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EFFECT OF CONNECTION DETAIL AT INTERFACE OF MASONRY-INFILLED RC FRAMES RETROFITTED WITH TRM.

C. Filippou [(1)], N. Kyriakides [(2)], C. Z. Chrysostomou [(3)]

[(1)] *PhD Candidate, Department of Civil Engineering and Geomatics, Cyprus University of Technology, ca.filippou@edu.cut.ac.cy*
[(2)] *Lecturer, Department of Civil Engineering and Geomatics, Cyprus University of Technology, nicholas.kyriakides@cut.ac.cy*
[(3)] *Professor, Department of Civil Engineering and Geomatics, Cyprus University of Technology, c.chrysostomou@cut.ac.cy*

Abstract

The behavior of masonry-infilled reinforced concrete (RC) frame structures during an earthquake has attracted the attention by structural engineers since the 1950's. During the last decade, the use of Textile Reinforced Mortar (TRM) as retrofitting material for masonry-infilled RC frames under in-plane lateral loadings has been studied.

This paper presents a numerical study that was conducted to replicate the in-plane behavior of a masonry-infilled RC frame retrofitted with TRM that was studied experimentally in the past. A two-dimensional finite element model was developed to simulate the results of an experimental test on a 2:3 scaled three-storey retrofitted masonry-infilled RC frame. The three-storey structure used in the test was designed and detailed for gravity loads only, without any seismic provisions, and was subjected to in-plane displacement-control cyclic loading. A masonry-infilled RC frame retrofitted with TRM numerical model was developed in the DIANA finite element analysis (FEA) software and eigenvalue and nonlinear structural cyclic analyses were performed. In order to create an accurate numerical model, suitable constitutive models, based on the total strain smeared crack approach, were used to characterize the non-linear response of concrete, masonry and TRM. The calibration of the model was based on the experimental results or inverse fitting based on the optimization of the simulation of the response. The numerical model proved capable of simulating the in-plane behavior of the retrofitted masonry-infilled RC frame with good accuracy in terms of initial stiffness and its deterioration, hysteric energy, maximum shear-force capacity and cracking-patterns on the infill walls.

The calibrated model was then used to perform a parametric study, through numerical experiments (case studies) in order to assess the effectiveness of placing textile-based anchors for increasing the bond condition between the retrofitted masonry and the surrounding frame on the behavior of the retrofitted structure under cyclic loading. The numerical results showed that fully anchoring the TRM on the columns, in addition to the full anchors on the beams, does not have significant contribution to the increase of the lateral capacity, stiffness, and dissipated energy of the structure, and on the decrease of the gap at the interfaces. Therefore, the presence of anchors, which provide full bond conditions between TRM and masonry-infilled RC frame, is significantly effective even if it is applied only at the beam-infill interface at the first floor of the structure.

In conclusion, this numerical model proves to be a reliable model in simulating the behavior of TRM retrofitted masonry-infilled RC frame under cyclic loading and can be used for further parametric studies.

Keywords: Masonry infill; Textile Reinforced Mortar (TRM); Seismic retrofitting; Numerical Modelling; Anchoring

1. Introduction

Masonry-infilled RC-frame structures are widely dispersed around the world and most of them are in seismic region such as the Mediterranean, Europe, Middle East, New Zealand and South Asia. Past earthquakes have revealed that non-ductile RC frames with masonry infills, built before the development of new seismic codes, are vulnerable to earthquake shaking. Therefore, seismic retrofitting of existing masonry structures is nowadays a challenging engineering problem, since the most significant seismic risk in the world today is associated with existing buildings. Different retrofitting techniques have been investigated and used in order to improve the performance of masonry-infilled RC-frames in terms of ductility, lateral resistance, strength and stiffness. Amongst them, Fiber Reinforced Polymers (FRP) have received extensive attention in the last years due to their high mechanical strength and ease of application. The use of ductile Fiber Reinforced Cementitious Composite (FRCM) has recently received attention as a sustainable and a more compatible solution for retrofitting concrete structures compared to the traditional method of concrete jacketing. Owing to the need of introducing innovative materials, more recently the research community has increasingly focused on the use of Textile Reinforced Mortar (TRM) for retrofitting masonry and cultural heritage structures. TRM material consists of two components; inorganic matrix (lime-based or cement based) and the fiber reinforcing textile. The variety of fibers and mortar-types lead to wide range of possible mechanical properties for the TRM. The research regarding the TRM as a retrofitting material begins at the early 2000's. More specifically the research regarding the effectiveness of TRM for retrofitting masonry structures begins from 2005 and it is mainly due to Papanicolaou et al.[1], Krevaikas [2] and Baravellas [3]. The interest of the research community for using TRM composite material for retrofitting masonry infill [4–8] or masonry-infilled RC frame is presented in Fig. 1 where the number of publications is plotted against the publication year.

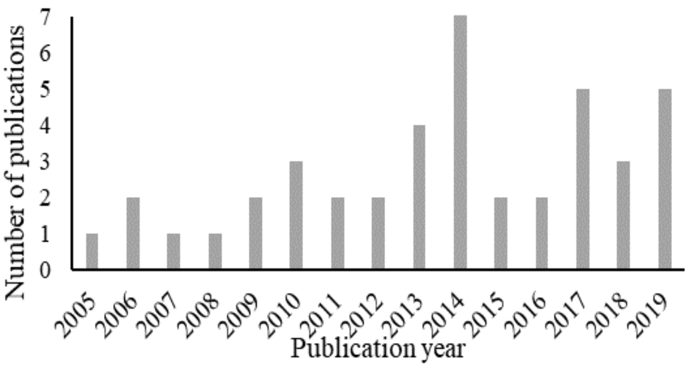


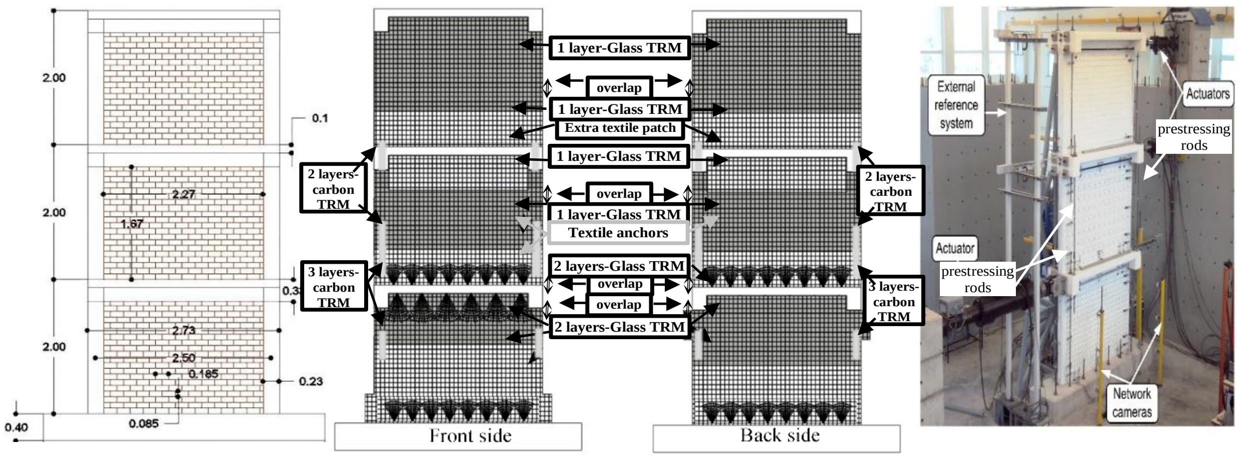
Fig. 1 – Number of publications per year in the field of retrofitting masonry infill wall structures with TRM.

This paper focuses on the behavior of masonry-infilled RC frame retrofitted with TRM under in-plane loading. Bernat et al. [9] tested nine real-size masonry walls retrofitted with TRM under eccentric compressive loads with the purpose of understanding the influence of three different types of mortar, two different types of fiber (glass and carbon grids) and the possible benefit of using anchors (rectangular pieces of glass and carbon grid were rolled to pass through a hole in the wall) to improve the connection between the walls and the external reinforcement. It was concluded that the connectors seemed necessary in strengthening of walls under eccentric compressive loads. The application of TRM has provided an increase of over 100% of the initial load-bearing capacity. Koutas et al. [10] performed an experimental study to investigate the effectiveness of TRM for retrofitting 2:3 scaled three-storey masonry-infilled RC frames under in-plane cyclic loading. In the retrofitted specimen, anchors were placed along the slab-infill interfaces on both sides of first and second storey. The results showed that the TRM provide 56% increase in the lateral strength, accompanied with a 52% higher deformation capacity at the top of the structure at ultimate strength state compared to the unretroffitted one. The presence of custom-fabricated textile-based anchors was proved particularly effective in delaying or preventing the debonding of TRM. Eight combined in-plane and out-of-plane tests on specimens composed of full-scale one-bay, one-storey RC frames, filled with non-load-bearing clay masonry walls using three different retrofitting solutions including TRM (glass and steel textile) were carried out by Da Porto et al. [11]. The additional use of anchorages (steel ties), connecting the TRM retrofitting system to the upper beam, does not significantly change the in-plane and out-of-plane response compared with TRM alone. Recently, Akhoundi et al.[12] studied the performance of seven half-scale masonry-infilled RC frames with and without glass TRM subjected to in-plane cyclic loading. The technique they used was similar to that used by Koutas et al. [10]. A special type of connector (L-shape glass grid) was used in this study to create better bond between TRM and masonry wall. Based on their results, retrofitting the masonry infills with TRM and connecting them to the RC frame by simply extending the retrofitting layers to the faces of the columns and the beam, yielded an increase in lateral stiffness and ultimate strength of about 40%. The energy dissipated in the specimens retrofitted with TRM was considerably higher (39-51%) compared to the unretrofitted one. Numerical studies have been also conducted for predicting the behavior of masonry infill wall retrofitted with TRM and most of them focused on the macro modeling approach and on the simulation of the TRM-retrofitted masonry infill under monotonic loading [13][14,15]. In addition, detailed finite element (FE) models have been developed to simulate the behavior of TRM-retrofitted masonry walls, using a microscopic smeared crack approach for modeling the masonry wall, while pushover analyses were performed for these models [14,16,17]. Only one study can be found in the literature concerning detailed numerical FE modelling of retrofitted infilled frames at a structural level, which focuses on the static monotonic nonlinear response of TRM-masonry infill [18].

This paper presents a numerical study that was conducted to replicate the in-plane behavior of a masonry-infilled RC frame retrofitted with TRM under cyclic loading that was studied experimentally in the past, as well as a parametric study, through numerical experiments (case-studies) in order to examine the influence of bond condition at the interface between TRM and RC frame members on the behavior of the retrofitted structure under cyclic loading. First an overview of the experimental case-study is presented followed by the FE modelling and calibration. Finally, the results of the parametric study are shown, and conclusions are drawn.

2. Brief overview of experimental case-study

The calibration of the numerical model is based on the experimental study conducted by Koutas et al. [10] at the University of Patra (Greece). In this study, the effectiveness of seismic retrofitting of existing masonry-infilled RC frame with TRM was studied. It was a 2:3 scale three-storey structure with non-seismic design and detailing subjected to in-plane cycling loading. Two masonry-infilled RC frames were designed and built with and without TRM. The scope of this design effort was the representation of a full height internal bay of an existing non-ductile building built in southern Europe in the 1960s. In this part of the paper, a short description of the selected experimental case-study is presented. Full details about the experimental case-study can be found in Koutas et al. [10].



(a) (b) (c)

Fig. 2 – Geometry of the masonry-infilled RC frame and (b) Strengthening scheme : textile anchors of first and second storey and TRM layer on the faces of masonry infill at the first, second and third storey and (c) Test set-up[10].

Fig.2 (a) shows the geometry of the masonry-infilled RC frame specimen. The modulus of elasticity and the compressive strength of concrete were 24.1 GPa and 27.8 MPa, respectively. The longitudinal ribbed reinforcement had 12mm diameter and mean yield stress equal to 550MPa, while smooth steel stirrups with a mean value of yield stress equal to 270MPa were used as transverse reinforcement for all concrete members.

Perforated, fired clay bricks were used for the construction of masonry infill while the perforations of the brick were running parallel to the unit's length in the x-direction. The modulus of elasticity of masonry perpendicular to the bed joints and compressive strength of the masonry was equal to 3.37GPa and 5.1MPa, respectively. The mean value of the shear modulus was 1.38 GPa while the value of diagonal cracking stress of masonry infill ranges from 0.3 to 0.8 MPa. Glass-TRM externally bonded on the face of masonry wall was used and six and eight anchors (the straight part of it was inserted into predrilled holes filled with injected epoxy resin and the fanned parts is bonded by hand pressure on the top of the first TRM layer) were placed along the interface of the first and second floor, respectively, as shown in Fig. 2(b). At the ends of RC columns, carbon-TRM was used. Commercial fiber-reinforced cement-based mortar was used for TRM with compressive and flexural strength equal to 18.9 and 4.3 MPa, respectively. In addition, the modulus of elasticity of carbon and glass textile was 736GPa and 225GPa, respectively, while their tensile strength per running meter was equal to 157kN/m and 115 kN/m, respectively. Prestressing rods were placed between the foundation beam and laboratory floor in order to provide full clamping between them as shown in Fig. 2(c). The specimen was subjected to a sequence of quasi-static cycles of a predefined force pattern. A history of imposed cycles of displacements was defined to be applied at the top while maintaining an inverted-triangular distribution of forces to the three levels until failure occurred. Permanent load is considered in the test by applying a vertical load of 80 kN per storey concurrent to the lateral loading action. The experimental results showed that the maximum base-shear force was attained during the fourth cycle of loading for the retrofitted specimen. After this cycle of loading, the lateral strength was decreasing due to complete debonding of the TRM from the beam surface on the backside of the first storey. In addition, the six TRM anchors placed at the top of the front-side first-storey were completely debonded during the sixth cycle of loading due to local crushing of masonry infill at the two upper ends of the columns at the first storey.

3. FE model simulation and calibration of TRM masonry-infilled RC frame

A two-dimensional numerical model was developed in DIANA FEA software Version10.2 [19], to simulate the nonlinear behavior of masonry-infilled RC frame retrofitted with TRM. This part of the paper presents a short description of the element type, size of meshing, boundary conditions, loading sequence and material models that were used in this numerical model. More details regarding the modeling of masonry-infilled RC frame retrofitted with TRM can be found in Filippou et al. [20,21].

3.1 Geometry, mesh, boundary constrains and loading scheme

This study used meso-modeling approach [22] for modelling the masonry-infilled RC frame retrofitted with TRM where the masonry, concrete and TRM elements are modeled as a continuum element using eight-node quadrilateral isoperimetric plane stress elements (CQ16M) and the interaction between the masonry infill and RC frame is modeled with interface elements using a three-point line interface element (CL12I). The steel reinforcement was modeled with two-node bar elements, which are automatically connected to the boundaries of the eight-node concrete elements at two additional external nodes. In this model (i) the continuity of TRM layer between the masonry and the bounding concrete elements, (ii) the anchoring provided by the presence of textile anchors and (iii) the debonding and rupture of TRM, are considered.

The geometry, the boundary constrains and the loading scheme of the TRM-retrofitted masonry-infilled RC frame model was similar as possible to the experimental one, as shown in Fig.3. A regular squared mesh [23] with the discretization as indicated in Fig. 3 was used. The strong-foundation RC-beam plate that was used at the bottom of the frame was simulated by restraining all nodes at the base of the first floor of the masonry-infill by preventing any translation in the x and y-directions. Two types of loads, representing the vertical compression and horizontal cyclic load, have been applied in the model. The dead load of the structure was simulated with a constant axial load equal to 174kN/mm at the top of each column. In addition, for the horizontal cyclic loading, prescribed deformation load at the top of each floor was applied to simulate as closely as possible the experimental loading as shown in Fig. 3.

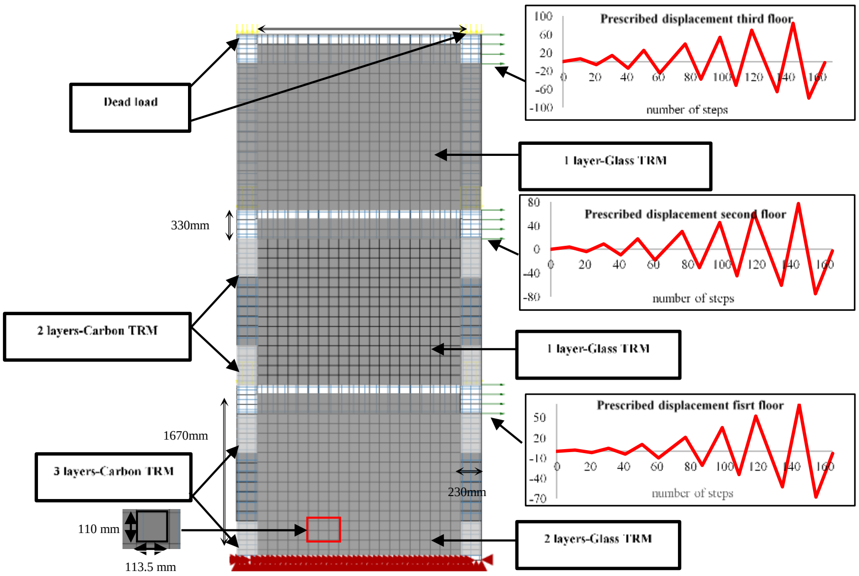


Fig. 3 – Geometry and mesh details of FE model.

3.2 Material models

Four constitutive models are considered in this numerical model: (1) Total Strain Crack model; (2) Menegotto-Pinto model; (3) New Engineering Masonry model, and (4) Fiber-reinforced Concrete model to reproduce the nonlinear behavior of masonry-infilled RC frame retrofitted with TRM. In addition, Coulomb Friction model is considered to represent the interaction between masonry infill and RC frame. In this study, most of the material properties are taken from the experimental case-study as described in section 2 of this paper and other properties were taken from the literature as described in the following paragraphs. The model was calibrated by comparing the numerical results to the experimental ones.

The Total Strain Crack model is used for simulating the behavior of concrete. Fig.4 presents the Total Strain Crack model in terms of stress-strain for one cycle of loading and unloading for concrete. Limited parameters are required for the Total Strain Crack model such, as Young modulus, tensile (2.15 MPa) and compressive strength (27.2 MPa) based on the Maekawa Fukuura model [24,25]. The fracture energy was determined based on the expression of the *fib* model code 2010 [26], and it is equal to 130 N/m. In addition, the modulus of elasticity was reduced to 9.1 GPa since the Total Strain Crack model does not take into account the reduction in stiffness due to the early cracking of the concrete section. This value was the result of eigenvalue analysis that gave the periods of vibration measured experimentally and it is about 50% of the elastic modulus. In order to define cracking orientation in this numerical model, the Rotating crack model is used [27].

For the simulation of the TRM composite material, the Total Strain crack model with the Fiber-reinforced concrete model for tensile behavior [26] were chosen, as well as the *fib* Model Code 2010 [26] model for its compressive behavior. The Total Strain crack model requires parameters for the tensile and compressive behavior of a composite material[21]. The required input parameters were obtained from the TRM-coupon tests conducted by Koutas et al. [10]. The Fiber-reinforced concrete model was specified as a function of the strains, in which the cracking of concrete is initiated at the strain when the tensile strength is reached. In addition, the maximum compressive and ultimate strains were obtained from *fib* model code 2010 [26]. The parameters adopted in DIANA FEA for the TRM model are given in Table 1.

The Menegotto-Pinto model was selected for simulating the nonlinear behavior of steel bar reinforcement since this model is available for embedded reinforcements including the cyclic behavior of steel bar reinforcement [28]. The parameters adopted for this model are the modulus of elasticity (207GPa), and the yield tensile stress for longitudinal reinforcement and stirrups equal to 549MPa and 295MPa, respectively.

The Engineering Masonry model, which is chosen for simulating the behavior of masonry infill, is a smeared failure model that covers tensile, shear and compression failure modes of masonry infill wall. The Engineering Masonry model describes the unloading behavior assuming a linear unloading for compressive stresses parallel to the initial elastic stiffness. In addition, a shear failure mechanism based on the standard Coulomb-friction failure-criterion is included in the model. The Engineering Masonry model requires a large number of mechanical properties and most of these properties were not measured in the experimental case-study. These mechanical properties were taken from the literature. The modulus of elasticity in the direction normal to bed joints, and the shear modulus of elasticity were obtained from the compression and diagonal compression tests on masonry infill conducted by Koutas et al. [10] and are equal to 3.37GPa and 1.38GPa respectively. The Young's modulus in the direction parallel to the bed joints is equal to 7GPa according to the ratio between the Young's modulus in x-direction and Young's modulus in y-direction, which ranges from 1.5 to 2 for different types of masonry [29][30]. The tensile strength normal to the bed joint was taken equal to 0.5 MPa according to Lourenço [32] and Rots [33] and the residual tensile strength was specified at 40% of the tensile strength. The compressive and tensile fracture energy were calculated according to Rots [33] equal to 40N/mm and 0.05N/mm, respectively. The cohesion was specified as 1.5 times larger than the tensile strength according to the relation that was proposed by Cur [34]. Following the Mohr-Coulomb failure criterion and considering the value of shear strength of the masonry as was obtained from the experimental results (section 2 of this paper), the friction angle (φ) is equal to 20 degrees. These values are then used to calculate the shear fracture energy according to equations included in DIANA FEA [19].

Table 1 – Material properties for TRM model.

Total strain crack model with fiber reinforced concrete		
	Glass –TRM	Carbon-TRM
Elastic modulus (GPa)	30.00	34.00
Total crack strain model	**Crack orientation Rotating**	
Tensile behavior	**Fib Fiber Reinforced Concrete**	
Tensile strength (MPa)	2.72	5.57
Tensile stress point I (MPa)	2.72	5.57
Strain at point I (%)	0.00009	0.00017
Tensile stress point J (MPa)	2.72	5.57
Tensile strain point J (%)	0.0021	0.001
Tensile stress point **k**(MPa)	12	15
Tensile strain point K (%)	0.015	0.007
Ultimate strain (%)	0.015	0.007

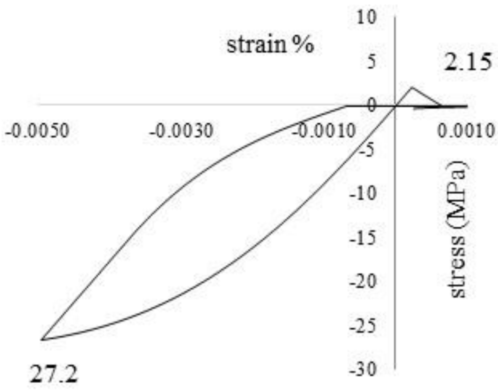


Fig. 4 – Total Strain Crack model

Table 2– Material properties for Interface model

	Y direction	X direction
Normal stiffness(Kn)	6000N /mm³	3000N /mm³
Shear stiffness (Ks)	60 N /mm³	30 N /mm³
Friction angle (φ)	30 degree	30 degree
Dilatancy (ψ)	0	0
Model for gap appearance	Brittle	Brittle
Tensile strength	1e-10 N /mm²	1e-10 N /mm²

An interface gap model, plasticity based proposed by Lourenço and Rots [31] was used for the interface elements, which describes the interaction between the masonry infill wall and the bounding RC frame. Therefore, in order to capture the gap opening and sliding between masonry infill and RC frame, the Coulomb friction model is used. The model includes a tension cut-off for tensile failure (mode I), a Coulomb friction envelope for shear failure (mode II) and a gap mode for compressive failure. In this study, it was decided to define the required material properties of the interface model using recommendations (equations) available in the literature ([32][35][36]) and at the same time by fitting the global and local numerical results to the results obtained from the experimental case-study regarding the gap opening and sliding. The interface Coulomb-friction model is defined in DIANA FEA with the parameters shown in Table 2. More details regarding the choice of these parameters can be found in Filippou et al. [20,37].

3.3 Calibration of the numerical model

In this part of the paper, the calibration of the numerical model is presented, by comparing the numerical results of the nonlinear cyclic analysis with experimental ones. Nonlinear cyclic analysis was performed (displacement control analysis) with the secant iteration scheme and automatic incrementation procedure, in which both the number of steps and the corresponding step size are automatically computed. The energy-based convergence criterion was applied with standard tolerance values (0.0001).

The comparison between the experimental (black line) and numerical (red line) results concerning the global performance of TRM-retrofitted masonry-infilled RC frame subjected to cyclic loading is presented in Fig. 5. Fig. 5(a) shows the base-shear versus top-floor displacement and Fig. 5(b) and (c) show the secant stiffness degradation and dissipated energy in relation to the number of cycles, respectively. The secant stiffness degradation of the model wall is expressed by (Eq. (1)):

$$K_i = \frac{|+V_{max,i}|+|-V_{max,j}|}{|+X_{max,i}|+|-x_{max,j}|} \quad (1)$$

where the j=i+1 and the |±Vmax,i| is the absolute value of the positive and negative peak base shear value of i^{th} cycle, and |±xmax,i| is the absolute value of displacement corresponding to the positive and negative peak base shear of the of i^{th} cycle. For easy calculations, the evolution of the dissipated energy of the model is expressed by (Eq. (2)):

$$S_i = S_{i-1} + 0.5 * (V_{b,i} + V_{b,i-1}) * (X_{b,i} + X_{b,i-1}) \quad (2)$$

where $(V_{b,i}, V_{b,i-1})$ is the base shear in two consecutive points of the response and the $(X_{b,i} + X_{b,i-1})$ is the corresponding displacement.

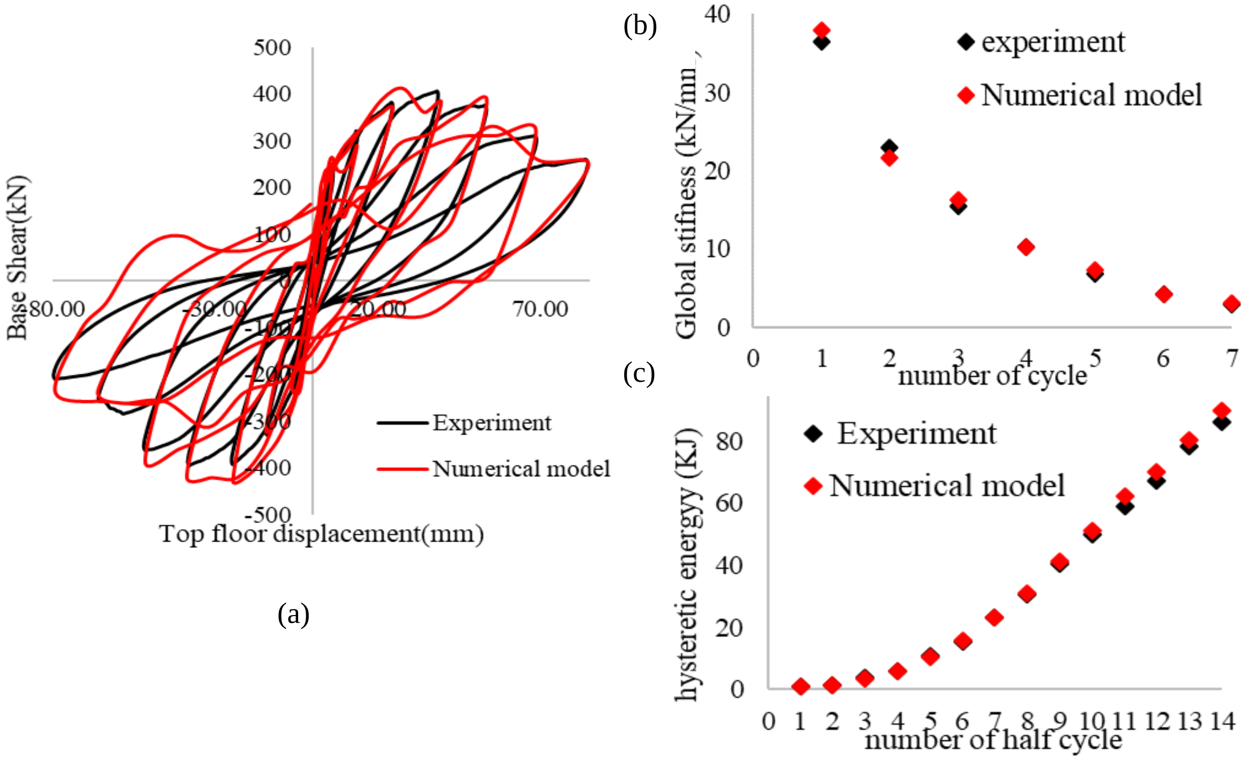


Fig. 5 – Comparison between experimental and numerical model results in terms of (a) base-shear top- floor displacement hysteric curves, (b) global stiffness and (c) global dissipated energy cycle.

Numerical results and experimental data of the TRM-masonry-infilled RC frame have been compared (Fig.5) and are in good agreement with the experimental ones regarding initial stiffness, stiffness degradation, maximum shear force and energy dissipation in a cycle. Based on the results from Fig. 5(a) and Fig. 5 (b), the shear-force capacity and the energy dissipation for the last cycle of unloading is overestimated by 15 % and 6 %, respectively. In addition, the proposed numerical model is capable of detecting the major features and crack propagation of the experimental behavior of the TRM-retrofitted masonry-infilled RC frame[20,37] .

4. Parametric study

After the calibration of the numerical model, numerical experiments (case studies) through a parametric study are performed to evaluate the influence of the bond condition at the interface between TRM and RC frame members, on the behavior of the retrofitted structure under cyclic loading. A parametric investigation of the response of the calibrated model is undertaken in order to assess the effectiveness of placing textile-based anchors for increasing the bond condition between the retrofitted wall and the surrounding frame. Three different configurations are considered; Case 1: the TRM elements of the beams and columns bridge the gap and are connected to the TRM elements of the masonry, Case 2: same as above for the columns but for the beams the TRM elements are fully anchored on the beams, and Case 3: the TRM elements of the wall are fully anchored on the beams and columns. The above cases apply for the first floor while for the rest of the floors Case 1 applies for all cases.

The comparison between the numerical results of the three different configurations in terms of stiffness and energy dissipation is presented in Fig.6 (a) and (b) respectively.

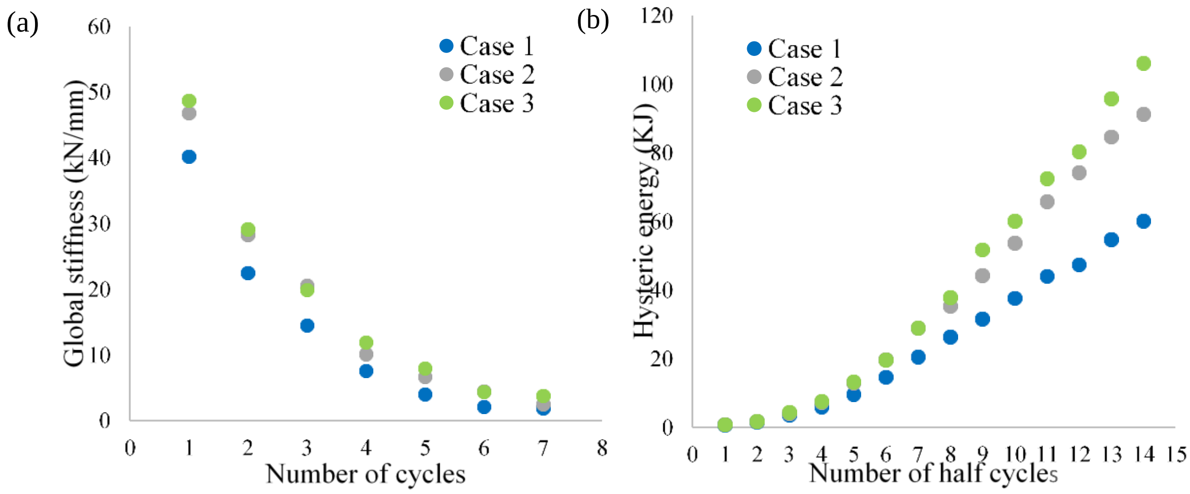
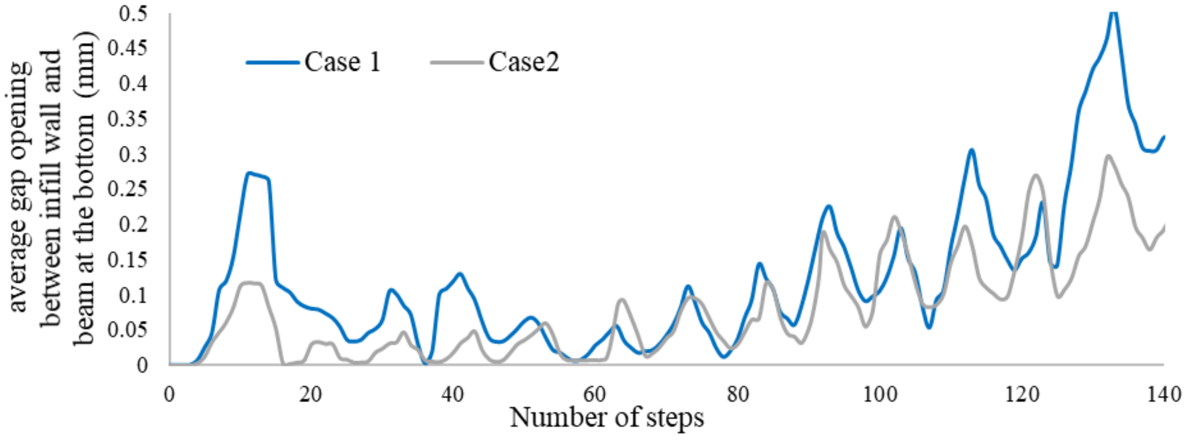


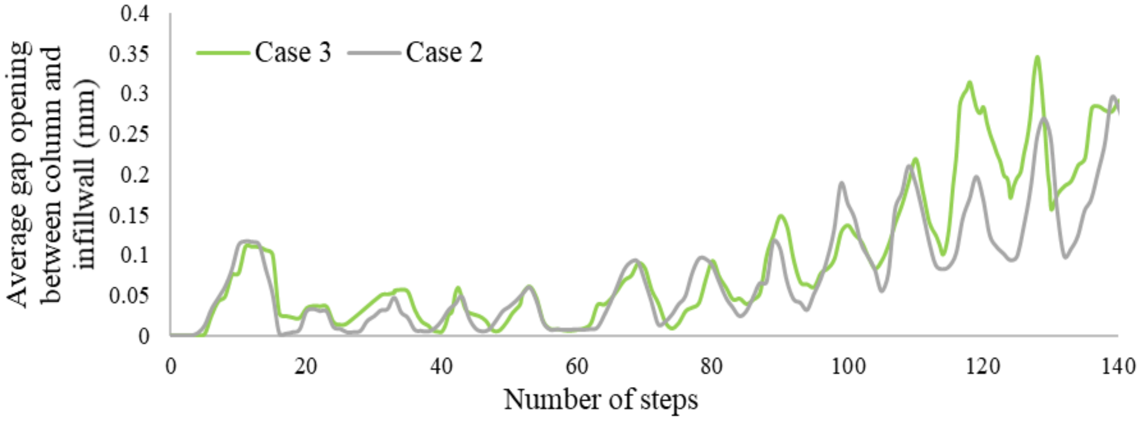
Fig. 6 – Comparison between numerical model results of three different configurations in terms of (a) global stiffness and (b) energy dissipation.

From Fig.6 (a) and (b) it is observed that comparing the results obtained from Case 2 with those obtained from Case 1, the global stiffness and the dissipated energy is increased by about 26-100% and 20-55%, respectively. In addition, comparing the results of Case 3 with those of Case 1, the global stiffness and the dissipated energy is increased by about 30-110% and 28-60%, respectively. Furthermore, comparing the results of Case 3 with the results obtained from Case 2 the dissipated energy and the stiffness are almost the same until the fourth cycle of loading, while the dissipated energy and the stiffness at the last cycles of loading is increased by about 12-17%. Therefore, the numerical results showed that fully anchoring the TRM on the columns, in addition to the full anchors of the beams, does not have significant contribution to the lateral capacity, stiffness, and dissipated energy of the structure.

The average gap opening, at the first floor, between infill wall and beam at the bottom of the structure is presented in Fig.7(a) and that between infill masonry and column in Fig.7(b). The infill-frame separation occurred at the very early stages of loading in the experiment and was reproduced in the numerical simulation [37]. From Fig.7(a) it is observed that the gap opening at the bottom of the structure for Case 2 is about 2 times smaller than that of Case 1, at the first and last cycles of loading. In addition, the results show that the gap opening between masonry infill and column for Case 2 is almost the same with Case 3 (Fig.7(b)). Therefore, fully anchoring the TRM on the columns, in addition to the full anchors on the beams, does not decrease significantly the gap opening between masonry infill and columns.



(a)



(b)

Fig. 7 – Comparison between numerical model results of three different cases in terms of average gap opening between (a) infill wall and column and (b) infill wall and beam

5. Conclusions

A numerical model that simulates the in-plane nonlinear behavior of a masonry-infilled RC frame retrofitted with TRM under cyclic loading using DIANA FEA software is presented in this paper. The test was conducted on a 2:3 scale three-storey structure with non-seismic design and detailing, subjected to in-plane cyclic loading through displacement control load. In this study, constitutive models based on the smeared total strain crack approach for each component of the structural system were selected and calibrated based on the experimental results or inverse fitting with clear identification and justification. The numerical model was capable of simulating the in-plane nonlinear behavior of the TRM retrofitted masonry-infilled RC frame with good accuracy in terms of initial stiffness, stiffness degradation and the maximum shear capacity.

After the calibration of the numerical model, numerical experiments (case studies) through a parametric study were performed to evaluate the influence of bond condition at the interface between TRM and RC frame members on the behavior of the retrofitted structure under cyclic loading. In this parametric study, three different configurations were considered; Case 1: the TRM elements of the beams and columns bridge the gap and are connected to the TRM elements of the masonry, Case 2: same as above for the columns but for the beams the TRM elements are fully anchored on the beams, and Case 3: the TRM elements of the wall are fully anchored on the beams and columns. The above cases apply for the first floor while for the rest of the floors Case 1 applies for all cases. The numerical results showed that fully anchoring the TRM on the columns, in addition to the full anchors on the beams, does not have significant contribution to the increase of the lateral capacity, stiffness, and dissipated energy of the structure, and on the decrease of the gap at the interfaces.

6. References

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