International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-9 Issue-3, January 2020

Behavior of Full and Partially Infilled Reinforced Concrete Frame Subjected to Horizontal Loading

U S Koushal, Ibrahim A G, Jairaj C, M T Prathap, Manjunath L

Abstract*: In this research work, six storey, three bay prototype structure were designed for strong earth quake load and bottom storey, interior bay was considered. A 1/3rd scaled three reinforced concrete (RC) frames of bare, partially infilled and full infilled RC frames was selected to check the behavior of full and partially infilled RC frames subjected to horizontal loading. The effect of lateral (horizontal) loads on any reinforced concrete frame that might arise as a result of seismic loads was investigated. The RC frames were scaled down to a modeled structure that was tested in a loading frame of capacity 20 tons. Bare frame with just columns and beams, masonry infill with openings and masonry infill without openings RC frames were the 3 different specimens that were made for testing after 28 days of curing. Lateral loading was applied by loading frame. The results showed that the full infill frame took maximum load as expected with least deflections, the bare frame took the least load and the infill frame with opening resisted little more load than bare frame but less than the infill frame without opening. However, at any given point of loading the deflection was highest for the bare frame and least for the full infill frame, which suggested that frames with infill performed better as compared to the bare frame.

Keywords* : Earth quake load, Loading frame, Masonry infill reinforced concrete frame, Strength ratio, Horizontal loading.

I. INTRODUCTION

In the beginning single dwelling houses were constructed as shelter to protect them from rain, sun and wind. The houses with single or double storey using timber, stones, mud blocks and lime etc. gradually construction practice changed for better shelter and this leads to new development and invention in civil engineering field. Nowadays trend is about slender and tall structures due to so many reasons. Therefore, the lateral load on these tall structures is gaining more importance. As we know, Earthquake is one the major disaster and study on this is done since many years. Infill panel is one form of cladding and it is built between structural members. This infill panel walls are considered as non-structural element and they provide self-supporting in the structural frame, weather resistance, fire resistance, sound insulation, natural ventilation and sufficient openings. Architectural components are infill walls, partition walls, parapet walls nonbearing walls, doors and windowpanes etc. failure of these components affect the safety of residents in the building and even outside the building. In normal design practice, these components are considered as nonstructural elements but these influences the structural behavior while earthquake occurs, so in some situations they are not ignored.

The behavior and various parameters of the infilled frame under vertical and lateral load has been studied by number of researchers. Armin B Mehrabi et.al (1996) has considered two types of frames. One is designed for strong earthquake forces and the other for wind loads as per in accordance with the present code provisions. Two types of masonry infill were considered that is hollow and solid, which represented strong and weak infill. The results showed that the specimens with strong infill exhibits better performance than those with weak infills. Floriana Petrone et.al (2016) mainly concentrated on collapse of the infill when loaded. The importance of modeling the floor slab is highlighted. The critical load bearing elements in the structure, which provides greater resistance to progressive collapse, is identified. A Kocak et.al (2013) studied how the infill wall and the small wall openings affect the stiffness of the structure. The results showed that infill wall would increase the stiffness of the structure but decreases the fundamental time. In addition, infill wall with small openings increase the fundamental time-period. Kai Qian M et.al (2017) studied progressive collapse of masonry infill wall of RC frames when subjected to lateral and vertical loads. The deformation, load-displacement curves, strains and modes of failure are measured for different patterns and results are compared. M Prakash et.al (2016) also studied collapse of a structure for bare and infilled frame when corner and middle columns are removed. The demand capacity ratio is found and the result showed that the enough resistance against progressive collapse is comparatively much greater and better in infill frame system than the bare frame system.

II. OBJECTIVE

The overall objective of this research is to improve the knowledge and understand how the masonry infill tend to behave under strong earthquake loads and to study how the infill interacts with the boundary frame during the earthquake. The comparison of behavior of full and partially infilled RC frame with the different failure patterns, load- deflection comparison and comparing strength ratio.

Revised Manuscript Received on January 5, 2020

* Correspondence Author

U S Koushal, M tech in Structural Engineering, Civil Engineering Department, NMIT, Bengaluru- 560064, Karnataka, India. Email: uskoushals@gmail.com

Ibrahim A G, M tech in Structural Engineering, Civil Engineering Department, NMIT, Bengaluru- 560064, Karnataka, India. Email: iconibbu786@gmail.com

Dr. Jairaj C, Associate Professor, Civil Engineering Department, NMIT, Bengaluru- 560064, Karnataka, India.
Email: jairaj67@gmail.com

III. METHODS

A. Prototype Structure

In this research study a reinforced concrete frame of three bays, six stories were selected as prototype structure. Height and length of each bay was considered as 3m and 4.5m respectively, height/length ratio was selected as 1/1.5 for each bay. This prototype structure was designed for strong earthquake load and it was considered as residential building. The reinforced concrete frame was modeled and analyzed in STAAD PRO and designed manually considering the loads as shown in Table 1. The reinforced concrete frame was analyzed for zone 5 earthquake loads, considering structure as ordinary moment resisting frames and soil site factor was medium soil. The depth of foundation was 2m and the structure was analyzed according to IS 1893-2002/2005.

Table 1: Intensity of load on members

Types of Loads	Members	Intensity of Loads	Codes
Dead load	Slab load	3.75 kN/m^2	IS 875 (Part 1)
	Floor finish	4.75 kN/m^2	
	Main walls	11.4 kN/m	
	Parapet walls	5.3 kN/m	
Live load	Floor load	3 kN/m^2	IS 875 (Part 2)
	Roof load	1.5 kN/m^2	

B. Scaling and Modeled structure

In Experimental investigation or analysis of large structures the scaled down models are used. Scale down of the structure is done for many reasons mainly for the space availability in the laboratory and to reduce the cost of the experimentation and testing facilities limitation. In the present research work the specimen were chosen to be 1/3 scale modeled structure. As for our convenience such as loading capacity, Spacing in the laboratory, cost and easy to accesses (for example: lifting and shifting the specimen). The specimen is scaled down in all the aspects such as concrete, steel, aggregates. In the modeled structure the length, width and thickness of the specimen is also reduced. This scaled down structured model was used for the experiment as shown in the figure 1. The table 2 represents the dimensions of prototype and modeled structures.

C. Design

The six storey prototype structure was analyzed and bottom storey, interior bay reinforced concrete frame was designed. As per the prototype structure dimensions of columns is 600mm x 450mm and beam is 450mm x 500mm was designed according to SP-16 and IS 456- 2000. The area of steel required for both columns and beam were calculated for the prototype reinforced concrete frame. In this research study experiment has to be conducted on the scale down reinforced concrete frame. The area of steel required for scale down reinforced concrete frame was done such that, percentage of steel in the prototype reinforced concrete frame should be same in the scale down modeled reinforced concrete frame. This method was followed separately for main bars and stirrups, the figure show the steel design. The concrete mix design was done for M30.

Table 2: Scaled down dimensions

Members		Prototype Structure (mm)	Modeled Structure (mm)
Columns	Length	3000	1000
	Width	600	200
	Depth	450	150
Beam	Length	4500	1500
	Width	450	150
	Depth	500	167

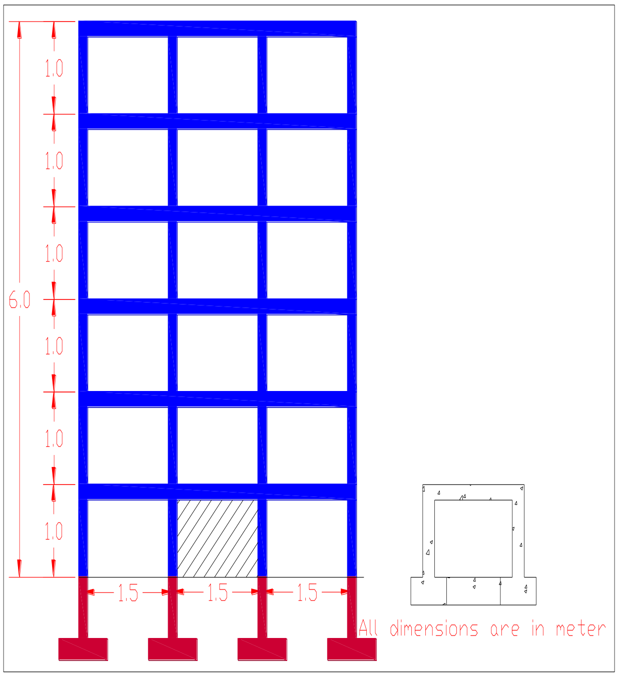
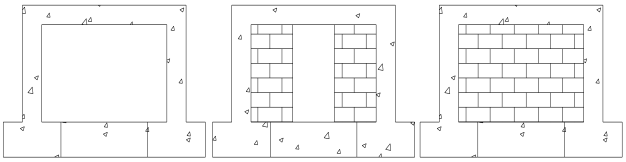


Fig 1: Scaled down modeled structure

D. Test specimens and brick work

In this research study, the three reinforced concrete frames were casted for testing according to steel and concrete design. In those three specimens, the first specimen was bare frame without masonry infill as shown in figure. The second specimen was partially infilled reinforced concrete frame that is masonry infilled reinforced concrete frame with opening, as shown in figure the opening is 1/3rd portion in between the reinforced concrete frame. The third specimen was full infill that is reinforced concrete frame without opening as shown in the figure. After casting of three specimens, it was cured for 28days using gunny bags. The expert mason according to test specimens required did the masonry infill panel construction. The mortar was prepared with 1:3 ratio mixes, it was constructed exactly at the center of the beams and masonry infill panel thickness is 125mm, the figure 2 shows all the three specimens. As usual practice clay burnt bricks are placed on the mortar layer and gaps were filled with cut piece bricks and mortar. The level tube and plumb bob was used to check the level and uniformity in the construction.

It was taken care that top layer was filled properly and finally surface of the specimen was cleaned. These masonry infilled specimens were cured for seven days, these specimens were painted before testing to identify the cracks and failure patterns. the dimensions of prototype and modeled structures.



(a) **(b)** **(c)**

Fig 2: Test specimens

E. Experimental setup

There was no actual proper horizontal loading mechanism, it was decided to setup the horizontal loading mechanism manually. To level the frame height with the horizontal loading jack, concrete flooring was prepared over which the frame was placed to ensure that height of the frame matches with the level at which the hydraulic jack was setup. The frame was shifted on the prepared concrete floor by using crane of four wheels of capacity two tons and with the use of manpower. The arrangements were made so as to ensure that the final specimen would have four removable wheels allowing for a easy transport option. Since there was no restriction for the horizontal movement of the frame, it was pre-determined that after the application of horizontal load from the hydraulic jack, the frame would move horizontally in the direction of load applied. Therefore, four numbers of 25 mm steel rods were used to hold the frame in the direction opposite to the application of load.

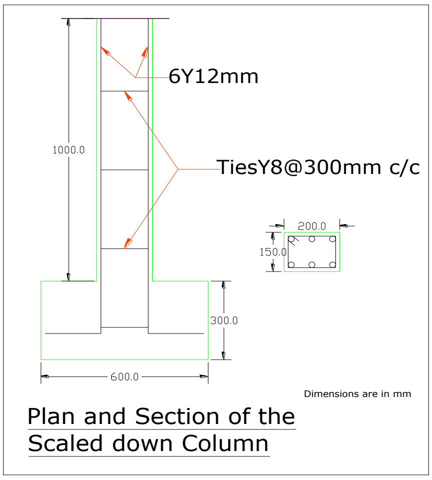


Fig 3: Plan and section of the scaled down column

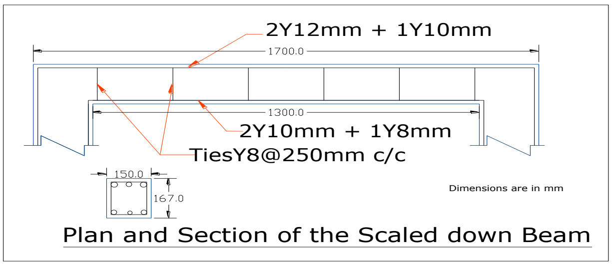


Fig 4: Plan and Section of the scaled down Beam

Pre-determined was the overturning of the frame, the overturning of the frame would take place because of the application of horizontal load from the jack during which the frame is firmly held horizontally not allowing any horizontal movement, which would result in an overturning of a frame. To ensure overturning of the frame does not takes place; the force responsible for the overturning was transferred back to the loading frame using an inclined I-section supported by six numbers of 25mm bars. The figure 5 shows the experimental setup of the bare frame. Now To fill the bottom gap between the loading frame and specimen, concrete cubes and steel plates were placed in the gap. Now to apply horizontal load, load cell was fixed to the hydraulic jack. The strain gauges were used to measure the strain experienced by the section of a specimen when load is applied. Hence, four strain gauges were used for each specimen. Two were placed on the highly compressive side and two on tension side. The main objective of using these strain gauges was to compare the theoretical values of strain according to the code books and experimental values. The strain gauges and the wires connected to the computer which shows the strain readings when the load is applied are connected by soldering. Now the two linear variable differential transducers (LVDT's) are made just in contact with the specimen and connected to the data acquisition system in the computer to give the readings of the deflection of a specimen.

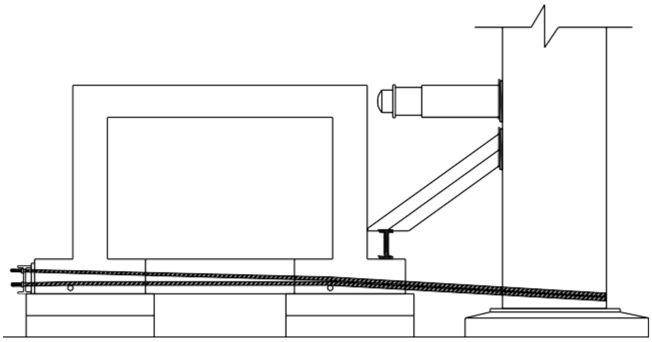


Fig 5: Experimental Setup

IV. MATERIALS

In this research study three specimens were casted, the materials such as cement, manufactured sand, 12mm coarse aggregate, steel and clay burnt bricks were used. The 12mm, 10mm and 8mm steel rods were used of Fe500 according to steel design. The clay burnt bricks of 225mm x 125mm x 75mm having compressive strength of 2.8N/mm^2 was used.

V. RESULTS AND DISCUSSION

A. Crack Analysis

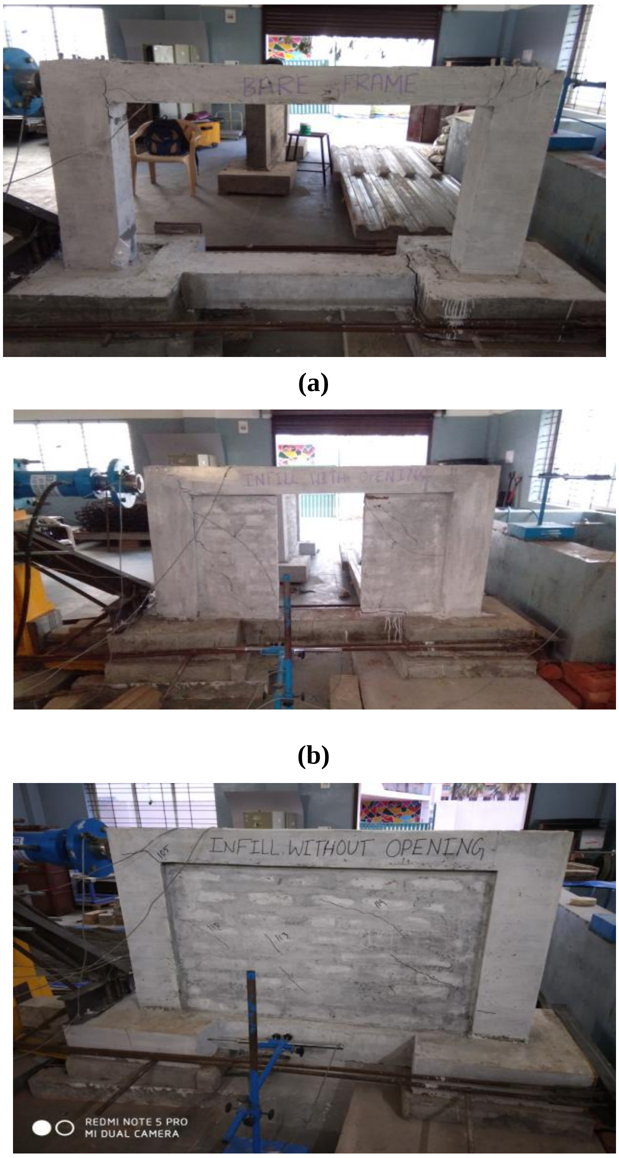
1) **Bare Frame:** The specimen was observed closely to check the cracks, upto 40kN there were no cracks observed. When the loading reached 42kN the cracks appeared at loading junction, and this started widening as the load increased. At 53kN loading, there was a crack in the bottom junction diagonally opposite to loading point, but the deflection had reached almost 13 mm for 50kN load.

This beam-column joint crack started widening at 72kN and another beam column joint was started to crack at this loading. When the load increased to 79kN, the crack started appearing in the bottom of the column of loading side and inner portion of the column of loading side. Also, at 87kN the cracks appeared on the column, Finally the load value increased till 88kN and the deflection reached to almost 33 mm the failure pattern shown in figure 6(a).

2) **Partially Infilled Frame:** The specimen was observed closely to check the cracks, upto 45kN there were no cracks observed in the specimen. When the load crossed 48kN there was a mild crack observed in the bottom layer of infill on diagonally opposite to loading side. When the load increased to 50kN the cracks were observed in the RC frame, simultaneously crack was extended and separating in the bottom infill at 55kN load. As the load increased to 68kN there was a crack observed in the top layer of the infill. Crack at the loading junction of the RC frame was extended when the load was 85kN. When the load was increasing from 86kN to 88kN at the loading side there was a crack in the column and was passed inside the infill frame and same pattern of cracks were observed on another wall. The figure 6(b) shows the failure patterns of partially infilled frame and the minor cracks was observed at loading side separating column and infill wall at 91kN and the bricks in the top layer was separated and it was found crushing when load was 95kN to 98kN. Finally, specimen stop taking load after 106kN and load was decreased.
3) **Full Infilled Frame:** The cracks did not appear in the specimen till 100kN. Beyond 100kN the cracks appeared at 105kN at the junction of the loading side that is at beam-column joint. But the deflection had reached almost 6 mm for 100kN load. After the crack in the beam-column joint, slowly a slight diagonal crack started appearing in the masonry infill bricks at 113kN. When the load is still more increased to 120kN, many cracks started appearing in the infill bricks in the diagonal direction. At 140kN, sudden major crack appeared in the footing of the loading side. Finally, the load value increased till 148kN and the deflection reached to almost 11 mm. The figure 6(c) shows the failure pattern of full infilled frame.

B. Load Analysis

1) **Bare Frame:** From the experimental results as shown in figure 7, it can be seen that with the increase in load, the deflection value also increases. The data however suggests that the deflection is not steep up to an increase in load of just a little above 20kN. The bare frame initially takes loading with least deflection. Above 25kN, the variation in the deflection with respect to applied load goes on increasing until peak load of 88kN.
2) **Partially Infilled Frame:** With respect to figure 7 it can be inferred that initially with the increase in load, the deflection value also increases. The data also suggests that the deflection is not steep up to an increase in load of just a little above 40kN. However, just above that value the deflection increases at a very rapid pace with increase in the load and the maximum deflection can be observed at a load of just above 106kN. Immediately above this value of load, the deflection with decrease in load increases to some extent.



(a)

(b)

(c)

Fig 6: Failure Pattern: (a) Bare frame failure pattern; (b) Partially infilled frame failure patterns; (c) Full infilled failure pattern

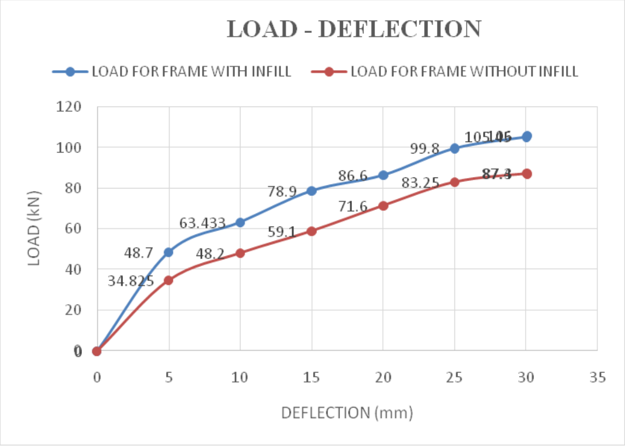
3) **Full Infilled Frame:** From the experimental results as shown in figure 7, it can be seen that with the increase in load, the deflection value also increases. The data however suggests that the deflection is not steep up to an increase in load of just a little above 30kN. In addition, it can be seen that with the further increase in the load, the deflection value increases very rapidly. The maximum deflection is observed at a load of just above 146kN.
4) **Comparison of All Specimens:** It is observed that with the increase in load, the deflection also increases for all the frames. With comparison to all frames, the bare frame took the least load, and the full infill took the maximum load. For all the frames, with increase in load of up to 20kN, the deflection pattern observed was similar.

After which the bare frame started deflecting more for given load, but the previous pattern continued in case of partial infill frame and full infill frame. Full infill frame has taken a load of little more than 140kN, with deflection value even lesser than that of the bare frame. However, at any given point of loading the deflection was highest for the bare frame and least for the full infill, which suggested that with infills the frames performed better as compared to the bare frame. The frames also recover the deflection with the removal of the load. For both the frames, recovery was with the decrease in the load. Thus, it can be concluded that the full infill frame has a better load bearing capacity and less deflection compared to bare frame. Figure 7 represents the comparison bare frame, partial infill and full infill respectively.

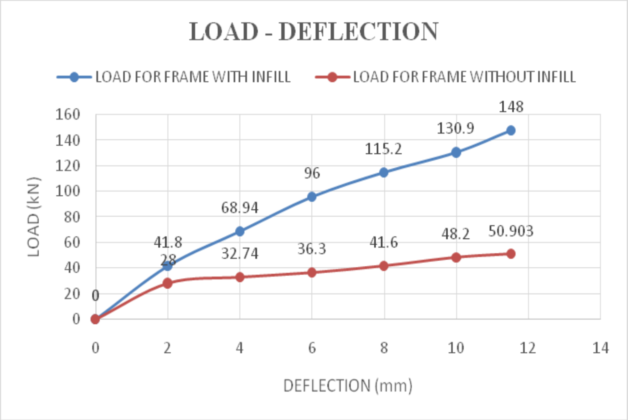
Fig 7: Comparison of bare frame, partially infilled frame and full infilled frame

C. Comparative load for constant deflection

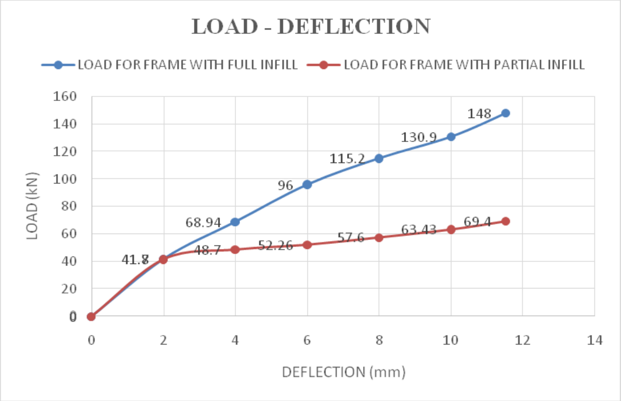
The comparison of load for constant deflection for bare frame and partially infilled frame is shown in figure 8(a). It is observed that both partially infilled frame and bare frame have similar pattern, for the 5mm deflection the load of 43.2kN and 37kN was achieved by infilled frame and bare frame respectively. These differences in load of both frames were all most constant and for deflection of 30mm the load of 105.8kN and 81.9kN was achieved by infilled frame and bare frame respectively. By this graph we can understand that the partially infilled frame takes more load by less deflection compared with bare frame. The difference between two loads for the respective deflection is increased at all the intervals. The comparison of load for constant deflection for bare frame and full infilled frame is shown in figure 8(b). Initially both the frames show same trend and the deflection varies linearly with the load applied. However as seen from the figure the load taking capacity or the deflection per unit load is maximum in case of load for frame without infill. In addition, after a deflection of 2mm the deflection per unit load increases significantly for frame without infill, whereas the frame with infill has a higher load taking capability with respect to bare frame. In addition, it can be seen that the frame with infill had almost three times load at the peak deflection. The maximum load taken is higher in case of frame with infill and the deflection per unit load is higher in case of frame without infill. The comparison of load for constant deflection for partially infilled frame and full infilled frame is shown in figure8(c). The load was 41.2kN for 2mm deflection in both the specimens, even here the full infilled frame performs better compared to partially infilled frame.



(a)



(b)



(c)

Fig 8: Comparative load for constant deflection

D. Comparative strength ratio

The Strength ratio is defined as the ratio of load taken by the frame with infill to load taken by the frame without infill for the figure 9 and figure 10. The strength ratio as per figure 11 is defined as the ratio of load taken by the partially infilled frame to load taken by full infilled frame. A comparison of strength ratio with respect to deflection is plotted as shown in figure 9.

The graph shows the constant strength ratio for different deflection. The graph was plotted from zero deflection and when deflection started from 5mm to 30mm the strength ratio is almost the straight line. By this it is understood that partially infilled frame takes 1.25 times more load compared to bare frame. The strength ratio 1.292 was the highest for the 30mm deflection.

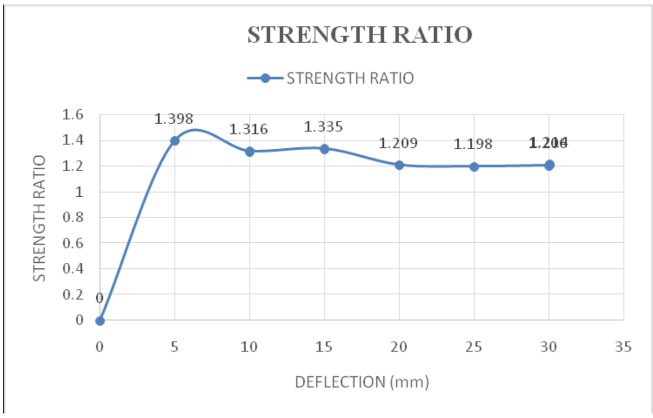


Fig 9: Strength ratio for bare frame and partially infilled frame

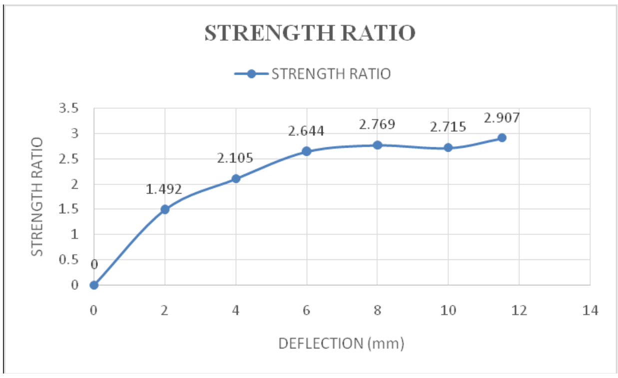


Fig 10: Strength ratio for bare frame and full infilled frame

A comparison of strength ratio with respect to deflection for infill without opening is plotted as shown in figure 10. The graph varies linearly initially. However, with the increase in deflection strength ratio also increases suggesting that the load taking capabilities of frame with infill increases with respect to load as compared to the frame without infill. This strength ratio reaches a maximum of 2.907, suggesting that at a peak deflection frame with infill can take almost three times the load of that of the frame without infill. A comparison of strength ratio with respect to deflection for infill without opening is plotted as shown in figure 11. The graph varies linearly initially, in this the strength ratio reaches 2.13, from the graph it is understood that full infilled frame takes 2 times more load than partially infilled frame. The table 3 represents the experimental results of all three specimens.

Table 3: Experimental results of three specimens

Sl No	Specimens	First crack Appeared (kN)	Maximum horizontal load (kN)	Maximum deflection at failure (mm)
1	Bare frame	42	88	33
2	Partially infilled frame	48	106	31
3	Full infilled frame	105	148	11

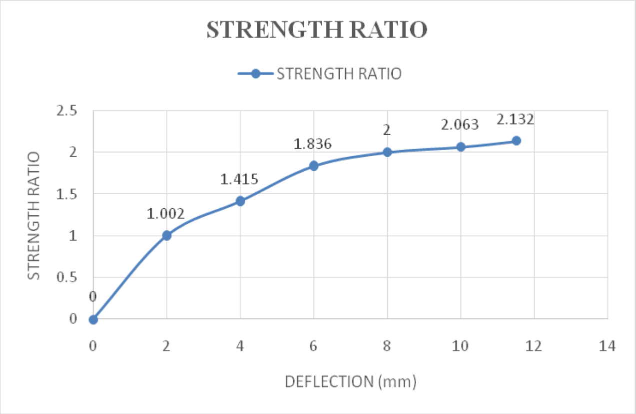


Fig 11: Strength ratio for partially infilled frame and full infilled frame

VI. CONCLUSION

Three types of frame specimens that were designed in accordance with current code provisions are considered. It was designed for strong earthquake forces. Bare, full infill and partial infill with clay burnt bricks were considered. The following conclusions are analysed.

1) The experimental results indicate that the infill panels can symbolically improve the performance of reinforced concrete frames.

2) The horizontal loads developed by the infilled frame specimens were constantly higher than that of bare frame.

3) Strength ratio of load for frame with infill and load for frame without infill was calculated.

4) The results showed that the full infill frame takes almost 3 times the load of that of frame without infill.

5) Partial infilled frame takes almost 1.25 times the load of that of frame without infill.

6) The full infilled frame takes almost 2 times the load of partially infilled frame.

7) The results showed that the load taking capacity is higher in case of infill frame with least deflection.

8) When the failure patterns and cracks are observed the full infilled frame performed best and partially infilled frame was better compared with bare frame.

9) The maximum load taken is also higher in case of full infill frame as compared to the bare and partial infill frame.

This study indicates that for a frame that is properly designed for strong seismic loads, infill panels will most likely have a beneficial influence on its performance. Further studies should be conducted to develop design guidelines for engineered infills. Also, the frame action for different infill openings should be investigated.

REFERENCES

1. Vitelmo Bertero F and Steven brokken (1983) “Infills in seismic resistant building” Journal of Structural Engineering, Vol. 109, No. 6, ISSN: 0733-9445/83/0006/-1337, pp. 1337-1361.
2. T C Liauw and K H Kwan (1985) “Unified plastic analysis for infilled frames” Journal of Structural Engineering, Vol. 111, No. 7, ISSN: 0733-9445/85/0007-1427, pp. 1427-1448.
3. Armin B. Mehrabi, P. Benson Shing, Michael P. Schuller and James L. Noland (1996) “Experimental evaluation of masonry-infilled RC frames”, Journal of Structural Engineering,vol.122, No.3, pp. 228-237.

4. Roger D. Flanagan and Richard M.Bennett (1999) “In-plane behavior of structural clay tile infilled frames”, Journal of Structural Engineering,vol.125, No.6, pp. 590-599.
5. S G Buonopane and R N White (1999) “Pseudodynamic testing of masonry infilled reinforced concrete frame” Journal of Structural Engineering, Vol. 125, No. 6, ISSN: 0733-9445/99/0006-0578-0589, pp. 578-589.
6. Sashi K. Kunnath, Wei-Jian Yi, Qing-Feng He, yan Xiao (2008) “Experimental study on progressive collapse-resistant behavior of reinforced concrete frame structures*”,* Journal of Structural Engineering,vol.105, No.4, pp. 433-439.
7. A Kocak, A Kalyoncuoglu and B Zengin (2013) “Effect of infill wall and wall openings on the fundamental period of RC buildings” WIT transactions on the built environment, vol.132, ISSN 1743-3509, pp. 121-131.
8. Ashik S Parasiya and Paresh Nimodiya (2013) “A review on comparative analysis of brace frame with conventional lateral load resisting frame in RC structure using software” International journal of Advanced Engineering Research and Studies, E-ISSN 2249-8974, pp. 88-93.
9. Saim Raza and M Khubaib Ilyas Khan (2015) “Seismic vulnerability assessment of bare and masonry infilled reinforced concrete frame structures” International Journal of Civil and Structural Engineering, Vol. 5, No. 4, ISSN: 0976-4399, pp. 392-402.
10. Floriana Petrone, Li Shan and Sashi K Kunnath (2016) “Modeling of RC frame buildings for progressive collapse analysis” International journal of concrete structures and materials, Vol.10, No.1, ISSN 1976-0485, pp. 1-13.
11. M Prakash, N Partha Sarathi, K S Satyanaraysnan and V Thamilarasu (2016) “Robustness evaluation of RC bare frame and infilled frame buildings to progressive collapse under corner and middle column removal scenario” International journal of chemical science, ISSN 0972-768X, pp. 135-148.
12. Ovidiu Bolea (2016) “The seismic behaviour of reinforced concrete frame structures with masonry infill in the Bucharest area” Sustainable solutions for energy and environment, ISSN: 1876-6102, pp. 60-76.
13. Kai Qian, Bing Li (2017) “Effects of masonry infill wall on the performance of RC frames to resist progressive collapse” Journal of Structural Engineering, ISSN 0733-9445, pp. 228-237.
14. N Rahul Verma, B Suresh and V Navodaya (2017) “Capacity analysis of Rcc frame structure with and without infill walls” IOSR journal of mechanical and civil engineering, e-ISSN: 2278-1684,p-ISSN: 2320-334X, Vol.14, Issue 4 Ver.III, pp. 84-91.
15. Valentino Bolis, Andreas Stavridis and Marco Preti (2017) “Numerical investigation of the in-plane performance of masonry-infilled RC frames with sliding subpanels” Journal of Structural Engineering, ISSN 0733-9445, pp. 01 - 18.

AUTHORS PROFILE

U S Koushal from Mysore, did UG (Civil Engineering) from Jain College of Engineering, Belagavi and pursuing PG (Structural Engineering) in Nitte Meenakshi Institute of Technology, Bengaluru, Karnataka - 560064

Ibrahim A G from Davangere, did UG (Civil Engineering) from Jain Institute of Technology, Davangere and pursuing PG (Structural Engineering) in Nitte Meenakshi Institute of Technology, Bengaluru, Karnataka - 560064

Dr.Jairaj C PhD published many national and international journal papers and conference papers.

Dr.M T Prathap Kumar PhD from UVCE and Published many national and international journal papers and conference papers.

Mr Manjunath L M tech completed M tech in UVCE and working as an Assistant professor in Nitte Meenakshi Institute of Technology, Bengaluru, Karnataka - 560064