Structural Engineering and Mechanics, *Vol. 61, No. 4 (2017) 511-518*
DOI: https://doi.org/10.12989/sem.2017.61.4.511

Effect of Ferro-cement retrofit in the stiffened infill RC frame

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(Received June 20, 2016, Revised November 3, 2016, Accepted November 22, 2016)

Abstract. This paper presents an experimental investigation on the contribution of RCC strip in the in-filled RC frames. In this research, two frames were tested to study the behavior of retrofitted RC frame under cyclic loading. In the two frame, one was three bay four storey R.C frame with central bay brick infill with RCC strip in-between brick layers and the other was retrofitted frame with same stiffened brick work. Effective rehabilitation is required some times to strengthened the RC frames. Ferrocement concrete strengthening was used to retrofit the frame after the frame was partially collapsed. The main effects of the frames were investigated in terms of displacement, stiffness, ductility and energy dissipation capacity. Diagonal cracks in the infill bays were entirely eliminated by introducing two monolithic RCC strips. Thus more stability of the frame was obtained by providing RCC strips in the infill bays. Load carrying capacity of the frame was increased by enlarging the section in the retrofitted area.

Keywords: RCC strip; Ferro-cement retrofit; load-displacement; stiffness; ductility; energy dissipation; load carrying capacity

1. Introduction

Infilled-frames have often demonstrated good earthquake-resistant behavior, at least for serviceability level earthquakes in which the masonry infill can provide enhanced stiffness and strength. Brick infill is valid upto its failure. After brick failure the frame is acted as bare frame. The failure of infill can be delay by providing stiffening elements. If ductile members are used to form a structure, the structure can undergo large deformations before failure. This is beneficial to the users of the structures, as in case of overloading, if the structure is to collapse, it will undergo large deformations before failure and thus provides warning to the occupants. This gives a notice to the occupants and provides sufficient time for taking preventive measures. This will reduce loss of life. Structures are subjected to unexpected overloads, load reversals, impact and structural movements due to foundation settlement and volume changes. These items are generally ignored in the analysis and design. If a structure is ductile than taken care by the presence of some ductility in the structure. In this study, RCC strips have been embedded in the brick infill bay. Partially damaged frame can be utilized to life cycle by providing appropriate retrofitting technology. Here in this study, Ferro cement retrofit has been used to strengthen the frame. Extensive literature reviews have been carried out during this study. Al-Chaar *et al.* (2002) conducted an experimental program to evaluate the behavior of five half-scale, single-story laboratory models with different numbers of bays. The results indicated that infilled RC frames exhibit significantly higher ultimate strength, residual strength, and initial stiffness than bare frames without compromising any ductility in the load-deflection response. Alok Madan *et al.* (2015) have been studied to numerically evaluate the adequacy of the capacity spectrum method using pushover analysis for performance based design of masonry infilled R/C frames for near-field earthquake ground motions. Asteris *et al.* (2003), have been studied the influence of the masonry infill panel opening in the reduction of the infilled frames stiffness. A parametric study has been carried out using as parameters the position and the percentage of the masonry infill panel opening for the case of one-story one-bay infilled frame. Calvi (2000) has been conducted a research on the behaviour of frames infilled with non-reinforced and MURFOR reinforced clay brick masonry walls. Cavaleri (2003) studied a new time domain identification technique for systems under Gaussian white noise input is presented, requiring for its application the measurement of the system response but no information about input intensity. The technique proposed is based on the statistic moment equations derived by using a special class of mathematical models named “potential models”. Della Corte *et al.* (2008) studied Two lateral-loading inelastic tests on a real masonry-infilled reinforced concrete (RC) building. Das *et al.* (2004) have been studied brick masonry infills in seismic design of RC framed buildings. Dubey *et al* (1996) have been conducted experimental analysis on the effect of reinforcement on ultimate strength of infilled frames, subjected to lateral loads. Ganesan *et al*. (2011) studied the effect of ferrocement wrapping system on strength and behavior of RC frames under reversed lateral cyclic loading. Mondala *et al.* (2008) studied a reduction factor for effective width of diagonal strut over

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http://www.techno-press.org/?journal=sem&subpage=8 ISSN: 1225-4568 (Print), 1598-6217 (Online)

that of the solid reinforced concrete (RC) infilled frame to calculate its initial lateral stiffness when a central window opening is present. The study is based on initial lateral stiffness which is taken at 10% of the lateral strength of the infilled frames. Zovkic *et al*. (2013) have been studied a contribution of various types of masonry infill to the behaviour of reinforced concrete frames under lateral loads is presented. Kakaletsis *et al*. (2008) investigated the influence of masonry infills with openings on the seismic performance of reinforced concrete (R/C) frames that were designed in accordance with modern codes provisions. Kara *et al*. (2006) have been conducted an investigation on the behavior of non-ductile reinforced concrete (RC) frames strengthened by introducing partial infills under cyclic lateral loading. Seven one-bay, two story, 1/3-scale test specimens were constructed and tested. The test frames had deficiencies commonly observed in residential RC buildings in Turkey. Korkmaz *et al.* (2010) studied to report on an experimental study about Turkish Earthquake Code on suggested strengthening method. The proposed method uses existing brick infill walls and the strengthening is done with the application of external mesh reinforcement and plaster. 5 nonductile 1/2 scaled, one bay, two storey RC specimens were tested under a reversed cyclic loading. Lila *et al*. (2015) have been conducted experimental tests to study the behavior of different single story frames infilled with brick masonry under the in-plane lateral load influence. Mehmet Kamanli *et al*. (2015) have been carried out the tests to an alternative strengthening technique for reinforced concrete buildings, which could be applied with minimum disturbance to the occupants. Generic specimen is two floors and one bay RC frame in 1/2 scales. Nateghi-Elahi *et al.* (2008), studied the method of equivalent strut for modeling infill walls is analyzed with the aid of finite element (FE) procedure, and then by defining the compressive and tensile strut behavior, URM infills are modeled both in un-retrofitted and retrofitted states. The results of nonlinear push-over analysis show that the proposed model can give the behavior close to the experimental specimens. Anil *et al.* (2007) have been studied to investigate the behaviour of ductile reinforced concrete (RC) frames strengthened by introducing partial infills under cyclic lateral loading. Perumal Pillai *et al.* (1994) have assessed the structural response of two, quarter size five storey, reinforced concrete frames with the without brick infill for earthquake performance based on ductility and energy absorption capacity. Schwarz *et al*. (2015) conducted an experimental investigation to assess some aspects of the influence of non-structural masonry infill walls on seismic resistance of RC frames. Earthquake code IS: 1893-2002 has been used for seismic load calculations. In this research, two three bay four RC frames with central bay brick infill in which the reinforcement strip from the frame was constructed in between each two layers of brick. The frame was subjected to static cyclic loading, simulating earthquake effects.

1.1 Objective

The objective of this investigation is to study the frame with RCC strips in the infill panels and to study the effect of retrofitting strengthening techniques. Also the the experiments have been carried out to quantify the behavior in terms of load-displacement, ductility, energy dissipation capacity, and stiffness of one quarter size three bay four storey R.C frame with central bay stiffened brick infill after retrofitting by Ferro cement and cement mortar grouting.

2. Test setup of frames

2.1 Materials

Materials have been used in this research were ordinary Portland cement of 53 grade. The cement used was tested for various properties as per IS: 4031-1988 having specific gravity of 3.0. Brick work construction was carried out in the central bay with cement mortar 1:4. The thickness of the brick masonry panel was 100 mm. Crushed granite angular aggregate of size 12 mm nominal size as coarse aggregate having specific gravity of 2.71 has been used.. Natural river sand confirming to IS-383 zone II having specific gravity of 2.60 was used as fine aggregate. Locally available potable water confirming to IS 456 was used. Mix design for M30 concrete was done as per IS 10262 (2009).

2.2 Test setup

The RCC frames were setup on the test floor. Hydraulic jacks and load cells have been used to apply lateral loads at top and middle floor levels. Linear variable displacement transducers LVDT have been used to measure displacements of frame as shown in Fig. 1. For each loading the readings were taken on LVDTs and also strain gauge readings were taken.

In this study, first frame was three bay four storey R.C frame with central bay brick infill with reinforced concrete strip in-between brick layers in each bay and it was subjected to cyclic loading upto failure. Second frame was subjected to partial damage in the initial and it was taken to retrofitting by ferro-cement concrete in the places where cracks found. The normal frame was placed in test floor is shown in Fig. 2.

2.3 Testing

Cyclic loading was applied on the frame with the help of

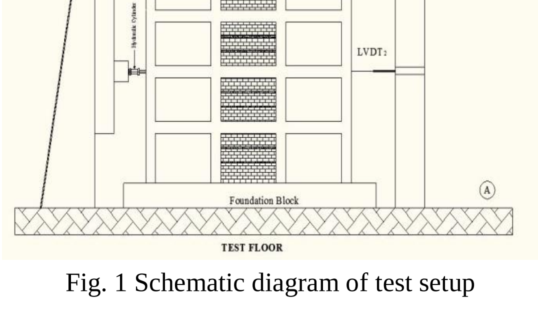

Fig. 1 Schematic diagram of test setup

Fig. 2 Test setup of normal frame

load cells. Concrete strains were recorded till the development of initial crack in the concrete and steel reinforcement strains were recorded upto maximum load. Second frame was tested up to partial damage of the frame. Then retrofitting was done in the places where cracks found by ferro-cement concrete technique. The sections were enlarged upto 15 mm and the cracks were filled using cement grouting techniques. The second frame was taken back from the test floor for retrofitting. The damaged brick portions were removed from the frame. Weld mesh of 16 mm spacing with 1.4 mm thickness was wrapped in the places where cracks found. Cement concrete mix consists of 1:1.5:3 with w/c ratio 0.4 was used for retrofitting with the application of 5 mm coarse aggregate. The thickness of ferro cement application was 15 mm. The frame was erected again on the testing platform and 100 mm thick brickwork was done on the middle bay. 20 mm thick concrete was laid in the RC strips.

2.4 Grouting

Grout injection was made to fill the voids in the frame. The main purpose of injections is to restore the original integrity of the retrofitted frame. The success of a retrofit by injection depends on the inject ability of the mix used, and on the injection technique adopted. The inject ability of the mix influences by mix's mechanical properties and its physical chemical compatibility with the frame to be retrofitted. The external surfaces are cleaned of non structural materials. Then, plastic injection holes are placed along the surface of the frame and were secured in place with epoxy sealants. After the sealant was cured, expansive cement and epoxy resin is injected into one port at a time, beginning at the lowest part of the frame until it was seen flowing from the opposite side of the frame (Fig. 3).

3. Experimental Investigations

3.1 Evaluation of load-deflection behavior of the frames

The relationship between Load-deflection of the first frame was observed upto elastic stage in the initial stage. Minor cracks were found when the load reached 120 kN, in

Fig. 3 Grouting done in retrofitted frame

between beams and brick work and brick work to RCC strips in the bottom storey. Since the RCC strips have been introduced in the brick infill, both RCC strips and brick works acted as integral parts and also were led to higher ductility and higher stiffness. RCC strips contributed to avoid the formation of diagonal cracks in the brick bays of the frame. Retrofitted frame was contributed to higher load carrying capacity. This was obtained by placing RCC strips and retrofitting along with the section enlargements in the portions. The relationship of Load-Deflection (P-Δ) curve in the normal frame without retrofit was

$$y = 2E^{-07}x^4 + 0.000x^3 - 0.042x^2 + 4.545x - 0.646 \quad (1)$$

with $R^2 = 0.999$ and the relationship of P-Δ curve in the retrofit frame was

$$y = -6E^{-10}x^6 + 3E^{-07}x^5 - 5E^{-05}x^4 + 0.004x^3 - 0.241x^2 + 7.837x + 2.623 \quad (2)$$

with R^2=0.997. The value are entered in Table 1 and Table 2 and the load-deflection behavior of the frames were shown in Fig. 4

Table 1 Load vs Deflection of frame without retrofit

Load Cycle	Load, kN	Deflection, mm
0	0	0
1	10	2.2
2	20	4.8
3	30	7.5
4	40	11.1
5	50	14.5
6	60	18.3
7	70	23
8	80	26.7
9	90	31.6
10	100	36.8
11	110	43
12	120	50.3
13	130	58.4
14	140	68
15	150	78
16	160	95
17	170	120.3
18	173	132

Table 2 Load vs Deflection of frame with retrofit

Load Cycle	Load, kN	Deflection, mm
0	0	0
1	10	1.00
2	20	2.20
3	30	3.70
4	40	5.40
5	50	7.50
6	60	9.70
7	70	12.30
8	80	15.40
9	90	18.80
10	100	22.00
11	110	27.00
12	120	33.50
13	130	39.40
14	140	45.00
15	150	50.00
16	160	57.00
17	170	65.00
18	180	73.50
19	190	90.00
20	200	107.50
21	210	123.90
22	220	137.80
23	230	155.00

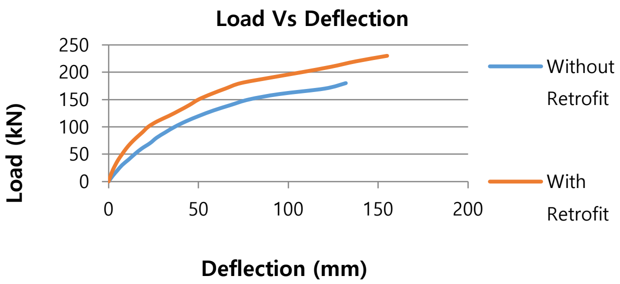

Fig. 4 Load vs Displacement of frames

3.2 Evaluation of stiffness of the frames

Stiffness of the frames was gradually reduced during cyclic loading in the initial stage. This was occurred due to bond failure, minute cracks formed in the frame. Stiffness was getting reduced higher due to yielding of steel reinforcements in the in-elastic stage. In the post cycle, cracks propagated and widened led to higher degradation of stiffness. Because of the presence of the RCC strips in the brick works led to higher stiffness of the frame. These strips contributed additional lateral load resisting capacity to the whole frame. Stiffness of the retrofitted frame was found higher than the normal frame. This was occurred due to retrofit and section enlargements. It is shown in Fig. 5. The value are entered in Table 3. The stiffness relationship of the normal frame was

$$y = 9E^{-07}x^6 + 2E^{-05}x^5 - 0.002x^4 + 0.035x^3 - 0.238x^2 + 0.433x + 4.305 \quad (3)$$

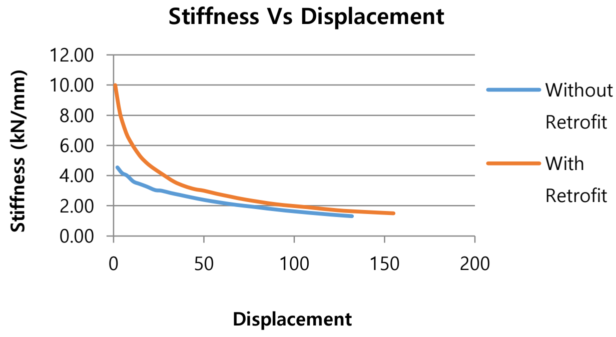

Fig. 5 Displacement vs Stiffness

Table 3 Stiffness vs Deflection

Deflection, mm		Stiffness, kN/mm	
Without Retrofit	With Retrofit	Without Retrofit	With Retrofit
2.2	1.00	4.55	10
4.8	2.20	4.17	9.1
7.5	3.70	4.00	8.1
11.1	5.40	3.60	7.4
14.5	7.50	3.45	6.7
18.3	9.70	3.28	6.2
23	12.30	3.04	5.7
26.7	15.40	3.00	5.2
31.6	18.80	2.85	4.8
36.8	22.00	2.72	4.5
43	27.00	2.56	4.1
50.3	33.50	2.39	3.6
58.4	39.40	2.23	3.3
68	45.00	2.06	3.1
78	50.00	1.92	3
95	57.00	1.68	2.8
120.3	65.00	1.41	2.6
132	73.50	1.31	2.4
_	90.00	_	2.1
_	107.50	_	1.9
_	123.90	_	1.7
_	137.80	_	1.6
_	155.00	_	1.5

with R^2=0.996 and that of retrofit frame was

$$y = 1E^{-06}x^6 - 7E^{-05}x^5 + 0.002x^4 - 0.028x^3 + 0.236x^2 - 1.620x + 11.46 \quad (4)$$

with R^2=0.999.

3.3 Evaluation of ductility of the frames

Ductility behavior allows a structure to undergo large plastic deformations with little decrease in strength. In this research, infill bay panel contributed more ductility than the plane panels. RCC strips contributed to more ductility of the frame. RCC strips reduced the brittle behaviour of brick work. Also these strips postponed the crack development in the brick work. Finally it was led to higher ductility. The

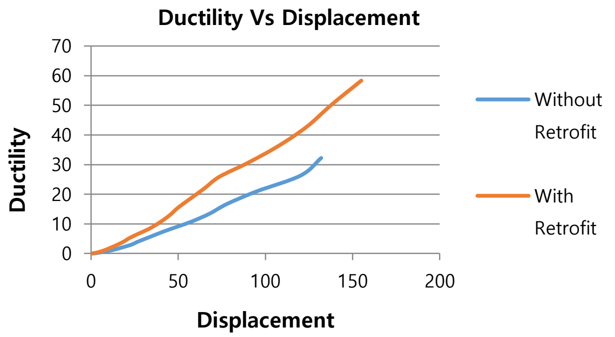

Fig. 6 Displacement vs Ductility

Table 4 Deflection vs Cumulative ductility

Deflection, mm		Cumulative Ductility	
Without Retrofit	With Retrofit	Without Retrofit	With Retrofit
0	0	0	0
2.2	1.00	0.10	0.05
4.8	2.20	0.30	0.17
7.5	3.70	0.60	0.37
11.1	5.40	0.98	0.65
14.5	7.50	1.47	1.05
18.3	9.70	2.12	1.56
23	12.30	2.95	2.21
26.7	15.40	3.94	3.03
31.6	18.80	5.08	4.02
36.8	22.00	6.30	5.19
43	27.00	7.71	6.61
50.3	33.50	9.21	8.39
58.4	39.40	10.94	10.47
68	45.00	13.43	12.85
78	50.00	16.72	15.50
95	57.00	20.96	18.51
120.3	65.00	26.33	21.95
132	73.50	32.22	25.84
_	90.00	_	30.60
_	107.50	_	36.29
_	123.90	_	42.85
_	137.80	_	50.14
_	155.00	_	58.34

ductility of normal frames were linearly increasing at the elastic stage. Subsequently, the ductility was steadily increasing due to the yielding of steel reinforcement and initiation of cracks. The ductility of retrofitted frame was on par with normal frame in the elastic stage, but appreciable at the inelastic stage. The ductility behavior of the normal frame was

$$y = 4E^{-06}x^5 - 2E^{-05}x^4 - 0.001x^3 + 0.013x^2 + 0.026x + 0.006 \quad (5)$$

with R^2=0.999 and the ductility behavior of the retrofit frame was

$$y = -8E^{-07}x^6 + 6E^{-05}x^5 - 0.001x^4 + 0.017x^3 - 0.100x^2 + 0.275x - 0.187 \quad (6)$$

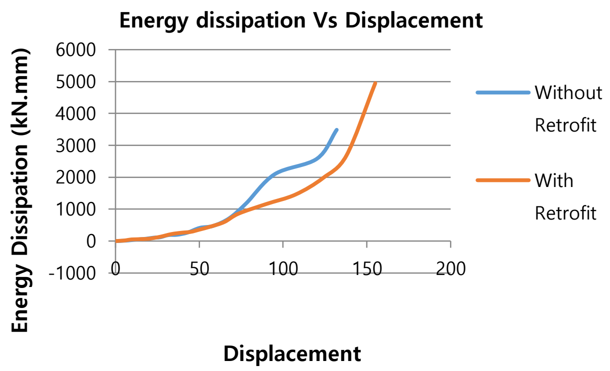

Fig. 7 Displacement vs Energy dissipation

Table 5 Deflection vs Energy dissipation

Deflection, mm		Cumulative Energy Dissipation, kN-mm	
Without Retrofit	With Retrofit	Without Retrofit	With Retrofit
0	0	0	0
2.2	1.00	0.10	0.05
4.8	2.20	0.30	0.17
7.5	3.70	0.60	0.37
11.1	5.40	0.98	0.65
14.5	7.50	1.47	1.05
18.3	9.70	2.12	1.56
23	12.30	2.95	2.21
26.7	15.40	3.94	3.03
31.6	18.80	5.08	4.02
36.8	22.00	6.30	5.19
43	27.00	7.71	6.61
50.3	33.50	9.21	8.39
58.4	39.40	10.94	10.47
68	45.00	13.43	12.85
78	50.00	16.72	15.50
95	57.00	20.96	18.51
120.3	65.00	26.33	21.95
132	73.50	32.22	25.84
_	90.00	_	30.60
_	107.50	_	36.29
_	123.90	_	42.85
_	137.80	_	50.14
_	155.00	_	58.34

with R^2=0.998, the ductility curve is shown in Fig. 6. The ductility values are entered in Table 4.

3.4 Evaluation of energy dissipation capacity

Capacity of energy dissipation in reinforced concrete (RC) frame rehabilitated using ferro-cement concrete was investigated. The seismic input energy imparted to a structure is dissipated by hysteretic behavior. It is generally recognized that there is a strong correlation between the energy dissipated by hysteretic action and the seismically induced level of damage. In this research, Static equivalent seismic load was applied and hysteresis loops were obtained. The dissipate energy were found form hysteresis loops. In the initial stage, narrow loops were obtained, this led to lower energy area. After elastic stage, loops were widened due to bonding failure, cracks development and yielding of steel reinforcement, so that the energy dissipation found more in both the frames. Retrofit strengthened frame contributed more energy dissipation capacity than the normal frame as shown Fig. 7. The energy dissipation values value are entered in Table 5.

The energy dissipation curve for normal frame was

$$y = -0.007x^6 + 0.386x^5 - 7.785x^4 + 74.13x^3 - 340.3x^2 + 692.1x - 446.0 \quad (7)$$

with R^2=0.996 and energy dissipation curve for retrofitted frame was

$$y = -0.001x^6 + 0.072x^5 - 1.580x^4 + 16.61x^3 - 85.61x^2 + 199.7x - 145.2 \quad (8)$$

with R^2=0.998.

3.5 Load carrying capacity

Retrofitted frame with section enlargement at the retrofitted places was resisted 33.0 percent more lateral load than the normal frame. Presence of ferrocement retrofit after filling minute cracks using grouting was led to higher lateral load resisting capacity. The lateral load resisting capacity is shown in Fig. 8

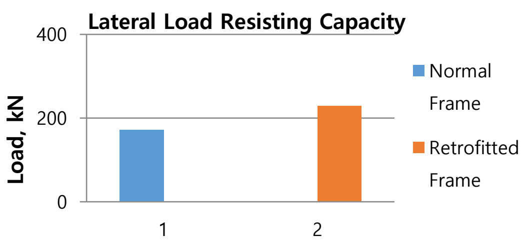

Fig. 8 Lateral load resisting capacity

4. Crack study

Onset of cracking due to lateral load has been studied in the frames. Hair line cracks normally would be acceptable for the damage onset, operational or continued occupancy operational levels. Onset flexural yielding marks a point beyond which component damage begun to accelerate as a result of in-elastic action. Yielding load was served as a simple index for damage onset, operational or continued occupancy performance levels. Buckling of longitudinal reinforcement led to loss of compression zone capacity of the frame and lead to fracture of confine reinforcement. As damage progressed in a component it lost not only its ability to participate positively as a component of the lateral resisting system, but also lost its ability to support gravity loads. Loss of gravity load carrying capacity led to cascading failure of the frames. The non-linearity of the post cracking behavior was governed by spreading of cracking along the length or shear span, by the tension softening due to concrete tension and bond-slip of the reinforcement between the cracks. After yielding, the resistance of the member keeps increasing, first because the reduction in neutral axis depth caused by the large post yield extension of the tension steel increases the level of arm of the internal forces and then because strain hardening of the tensile reinforcement begun. Spalling of the concrete cover at extreme compressive strain beyond 0.002 had a negative effect on the resistance. The magnitude of the imposed deformation and strains the compression steel yielded as well and stopped contributing to the tangent stiffness of the members. Bottom storey subjected to sever damage in the frame. Surface cracks were found in the beam column junctions (Fig. 9 and Fig. 10). Seperation of concrete cover and core concrete separated out at the bottom of windward column (Fig. 11). Shear buckling and bond failure were found in the leeward column bottom and in the infill bay leeward column bottom of the whole frame (Fig. 12).

Fig. 9 Map cracks in the column-beam junction of normal frame

Fig. 10 Cracks at the tension zones

Fig. 11 Hinge formation at leeward column of normal frame

Fig. 12 Shear buckled cracks in the leeward column of fetrofitted frame

5. Conclusions

The following conclusions were drawn:

• Rough interface between the frame and the infills leads to a remarkable increase in the lateral load resistance and stiffness of the infilled frame

• RCC strips along with brick infill leads to additional lateral load resistance, stiffness and ductility of the frames

• Ferro-cement concrete strengthened frame leads to higher lateral load resistance, stiffness and ductility of the frames than the normal frame along with RCC strips.

• RCC strips improves the stiffness and lateral load resistance of the infilled frame. It also prevents severe damages to the infill and keeps it integrated. Stiffness achieved in the retrofitted frame was 22 percent higher than the normal frame

• This effect of brick infill and RCC strips should be considered when developing simplified model for analysis and design of infilled frame

• The difference in stiffness for the frames becomes significant in addition to the ductility and energy dissipation capacity of retrofitted frame compared to normal frame. Therefore, the contribution of infills, RCC strips, ferro-cement concrete section enlargement to the lateral resistance should not be totally ignored in design.

• Formation of diagonal cracks in the infill bays were entirely eliminated by introducing two monolithic RCC strips. The strips resisted applied lateral loads along with regular beams. The infill bay with RCC strips resists more lateral load than the infill bay without strips.

• The central infilled bays with RCC strips contributed more stiffness and ductility to the whole frame and also gave additional stability.

• Ductility achieved in the retrofitted frame was 80 percent higher than normal frame. This was achieved by introducing ferrocement enlargement at the junctions.

Acknowledgments

This research was supported by the Coimbatore Institute of Technology, Coimbatore, India. We are thankful to our former Head of Civil Engineering Department Dr. K.Subramanian, who provided insight and expertise that greatly assisted the research, although who continuously encouraged us to complete the project.

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