Workshop for Young Researchers
Feb. 13, 2020 Tokyo Tech

Investigation on Ferro-cement laminated masonry infilled RC frame and capacity evaluation

Debasish Sen[1], Hamood Alwashali [2], Zasiah Tafheem[3], Md. Shafiul Islam[4], Masaki Maeda[5]

[1]*Tohoku University, dsendip@rcl.archi.tohoku.ac.jp*
[2]*Tohoku University, hamood@rcl.archi.tohoku.ac.jp*
[3]*Tohoku University, zasiah@rcl.archi.tohoku.ac.jp*
[4]*Tohoku University, shafiul@rcl.archi.tohoku.ac.jp*
[5]*Tohoku University, maeda@rcl.archi.tohoku.ac.jp*

Abstract— **This study aims to investigate the effect of mesh reinforcement area ratio in ferro-cement on lateral behaviour of ferro-cement laminated masonry infilled RC frame. The experimental program consisted of two masonry infilled RC frames, where infill masonries have been strengthened by ferro-cement lamination with relatively low and high mesh ratio. The experimental results demonstrated that the failure mechanism is flexural yielding of RC frame at peak resistance, however, column punching and top joint failure has also been observed at post peak stage of specimen with low mesh reinforcement. The observed failure modes have been evaluated and verified with fair agreement.**

I. Introduction

Development of low cost strengthening method of RC buildings is very important, especially for developing countries. Masonry infilled RC frame is very common structural system in developing countries. Therefore, utilization of those existing masonry walls, with ferro-cement (FC) lamination, to strengthen the RC buildings would be an economically viable solution. Ferro-cement is steel wire mesh embedded mortar layer which is relatively cheaper and easier to apply at site. However, in building design codes there is no guideline for ferro-cement lamination design and construction.

This study aims to investigate the effect of the amount of mesh reinforcement in ferro-cement on structural behaviour of ferro-cement retrofitted masonry infilled RC frame and also to evaluate strength capacities of the observed failure mechanisms.

II. Experimental Program

A. Specimen Details

Two half scaled ferro-cement strengthened masonry infilled RC frames have been studied. Details of specimens are shown in Table I. The main variable was wire mesh reinforcement ratio in ferro-cement. The overall geometry of the ferro-cement retrofitted RC frames is shown in Figure 1.

B. Material Properties

The material tests have been conducted simultaneously with the frame loading. The mechanical properties of concrete reinforcing steel, masonry, and ferro-cement are shown in Table II.

TABLE I: Details of Specimen

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

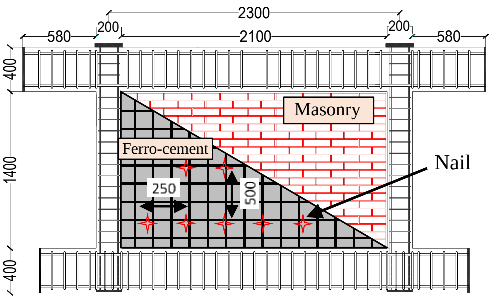

Figure 1: Geometry of masonry infilled RC frame (dimensions are in mm)

TABLE II: Mechanical Properties of Materials (all values are in MPa)

Specimen	$f_{c'}$	f_y	f_{mas}	$f_{mor,FC}$	$f_{u,wm}$
IM-FC-1	24	350	27	26	378
IM-FC-2	26		29	29	318

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

III. Experimental Results

A. Lateral Behaviour

The hysteresis curves, along with envelope curves, of ferro-cement laminated masonry infilled RC frame (IM-FC-1 and IM-FC-2) are shown in Figure 2. Comparing the peak resistance, it can be summarized that wire mesh ratio did not affect the lateral strength much because at peak resistance load transfer mechanism has been mainly governed by flexure for both specimens which is discussed in the following subsection. Specimen with 0.16% mesh ratio, IM-FC-1, showed 25% capacity drop after peak resistance due to bond failure at top joint following by sliding. The specimen with 0.56% mesh ratio IM-FC-2, showed very gradual post peak declination which indicates a relatively ductile behavior.

B. *Failure Mechanism Identification*

The contributions of shear and flexure deformation in total story deformation are shown in Figure 3. In specimen IM-FC-1, flexural contribution is relatively more at lower story drifts as shown in Figure 3(a). At higher story drifts, tension column experienced direct punching shear failure following sliding at top joint which led to an increase in shear deformation. Another strengthened RC frame, namely IM-FC-2, experienced a flexure domination throughout course of the lateral drift as shown in Figure 3(b). In other word, IM-FC-1 behaved as flexural wall at the drift lower than 0.4% and then failed in punching shear of column, however IM-FC-2 specimen behaved like a flexural wall for all story drifts.

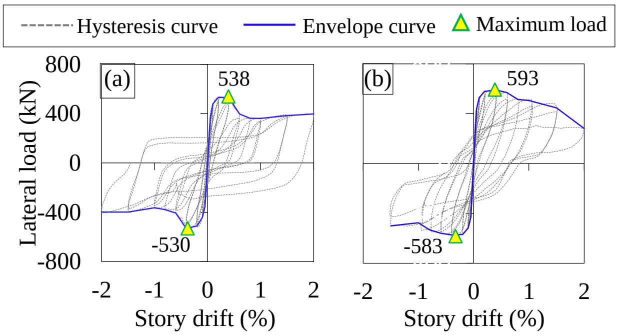

Figure 2: Lateral load-story drift relationship of specimen (a) IM-FC-1, and (b) IM-FC-2

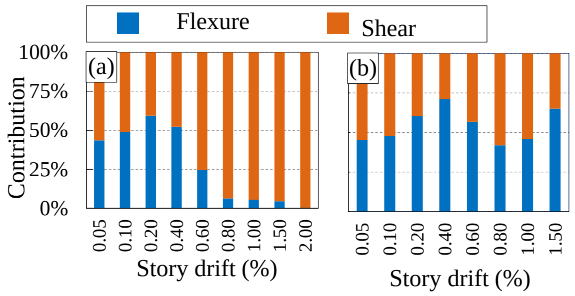

Figure 3: Contribution of shear and flexural components in story deformation of (a) IM-FC-1, and (c) IM-FC-2

C. *Lateral Strength Evaluation*

Flexural yielding of RC frame

The lateral capacity at flexural yielding (Q_{fl}), as shown in Figure 4, of the FC laminated masonry infill in RC frame has been computed from flexural theory, using Eq. 1. In ultimate moment calculation by Eq. 2, the contribution of wire meshes has been ignored for simplicity because wire meshes have been connected at intervals with stub beam.

$$Q_{fl} = {M_u}/{h_o} \tag{1}$$

$$M_u = a_t f_y l_c + 0.5 N l_c \tag{2}$$

where, M_u = ultimate moment capacity of RC frame, h_o = clear height of column, a_t = cross sectional area of column longitudinal reinforcements, f_y = yield strength of column longitudinal reinforcement, l_c = c/c distance of boundary columns, N = axial load on RC columns.

Column punching and top joint failure

The lateral capacity at column punching and top joint failure (Q_{sh}), as shown in Figure 5, of the FC laminated masonry infill in RC frame, which actually occurred in specimen IM-FC-1 at higher story drifts. The total residual shear capacity (Q_{sh}) can be evaluated by Eq. 3.

$$Q_{sh} = {}_{ps}Q_c + {}_{js}Q_w + {}_{f}Q_c \tag{3}$$

where, ${}_{ps}Q_c$ = punching shear resistance of tension column, ${}_{js}Q_w$ = shear resistance at construction joint, and ${}_{f}Q_c$ = flexural shear resistance of compression column.

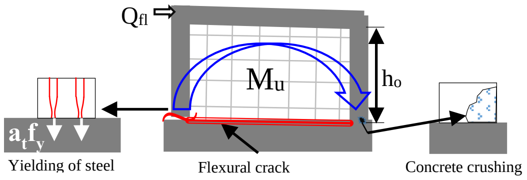

Figure 4: Load transfer mechanism of flexural yielding

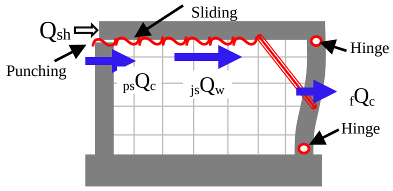

Figure 5: Load transfer mechanism of column punching and joint failure

IV. VALIDATION OF CAPACITY EVALUATION

All the computed capacities are shown in Table 3 and Figure 6. It is evident by comparing experimental and calculated values (Eq.1), that the flexural capacity without considering wire mesh can give fair approximation of lateral load capacity of FC retrofitted masonry infilled RC frame. The plot on Figure 6(a) also shows that the proposed estimation method gave a conservative estimation of residual shear resistance.

Table III: Lateral capacity of specimens

Lateral capacity (kN)		Specimen	
		IM-FC-1	IM-FC-2
Experimental	Peak (avg.)	534	588
	Residual (avg.)	373	-
Flexural capacity, Q_{fl}		494	494
Residual shear capacity, Q_{sh}		278	481

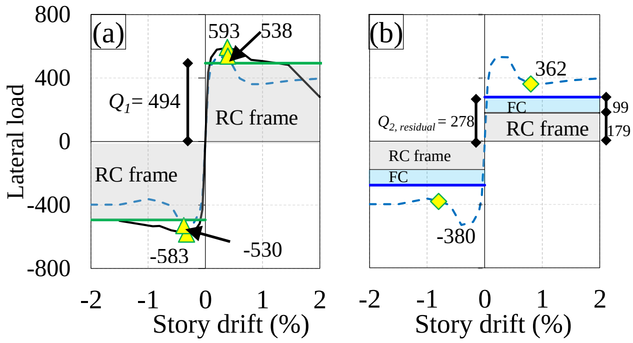

Figure 6: Calculated (a) capacity of flexural yielding of RC frame and (b) residual shear capacity at column punching and joint failure

V. Conclusions

Following conclusions can be drawn from this study-

a) The observed failure mechanism was mainly flexural yielding of RC frame at peak resistance. Therefore, wire mesh ratio, 0.16% and 0.56%, did not strongly affect the lateral capacity, however controlled post peak behaviour.

b) Lateral capacity estimation method for the observed failure modes have been proposed and verified with fare agreement.

Acknowledgment

This research is supported by SATREPS project lead by Prof. Nakano Yoshiaki, U. Tokyo and JSPS KAKENHI Grant Number JP18H01578 (Principal investigator: Prof. Masaki Maeda, Tohoku University).