ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, Vol 8(30), DOI: 10.17485/ijst/2015/v8i30/55058, November 2015 ISSN (Online) : 0974-5645

Influence of Ferro Cement Retrofit in the Stiffened In-fill RC Frame

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Abstract

The design of RCC frame usefully ignored the beneficial or adverse effect of infill walls. By strengthening the interface of frame and infill RC frame system can be kept together and forcing them to work as a whole until the end of the earthquake. The present study deals with the load carrying capacity of three bay four storey retrofitted RC frame with central bay stiffened brick infill under cyclic loading. The effectiveness of the retrofitted frame under cyclic load is to be investigated in terms of displacement, stiffness, and ductility and energy dissipation.

Keywords: Ductility, Energy Dissipation, Load-Displacement, Retrofit, Stiffness

1. Introduction

Infill-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. It is expected that this structural system will continue to be used in many countries because the masonry infill panels are often cost-effective and suitable for temperature and sound insulation purposes. Experimental and analytical results by Ju R. S. et al.[1] showed that the stiff RC infill wall dominated in the lateral resistance and drift capacity. Mrs. Umarani[2] examined the behavior of infilled frames [5 storeys] for lateral loading. Test focused on the increase of energy dissipation over and above the base frame. Asteris[3] reported a new finite element technique for the analysis of brickwork infilled plane frames under lateral loads. Govindan[4] has compared the experimental behavior of a quarter size seven-storey infilled reinforced concrete frame with that of a reinforced concrete frame without infill subject to lateral loads, and assessed the failure mode of the brick infilled frame. Dubey et al.[5] has conducted experimental analysis on the effect of reinforcement on ultimate strength of infilled frames, subjected to lateral loads. Diptesh Das et al.[6] have reported on the Non-linear pushover analysis performed on five reinforced framed buildings with brick masonry infills for the seismic hazard as per Eurocode8, Nepal building code and Indian code. Cavaleri et al.[7] have reported a new time domain identification technique for systems under Gaussian white noise input, requiring for its application in the measurement of the system response. The technique proposed was based on the statistics moment equations derived by using a special class of mathematical models named "potential models". Mehrabi Armin et al.[8] reported the influence of masonry infill panels on the seismic performance of reinforced concrete frames that were designed in accordance with current code provisions. Perumal Pillai et al.[9] 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. S. Z. Korkmaz[10] used the existing brick infill walls and the strengthening was done with the application of external mesh reinforcement and plaster. 5 non ductile 1/2 scaled, one bay, two storey RC specimens were tested

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under a reversed cyclic loading. It was observed that, at low levels of lateral forces, the frame and infill wall behaved monolithically. However, as the lateral force level increased, the frame deformed in a flexural mode while the infill corners damaged. Achintya et al.[11] presented the behavior of brick in filled reinforced concrete frames subjected to lateral loading, through an experimental approach and reported that the stiffness of the in filled frame decreased very rapidly after the formation of initial crack. To avoid the adverse effect of infill interface of the frame and infill is strengthened by RCC strips in brick infill. The most of the existing buildings which do not fulfill the current seismic requirements may suffer extensive damage or even collapse if shaken by a severe ground motion. Hence it is to be assessed the seismic capacity of the building and the cost involved for the retrofitting to meet out the current seismic codes. Their earthquake resistance can be upgraded to the level of present day codes by appropriate seismic retrofitting techniques. In this research, Earthquake code IS: 1893-2002[12] was used for seismic load calculations.

1.1 Objective

The objective of this investigation is to quantify the behavior in terms of load-displacement, ductility, energy dissipation capacity, and stiffness of one quarter size three bay four storey RC frame with central bay stiffened brick infill after retrofitting by Ferro cement and cement mortar grouting. The middle bay of the frame is brick in-filled in which the reinforcement strip from the frame is present in between each two layers of brick. The frame was subjected to static cyclic loading, simulating earthquake effects. This paper presents research work on the structural behavior of RC infill frames with reinforcement in between the brick layer and the effect of retrofit using Ferro cement.

2. Experimental Investigation

2.1 Materials

Materials were used in this research are Ordinary Portland cement of 53 grade. The cement used was tested for various properties as per IS: 4031-1988 and found to be confirming to various specifications of IS: 12269-1987 and having specific gravity of 3.0. Brick work construction was carried out on the next day of the erection. For infilling the central bay of the frame with brick masonry, cement mortar 1:4 was used. The thickness of the brick masonry panel was 100mm. Crushed granite angular aggregate of size 12 mm nominal size as coarse aggregate having specific gravity of 2.71. 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][13,14].

2.2 Frame Sections and Dimensions

The cross section of the beam and column in the frame is taken as 150 x 100 mm.

Frame along X axis: 3m
Frame along Y axis : 2.8m
No of storey : 4
Height of each storey : 0.7m
No of bays : 3
Width of each bay : 1m
Mix ratio : 1:1.7:2.72

The layout of the testing frame is shown in Figure 1.

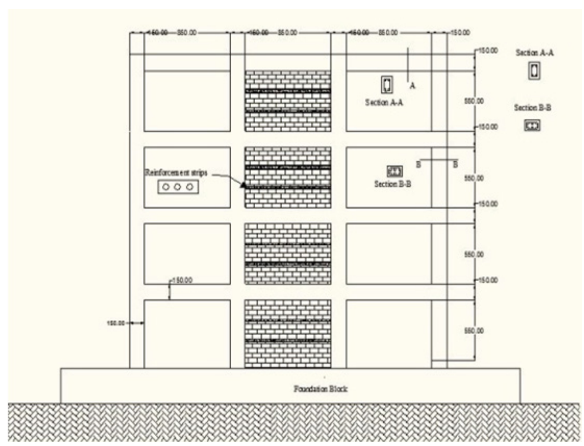

Figure 1. Reinforcement strip in Brick Layers.

2.3 Test Setup

The frame was erected on the test floor. Loads were applied at top and middle floor levels using hydraulic jacks and load cells and LVDTs were fixed in 2nd and 4th floors of lee-ward side to measure displacements of frame as shown in Figure 2. For each loading the readings were taken in LVDTs and strain gauge readings were taken on both concrete and steel. Concrete strains were noted till the initial failure of concrete and steel strains were noted for the zero reading and up to ultimate load. Dial gauges were fixed on the two sides of foundation blocks to check the foundation movements. The test set up of the frame is shown in Figure 2.

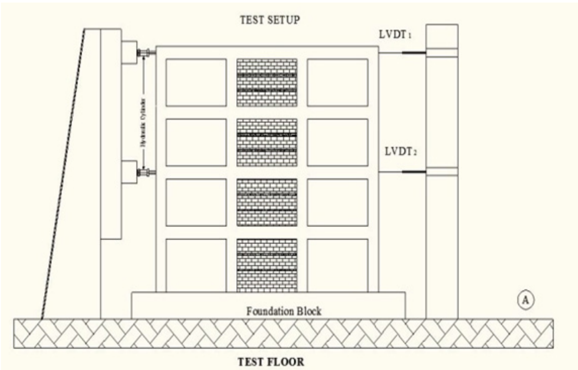

Figure 2. Test setup.

3. Experimental Investigations

3.1 Test Specimens

Two Frames were constructed, one frame tested under cyclic loading up to failure. Another frame tested up to partial failure and is taken for retrofitting. The mould, casting, curing, erections are shown in the Figure 3 to 6.

Figure 3. Wooden mould and reinforcement grill placed in position.

3.2 Testing

First frame was tested in the loading frame under cyclic load. Cyclic loading was applied on the frame with the help of load cells till the frame got failed. For each loading the readings were noted in LVDTs and dial gauges and strain readings were also taken on both concrete and steel. Concrete strains were noted till the initial failure of concrete and steel strains were noted for the zero reading and up to ultimate load. Second frame was tested upto 60% of load of first frame in the initial. Then retrofitting was done in the cracked places by ferro cement concreteing. The sections were enlarged to 15 mm and the cracks were filled with cement grouting.

Figure 4. Placement of concrete.

Figure 5. Curing of frames.

Figure 6. Test Setup for Frame 1.

4. Retrofitting

The frame 2 was taken back from the test bed for retrofitting. The loose materials were removed from the frame. Weld mesh of ½ inch spacing with 4mm thickness was wrapped over the frame where it got cracked. Cement mortar mix consists of 1 part cement: 1.5 parts sand with approximately 0.4 w/c ratio and coarse aggregate less than 5mm was used. The thickness of Ferro cement application was 15mm. The frame was erected on the testing platform and 100mm thick brickwork was done on the middle bay. 20 mm thick concrete was laid on the reinforcement strip in between the two layers of brickwork.

Figure 7. Grouting of retrofitted frame.

4.1 Grouting

Grout injection is a popular strengthening technique, as it does not alter the aesthetic and architectural features of the existing buildings. The main purpose of injections is to restore the original integrity of the retrofitted frame and to fill the voids and cracks, which are present due to the partial collapse. 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. For injection, expansive cement and epoxy resin is used for relatively mild cracks [less than 2 mm wide] present in the frame [Figure 7].

5. Results and Discussion

5.1 Load vs. Deflection

The load-displacement behavior was studied in two frames and the results were compared. The deflection of normal frame was gradual up to 120 kN. At this load, the concrete transferred the load to steel reinforcements and steel started yielding which leads to more deflection afterwards. In the retrofitted frame, the deflection was gradual up to 145 kN and increased appreciably after the load transferred from concrete to steel. The load carrying capacity increased due to retrofitting and enlargement. The load deflection behaviors are shown in Figure 8.

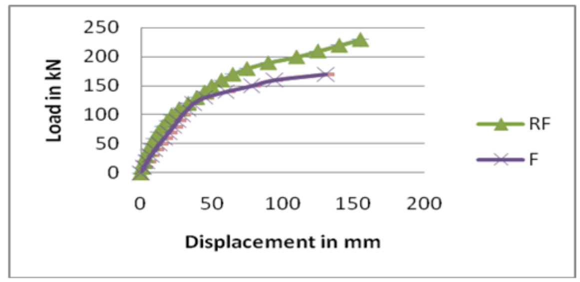

Figure 8. Load vs. Displacement.

5.2 Load Cycle vs. Stiffness

Stiffness degradation of normal frame was gradual up to 120 kN. Due to yielding of reinforcements, the stiffness degradation curve was steeper after forming cracks. Stiffness of retrofitted frame was higher than normal frame. The ferro cement retrofit and section enlargement contributed higher stiffness. The stiffness degradation curves are shown in Figure 9.

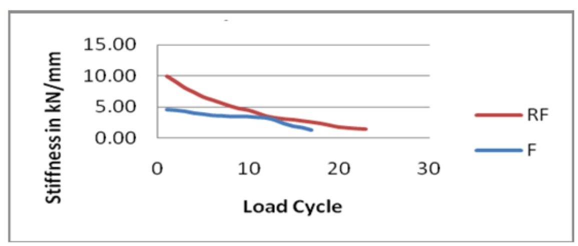

Figure 9. Load Cycle vs. Stiffness.

5.3 Ductility

The ductility of normal frame was found gradual up to 120 kN. At this stage, cracks were propagated and reinforcements started yielding. After this load, ductility curve slope increased. The ductility of retrofitted frame was gradual up to 140 kN. Beyond this load, cracks were appeared and found bond failure in retrofitting. Also reinforcements were getting started to yield. Hence the slope of ductility curve increased as shown in Figure10.

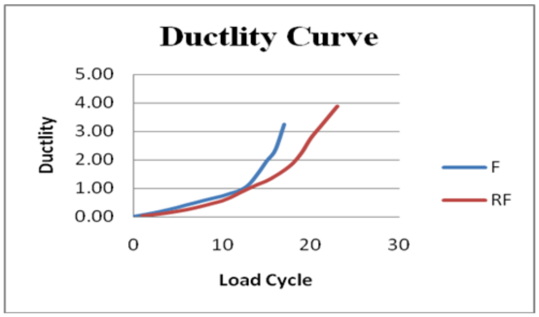

Figure 10. Load Cycle vs. Ductility.

5.4 Energy Dissipation

The energy dissipation for both normal and retrofitted frame was gradual until 130kN and slope of the curve was very less. Beyond this load, more deflections were found due to yielding of reinforcement and bond failure between concrete and reinforcement. This leads to higher energy dissipation. The energy dissipation capacity curve is shown in Figure11.

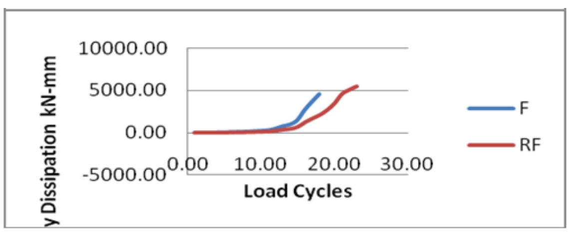

Figure 11. Load cycle vs. energy dissipation.

Figure 12. Marking of cracks in frame 1.

5.5 Crack Pattern

In the testing of frame1, initial cracks have started at 50 KN. The major cracks developed at 130kN. The frame 1 was tested until its collapse which was at 170kN. The load carried by the column shifted to longitudinal reinforcement of the column. This additional load caused the buckling of longitudinal reinforcement and failed due to short column effect Figure 12 to 14. The failure occurred in bottom of wind ward column due to tensile stress.

The retrofitted frame failed at the lee ward side column due to the formation of plastic hinge and shear buckling at the bottom. The crack patterns are shown in Figure 15.

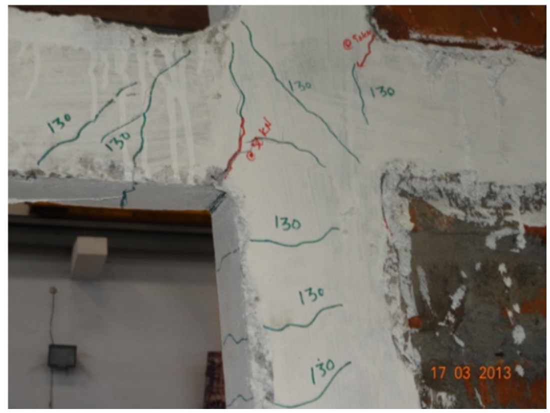

Figure 13. Marking of cracks in frame 1.

Figure 14. Hinge failure of frame 1.

Figure 15. Separation and Shear Buckling Failure of retrofitted frame at lee ward side.

6. Conclusion

Frames damaged due to earthquake shall be retrofitted effectively by the application of Ferro cement with cement mortar grouting. Further it can be concluded that the retrofitted frame is capable of taking 30% extra load over the original designed load. It is to be noted that due to the proper interfacing between the frame and infill, the adverse effect of infill is nullified. The application of Ferro cement technique is a cost effective one and can be executed with less skilled labor.

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