Progressive Collapse Analysis of RC Framed Structures

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Abstract— The term progressive collapse defined as the spread of local damage, from an initiating event, from element to element resulting, eventually, in the collapse of an entire structure or a disproportionately large part of it is known as progressive collapse. The progressive collapse of structures during severe loading caused by earthquakes, blasts, and other effects causes catastrophic loss of life. Such collapse is typically caused by the inability of the structural system to redistribute its loads following the failure of one or more structural members to carry gravity loads. In reinforced concrete (RC) structures, the loss of gravity load carrying capacity in columns has been observed to trigger a chain of collapse events

Key words: Progressive Collapse, GSA, Demand Capacity Ratio, Etabs software

I. INTRODUCTION

Progressive collapse in a structure occurs when major structural load carrying members (typically columns) are removed suddenly, and the remaining neighboring structural elements cannot support the weight of the building and fail. This failure usually occurs in a domino effect and leads to a progressive collapse failure in the structure. In general, buildings are designed to resist the normal anticipated loads like gravity, occupancy, wind and seismic. However, some structures occasionally are being exposed to unforeseen loads due to natural, man-made, intentional or unintentional reasons. These unexpected loads induce progressive collapse event. The phenomenon of progressive collapse was first realized after the collapse of the Ronan Point Apartment tower in England in 1968. The partial collapse of the 22 story pre-cast concrete triggered by a very modest gas explosion in the kitchen of the 18th floor knocked out the precast concrete panels and resulted in a chain reaction of collapse all the way to ground due to loss of their support. The impact of the upper floors on the lower floors caused more failure in the exterior wall. As a result, the entire corner of the building was collapsed.

II. DESCRIPTION OF STRUCTURAL MODEL

For the analysis purpose, Symmetrical and Unsymmetrical frame model of plan as shown in Fig.1 & 2 and of height 31.3m.The ground and the rest of the storey are taken to be 3.1m high. The column cross section is taken as 0.40m x 0.70m. Beam size is taken as 0.40m x 0.70m. The thickness of slab is 150mm. Wall having 230mm thickness is considered on all the beams. All the supports are modeled as fixed supports. Linear analysis is conducted on each of these models. Zone – V, Zone factor = 0.36, Soil Type = Type –II, Medium Class, Importance Factor = 1.0 and Response Reduction Factor = 5.0. Floor finish is taken as 1.5 kN/m2 and live load on floors is 3 kN/m2 and on roof is 1.5 kN/m2.The characteristic compressive strength of concrete (fck) is 25 N/mm2 and yield strength of reinforcing steel (fy) is 415 N/mm2. Analysis and design of building for the loading is performed in the ETABS.



Fig. 1: Plan of symmetrical framed structure

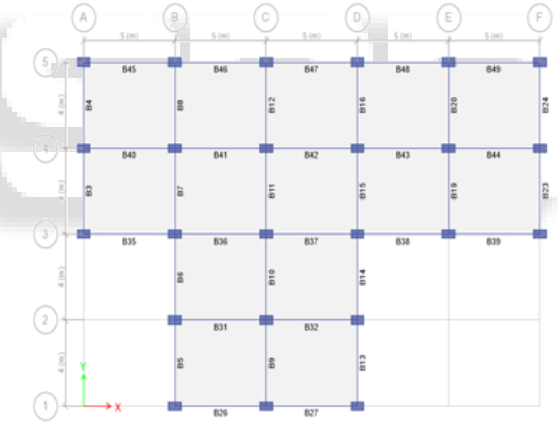


Fig. 2: Plan of unsymmetrical framed structure

A. GSA Guidelines:

The aim of General Service Administration (GSA) guidelines is to help in evaluating the risk of progressive collapse of buildings. The following analysis cases should be considered as per GSA guidelines.

1) Analyze for the instantaneous loss of an exterior column located near the middle of the long side of the building.
2) Analyze for the instantaneous loss of an exterior column located near the middle of the short side of the building.
3) Analyze for the instantaneous loss of a column located at corner of the building.
4) Analyze for the instantaneous loss of a column located at or near the center of the building.

B. Acceptance Criteria:

Demand Capacity Ratio is defined as the ratio of the structural member force after the instantaneous removal of column to the member capacity.

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DCR = QD / QC … (Eq 1)

Where,

QD = Acting force (Demand) determined in the member.

Qc = Expected Capacity of the member.

For safety of the structure, permissible DCR values as per GSA guidelines should be:

- Demand capacity ratio (DCR) < 2.0 for typical structural configurations.
- Demand capacity ratio (DCR) < 1.50 for atypical structural configurations.

When analyzing the structure for progressive collapse, GSA recommends a general loading factor to be used

LOAD = 2(DL+0.25LL) … (Eq 2)

Where,

DL=Dead load

LL=Floor Live Load

C. Calculation of Demand Capacity Ratio:

The member capacity is calculated as per IS 456:2000 from the obtained reinforcement details after analysis and design. The DCR after column removal is found out considering the member force as per GSA guidelines. The member forces are obtained by analysis results carried out in ETABS.

III. ANALYSIS

To evaluate the potential for progressive collapse, a ten storey unsymmetrical and symmetrical reinforced concrete building is considered and by linear static analysis, columns are removed at different locations. DCR ratios are calculated. The below figures shows the different location of the column removed for both symmetrical and unsymmetrical building.

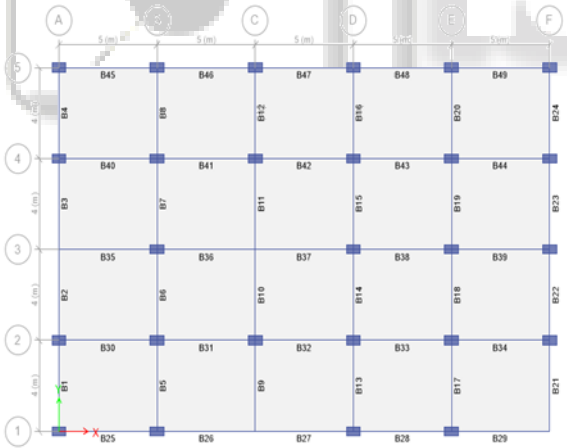


Fig. 3. Plan showing removal of column at different locations for symmetrical structure.

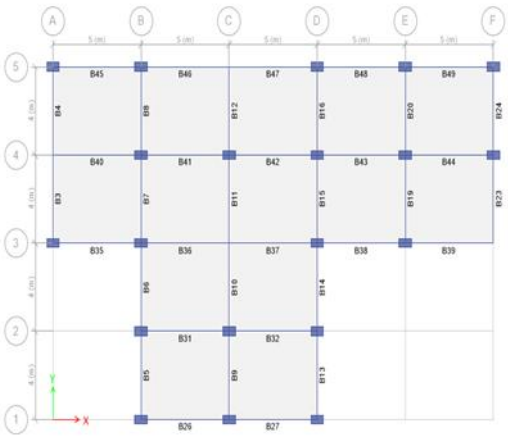


Fig. 4: Plan showing removal of column at different locations for unsymmetrical structure

IV. RESULTS AND DISCUSSION

A. General:

The DCR values of the members adjacent to the removed columns for all cases of column removal are calculated and the graphs of DCR Vs. storeys is plotted.

B. Graphical Representation of DCR:

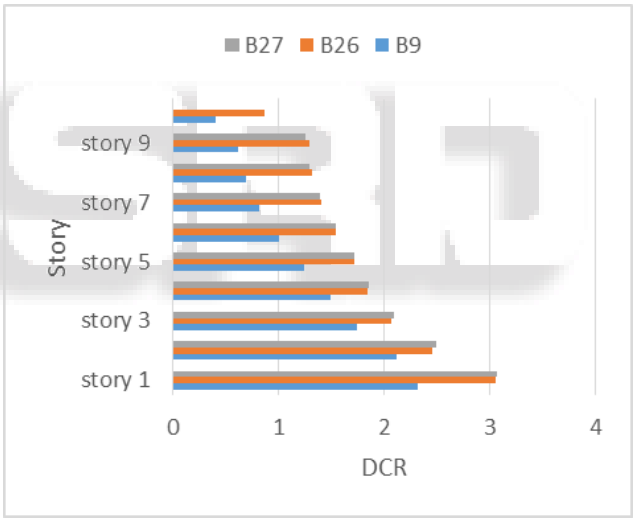


Fig. 5: Exterior column C1 of symmetrical building removed

For removed column at C1 DCR values of beam B-9, B-26 and B-27 exceed 2 from storey 1 to storey 3 and therefore need additional reinforcement to prevent progressive collapse and from storey 4 and above DCR values are less than 2, all other beams do not need additional reinforcement.

Fig.6. Exterior column at A3 of symmetrical building removed

- For removed column at A3, DCR values of beam B-3 exceed 2 from storey 1 to storey 3 and therefore need additional reinforcement to prevent progressive collapse and from storey 4 and above DCR values are less than 2 and therefore all other beams do not need additional reinforcement.
- For removed column at A3, DCR values of beam B-35 exceed 2 at storey 1 and therefore need additional reinforcement to prevent progressive collapse and from storey 2 and above DCR values are less than 2 and

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therefore all other beams do not need additional reinforcement.

– For removed column at A3, DCR values of beam B-2 exceed 2 from storey 1 to storey 3 and therefore need additional reinforcement to prevent progressive collapse and from storey 4 and above DCR values are less than 2 and therefore all other beams do not need additional reinforcement.

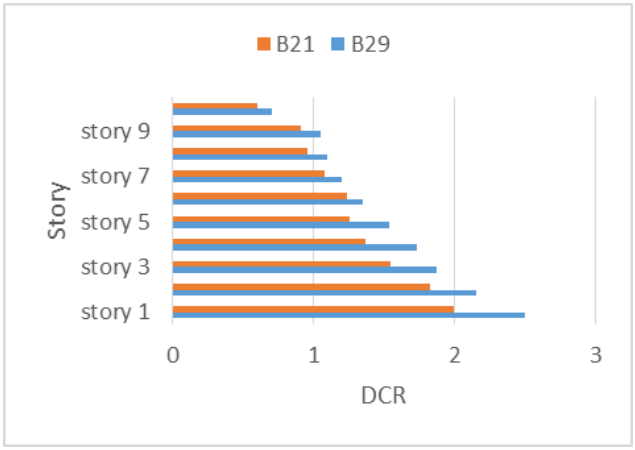


Fig. 7: Corner column of the symmetrical building removed at F1

– For removed column at F1, DCR values of beam B-29 exceed 2 from storey 1 to storey 2 and therefore need additional reinforcement to prevent progressive collapse and from storey 3 and above DCR values are less than 2 and therefore all other beams do not need additional reinforcement.

– For removed column at F1, DCR values of beam B-21 exceed 2 at storey 1 and therefore need additional reinforcement to prevent progressive collapse and from storey 2 and above DCR values are less than 2 and therefore all other beams do not need additional reinforcement.

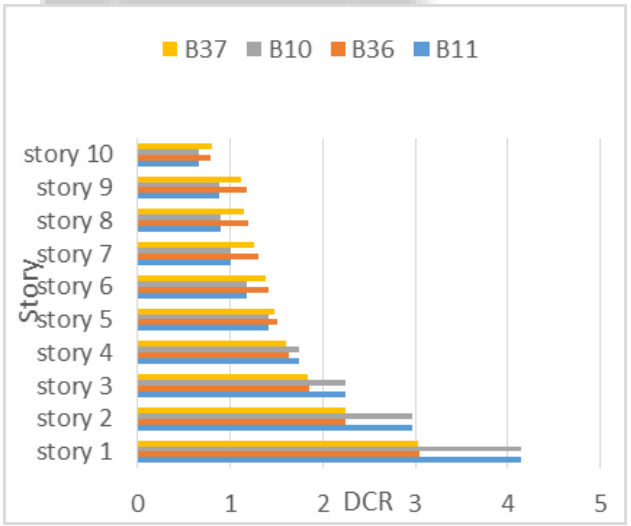


Fig. 8: Interior column of the symmetrical building removed at C3

– For removed column C3 DCR values of beam B-10 and B-11 exceed 2 from storey 1 to storey 3 and therefore need additional reinforcement to prevent progressive collapse and from storey 4 and above DCR values are less than 2 and therefore all other beams do not need additional reinforcement

– For removed column at C3 DCR values of beam B-36 exceed 2 from storey 1 to storey 2 and therefore need additional reinforcement to prevent progressive collapse and from storey 3 and above DCR values are less than 2 and therefore all other beams do not need additional reinforcement.

– For removed column at C3 DCR values of beam B-37 exceed 2 from storey 1 to storey 2 and therefore need additional reinforcement to prevent progressive collapse and from storey 3 and above DCR values are less than 2 and therefore all other beams do not need additional reinforcement.

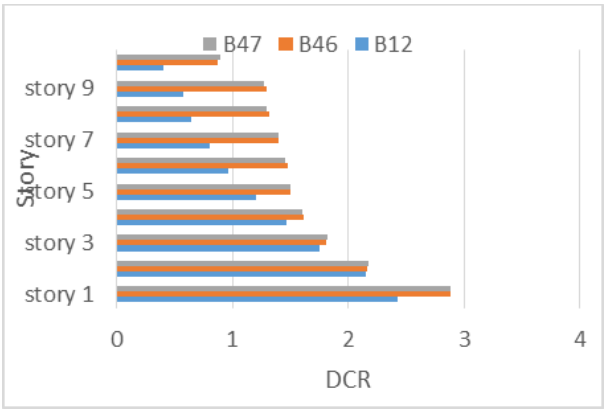


Fig. 9: Exterior column of the unsymmetrical building removed at C5

– For removed column at C5 DCR values of beam B-46 and B-47 exceed 1.5 from storey 1 to storey 5 and therefore need additional reinforcement to prevent progressive collapse and from storey 6 to storey 10 DCR values are less than 1.5 therefore all other beams do not need additional reinforcement.

– For removed column at C5, DCR values of beam B-12 exceed 1.5 from storey 1 to storey 3 and therefore need additional reinforcement to prevent progressive collapse and from storey 4 to storey 10, DCR values are less than 1.5 therefore all other beams do not need additional reinforcement.

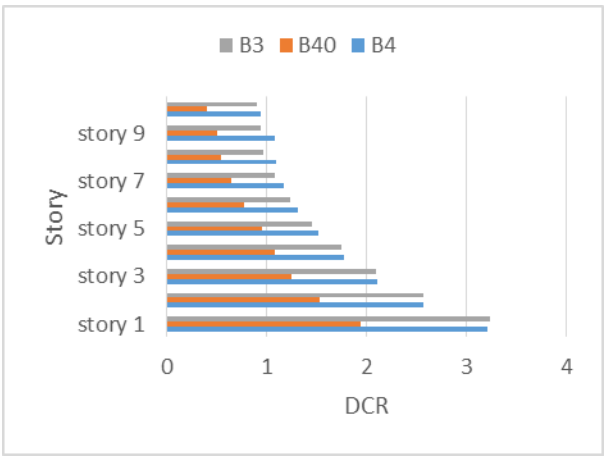


Fig. 10: Exterior column of the unsymmetrical building removed at A4

– For removed column at A4, DCR values of beam B-3 exceed 1.5 from storey 1 to storey 4 and therefore need additional reinforcement to prevent progressive collapse and from storey 5 and above DCR values are less than 1.5 and therefore all other beams do not need additional reinforcement.

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- For removed column at A4, DCR values of beam B-4 exceed 1.5 from storey 1 to storey 5 and therefore need additional reinforcement to prevent progressive collapse and from storey 6 and above DCR values are less than 1.5 and therefore all other beams do not need additional reinforcement.
- For removed column at A4, DCR values of beam B-40 exceed 1.5 from storey 1 to storey 2 and therefore need additional reinforcement to prevent progressive collapse and from storey 3 and above DCR values are less than 1.5 and therefore all other beams do not need additional reinforcement.

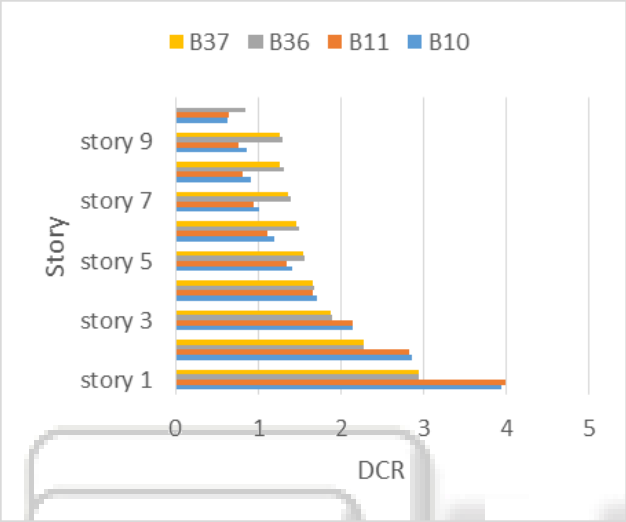


Fig. 11: Corner column of the unsymmetrical building removed at F3

- For removed column F3, DCR values of beam B-39 exceed 1.5 from storey 1 to storey 5 and therefore need additional reinforcement to prevent progressive collapse and from storey 6 and above DCR values are less than 1.5 and therefore all other beams do not need additional reinforcement.
- For removed column F3, DCR values of beam B-23 exceed 1.5 at storey 1 to storey 2 and therefore need additional reinforcement to prevent progressive collapse and from storey 3 and above DCR values are less than 1.5 and therefore all other beams do not need additional reinforcement.

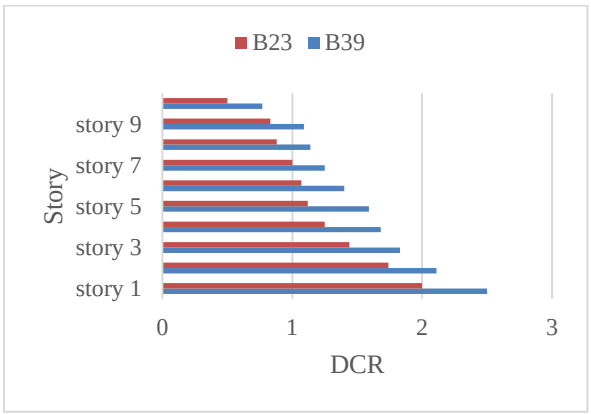


Fig.12. Interior column of the unsymmetrical building removed at C3

- For removed column C3 DCR values of beam B-10 and B-11 exceed 1.5 from storey 1 to storey 4 and therefore need additional reinforcement to prevent progressive collapse and from storey 5 and above DCR values are less than 1.5, therefore all other beams do not need additional reinforcement.
- For removed column C3 DCR values of beam B-36 and B-37 exceed 1.5 from storey 1 to storey 5 and therefore need additional reinforcement to prevent progressive collapse and from story 6 and above DCR values are less than 1.5 therefore all other beams do not need additional reinforcement.

V. CONCLUSIONS

The conclusions that are to be drawn from above obtained results are as follows.

- When columns at different locations in a symmetric and unsymmetrical building was removed among the intersecting beams the shorter span tend to take the extra burden load and DCR values of that beams were more compared to longer span beams.
- When columns at different locations in a symmetric and unsymmetrical building was removed the most critical case was removal of central column in the building.
- To avoid the progressive failure of beams and columns, caused by failure of particular column, adequate reinforcement is required to limit the DCR within the acceptance criteria.
- The adequate reinforcement provided in extra to beams which are unsafe can develop alternative load paths and prevent progressive collapse due to the loss of an individual member.
- Increasing beam size will be more effective in avoiding or delaying collapse rather than increasing column size.
- In general, Modifying the beam dimension results in increase of cost of structure, but negligible when compared to loss of life and property

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