Effect of Progressive Collapse in Reinforced Concrete Building with Different Number of Bays and Locations of Column Removal

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Abstract— **Structural safety is an inevitable aspect in the design of civil engineering projects. Over the past years, one mechanism of structural failure that has gathered greater attention is progressive collapse. Progressive collapse is a state in which local failure of a primary structural component initiates the collapse of adjacent members that causes additional collapse. The capability to speculate the progressive collapse potential can provide adequate information that can be used for arresting the failure due to progressive collapse. The present study examines the influence of different locations of column elimination and variation in number of bays in a building on progressive collapse by analyzing a five storey reinforced concrete building using SAP2000 .**

Keywords— Progressive collapse potential, Progressive collapse, Reinforced concrete

I. INTRODUCTION

The world has recently witnessed tremendous increase in terrorist activities. The infrastructure around the world has become more vulnerable to blast loads due to the increasing threat of terrorism, the proliferation of weapons and accidental explosions. Safety in structural design is typically addressed by considering uncertainties in both the structure and the expected loads and introducing safety aspects in the design process. A number of engineering failures, however, are related to accidental loading effects that are hard to compute and incorporate in the original design. One mechanism of structural failure that has gathered greater attention over the past few years is progressive collapse. Whatever the cause (accident, terrorist attack or earthquake), the building collapses progressively due to the sudden failure of one or several structural members. This phenomenon is now gradually taken into account in design standards because of the catastrophic nature of its consequences, rather than for its high probability of occurrence.

Progressive collapse refers to the spread of an initial local failure in a structure. The partial or total failure of the structure occurs due to local failure caused by the loss of certain load carrying members. Following the initial event, the load originally carried by the affected portions are transferred through alternate load paths to the adjoining undamaged members. Further collapse of overloaded structural elements takes place since the undamaged members may or may not possess sufficient resistance to withstand the additional loads, which in turn will cause more redistribution of loads until an equilibrium state is reached. However equilibrium can only be achieved when massive parts of the structure has already failed due to the effect of the loads involved. Therefore, the important characteristics of progressive collapse is that the final destruction will be excessively greater than the local damage which initiated the collapse.

The design procedures for progressive collapse are given by several normalization committees such as the United States Department Of Defense (DOD) or UFC, General Services Administration (GSA) which have issued guidelines for examining the progressive collapse hazard ,which provides general information about the approach and method of evaluating the progressive collapse potential. Alternate load path approach was chosen as the most suitable one by several standards, such as GSA and UFC. The Alternate load Path Method involves designing the structure so that after the loss of a vertical load bearing element, stresses can be redistributed.

The study aims to examine the influence of locations of column elimination and number of bays on progressive collapse of reinforced concrete building and to evaluate the progressive collapse potential of reinforced concrete building designed as per Indian Standard Code. For this, five storey reinforced concrete buildings were designed with different locations of column elimination and different number of bays.

II. MODELLING DETAILS

Five storey reinforced concrete buildings were modelled to study progressive collapse. Nonlinear static analysis was done in SAP 2000. The following two cases are considered in this study.

- CASE 1- Elimination of column from different locations
- CASE2 – Variation in number of bays

A. *Material Properties*

a) Grade of Concrete : M25
b) Grade of Steel Reinforcement Bars : Fe 415

B. *Loading Conditions*

a) Dead loads

- Wall load on beams = 13 kN/m^2
- Self-weight of structural elements

b) Live loads

- Live load on floor: 3 kN/m^2
- Live load on roof: 1.5 kN/m^2

c) Earthquake loads

The earthquake loads are considered for the seismic parameters as per IS 1893:2002.

- Seismic zone factor- 0.36
- Soil type – II,Medium
- Importance factor -1

C. Structural element sizes

a) Size of column : 300 x 400mm
b) Size of beam : 300 x 400mm
c) Slab : 150mm thick

D. Building Description

The details of the buildings are:

- number of bays in both directions = 4 x 4
- bay width = 4m
- floor to floor height = 3m

CASE 1- Elimination of columns from different locations

In the present study, exterior analysis cases as per General Services Administration (GSA) guidelines which are middle column removal and corner column removal are considered as locations of column removal. The following figures (Fig. 1,Fig. 2,Fig.3) shows the intact building, middle column removed building and corner column removed building.

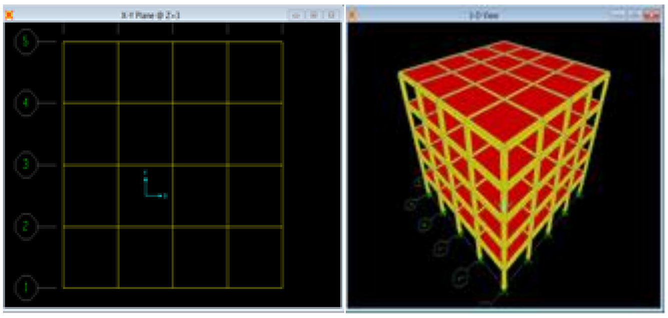


Fig. 1. Plan and 3D view of intact building

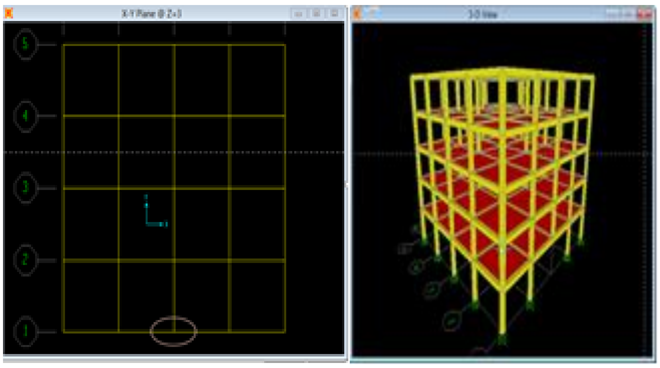


Fig. 2. Plan and 3D view of middle column removed building

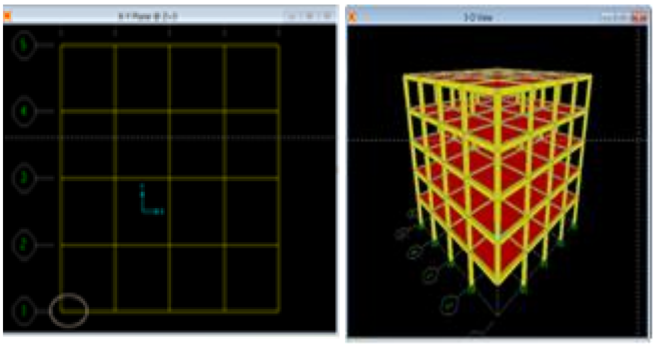


Fig. 3. Plan and 3D view of corner column removed building

CASE 2- Variation in number of bays

Models with number of bays 4 x 4, 5 x 5 and 6 x 6 are considered for the study. Intact models and corner column removed models for different number of bays were designed

III. RESULTS AND DISCUSSIONS

E .Demand Capacity Ratio(DCR)

Acceptance criteria for the primary and secondary structural components as per GSA shall be:

$$DCR = Q_{UD} / Q_{CE}$$

where;

Q_{UD} is the acting force (demand) in component or joint or connection(moment, axial force, shear, and possible combined forces)

Q_{CE} is the expected ultimate unfactored capacity of component or joint(moment, axial force, shear, and possible combined forces)

As per GSA, structural elements that have DCR values that are more than allowable DCR value which is 2 are considered to have high potential for progressive collapse or severely damaged. Figure 4 and figure 5 shows DCR when middle column is removed and corner column is removed.

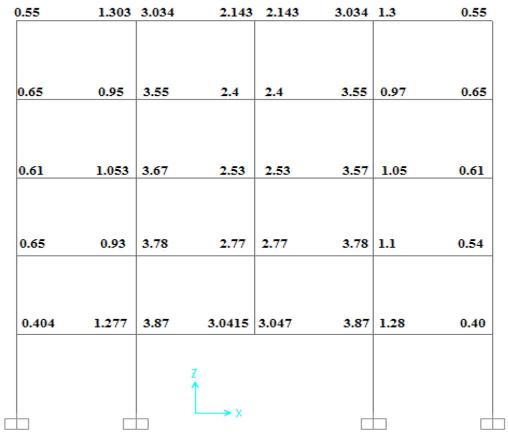


Fig. 4.DCR for flexure-Middle column removed

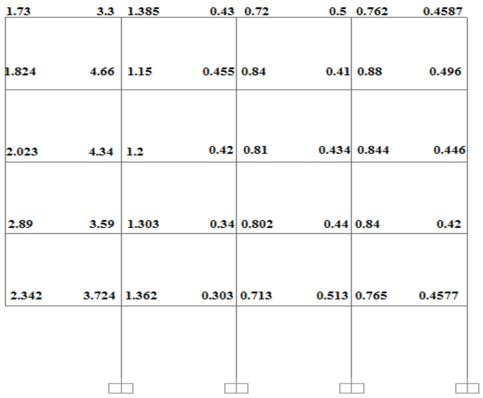


Fig. 5.DCR for flexure-Corner column removed

F . Pushover analysis

To study the performance point of the building in terms of base shear and displacement, non-linear static pushover analysis is carried out on the above building. For pushover analysis, various pushover cases are considered such as push gravity, push X , push Y. The various load combinations were used for this purpose. After pushover analysis the demand curve and capacity curves are obtained to get the performance point of the structure. Capacity spectrum curves for elimination of column from different locations and variation in number of bays are shown in table I and table II. The base shear for PUSH X load case and for PUSH Y at performance point for different locations of column elimination and variation in number of bays are shown in table III and table IV:

TABLE I : Capacity spectrum curves for different locations of column removal

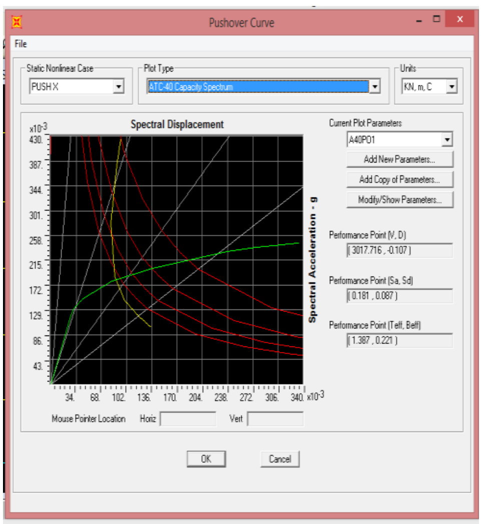
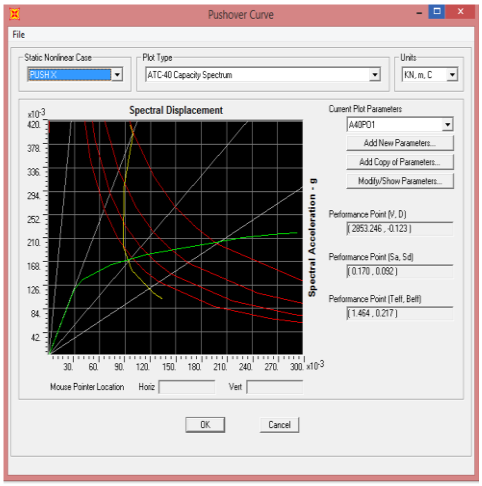
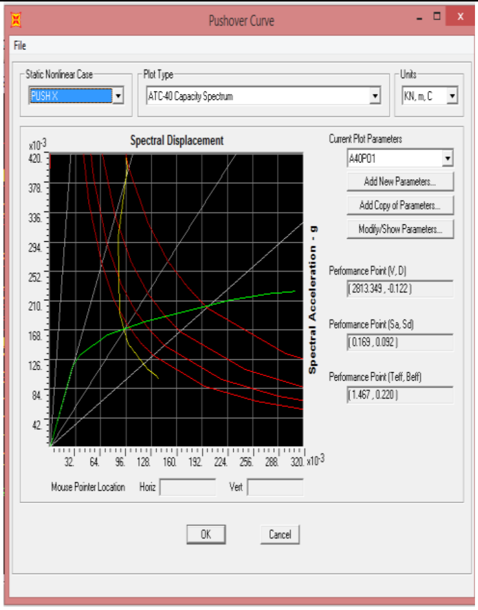
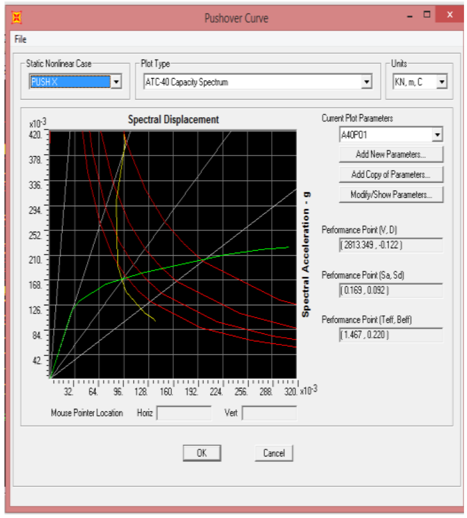
Si no	model	Capacity Spectrum curve(x direction)
1	Intact Building	
2	Middle column removed building	
3	Corner column removed building	

TABLE II. : Capacity Spectrum curve for variation in number of bays

Si no	model	Capacity Spectrum curve(x direction)
1	4x4 bay building	

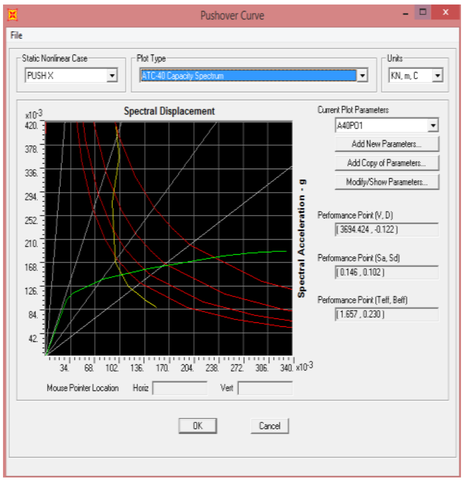
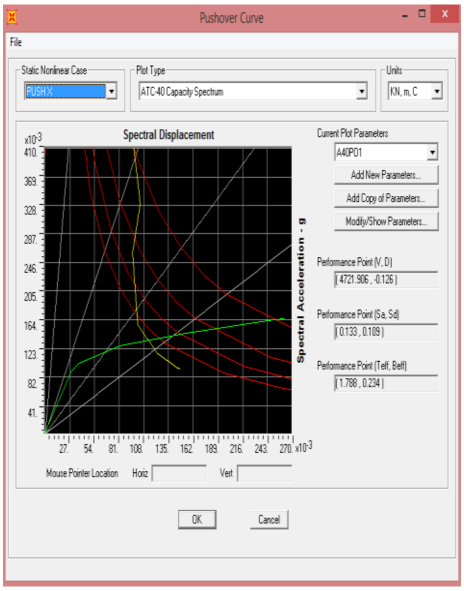
2	5x5 bay building	
3	6x6 bay building	

TABLE III. : Variation of Performance Point (X & Y Direction) for different locations of column removal

Si No.	Model	PUSH X		PUSH Y	
		Base shear (kN)	***Displacement (m)***	***Base shear (kN)***	***Displacement (m)***
1.	Intact Building	3017.716	0.107	2589.072	0.123
2.	Middle column removed building	2853.246	0.123	2363.688	0.131
3.	Corner column removed building	2813.349	0.122	2341.925	0.136

TABLE IV. : Variation of Performance Point (X & Y Direction) for variation in number of bays

Si No.	Model	PUSH X		PUSH Y	
		Base shear (kN)	***Displacement (m)***	***Base shear (kN)***	***Displacement (m)***
1.	4x4-Intact	3017.716	0.107	2589.072	0.123
2.	4x4 Corner column removed	2813.349	0.122	2341.925	0.136
3.	5x5-Intact	3862.383	0.109	3341.394	0.139
4.	5x5 Corner column removed	3694.424	0.122	3111.394	0.141
5.	6x6-Intact	4872.289	0.115	4209.853	0.145
6.	6x6-Corner column removed	4721.906	0.126	4009.853	0.148

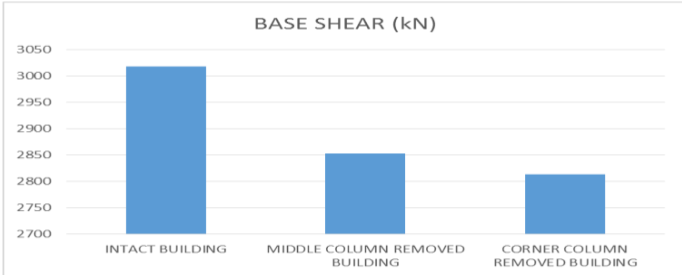


Fig. 6.Variation of base shear at performance point for different column removal location

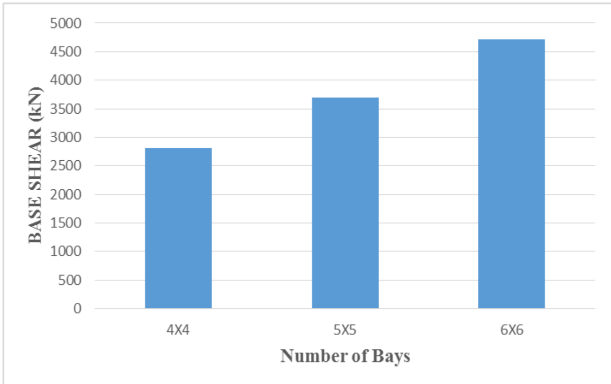


Fig. 7.Variation of base shear at performance point for variation in number of bays

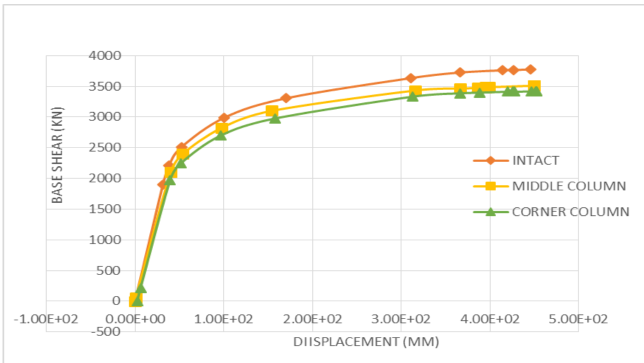


Fig.8.Base shear displacement curve for different locations of column removal

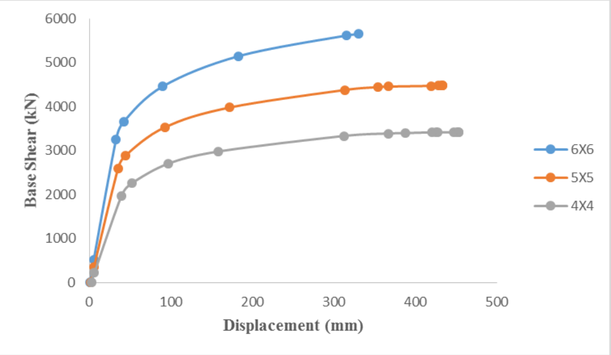


Fig.9.Base shear displacement curve for variation in number of bays

G. *Residual Reserve Strength Ratio (RRSR)*

Robustness is the ability of a structure to resist damage due to explosion, impacts, fire etc without premature or brittle failure. Structural robustness is measured in terms of Residual Reserve Strength Ratio

$$\text{RRSR} = V((damaged))/V((intact))$$

where; V = base shear capacity

TABLE IV: RRSR for different locations of column removal

Column removal location	V(intact) (kN)	V(damaged) (kN)	RRSR
Middle	3773.321	3511.12	0.9305
Corner		3416.607	0.905

TABLE V : RRSR for variation in number of bays

Number of bays	V(intact)	V(damaged)	RRSR
4X4	3773.321	3416.607	0.905
5X5	4708.797	4472.83	0.94988
6X6	5612.534	5500.82	0.98

CONCLUSION

1. When the middle column is removed, demand capacity ratio of adjacent beams above removed column at all floors exceeds the permissible value of 2 as specified by GSA guidelines and are considered to have high potential for progressive collapse.
2. When corner column is removed, demand capacity ratio of adjacent beams exceeds permissible value specified by GSA guidelines and are greater than that when middle column is removed.
3. The reinforced concrete building designed as per Indian Standard Code has high potential for progressive collapse as the demand capacity ratio exceeds the allowable limit of 2.
4. Residual reserve strength ratio is more when middle column is eliminated than when corner column is removed.
5. The structure is more robust when middle column is removed
6. The location of the damaged element has a significant effect in structural robustness
7. Column elimination has an effect in base shear capacity reduction
8. In comparison with intact building, base shear at performance point is reduced by 7.2% when corner column is removed and 5.4% when middle column is removed and corner column removal is found to be more critical.
9. Progressive collapse potential reduced with increasing bays as more number of elements are participating in resisting progressive collapse.
10. Number of bays induces higher residual reserve strength ratio, hence the structure becomes more robust.
11. For 6x6 bay,the base shear value is found to be increased by 67% in 6x6 bay when compared with 3x3 bay structure

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