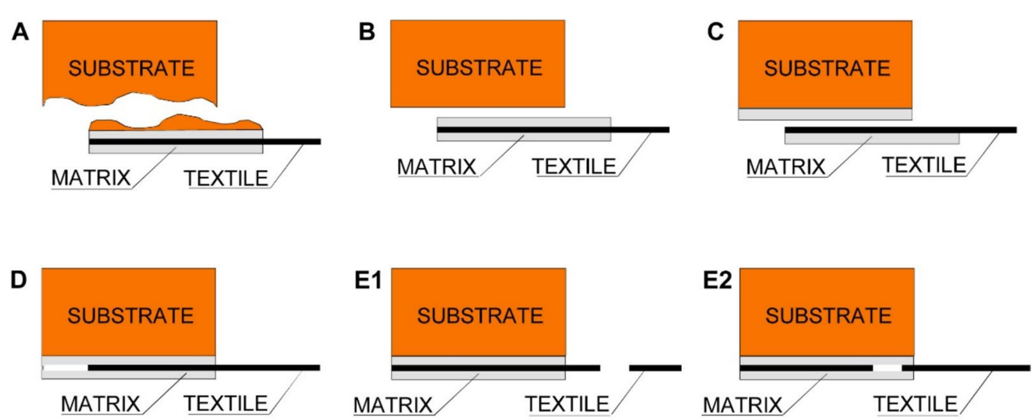


Fig. 12 Classification of failure modes in shear bond tests. Reprinted from De Santis et al., (2017)

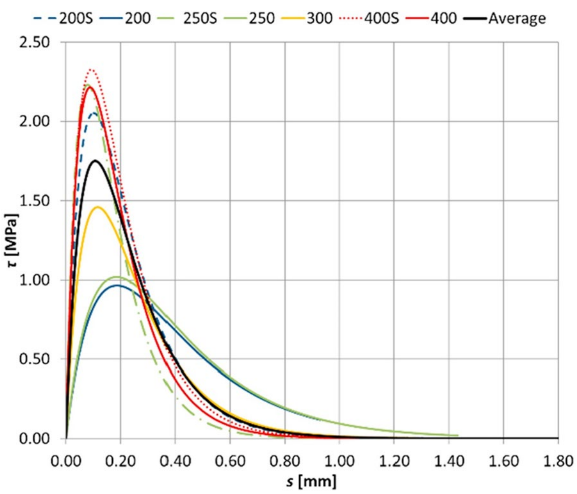


Fig. 13 Cohesive interface bond-slip law. Reprinted from Bencardino et al., (2017)

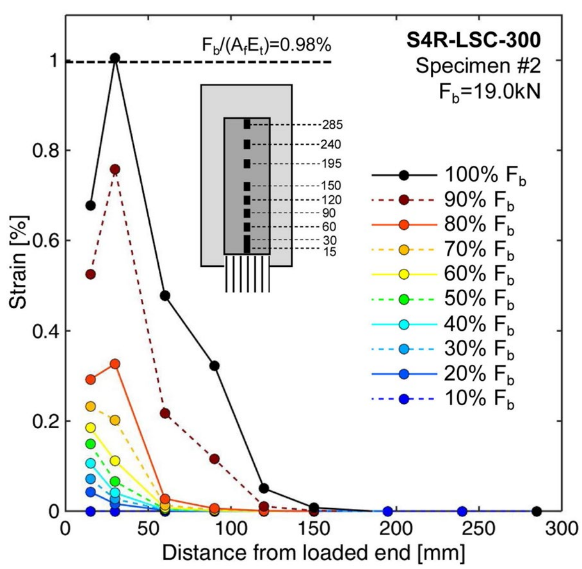


Fig. 14 Strain profiles (from resistive strain gauge measurements) along the bonded area. Reprinted from Napoli et al., (2016)

4.1 Out-Of-Plane Behaviour

The out-of-plane behaviour of masonry-infilled RC frames is typically studied through force–displacement response curves obtained from OOP performance tests, where the infill wall is pushed out of the RC frame. Recent tests on masonry-infilled RC frames retrofitted with FRCM systems are grouped in several studies, including Akhoundi et al., (2021); De Risi et al., (2020); De Risi et al., (2022); Furtado et al., (2021); Ismail et al., (2020); Koutas et al., (2015); Koutas and Bournas, (2019); Minotto et al., (2020); Sagar et al., (2019); Verderame et al., (2019).

To conduct OOP performance testing on masonry-infilled RC frames, the RC members are fixed with stiff steel frames, and a fluctuating incremental load is applied horizontally to the masonry wall until the surrounding interfaces of masonry debond from the concrete or the wall collapses. The common test setup is shown in Fig. 20, developed by Koutas and Bournas, (2019).

Apart from the commonly known FRCM system used to enhance the flexural strength of masonry, De Risi et al., (2020) attempted to use connectors to improve the connection between masonry and the concrete frame, as illustrated in Fig. 21. This local reinforcement method compensates for the insufficient bond strength between the FRCM and the masonry, preventing premature collapse due to debonding around the masonry and RC frame. Therefore, the OOP strengthening system for masonry infills should focus on the FRCM-to-frame connection system.

Koutas and Bournas, (2019) also performed integral retrofitting of masonry-infilled RC frames using FRCM sheathing overlays. The OOP force–displacement response curves of the wall at the centre are grouped in Fig. 22. By reinforcing the masonry and the frame horizontally with an outer layer of FRCM, the connection between them is strengthened, and the concrete members are partially reinforced into TRC, improving the overall seismic performance of the structure long-term.

Finally, Furtado et al., (2022) categorized existing techniques to combine seismic efficiency with environmental benefits of mitigating damage and/or demolition caused by earthquakes. The results are presented in a graph with two tables, as shown in Fig. 23. It is evident that external thermal insulation reinforcement measures cannot be entirely replaced. The composite system of FRCM, which combines textile-reinforced mortar and external thermal insulation, exhibits greater compatibility. A multidisciplinary approach has been adopted to enhance building performance, with equal emphasis on seismic and energy efficiencies, as demonstrated by Triantafillou et al., (2017). The system combines FRCM overlayers with traditional XPS sheets, tested on brick masonry wallettes under OOP cyclic bending. Some wallettes underwent fire testing before mechanical testing to evaluate the effectiveness of the new system under realistic fire conditions.

4.2 In-Plane Behaviour

The in-plane behaviour of masonry-infilled RC frames is generally investigated through pull–push reciprocating cyclic loading on concrete frames by actuators, primarily

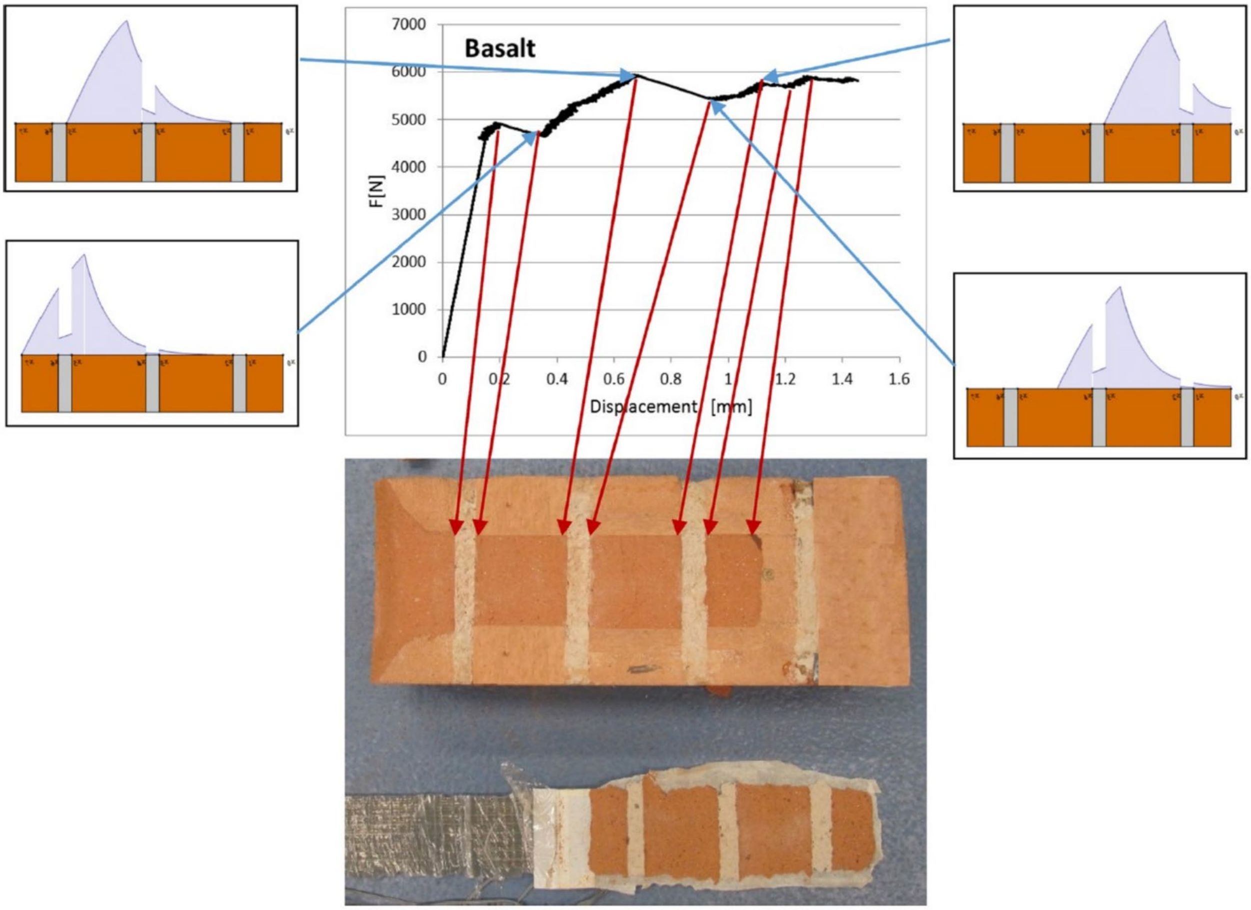


Fig. 15 Load–displacement response curve of one shear bond test of BFRP on masonry specimen. Reprinted from de Felice et al., (2015)

Fig. 16 Vertical compression test method of wallette. Reprinted from Minotto et al., (2020)

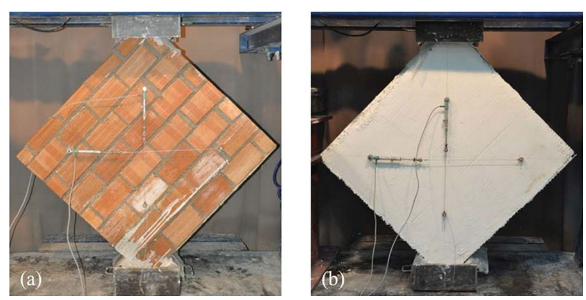


Fig. 17 Diagonal compression test method of wallette. Reprinted from Gkournelos et al., (2020)

expressed as a force–displacement hysteresis curve obtained by the IP performance test.

For IP performance testing of masonry-infilled RC frames, the frame must remain untwisted along the horizontal direction, allowing the infill wall to bear loads until crushed without collapsing. Static or quasi-static loads are then applied axially to the concrete beam until the masonry is thoroughly damaged or the RC frame deforms to failure. The typical test setup is shown in Fig. 24, based on the research conducted by Ismail et al., (2018).

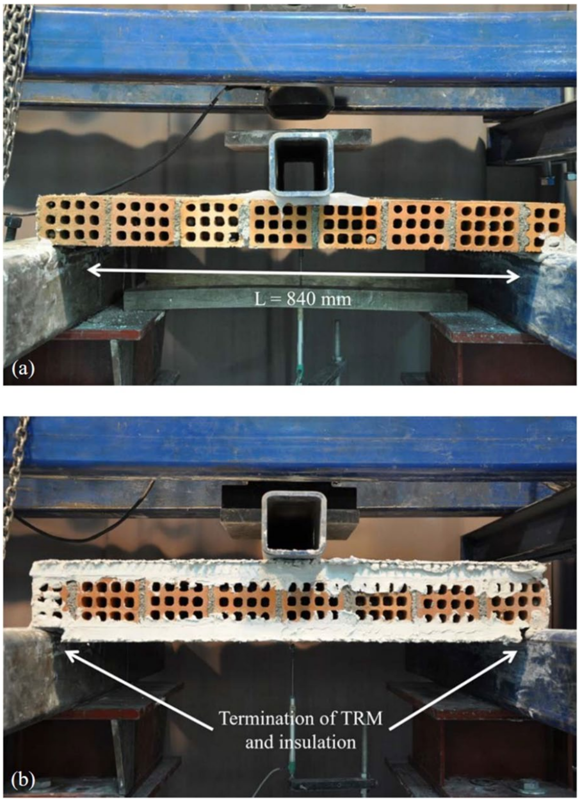


Fig. 18 Flexural bending test method of wallette. Reprinted from Gkournelos et al., (2020)

The infill wall is easily damaged by diagonal extrusion due to the deformation of the frame. The local retrofit method of FRCM composites on masonry-infilled RC frames involves targeted reinforcement in the diagonal bands. The force–displacement hysteresis curves tested by Ismail et al., (2018) are shown in Fig. 25. The study tested nine single-storey, one-bay test frames subjected to quasi-static cyclic in-plane loading while maintaining a constant axial load of 120 kN over each column. Three types of reinforcement fabrics were used to retrofit the test frames. The RC frame filled with masonry requires a larger load than the bare frame to deform to the same lateral displacement, while the specimen reinforced with FRCM displaces less under the same load. The hysteretic behaviour of the whole wall reinforcement method is superior to the local method, indicating that FRCM retrofitting techniques can be tailored to specific needs, with local and global methods offering different approaches to improving the structure's performance.

Additionally, Sagar et al., (2019) attempted to enhance the in-plane performance of masonry infill frames by fixing the fabric onto the RC frame at a 45-degree angle using mechanical anchors, assembled with bolts, nuts, and washers. The layout used in the study is shown in Fig. 26. The paper evaluated three parameters: fabric application mode, mechanical anchor presence, and fabric orientation. The direct application produced better results than the sandwich application due to its higher bond strength and ability to reinforce the masonry wall rather than merely reinforcing the mortar coating.

Finally, the seismic behaviour of an RC frame can be evaluated based on three important factors: ductility, stiffness, and energy dissipation capacity. A damping coefficient for analysing the force–displacement hysteresis curve is detailed by Su et al., (2017) in Fig. 27.

In summary, developing an FRCM system combined with PCMs and XPS plates aims to achieve adequate physical, mechanical, and thermal properties for reinforced concrete and masonry buildings. Based on a

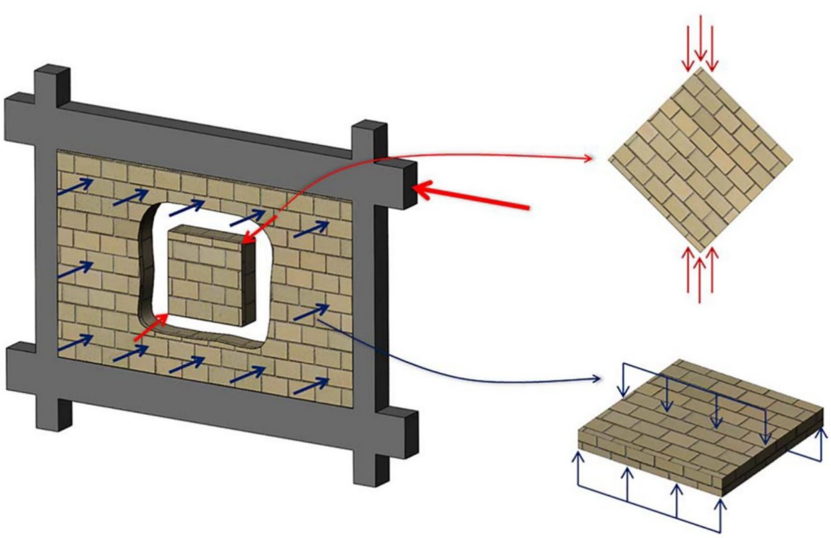


Fig. 19 Experimental representation of a masonry infill behaviour. Reprinted from Gkournelos et al., (2020)

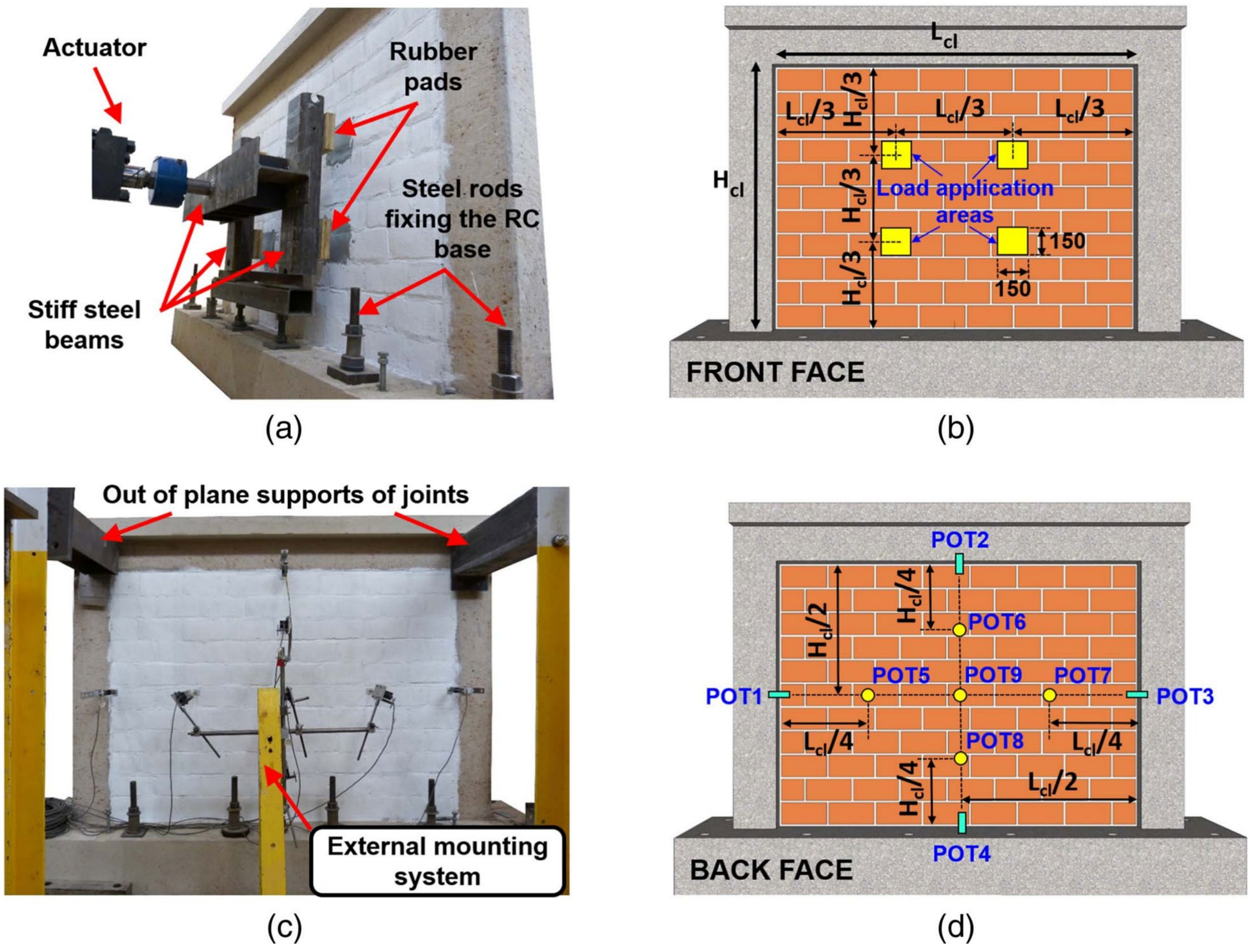


Fig. 20 Test method for out-of-plane behaviour. Reprinted from Koutas and Bournas, (2019)

comparison of the three retrofitting methods, the FRCM sheathing overlay, used as a global method, appears to be the better choice for retrofitting masonry-infilled RC frames. This method can improve both out-of-plane and in-plane performance with a single setting, addressing the needs of both the RC members and the infill wall simultaneously. Therefore, experimental research was carried out by Wang, (2023) focused on evaluating this new system comprehensively by calculating hysteresis curves, comparing lateral stiffness, ductility, and energy dissipation capacity, measuring specimen deformations, and analysing failure modes mechanically.

Additionally, shake table testing has gained more attention in the field of structural seismic research because it can simultaneously study the in-plane and out-of-plane behaviours of a single-storey RC frame in one test setup, as shown in Fig. 28 from Sagar et al., (2019). It can also be used for 3D buildings, as demonstrated by Maddaloni et al., (2018). The load form that the shaking table simulates is more accurate to the real situation, especially when the structural frame absorbs the out-of-plane loading. As the structure shakes excessively, the infill masonry is loaded in-plane due to the lateral deformation of the RC frame, and the displacement range amplitude increases from bottom to top.

Seismic energy is transmitted in waves from the mantle and surface of the earth, causing mechanical vibrations from the bottom to the top of buildings. However,

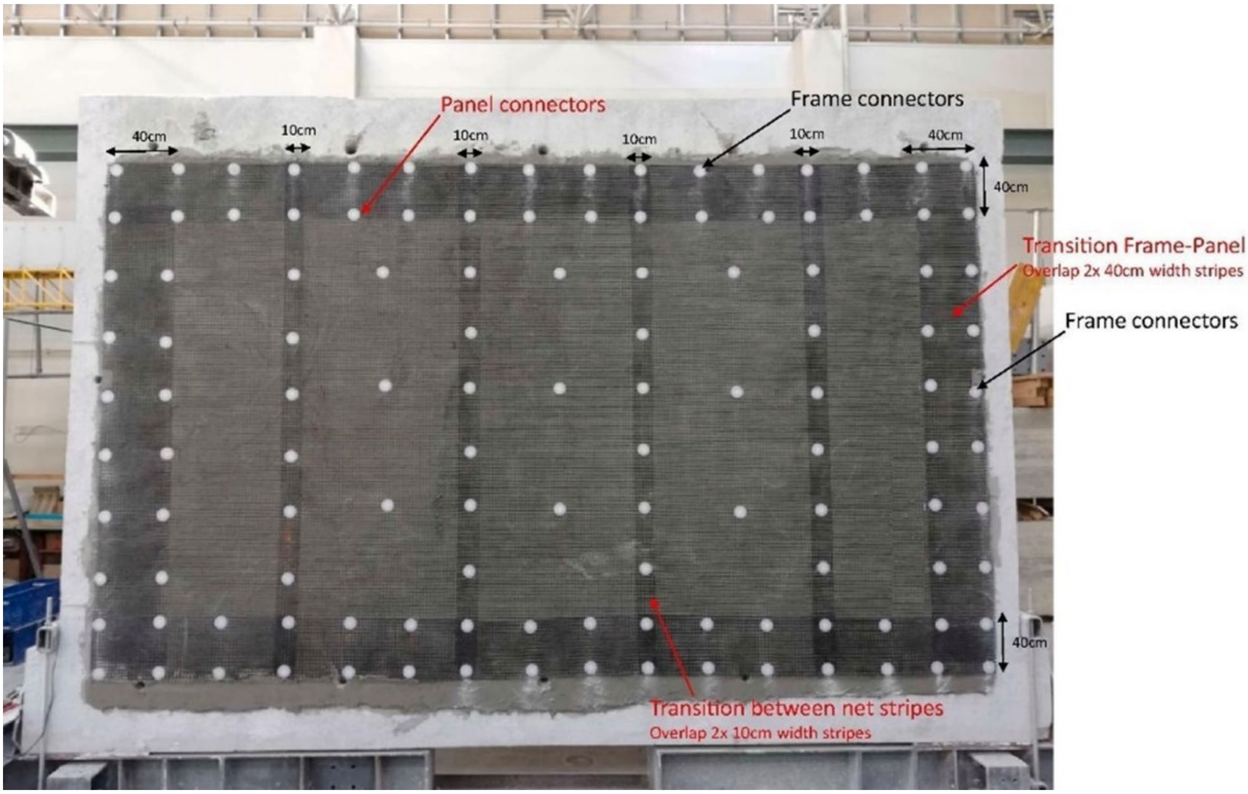


Fig. 21 Schematic layout strengthening by the plastic connectors. Reprinted from De Risi et al., (2020)

hydraulic actuators apply load to the frame beams to transfer the lateral displacement from the frame node to the base. Therefore, if the cost of the experimental equipment is not considered, the 8-direction 6-degree of freedom shaking table is indeed the most advanced experimental method for structural seismic research. This sophisticated equipment allows for a comprehensive simulation of seismic activity, providing valuable data on the complex interactions and failure mechanisms within the structure under realistic earthquake conditions.

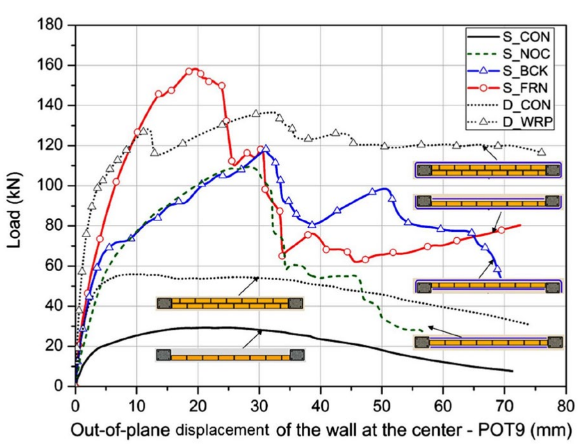
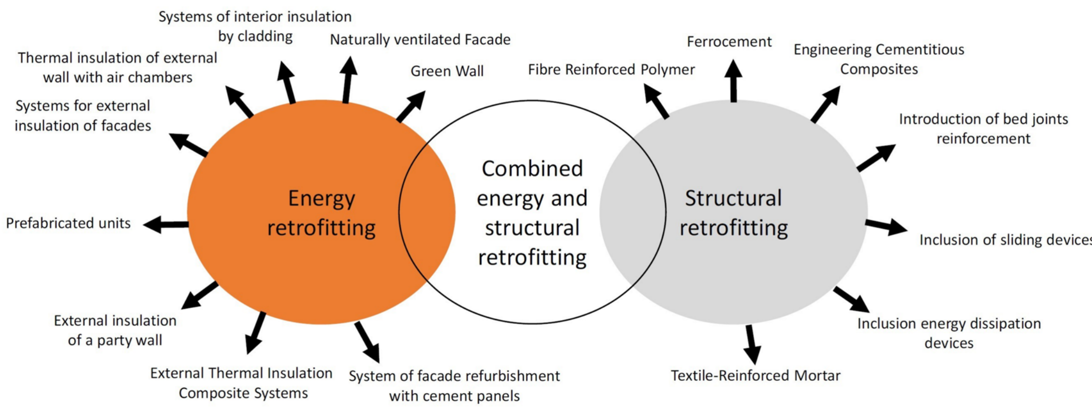


Fig. 22 Out-of-plane force–displacement response curves. Reprinted from Koutas and Bournas, (2019)

5 Conclusions

Recent years have seen significant advancements and widespread applications of Fabric-Reinforced Cementitious Matrix (FRCM) technology in reinforcing existing buildings. Originating in the Americas and gaining traction among European scholars over the past decade, this technology is now attracting attention from researchers worldwide, including in Asia, Africa, Oceania, and beyond. There is a unanimous consensus among scholars that FRCM presents a viable alternative to FRP materials.

The benefits of FRCM technology are diverse. These include the conservation of fibre materials and the enhancement of bonding between the fabric mesh and the cementitious matrix. The grid structure of the fabric facilitates better integration with the cement matrix, while the use of multiple fabric layers improves the overall stiffness of the FRCM system.



Retrofitting Technique	Retrofitting of Existing Buildings or New Buildings	Cost of Implementation	Return Period	Compatibility with Energy Retrofitting
Fiber-reinforced polymers	Both	●●●●	●●●	●●●
Engineering cementitious composites	Both	●●●●	●●●	●●●
Inclusion of sliding devices	New buildings	●●●●●	●●●●	●
Inclusion energy dissipation devices	New buildings	●●●●●	●●●●	●
Textile-reinforced mortars	Both	●●	●●●	●●●●●

●—very low; ●●—low; ●●●—medium; ●●●●—high;●●●●●—very high.

Retrofitting Technique	Retrofitting of Existing Buildings or New Buildings	Cost of Implementation	Return Period	Compatibility with Structural Retrofitting
External thermal insulation composite systems	Both	●●●	●●●	●●●●●
External insulation of party wall	Both	●●	●●●	●●●
Prefabricated units for external wall insulation	New buildings	●●●	●●●	●
Cement panels for façade refurbishment	Both	●●●●	●●●●	●
Internal thermal insulation	Both	●●●	●●●	●●●●●
Thermal insulation of external walls by injecting insulation material	Existing buildings	●	●●●●	●
Naturally ventilated façades	New buildings	●●●	●●●●	●
Green walls	New buildings	●●	●●●●	●

●—very low; ●●—low; ●●●—medium; ●●●●—high; ●●●●●—very high.

Fig. 23 Summary of techniques available for energy and structural retrofitting of masonry infill walls. Reprinted from Furtado et al., (2022)

Furthermore, continuous advancements in experimental methods and equipment aim to enhance the effectiveness and accuracy of tests. Researchers worldwide have refined specimen preparation techniques, improved loading and measurement devices, and developed more stable testing platforms. These improvements aim to enhance the validity of experiments and the precision of results.

By integrating existing theoretical frameworks with structural testing data, this paper has outlined mainstream experimental research methods and synthesized

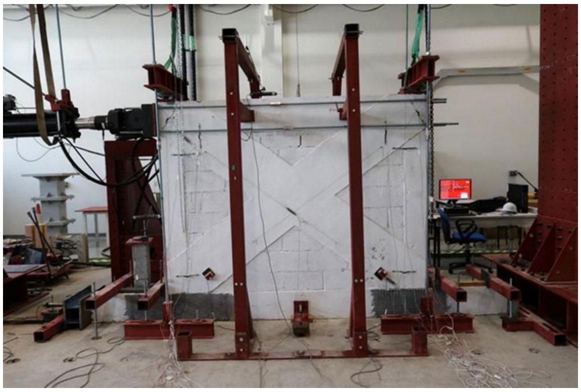


Fig. 24 Test method for in-plane behaviour. Reprinted from Ismail et al., (2018)

them into a comprehensive theoretical framework for studying the seismic performance of masonry-infilled RC frames strengthened with FRCM. This framework serves as a valuable reference for related research endeavours, providing a systematic groundwork for further exploration of the potential and efficacy of FRCM technology in structural reinforcement, as illustrated in Fig. 29.

This theoretical framework offers a structured approach to investigating the seismic performance of masonry-infilled RC frames, laying the groundwork for future research to expand upon and refine our understanding of FRCM technology's role in structural reinforcement.

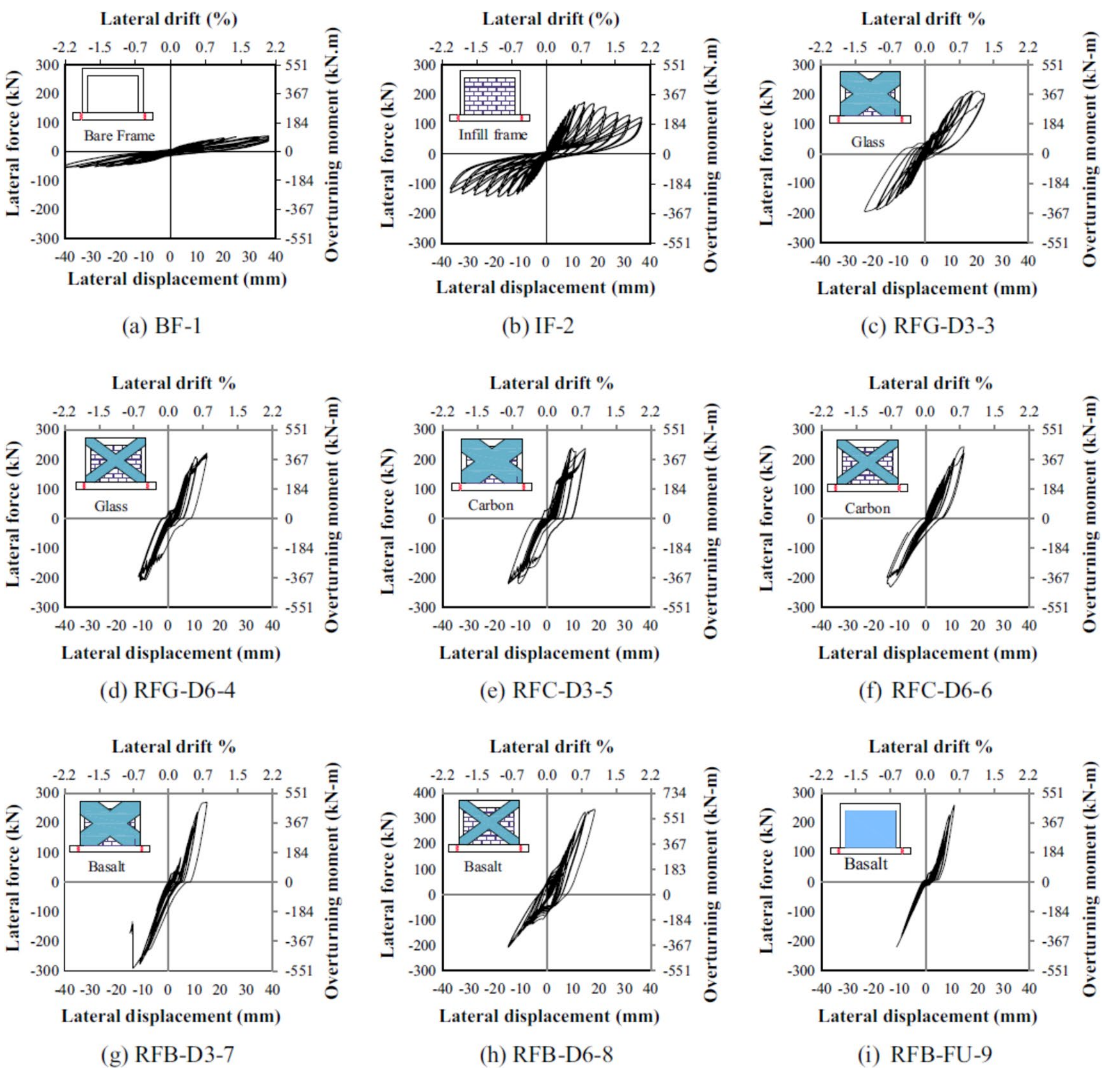


Fig. 25 In-plane force–displacement hysteresis curves. Reprinted from Ismail et al., (2018)

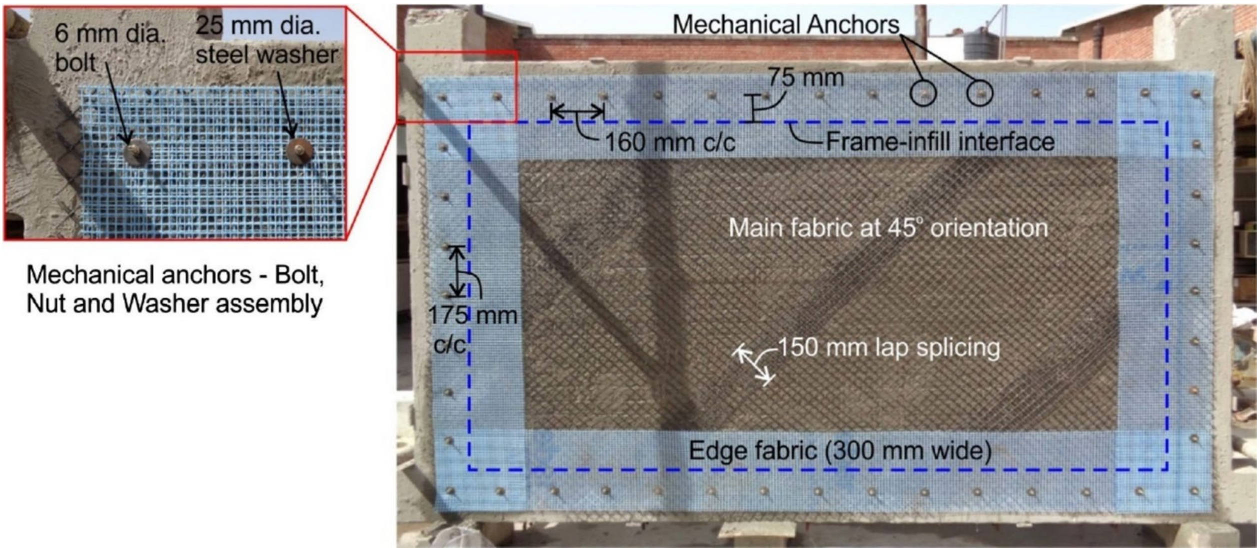


Fig. 26 Schematic layout strengthening by the mechanical anchors. Reprinted from Sagar et al., (2019)

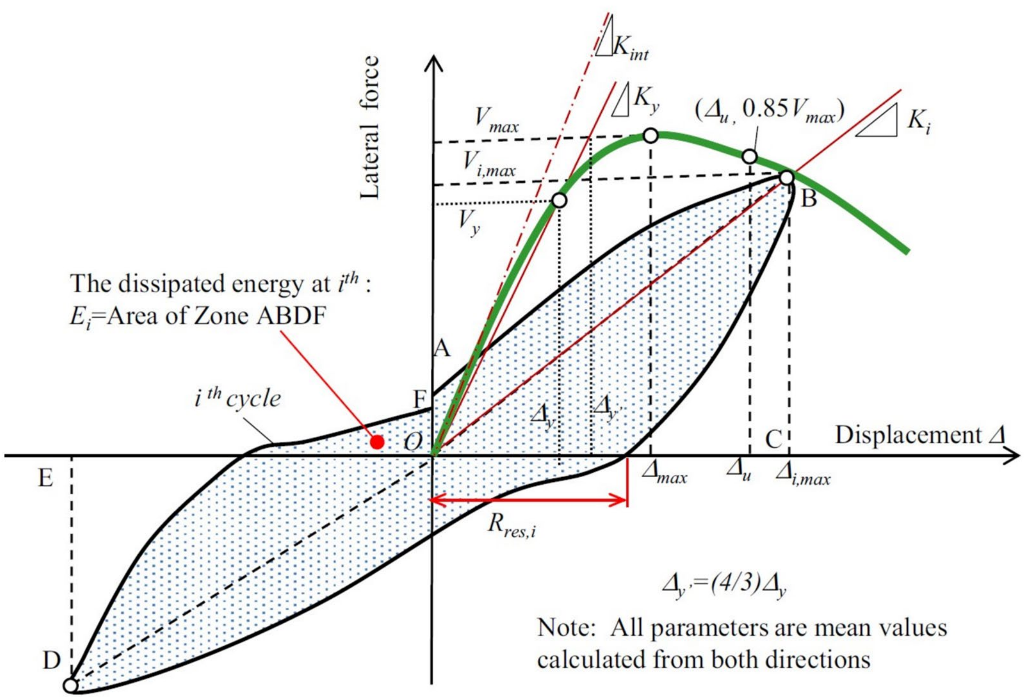


Fig. 27 Definition of equivalent viscous damping coefficient. Reprinted from Su et al., (2017)

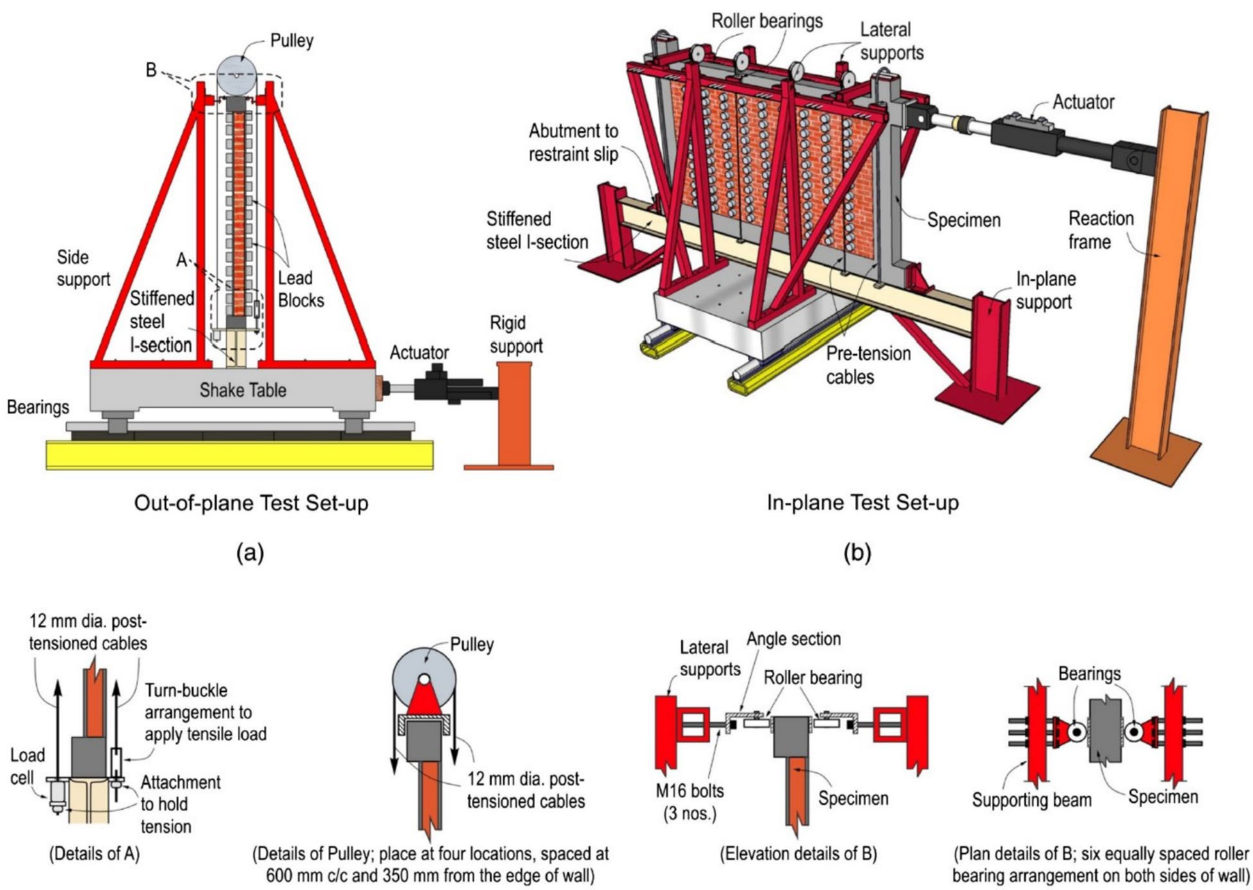


Fig. 28 Shake table test setup for OOP and IP performance. Reprinted from Sagar et al., (2019)

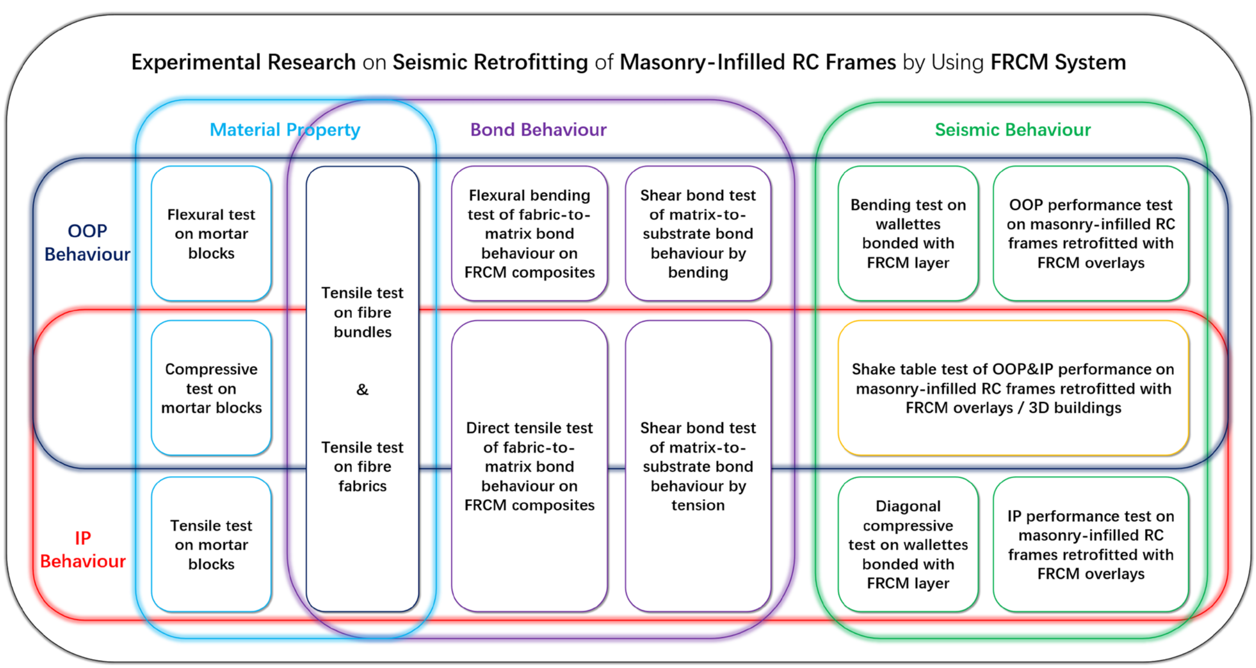


Fig. 29 Theoretical framework for experimental research on seismic performance of masonry-infilled RC frames

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40069-025-00797-x.

Supplementary material 1.

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Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The author declares that he has no competing interests. The content of this Review Article is derived from the author's PhD dissertation, and the copyright belongs to the author in accordance with the regulations of Cyprus University of Technology.

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