Experimental investigation of Ferro-cement laminated masonry infilled in RC frame
Part 1: Experimental program

Keywords
Masonry infill Ferro-cement
Strengthening Infilled RC frame

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1. Introduction:

Seismic strengthening of RC buildings is one of the most important concern for structural engineers, especially in developing countries which has already been proved by the severe damage and large number of injuries during the past earthquakes, such as Nepal Earthquake 2015. RC buildings with masonry infill are one of the most popular structures in developing countries. The masonry infill walls are used as partition walls and commonly considered nonstructural elements. In this context, strengthening of existing non-structural component of RC frame, i.e. infill masonry, and using it as structural element would be a feasible and low cost solution. Ferro-cement (FC) lamination, Textile mortar reinforcement (TRM), Fiber reinforced mortar etc. are probable candidates for masonry strengthening. Among these methods, Ferro-cement lamination is low cost, can be easily applied and low labor intensive.

In general, Ferro-cement retrofitting of masonry refers to the application of an initial mortar layer on the both faces of masonry wall which is followed by the placement of steel wire mesh and a second mortar layer. Some anchorages are also being used to attach wire-mesh to masonry and RC frame. Though, Ferro-cement has been studied for decades as a construction material, there is no design specification e.g. amount of mesh reinforcement, mortar thickness etc. for using as a shear strengthening material on unreinforced infilled masonry. In addition, the estimation of improvement of seismic capacity by Ferro-cement is still unclear. Therefore, the objective of this study is to experimentally investigate the seismic capacity of Ferro-cement laminated masonry infilled RC frame. Part 1 of this study will introduce the experimental program and main results. Part 2 shows the analysis and discussion of the experimental results.

2. Literature review:

In this study, primarily experimental results of several half scaled masonry infilled RC frames, with and without Ferro-cement retrofitting, have been acquired from literature [1-7] to get an idea about the practices in research field. All the studied FC laminated masonry walls contain square wire mesh on solid or hollow bricks. The lateral contribution of Ferro-cement layer has been determined from the difference in lateral capacity of retrofitted and without retrofitted specimens. Afterward, the shear stress on FC lamination (τ_{FC}) has been computed considering cross sectional area of FC laminate. Figure 1 shows the relation of in-plane shear strength of Ferro-cement to the area of wire-mesh. The shear stress on laminate is presented as a function of normalized horizontal mesh reinforcement area (A_{hs}/A_{mas}), where A_{hs} = total area of horizontal mesh reinforcement and A_{mas} = horizontal cross sectional area of masonry (length x thickness). As shown in Figure 1, the previous studies had horizontal mesh reinforcement between 0.05~0.8% of the horizontal masonry area. The shear stress on FC layer varied greatly between specimens. This large variation in past experimental results could be due to varying materials types and connections of Ferro-cement layer with the surrounding RC frame.

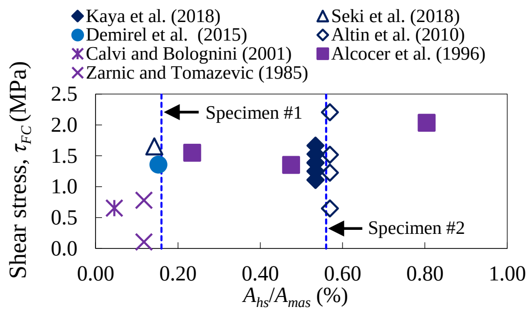

Figure 1: Shear strength of FC layer as a function of mesh reinforcement ratio

2. Experimental Program:

The influence of area of wire-mesh on shear strength capacity is unclear in the literature review. Therefore, two specimens were designed and retrofitted with wire mesh considering the lower and upper boundary of mesh reinforcement ratio from literature survey and set to be 0.16% and 0.56% of horizontal masonry area as shown by dotted blue lines in Figure 1.

2.1 Details of Specimens:

Two half scaled masonry infilled RC frames have been constructed and infill masonry has been retrofitted with Ferro-cement. The control infilled masonry specimen (IM) (without retrofit) has been adopted from a previous study by Alwashali H. et al. [8]. The Ferro-cement laminated specimens (IM-FC-1 and IM-FC-2) have the same geometric configuration and material composition as the control specimen (IM). The overall geometry of RC frame is shown in Figure 2(a). The details of all the specimens are shown in Table 1. The construction procedure of specimens is as follow: First, RC frame has been constructed and then masonry panel has been built inside the frame, with solid bricks of 210x100x60 mm, in running bond manner. After seven days of masonry construction, 10mm thick mortar has been mounted on the both faces of masonry wall. This is followed by the attachment of square wire mesh to the RC frame and masonry wall. The wire mesh has been connected to surrounding RC frame with bolt (inserted into pre-installed thread) and steel plate as shown in Figure 2(b). In addition, the wire mesh has been connected with masonry infill by 32mm nails to hold the wire mesh in place during application of second layer mortar. The nails have been placed in drilled holes at a horizontal and vertical center to center distance of 250mm and 500mm, respectively. After seven days, the second layer of mortar, having 15mm thickness, has been applied on wire mesh.

Table 1: Details of specimen

Specimen	RC column (mm)	Wire-mesh: Wire diameter (mm)	Wire-mesh: Spacing (mm)	Wire-mesh: Mesh reinforcement (%)
IM	200x200	-	-	-
IM-FC-1		0.9	5.45	0.16
IM-FC-2		1.6	4.75	0.56

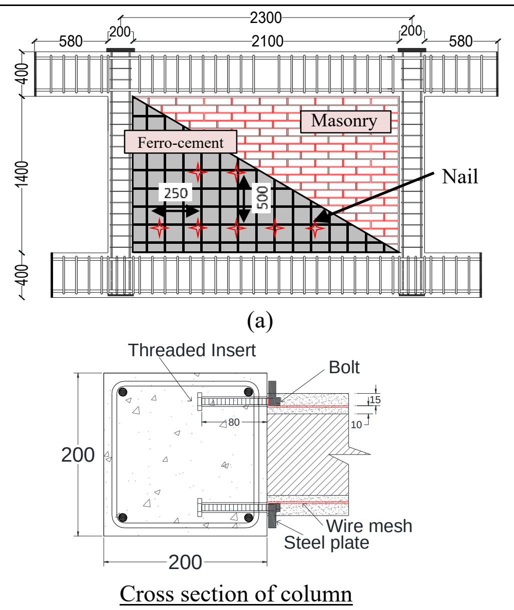

Figure 2: (a) Geometry of masonry infilled RC frame and (b) connection of wire mesh to RC frame (dimensions are in mm)

2.2 Material properties:

The material tests were conducted for each specimen individually and simultaneously with the frame loading. The mechanical properties of concrete, reinforcing steel, masonry, mortar and wire-mesh are shown in Table 2.

2.3 Instrumentation and Loading:

All specimens were subjected to cyclic lateral loading and 200kN constant vertical loads on each column. The cyclic lateral loading program consisted of two cycles for each lateral drift of 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0%. The lateral drift is defined as the ratio of the top lateral displacement, measured at the center of beam, (h=1600mm).

3. Experimental results:

3.1 Response under cyclic lateral load:

The overall lateral response, along with envelope curves, of all the tested specimens are shown in Figure 3(a)-(c). Comparing the peak resistance of strengthened and un-strengthened specimens, it can be summarized that Ferro-cement lamination on masonry, irrespective to the mesh reinforcement content, showed a lateral capacity which is almost twice than that of for masonry infilled RC frame. The FC laminated specimen IM-FC-1 showed 30% capacity drop after peak resistance which is less than that of for specimen IM, where capacity drop was 44%. The specimen IM-FC-2, showed very gradual post peak declination which indicates a relatively ductile behavior. Detailed analysis, discussion and conclusion are shown in Part 2.

Table 2: Material properties (all values are in MPa)

Specimen	$f_{c'}$	f_y	f_{mas}	$f_{mor,mas}$	$f_{mor,FC}$	$f_{y,wm}$
IM	24.2	350	17.3	20	-	-
IM-FC-1	24.9	384	27.3	37	23	378
IM-FC-2	26.5		29.5	34	29	318

$f_{c'}$= concrete compressive strength, f_y/ $f_{y,wm}$ = yield strength of long reinforcement (D10) / wire mesh, f_{mas}= masonry compressive strength and $f_{mor,FC}$ /$f_{mor,FC}$ = compressive strength of masonry joint/Ferro-cement mortar.

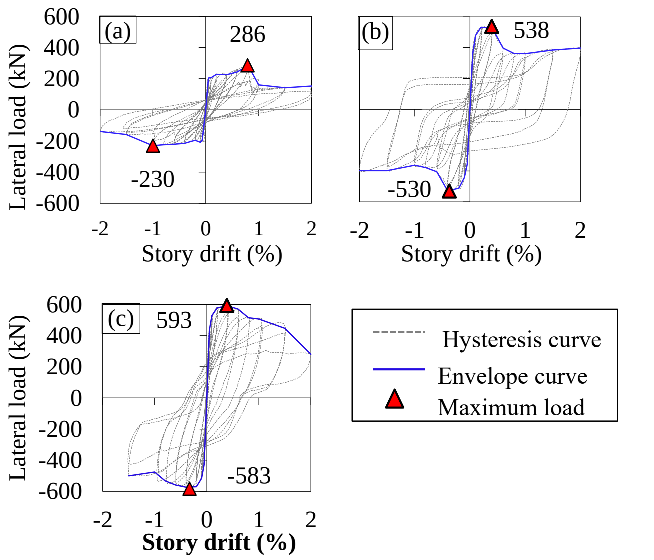

Figure 3: Lateral load-story drift relationship of specimen (a) IM, (b) IM-FC-1, and (c) IM-FC-2

References

1) Kaya, F., Tekeli, H., and Anil, Ö.: Experimental behavior of strengthening of masonry infilled reinforced concrete frames by adding rebar - reinforced stucco, Structural Concrete, pp. 1-14, 2018.2
2) Seki, M., Popa, V., Lozinca, E., Dutu, A., and Papurcu, A.: Experimental study on retrofit technologies for RC frames with infilled brick masonry walls in developing countries, In Proceedings of the 16th ECEE, Romania, 2018.6
3) Demirel, I. O., Yakut, A, Binici, B. and Canbay, E.: An Experimental Investigation of Infill Behaviour in RC Frames, In Proc. of the 10th PCEE, Australia, 2015.11
4) Altın, S., Anıl, Ö., Kopraman, Y., and Belgin, Ç.: Strengthening masonry infill walls with reinforced plaster, In Proc. of the Institution of Civil Engineers-Structures and Buildings, 163, pp. 331-342, 2010
5) Calvi, G. M., & Bolognini, D.: Seismic response of reinforced concrete frames infilled with weakly reinforced masonry panels, Jour. of Earthq. Engg., Vol. 5, pp. 153-185, 2001
6) Alcocer, S. M., Ruiz, J., Pineda, J. A., and Zepeda, J. A.: Retrofitting of confined masonry walls with welded wire mesh, In Proc. of the 11th WCEE, 1996.6
7) Žarnić, R., and Tomaževič, M.: Study of the behaviour of masonry infilled reinforced concrete frames subjected to seismic loading, 1985.
8) Alwashali, H., Torihata, Y., Jin, K., and Maeda, M. (2018). Bul. of Earthq. Engg., 16 (2018), 1373-1397.

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