IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 2 Ver. V (Mar- Apr. 2014), PP 51-57
www.iosrjournals.org

Experimental investigation of RC frames with infills subjected to simulated lateral loading

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Abstract: *This paper presents an experimental investigation on the strength and stiffness behavior of reinforced concrete (RC) frame with and without infills. The types of materials used for the infills are brick masonry and brick masonry with ferro-cement mesh bands. The behavior of brick masonry infills with central opening is also studied. The frame specimens of size 830 mm X 110 mm X 170 mm, were cast with open bare frame (without infills), brick masonry infills, brick masonry infills with the ferro-cement mesh bands and brick masonry infills with the central opening. In the present work, the portal frame with lateral loading has been simulated and modified to vertical diagonally loaded frame due to practical testing limitation for the lateral load. The test results indicate that the introduction of infill increases the first crack load and ultimate load markedly. The stiffness of infilled frame has been found to be approximately 2.0 times greater than that the open bare frame (without infills). Amongst different infills tested, reinforced concrete brick masonry infilled frame with ferro-cement mesh bands provided along the bed joints was found to give better performance with regard to strength and stiffness.*
Keywords: *Infills, RC frame, stiffness, strength, deflection.*

I. Introduction

In multistory buildings, the ordinarily occurring vertical loads, dead and live, do not pose much of a problem, but the lateral loads due to wind or earthquake are a matter of great concern and need special consideration in the design of buildings. These lateral forces can produce the critical stress in a structure, set up undesirable vibrations and, in addition, cause lateral sway of the structure, which could reach a stage of discomfort to the occupants. Lessons learnt from failures of structural frames due to earthquakes have very clearly indicated that infills contribute a lot to lateral load resistance. Many structural frames have miserably failed due to soft storeys where infills were absent.

The behavior of infilled frames under lateral loads has been investigated by a number of researchers. Smith [1] studied the lateral stiffness of infilled frames and concluded that an infilled frame subject to lateral loads may be approximately represented by an equivalent frame in which the infills are replaced by diagonal struts, provided no permanent bonding occurs between frame and infill. Mallick and Garg [2] investigated the effect of different opening positions on the lateral stability of infilled frames. Barua et al.[3] studied the behavior of one-storey reinforced concrete frame with brick masonry infill under lateral loads experimentally and found that the modes of failure observed is governed by the quality of mortar in the brickwork. Riddington [4] studied the influence of initial gaps on infilled frame and concluded that they should be avoided wherever possible and corners of the infill should be designed so as to prevent local crushing failure. Dhanasekar and Page [5] carried out an investigation on the influence of brick masonry infill properties on the behavior of infilled frames and concluded that modulus of elasticity of the infill masonry significantly influences the load-deflection characteristics of the composite frame. Liauw and Lo [6] studied the non-linear behaviour of multibay infilled frames in conjunction with single bay infilled frames. Anand [7] experimentally studied the behavior of ferro-cement infilled frame and found that with the increase in infilled frame opening sizes, the horizontal and vertical deflection increases but the stiffness and ultimate load decreases. Choubey and Sinha [8] carried out an experimental program to bring out the behaviour of reinforced concrete frames infilled with and without brick masonry under lateral cyclic loading. It was also found that lateral load capacities, stiffness, energy dissipation capacity of infilled frame were more when compared to bare frame. Amit Peshkar [9] studied analytically the behavior of laterally loaded infilled frames with various sizes and positions of openings, with different relative stiffness of beams and columns of frames. It was found that deflection increases and stiffness decreases with the increase in size of openings, but by providing stiffened openings, the contribution of infill towards lateral load resistance can still be obtained.

Literature review reveals that contribution of infills to lateral load resistance has been recognized and investigations to exploit the same has been given tremendous attention. Analytical and experimental studies have been carried out to understand behavioral aspects qualitatively and attempts have been made to quantify contribution of infills to strength and stiffness of frames. Present work envisages investigating the contribution of brick masonry infill to lateral load resistance of frames. Brick masonry can only contribute by virtue of its effectiveness as compression diagonal over a limited width. Along the tension diagonal it is ineffective. Hence it has been proposed to introduce ferrocement bands at bed joints to investigate the probable improvement in its effectiveness. Also openings were made in the infills to study the effect of openings in masonry infilled frames to lateral loads.

II. Experimental Programme

The details of RC infilled frames specimen cast are given in Table 1. The overall dimensions of the RC infilled frames used in this study are as shown in Fig 2.

Materials

Ordinary Portland cement of 53 grade conforming to IS: 4031-1988 was used. The naturally available river sand conforming to Zone–III of IS 383-1970 was used and fineness modulus was 2.26. The locally available crushed granite stone passing through 10 mm IS sieve with a fineness modulus of 8.70 was used. Concrete mix proportion M_{20} mix is obtained referring to IS 10262-1982 as recommended. The proportion of cement, fine aggregate and coarse aggregate was 1:1.4:2.8 by weight and water-cement ratio of 0.50 by weight was used throughout the investigation. Clean portable water available in the laboratory was used to prepare the specimens. High yield strength deformed (HYSD) bars designated as Fe_{415} has been used for main reinforcement. The steel was tested for yield stress and obtained value is 424.8 N/mm^2. Mild steel bar of Fe_{250} was used as lateral reinforcement.

All the frames are reinforced with 2 main longitudinal bars of 10 mm diameter on both sides i.e. top and bottom of the section throughout the frame. The lateral reinforcement is provided with 6mm diameter 2-legged vertical stirrups @100 mm c/c throughout the frame as shown in Fig 3.

Infills

(i)Brick masonry infill: The masonry consisted of table moulded clay bricks of size 230 mm x 110 mm x 68 mm. The crushing strength of brick was 5.33 N/mm^2. Cement to sand ratio of cement mortar was 1:3 by weight.The mortar strength(1:3) was found to be 22 N/mm^2.

(ii) Brick masonry infill with ferrocement: The brick masonry consisted of cement mortar reinforced with a layer of square woven mesh having a clear clover of 8 mm. The meshes were laid parallel to the bed joints as shown in the Fig 1. The ratio of cement-sand mortar used for making the ferrocement bed joints was 1:3 by weight.

Fig 1: Mesh bands along bed joints

(iii) Opening in infill: A central opening of 25% was made in the brick masonry.

Table 1: Details of specimens

Specimen designation	Type of specimen
FL0	Frame with lateral ties (Bare frame)
FLBI	Frame with lateral ties with continuous brick infill
FLBIO	Frame with lateral ties with brick infill with opening
FLBIF	Frame with lateral ties with brick infill with ferrocement bands

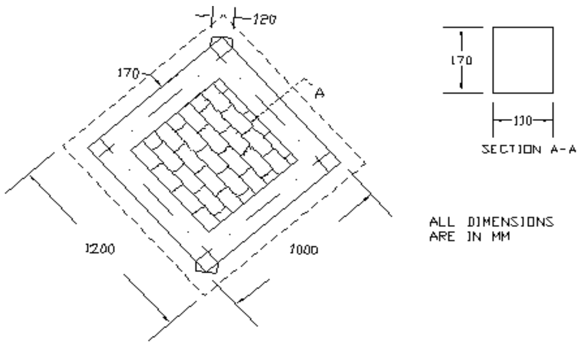


Fig 2: Dimension of infilled frame specimen

Casting and construction of brick work

The arrangement and details of reinforcement in the frames is shown in Fig 3. The frames were cast in horizontal position and cured for 21 days under damp burlap. They were positioned vertically for constructing the brickwork. At the time of test, the age of the brickwork varied between 21 to 40 days.

Fig 3: Details of reinforcement in the frame

Test setup and instrumentation

In the present work, conventional portal frame with lateral loading has been simulated and modified to vertical diagonally loaded frame as shown in Fig 4 due to practical testing limitation for the lateral load. By the principles of mechanics, the resolution of the vertical load into two perpendicular components gives the behavior, as such it is laterally loaded.

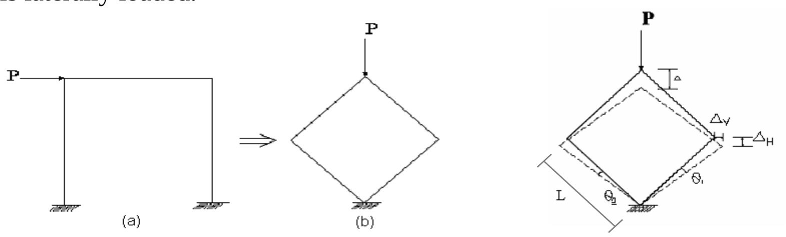


Fig 4: Conventional portal frame with lateral load simulated to vertical diagonally loaded frame

The specimens were tested in the loading frame arrangement as shown in Fig 5. This general testing procedure has been found to provide a good simulation of the behavior of infilled frames under in-plane lateral force. The frame is vertical diagonally loaded at one end and the opposite end is made to rest on the flat base.

Fig 5: Typical test setup of a Bare Frame

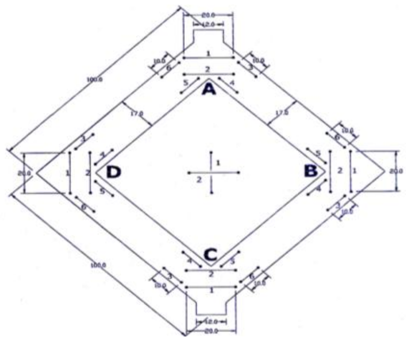


Fig 6: Frame with position of demec gauge targets around typical joint (All dimensions in cms)

In the Fig 6, the joints of the frame are named as A, B, C and D and the demac gauge targets at each joint are arranged. The targets having 200mm gauge length are numbered as 1, 2 and the targets having 100mm gauge length are numbered as 3, 4, 5 and 6. For infilled frames, demac gauge targets were arranged at center along compression and tension diagonals. Surface strains are measured using mechanical strain gauges (demac gauge) with gauge lengths 200mm and 100mm at their respective targets. Dial gauges having a travel of 25 mm with a least count of 0.01 mm are used to measure horizontal and vertical displacements. The dial gauges were mounted on the inner corner below the joint A for getting the vertical displacement. The horizontal and vertical displacements were got by mounting dial gauges on outer joint of joint B and D as shown in Fig 5. The specimens prior to the test were white washed in order to get a clear view of cracks.

Testing Procedure

All the specimens were tested in a loading frame of 200kN capacity. In order to note down the applied loading precisely, proving ring of dial gauge of 0.1kN was used. Load was applied at increments of 10 kN. The strain measurements were made on top and bottom face of the section across the gauge depth on the either side of the joint. The displacement readings were recorded at the joints. The specimens were visually inspected for cracks. The crack patterns on the frame were marked, indicating the progressive development of cracks for various loading stages. Tests were terminated when deformation was judged to be extensive.

III. Results and Discussions

The test results have been plotted for load vs. vertical displacement and stiffness vs load to study the structural behavior of RC infilled frame under the load as shown in Fig 7 and Fig 8. The performance evaluation is done by comparing FLBI, FLBIF, FLBO and FL0. The comparison stiffness of different frames and the factors by which the stiffness increases and ultimate loads and cracking loads of the specimens are shown in Table 2 and Table 3 respectively

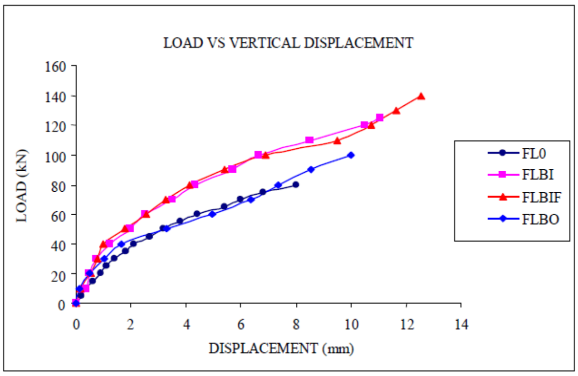


Fig 7: Comparison of Load vs. Vertical displacement

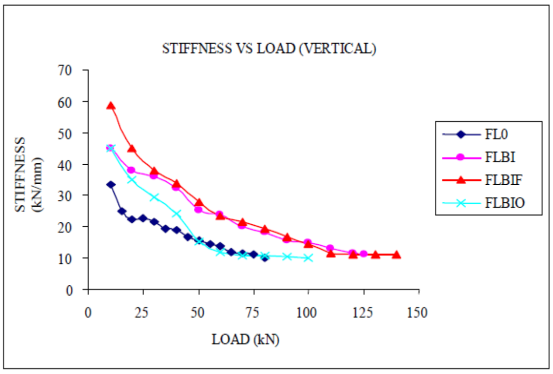


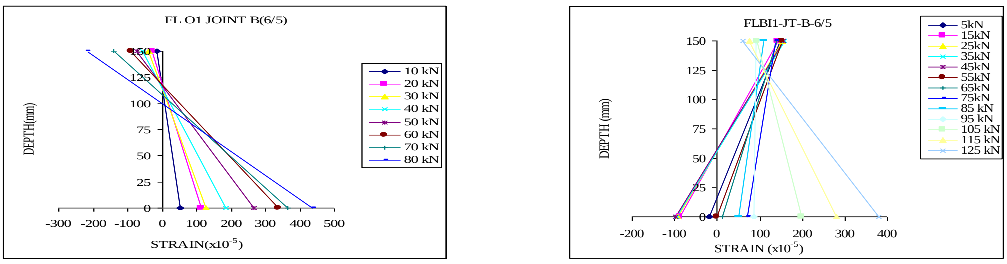
Fig 8: Comparison of Stiffness vs. Load (Vertical)

Table 2: Stiffness of different frames and the factors by which the stiffness increases as against bare frame

Frame Designation		Stiffness, kN/mm		Increase in stiffness by factor of	
		At infill cracking load	At frame cracking load	At infill cracking load	At frame cracking load
Fl01	Vertical	-	22.72	-	-
	Horizontal	-	185.18	-	-
FLBI1	Vertical	39.47	24.00	1.84	1.76
	Horizontal	250	52.63	1.41	1.34
FLBIF1	Vertical	39.60	19.41	2.08	1.94
	Horizontal	142.85	31.74	1.46	1.45
FLBO1	Vertical	29.41	24.24	1.37	1.27
	Horizontal	188.82	100	1.07	1.02

Table 3: Ultimate loads and cracking loads of the specimens

Frame Designation	Infill cracking load in kN (ICL)	Frame cracking load in kN (FCL)	Ultimate load of the specimen in kN Pu	FCL / ICL	ICL / Pu	FCL / Pu	Ultimate load of infill frame / Ultimate load of bare frame
FL01	-	25	81.9	-	-	0.305	1
FLBI1	30	60	133	2	0.225	0.451	1.623
FLBIF1	40	80	150	2	0.266	0.533	1.831
FLBIO1	30	40	110	1.33	0.272	0.363	1.343



(a) Bare frame (b) Infilled frame

Fig 9: Typical Strain distribution across the depth at joint B (6/5)

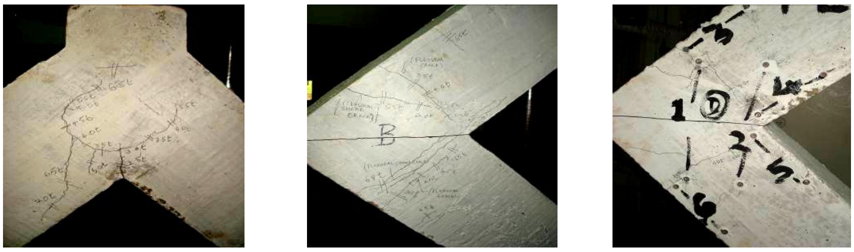


Fig 10: Failure patterns of joint A, B and D of the bare frame (FL0)

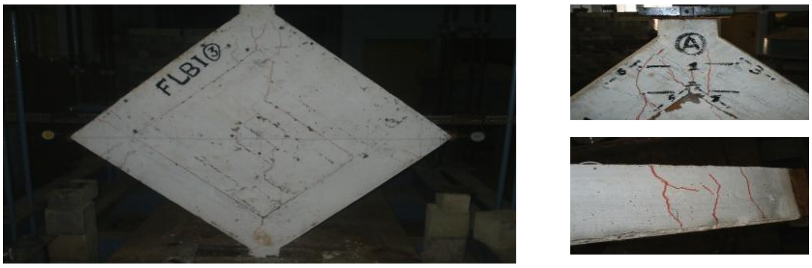


Fig 11: Failure pattern of continuous infilled frame (FLBI)

Fig 12: Failure pattern of infilled frame with ferrocement bands (FLBIF)

Fig 13: Failure pattern of infilled frame with central opening (FLBIO)

Bare Frame (FL0)

From the load displacement curve of the Fig 7, it can be seen that bare frame (FL0) exhibited an elasto-plastic behavior characterized by an initial linear response. The elastic linear behavior was observed till the first crack in the frame occurred i.e. at the load of 25 kN. With the further increase in the load, the plastic behavior was observed. The ultimate load at failure was 81.9 kN. It was observed that as the loading increases, the stiffness decreases as shown in the Fig 8. The stiffness at the first crack load in frame is 22.72 kN/mm while that at ultimate is 10 kN/mm. As the specimen reaches ultimate load, the specimen stiffness gets lower with the increase in the diagonal deformation. The failure patterns of joints A, B and D of the bare frame are shown in the Fig 10. Stress concentration effects were clearly visible as extensive cracking was observed at joints of the frame. Along the frame members the cracks were negligible.

lnfilled frame with continuous infill (FLBI)

From the Fig 7, the plot of load vs. vertical diagonal displacement of infilled frame with continuous infill (FLBI) specimens show that, their overall behavior can be divided into pre-cracking and post-cracking stages followed by the ultimate stage. In the pre-cracking stage, load vs. displacement curve was linear untill the first diagonal crack in the masonry infill was observed i.e. at 30 kN. The load at which the curve deviates from the linearity is called the first crack load. The stiffness at first crack load in infill is found to be 1.84 times that for the corresponding load in bare frame. The increase in stiffness value may be due to the reason that the brick masonry is strong along the compression diagonal. The post-cracking stage is characterized after the first crack load. Beyond this point, on further loading, crack propagated towards the loaded corners in the infill. Also separation crack between frame and the panel at the corners on the tension diagonal was observed. The first crack in the frame occurred at a load of 60 kN. As cracking in the infill propagated, the stiffness of the composite system decreased as shown in the Fig 8. Observed cracks were approximately parallel to the infill diagonal direction. This resulted in a nonlinear behavior of the composite system leading to deterioration of mortar joints. Under increased loading, the diagonal crack widened at the center of the masonry panel. From the observations it was noted that in the case of brick infilled frames, the failure of infill occurred before the failure of the frame. As the loading reaches the ultimate stage, the brick units of the infill underwent substantial slip and rotation in order to fit the deformed shape of the surrounding reinforced concrete frame. The ultimate strength is found to be 1.623 times that of an open bare frame. It was found that when the infill cracks and loses its strength, it will only be a bare frame behavioral action. Failure pattern of continuous infill frame specimen (FLBI) is shown in Fig 11.

lnfilled frame with continuous infill with ferro-cement mesh bands along bed joints (FLBIF)

From the Fig 7, the plot of load vs. vertical diagonal displacement of infilled frame with continuous infill with ferro-cement mesh bands along bed joints (FLBIF) specimen shows that their behavior is similar to that of an infilled frame with continuous infill (FLBI). The recorded load at which diagonal crack occurred in the infill was 40 kN which is 1.33 times higher when compared to infilled frame with continuous infill (FLBI). The stiffness at first crack load in infill was found to be 1.21 times and 2.08 times than that of infilled frame with continuous infill (FLBI) and open bare frame (FL0) respectively for the corresponding load. The Fig 8 shows that the stiffness decreases with the increase in load. The ultimate strength was found to be 1.831 times that of an open bare frame (FL0). The considerable improvement in stiffness values in infilled frame with continuous infill with ferro-cement mesh bands (FLBIF) may be attributed to presence of brick masonry which is strong along the compression diagonal and tensile strengthening of brick masonry by providing the mesh bands along the bed joints in the infilled frame which is weak along the tension diagonal. The failure pattern of infill frame with ferro-cement mesh bands along bed joints (FLBIF) specimen is shown in Fig 12.

Infilled frame with central opening (FLBIO)

The 25 percent of the infilled portion was provided with central opening. From the Fig 7, the plot of load vs. vertical diagonal displacement behavior of infilled frame with central opening (FLBI)) is shown. The first crack in infill started at 30kN at joints A and C from the opening end of the infill. On further loading, the cracks propagated towards the frame. The provision of 25% opening at the center of infill has resulted in the considerably reduced stiffness by 34.3% when compared with continuous infilled frame (FLBI) due to the absence of brick masonry which is now ineffective in resisting the compression diagonal vertical load. The stiffness has increased by 1.37 times at first crack load in infill when compared to the open bare frame (FL0). The reason may be due to the presence of 75% of brick masonry infill panel when compared to open bare frame. The Fig 8 shows that the stiffness decreases with the increase in load. The ultimate strength increased by 1.343 times when compared to a bare frame (FL0) and reduced by 0.82 times when compared to continuous infilled frame (FLBI) respectively. The diagonal and shear cracking took place in the masonry panels. Negligible cracks were observed along frame members. Fig 13 shows the failure pattern of infilled frame with the central opening (FLBIO) specimen.

Discussion on strain profiles along the depth of frame members (for infilled frames):

Strain profiles were drawn for the variation of the strain along the gauge depth for the increment of load of 10 kN. Strain profiles (Fig 9) plotted shows that, at low levels of load, the frame and infill panel will act in a fully composite system, as a structural wall with boundary elements. Initially due to the stiffening effect of infill, the frame elements are restrained from bending. When the infill is ineffective and as the lateral deformations increase, the behavior becomes more complex as a result of the frame attempting to deform in a flexural mode while the panel attempts to deform in a shear mode.

IV. Conclusions

In the light of experimental investigations presented herein, the following conclusions have been drawn:

1. Frames with infills exhibited three distinct stages of behavior namely pre-cracking, post-cracking and ultimate, which were significantly different from the behavior of bare frame.
2. The experimental results indicate that infill panels can significantly improve the performance of RC frames in terms of strength and stiffness.
3. Strength enhancement of infilled frames was 62% and 83% over bare frames for infills and infills with ferro-cement bands respectively. About 50% drop in strength due to a central opening of 25% of the infill size has been observed when compared to continuous infill frame.
4. Stiffness substantially improves with infills. Stiffness of frames with and without ferro-cement bands is 2.08 and 1.84 times that of bare frame. A 25% drop in stiffness for frame with 25% central opening has been observed when compared to continuous infill frame.
5. At initial stages of loading the frame elements are prevented from deformation in flexural mode by the infill. As load increases, effectiveness of infill drops and behavior becomes complex with frame deform in flexural mode and panel deforms in shear mode.

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