Investigation on the Behaviour of Masonry Infill Walls Strengthened With Fabric Reinforced Cementitious Matrix

M Bhaskar [1], D. Bhunia [2]

[1] Research Scholar, Department of Civil Engineering, BITS-Pilani, p20180420@pilani.bits-pilani.ac.in
[2] Associate Professor, Department of Civil Engineering, BITS-Pilani, dbhunia@pilani.bits-pilani.ac.in

Abstract

New technologies and online resources for strengthening purposes of structures inspire researchers to approach structural behavior from a different angle with the aim to professionally improve the performance of those structures, particularly in earthquake-prone areas. From this perspective, Textile Reinforced Concrete (TRC) among all available strengthening techniques, although it is in use from the past two decades seems to be a more promising method to improve the performance of Masonry Infilled Walls (MIW) during seismic action. The present study aims to study the behavioral aspect of MIW strengthened with TRC, in layers at the joints of infills with the surrounding Reinforced Concrete (RC) frame to identify the behavioral changes and failure patterns of MIW. The numerical simulation is presented in this paper for which the validation will be carried out with the results after the completion of the experiment. Modeling of MIW strengthened with TRC is done in the commercially available software ABAQUS. The results finalize that the presence of TRC has enlarged the load-carrying capacity of the MIW.

Keywords: Earthquakes; Fabric Reinforced Cementitious Matrix (FRCM); Masonry infill; Seismic actions; Strengthening; Welded Wire Mesh (WWM)

1. Introduction

Earthquake is one of the most devastating natural disasters occurring on this planet which results in loss of life and heavy property. But if we brood over, it's actually the buildings and structures that are constructed by us are the main reason for this collapse causing casualty and damage all around. Hence it is our responsibility; moreover, it's a civil engineer's responsibility to prevent a structure from its failure during a seismic action. For that, we need to design and build earthquake resisting structures by practicing better engineering methods. Most vulnerable structures to collapse during an earthquake event are unreinforced masonry infill frames. From previous literature, the undeniable fact is that the masonry infills confer with increasing the horizontal stiffness of the whole erection. Masonry wall itself being a composite structure to predict its behavior under seismic actions since it is made with separate brick units joint together with the help of brick mortar. This composite is used to fill the empty space between the bounding RC frames, on the whole becoming another composite structure. Generally, the infills are ignored in the seismic analysis considering only the RC Frame which is not always safe, because when they are subjected to lateral actions, infills minimized the maximum ground acceleration which can be withstood by the structure hitherto elastic limit state [1]. Further, it may also be the reason for the occurrence of torsion to the structure, short column repercussion, out of plane failure, soft storey failure which triggers the calamitous failure of a part or whole structure. Hence, in the process of strengthening of these kinds of structures is crucial to inspect the impact of infills in the seismic analysis. This technique has proved to be more promising according to the literature survey. [2] examined both tensile failure and shear failure of the RC frame packed to the hilt with brick masonry that leads to the conclusion that the RC frame packed fully with masonry improved the overall stiffness of the system in comparison to the bare frame and partly packed frame. The increment of strength as well as stiffness pertaining to the overall RC frame structure due to the presence of brick infills by carrying static pushover analysis for different infill configurations [3]. Usually, strengthening of these kinds of structures follows the strategy of externally bonded reinforcement with Fiber Reinforced Polymer (FRP) Laminates, Welded Wire Mesh (WWM) or Textile Reinforced Concrete (TRC) among which TRC is an upcoming and promising method. Since enough research work has been carried out on methods such as FRP, WWM, Engineered Cementitious Composite (ECC) etc., this paper investigates the performance of masonry infill walls strengthened with TRC.

Masonry infills render qualities, endurance to the structure and help to keep up the temperature inside and outside just as keeps shield the structures from the external world. Infills in the outlines decrease the horizontal deflection of the structure. The IS code arrangements don't give any rules for the investigation of RC outlines with infill walls. The workmanship infill boards in structures, for the most part, are not considered for the seismic plan process and might be treated as non-basic segments. Yet, the nearness of masonry infill boards has an incredibly huge effect on the seismic reaction of the RC framed structure as they decrease horizontal deflection and consequently diminishing the likelihood of the crumbling [4]. Late earthquakes have indicated that numerous such structures are seismically helpless. Subsequently, masonry seismic appraisal strategies have normally lingered a long way behind evaluation techniques for current steel and concrete structures [5]. Seismic conduct of two half-scale masonry models with various fortifying measures under cyclic loading in quasi-static test provision up to a definitive failure and their lateral strength, deformability, energy dissipation capacity, hysteretic conduct, damping and crack effect [6]. The conduct of various single-story frames with brick masonry infill under the in-plane horizontal loading impact utilizing glass fiber reinforced polymer (GFRP) sheets, steel rebar obstructed in frame, plastering and ferrocement networks were considered [7]. Fitting measures were suggested to improve both in-plane and out-of-plane nobility and the performance conduct under seismic activities of outside leaf of double-leaf cavity walls just as premature breaking down of the masonry infills [8]. In-plane conduct of timber frames with masonry infill walls, portrayed by an incredible pliability limit as saw during static cyclic experiments on the infill panels. [9]. The aptness and efficacy of fiber-reinforced polymers (FRP) in fortifying or fixing unreinforced masonry infills in reinforced concrete fixture which are exposed to in-plane seismic or cyclic actions were inspected

[10]. An experimental test performed on reinforced concrete (RC) frames with various sorts of masonry infill walls, in particular, standard and locked bricks where earthquake impacts are initiated on the RC constructions by quasi-static tests then, compared with each other through different strength, stiffness, and energy-related parameters were exhibited [11]. The experimental tests and results accomplished by enacting cyclic out-of-plane loads brick masonry infill RC outlines which were recently destructed subjected to in-plane cyclic loads on which the cyclic out-of-plane loads were already applied [12]. Results of Quasi-static analyses were performed on RC frames with masonry infill walls which were provided with openings showed that the failure modes of the infill frames can be characterized into different modes [13]. The load resisting capacity of an RC infill frame depends to an enormous degree on the connection between the infill wall and the frame, but can't be considered as a straightforward total of the resistances of the frame without infill and independent wallboard were abridged [14]. In-plane and out of plane quasi-static cyclic tests were conducted on European masonry infill frames using hydraulic actuator for former test and the latter was performed using an airbag guided by a software [15]. Tests were performed on RC frames packed with masonry infills of various strength values of hollow blocks such as high and low strengths for the results concluded that the frames with masonry infills displayed high stiffness than that of the bare frames[16]. The main objective of this research is to thoroughly investigate the behavior of MIW strengthened with TRC to identify the propagation of cracks on the infill during the process of analysis and to evaluate the load-displacement relationship of the infill.

2. Textile Reinforced Concrete

The reason for the success of textile reinforced concrete (TRC) as a reinforcing medium for concrete or masonry buildings is its high tensile strength compared to other strengthening materials such as FRP etc. Generally, it won't fail due to the loads which act on the building when used as reinforcement. The adhesive material which is used as bonding material like cementitious material will fail before TRC. There are many types of fibers that are used to form TRC. Among them, the popular ones are glass, carbon, basalt. In glass fibers, there are again many types such as C-glass (high boron oxide content, known as alkali-lime glass), S-glass (alumino-silicate glass with large amount of MgO content and without CaO resulting in high tensile strength), AR-glass (Alkali-Resistant Glass), etc. which will be used according to the requirement. AR-glass is used when the silica present in the glass and alkalinity present in the cement should not be reacted, to prevent it, 19% of zirconium oxide is added to the glass. A typical TRC sheet used to apply on the masonry wall is shown in Figure 1.

Fibers combined into a thread-like structure called yarn and yarn will be formed into fabrics. If the fibers are placed in only one direction, it is uni-directional fiber, if it is placed in two directions (i.e. X & Y direction), it is called bi-directional layer, where these two types are combined known as 2D reinforcement. 3D reinforcement is the one in which, fibers are kept together in multi directions as shown in the figure. It can also be said as TRC is the advanced version of FRP in the method called externally bonded reinforcement. In the previous two decades research work about TRC has been done on a huge scale.

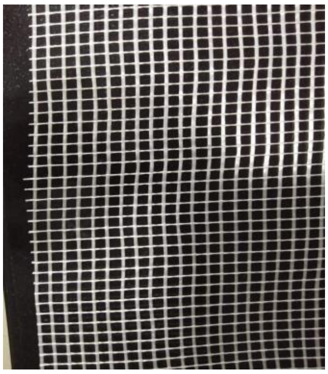


Fig. 2 – Textile Reinforced Concrete (TRC) (Source: MAP Products)

Masonry substrates strengthened with TRC can contribute to increasing the flexural or shear capacity, stiffness, and performance of concrete structures [17]. Test on a system combining both TRM and thermal insulation which turned out to be a highly effective technique in improving the ability to withstand the in-plane loads acting on the masonry walls [18]. Two modes of fabric application namely direct application (fabric is present on the masonry surface without mortar) another is sandwich application (initially cement mortar is applied on the concrete veneer on which fabric is placed and again closed with cement-mortar) were evaluated to strengthen the masonry infill RC frames where the former method proved to be effective than the latter method [19]. Hollow concrete masonry panels of 150 mm and 200 mm thickness strengthened with TRM under in-plane shear loading were tested and detected about 56% increment in the shear strength for 150 mm thick masonry panel [20]. The durability behavior of the textile matrix (TRC) under tension along with bending in the dotage of 14, 90, and 120 days were compared [21]. Steel mesh added to the TRM in masonry infills which brought about a little increment in the strength and ductility of the test wall specimens [22]. Experimentally the effectiveness of TRM jackets and FRP jackets as a method for impounding RC column sections were compared and finalized that TRM jacketing is a very encouraging arrangement [23]. The presentation of antiquated masonry structure reinforced with TRM frameworks with various glass fiber networks and a Near Surface Mounted (NSM) framework were introduced [24]. The inflexible conduct of reinforced concrete frames was considered with a hollow concrete masonry infill reinforced with FRCM exposed to cyclic in-plane loading [25]. The diagonal shear and out of plane bending quality of masonry substrates fortified utilizing glass fabric–reinforced cementitious matrix (FRCM) were assessed [26]. Investigation using the Round Robin test was accounted for on the tensile and bond conduct of GFRCM examples [27]. Five different types of FRCM materials made with different fiber grids for masonry strengthening was investigated [28]. The principle highlights of elastic and bond conduct of TRM compounds were depicted and proposed recommendations to perform tests on direct tensile and shear bond properties [29]. The consequences of malleable and bond trial of TRC frameworks clung to masonry substrates and were checked using Digital Image Correlation (DIC) system were shown [30]. The FRCM framework to URM dividers were applied to decide its achievability as an elective external reinforcing innovation under diagonal compression [31]. The conduct of FRCM coupon specimen under tensile tests directed by methods for 2D FE models were researched [32]. Experimentally the in-plane performance of masonry infills provided with cavity strengthened with Textile Reinforced Concrete was investigated [33]. The adequacy of FRCM frameworks in improving the out of plane limit of an already damaged and another reinforced clay block masonry wall under out of plane pressure was assessed [34]. Exploratory tests on masonry boards constructed utilizing volcanic tuff stones from the Latium Region, Italy, strengthened remotely were carried out on bonded Basalt textile-reinforced mortar (BTRM) composite [35]. An investigation on URM infills were directed for the evaluation of their out of plane (OOP) reaction and of the consequences for it of in-plane (IP) harm (IP/OOP collaboration) [36]. The primary viewpoints identified with the bond among concrete and cement-based fiber-reinforced composite materials were investigated [37].

The adequacy of the TRM reinforcing method in improving the out of plane behavior of masonry infill walls in RC outlines was examined [38]–[41]. TRM is economical, worker-friendly, well-suited for placing on concrete surface and masonry wallets can be employed on moist surfaces as well as in lower temperatures, higher resistance to fire. Considering these advantages, TRC has become a very popular medium for strengthening of existing structures even though FRP is still in the usage. Despite the fact that the TRC technique has been utilized for concrete members, applications for strengthening of masonry structures or heritage structures displayed optimistic results, scrutinizing the drawbacks of FRP elements (mainly related with epoxy resins) namely – uneconomical, unable to apply on wet surfaces, incompatible over masonry substances. TRC hybrid material comprises of fiber yarns organized in two or more directions to use as a reinforcement material. These fibers are placed at a certain distance to form a grid/mesh-like structure. The space between the fiber layers contribute to holding the cement mortar matrix and the TRC. Sometimes, coated textiles are used to increase the stability and maintaining the form of the fibers so that the tensile strength of the textile reinforced substance is increased. Moreover, the TRM matrix is rustproof and moisture resistant. The spacing between the fibers in TRC usually can be varied at the time manufacture. The grid size sometimes ranges between 8 mm and 30 mm, whilst weight will be between 0.15 and 0.6 kg/m^2, however, it depends on the type of the fiber material used. A remarkable advancement in the last two decades in civil technology has been the development of 3-D textiles which possesses the modern, unique properties compared to planar (2D - textiles structures. The main difference between the planar and modular textiles is that, in 3D textiles, the fibers or yarns can be woven in the third direction in space, which includes the thickness orientation. The main reason for the success of 3D woven textiles is its wide range of requirement oriented applications including high tensile strength, resistance to impact actions, high energy absorption. The spacing in the 3D fibers are provided and maintained using spacer fabrics which contain upper and lower surfaces and can be open or closed grid structure. Among these two, the open mesh structure is most suitable for strengthening concrete matrices thanks to the better flow of the cement-mortar mixture into the fibers. Here, the efficiency of the TRC jackets as a strengthening material is decided by the bondage between TRC and the concrete matrix. The parameters which decide the confinement between TRC and concrete matrix are nature and geometry of the fiber yarns, percolation of fibers with the cement mortar and standard of the surface of the concrete matrix. The bondage between TRC and concrete matrix usually is evaluated by conducting lap shear tests on TRC strips. Many researchers have investigated the bond between different types of TRC such as glass, steel, polyphenylene bezobisoxazole (PBO). Most of the results displayed the failure of specimens is due to the slippage of fiber material along the cement-mortar.

3. Analytical Work

Available three methods for modeling masonry walls in ABAQUS are macro modeling, simplified micro-modeling and micro-modeling. In this research, the macro modeling technique is adopted to model MIW. The minute differences between the mentioned methods are mentioned in Table 1.

Table 1 – Differences between modeling techniques

Macro Modelling	Simplified Micro-Modelling	Micro Modelling	Source
Less computational effort	More computational effort	More computational effort	[42]
Can be completed in less time	Time-consuming	Time-consuming	[43]
Used to determine the global response of the structure	Used to determine the local response of the structure	Best suited for local response/behavior of the structure	
Accuracy of the obtained results is high	Less accuracy of the values of the results	Less accuracy of the values of the results	[44]

But, few researchers have concentrated on the macro-modeling technique to numerically simulate the strengthened masonry infill wall. Literature is available on the investigation of MIW with strengthening methods such as FRP, ECC, etc., and even the output has shown some good results. But the strengthening of MIW with TRC is at a premium. A literature survey on the strengthening of MIW suggests that still more work has to be progressed on different types of brick masonry with the application of lateral loads. In this paper, macro-modeling technique using the commercial software ABAQUS is adopted to study the in-plane response of masonry infills strengthened with Textile reinforced mortar.

Right now, macro-modeling was carried out by considering the masonry infills as a homogeneous material. The essential element of the homogeneous material is that solid mortar, weak block unit, and unit–mortar bond is spread so that the entire block masonry is described by the homogeneous isotropic material.

For the purpose of modeling the specimen in ABAQUS CAE, the Standard/Explicit model is used where the dimensions, shape, and size are given in the part module. The material properties of all the elements are given in the property module that is shown in Table 2.

Table 2 – Material properties for the materials used in the numerical model

Material	Parameter	Value	Material	Parameter	Value
Concrete	Density (kg/m^3)	2400	Steel	Density (kg/m^3)	8050
	Modulus elasticity (N/m^2)	17e9		Modulus elasticity (N/m^2)	200e9
	Poisson ratio	0.19		Poisson ratio	0.3
Masonry	Density (kg/m^3)	2000	TRC	Tensile Strength (MPa)	3800
	Modulus elasticity (N/m^2)	15.8e9		Modulus elasticity (GPa)	225
	Poisson ratio	0.19		Weight (kg/m^2)	0.348

The assemblage of each part created is done in the assemblage module. Then the interaction and the constraints are applied in the interaction module. Following this, the boundary conditions and the loads are given in the load module. The next step is to create mesh, submitting the job and evaluating the results. The concrete-damage plasticity (CDP) parameters are taken from the literature. The CDP model is a continuum plasticity-based model exclusively used for simulating the performance of concrete. To depict the inelastic performance of the concrete, ABAQUS adopts the notion of isotropic damage along with the inclusion of tensile and compression plasticity (Dassault Systèmes Simulia Corporation, 2017).

The geometry of the masonry wall as shown in Figures 2 and 3 is selected on the basis of the dimension of the available loading frame. The height of the frame was 1500 mm and the outer-to-outer distance between the columns was 1900 mm. The width of the masonry infill was 1700 mm and the height of the same is 1475 mm. the cross-sectional area of the column was 140 x 200 mm where the longer dimension is in the longitudinal direction of the frame. The beam cross-sectional area is 140 x 250 mm.

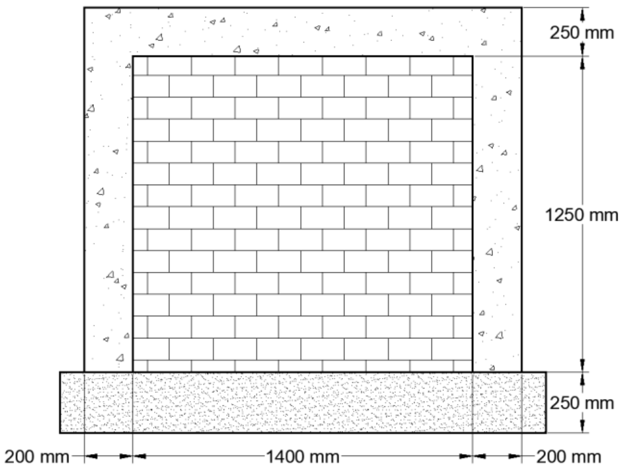


Figure 2. Geometrical front view of the masonry infill frame

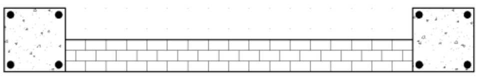


Figure 3. Geometrical top view of the masonry infill frame

The ABAQUS model of MIW is shown in Figure 4. The modeling is carried out in a process where the masonry infill wall is modeled as a single unit, the beam and the column of the bounding frame is modeled as a monolithic structure. The meshed model is shown in Figure 5.

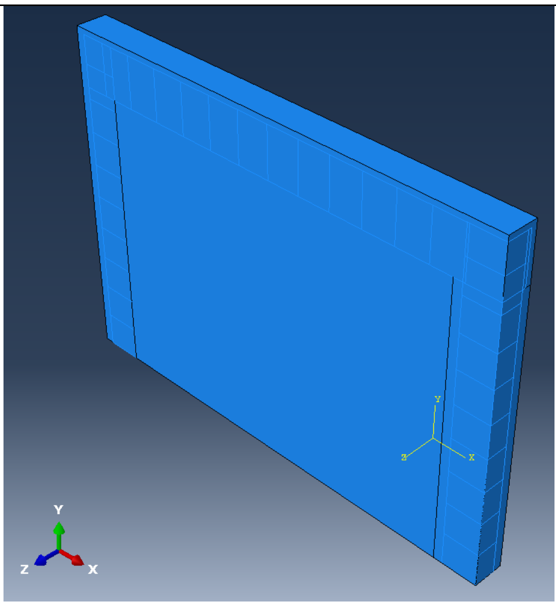


Figure 4. Model set-up in ABAQUS

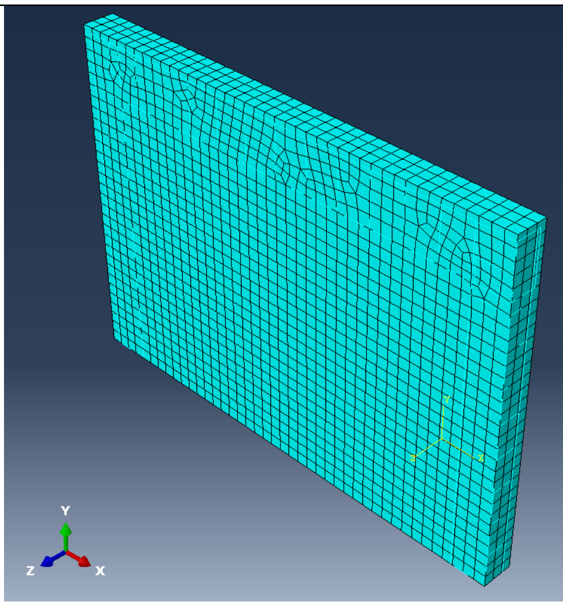
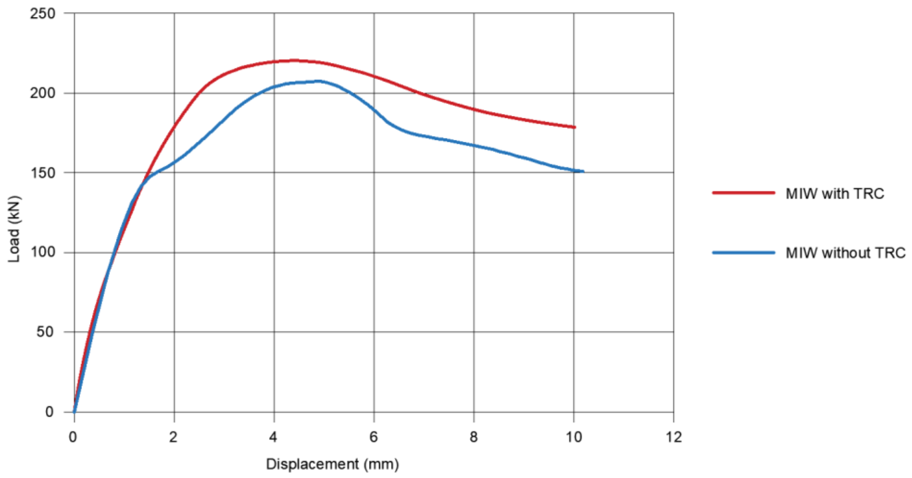


Figure 5. Model of meshed MIW

Explicit solver in ABAQUS was picked to display the masonry infill wall. This strategy is computationally effective and skilled for simulating quasi-static loads used for this investigation. Additionally, it can keep away from the assembly issue which can exceptionally happen implicitly. Blocks and mortar will be displayed utilizing the C3D8R component. They were modeled as a continuum component and demonstrated utilizing an inelastic constitutive model accessible in ABAQUS. Tangential and Normal behavior were utilized to demonstrate the interaction between the blocks. It is expected that when two surfaces in contact, they, for the most part, transmit shear just as should be expected powers over their interface. A general connection between these two power segments is known as grinding between the reaching bodies.

4. Results and Discussion

The load-deflection behavior of the masonry infill wall modeled numerically is presented in Figure 6. This numerical simulation presents a database of the behavior of masonry infill wall under in-plane loading. The performance of TRC strengthened masonry frames was simulated using ABAQUS. The target of this examination was to research the capacity of numerical finite element models to foresee the behavior of RC frames infilled with a masonry brick wall. It is demonstrated that aligned finite element models can fill in as a useful apparatus for additional investigation of infilled outlines. The results show that the process of strengthening MIW with TRC has increased the load-carrying capacity of the infill wall up to 218.76 kN. The brown line represents the strengthened infill wall whereas the blue line denotes the conventional infill wall with a load of 207.16 kN. The displacement of the strengthened infill wall was 5.112 mm whereas the conventional wall has displacement value up to 5.103 mm. From the graph, it can be inferred that the strengthening material TRC as an Externally bonded reinforcement is favorable compared to the infill wall without TRC. The experimental work has to be carried out to validate the results.



5. Conclusion

The behavior of masonry infill walls in and around the seismic province has been discussed broadly. The strengthening method for the infill panels also have been discussed. Textile Reinforced Concrete (TRC), also known as Textile Reinforced Mortar (TRM) or Fiber Reinforced Cement Matrix (FRCM) in the specialty of seismic strengthening concrete or RC structures is used as a strengthening material. This paper describes the manufacturing process, bond characteristics, failure modes, kinds of TRC, key parameters being investigated about TRC. In general, for every one of the investigations considered right now, fortifying concrete elements with TRC are culminated to be a beneficial technique to amplify a definitive bending or shear limit of RC elements with standard divisions. TRC escalates the stiffness and the behavior of the masonry structures under design loads. Furthermore, cracking is highly governed. It will be concluded as, the seismic strengthening of concrete and masonry constructions with textile material substrates is an extremely favorable method, which draws enlarging curiosity of research organizations around the globe. Further development in this domain should be conducted at upgrading the textile fortification. This study displays that the finite element method can evaluate the behavior of strengthened MIW in detail. The experimental work will be carried out in the coming months and once it is completed, the results will be validated with the simulation.

6. References

[1] B. Meharbi and P. Shing, "Seismic analysis of infilled reinforced concrete frames," *Comput. Struct.*, vol. 30, no. 3, pp. 457–464, 1988.

[2] Y. Chiou, J. Tzeng, and Y. Liou, "Behaviors of framed masonry walls," *Proc. 12th World Conf. Earthq. Eng. Auckland, New Zeal.*, vol. Paper No., pp. 1–7, 2000.

[3] G. Manfredi, "Influence of infill panels and their distribution on seismic behavior of existing reinforced concrete buildings," *Open Constr. Build. Technol. J.*, vol. 6, no. 1, pp. 236–253, 2012.

[4] L. M. Thomas and P. E. Kavitha, "Effect of infill walls on the seismic performance of the multistoried buildings," vol. 175, pp. 90–96, 2015.

[5] A. Fiore, F. Porco, G. Uva, and M. Sangirardi, "The influence of uncertainties of infill panels relative to the seismic response of RC existing buildings," vol. 141, pp. 479–490.

[6] P. J. Agarwal and S. K. Thakkar, "A comparative study of strengthening and retrofitting measures for unreinforced brick masonry model under cyclic testing," vol. 2469, 2008.

[7] L. M. Abdel-Hafez, A. E. Y. Abouelezz, and F. F. Elzefeary, "Behavior of masonry strengthened infilled reinforced concrete frames under in-plane load," *HBRC J.*, vol. 11, no. 2, pp. 213–223, 2015.

[8] R. Vicente, H. Rodrigues, and A. Costa, "Masonry enclosure walls : lessons learnt from the recent Abruzzo earthquake."

[9] A. Dutu, H. Sakata, A. M. Asce, Y. Yamazaki, and T. Shindo, "In-plane behavior of timber frames with masonry infills under static cyclic loading," vol. 04015140, no. 18, pp. 1–18, 2016.

[10] T. H. Almusallam and Y. A. Al-Salloum, "Behavior of FRP strengthened infill walls under in-plane seismic loading," vol. 11, no. June, pp. 308–318, 2007.

[11] I. S. Misir, O. Ozcelik, S. Can, and S. Kahraman, "Experimental work on seismic behavior of various types of masonry infilled RC frames," vol. 44, no. 6, pp. 763–774, 2012.

[12] M. F. Paulo, M. F. Neto, and J. E. Dias, "Behavior of masonry infill panels in RC frames subjected to in-plane and out of plane loads specimens characterization," 2011.

[13] P. G. Asteris, "Failure modes of in-filled frames," vol. 11, no. 1, 2011.

[14] P. B. Shing and A. B. Mehrabi, "Behaviour and analysis of masonry-infilled frames," pp. 320–331, 2002.

[15] F. Akhoundi, G. Vasconcelos, P. Lourenço, C. Palha, and L. Silva, "In-plane and out-of-plane experimental characterization of RC masonry infilled frames," no. July, pp. 26–30, 2015.

[16] J. Zovkic, V. Sigmund, and I. Guljas, "Cyclic testing of a single bay reinforced concrete frames with various types of masonry infill," no. October 2012, pp. 1131–1149, 2013.

[17] L. N. Koutas, Z. Tetta, D. A. Bournas, and T. C. Triantafillou, "Strengthening of concrete structures with textile reinforced mortars: state-of-the-art review," *J. Compos. Constr.*, vol. 23, no. 1, pp. 1–20, 2019.

[18] T. C. Triantafillou, K. Karlos, P. Kapsalis, and L. Georgiou, "Innovative structural and energy retrofitting system for masonry walls using textile reinforced mortars combined with thermal insulation: in-plane mechanical behavior," *J. Compos. Constr.*, vol. 22, no. 5, pp. 1–15, 2018.

[19] S. L. Sagar, V. Singhal, and D. C. Rai, "In-plane and out-of-plane behavior of masonry-infilled RC frames strengthened with fabric-reinforced cementitious matrix," *J. Compos. Constr.*, vol. 23, no. 1, pp. 1–14, 2019.

[20] N. Ismail, T. El-Maaddawy, N. Khattak, and A. Najmal, "In-plane shear strength improvement of hollow concrete masonry panels using a fabric-reinforced cementitious matrix," *J. Compos. Constr.*, vol. 22, no. 2, pp. 1–13, 2018.

[21] K. Kong, Z. Mesticou, M. Michel, A. Si Larbi, and A. Junes, "Comparative characterization of the durability behavior of textile-reinforced concrete (TRC) under tension and bending," *Compos. Struct.*, vol. 179, pp. 107–123, 2017.

[22] N. Ismail and J. M. Ingham, "In-plane and out-of-plane testing of unreinforced masonry walls strengthened using polymer textile reinforced mortar," *Eng. Struct.*, vol. 118, pp. 167–177, 2016.

[23] D. Bournas and T. Triantafillou, "Innovative seismic retrofitting of old-type RC columns through jacketing: Textile-Reinforced Mortars (TRM) versus Fiber-Reinforced Polymers (FRP)," *Proceeding 14 World Conf. Earthq. Eng.*, pp. 1–8, 2008.

[24] F. G. Carozzi, T. D'Antino, and C. Poggi, "In-situ experimental tests on masonry panels strengthened with Textile Reinforced Mortar composites," *Procedia Struct. Integr.*, vol. 11, pp. 355–362, 2018.

[25] N. Ismail, T. El-Maaddawy, and N. Khattak, "Quasi-static in-plane testing of FRCM strengthened non-ductile reinforced concrete frames with masonry infills," *Constr. Build. Mater.*, vol. 186, pp. 1286–1298, 2018.

[26] S. L. Sagar, V. Singhal, D. C. Rai, and P. Gudur, "Diagonal shear and out-of-plane flexural strength of fabric-reinforced cementitious matrix-strengthened masonry walletes," *J. Compos. Constr.*, vol. 21, no. 4, pp. 1–13, 2017.

[27] M. Leone *et al.*, "Glass fabric-reinforced cementitious matrix: Tensile properties and bond performance on masonry substrate," *Compos. Part B Eng.*, vol. 127, pp. 196–214, 2017.

[28] F. G. Carozzi and C. Poggi, "Mechanical properties and debonding strength of Fabric Reinforced Cementitious Matrix (FRCM) systems for masonry strengthening," *Compos. Part B Eng.*, vol. 70, pp. 215–230, 2015.

[29] S. De Santis, F. G. Carozzi, G. de Felice, and C. Poggi, "Test methods for textile reinforced mortar systems," *Compos. Part B Eng.*, vol. 127, pp. 121–132, 2017.

[30] A. Bilotta, F. Ceroni, G. P. Lignola, and A. Prota, "Use of DIC technique for investigating the behavior of FRCM materials for strengthening masonry elements," *Compos. Part B Eng.*, vol. 129, pp. 251–270, 2017.

[31] S. Babaeidarabad, F. De Caso, and A. Nanni, "URM walls strengthened with fabric-reinforced cementitious matrix composite subjected to diagonal compression," *J. Compos. Constr.*, vol. 18, no. 2, pp. 1–9, 2014.

[32] E. Bertolesi, F. G. Carozzi, G. Milani, and C. Poggi, "Numerical modeling of fabric reinforce cementitious matrix composites (FRCM) in tension," *Constr. Build. Mater.*, vol. 70, pp. 531–548, 2014.

[33] F. Akhoundi, G. Vasconcelos, P. Lourenço, L. M. Silva, F. Cunha, and R. Fangueiro, "In-plane behavior of cavity masonry infills and strengthening with textile reinforced mortar," *Eng. Struct.*, vol. 156, no. December 2017, pp. 145–160, 2018.

[34] C. D'Ambra, G. P. Lignola, A. Prota, E. Sacco, and F. Fabbrocino, "Experimental performance of FRCM retrofit on out-of-plane behavior of clay brick walls," *Compos. Part B Eng.*, vol. 148, no. April, pp. 198–206, 2018.

[35] G. Marcari, M. Basili, and F. Vestroni, "Experimental investigation of tuff masonry panels reinforced with surface bonded basalt textile-reinforced mortar," *Compos. Part B Eng.*, vol. 108, pp. 131–142, 2017.

[36] P. Ricci, M. Di Domenico, and G. M. Verderame, "Experimental investigation of the influence of slenderness ratio and of the in-plane/out-of-plane interaction on the out-of-plane strength of URM infill walls," *Constr. Build. Mater.*, vol. 191, pp. 507–522, 2018.

[37] L. Ombres, S. Mazzuca, and S. Verre, "Analysis of the bond between fabric-reinforced cementitious mortar (FRCM) strengthening systems and masonry," *Rehabend*, vol. 2016-May, pp. 1269–1276, 2016.

[38] L. N. Koutas and D. A. Bournas, "Out-of-plane strengthening of masonry-infilled RC frames with textile-reinforced mortar jackets," *J. Compos. Constr.*, vol. 23, no. 1, pp. 1–13, 2019.

[39] G. Vasconcelos, S. Abreu, R. Fangueiro, and F. Cunha, "Retrofitting masonry infill walls with textile reinforced mortar," *15th World Conf. Earthq. Eng. Lisbon Port.*, 2012.

[40] F. A. Kariou, S. P. Triantafyllou, D. A. Bournas, and L. N. Koutas, "Out-of-plane response of masonry walls strengthened using textile-mortar system," *Constr. Build. Mater.*, vol. 165, pp. 769–781, 2018.

[41] D. A. Bournas, P. V. Lontou, C. G. Papanicolaou, and T. C. Triantafillou, "Textile-reinforced mortar versus fiber-reinforced polymer confinement in reinforced concrete columns," *ACI Struct. J.*, vol. 104, no. 6, pp. 740–748, 2007.

[42] G. Blasi, F. De Luca, and M. A. Aiello, "Hybrid micro-modeling approach for the analysis of the cyclic behavior of RC frames," *Front. Built Environ.*, vol. 4, no. December, pp. 1–12, 2018.

[43] S. K. Kunnath, "Modeling of reinforced concrete structures for nonlinear seismic simulation," *J. Struct. Integr. Maint.*, vol. 3, no. 3, pp. 137–149, 2018.

[44] Ali. Abbas and H. Saeed, "Representation of The Masonry Walls Techniques By Using FEM," *Aust. J. Basic Appl. Sci.*, vol. 11, no. November, pp. 39–48, 2017.

