Assessment of Progressive Collapse for a Multi-Storey RC Framed Structure using Linear Static Analysis Technique

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Abstract

The structures normally get collapsed due to the failure of one or a few structural components which then progresses over the other successive components. This process is known as progressive collapse of the structure. Progressive collapse is the process of extensive failure initiated by local structural damage, or a chain reaction of failures. Local damage that initiates progressive collapse is called initiating damage. Progressive collapse can be triggered by many different actions and the prediction of such abnormal actions is very difficult and depends on many factors Hence, there occurs the loss in load-carrying capacity of the small portion of a structure due to abnormal or haphazard load which progresses in series of failures of other components and thus the collapse of the building take place.

Therefore, a linear static analysis approach has been adopted here for determining robustness against the local failure and accidental occurrences for a RC framed structure to evaluate the demand capacity ratio and the safety of the structure. A finite element model has been developed for the 10 storey building and then the analysis is carried under critical column removal scenario as per the guidelines provided in GSA (2003) considering the provisions of IS 1893:2002 to simulate dynamic collapse mechanism using ETABS software v16.2.1 (software for modelling or analysis of structure) to assess the vulnerability to progressive collapse of atypical RC framed structures. Thus, the influence of critical eliminated elements has been discussed and the parameters such as Demand capacity ratio, collapse resistance and Robustness indicator has been calculated and checked against the acceptance criteria to draw the final conclusions.

Keywords— *Linear static analysis; Progressive Collapse; DCR; Robustness Indicator; ETABS Software*

I. INTRODUCTION

Progressive collapse happens when relatively local structural damage, causes a chain reaction of structure elements failures, disproportionate to the initial damage, causing in partial or full collapse of the building. Local damage that initiates progressive collapse of building is called initiating damage. In general, progressive collapse occurs in a very short time in seconds. It is also possible that it can be characterized by the loss of load-carrying capacity of a relatively small portion of a building due to an atypical load which, in turn, initiates a falls of failures affecting a main portion of the structure. The major events of progressive collapse has been seen in the structures viz. Roman point apartment (U.K., 1968), Alfred p. Murrah Federal Building structure (Oklahoma City, 1995) and World Trade Center Towers (2001)

A progressive collapse is forceful event as it comprises of the vibrations of structural components and results in forceful internal forces. These internal forces could be such as inertia forces etc., whose intensity is not absorbed by the building structure. Progressive collapse is a natural non-linear event, in which structural components are stressed beyond their elastic limit to occur the failure.

Therefore, the loading design or boundary conditions have been changed here such that structure elements inside the building are loaded beyond their capability resulting in the failure to lead to the progressive collapse. Therefore, the loads applied to it get redistributed through the alternate load paths provided for the purpose. This process continues further till the equilibrium condition of the structure is reached either by provision of load-bearing bracing, or by stable alternative load paths.

II. LITERATURE REVIEW

In 2016, Shaikh Akhibuddin, L.G.Kalurkar have conducted progressive collapse analysis using Linear Static Method on 12 storey RC Special Moment resistance frame (SMRF) building having 7 and 5 bays each of 4.5 m in X and Y direction respectively using GSA guidelines. They carried the analysis by removing the four columns each at a time and concluded that the Shear force in beam and columns (except C24) are not critical in progressive collapse process and found that the interior column as most critical and exterior corner column as least critical. In case of removal of column at ground and seventh floor it is found that the upper 4 storey beams (B64) are more stressed than lower storey beams. Thus requires the redesigning of beams in flexure.

Syed Asaad Mohiuddin Bukhari and other studied in June, 2015, "Analysis of Progressive Collapse in RC Frame Structure for Different Seismic Zones". The buildings having 5 stories and 8 stories to from different-different seismic zones (zone ii and zone v) were considered for analysis using ETABS Ver.15.0 Software. It is concluded that progressive collapse susceptibility is decreased with increase in additional reinforcement in the beams. It is also seen that higher storey buildings are more sensitive to progressive collapse than low rise buildings and increase in beam size is more effective than increasing size of column in avoiding the progressive collapse.

III.PROVISIONS FOR DESIGN

A. IS 1893:2002 (Part 1): Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings (Fifth Revision).

B. IS 875 Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures {(Part 1 for Dead Loads, Part-2 for Imposed load, Part-3 for wind load and Part-5 for special loads and load combinations)}:

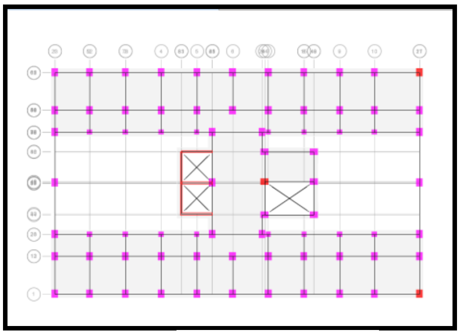
C. IS 4326: Earthquake Resistant Design and Construction of Buildings Code of Practice (Second Revision).

D. IS 456:2000: Plain and Reinforced Concrete - Code of Practice.

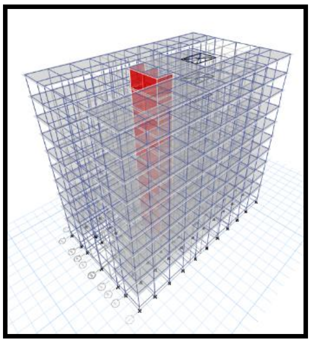
E. BVN:2012 – Bhumi Vikas Niyam of Madya Pradesh State (India)

IV.PROVISIONS FOR DESIGN

A finite element model of 10-story RC (Reinforced concrete) multi-story hotel building from Zone-II with height 33 m as defined in BVN: 2012 part-1 clause no. 2 has been developed with overall dimensions of 22.5m X 36m to study the progressive collapse mechanism. The structure is then designed for the Seismic loads as per IS: 1893:2002. The 2D model of building has been generated in the Auto CAD software and 3D model of structure is proposed to be designed using ETABS v16.2.1 software per IS 875 part 1 & 2 and IS 875 Part-3Recommended font sizes are shown in Table 1.



(a) Building Floor Plan



(b) 3D model in ETABS software

Fig.1 2D Planning and 3D Model Of A G+9 Story Building Considered for Present Study

V. DETAILED DATA OF THE BUILDING

Span in X direction (22.5 m), Span in Y direction (36 m), Ground Floor Height (4 m), First Floor Height (3.4 m), Second Floor to Tenth Floor Height (3.2m), Beam of Ground Floor and First Floor (600 mm x 350 mm), Beam on Second Floor onwards (500 mm x 300 mm), Column size on Ground/First Floor (800 mm x 650 mm), column size on Second Floor and above (800 mm x 350 mm), Corridor column (500 mm x 350 mm), support conditions as fixed, slab thickness of 125 mm, Seismic Zone-II, M 30 Concrete, Shear and Brick wall thickness of 200 mm, Steel (Fe 500 and Fe 250), Unit weight of RCC (25 KN/m3), Unit weight of bricks (20 KN/m3).

VI. METHODOLOGY

The linear static analysis is carried out through following steps –

- Develop the finite element model.
- Analyze the building first with gravity load (Dead load, live load) and obtain the output results for moment and shear without removing any column.
- Remove an identified vertical support (column) from the position and carry out the linear static analysis to the altered structure.
- Enter the static load combinations into ETABS v16.2.1 program and generate a model of the building. Execute the computer simulation for

each case of column removal using ETABS software and review the result.
- Compare the DCR values with allowable limits and draw the conclusions.
- If DCR value exceeds its acceptance criteria (specified by GSA: 2003) then will leads to progressive collapse.

VII. ANALYSIS LOADING

Table I Loading For the Analysis As Per is are Given Below.

Gravity Loads as per IS 875 part 1	**Other Loads**
Dead Load	Wind Load as per IS 875 Part 2
• Self-Weight – 1KN/mm2 • Wall load on all beams – a) Ground Floor Exterior wall-14.8KN/m2 Interior wall – 7.4 KN/m2 b) First Floor Exterior wall –12.4 KN/m2 Interior wall – 6.2 KN/m2 c) 2^{nd}-10^{th} Floor Exterior wall-11.6 KN/m2 Interior wall – 5.8 KN/ m2 • Floor + Floor finish load – 5 KN/m2	• Wind load criteria for Bhopal, Madhya Pradesh (India) are:- Wind Speed – 39 m/s Terrain Category – II Importance Factor – 1 Response Reduction (R) – 5
Live Load	Seismic Loads as per IS 1893:2002
a) On Floor – 3 KN/m2 b) On Roof – 1.5 KN/m2	seismic zone-II Zone Factor – 0.10

VIII. ANALYSIS LOAD COMBINATION

For seismic analysis of a building, following are the load combinations as per IS 1893:2002:

• 1.5(DL + LL) • 1.2(DL + LL ± EL) • 1.5(DL ± EL) • 0.9 DL ± 1.5 EL

IX. PERMISSIBLE CRITERIA AS PER GSA 2003

A. Demand-Capacity Ratios (DCR)

The magnitudes and distribution of potential demands on both the primary and secondary structural elements have been identified through linear elastic analysis to quantify the potential collapse areas. These magnitude and distribution of demands are being indicated by Demand-Capacity Ratios (DCR).

An acceptance criterion for the primary and secondary structural components is determined as:

$$D.C.R = Q_{UD} / Q_{CE}$$

Where,

Q_{UD} = Demand force (acting) such as bending moment, axial force, shear force)

Q_{CE} = Expected ultimate, un-factored capacity of the component and/or connection/joint (moment, axial force, shear and possible combined forces)

The load bearing structural elements are considered to be severely damaged or collapsed if their DCR values through linear elastic approach exceed the allowable values. The allowable value of DCR is:

DCR value has to be less than 1.5 for atypical structural configurations (GSA 2003 Section 4.1.2.3.2)

B. 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 limiting value of Robustness indicator is 1, to allow for an alternative load path.

X. ANALYSIS

Initially, the plan of the building is developed using Auto-CAD which has been then incorporated in ETABS v16.2.1 software along with the provisions of IS 1893 for design and load combinations. Then the linear static analysis is carried out separately for each case of column removal and check the structure for progressive collapse potential.

A. Identification of Critical Columns

Three column removal conditions have been considered as mentioned in GSA 2003 guidelines to evaluate the potential for progressive collapse of G+9 atypical reinforced concrete structure and the method of analysis used here is linear static analysis techniques.

Thus, there are four cases under consideration. 1. Removal of C-31 on Ground Floor situated at the

Long side corner of the building; 2. Removal of a column C-12 on Ground Floor situated at the Short side corner of the building; 3. Removal of column C-76 on Ground Floor situated at the interior of the building; 4. Removal of all three critical columns (C-31, C-12, and C-76) on Ground Floor together. The building analysis is carried out according to the load combination of IS 1893:2002. In all these four cases, the behavior of bending moments and the load transfer through alternative load paths are studied and checked for the vulnerability through DCR values and Robustness indicator values.

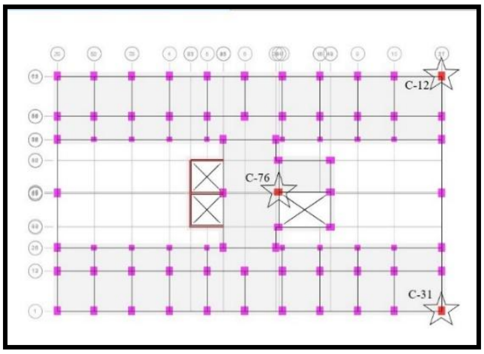


Fig. 2 Plan of a typical G+9 Storey RC Building Showing Removed Column Location Cases (C-31, C-12, and C-76)

XI. RESULTS AND DISCUSSIONS

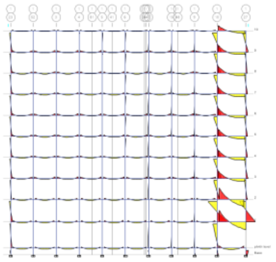
Table II Maximum storey Displacement for Each Cases are

Case No.	+X Direction	-X Direction	+Y Direction	-Y Direction
1	24.100 mm	16.500 mm	18.500 mm	39.000 mm
2	24.190 mm	16.500 mm	32.500 mm	20.440 mm
3	17.400 mm	16.000 mm	22.000 mm	30.000 mm
4	22.500 mm	11.500 mm	22.500 mm	31.0 mm

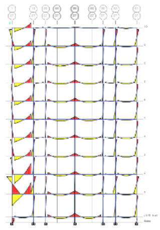
Table III Comparison of the Values of the Axial Load (AL), Bending Moment (BM), and Shear Force (SF) results for the Case of Removal of Critical Columns:

Case No.	Remove Column	Parameters Related to	Building Parameters	Value in Damaged condition	Value in Intact condition	Increment in Percentage
1	C-31	C-48	AL (kN)	4355.7457	2991.4167	45.6%
			BM (kN-m)	3243.0849	2227.2692	45.6%
			SF (kN)	28.5770	16.050	78%
2	C-12	C-23	AL (kN)	4652.3875	2989.5737	55.6%
			BM (kN-m)	3463.9505	2225.8970	55.6%
			SF (kN)	28.5770	16.0481	78%
3	C-76	C-74	AL (kN)	2277.4807	1453.2361	56%
			BM (kN-m)	81.3134	52.2681	55.5%
			SF (kN)	4.5539	3.671	24%
4	C-31	C-48	AL (kN)	4310.6679	2991.4167	44%
			BM (kN-m)	3209.5221	2227.2692	44%
			SF (kN)	28.5770	16.050	78%
	C-12	C-23	AL (kN)	4298.8367	2989.5737	44%
			BM (kN-m)	3200.7131	2225.8970	44%
			SF (kN)	28.5770	16.0481	78%
	C-76	C-74	AL (kN)	2272.4448	1453.2361	56%
			BM (kN-m)	81.7323	52.2681	56%
			SF (kN)	4.7550	3.6710	30%

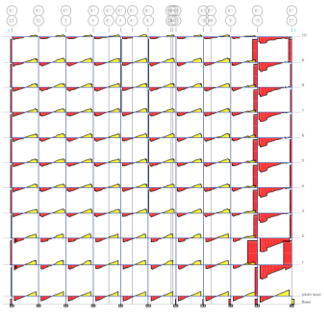
XII. BENDING MOMENT DIAGRAMS



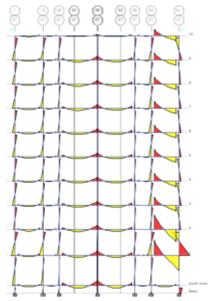
(a) case 1 (Removal of critical column C-31 in x direction)



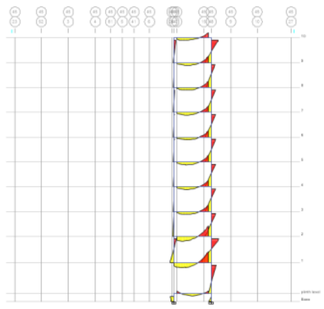
(b) case 1 (Removal of critical column C-31 in y direction)



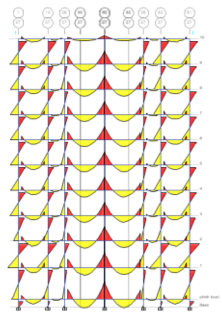
(c) case 2 (Removal of critical column C-12 in x direction)



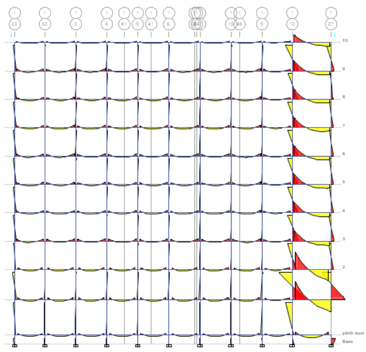
(d) case 2 (Removal of critical column C-21 in y direction)



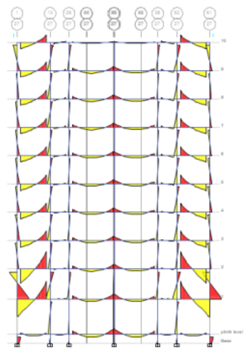
(e) case 3 (Removal of critical column C-76 in x direction)



(f) case 3 (Removal of critical column C-76 in y direction)



(g) case 4 (Removal of critical column C-31, C-12, C-76 in x direction)



(h) case 4 (Removal of critical column C-31, C-12 C-76 in y direction)

Fig.3 Bending Moment Diagrams for Each Case of Removal of Critical Column

Table IV: Demand Capacity Ratio of the Adjacent Member of the Critical Columns for Each Case:

Case No.	Damaged column No.	DCR Value	Permissible Limit	Remark
1	C-48	1.780	1.500	Failed in shear
2	C-23	1.560	1.500	Failed in Axial loading
	C-23	1.560	1.500	Failed in Bending
	C-23	1.780	1.500	Failed in Shear
3	C-74	1.560	1.500	Failed in Axial loading
	C-74	1.550	1.500	Failed in Bending
4	C-48	1.780	1.500	Failed in Shear
	C-23	1.780	1.500	Failed in Shear
	C-74	1.600	1.500	Failed in Axial loading
	C-74	1.600	1.500	Failed in Bending

XIII. CONCLUSION

The behaviour of the ten storey RC building structure has been studied for its progressive collapse using linear static analysis and parameters such as axial force, bending moments and shear force, demand capacity ratio, and robustness of the structure have been determined for these cases to draw the following conclusion:

- In the linear static analysis, it is found that the column number C31, C12 and C 76 are found to be critical as they fail in design criteria and thus leading to the four cases of column removal for analysis.
- As the DCR value for all the beams in the analysis is less than 1.5 (as specified in GSA guidelines), there is no beam that has encountered the failure for all the column removal cases under consideration.
- In Case 1, the column C-48 adjacent to the critical column C-31 has been failed in shear and has the DCR value as 1.78, which is greater than the acceptable limit of 1.5 as provided in GSA guidelines.
- In Case 2, the column C-23 adjacent to the critical column C-12 has been failed in axial, bending and shear and has the DCR value as 1.56, 1.56 and 1.78 respectively, which is greater than the acceptable limit of 1.5 as provided in GSA guidelines.
- In Case 3, the column C-74 adjacent to the critical column C-76 has been failed in axial and bending and has the DCR value as 1.56 and 1.55 respectively, which is greater than the acceptable limit of 1.5 as provided in GSA guidelines.
- In Case 4, the column C-48, C-23 and C-74 adjacent to the critical column C-31, C-12 and C-76 respectively has been failed in axial and bending and has the DCR value as 1.78, 1.78 and 1.60 respectively, which is greater than the acceptable limit of 1.5 as provided in GSA guidelines.
- It is observed in the analysis that there is approximately 78 % increment of the initial value in the immediate adjacent members (except C-74), of the removed element due to large redistribution of forces in both longer and shorter direction whereas there is transfer of around 24 % to 30 % increment of the initial value in the adjacent column in interior location.
- The load transferring effect on the nearest member of the removed column is more and is negligible when moved away from the removed column.
- Since DCR ratio for most of the column (except ground floor columns C-48, C-23, C-74) is less than 1.5, these columns are not critical in progressive collapse process of the building.

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