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Experimental Study of RC Frame Structure by Dynamic Loading

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ABSTRACT—

Structural frames are often filled with masonry walls serving as partitions or as cladding. Although infills usually are not considered in the structural design, their influence on the behavior of the frame is considerable. Up until the infill's cracks, the contribution of the infill to both lateral stiffness and strength is very significant. The infill also changes the dynamic characteristics of the frames. The change in lateral stiffness, strength and natural period of the frames structure due to the presence of infill's change the behavior of the building under seismic action. According to that, the aim of our project is to improve interaction between frame and in filled walls. In our project two types of specimens are prepared for studying the influence of in filled wall in framed structure by through three bay of structure. Here two specimens are going to be analyzed under the following methodologies, R.C frame without infill, R.C frames with infill using reverse cyclic loading. The properties of concrete and steel are also measured for analysis of experimental work. According to the code IS456: 2000 Plain and Reinforced Concrete Code of practice, the specimens are prepared and testing of specimens are going to carried out through the loading frame.

Keywords—RC Frame, Dynamic loading, Reverse cyclic loading.

I. INTRODUCTION

Recently, it becomes important to determine the behaviour of structure with infill walls. Reinforced concrete frame buildings with masonry infill walls have been widely constructed for commercial, industrial and multi-family residential uses in seismic-prone regions worldwide. Masonry infill typically consists of brick, clay tile or concrete block walls, constructed between columns to beams of a RC frame. Masonry infill walls can be found as interior partitions or exterior partitions or erection facades in reinforced concrete and steel frame structures. Masonry infill walls are found in most existing concrete frame building systems. Infilled frame designates a composite structure formed by one or more infill panels surrounded by frame, the frame is built first and then infilled with one or more masonry panels.

The interaction with the surrounding frame when the structure is subjected to wind or earthquake loads; the resulting system is referred to as an infill frame. Masonry infill panels have been used in reinforced concrete RC frame structures as exterior and interior partition walls for a long time. The infill provide excellent insulation and isolation from climatic forces such as heat, sun, wind, rains extreme cold etc., apart from easy of construction and economy.

Moreover the walls have a very good fire resistance too. The infills are invariably constructed after the basis frame work of beams, columns and slabs have gained sufficient strength. The stiffness of the frame increase in the presents of infill which reduces the lateral deflection. The masonry infill walls which constructed after completion of concrete frames are considered as non-structural elements.

The presence of non-structural masonry infill walls can affect the seismic behaviour of framed building to large extent. These effects are generally positive: masonry infill walls can increase global stiffness and strength of the structure. On the other hand, potentially negative effects may occur such as torsional effects induced by in plan- irregularities, soft storey effects induced by irregularities and short column effects. It has been generally recognized that infill frame structure exhibit poor seismic performance, since numerous buildings have failed in past earthquakes. The infill frames have greater strength as compared to frames without infill walls. The presence of the infill walls increases the lateral stiffness considerably. Recent earthquakes showed that infill walls have an important effect on the resistance and stiffness of building. However, the effect of the infill walls on the building response under seismic loading is very complex.

Full scale experiments test are best option for better understanding of the behaviour of infill frames. But full scale experimental test are too expensive, so experimental studies in reduced scale specimens up to three stories are tested.

II. REVIEW OF LITERATURES

C.Rudra srinivasa reddy and Amlan k.sengupta was presented a paper on "Validation of indices for assessing seismic vulnerability of multi-storeyed buildings with typical vertical irregularities using push over analysis" assessment of seismic vulnerability of reinforced concrete building can be carried out by various approaches. In this paper, an approach based on push-over analysis was used for generating vulnerability indices. First, a regular mid-rise building was analyzed to evaluate the vulnerable indices. The modeling and analyses were performed using SAP 2000. Next, variations of the building with typical vertical irregularities were studied. It was observed that for the buildings with soft and weak storey or vertical geometric irregularity or in-plane discontinuity in the vertical elements of the lateral load resisting system, the indices based on the performance of columns in a storey drift ratio showed the maximum deficiency. It was concluded that the indices can indeed be used to identify such typical deficiencies in existing buildings.

P.L.Pradha,C.V.R Murty,K.V.Hoiseth and M.P.Aryal was presented a paper on "computer aided non-linear simulation of brick masonry reinforced concrete infill frame under in-plane lateral load" Analytical and experimental studies are carried out on the effect of central window opening with different sizes in one-bay one storey brick masonry infill frames subjected to in-plane lateral loads. In the analyses, the brick elements are modeled using plane-stress elements, and motar joints by link elements. The parameters investigated include lateral deflection and lateral stiffness of infill frame. Analytical and experimental results are compared. Overall results showed that wall panel significantly reduces performance of infill frames with the increase in opening size, whereas the infill walls possess remarkably high lateral stiffening capacity in comparison to the frames.

Kasim Armagan Korkmaz,Fuat Demir and Mustafa Sivri was presented a paper on "Earthquake Assessment of R/C Structures with masonry infill walls" In this study, a 3-story R/C frame structure with different amount of masonry infill walls is considered to investigate the affect of infill walls on earthquake response of these type of structures. The diagonal strut approach is adopted for modeling masonry infill walls. Push over curves are obtained for the structures using nonlinear analyses option of commercial software SAP2000.Non linear analyses are realized to sketch pushover curves and results are presented in comparison and the effects of irregular configuration of masonry infill wall on the performance of the structure are studied. From the pushover curves, story displacements, relative story displacements, maximum plastic rotations are deremined.Regarding with the analysis results, the effects of irregularities are determined in the structural behavior under earthquake.

Liang Xingwen ,Yang Kejia and Li Xiaowen was presented a paper on "Experimental investigation on seismic behavior of brick masonry buildings with frame-shear wall structure at first two stories" Brick masonry buildings with frame-shear wall structure at first two stories are widely used in building adjacent streets in town. However, its seismic behavior is still concerned by structural engineers. This paper performed pseudo dynamic test on the ½ scale model of a brick masonry building with frame-shear wall structure at first two storeys and brick masonry structure at the other four. Based on the experiment, this paper investigated the dynamic response and failure law of the model. Meanwhile, seismic capacity of the structure was estimated.Ivestigating results shown that, designed properly, this kind of building has better seismic capacity than normal brick masonry building and building with frame-shear wall structure at the first story and brick masonry at the others.

Yeou-Fong Li and Cheng-Wei Chen was presented a paper on "TheAnalysis of RC frames with brick walls by using theEquivalent column model" In this paper, three RC frames with nil, half-height and full height brick walls are tested at the National Center forResearch on Earthquake Engineering (NCREE). After the columns of these non- ductile RC frames are damaged, steel wire cables with non- shrinkage mortar and carbon fiber reinforced plastics (CFRP) are used in the proposedmethod to confine reinforced concrete columns. The stress-strain relationship of the confined concrete, proposed by Li et al. (2003), is used in the theoretical sectional analysis. The "equivalent column model" is proposed in this paperand is used to analyze the brick panel inside the RC frames. Finally, the frame and the equivalent column are engaged and then analyzed following a non-linear pushover analysis to obtain the lateral strength- displacement envelope of each frame. The analytical results can reasonably predict the lateral force displacement relationships of these RC frames.

M.Shahria Alam Khan Mahmud Amanat,M.M.Maksudual Alam was presented a paper on "Experimental investigation of the use of ferrocement laminates for repairing masonry in filled RC frames" An experimental study was carried out to investigate the in-plane strength of masonry infilled reinforced concrete portal frame rehabilitated with ferrocement.A model of a portal frame having masonry infill panel was constructed and tested in the laboratory for this purpose. The load was applied monotonically at the top of the frame till the ultimate capacity was reached accompanied by substantial formation and propagation of cracks. Then both the infill and frame were repaired by ferrocement coating. After rehabitation,the frame was tested in the lab following the same procedure as for the original frame. The masonry infill frame repaired with ferrocement showed significant improvement in performance and more than original strength was achieved. This reveals the potential use of ferrocement as a retrofitting and strengthening material of the existing infilled frame.

III. EXPERIMENTAL INVESTIGATION

The experimental investigation consists of testing 2 numbers of one-third scale model of two-storey, two-bay reinforced concrete frame strengthened with suitable width of masonry inserts. For first frame brick masonry infill was provided fully in the second storey and it was provided with partial infill in the first storey. In second frame, masonry inserts were provided at the direction of lateral load, since the loading is unidirectional. The frames were cast insite with quality raw materials. Sufficient care was taken to ensure quality control and frames were cured as per codal provisions.

A. Experimental Investigation

Ordinary Portland Cement conforming to IS: 269-1976 was used for concrete. Well-graded, crushed and uniform size hard blue granite metal of 6mm down size was used as coarse aggregate. Well graded sand was used as fine aggregate. Potable water was used for concreting, construction of brickwork and curing of the specimen. The reinforcement grill works was prepared using high yield strength deformed bars of various sizes of Fe 415 grade for flexural reinforcement and Fe 250 as shear reinforcement. To provide cover to the reinforcement, precast cover blocks of 13mm thick were used for columns and 8mm for beams. Good quality, burnt clay bricks of size 77x33x25mm were procured and used as infill in the frames. Concrete mix of 1:2:4 (volumetric mix) was used for beams and columns.

TABLE I. MIX PROPORTION

Water	**Cement**	**Fine aggregate**	**Coarse aggregate**
191.6	425.7	547.11	1192.08
0.45	1	1.23	2.63

Test models was fabricated to 1:3 reduced scale following the laws of similitude by scaling down the geometric and material properties of the prototype for Frame (1) and Frame (2). The geometry of frame models are shown in Fig.5.1. The foundation portion of the frame was made between the loading frame columns, so as to cater to the loading of the frames as a vertical cantilever.

TABLE II. PROPERTIES OF THE MATERIAL USED FOR MODEL

S. No	**Description**		**Characteristic strength N/mm^2**
1.	Cube compressive strength		19.00
2.	Flexural strength of concrete		3.60
3.	Tensile strength of concrete		2.10
4.	Modulus of elasticity of concrete		22.625 x 10^3
5.	Yield strength of steel	10mm dia	484.00
		8mm dia	463.00
		4mm dia	255.00
6.	Modulus of elasticity of Steel		2.12 x 10^5
7.	Brick prism strength		4.35
8.	Modulus of elasticity of brick prism		3333

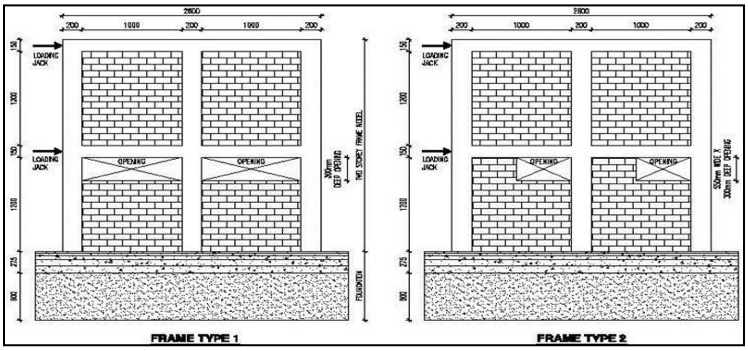

FIG I. GEOMETRY OF THE FRAME MODEL

A. *Reinforcement Detail*

The dimensions of the beams and columns with reinforcement details are shown in Fig 5.2. Four numbers of 10mm diameter High yield strength deformed (HYSD) bars were provided for columns. Two numbers of 10mm diameter HYSD bars were provided both at top and bottom for beams. The transverse reinforcement were in the form of closed rectangular two-legged stirrups of 4mm diameter mild steel bars, provided at 100mm c/c near the ends of the beams whereas in the middle portion of the beams, the spacing adopted was 150mm c/c.

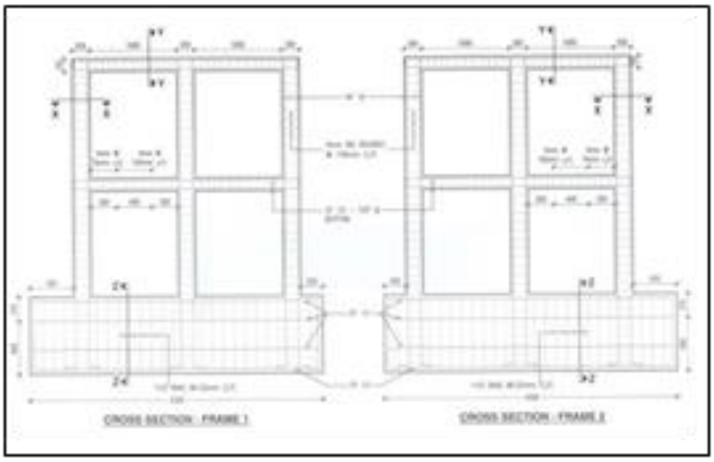

FIG II. DIMENSIONS OF THE BEAMS AND COLUMNS WITH REINFORCEMENT DETAILS

For the column, the spacing of ties was 100mm c/c. At the base, to ensure fixity, the column reinforcement were taken beyond the full depth of footing and bent to achieve adequate anchorage length. Similarly the beam rods were bent to the required development length and inserted into according to IS: 456 and SP-34.

FIG III. BRICKWORK OF FRAME 1 AND FRAME 2

B. Test Setup

Test frame set up available in the Structural Engineering laboratory is shown in Fig. 5.14. Schematic diagram of the Test frame is also shown in Fig. 5.15. Two numbers of the two storey, two-bay R.C frame with partial infill in the bottom storey and complete infill in the top storey [Frame (1)

- without insert and Frame (2) - with insert] were ready for test under a lateral cyclic loading. It consists of the following arrangements.

- Loading arrangement
- Instrumentation for measuring deflections

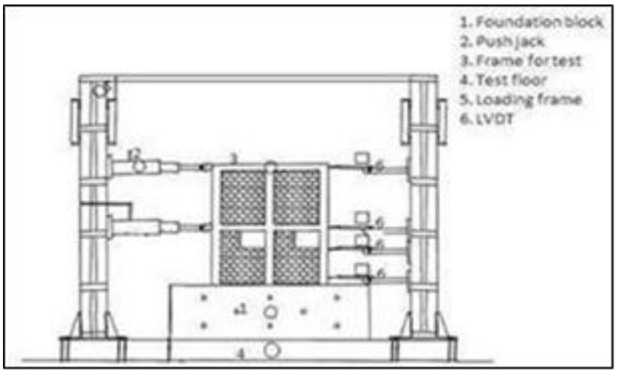

FIG IV. SCHEMATIC DIAGRAM OF TEST FRAME

Two load points were located at first storey and second storey levels in line with the beams. The reaction frame, which is used for loading arrangements, is rigidly fixed to the test floor. Jacks of 500kN in capacity at the top level and 100KN at the middle levels are placed. Pressure gauges are used to measure the applied load. Two numbers of hand- operated oil pumps were used for the application of load through jacks. The lateral movement of the loading frame at the higher loads was avoided by providing suitable struts using mild steel channels, welded to the top of frame.

LVDT (Linear Variable Differential Transformer) of least count 0.01mm was used for measuring deflections at all storey levels including one at partial infill opening level. For measuring surface strain of concrete, pellets were pasted of the end of beam and columns.

C. Testing Of Frames

The effectiveness of instrumentation set up and the loading were checked in the beginning by loading and unloading the frame with small loads (in the order of 1.0 kN at the two load points) till all the readings was repeatable. The frame was subjected to lateral cyclic loading. Lumped mass distribution was calculated and lateral loads were distributed as 80% for top storey & 20% for bottom storey. All applied cyclic loads were divided accordingly. Frame (1) was tested of first increments of 10 kN base shear for each cycle and released to zero after each cycle. The deflections at all storey levels were measured at each increment and decrement of the load. The strain in concrete surface was monitored at maximum load of each cycle and at unloading conditions of frame (i.e., when the load is released fully) during all cycles of loading. The formation and propagation of cracks, hinge formation and failure pattern were recorded.

FIG V. TESTING OF FRAME

IV. RESULTS AND DISCUSSION

A. Loading and Load-Deflection Behaviour (P-Δ)

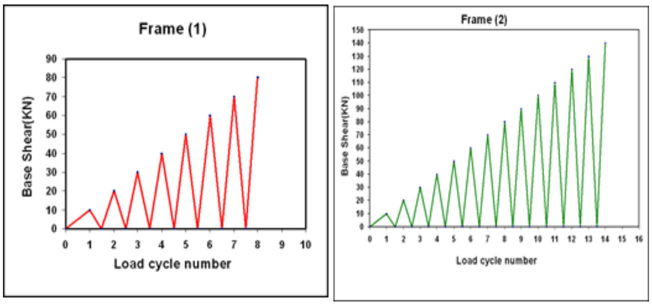

FIG VI. SEQUENCE OF LOADING FOR THE FRAME 1 & 2

The frame was subjected to unidirectional lateral cyclic loading. The load was applied in increment of 10 kN base shear for each cycle and released to zero after each cycle.

The deflections at all storey levels were measured using LVDT at each increment or decrement of load. The strains in concrete surface were measured at maximum load of each cycle and at unloading conditions of frame (i.e. when the load is released fully). The formation and propagation of cracks, hinge formation and failure pattern had been recorded. The same test procedure was adopted in frame with masonry insert.

TABLE III. LOAD CYCLES, LOAD AND DEFLECTION FOR FRAME 1 & 2

Load Cycle no.	**Load(KN)**	**Deflection (mm)**
0	0	0
1	10	2
2	20	3.89
3	30	6
4	40	8.12
5	50	13.69
6	60	21.23
7	70	34.33
8	80	47

B. Ductility Factor

The ductility factor (μ) was calculated. For frame (1), the first yield deflection (Δy) for the assumed bi-linear load- deflection behaviour of the frame was found to be 6 mm for 30 KN base shear, while for frame (2), the same is found to be 11.79mm for 80 KN base shear. The ductility factor value μ = (Δ1/Δy) for various load cycles of the frames was worked out and the variation of ductility and cumulative ductility factor for both frames with load cycles.

TABLE IV. LOAD CYCLE VS DUCTILITY AND CUMMULATIVE DUCTILITY FACTOR FOR FRAME I

Load Cycle Number	**Base Shear in KN**	**Deflection in mm**	**Ductility factor**	**Cumulative ductility factor**
0	0	0	0.000	0.000
1	10	2	0.333	0.333
2	20	3.89	0.648	0.698
3	30	6	1.000	1.698
4	40	8.12	1.353	3.051
5	50	13.69	2.282	5.333
6	60	21.23	3.538	8.871
7	70	34.33	5.722	14.593
8	73	47	7.833	22.423

C. Energy Dissipation

The energy dissipation capacity of the frame during various load cycles were calculated as the area bounded by the hysterisis loops from the base shear versus top storey deflection diagram and tabulated for frame (1) & (2) in Table 7.3(a) & 7.3(b). The energy dissipation in the frame (1) is 46.533 kN/mm whereas the energy dissipation in frame (2) is 218.92 kN/mm. This is due to the masonry insert provided in frame (2) which mean the frame can dissipate more energy under lateral loading.

TABLE V.ENERGY DISSIPATION CAPACITY AND CUMULATIVE ENERGY DISSIPATION CAPACITY

Load cycle	**Load**	**Energy Dissipation (KNmm)**	**Cumulative energy Dissipation (kNmm)**
0	0	0	0
1	10	0.7036	0.7036
2	20	3.3601	4.0637
3	30	5.3736	9.4373
4	40	6.3692	15.8065
5	50	15.8716	31.6781
6	60	29.5635	61.2416
7	70	36.7968	98.0384
8	80	46.5353	144.5737

D. Behaviour and Mode of Failure

First crack was observed (horizontal hairline) at 30kN at the junction of loaded side of the beam and column at the bottom storey, where moment and shear forces are maximum while loading further, similar cracks were developed in the other bay columns and flexural cracks were developed from the junction of the loaded areas. Separation of infill occurred at the tension corners. At the ultimate failure load of 70 KN, crushing of loaded corner, widening of diagonal cracks in columns and infill, layer separation of brick infill were also observed. Width of the cracks was ranging from 3mm to 15mm in concrete and masonry. The crack pattern indicated a combined effect of flexure and shear failure. Also plastic hinges formation was observed first at loaded point and later to the middle column and finally at the leeward column. Captive column phenomenon was identified with the failure pattern of loaded column. It was also noticed that flow of diagonal crack from the loaded column adjacent to the opening was discontinuous, due to incomplete strut action.

E. Ansys Comparison

Comparative study was made between experimental and analytical values. Non-linear finite element analysis has been carried out using ANSYS-10 software for Frame (1) & (2). After every cyclic loading, deformations were recorded. Also stress distribution and strain distribution were also studied.

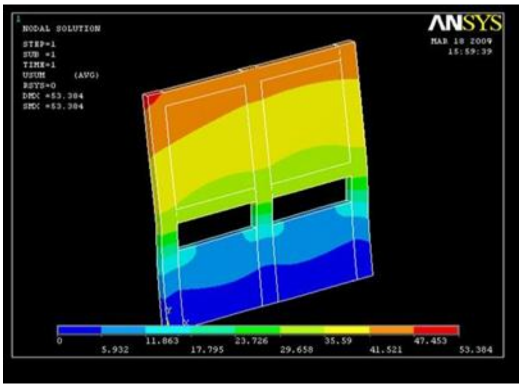

FIG VII. DEFORMED SHAPE OF FRAME IN ANSYS

The results obtained from analytical for Frame (1) & (2) are compared with experimental and tabulated. Analytical results by ANSYS- 10 underestimates the experimental results in the range of 6 – 15% in the final stages. In analytical study, it is noticed that a sudden increase in deflection after the base shear of 40 kN (nearly equal to experimental value of 40 kN) for Frame (1) and affect the base shear of 80 kN (nearly equal to experiemtnal value of 80 kN) for Frame (2). This proves the initiation of captive column behaviour adjacent to gap region.

TABLE VI. COMPARISON OF BASE SHEAR VS TOP STOREY DEFLECTION

Load Cycle No.	**BaseShear in kN**	**Deflection in mm**	
			Analytical
		Experimental	**ANSYS10**
1	10	2	1.412
2	20	3.89	3.402
3	30	6	6.724
4	40	8.12	8.332
5	50	13.69	14.262
6	60	21.23	21.365
7	70	34.33	34.931
8	80	47	47.453

V. CONCLUSION

From the experiments conducted on the two frames (with and without masonry insert) the following conclusions are drawn.

1. The ultimate base shear of 140 kN is reached in the fourteenth cycle of loading for frame with insert whereas only 73 kN reached in the eighth cycle itself. After reaching the ultimate load, post ultimate cycles are performed to study the behaviour of the RC frame till final collapse.

2. It is observed in frame with masonry insert that at a base shear of 80 kN, cracks are initiated at the junction of the loaded and middle end of the beam and column of the bottom storey where the moment and shear forces are maximum whereas in frame without insert, the first crack developed at 30 KN itself. The crack pattern indicated a combined effect of flexure and shear failure. However, it could be evidently seen that the shear carrying capacity of the frame is increased due to the presence of masonry inserts.

3. Separation of infill occurred at the tension corners and the high stress concentration at the loaded diagonal ends lead to early crushing of the loaded corners.

4. Diagonal cracks flown through the brick work where masonry inserts are provided showing clear strut action. While further loading of frames, further cracks are initiated and noticed are much dissimilar between a RC frame with partial infill and with masonry insert.

5. It is observed that after a base shear of 80 kN (initiation of cracks in column adjacent to masonry inserts), there is a sudden increase in the deflections of LVDT 3 and LVDT 4. This shows the development of cracks in the top and bottom of the column region adjacent to the gap in the infill.

6. The stiffness of the partially-infilled frame with and without insert for various load cycles is calculated and the variation of stiffness with respect to load cycles is plotted. The stiffness of the brick infilled RC frame with masonry insert is observed to be very high when compared to frame without insert. This shows greater increase of stiffness while introducing masonry insert.

7. The ductility factor value $\mu = (\Delta 1/\Delta y)$ for various load cycles of the frame is worked out for frames with and without insert and the variation of ductility factors and cumulative ductility factors for both frames with reference to load cycles is plotted. From the values, it may be noted that ductility factor for frame with masonry insert is reduced whereas cumulative ductility factor for both frames is more or less same.

8. Energy dissipation of both frames was calculated and found tht energy dissipation of frame (2) is very higher (218.92 kN/mm) whereas for frame (1), it is 46.533 kN/mm. This proves that energy dissipation increases due to energy insert.

9. At a base shear of 100 kN, flexural hinges were formed and diagonal shear cracks started in the loaded and middle-bottom storey columns near the top of the partial infill in the frame with insert whereas frame without insert, flexure hinges formed at 50 kN and found early.

10. Cracks were developed in the leeward column (opposite to the loaded end) of the bottom storey at the base because of diagonal strut compression of the infill in the frame with masonry insert.

11. The partial-infilled RC frame failed with hinges at the portion of columns adjacent to the gap in the bottom storey indicating a distinct “captive column effect” whereas frame with masonry insert strut action took place and diagonal crack flow clearly. Also after the localised separation of the infilled panel from the frame in the bottom storey, the stress flow is mostly along the line connecting the load point to the diagonal opposite corner support indicating the “diagonal strut” concept. Therefore, it could be evidently proven that the lateral strength of the RC frame is considerably increased due to the presence of masonry inserts.

12. The partial masonry infill failed with a diagonal crack by shear along the mortar and/or bricks joints.

13. In frame without masonry insert no crack is developed in the columns, beams and in the infill of top storey clearly depicting that the frame has failed only by hinges in columns due to captive column effect. But, it was noticed that the development of crack is postponed when the frame is provided with masonry inserts.

14.The partial infill reduces the stiffness of the frame leading to critical damages. However, this could be improved to some extent by the provision of masonry inserts.

15. In analytical study, it is noticed that a sudden increase in deflection after the base shear of 40 kN (nearly equal to experimental value of 40 kN) for Frame (1) and affect the base shear of 80 kN (nearly equal to experiemtnal value of 80 kN) for Frame (2). This proves the initiation of captive column behaviour adjacent to gap region.

16. Analytical results by ANSYS-10 under estimate the experimental results in the range of 6 – 15% in the final stages.

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