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Review

Review of Methods for Seismic Strengthening of Masonry Piers and Walls

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Abstract: The seismic strengthening of buildings in earthquake-prone areas has been a hot topic in recent years, especially for masonry structures. Because there are so many masonry structures and because most were built before seismic codes existed, their seismic vulnerability is an unavoidable issue. Over the years, several methods for seismic strengthening of masonry piers and walls have been developed that may roughly be classified as traditional or modern. In this paper, an overview of the most commonly used and effective methods will be presented with an emphasis on modern methods based on a Fabric-Reinforced Cementitious Matrix. The advantages and disadvantages will be discussed from the point of view of usability, feasibility, and effectiveness. Finally, a comparison will be drawn between traditional and new methods based on composite materials.

Keywords: seismic strengthening; unreinforced masonry structures; composite materials; new methods; FRCM; sustainable materials; earthquakes

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Citation: Hafner, I.; Kišiček, T.; Gams, M. Review of Methods for Seismic Strengthening of Masonry Piers and Walls. *Buildings* **2023**, *13*, 1524. https://doi.org/10.3390/buildings13061524

Academic Editor: Bartolomeo Pantò

Received: 19 May 2023
Revised: 9 June 2023
Accepted: 12 June 2023
Published: 13 June 2023

1. Introduction

As a building material, masonry is one of the most commonly used materials in the world. In [1], an estimation is given that 70% of the world's building stock is masonry buildings built with different types of material (bricks, blocks, stones). The popularity stems from the fact that masonry is cheap, easily available material and simple to build with. Masonry is also fire resistant and exceptionally durable. Due to the mass of masonry structures, they have inherently good resistance to wind. On the other hand, masonry structure are vulnerable to earthquakes [2] due to their mass, lack of tensile strength and brittleness. Although earthquakes are not a major problem in every part of the world, it is well-known that earthquakes can be devastating for masonry structures, which represents a danger to human lives and the economy.

Because most of existing masonry structures were built before seismic codes even existed, and because many have cultural and historical value, the assessment and retrofitting methods for masonry structures must be carried out with care and due diligence. The phase of assessment and obtaining material characteristics is especially important, as is explained in detail in Valuzzi's paper on the topic [3]. This publication also analyzes the possibilities and limitations of the assessment procedures in light of rigorous criteria of the preservation and restoration by governmental bodies, which often allow only non-destructive, and semi-destructive methods in historical masonry structures.

The most commonly used non-destructive methods are the rebound hammer for masonry and mortar, ultrasonic pulse velocity test for masonry homogeneity and variability, impact hammer with an accelerometer, ground penetrating radar, thermography cameras, flat jacks and many more, as described in detail by Stepinac et al. in [4]. The importance of post-earthquake visual assessment and non-destructive and semi-destructive techniques in the assessment process are also highlighted in publications [5,6]. An adequate number of assessment procedures, high overall quality of the entire assessment process and precise numerical modelling are the foundation for the entire retrofitting process.

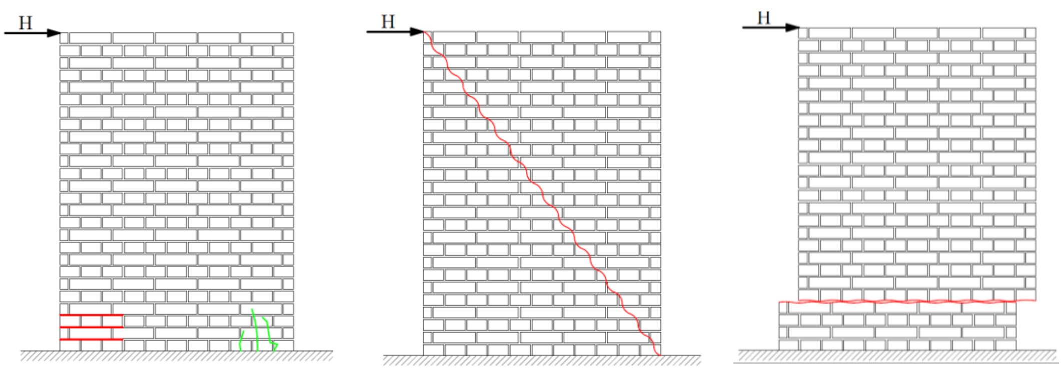
Once the structure (and the masonry material) has been thoroughly inspected, a strengthening strategy is chosen. The first step is always to ensure proper tying of structural elements so that the structure can maintain its integrity during an earthquake and respond to seismic loads with a box-like behavior [7]. Tying consists of connecting walls and floors, perpendicular walls, and, in case of weak wooden floors, also of stiffening floor structures. In a structure where structural elements are not connected, each responds to seismic load on its own, and the collapse of the structures occurs when the weakest element fails. In the case of box-like behavior, on the other hand, seismic loads are distributed among all of the elements. The crucial aspect here is that in-plane loaded walls provide virtually all of the resistance.

Even properly tied structures can fail under seismic loads if the masonry is not strong enough. In such cases, the masonry needs to be strengthened. Many methods for strengthening masonry exist, and some of them are presented in this paper.

2. In-Plane Behavior of Unreinforced Masonry Piers and Walls

In this research, only the in-plane behavior and strengthening of unreinforced masonry piers and walls [8] will be examined as they are the most important parts of the structure for resisting lateral loads. Unreinforced masonry walls/piers exhibit three typical in-plane failure modes (Figure 1) [9]:

1. Flexural failure (toe crushing or rocking): failure due to exceeding the compressive strength (vertical cracks—Figure 1a–green lines) at the compressed part of the cross-section. The failure is normally accompanied by the opening of a crack at the tensile side (horizontal cracks—Figure 1a–red lines). The failure mode is typical for slender walls with high compressive stress. In case compressive stress is low, a crack opens on the tensile side, but there is no crushing on the compressed side. Such a response is called rocking.
2. Diagonal shear failure: failure related to the exceeding of the tensile strength of masonry along the principal tensile direction and characterized by diagonal cracks through units or through the mortar joints [9] (Figure 1b). This is the most common failure mode.
3. Sliding shear failure: in case of low compressive stress and high horizontal force, failure can occur along a horizontal mortar joint (Figure 1c). This mechanism is rare and can be mischaracterized because it produces the same damage pattern as rocking.



(**a**) (**b**) (**c**)

Figure 1. In-plane failure modes of unreinforced masonry walls/piers—(**a**) flexural failure. (**b**) Diagonal shear failure—straight or stair-step pattern. (**c**) Sliding shear failure.

The most important parameters that affect the failure modes are the geometry of the walls, the level of compressive stress and the compressive and tensile strength of the masonry units [10]. Some research suggests that the type and dimensions of masonry units also significantly affect the failure mode and the crack pattern. Masonry from units with high strength tends to fail in shear, whereas masonry from weak units tends to fail in flexure [11].

3. Traditional Methods for Seismic Strengthening of Masonry Walls

3.1. Tying to Provide Stuctural Integrity

The most crucial and first step for improving the seismic response of existing masonry structures is the tying of masonry walls and floors, which provides structural integrity and box-like behavior [7]. The tying is usually done by adding steel or reinforced concrete ties at the floor level. Vertical tying elements may be added as well, but this is rarely used because the corners of the masonry walls are their strongest part. Experimental investigation and the review of theoretical approaches have shown that tying resulted in an increased compressive strength and, more importantly, in-plane shear strength of masonry walls [12]. In [13], masonry walls with proper ties were subjected to cyclic testing, which showed stiffness increase by 10 do 26% depending on the connection detailing between the masonry wall and the concrete elements. Secondly, the lateral load bearing capacity of the wall was increased by 70 to 90% and finally, the ductility was increased by 78 to 88%. This research also showed that the detailing of the connections between the masonry and concrete elements did not have a significant impact on the results.

The main drawbacks of tying are difficulties related to construction and the requirement of skilled labor. Additionally, poor design, detailing and construction is sometimes observed [14]. Finally, the method may not be applicable to historic masonry structures because of its invasiveness [15]. Even a properly tied masonry structure may be vulnerable to earthquakes because masonry as a material is not strong enough. In those cases, the masonry needs to be strengthened, as is described in the following sections.

3.2. Concrete Jacketing (Shotcrete)

Concrete jacketing or shotcrete is one of the most commonly used methods for seismic strengthening of existing masonry structures. The idea is to place steel meshes on the wall's surface and apply concrete under high pressure. The coating needs to be properly connected to the wall, which is usually achieved by anchoring. Proper anchoring of the mesh to the foundations must also be achieved. The method can be applied from one or two sides of the wall. It is desirable to apply the method on both sides of the wall to achieve a symmetrical cross-section, a more ductile response and larger energy dissipation [16]. The strengthening method and the connection details are shown in Figure 2. Figure 2a shows a typical foundation of concrete jackets with a proper connection to the masonry wall using anchors. Figure 2b shows the connection between the single-sided concrete jacket and the masonry wall by anchors. There is a possibility of achieving a connection between the concrete jacket and the masonry via anchoring pockets, as shown in Figure 2c.

The advantages of jacketing are the increased load-bearing capacity, displacement capacity, ductility, and energy dissipation. Unfortunately, concrete jacketing adds mass and stiffness to the structure, which increases the seismic demand (forces). Additionally, the global behavior of the structure is altered, which may cause torsional effects of the entire building and changes in the redistribution of stiffness [17]. From a durability standpoint, the probable oxidation and corrosion of the steel meshes may reduce durability. Additionally, this method is quite expensive and labor-intensive. Finally, the dirtiness, the altered façade and a reduction of inner spaces make this method undesirable from the residents point of view [16,18,19].

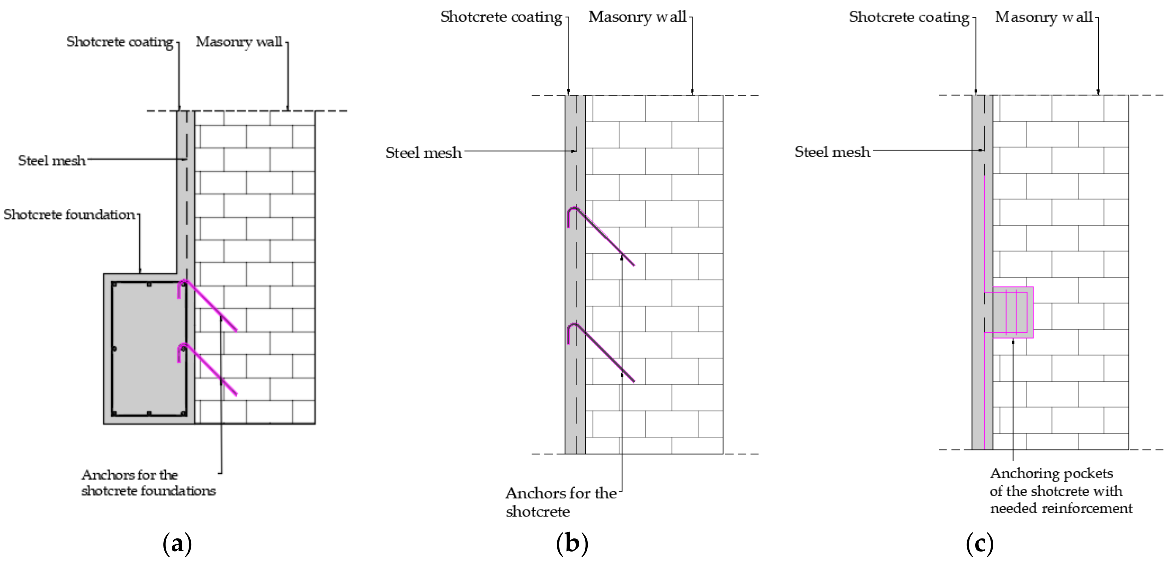


Figure 2. Details for single-sided concrete jacketing—(**a**) foundation detail. (**b**) Anchors for concrete jacketing. (**c**) Anchoring pockets for concrete jacketing.

An alternative to concrete jacketing is the use of cement-based mortar instead of concrete, which is applied as the plaster of the masonry walls [20]. The mortar is applied in a much smaller thickness than the concrete, so the additional mass to the masonry structure is smaller. Additionally, this way, the problems regarding the dirtiness of the concrete jacketing method are alleviated. Finally, it is important to underline that this method requires the application of a steel mesh on both sides of the wall and that the meshes need to be connected through the wall's cross-section and that the corrosion problem remains.

3.3. Other Traditional Strengthening Methods—Short Overview

Mortar replacement (repointing) is a common traditional method of strengthening in which the old, damaged mortar is removed to a certain depth in the joints. After that, a new, stronger mortar with better mechanical properties and durability is installed. It must be noted that this method can only be used when damage appears only in the mortar joints. On the other hand, when bricks are damaged after an earthquake in one section of the masonry wall, the local removal and reconstruction of bricks is a possibility. The damaged bricks and mortar are removed, and new brick elements and mortar are used. The main goal is to achieve compatibility between the old and new sections of the wall. For this purpose, a mortar with similar mechanical, chemical and physical characteristics must be used or the mortar must be applied in thin layers [21].

In the case of stone masonry walls, grout injections are a widely used method of strengthening. The method is effective if there are enough voids in the walls. A grout injection is injected into the wall under pressure, and when it hardens, it connects the leaves of walls into a homogenous element, which behaves much better under seismic loads.

Although numerous other traditional methods exist, modern and more sustainable methods seismic strengthening of masonry structures are mostly used today [22].

4. New Methods for Seismic Strengthening of Masonry Walls/Piers

The main difference between traditional and modern methods is in the materials used. Modern methods are based on the use of composite fiber-reinforced polymer (FRP) materials, which are lightweight, strong, and can be applied to the wall more quickly, easily, and cleanly.

FRPs consist of fibers embedded in a polymeric resin matrix [23]. Resin is a bonding agent that also protects the fibers from the elements. The main distinction between different types of FRP is the material of the fibers. The most common types are Aramid Fiber

Reinforced Polymer (AFRP), Carbon Fiber Reinforced Polymer (CFRP), and Glass Fiber Reinforced Polymer (GFRP) [24–27]. Different forms and shapes of FRP products exist such as bars, strips that come in the form of fabrics, strips that come in the form of laminates and fabrics in mesh configurations (Figure 3) [22]. Regardless of the type of fibers and form, it is crucial to ensure proper anchorage to the wall and into the foundation. From FRPs, an additional method was developed called Fabric-Reinforced Cementitious Matrix (FRCM). In these systems, the typical epoxy resin was replaced by a mortar matrix. In FRCM systems, the only form of reinforcement is a mesh which should also be anchored to the wall and into the foundation. This method has been extensively researched in recent years [28].

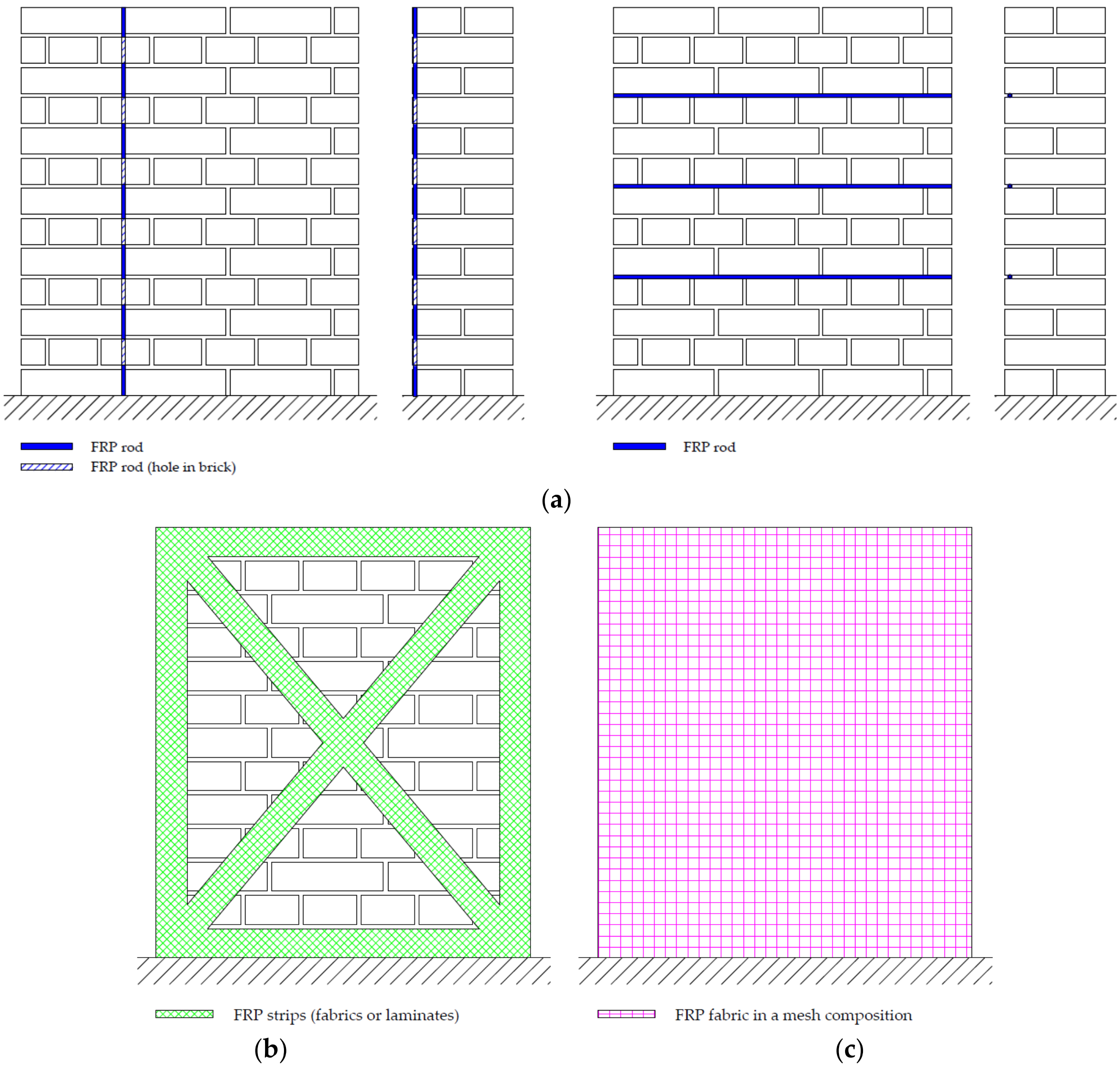


Figure 3. Shapes of FRP reinforcement—(**a**) FRP rods placed in vertical and horizontal directions. (**b**) Typical layout of FRP strips. (**c**) Typical mesh layout of the FRP fabric (entire wall surface).

4.1. Fiber-Reinforced Polymers (FRPs)

In masonry structures, especially those with historical and cultural value, the use of FRP products is preferred since it does not take a lot of time and work because of the low weight of the product and it does not affect the aesthetics of the building [25]. Additionally, the method is cleaner, simpler and has better corrosion resistance than traditional methods [29]. The cost of FRP materials has been steadily decreasing and it is financially very competitive compared to other materials.

The earliest methods based on the use of composite materials were different attempts at applying FRPs to the masonry by epoxy resin glues. Main advantages of FRP are corrosion resistance, light weight, and high tensile strength which are all very important when talking about seismic reinforcement. Excellent corrosion resistance is more of an advantage when used in reinforced concrete structures in aggressive environments, but can also help when applied in masonry structures. The light weight makes it easier to apply, which reduces labor costs. Other favorable characteristics are a significant strength to weight ratio, increase in shea load capacity, excellent behavior under dynamic loads, ability to assume various shapes and lengths, ease, and speed of application [30,31].

A number of disadvantages related to FRP use have been reported throughout the years. The FRP systems are usually applied in a wet lay-up manner. The application of FRPs on moist surfaces or at lower temperatures is quite difficult [32], and epoxy materials change once above the glass transition temperature. Another problem is the lack of permeability of the epoxy matrix in FRP systems, which prevents their use in existing masonry structures. Mechanically, the drawback of FRPs is the possibility of an early debonding from a weak substrate. Durability issues of the method were raised in a number of research papers. In [33], the effect of hygrothermal conditions on the durability of brick masonry strengthened with FRP was examined. The accelerated ageing tests showed a degradation trend in the epoxy resin and GFRP. It was concluded that the cause of the degradation was related to moisture absorption. Similar conclusions were reached in [34], where the overview of experimental activities on durability of externally bonded FRPs was presented. The elements were subjected to water immersion and hygrothermal conditions. The experiments showed a loss in bond strength and a deterioration of mechanical properties.

4.2. Fabric-Reinforced Cementitious Matrix (FRCM)

4.2.1. Introduction and Application Procedure

Due to the listed shortcomings of FRPs, the organic matrix (epoxy) was replaced by an inorganic one (cementitious or lime mortar). The modified system is called the Fabric-Reinforced Cementitious Matrix (FRCM). It is established that in moist and damp conditions and under high temperatures the inorganic matrix has significantly better properties than the epoxy resin [35]. Furthermore, the stiff epoxy was too mechanically incompatible with the deformable masonry, and mortars are much more compatible. In contrast to FRPs, the FRCMs are usually applied to the entire wall surface and reinforced by meshes (grids). The interaction between the FRCM coating and the masonry substrate is essential and requires dedicated mechanical anchoring (usually 4–6 per m^2) in case of earthquake loads.

The application procedure for FRCMs is very simple. The first step is to clean the wall of plaster and remove mortar from the joints to a depth of a few centimeters. After this, the holes for the connectors are drilled in the wall. Then, a layer of mortar, usually 7–10 mm thick, is applied. After that, the dry mesh is pressed against the matrix layer that acts as a bonding element between the mesh and the masonry. In the next phase, mechanical connectors should be installed. The main reason for the use of such connectors/anchors is to achieve the best possible connection of the FRCM system to the wall. The importance of connectors will be discussed later on. In the final phase, another layer of mortar, which is also 7–10 mm thick, is applied. This layer encases the grid and provides protection from the environment. The composition may be seen in Figure 4.

4.2.2. Basic Response Mechanism of FRCMs

Since fibers with good tensile properties are embedded in the mortar matrix with poor tensile properties, the mortar cracks first, which activates the fibers [36]. The fibers carry tensile forces long after the initial cracking. This can be observed in uniaxial tensile tests conducted on prismatic (coupon) samples. By dividing the tensile force by the cross-sectional area of the fabric, the stress–strain curves of the FRCM are obtained [36], which can be idealized by a trilinear curve [36,37].

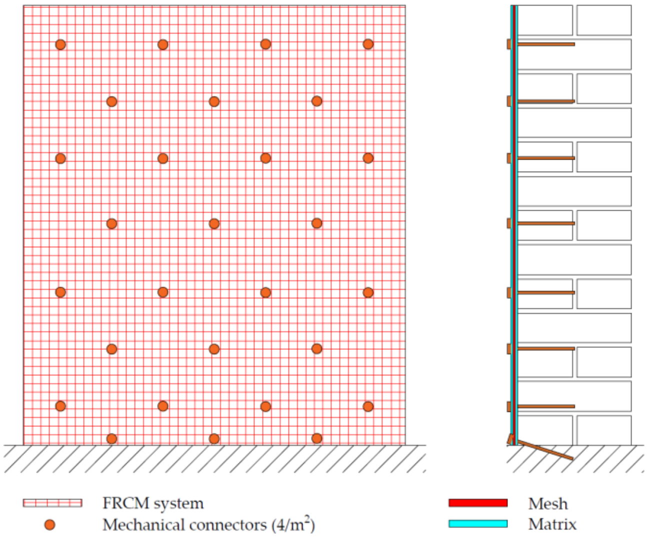


Figure 4. The layout of the single-sided FRCM system with the arrangement of mechanical connectors (front cross-section and side view).

The parts of the trilinear curves represent the physical states of FRCM (Figure 5):

1. The initial elastic phase (Part 1)—A linear curve that represents the uncracked state of the samples where the FRCM system behaves as a composite material. The stiffness is determined by the matrix (mortar) properties.
2. The crack development phase (Part 2)—Initial cracks (transverse, normal to loading direction) appear in the matrix. Due to the presence of fibers, usually, many cracks can be observed along the length of the specimen. Crack development is accompanied by a significant decline in stiffness.
3. The crack widening phase (Part 3)—With the widening of existing cracks in the matrix, the fibers carry the entirety of the tensile load. This can be observed by the slope of the final phase that reflects the Young's modulus of the dry fabric.

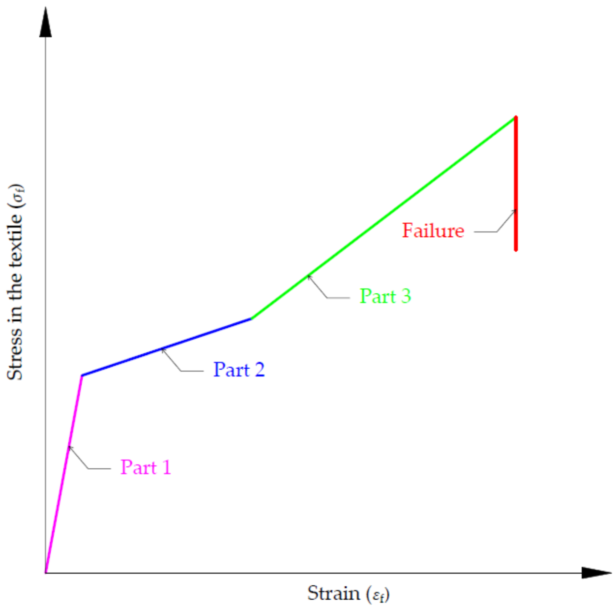


Figure 5. Stress–strain curves of the FRCM composite under tensile loading.

In the final part of the stress–strain curve, the crack propagation increases rapidly, resulting in the ultimate failure of the FRCM. There are six typical failure modes of FRCM [38]: debonding inside the masonry, debonding at the FRCM–masonry interface, debonding inside the coating, pure fiber slippage within the coating, fiber slippage with cracking of the substrate, and tensile fracture of the fibers.

4.2.3. Advantages of the FRCM System

In masonry, the FRCM strengthening system can be used for brick and stone masonry walls. In brick masonry walls, using the FRCMs as a single-sided or double-sided strengthening system is possible and results in a significant ductility enhancement [39]. For single-sided strengthening and double-sided strengthening, increases of 18 % and 29 % were observed, respectively. The same conclusions were drawn in [40], where the efficiency of the FRCM system was confirmed by conducting diagonal compression tests on brick masonry walls. In stone masonry walls as well, the use of FRCMs resulted in a significant increase in shear modulus (620 %) and shear strength (420 %) [41]. In [42], it was found that stone masonry confined by FRCMs generated more ductile failures with an increase in shear strength by 26 %. An increase in the failure load and shear stiffness of a stone masonry wall when using FRCM was also reported in [43]. Same results were observed when the FRCM system is applied in masonry structures and not just masonry walls and piers [44].

Besides the improvements that the FRCMs bring to the behavior of masonry walls, the use of FRCMs also helps in slowing down the deterioration of masonry walls in aggressive environments. In [45], a probabilistic model was formed that showed a lower degradation of masonry walls when the FRCM system was used. The effect of different environmental conditions on the FRCM composite was also observed in [46], where a number of single shear bond tests were conducted. The main purpose of this research was to examine the effect of the environment on the properties of materials used in the FRCM system and the effect it has on the bond behavior of matrix-to-substrate and fabric-to-matrix interfaces. In all tests and aging protocols used, no significant effects on the mechanical properties of the inorganic matrix were observed. Since the matrix is the most exposed part of the system, it is considered that the system has an adequate resistance to environmental exposure. A problem that may occur in FRCMs is water saturation, which can lead to salt crystallization patterns. In [47], it is concluded that when a cementitious mortar matrix is used, water saturation does not have an effect on the strengthening system.

4.2.4. Design Procedures and Analytical Modeling

The application of FRCM must be conducted at a very high level in design and construction, and a number of things must be considered in the design phase to achieve the intended increase in the shear capacity and ductility of masonry walls. The analytical part of the FRCM design process is very important, and the latest and most updated design guidelines are the CNR guidelines developed and published by the National Research Council in Italy after the 2000s earthquakes [48]. As is usually the case, the CNR guidelines are quite conservative. This was observed by comparisons between analytical and experimental results for shear strengthening of masonry walls with FRCM presented in [49]. In [50], a problem was observed regarding the conservative nature of CNR guidelines. It was found that the ductility capacity of masonry walls is not properly considered, which may lead to over reinforcing with FRCM, resulting in a brittle failure.

A new analytical approach was proposed in [51], which is based on an extensive experimental campaign dealing with the capacity of FRCM strengthened masonry panels. The strengthened masonry panels were tested in diagonal compression and a very important observation was made regarding the results. In the majority of the samples, the cracking of the mortar matrix corresponded to the shear capacity of the strengthened masonry panels. Seeing that the contribution of the mortar matrix is not considered in the CNR guidelines that are available today, a new analytical approach is proposed. Another proposition is given in [52] where a theoretical model is developed. The idea is to study and consider the tensile behavior of FRCMs based on the local behavior at the level of the mortar matrix, reinforcement, and reinforcement-to-matrix interface.

4.2.5. Failure Modes of the FRCM System

In practice, the behavior of the FRCM system is very complex. Several types of failure of the composite system applied on the masonry substrate are possible. According to [53], the tensile rupture of fibers is the most common type of failure. This conclusion is based on an extensive review of over five hundred samples from numerous experimental campaigns. In [54], similar results were obtained in an experimental campaign where the most common failure mode was the cracking of the mortar matrix, which is in direct correlation to the fiber rupture. Everything that was concluded in [53,54] was verified with an analytical-numerical approach based on 3D modelling and a Sequential Quadratic Programming routine in [55]. Finally, another extensive experimental campaign in which a series of diagonal tensile tests on masonry wallets strengthened with FRCM was conducted [56]. The main idea was to use different types of fibers to see which one has the best mechanical properties. In the end, the type of fibers had no effect on the results since the cracking of the mortar matrix appeared beforehand. Another type of failure that may occur is the debonding of the FRCM system. In this case, numerous problems may occur. In [57], a model is developed to predict the FRCM debonding. It was found that the strength of the mortar matrix had no impact on the results and the debonding failure of the entire FRCM system. It is very important to know that the debonding mechanism can also appear between the reinforcement and the mortar matrix of the system [58]. By comparing the analytical approach based on the bond-slip law and the experimental campaign, it is evident that the friction stresses have a great impact on the bond behavior between the FRCM system and the masonry substrate and between the individual parts of the strengthening system [59]. On the other hand, it was found that under the influence of load cycles, the behavior of the bond between composites was unaffected [60]. Unfortunately, this study was conducted on small samples and verification on larger samples is needed. In [61], an experimental campaign involving strengthened single masonry piers was conducted. In the analysis of the results, it was concluded that by preventing or minimizing the delamination of the FRCM coating, the shear resistance and displacement capacity of unreinforced masonry structures is drastically improved.

4.2.6. Implementation of Anchors/Connectors

As is concluded in the previous chapter, the delamination or debonding are the main issues when using the FRCM system. The main tool for fixing the debonding/delamination problem are different types of anchors/connectors to the masonry substrate and to the foundations. The effectiveness of these connectors is most noticeable in multi-leaf masonry walls [62]. The idea in [62] was to see the effect different types of connectors have on the failure mode under a horizontal in-plane force. Since the rupture of connectors was not observed in any of the samples, it can be concluded that they are very effective. A similar research investigation by the same authors for out-of-plane behavior is presented in [63], and comes to the same conclusions as in [62]. For a proper effect of the anchors, they must possess a high axial stiffness and must be fixed within the masonry (use of inorganic matrices or chemical anchoring) [64]. Furthermore, when transversal connections are used and adequately connected to the wall, the texture of the masonry wall upon which the FRCM system is applied does not affect the shear in-plane behavior of the wall [65]. Additionally, with the use of proper transversal connections in a proper arrangement, the delamination of the entire strengthening system from the masonry substrate becomes less problematic [29]. The only problem that is yet to be solved is the numerical modeling of the transversal connections. Because connectors, their arrangement, number and effect cannot be modeled, usually a perfect connection between the FRCM system and the masonry substrate is assumed [66].

The use of anchors is also very helpful when the out-of-plane behavior of a masonry wall is considered. It was shown that when a masonry wall is subjected to an axial force and out-of-plane load, the reinforcement system prevented the formation of a hinge at the center of the wall [67]. The failure modes of the specimens were usually connected to the rupture of fibers that occurred before the debonding from the masonry substrate. In similar investigations, it was concluded that when FRCM is applied, the load capacity of the strengthened wall increased drastically when compared to the unstrengthen sample [68,69].

4.2.7. Single- or Double-Sided Strengthening

FRCM strengthening is most effective and mostly researched for double-sided strengthening [70]. Strengthening on one side, on the other hand, is less researched. In [71], it was concluded that when the FRCM is applied on one side of the wall, the masonry panel failed under a lower maximum load than the wall strengthened on both sides. It was also reported that the failure appeared as a unique crack on the unreinforced side. Another problem in single-sided strengthening is the occurrence of out-of-plane bending when the wall is subjected to an in-plane force. This is because of the asymmetrical distribution of stiffness after the coating is applied on only one side of the wall and can lead to a smaller force capacity of the entire masonry wall [72]. Furthermore, it was found that the bond issue between the wall and the FRCM system is more critical in single-sided strengthening of masonry walls. This research gap is the largest problem in regard to the FRCM systems. Different solutions are sought mainly in the direction of anchor detailing and layout as was mentioned in the previous section. Additionally, new detailing of the FRCM system in itself is a solution being developed. For example, bending the coating around the corners at the sides of the wall and fixing them with additional connectors is a solution being developed by the authors of the manuscript. The numerical and experimental research on this topic will be presented in future research papers.

Another factor that is very important when talking about FRCM performance is the number of layers of fabric being used. In a recent study, two groups of FRCM reinforced clay brick walls were tested. One group had four plies of fabric and the other one had one plie of fabric. It was concluded that the use of four plies does not equate to four times the ultimate in-plane force capacity of the masonry wall (in fact not even two times) [73]. An additional aspect that should be considered is the need for a fabric overlap in the FRCM system. The meshes of the FRCM system are produced as 1 m wide and most of the walls and piers are wider than that. In that case, an overlap is needed. It was concluded that a minimum overlap of 150 mm is needed to provide continuation and integrity of the mesh and to achieve a proper transfer of the tensile stresses between the meshes [74].

In conclusion, although two-sided strengthening would be preferable, it is not a feasible or possible solution for historic structures because of the need for façade removal. Wrapping walls with the FRCM system around the entire perimeter of the wall has the same problem, and additionally requires removal of the windows.

5. Conclusions

In this paper, the most commonly used methods for strengthening of masonry walls and piers are presented and compared. Traditional methods such as the use of tying elements, application of shotcrete or the implementation of various other methods are widely used for seismic strengthening of masonry walls and piers. The literature on the application, testing and benefits of these methods is quite extensive. These methods provide an increase in ductility and capacity of masonry walls and piers. The majority of companies that deal with this kind of strengthening method have labor workers who are far more familiar with the traditional methods than the newer ones. Finally, the initial cost of these methods is still lower than of the composite-materials-based ones, although the overall cost that includes future repairs and replacements is greater with the use of the traditional methods. The main reason for this problem is the oxidation of the steel meshes that appears especially in the shotcrete method. Besides that, in most cases, the tenants need to relocate during the retrofitting period and the methods in themselves are very dirty.

On the other hand, new composite material-based methods are easier to use and apply. In the very beginning the biggest obstacle to the use of new methods was the financial aspect. Today, the gap between the overall costs of the traditional and new methods has decreased substantially. Additionally, the research community turned towards the study of new methods, making the literature on these methods very extensive. FRP in different shapes such as rods, strips and meshes were the first ones to be introduced. The increase in ductility and capacity of masonry walls was widely reported, but several issues regarding the durability were also reported. Poor behavior under low and high temperatures, low permeability, irreversibility, and the possibility of early debonding are just some of them. The main reason for this is the use of an epoxy matrix. Many of the problems were alleviated by the FRCM, which uses an inorganic matrix. The application of FRCMs in unfavorable conditions is possible. In the last decade, the amount of research on the topic of FRCMs has exploded. Some small disadvantages were reported, such as debonding and delamination, but with the introduction of transversal connectors/anchors, most of them were addressed.

Author Contributions: Conceptualization, I.H., T.K. and M.G.; methodology, I.H.; formal analysis, T.K. and M.G.; investigation, I.H.; resources, T.K.; data curation, I.H.; writing—original draft preparation, I.H., T.K. and M.G.; writing—review and editing, T.K. and M.G.; visualization, I.H.; supervision, T.K. and M.G.; project administration, T.K.; funding acquisition, T.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy reasons.

Conflicts of Interest: The authors declare no conflict of interest.

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