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Effect of Combined Beam Slab Interactive Resisting Mechanism for Progressive Collapse

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Abstract*: *In reinforced concrete structures slab, beam and column plays an important role in load transfer mechanism. When a column fails due to earthquake or attack, progressive collapse may occur. There is a need to study and understand the performance of the RC framed structure under progressive collapse to design a better structure. This study investigates the effect of combined Beam-Slab interactive resisting mechanism against progressive collapse using finite element software. Linear static analysis was used to study the progressive collapse of the RC framed structure. The models of symmetrical regular building with bare frame, frame with slab and frame slab with infill were studied. The parameters like load carrying capacity, energy dissipation factor and stiffness degradation were analysed. The analysis results showed that frame slab with infill showed better resistance during progressive collapse.

Keywords : Progressive Collapse, column removal, Slab-beam assembly, energy dissipation, stiffness, Abaqus.

I. INTRODUCTION

In the past few years, number of terrorist attacks has increased across the globe. There is a need to improve the performance of the structures to make them safer and less vulnerable to progressive collapse. Progressive collapse is defined as "a situation where local failure of a primary structural component leads to the collapse of adjoining members, which, in turn, leads to additional collapse [1]. Hence the total damage is disproportionate to the original cause".

Loss of a structural component could be due to impact of a car, fire, earth quake, flood, explosion or an airplane crash etc. The key factor in designing structures is their ability to prevent total collapse after the loss of load-carrying component.

During progressive collapse the structure goes through the following mechanisms to resist collapse contributions from infill walls and slabs, flexural action of beams, vierendeel action, compressive arch action of the frame and catenary action [2], [3] as a column is removed the beams resting on the column go into flexural action trying to resist deflection. As the load increase beams elongate leading to large deformation, yielding and cracks, this leads to lateral force on the columns supporting the beams to resist failure this behavior is called compressive arch action [3].

As deflection further increases the beams further deflects forming a catenary like shape to resist failure and behaviors like a tension member. Catenary action will happened only under large displacements and deformations of beams and it will also occurs when the beams no longer act as structural elements subjected mainly to bending, and the vertical loads are instead transferred to the adjacent vertical structural elements [3]. During this failure mechanisms, the shear force increases in the beams, leading to formation of hinges in the critical locations mostly near the columns. This mechanism is called vierendeel action [4]. In previous works, progressive collapse was studied by the sudden loss of center column in a 3D frame. In few literatures improvement in collapse resistance due to the contribution of slab was also studied [2]. In this work, the contribution of brick-infill was investigated in addition to the influence of slab in beam column assembly. The effect of sudden loss of one corner column was explored. Parameters like load displacement relationship, energy dissipation and stiffness degradation were used to compared the performance of various models.

II. FINITE ELEMENT MODELING AND ANALYSIS

ABAQUS software was used to analyze the various models involved in this work [4], [11]. A 3D RC frame with two bay and two stories was created with open base as shown in Fig.1 and Fig. 2. The cross section of the beams and columns were 230 mm x 380 mm. The 8 nodal hexahedral brick element with reduced hour glass control was used to model the concrete element with the constant mess size of 10 mm. The 2 nodded truss elements were used to represent steel reinforcements with the mesh size of 15 mm. The embedded contact algorithm available in ABAQUS was used to create the bond between steel and concrete. The material properties of concrete and steel are given in Table-I. Concrete damaged plasticity approach was used to study the concrete failure and steel failure behavior was represented using the elastic approach [3], [5].

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Table- I: Properties of Materials

Property	Material		
	Concrete	Steel	Brick
Density (kN/m^3)	24.00	78.50	21.00
Young's Modulus (N/mm^2)	25000	21000	20000
Poisson's ratio	0.18	0.3	0.26

Three different models were created to study the effect of slab and brick infill in resisting progressive collapse. Model-1 an ordinary bare frame with only beam-column assembly (Fig. 3). The loads from slab and brick infill were applied as pressure loads on beams. The loading was increased until the frame reached failure. The design of bare frame was carried out as per IS standards using STAAD.Pro software. The reinforcement details provided in the structural element are listed in Table-II. Fixed support conditions were applied at the base of all columns of the frame.

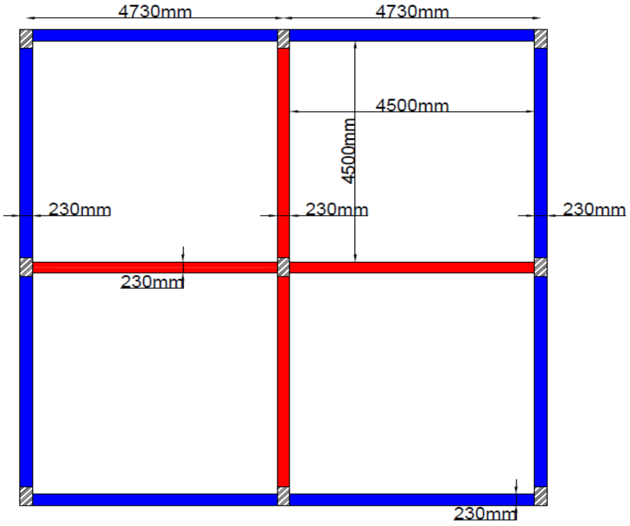

Fig. 1.Plan of the RC Frame

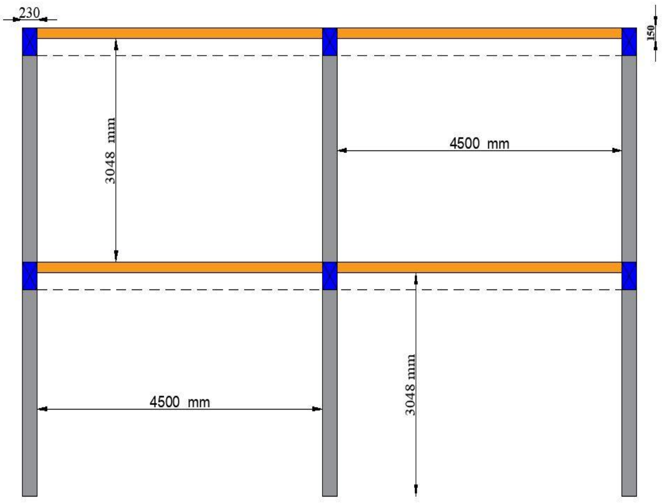

Fig. 2.Elevation of the RC Frame

Fig. 3.Assembly and Support condition of Model-1

In Model-2 frame with only slab assembly was made (Fig.4). The slabs were of 150mm thickness. The load from brick infill was applied as pressure loads on beams. Beams and slabs were connected using surface to surface contact to enable truthful interface. The live load in slab and dead load of beam was applied as pressure on the slabs and beams. So that the load values was similar the Model-1

Fig. 4.Assembly and Support condition of Model-2

In Model-3 frame was modeled with concrete slab and brick infill (figure 5). Brick infill was provided in all the beams in the second story [6] and surface to surface contact was created for proper interface. The live load on the slab was applied as pressure and the equal load values were applied on all the models.

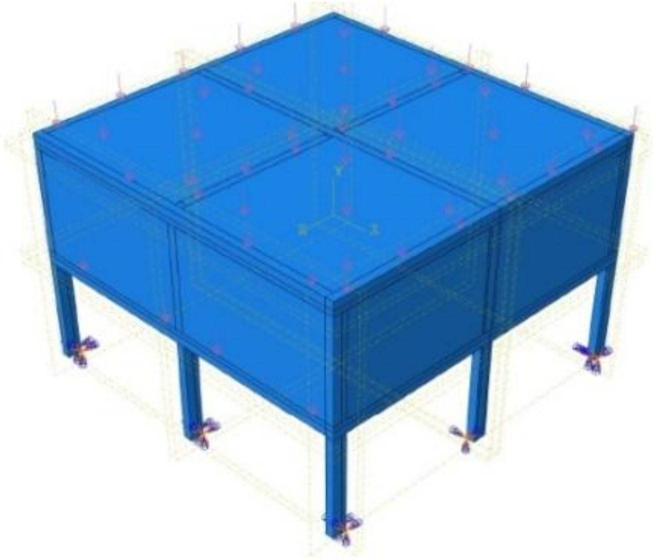

Fig. 5.Assembly and Support condition of Model-3

Table- II: Reinforcement Details

Specimen	**Size**	**Reinforcement**		**Stirrups**
Outer beams	230×380mm	top	4#10mmϕ	8mmϕ at 130mm c/c
		bottom	4#10mmϕ	
Inner c/c beams	230×380mm	top	4#12mmϕ	8mmϕ at 250mm c/c
		bottom	3#12mmϕ	
Column	230×380mm	4#12mmϕ		8mmϕ at 200mm c/c
Slab	4500×4500mm 150mm tk	Main Rod	10mmϕ @ 200mm c/c	
		Distribution Rod	8mmϕ @ 230mm c/c	

The Static general solver was used for the analysis [7]. The Fig. 6, Fig. 7 and Fig. 8 shows the stress distribution in the Model-1, Model-2 and Model-3 respectively. Further one column at the corner of the frame was removed and the behavior of the frame was analyzed [4]. The beam attached adjacent to the removal column was selected for the study. The various results from the mid span node of the chosen beam. The Fig. 9, Fig. 10 and Fig. 11 shows the stress distribution after corner column removal in the Model-1, Model-2 and Model-3 respectively.

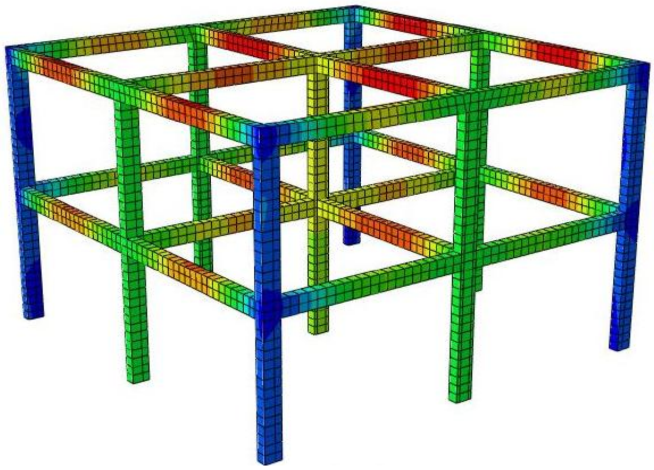

Fig. 6.Stress distribution of Model-1

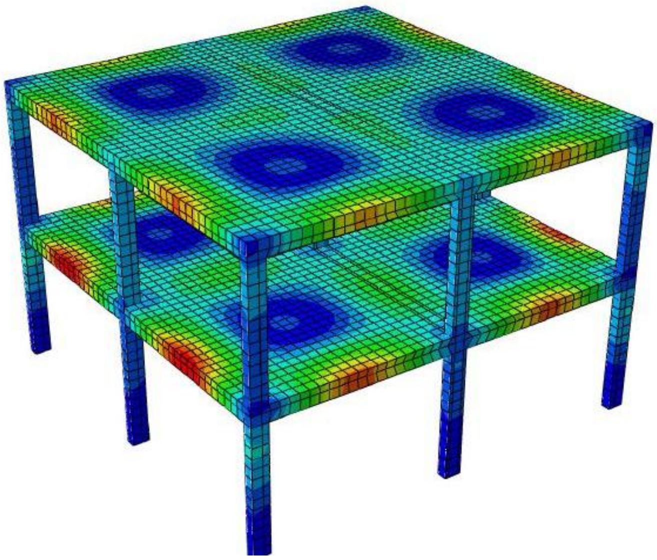

Fig. 7.Stress distribution of Model-2

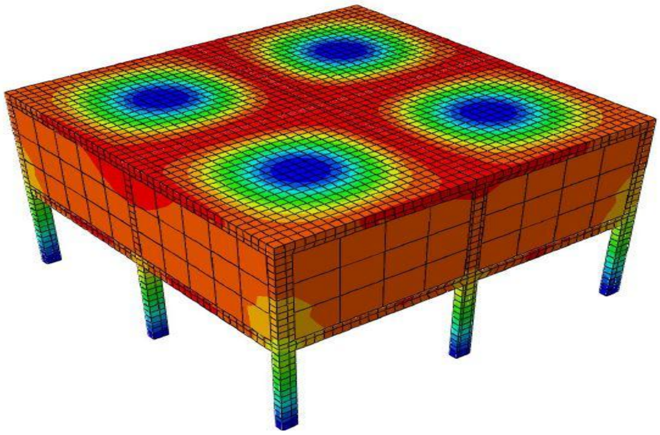

Fig. 8.Stress distribution of Model-3

III. RESULT AND DISCUSSION

Load displacement graph (Fig. 12) shows the Model-1 has a maximum deflection of 4.73mm at an average load capacity of 56kN. Model-2 and Model-3 had a deflection of 3.40mm and 2.93mm with an average load capacity of 66kN and 84kN respectively. The Model-2 and Model-3 had increased deflection resistance of 28.11% and 38.05% respectively compared to Model-1.

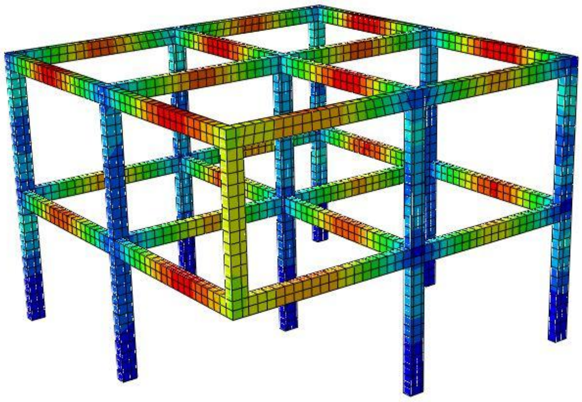

Fig. 9. Stress distribution of Model-1 after column loss

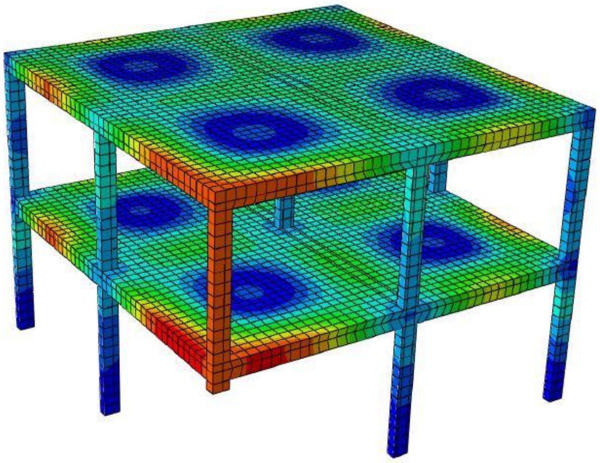

Fig. 10. Stress distribution of Model-1 after column loss

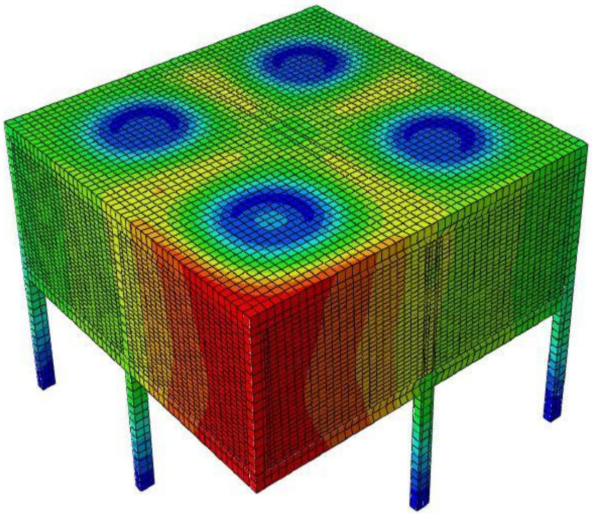

Fig. 11. Stress distribution of Model-1 after column loss

Similarly when a corner column was removed from the model, progressive collapse will occur. When the corner column was removed, load displacement graph (Fig. 13), showed Model-1 has a maximum deflection of 32.56mm with an average load capacity of 92kN. Model-2 and Model-3 had a deflection of 14.6mm and 8.01mm with an average load capacity of 221.67kN and 265.36kN respectively. The Model-2 and Model-3 had increased deflection resistance of 55.16% and 75.39% respectively compared to Model-1.

RC frame with slab and brick infill enhanced the strength of the specimens and also provided better displacement resistance due to diaphragm effect. Based on the above data, we can conclude that frame slab with brick infill simultaneously was behaving better to resist collapse than Model-1 and Model-2 [8], [10].

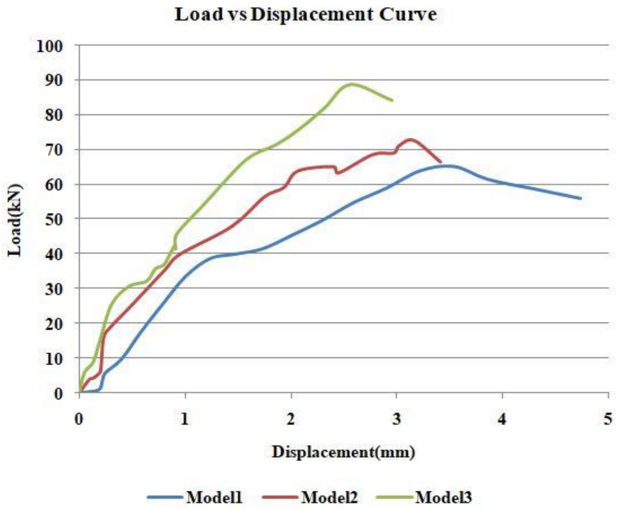

Fig. 12. Load vs. Displacement curve with no column removal

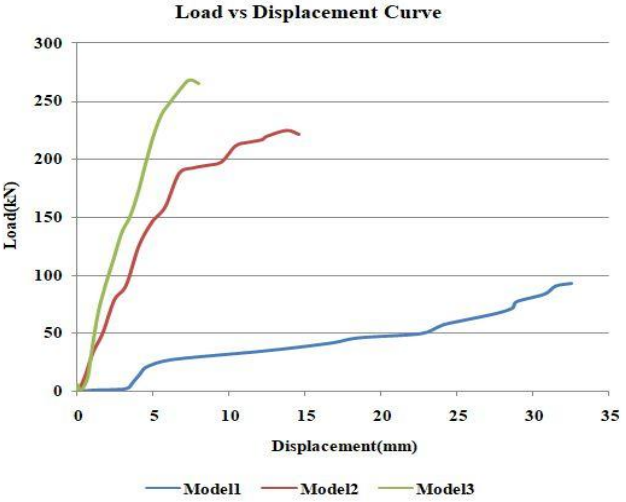

Fig. 13. Load vs. Displacement curve with column loss

Energy dissipation graph (Fig. 14 & Fig. 15) shows the energy dissipation for the Model-1 was higher than Model-2 and Model-3. This implies that the Model-1 reaches failure with maximum deflection for the given loading condition. But in Model-2 and Model-3 the energy capacity has not reached the ultimate and hence it can accommodate more load. RC frame with slab and brick infill enhanced the strength of the specimens and also provided alternate load path for load redistribution. Hence Model-2 and Model-3 serves a reasonable energy dissipation mechanism and can reduce damage, making the structures better collapse-resistant. The energy dissipation graph shows that, the energy dissipation for the Model-1 was higher than Model-2 and Model-3 after the sudden loss of a corner column [10].

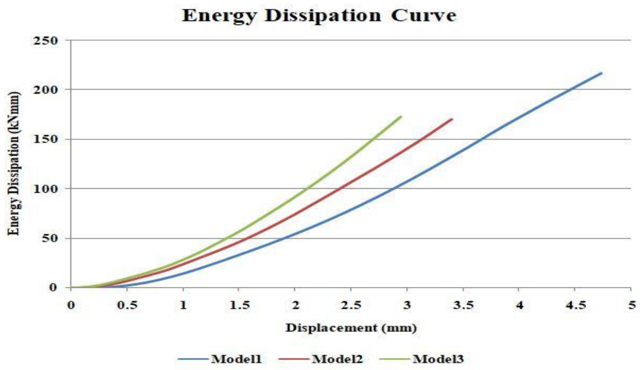

Fig. 14. Energy dissipation curve with No column removal.

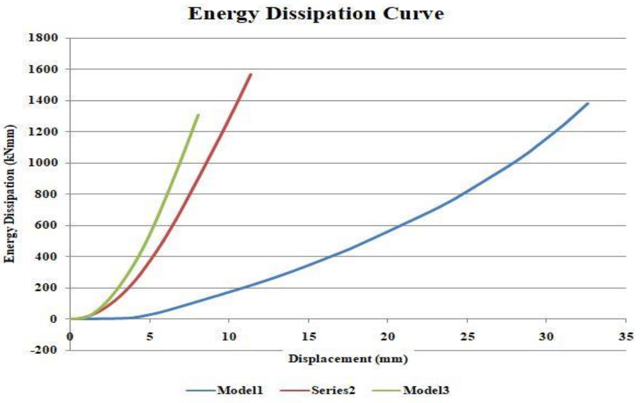

Fig. 15. Energy dissipation curve after column loss.

Stiffness (Fig. 16 & Fig. 17) of models with slab and brick-infill was high. Stiffness degradation curve shows that the behaviour of RC frame with Slab and infill was performing better than bare frame. It was noticed the stiffness degradation of Model-1 was relatively horizontal compared to other two models. This must be due the additional resistance provided by the infill and slab. Stiffness degradation of Model-2 and Model-3 was following a liner path, this shows a better energy absorption [9], [10]. The enhanced stiffness behavior of Model-2 and Model-3 is due to the resistance offered by the diaphragm effect of the models.

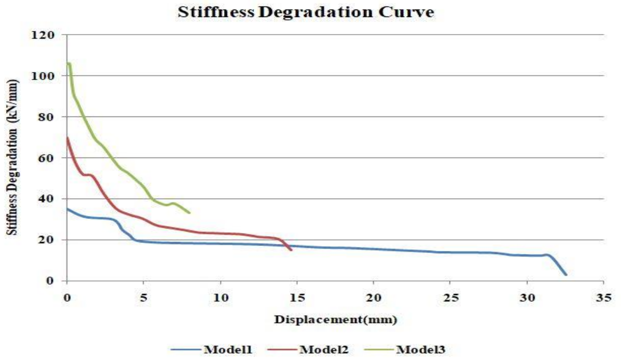

Fig. 16. Stiffness degradation after column loss.

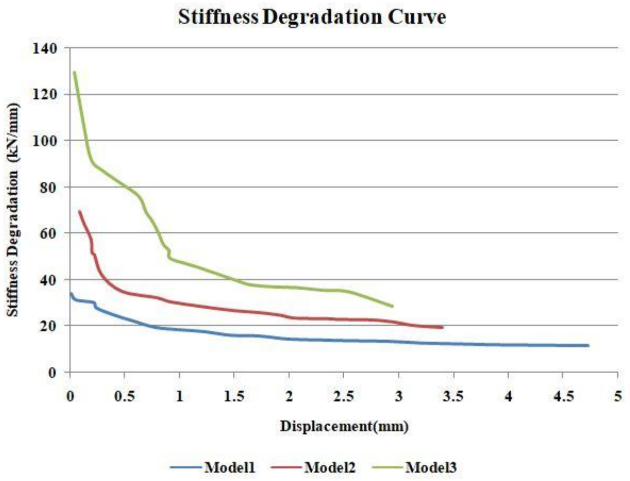

Fig. 17. Stiffness degradation with No column removal

IV. CONCLUSION

The effect of slab and brick-infill in the behavior of 3D frame was investigated in this work. Load-displacement relationship, energy dissipation and stiffness degradation were used to compare the performance of the different frames.

Displacement of the bare frame was high when compared to the frames with slab and infill. The energy dispersion of frame with slab and brick-infill was better due energy absorption and distribution by the added diaphragm elements.

The stiffness degradation showed an enhanced behavior when slab and brick-infill was present because of its ability to resist deformation and delay the displacement.

The frame with slab was showing a better performance compared to the bare frame. The frame with slab and brick-infill was showing a superior performance. So considering the effect of slab and brick-infill during the design of structures to resist progressive collapse will make the design economical as well as safe.

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