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SEISMIC STRENGTHENING OF PARTIALLY INFILL RC BUILDINGS USING BRICK INSERTS - EXPERIMENTAL INVESTIGATION ON 3D MODEL STRUCTURE

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ABSTRACT

In partially infill structures, columns with short gap will behave as short column during earthquake and attract larger forces due to inplane stiffness of the infills and can damage the column seriously due to excessive shear forces, which is known as captive column effect. Since it is complex to consider the contribution of strength and stiffness of these partial infills, structure is analyzed and designed as bare frames. But actual structural behaviour for partial infill structures during earthquake is with captive column effect. One of the major failures of structure during earthquake is due to captive column effect. Several literature and research papers were published in the area of seismic strengthening of existing structures. To overcome this type of failure in the structure due to this effect, it should be ensure that the shear forces should flow smoothly by means of a strut action. This is achieved by inserting a brick masonry adjacent to columns in the partially infill areas in order to ensure shear flow is smooth and thus improving the lateral capacity of the structure. An experimental investigation was carried out in the '3D' model structure to study the effect of this captive column effect and to reduce this effect by introducing brick insert adjacent to column face. This study clearly indicates that with the help of brick insert, captive column effect is reduced, lateral capacity increases and thus preventing critical damage to the structure by the seismic load during earthquake. A Comparative study was made between experimental and analytical method by using - ANSYS 10 and the values are found to be nearly equal.

Keywords: partial Infill, masonry inserts, seismic strengthening, captive column effect.

I. INTRODUCTION

During earthquake at Bhuj in 2001, several buildings were subjected to failure predominantly due to captive column failure and buildings with soft storey. Designers have started to take action to prevent similar damages during future earthquakes for the buildings with these deficiencies. But many buildings, which were constructed, need to be prevented from failure due to these effects from future earthquakes. The purpose of the present study is to investigate the improvement of strength of the existing structure by adding brick inserts in the partially infill structure as seismic retrofit.

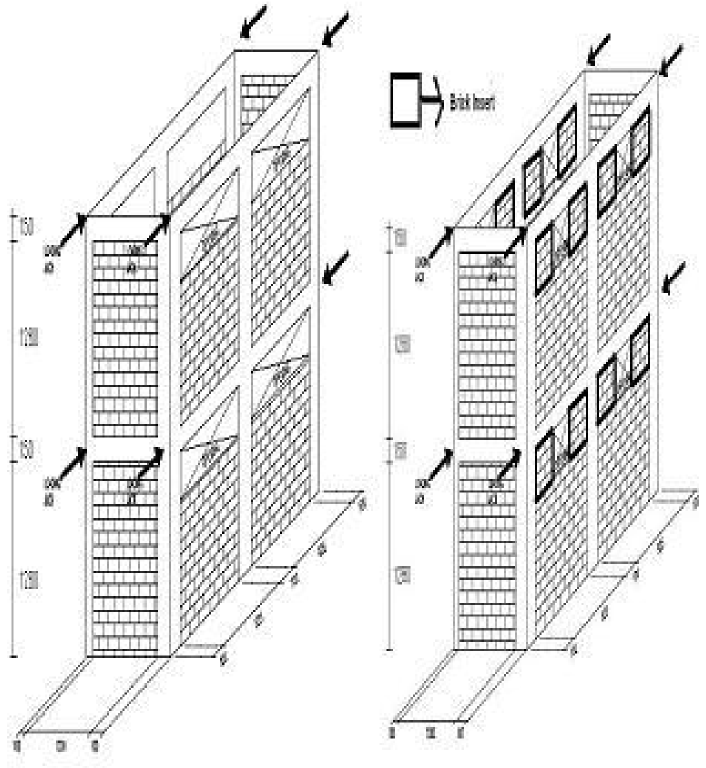
Previous experimental research on the behaviour of brick infilled RC structures (Achintya *et al*., 1991; Yaw-jeng Ciou *et al.*1999; Diptesh Das *et al*., 2004; Ismail *et al*., 2004; Marina *et al*., 2006) have shown that the structural behaviour of the structured masonry wall subject to in - plane monotonic loading on partial fill masonry wall induce a short column effect and leads to severe failures of the column. Further experimental research of Mehmat Emin Kara *et al*., (2006) have shown that partially infilled non-ductile RC structures exhibited significantly higher ultimate strength and higher initial stiffness than the bare structure. Prabavathy *et al*., (2006) have shown that infill panels can significantly improve the performance of RC Structures. Alidad Hashemi *et al*., (2006) have shown that infill wall changes the load path and the distribution of forces. Kasim Armagan Korkmaz *et al*. (2007) shown that presence of nonstructural masonry infill walls can modify the global seismic behaviour of structured building to a larger extent. Umarani (2008) examined the behaviour of infilled structures (5 storeys) for lateral loading. Test focused on the increase of energy dissipation over and above the base structures. Santiago pujol *et al*. (2008) shown that masonry infill walls were effective in increase the strength (by 100%) and stiffness (by 500%) of the original reinforced concrete structures. Salah El - Din Fahmy Taher *et al*. (2008) observed that lower location of infill structures yields the higher strength, stiffness and frequency of the system.

Further to these research work, an experimental and analytical investigation was planned to study the behaviour of captive column effect in partially infilled, two-bay two - storied '3D' structure viz. one structure with full opening and the other structure with masonry inserts, under the push pull loading. This experimental investigation clearly shows that the capacity of the structure increased by adding brick insert in the partial infill structure.

2. EXPERIMENTAL INVESTIGATION

2.1 Modeling of structures

Test models were fabricated to 1:3 reduced scales following the laws of similitude by scaling down the geometric and material properties of the prototype for structure (1) and structure (2) (Figure-1).



**Structure (1)
Without Insert**

**Structure (2)
With Insert**

Figure-1. Geometry of the 3D structure model 1 and 2.

The details of geometrical properties of prototype and model structure is tabulated is Table-1.

Table-1. Geometric properties of the prototype and model.

S. No.	Property	Prototype	Model
1	**Storey height** Ground floor First floor	 3600 3600	 1430 1430
2	Structure spans (Two bays)	3000	925
3	Beams	300 x 450	100 x 150
4	Column	300 x 300	100 x 100
5	Beam reinforcement top and bottom	2 – 25mmϕ - Fe415	2 - 10mmϕ - Fe415*
6	Column reinforcement	4 – 25mmϕ - Fe415	4 - 10mmϕ - Fe415*
7	Stirrups	8mmϕ - Fe415	4mmϕ - MS*
8	Brick	230x100x75	77x33x25

The properties of material used for model test structure specimens are shown in Table-2.

Table-2. 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		22.65 x 10^3
5	Yield strength of steel	10mm dia	484.00
		8mm dia	463.00
		4mm dia	355.00
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

2.2 Testing of structures

Lumped mass loads for top and bottom storey were calculated and applied on push and pull basis. Structure 1 was applied with 5kN push and pull load and released to zero and increased in steps of 5kN at every loading and releasing stages. Top storey deflections were measures using LVDT. The histories of sequence of loading for both structures are shown in Figures 2 and 3. The ultimate base shear of 105kN was reached in the Twenty first cycle of loading and ultimate base shear of 195kN was reached in thirty nineth cycle for structures 1 and 2, respectively. The formation and propagation of cracks, plastic hinge formation and failure pattern were recorded. This procedure was repeated for structure (2) with masonry insert.

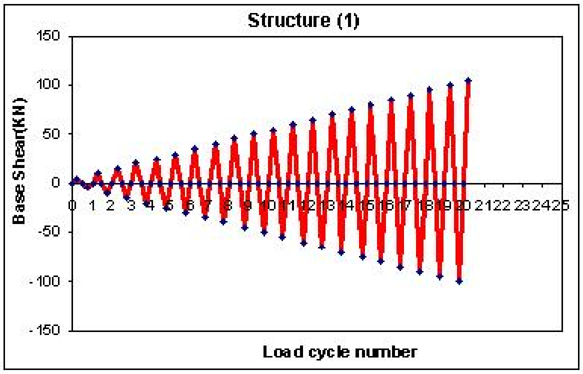


Figure-2. Sequence of loading for structure (1).

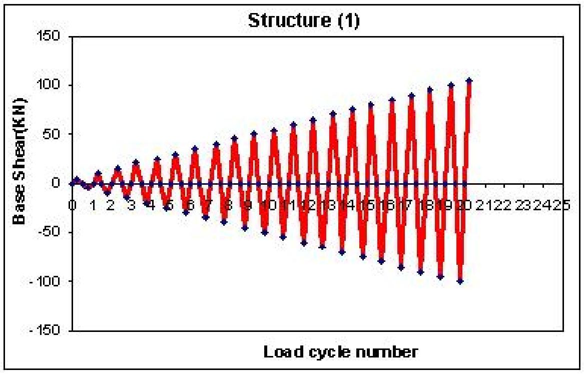


Figure-3. Sequence of loading for structure (2).

2.3 Results and discussions

The results of various parameters, viz., load Vs deflection, stiffness degradation, ductility factor, energy dissipation were considered for study of the captive column behaviour of the structures.

2.3.1 Loading and load-deflection behaviour (P-Δ)

The structure was subjected to push and pull loading. The push and pull load was applied in increment of 5 kN base shear for each cycle and released to zero after each cycle. The deflections at top storey levels were measured using LVDT at each increment or decrement of load. The ultimate base shear of 105 kN was reached in the twenty first cycle of loading and ultimate base shear of 195 kN was reached in thirty nineth cycle for structures 1 and 2, respectively. The push pull curve for top storey displacement versus base shear for both structures is represented in Figures 4 and 5. At the ultimate base shear the top storey deflection was found to be 58.24mm for structure (1) and 71.15mm for structure (2).

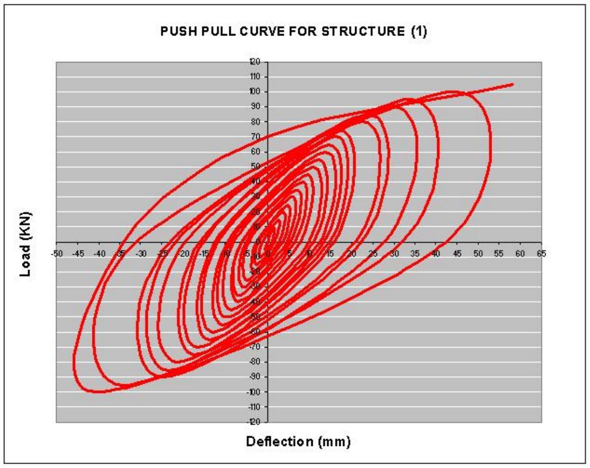


Figure-4. Push and pull curve for structure (1).

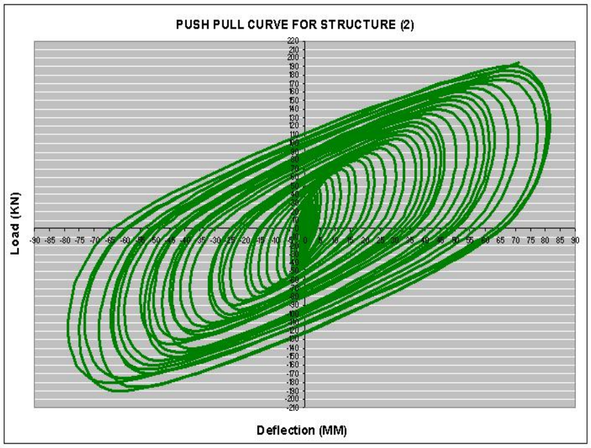


Figure-5. Push and pull curve for structure (2).

2.3.2 Ductility

The ductility factor (μ) was calculated. For structure (1), the first yield deflection (Δy) for the load-deflection behaviour of the structure was found to be 9.605mm for 45 kN base shear, while for structure (2), the same is found to be 17.404mm for 80 kN base shear. The ductility factor value μ = (Δ1/Δy) for various load cycles of the structures was worked out and the variation of ductility factor for both structures with load cycles are shown in Figure-6.

The ductility factor is found to be increasing more from 1 at nineth cycle to 6.06 at twenty first cycle for structure (1). While for structure (2), the ductility factor is 1 at sixteenth cycle of loading and only 4.08 at thirty nineth cycle of loading. This behaviour shows the reduction of ductility of structure due to the provision of masonry insert and is shown in Figure-6.

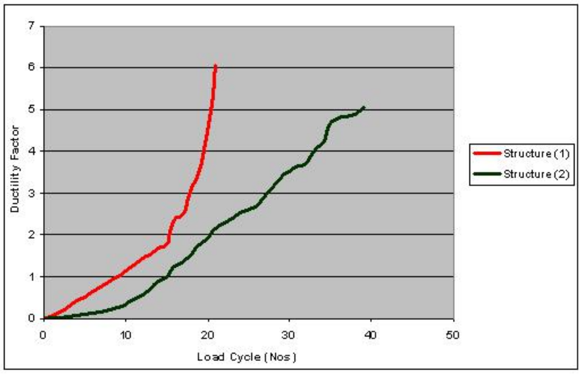


Figure-6. Ductility factor for both structures.

2.3.3 Stiffness degradation

The stiffness of the member was obtained from the relationship,

K=P/Δ;

where

K = stiffness of the member
P = Load applied in the structure in kN
Δ = Deflection in mm

The stiffness of the partially-infilled structures for various load cycles is calculated and presented. The variation of stiffness with respect to load cycles is shown in Figure-7. For structure (1), it may be noted that stiffness decreases from 6.7KN/mm in first cycle to 1.8 kN/mm in twenty first cycle. A sudden reduction in stiffness takes place after the first crack occurrence in 45 kN load.

For structure (2), the initial stiffness of structure is 18.69 kN/mm against 6.7 kN/mm of the first structure and stiffness is sustained for a longer duration until the development of first crack and is reduced to 2.74 kN/mm in Thirty nine cycle.

This behaviour shows that the initial stiffness of structure (1) is comparatively very low and flexural hinges and shear cracks are developed at an early stage of loading. For structure (2) with masonry insert, initial stiffness is increased and occurrence of flexural hinges and shear cracks in concrete and masonry takes place only after the sixteenth cycle. Also, it could be noted that the initial stiffness is increased by 2.8 times due to the introduction of masonry insert and the stiffness is sustained for a longer duration of loading. The behaviour of structure for stiffness values is shown in Figure-7.

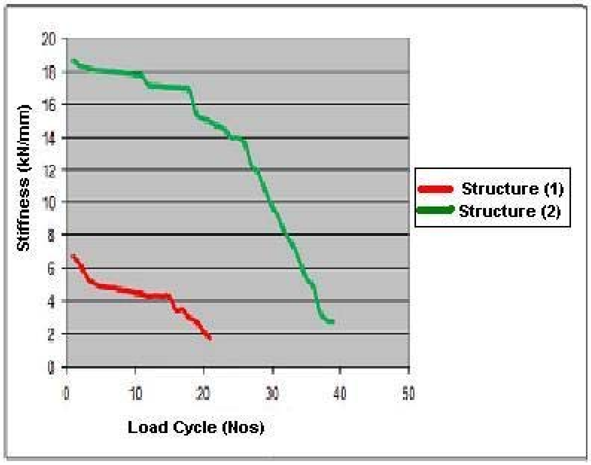


Figure-7. Stiffness degradation curve for both structures.

2.3.4 Energy dissipation

The energy dissipation capacity of the structure during various load cycles were calculated as the area bounded by the hysterisis loops from the base shear versus top storey deflection diagram for structures (1) and (2). The energy dissipation in the structure (1) is 3780 kNmm whereas the energy dissipation in structure (2) is 13120 kNmm. This is due to the masonry insert provided in structure (2), which means the structure can dissipate more energy under lateral loading. The energy dissipation curve behaviour for structures (1) and (2) is shown in Figure-8.

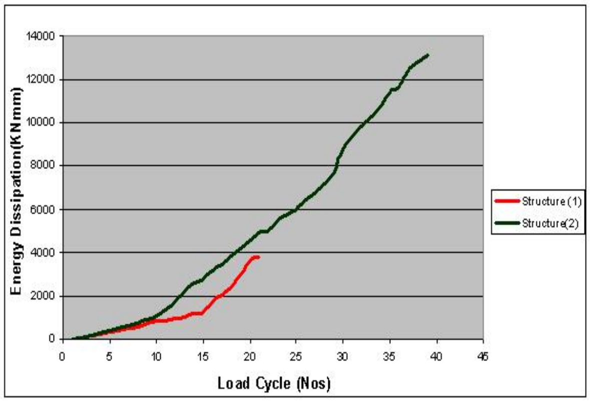


Figure-8. Energy dissipation capacity curve for both structures.

2.3.5 Behaviour and mode of failure

a) Structure-1 without masonry insert

First crack was observed (horizontal hairline) at 45kN 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 area. Separation of infill occurred at the tension corners. At the ultimate failure load of 105 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 17mm 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 (Figure-9).

Figure-9. Test structure (1) with failure in the bottom and drift of the top storey (Constructed at VLBJCET, Coimbatore).

b) Structure-2 with masonry insert

First crack was observed (inclined downwards) only at 80 kN, (against 45 kN for the structure without insert) at loaded side of the beam and column junction of the bottom storey where moment and shear forces were maximum. While loading further, similar cracks were found to propagate in middle column beam junctions and diagonal cracks were initiated in the first (loaded) bay. Further, diagonal cracks were seen to flow through the brick infill. Separation of infill occurred at the tension corners. Due to the presence of insert, diagonal cracks were observed to flow from the loaded beam - column junction to the diagonally opposite corner, clearly depicting the expected strut action (Figure-10). At ultimate load of 195 kN, plastic hinge formation and failure of structure at all bottom storey junctions were noticed. The width of the cracks was ranging from 2mm - 10mm in concrete and masonry. The crack pattern indicated a combined effect of flexure and shear failure and the direction of flown crack showed the developed strut action through the brick infill, due to the presence of masonry insert.

Figure-10. Test structure-2 with failure in the bottom and drift of the top storey (Constructed at VLBJCET, Coimbatore).

A crack in leeward column of the bottom storey at the base was also observed (Figure-11). Separation of infill occurred at the tension corners and the high stress concentration at the loaded diagonal ends led to early crushing of the loaded corners (Figure-12).

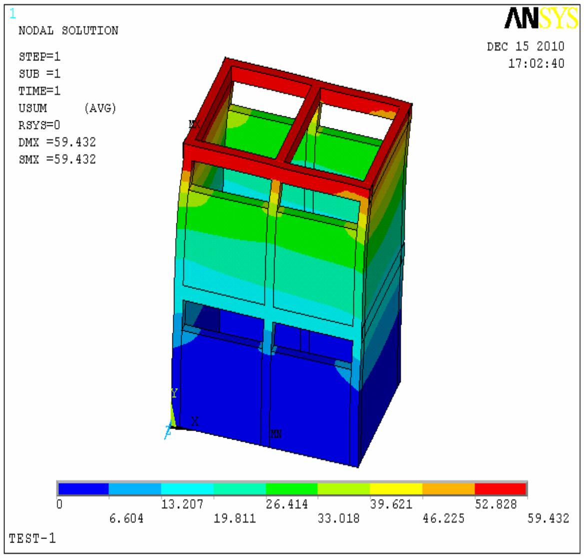
It is also evident from the propagation of cracks at bottom storey level of the sixteenth cycle (80 kN Base shear). Cracks in tension face of leeward column were developed after twenty first cycle of loading. Also separation of infill from columns at highly stressed tension faces of column was seen at twenty first cycle of loading. Further, shear flow was observed in structure 2 from the columns through the insert and brick infill, creating a largely visible crack (about 12mm wide), which is extended to the adjacent columns. This phenomenon is clearly exhibits the development of strut action through masonry inserts.

Figure-11. Crack in leeward column.

Figure-12. Crushing of the loaded corners.

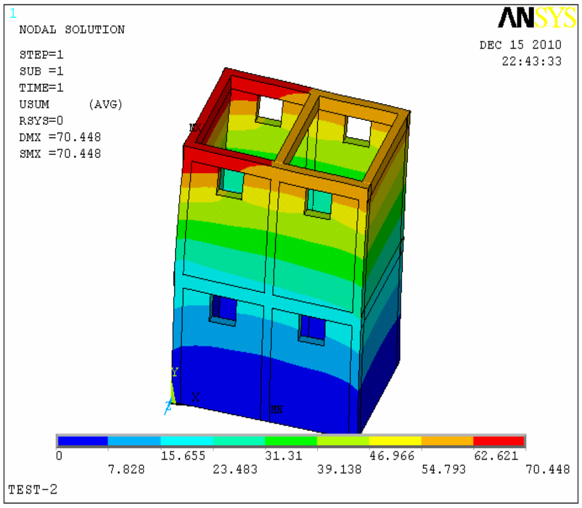
3. FINITE ELEMENT ANALYSIS - ANSYS - 10

A comparative study was made between experimental and analytical values. Non-linear finite element analysis has been carried out using ANSYS-10 software for Structures (1) and (2). The deformed shape of the software model for ultimate load for Structure (1) and (2) is shown in Figures 13 and 14.



Load - 105 KN, Deflection - 59.432

Figure-13. Ultimate deformed shape of the software model for structure (1).



Load - 195 KN, Deflection - 70.448

Figure-14. Ultimate deformed shape of the software model for structure (2).

The results obtained from analytical by ANSYS-10 for Structures (1) and (2) are compared with experimental results and the variation is marginal (Figure-15).

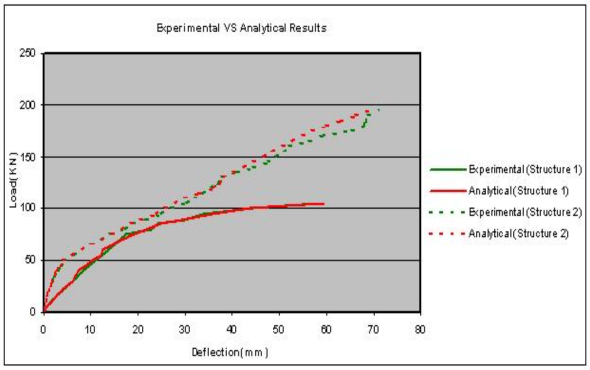


Figure-15. Comparison of base shear Vs top storey deflection for structure 1 and 2 with experiment and ANSYS results.

4. RESULTS AND DISCUSSIONS

Based on the experiments conducted on the two structures (with and without masonry insert) the following observations can be summarized.

It is observed in structure with masonry insert that at a base shear of 80kN, 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 structure without insert, the first crack developed at 45kN 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 structure is increased due to the presence of masonry inserts.

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.

Diagonal cracks propagated through the brick work in case of the structure (2) where masonry inserts were provided indicating clear strut action. Whereas in structure (1) shear could not flow due to captive column failure.

In the case of the structure (2), it was observed that after initiation of cracks in column adjacent to masonry inserts, there was a sudden increase in the deflections (after a base shear of 80 kN). This shows the development of cracks in the top and bottom of the column region adjacent to the gap in the infill.

The stiffness of the partially-infilled structure 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 structure with masonry insert is observed to be very high when compared to structure without insert. This shows greater increase of stiffness while introducing masonry insert.

The ductility factor value μ = (Δ1/Δy) for various load cycles of the structure is worked out for structures with and without insert and the variation of ductility factors for both structures with reference to load cycles is plotted. From the values, it is noted that ductility factor for structure with masonry insert is reduced.

Cracks were developed in the leeward column (both side of the loaded end) of the bottom storey at the base because of diagonal strut compression of the infill in the structure with masonry insert.

The partial-infilled RC structure failed with hinges at the portion of columns adjacent to the gap in the bottom storey indicating a distinct “captive column effect” whereas structure with masonry insert. Strut action took place and diagonal crack flow smoothly. Also after the localised separation of the infilled panel from the structure 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 structure is considerably increased due to the presence of masonry inserts.

The partial masonry infill failed with a diagonal crack by shear along the mortar and/or bricks joints.
The partial infill reduces the stiffness of the structure leading to critical damages. However, this could be improved to some extent by the provision of masonry inserts.

In analytical study, it is noticed that a sudden increase in deflection after the base shear of 45 kN (nearly equal to experimental value of 45 kN) for Structure (1) and affect the base shear of 80 kN (nearly equal to experimental value of 80 kN) for Structure (2). This proves the initiation of captive column behaviour adjacent to gap region.

Analytical results by ANSYS-10 variations are marginal when compared to experimental results.

5. CONCLUSIONS

An experimental work was carried out in ‘3D’ RC structure with partial infill works shows failure of structure due to captive column effect and by adding a brick insert in the same structure the capacity of the structure increases considerably as a result of reducing captive column effect.

It was observed from the experimental study that the partial infill structure (1) showed early formation of plastic hinges and structures failed at an early load stage itself. Whereas the partial infill 3D structure (2) with brick insert showed a delayed formation of plastic hinge and improving the lateral capacity of the structure.

The experimental investigations clearly show that introduction of brick insert helps in increasing the capacity of building for seismic load which delays the failure of the structure during earthquake and hence recommended for practice.

REFERENCES

Yaw-Jeng Chiou, Jyh-Cherng Tzeng and Yuh-Wehn Liou. 1999. Experimental and Analytical Study of Masonry Infilled Frames. Journal of Structural Engineering. 125(10): 1109-1117.

Murtthy C.V.R. and Das Diptesh. 2000. Beneficial Effects of Brick Masonry in Fills in Seismic Design of RC Frame buildings. Engineering Structures Journal. 21(4): 617-627.

R. Morshed and M.T. Kazemi. 2005. Seismic shear strengthening of R/C beams and columns with expanded steel meshes. Structural Engineering and Mechanics. 21(3): 333-350.

Galal K.E., Arafa A. and Ghobarah A. 2005. Retrofit of RC square short columns. Engineering Structures Journal. 27(5): 801-813.

Melhmet Mehmet Emin Kara and Altin Sinan. 2006. Behavior of reinforced concrete frames with reinforced concrete partial infills. ACI Structural Journal. 103(5): 701-709.

FEMA 306. Evaluation of earthquake damaged concrete and masonry wall buildings. Applied Technology Council, USA.

NEHRP guidelines for the seismic rehabilitation of buildings. FEMA Publication 273. Multidisciplinary Center for Earthquake Engineering Research (MCEER), USA.

C.V.R. Murthy. 2005. Key notes on seismic resistance buildings.