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Progressive Collapse Analysis of a Multistorey RCC building using Pushover Analysis

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***Abstract*—The term "progressive collapse" defined as the ultimate failure or proportionately large failure of a portion of a structure due to the spread of a local failure from element to element throughout the structure. The research work was focused on progressive collapse analysis of reinforced concrete framed structure under column removal consideration using commercially available computer program ETABS. A G+8 RCC Educational building was considered and designed as per Indian Building Code and Pushover analysis was carried out. Then critical columns were identified and removed to initiate the progressive collapse. And parameters such as Demand capacity ratio and Robustness indicator were checked for the acceptance criteria provided in GSA 2003. And result comparison was done for these parameters before and after the progressive collapse of the building. Finally influence of critical eliminated elements has been discussed.**

Keywords— Progressive collapse, Pushover analysis, Demand Capacity Ratio and .

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.

Progressive collapse as a structural engineering point of view started taking attention when partial collapse of 22 storey Ronan Point apartment building occurred in London on May 16, 1968. This collapse generated considerable concern over the adequacy of existing building codes. After the partial collapse of Ronan Point apartment building, number of other collapses around the world took place, which could be placed in to category of progressive collapse. The collapse of Skyline Plaza in Virginia, the Civic Arena roof in Hartford, the Murrah Federal Building in Oklahoma City, the Khobar Towers - Saudi Arabia, the U.S. embassies in Kenya and Tanzania, WTC Towers in New York were important collapse events in the history of progressive collapse which changed the perspective of the structural design.

In normal design practice, the abnormal events like, gas explosions, bomb attack, vehicle impacts, foundation failure, failure due to construction or design error etc are not considered. It is not economical as well to design the structures for accidental events unless they have reasonable chance of occurrence. Considering these aspects, many government authorities and local bodies have worked on developing some design guidelines to prevent progressive collapse. Among these guidelines, U.S. General Services Administration (GSA) and Department of Defense (DoD) guidelines by United Facilities Criteria (UFC) - New York, provide detailed stepwise procedure regarding methodologies to resist the progressive collapse of structure. In this procedure, one of the important vertical structural elements in the load path i.e. column, load bearing wall etc. is removed to simulate the local damage scenario and the remaining structure is checked for available alternate load path to resist the load.

II. Analytical Work

A. Pushover Analysis

In the Pushover analysis (otherwise called as Non linear Static Analysis) first the G+8 structure has been analyzed with the gravity load, Wind load and Seismic load. Then column is removed from the location being considered and Non linear static has been once again carried out. From the analysis results demand at critical locations are obtained and from the original seismically designed section the capacity of the member is determined. Check for the DCR in each structural member was carried out. If the DCR of a member exceeds the acceptance criteria, the member was considered as failed. The demand capacity ratio calculated from linear static procedure helps to determine the potential for progressive collapse of building. And the Robust indicator of the building was also obtained.

B. Analysis loading

Gravity loads were calculated as per IS 875 part 1 and assigned, Wind loads were calculated as per IS 875 part 2 and assigned, Seismic loads were calculated as per IS 1893, Design load Combinations and service load combinations were given as per IS 875 part 5.

C. Acceptance criteria as per GSA guidelines

The intent of GSA (General Services Administration) guidelines is to provide guidance to reduce and assess the potential for progressive collapse of Federal buildings for new or existing construction.

Demand Capacity Ratio:

Demand Capacity Ratio (DCR) is the ratio of Member force to the Member strength.

DCR = Member Force / Member Strength

Allowable DCR < 2, for typical structural configuration,

< 1.5, for atypical structural configuration.

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Robustness Indicator:

Robustness indicator (R) is defined as the ability of building to survive the local failure to withstand the loading and does not cause any disproportionate damage.

$R = V_d / V_i$

Where, V_d is the Base shear of damaged building,

V_i is the Base shear of intact building.

The value of Robustness indicator must be equal to 1,then the structure is able to provide an alternative load path.

III. MODELLING OF THE BUILDING

For the Pushover analysis, a G+8 atypical building of height 31.3m is considered. It is modeled using ETABS v9.7software. The column cross section, Beam cross section, Slab cross section and Wall cross section were fixed based on the preliminary analysis. All the supports were modeled as fixed supports.

Here the structure is designed for the Seismic loads also. The gravity load and wind load acting on the structure is carried out as per IS 875 part 1&2 and IS 875 Part3. Seismic loading is carried out as per IS: 1893 [10].

The basic wind speed is 55m/s, building is situated in Zone V and Soil type is III. The characteristic compressive strength of concrete (fck) is 30N/mm^2 and yield strength of reinforcing steel (fy) is 500N/mm^2.

A. Building Description

The total height of the building is 31.3m. The building plan is showing with dimension is given in the below figure. The beam sizes are (250mmx700mm), (450mmx450mm), (450mmx600mm), (250mmx300mm), (250mmx900mm), (300mmx900mm) and (300mm x450mm) and column sizes are (800mm x650mm) and (600mm x 350mm) are considered for the building. The walls having 230mm thickness is present on all the beams and slab thickness is taken as 125mm. The characteristic compressive strength of concrete (fc´) is 30 N/mm2and yield strength of steel (fy) is 500 N/mm2.

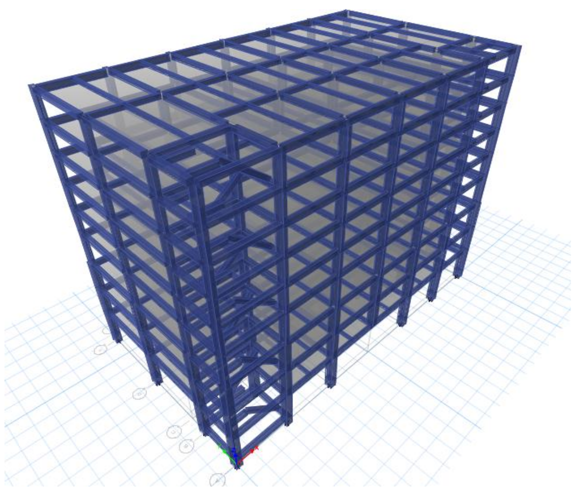

Fig.1. Isometric View of the Building

B. Identification of Critical Columns

The Push over Analysis is carried out for three cases. In the first case a critical column is removed from the middle in longitudinal direction, in the second case an inner critical column is removed and in the third case a corner critical column is removed. The building analysis is carried out according to the load combination of IS 875 Part 5. The gravity load and Lateral loads are imposed on the frame structure and the analysis is carried out. The Bending Moment behavior in all the three cases are studied for structural elements and the load flow of alternate path method is studied and checked. The demand to capacity ratios (DCR) were calculated to assess the state of the building with damaged column. And the vulnerability of the building with respect to all the three cases is checked by determination of Robustness indicator. Finally Check for the demand capacity ratio (DCR) in each structural member is carried out. If the DCR value of a member exceeds the criteria for acceptance as per GSA guidelines, the member is considered as failed. The DCR values calculated from linear elastic method helps to define the possible potential for progressive collapse of frame structure.

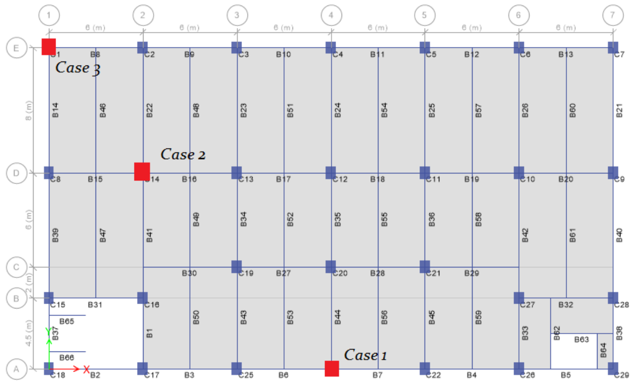

Fig.2. Plan of the Building

IV. RESULTS AND DISCUSSIONS

A. Bending Moment Behavior

The Bending moment of intact structure and all the three cases were compared. The ratio of increased bending moment after the removal of column was obtained.

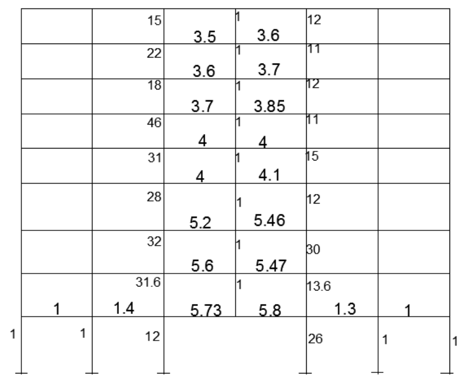

Fig.3. Ratio of Increased Bending moments of Case1

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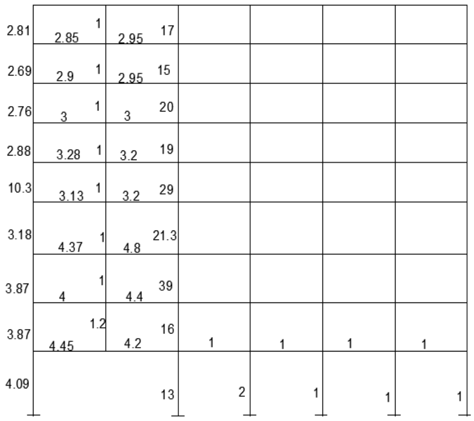

Fig.4. Ratio of Increased Bending moments of Case2

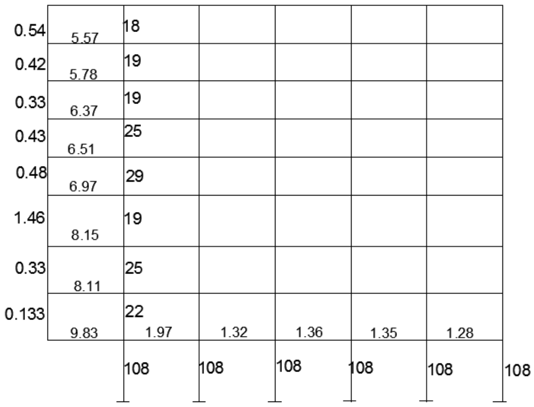

Fig.5. Ratio of Increased Bending moments of Case3

In the case1 the bending moment of the columns in the storeys above the location of removed column remains unchanged, where as the bending moment of the columns in the storey adjacent to either side of the removed column as been increased. And the bending moments of adjoining beams were also increased.

In the case2 also the bending moment of the columns in the storeys above the location of removed column remains unchanged and the bending moment of columns in the storey adjacent to either side of the removed column as been increased. And the bending moments of adjoining beams were also increased.

In the case 3 the bending moment of the columns in the storeys above the location of the removed column has been reduced and the bending moments has been increased for the remaining columns in the ground storey. And the bending moments of adjoining beams were also increased.

B. Demand Capacity Ratio

The frame A-A, D-D and E-E are considered as per the three cases and the DCR values for the beams in those frames are calculated.

According to the GSA guideline atypical frame building having DCR values greater than 1.5 indicate that the portion is severely damaged and have more damage potential. It can be seen from the figure that in the third case that the demand to capacity ratio (DCR) values exceeds the acceptance criteria in the first and second storey beams. But in other spans damage could not propagate. The maximum DCR value experienced by the frame is 1.71. So in the third case there is possibility for the spread of collapse.

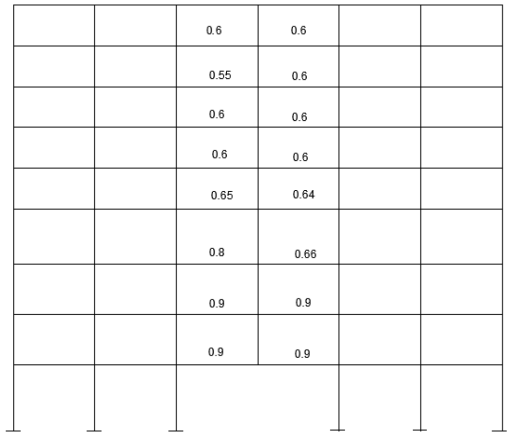

Fig.6. DCR values of frames A-A for case 1

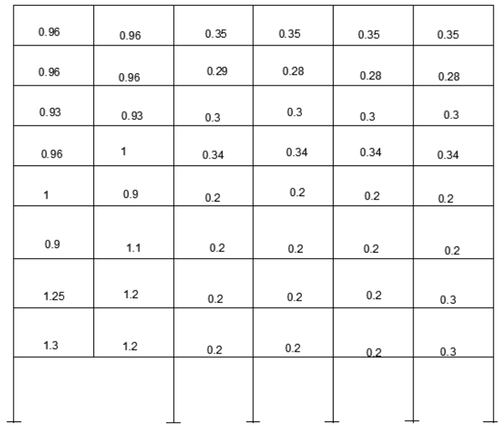

Fig.7. DCR values of frame D-D for case 2

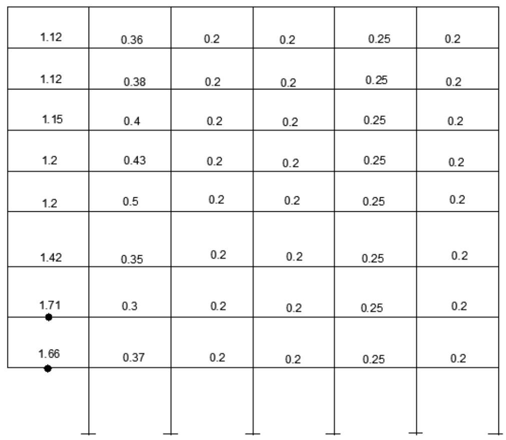

Fig.8. DCR values of frame E-E for case 3

C. Robustness Indicator

Robustness is defined as insensitivity to local failure. In other words, robustness describes the structural ability to survive the event of local failure. A robust structure can withstand loading, so that it will not cause any disproportionate damage. In order to better classify the results.

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TABLE I. ROBUSTNESS INDICATOR

Cases	Removed column	V damaged	Robustness indicator
Case1	Middle	6837KN	0.99
Case2	Inner	6837KN	0.99
Case3	Corner	6836KN	0.94

Here since the robustness Indicator is almost equal to 1, the structure is able to provide an alternative load path if the structure is damaged.

V. CONCLUSION

1. The Considered RCC building has minimum potential for progressive collapse only when the corner column is removed (for case 3).
2. The beams that are adjacent to the removed column have maximum Bending Moment compared to the beams which are away from the damaged column joint.
3. Collapse pattern is in such a way that the Demand Capacity Ratio of the beam increases near the removed column and further away from it decreases.

Therefore it has been concluded that the ground level column losses activate the damage above the column removal and don't propagate to its neighboring spans. And Seismically Designed building resist progressive collapse, since the Robustness Indicator is almost equal to 1 for all the three cases.

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