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Progressive Collapse Analysis of Composite Structures

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Abstract— **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. Hence, the extent of total damage is disproportionate to the original cause. Progressive collapse of building structures is generally triggered by a local failure due to accidental actions, followed by subsequent chain effect of the structures which may result in wide range failure or even collapse of the entire buildings. In the recent past years, there have been many incidents of structural collapses in terms of buildings or other structures, whether they were because of improper designs, poor maintenance, natural calamities or terrorist attacks. The research towards collapse or progressive collapse has been increasing. This will make the structure more safe avoiding casualties. So far the work done in this areas are for progressive collapse analysis in different number of stories and for different dynamic conditions. They found that progressive collapse potential decreased as the number of story increased since more structural members participate in resisting progressive collapse and by increasing damping ratios in dynamic analysis the maximum lateral deflection decreased for all frames. In this paper, we consider two different analysis procedures, linear static and nonlinear dynamic analysis of composite structures with different plan shapes of same area and for different heights of structure.**

Index Terms— **progressive collapse, linear static analysis, nonlinear dynamic analysis.**

I. INTRODUCTION

Progressive collapse is the result of a localized failure of one or two structural elements that lead to a steady progression of load transfer that exceeds the capacity of other surrounding elements, thus initiating the progression that leads to a total or partial collapse of the structure. The progressive collapse of building structure is initiated when one or more vertical load carrying members (typically column) are removed. Once a column is removed due to vehicle impact, fire, earthquake or any other man made or natural hazards, the building's weight (gravity load) transfer to neighbouring columns in the structure. Due to the redistribution of forces, the stresses within the remaining structural elements such as other columns and beams would be changed and if the stresses exceed the yield stresses of the element it fails. This failure can continue from an element to another and eventually the building collapses. This failure is defined as progressive collapse of the multi-storey buildings.

Progressive collapse is generally a rare accident in developed countries, but its effect on buildings is very dangerous and costly. Without significant consideration of adequate continuity, ductility and redundancy, the progressive collapse cannot be prevented.

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II. OBJECTIVES

- To perform the progressive collapse analysis in composite structures after column removal.
- To develop finite element model and study the behaviour of building after column removal by linear static analysis and nonlinear dynamic analysis in ETABS
- To study the behaviour of structure for end, intermediate and middle column removal.
- To conduct progressive collapse analysis for structures with different height and for different plan shape.

III. SCOPE

The focus of this analysis is to determine if a structure is susceptible to progressive collapse and study the effects of instantaneous removal of a load bearing element such as column and suggest the possible way to prevent the progressive collapse.

IV. MODELING

21 models of different geometry, i.e., different heights and plan shapes with column removal from different positions were analysed. Different heights considered were G+9, G+14, G+19 and G+24. Different plan shapes were rectanglular, U-shape, T-Shape and L-Shape. Column removal positions are middle, intermediate and end from front elevation. Uniform column spacing is of 8.25 m in both longitudinal and transverse direction. Main girders are IS W21X57. Floor-to-floor height for every story is 4.3 m. Composite columns of size 350X350X15mm are used. The floor diaphragms are constructed of concrete with slab thickness of 90 mm.

V. RESULT AND DISCUSSIONS

1. Linear Static analysis.

As per GSA guidelines, in linear static analysis demand capacity ratio (DCR) is used to understand progressive analysis.

$$DCR = \frac{M_{max}}{M_p}$$

Where M_{max} is the maximum moment in critical element of the structure and M_p is the plastic moment.
As per GSA guidelines,

DCR>3 , Structure is unsafe
DCR<3 , Structure is safe

Table 1 DCR for Structures with Different Heights

No. of Storeys	DCR Values		
	Middle column removal	Intermediate column removal	End column removal
G +9	1.73	1.74	2.02
G+ 14	1.87	1.88	2.18
G +19	2.07	2.08	2.40
G+ 24	2.3	2.31	2.70

Table 2 - DCR for Structures with Different Plan Shapes

Plan shapes	DCR		
	Middle column removal	Intermediate column removal	End column removal
Rectangular	1.73	1.74	2.02
U shape	1.71	1.73	2.00
T shape	1.65	1.67	1.87
L shape	1.71	1.77	2.03

DCR increases with height of the building. It's greater for end column removal in all structures. But in case of structures with same base area but different shapes DCR does not give a proper trend. Because DCR only depends on critical element of the structure, whole structure is not considered. Linear static analysis is limited in case of structures of different plan shapes

2. Nonlinear dynamic analysis

Nonlinear dynamic analysis used is time history analysis. Maximum base shear, Top floor displacement, Storey drift and storey displacements are obtained using nonlinear dynamic analysis. G+9 structures with different plan shapes were used.

Table 7.3 Maximum Base Shear for Structures with Different Plan Shapes

Plan shape	Max base shear in x-direction (kN)		
	Middle column removal	Intermediate column removal	End column removal
Rectangular	1401.29	1402.08	1419.61
U shape	1415.44	1415.49	1425.06
T shape	1416.2	1416.15	1427.23
L shape	1536.03	1542.04	1551.45

Table 4 Top Floor Displacement for Structures with Different Plan Shapes

Plan shape	Top Floor displacement (mm)		
	Middle column removal	Intermediate column removal	End column removal
Rectangular	25.616	25.622	25.642
U shape	26.33	26.33	26.46
T shape	28.25	28.252	28.312
L shape	29.41	29.41	29.436

Fig 1 Storey Drift for Middle Column Removal

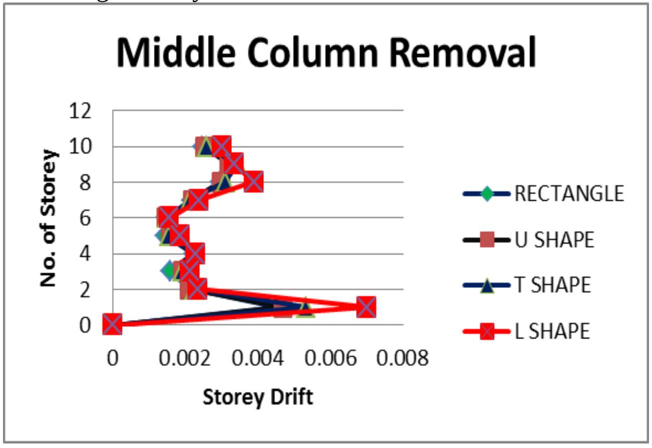


Fig 2. Storey Drift for Intermediate Column Removal

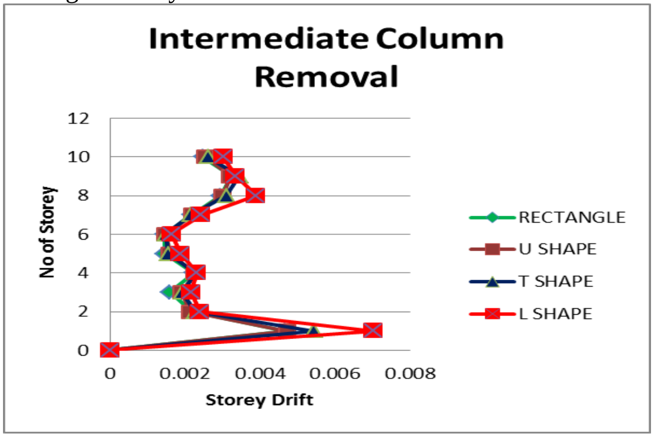


Fig. 3 Storey Drift for End Column Removal

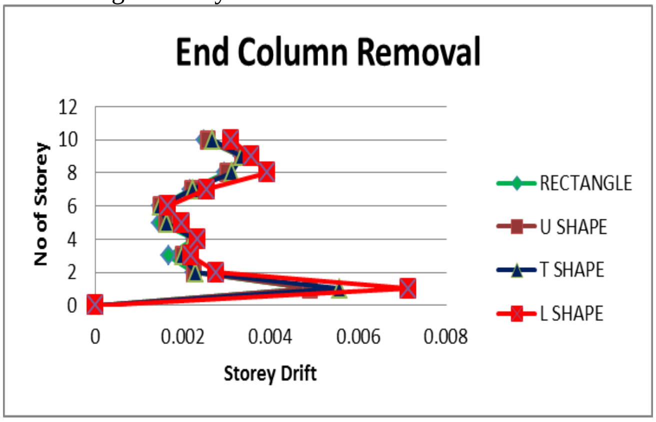


Fig 4. Storey displacement for middle column removal

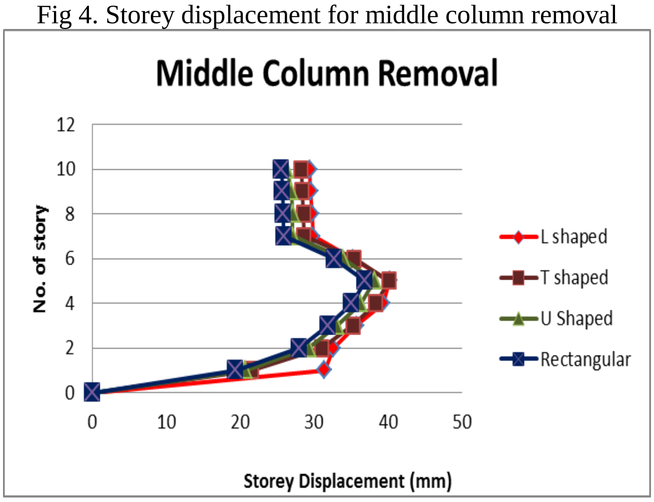


Fig 5. Storey displacement for intermediate column removal

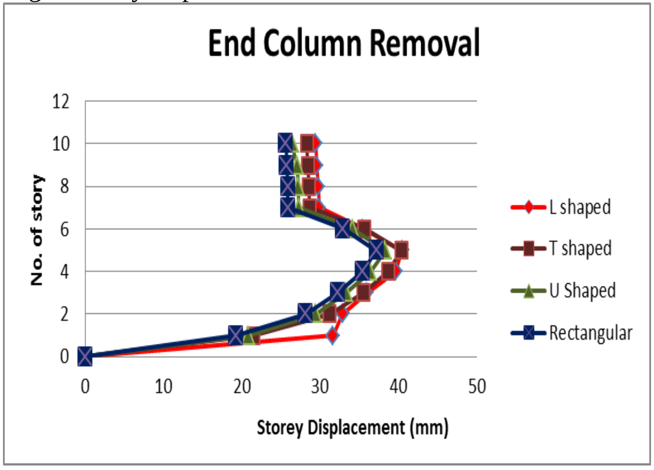
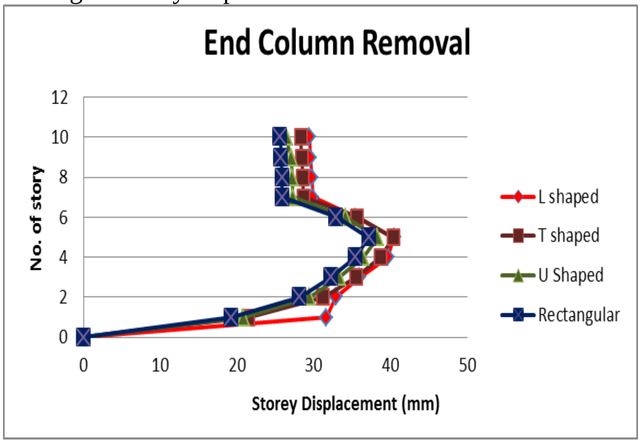


Fig 6. Storey displacement for end column removal



From the results it is clear that, L shaped plan structures shows much greater base shear than rectangular, U shaped and T shaped plan structures. U shaped, T shaped and L shaped plan structure shows 0.38%, 0.53 % and 9.22% percentage increase with respect to rectangular plan shaped structure. L plan shaped structure is the most worst condition.

Similar to maximum base shear, top floor displacement was greater for L shaped plan structures. U shaped, T shaped and L shaped plan structure showed 3.19%, 10.41 % and 14.79% percentage increase with respect to rectangular plan shaped structure.

In the case of storey drift, we can see that, there was an initial increase in storey drift values for lower stories and further decrease along the height of structure. From this we can see that L shaped structure shows greater storey drift. It can be noted that there is about 46.81% increase in maximum drift value for L- plan shaped structure with respect to rectangular plan shaped structure. It again proves L shaped structure with any column removal is worst condition.

In the case of storey displacement, L shaped planed structure shows greater storey displacement. Maximum value of displacement occurs in fifth story. There is about 8.89 % increase in maximum displacement value with respect to rectangular planed structure. It again proves L shaped structure with any column removal is worst among other plan shaped structures.

VI. CONCLUSIONS

- By removing the corner column, a great force is imposed to its adjacent column which shows progressive collapse direction. This situation does not have great influence to the other columns; however, in some columns axial force is decreased.
- By removing the middle column, the axial force is transferred to its two adjacent columns.
- Removing the corner column is more critical in comparison with removing the middle column and intermediate column.
- By comparing DCR values in all the column removal conditions, we can conclude that corner column removal in base is the worst condition.
- For same plan area, an increase of 0.38%, 0.53% and 9.22% in maximum base shear values were seen in U shaped, T shaped and L shaped plan structures when compared with rectangular shaped plan structures.
- For same plan area, an increase of 3.19%, 10.41% and 14.79% in top floor displacement were seen in U shaped, T shaped and L shaped plan structures when compared with rectangular shaped plan structures.
- L shaped plan structures shows 46.81% increase in maximum storey drift with respect to rectangular shaped plan structures.
- L shaped planed structure shows 8.89 % increasein maximum storey displacement with respect to rectangular shaped plan structure.

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