STRENGTHENING OF RC FRAMES AGAINST PROGRESSIVE COLLAPSE USING CFRP COMPOSITE AND PERFORATED STEEL PLATED INFILL WALLS

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Abstract – *Masonry-infilled (MI) panels that function as partitions in buildings are generally considered as architectural components. Therefore the resistances of such components are often assumed insignificant in design procedures. However infill walls stiffness becomes significant to the frame under progressive collapse. It is necessary to quantify the contribution of MI walls on the load resisting capability of RC frames to mitigate progressive collapse. Numerical studies are carried out on this subject to study the same. To further assist the strength of MI walls composite CFRP infill walls, and infill walls with perforated steel plates are introduced to study their influence on the structural behavior. Numerical studies on different RC frame configuration shows that CFRP and perforated steel plate increases the strength of RC frames to an extent. However the increase in strength is influenced by the CFRP fiber alignments, thickness and bolt spacing of the plates. Preliminary studies on these factors are also made part of this paper.*

***Key Words*: CFRP Composite walls, Infill walls, Progressive Collapse, RC Structure strengthening, Steel Plated infill walls, Masonry walls**

1. INTRODUCTION

A building structure is a perfect example of group work where different members are connected to form a whole structure. When a member of the structure fails, the load which that member has to carry is now to be distributed among the remaining members. This excess load can cause further member failure and ultimately lead to whole building collapse. This chain reaction of structural element failures, disproportionate to the initial damage, resulting in the partial or full collapse of the structure is called Progressive collapse occurs.

Progressive collapse is a nonlinear event in which elements are stressed beyond their elastic limit to failure. Frames in structures consisting of columns and beams are often in-filled with brick walls. However, when the brick infill walls are subjected to a small lateral drift, they suffer significant damage, and therefore their contributions to the frame are lost. As a result of this brittle behavior, brick infill walls are for the most part not accepted as a load-bearing member. However under progressive collapse, the presence of infill walls provides an additional stiffness and strength to the frame. This alters the behavior of the structure under progressive collapse. This complicated behavior is not considered in simple structural analysis and hence several researches have been focused to study the influence of infill walls on RC frames.

There have been many attempts to strengthen these brick walls by using different methods and materials to make them behave similarly to a ductile RC wall system. Generally, in these studies the strengthening is achieved by using various polymer materials, precast concrete panels, structural steel elements, and reinforced mortar. In recent years studies have been also shedding light to the use of reinforced polymer and other geo synthetic materials to enhance infill walls.

It is observed that none of the methods mentioned in previous studies involve sufficient ductility, low cost, and easy to use criteria at the same time. As a practically and economically feasible option, this study puts forward the use of perforated steel plates and CFRP (Carbon Fiber reinforced polymer). Use of Fiber reinforces polymer have been proven effective in seismic strengthening [4] and is a promising area of research on its application in other fields. Perforated steel plates being more ductile than plain steel plates thanks to their holes, and are favorable for strengthening infill walls. The effectiveness of perforated steel plates was first investigated in studies on strengthening beams against flexure [7]. This advantage is further extended to improve RC frames under progressive collapse.

This paper investigates the effect of progressive collapse on an ordinary RC frame using numerical modeling. Different structural models are subjected to non linear analysis to better understand the behavior of the structure under progressive collapse. Micro model of frames are modeled using ANSYS_Workbench. Infill walls, CFRP and steel plated alternatives are also introduced in the micro model to study their influence on progressive collapse resistance. A parametric study on plate thickness, hole diameter and CFRP fiber alignment is also made to improve the effectiveness of the module.

The study progresses in three stages. The first stage involves the study of behavior of infill walls in a 2D bare RC frame. The second stage introduces CFRP and perforated steel infill walls to the frame and analysis is carried out for different frame configurations using ANSYS. The third stage aims in optimizing the parameters like plate thickness, bolt spacing and CFRP alignment to arrive at the best possible result from the structure.

Although total prevention of progressive is not always feasible, the study aims to provide a viable and effective solution to improve the strength of RC frames will infill walls under progressive collapse.

2. METHODOLOGY

The project includes analytical study of RC frames against progressive collapse using CFRP composite and perforated steel plated infill walls. Micro-modeling of brick infill wall and three different configuration of infill wall using CFRP strips and perforated steel plated infill with different thickness and bolt spacing were analyzed for total deformation. The modeling and analysis were done using ANSYS Workbench 15.0

3. FINDINGS

Several researches have been carried out in the area of progressive collapse and its mitigation. Most of which studied the effect of infill walls with macro modeling infill walls into compressive struts [8]. Though the strut model is widely adopted, provides a rudimentary understanding of the actual behavior. Works conducted on strengthening of walls mostly focuses on structural steel [7], precast concrete panels, reinforced mortar [10] etc. The current study aims at providing a better understanding to the actual behavior of the structure and to simulate real life scenario of progressive collapse in loading as well as modeling of elements.

4. MODELLING

4.1 Dimensions of frame elements

A 4000x3200mm frame of 3 bays with brick infill walls was analysed. The supports are fixed. Column size of 300 x 450 mm and beam size of 300 x 380 mm is adopted. The Young's modulus for steel is taken as 2x10e5 and poison's ratio as 0.3.

The concrete is of grade M25 and overall depth of slab is 150 mm. The nonlinear stress strain curve for steel and concrete adopted to impart material nonlinearity. This is done by manual input of stress strain curve in ANSYS. The maximum strain in the steel and concrete is taken as 0.0038 and 0.003 respectively.

4.2 Modelling of CFRP infill walls

Finite element modelling consisted of the creation of two parts; one for the masonry wall and one for the CFRP strips. The epoxy glue, which can be regarded as the contact surface between masonry and CFRP strips is maintained by the surface to surface contact elements. This option sets the behaviour of contact pair to 'bonded always' for the surfaces and are not separated in normal and tangential directions at the beginning and during the deformation of contact surface.

Table (1) Properties of CFRP strips

Properties	Values
Thickness	0.12 mm
Density	1600kg/m^3
Poisson's ratio	0.2
Modulus of elasticity	2772MPa

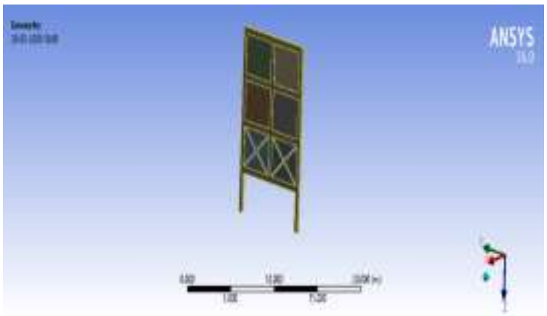


Fig-1: Model of frame with CFRP infill (model 1**)**

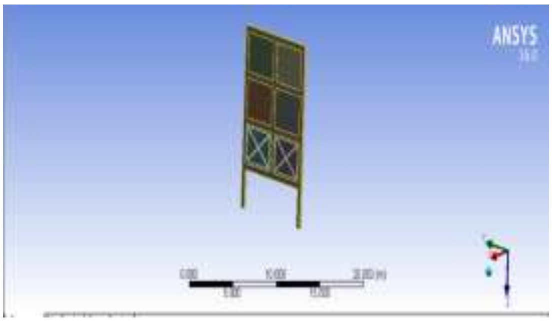


Fig-2: Model of frame with CFRP infill (model 2)

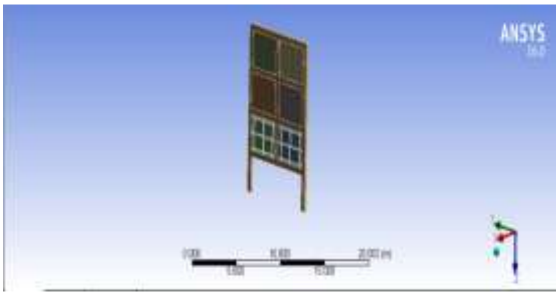


Fig-3: Model of frame with CFRP infill (model 3)

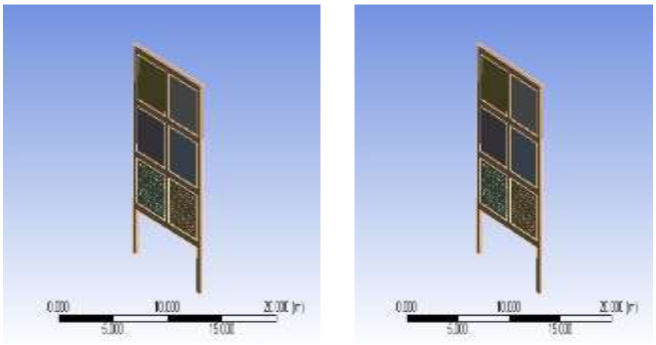
4.3 Modelling of perforated infill walls

A 4000x3200mm frame of 3 bays with perforated infill walls was analysed. The infills were strengthened with perforated steel plates on both faces with three different thickness i.e. 1.0, 1.5, and 2.0mm. The specimens had three different bolt spacing values, which are 100, 150 and 200mm. M6 anchor bolts were used.

The material property values of steel and concrete were inputted in the respective material sections as per the standard data. The five different slab cases were modeled as per dimensions and configurations using ANSYS Workbench 15.0.

Table (2) Dimensions of modelled perforated steel plated infill walls

Specimen	Plate thickness(mm)	Bolt spacing(mm)
S1.0-100	1.0	100
S1.0-150	1.0	150
S1.0-200	1.0	200
S1.5-100	1.5	100
S1.5-150	1.5	150
S1.5-200	1.5	200
S2.0-100	2.0	100
S2.0-150	2.0	150
S2.0-200	2.0	200



(a) (b)

Fig-4: (a) frame with plate S1.0-100 (b) frame with plate S1.0-150

The modeled frame includes fixed support and maximum displacement of 500 mm is applied on the central column.

5. ANALYSIS RESULTS

RC frames with brick infill wall, three different configurations of infill walls with CFRP strips and nine different configurations of perforated steel plates with varying thickness and bolt spacing were subject to progressive loading until collapse were analyzed. Material properties are assigned to solid and surface elements of the model. Meshing was done for a relevance factor of 80 and with element size of 1mm for both concrete and structural steel elements. The analysis settings were properly fixed for the analysis. Material failure was allowed in the analysis.

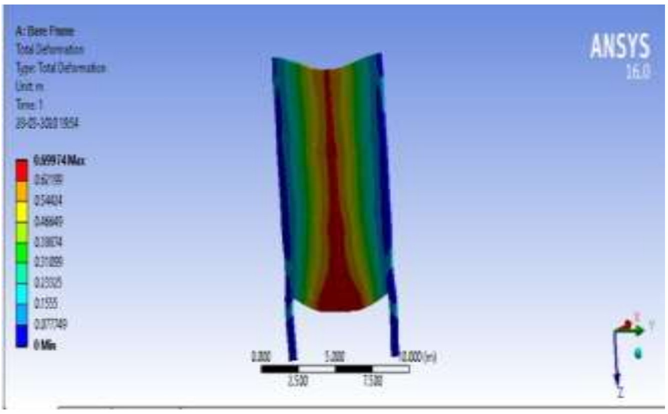


Fig-5 : Total deformation of frame with brick infill wall

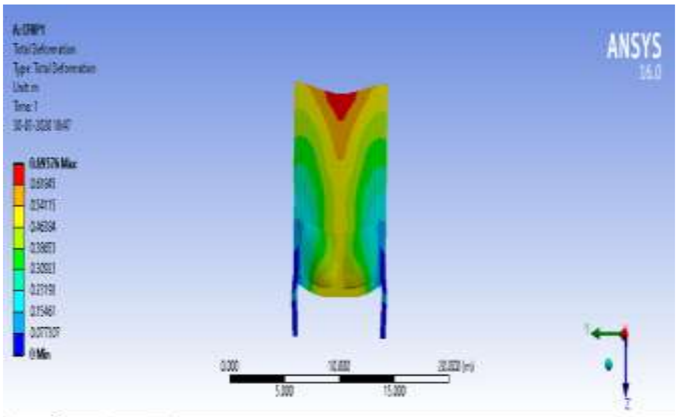


Fig-6 : Total deformation of frame with CFRP model 1 infill wall

Total deformation of frame with four different infill walls are analysed for maximum displacement controlled loading and results obtained from ansys as shown in chart 1

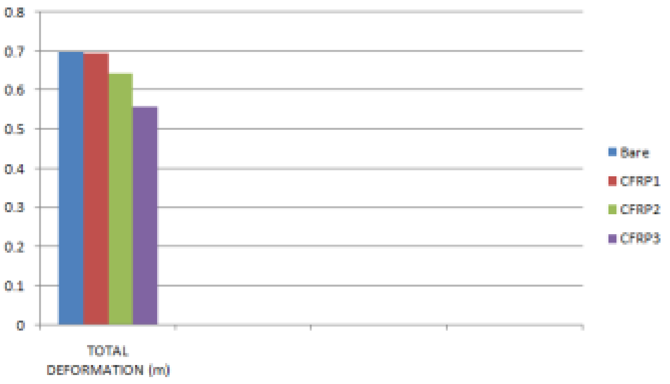


Chart – 1 : shows the total deformation variation of bare frame, CFRP1, CFRP2 & CFRP3

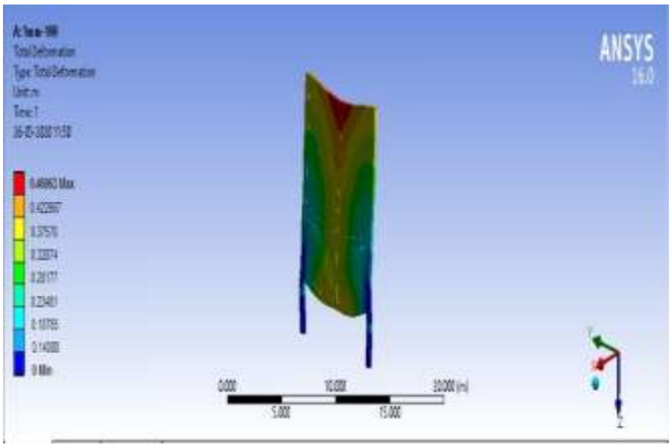


Fig-7 : Total deformation of frame with S1.0-100 infill wall

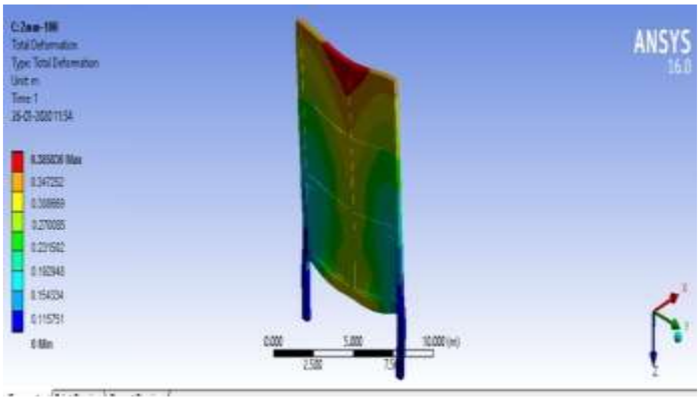


Fig-8 :Total deformation of frame with S2.0-100 infill walls

Total derormation of frame with nine different perforated steel plated infill walls with varying thickness and bolt spacing and results were shown in chart 2

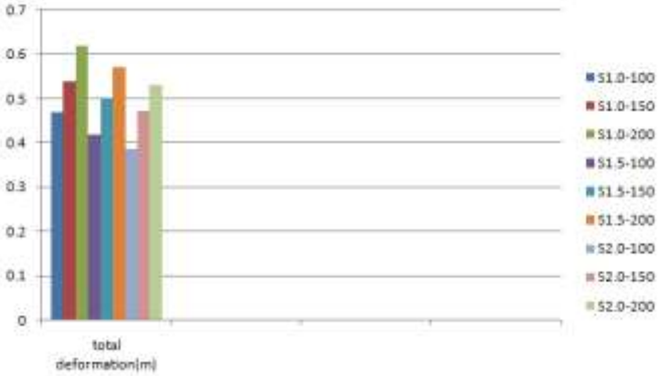


Chart-2 : shows the variation of total deformation of all perforated plated infill walls

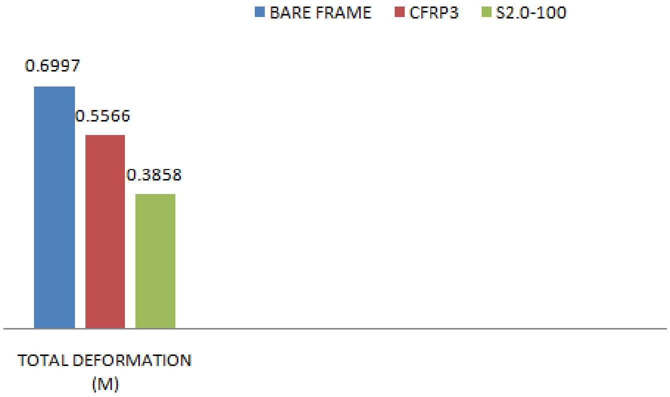


Chart -3: shows the variation of total deformation of brick infill wall, CFRP3 & S2.0-100 infill walls

Table (3): Comparison of analysis results

Type of infill walll	Total deformation (m)	Percentage variation with respect to brick infill wall
CFRP model 1	0.69576	0.56
CFRP model 2	0.64358	8.02
CFRP model 3	0.55661	20.45
S1.0-100	0.46963	32.88
S1.0-150	0.540084	22.81
S1.0-200	0.61992	11.40
S1.5-100	0.419387	40.06
S1.5-150	0.502818	28.14
S1.5-200	0.570328	18.49
S2.0-100	0.385836	44.85
S2.0-150	0.472649	32.45
S2.0-200	0.530405	24.57

RC frames with different infill walls were analysed. Among all brick infill wall poses maximum deformation. CFRP model 1 and brick infill wall shows similar trend in behaviour. Among CFRP models, model 3 shows minimum deformation against progressive collapse.

For frames with perforated plated infill walls, variation of thickness of plate and bolt spacing affects the resistance against progressive collapse. Plate with maximum thickness (ie; 2mm) and minimum bolt spacing (ie;100 mm) shows minimum deformation of 0.385836m among all the alternatives.

6. CONCLUSIONS

The following observations and conclusion can be drawn based on the analytical results of the study

1. Infill walls strengthen RC frames against progressive collapse.
2. Among three CFRP models, model 1 shows has negligible effect on total deformation of brick infill wall.

3. CFRP model 3 shows minimum deformation as compared with brick infill wall with a reduction of 20.45%.
4. For perforated plated infill walls, thickness of plate and bolt spacing influence the resistance against progressive collapse.
5. Perforated plate with maximum thickness (2 mm) and minimum bolt spacing (100 mm) shows the best results in terms of deformation and increases strength of infill walls by 45%.

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REFERENCES

[1] Alaa I. Chehab, Christopher D. Eamon, and Joshua Griffin, "Collapse Resistance of RC Moment-Resisting Frame and Shear Wall Structural Systems Exposed to Blast", Journal of Performance of Constructed Facilities, 2016, ASCE, ISSN 0887-3828.

[2] Iman Tabaeye Izadi, Abdolrasoul Ranjbaran, "Investigation on a mitigation scheme to resist the progressive collapse of reinforced concrete buildings", Higher Education Press and Springer-Verlag Berlin Heidelberg, 2012, 6(4): 421–430

[3] Mohamed Ahmed Galal1; Milan Bandyopadhyay and Atul Krishna Banik, "Vulnerability of Three-Dimensional Semirigid Composite Frame Subjected to Progressive Collapse", Journal of Performance of Constructed Facilities, 2019, ASCE, ISSN 0887-3828.

[4] Mohamed Husain, Ahmed S Elsa and Mohamed M Hegazy, "Strengthening of reinforced concrete shear walls with openings using carbon fiber reinforced polymers", International Journal of Advanced Structural Engineering, 2019, 11;129-150.

[5] Mohammad R. Ameri, Ali Massumi and Hassan Masoomi, "Effect of Structural Redundancy on Progressive Collapse Resistance Enhancement in RC Frame Structures", Journal of Performance of Constructed Facilities, 2019, ASCE, ISSN 0887-3828

[6] Mohsen Ali Shayanfar1 and Mohammad Mahdi Javidan2, "Progressive Collapse-Resisting Mechanisms and Robustness of RC Frame–Shear Wall Structures", Journal of Performance of Constructed Facilities, 2017, ASCE, ISSN 0887-3828.

[7] Ricky Chan, Faris Albermani and S. Kitipornchai, "Stiffness and Strength of Perforated Steel Plate Shear Wall", Procedia Engineering, 2017, 14, 675-679

[8] Shuang Li, Aff.M, Mehmet Metin Kose, Sidi Shan, and Halil Sezen, "Modelling Methods for Collapse Analysis of Reinforced Concrete Frames with Infill Walls", Journal of Structural Engineering, 2019, 145(4): 401-9011

[9] Shuang Li, Mehmet Metin Kose, Sidi Shan and Halil Sezen, "Modelling Methods for Collapse Analysis of Reinforced Concrete Frames with Infill Walls", Journal of Structural Engineering, 2019, ASCE, ISSN 0733-9445.

[10] Yihai Bao, Sashi K. Kunnath, "Simplified progressive collapse simulation of RC frame–wall structures", Engineering Structures32, 2010, 3153–3162.

[11] Zhongxian Li, Xuejie Zhang; Yanchao Shi and Qingfeng Xu,," Experimental Studies on Mitigating Local Damage and Fragments of Unreinforced Masonry Wall under Close-in Explosions", Journal of Performance of Constructed Facilities, 2019, ASCE, ISSN 0887-3828.