Progressive Collapse Analysis of High Rise RC Framed Structure

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Abstract— In the present study, the demand capacity ratio (DCR) of thirteen storey RC framed symmetrical and unsymmetrical structures are evaluated as per U.S. General Services Administration (GSA) guidelines. The Linear static analysis is carried out using software, ETABS V13 according to IS codes. To study the progressive collapse of a structure, typical columns are removed one at a time, and continued with design and analysis. 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 shorter span beams were more compared to longer span beams. The DCR values obtained show that columns of both symmetric and unsymmetrical structure are safe and beams of both symmetric and unsymmetrical structure to be reinforced additionally.

Key words: Progressive Collapse, Demand Capacity Ratio (DCR), ETABS, Linear Static Analysis, Column Removal, General Service Administration (GSA)

I. Introduction

The progressive collapse of RC frame structures is mainly caused due to the elimination of one or more vertically load carrying elements (mainly columns). When a column is eliminated due to the earthquake, fire, vehicle impact man-made or natural hazards the weight of the building gets transferred to neighboring elements in the structure, if the neighboring elements are not capable of withstanding the extra load, this results to the progressive collapse of neighboring members and finally results in failure of a part or the entire structure. One of the main features of progressive collapse is that final damage is not proportional to the initial damage. Progressive collapse of a structure occurs when a structure has its loading pattern changed such that some elements of the structure are loaded beyond their capacities. The neighboring structures are then forced to seek alternate load paths to distribute the extra load s from damaged elements. There are many situations where progressive collapse of buildings had occurred in the past due to different reasons. Many engineers and researchers had given the importance to progressive collapse since the progressive collapse of a part of the 22-storey Ronan Point apartment building in London, England in 1968, progressive collapse of Alfred P Murrah Federal Building and world trade center (WTC).

II. General services administration (GSA)

The GSA criteria for new and existing structures provide guidelines for both symmetric and unsymmetrical structures. To know the ability of progressive collapse for both symmetrical and unsymmetrical structure the designer can perform structural analysis in which the removal of first floor columns one at a time is assume:

- Instantaneous loss of column at the middle of long side of the column.
- Instantaneous loss of column at the middle of short side of the column.
- Instantaneous loss of corner column of the building.
- Instantaneous loss of center column of the building.

A. Linear Static Analysis

Linear static analysis for the column removed from the location being considered is carried out with the gravity load imposed on the structure and linear static analysis with the gravity load imposed on the structure. From the analysis results obtained after removal of column demand are obtained and from the design results obtained before removal of column the capacity of the member is calculated. Check the DCR in each structural member. If the DCR of any structural member exceeds the acceptance criteria as per GSA guidelines the member is considered as failed.

B. Analysis Loading

For static analysis purposes the following gravity load shall be applied to each structural element under investigation:

$$Load = 2(DL + 0.25LL)$$

Where,
DL = dead load
LL = live load

C. Acceptance Criteria

According to GSA (2003) guidelines the demand capacity ratio (DCR), i.e. the ratio of member force to member strength of any structural member in both symmetric and unsymmetrical is calculated from the following equation

$$DCR = \frac{Q_{UD}}{Q_{CE}}$$

QUD = Acting force (demand) determined in component of the structure

Q_{CE}= Expected ultimate capacity of the structural element

In order to prevent the progressive collapse of the structure, the DCR values calculated for each structural element should be less than or equal to the following

- DCR < 2.0 for typical structural configurations.
- DCR < 1.5 for atypical structural configurations.

III. Modeling of building

For the analysis, a symmetric and unsymmetrical RC frame model of plan as shown in Fig.1 and Fig.2 and both of height 40.6 m are modeled using ETABS v13 software. For both symmetric and unsymmetrical buildings, the ground storey height and the rest of the storey height are taken to be 3.2 m high. The column cross section of both symmetric and unsymmetrical building is taken as 0.70m x 0.40m. Beam size of symmetric building is taken as 0.3m x 0.6 m and for unsymmetrical building is taken as 0.4 x 0.6. The floor slabs are of 0.15m thickness. Wall having 230 mm thickness is considered on all the beams. All the supports are modeled as fixed supports. Linear static analysis is carried on each of these models.

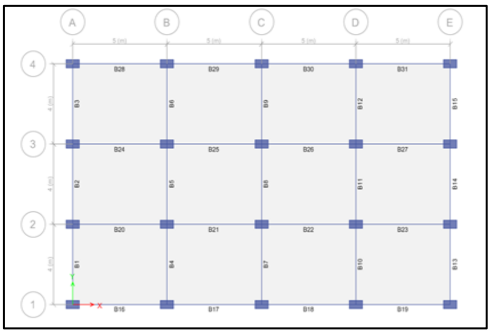

Fig. 1: Plan of symmetrical RC framed structure

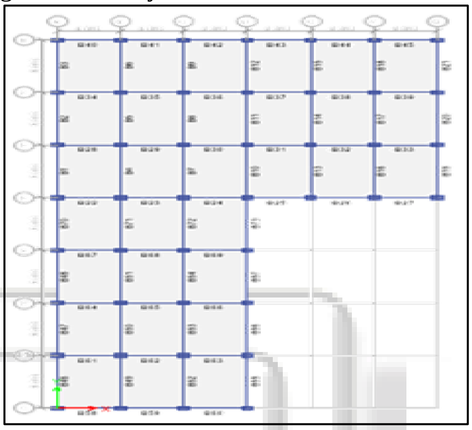

Fig. 2: Plan of unsymmetrical RC framed structure

A. *Dead load*

Self-weight of the structural elements
Floor finish = 1.5kN/m^2 and
Wall load on all beams is 12kN/m^2

B. *Live load*

On roof 1.5kN/m^2, and on floors 3.0kN/m^2
Seismic loading as per IS: 1893 [10]

1) Zone V

Soil type II, Response Reduction Factor = 5
Importance factor =1

The characteristic compressive strength of concrete (f_{ck}) is 30 N/mm^2 and yield strength of reinforcing steel (f_y) is 415 N/mm^2. Analysis and design of building for the loading is performed in the ETABS 13. (G+12) storey building is designed for seismic loading in ETABS 13 according to the IS 456:2000.

IV. ANALYSIS

To determine the capacity for progressive collapse of a (G+12) storey symmetrical and unsymmetrical reinforced concrete building using the linear static analysis four different positions of column removal is considered. First building is designed in ETABS v13 [11] for the IS 1893 load combinations. Then separate linear static analysis is performed for different position removal of column. Demand capacity ratio at all storeys is calculated for all the four cases of column removal in both symmetric and unsymmetrical structures. In symmetric structure Column C-4, A-2, E-5 and C-3 are removed and for unsymmetrical structures column A-5, D-8, G-8 and D-6 are removed for progressive collapse analysis.

A. *Calculation of Demand Capacity Ratio*

Capacity of any member is calculated from the obtained reinforcement details as per IS 456:2000 after the analysis for the structure before removal of column. Demand after removal of column is found out considering the member force for the load combination as per GSA guidelines. Member forces are obtained by analysis results carried out in ETABS 9.7.

V. RESULTS AND DISCUSSION

The DCR values obtained for the columns for removal of columns at different position in all four cases do not exceed the acceptance criteria value suggested by GSA guidelines and hence columns are safe against progressive collapse and hence do not need additional reinforcement. But when the column was removed from a position its adjacent beams DCR values exceed the acceptance criteria value suggested by GSA guidelines i.e. DCR values of adjacent beams are greater than 2. The DCR values of all beams are graphically represented.

A. *Graphical Representation of DCR*

After obtaining the DCR values of all beams at all storeys for different removal of columns, graph is plotted DCR vs Storeys

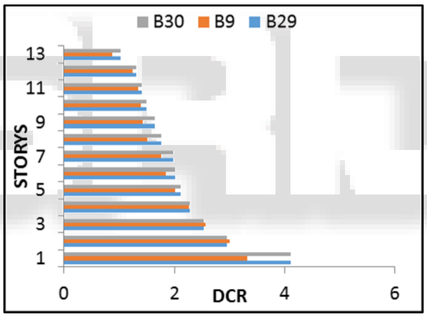

Fig. 3: Exterior column near the middle of the long side of the building removed C4

For C-4 column removed adjacent beams B30, B9 and B29 exceed acceptance criteria value suggested by GSA for progressive collapse guidelines as in Fig. 3 respectively. For removed column C-4 adjacent beams B30 and B29 exceed 2 up to storey 6 and adjacent beam B-9 exceed 2 up to storey 5.

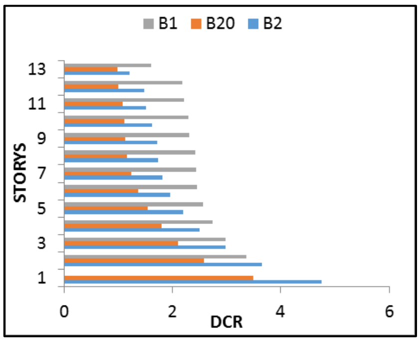

Fig. 4: Exterior column near middle of the short side of the building removed A2

For A-2 column removed adjacent beams B1, B20 and B2 exceed acceptance criteria value suggested by GSA for progressive collapse guidelines as in Fig. 4 respectively.

For removed column A-2 adjacent beam B2 exceed 2 up to storey 5, adjacent beam B-20 exceed 2 up to story 3 and adjacent beam B-1 exceed 2 up to storey 12.

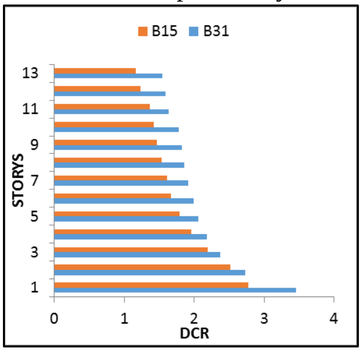

Fig. 5: Exterior column located at corner of the building removed E4

For E4 column removed adjacent beam B15 and B31 exceed acceptance criteria value suggested by GSA for progressive collapse guidelines as in Fig. 5 respectively. For removed column E4 adjacent beam B-31 exceed 2 up to storey 5 and adjacent beam B-15 exceed 2 up to storey 3.

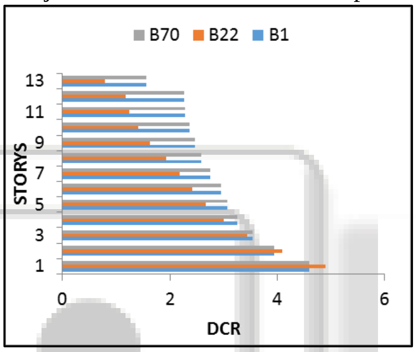

Fig. 6: Exterior column near the middle of the long side of the building removed A5

For A5 column removed adjacent beams B70, B22 and B1 exceed acceptance criteria value suggested by GSA for progressive collapse guidelines as in Fig. 6 respectively. For removed column A5 adjacent beams B-1 and B-70 exceed 2 at all 13 storeys and adjacent beam B-22 exceed 2 up to storey 9.

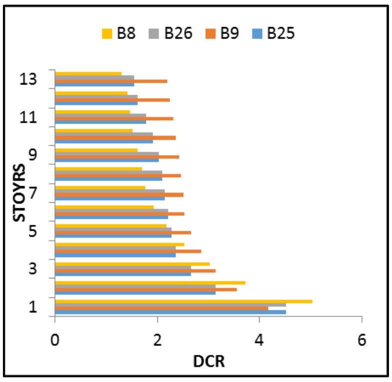

Fig. 7: Interior column located at the center of the building removed C3

For C3 column removed adjacent beams B-8, B-26, B-9 and B-25 exceed acceptance criteria value suggested by GSA for progressive collapse guidelines as in Fig. 7 respectively. For removed column C3 adjacent beam B-25 and B-26 exceed 1.5 up to storey 9, adjacent beam B-9 exceed 1.5 at all 13 storeys and adjacent beam B8 exceeds 1.5 up to story 5.

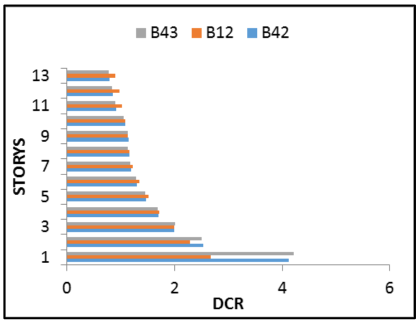

Fig. 8: Exterior column near the middle of the short side of the building removed D8

For D8 column removed adjacent beams B43, B12 and B42 exceed acceptance criteria value suggested by GSA for progressive collapse guidelines as in Fig. 8 respectively. For removed column D8 adjacent beams B-43 and B-42 exceed 1.5 up to storey 4 and adjacent beam B-12 exceed 1.5 up to storey 5.

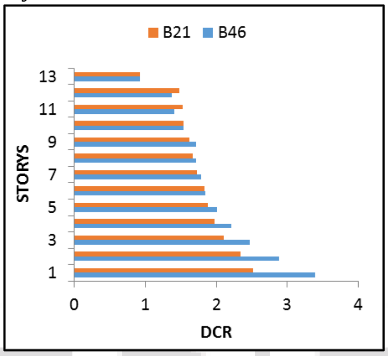

Fig. 9: Exterior column located at the corner of the building removed G8

For G8 column removed adjacent beam B21 and B46 exceed acceptance criteria value suggested by GSA for progressive collapse guidelines as in Fig. 9 respectively. For removed column G8 adjacent beam B21 exceeds 1.5 up to storey 11 and adjacent beam B-46 exceed 1.5 up to story 10.

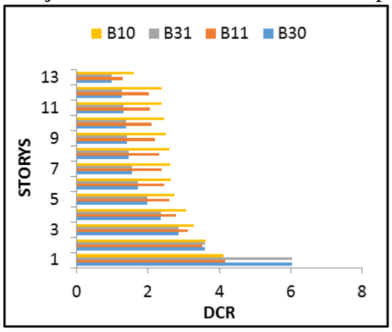

Fig. 10: Interior column located at the center of the building of the building removed D8

For D8 column removed adjacent beams B10, B31, B11 and B30 exceed acceptance criteria value suggested by GSA for progressive collapse guidelines as in Fig. 10 respectively. For removed column D8 adjacent beams B11 and B10 exceed 1.5 up to storey 12 and adjacent beams B31 and B30 exceed 1.5 up to story 7.

VI. Conclusion

Based on the above study of DCR for both symmetric and unsymmetrical structure following conclusion can be made

- The DCR values of column obtained after removal of columns at different positions are less than 2 and therefore all columns are safe as per GSA guidelines.
- The DCR values of beams for removal of column at different positions was found to be greater than 2 for symmetric structure and was found to be greater than 1.5 for unsymmetrical structure and therefore are susceptible to progressive collapse as per GSA guidelines.
- As DCR values of all columns for both symmetric and unsymmetrical structure are less than 2 do not need additional reinforcement but the DCR values of some of the beams exceed the acceptance criteria therefore need additional reinforcement.
- 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 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.

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