Progressive Collapse Analysis of R.C.Building Using Linear Static and Nonlinear Static Method

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ABSTRACT: To study the effect of failure of column on the entire structure; in this Study justify effects of the progressive collapse potential on building. Linear static and non linear static analysis is performed using structural analysis program SAP2000 by following alternate load path method to find out the Demand Capacity Ratio (DCR). The DCR found for G+4 RC building using linear static analysis are compared with the G+8 and G+10 RC building.

INTRODUCTION

Progressive collapses have become a subject of interest for structure designers starting with the partial Collapse of a Ronan point London tower. The design of progressive collapse resistant buildings is not a new problem in the field of structural engineering. progressive collapse in a structure takes place when major structural load carrying members (commonly columns) are abruptly collapsed due to abnormal events, bomb assault, failure due to construction or design error, fuel explosion, vehicle impact, fire, earthquake, or different man-made or natural hazards. When a load carrying members is collapsed, the remain part cannot take the load of the building. As a result, a part of the structure may collapse, causing larger damage to the structure than the initial impact. Thus it is necessary to stop progressive collapse. Many government authorities and local bodies have worked on developing some design design guidelines to prevent progressive collapse. Among these guidelines, the U.S. General Service Administration (GSA) and provide detailed step wise procedure concerning methodologies to resist the progressive collapse of building structures. Progressive collapse is a situation wherever local failure of a predominant structural element leads to the collapse of connected members, which in turn results in additional fall down. It is like successive fall of cycles, in a cycle stand, when the initial one is pushed.

Progressive collapse is defined as the spread of an initial local failure from element to element leading to the collapse of a whole structure or a disproportionately. Disproportionate collapse results from tiny damage or a minor action resulting in collapse of a relatively whole part of the structure. So guidelines emphasis on reducing the disproportionate collapse by altering some another path for load transfers. Progressive Collapse is a dynamic event that produces harmful effects at the building systems. Hence a designer should ensure safety at two levels, at "local level" and at "global level". The local level safety can be ensured by designing the key structural elements for abnormal loads, whereas global level safety can be ensured by providing alternate load path in the structural system. The global level safety will help in avoiding disproportionate collapse of structure when local damage has already occurred. Of these two design requirements, guidelines think on the later. The method of ensuring global level safety is known as "Alternate load path method"

BUILDING CONFIGURATION

To study the effect of column removal condition on the structure, 5, 9&11 storey Building Considered. Progressive collapse analysis is based on the GSA guidelines. Structure considered in this analysis is an existing framed building located under seismic zone-IV. The building is symmetric in plan and elevation. This building having 4 bays in X- direction and 5 bays in Y- direction while storey height is 3m. Dimension of this building is 17.1m x 15.14m along X and Y direction respectively. The brick wall thicknesses are 230 mm for external walls and 115 mm for internal walls. Figure shows typical floor plan.



Figure- 1: Typical floor plan of building

LOADING DATA

Live load on typical floor: 2.0 kN/m2 Floor finish: 1.5 kN/m2 Wall load: 13.8 kN/m for 230mm thick wall

7.2 kN/m for 115mm thick wall

MATERIAL PROPERTIES:

Grade of concrete: M25 Grade of steel: Fe415 Seismic Zone: 4 Zone factor: 0.24 Soil Type: Type II Importance factor: 1 Response reduction factor: 3

LOAD COMBINATIONS:

Following primary load cases are considered for design of building.

- 1. Dead Load (DL)
- 2. Live Load (LL)
- 3. Floor Finish (FF)
- 4. Wall Load
- 5. Earthquake Load along X direction
- 6. Earthquake Load along y direction
 - Seismic design of the building is carried out for the maximum of following load combinations as suggested by IS 1893 (part 1): 2002.
 - 1. 1.5 (DL + LL)
 - 2. 1.2 (DL + LL \pm EQx) and 1.2 (DL + LL \pm EQy)
 - 3. 1.5 (DL \pm EQx) and 1.5 (DL \pm EQy)
 - 4. $(0.9DL\pm1.5EQx)$ and $(0.9DL\pm1.5EQy$)

BUILDING DESIGN

Modeling of the building is carried out in computer program SAP2000 with the slab thickness 150 mm; beam size 230×500 mm for all floor beams, plinth beam size 230×380 mm and column size 300×675 mm for ground floor, 230×675 for 1st & 2nd floor, 230×600 for 3rd & 4th floor.

PROGRESSIVE COLLAPSE ANALYSIS

Progressive collapse analysis is performed by removing one or several columns and analyzing the building. Progressive collapse is a dynamic event. Three column removal cases for Progressive collapse analysis are considered.

For Case-1 Middle column from short side of building For Case-2 Interior Column For Case-3 Nearly middle Column of Longer side of building. Fig.2. Showed column removal locations.



Figure- 2: Various column removal location are shown by Red circle

1. Linear static analysis

In linear static analysis column is removed from the location being considered and analysis is carried out for following vertical load which shall be applied downward on the structure.

As per GSA guideline, Load = 2(DL + 0.25LL)

Where,

DL = dead load

LL = live load

Steps to perform linear static analysis: Linear static analysis procedure involves the following steps

Step-1: Build a computer model;

Step-2: Remove the column from the model.

Step-4: Apply static load combinations as per GSA guidelines

Step-5: Perform static linear analysis, a standard analysis procedure in SAP2000

Step-6: Find DCR for beams and Columns.

Calculation of Demand Capacity Ratio (DCR) GSA as per Guidelines

From the analysis results, demand at critical points is obtained and from the designed section the capacity of the member is determined. With the help of calculated demand and capacity, check for the DCR in each structural member is carried out. The Demand Capacity Ratio (DCR) of each member of the alternate load path structures is calculated from the following equation.

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

QUD = Acting force (demand) determined in member or connection (moment and shear)

QCE = Expected ultimate, unfactored capacity of the member and connection (moment and shear)

If the DCR of a member exceeds the acceptance criteria, the member is considered as failed. The demand capacity ratio calculated from linear static analysis procedure helps to determine the potential for progressive collapse of building.

As per the GSA guidelines, the DCR values for each structural element must be less than or equal to following to prevent the collapse.

DCR < 2.0 for symmetric structural configuration

DCR < 1.5 for Asymmetric structural configuration

Ultimate capacity of the member at any section is calculated as per IS 456:2000 by applying the material strength increase factor of 1.25 for both steel and concrete as specified in the guidelines

2. Nonlinear static analysis

Nonlinear static analysis is widely used to analyze a building for a lateral load and is known as "pushover analysis". In this study vertical pushover analysis procedure is adopted to understand the behavior of building structure.

Steps to perform nonlinear static analysis: Nonlinear static analysis procedure is carried out in the following steps in using SAP2000

Step-1: Build a computer model;

Step-2 Define and assign nonlinear plastic hinge properties, to beams and columns;

Step-3: Apply static load combination

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Step-4: Perform nonlinear static analysis; Step-5 Verify and validate the results based on hinge formation. Nonlinear static analysis is carried out for following vertical load which shall be applied downward on the structure. As per GSA guideline, Load = 2(DL + 0.25LL) Where, DL = dead loadLL = live loadLoad Case Data - Nonlinear Static Load Case Name Load Case Type Notes Set Def Name ▼ Design… Nonlinearstatic Modify/Show.. Static Initial Conditions Analysis Type Zero Initial Conditions - Start from Unstressed State C Linear ŵ Nonlinear Continue from State at End of Nonlinear Case Important Note: Loads from this previous case are included in the Nonlinear Staged Construction C current case Modal Load Case Geometric Nonlinearity Parameters MODAL ٠ All Modal Loads Applied Use Modes from Case None C P-Delta Loads Applied C P-Delta plus Large Displacements Load Type Load Name Scale Factor Load Patterr 💌 Live Load ▼ 0.5 Load Pattern DEAD 2 Add 2 Load Pattern FF Wall load Load Pattern Modify oad Pattern Delete Other Parameters OK Full Load Modify/Show. Load Application Multiple States Modify/Show. **Results Saved** Cancel Default Modify/Show. Nonlinear Parameters

Figure-3: Nonlinear static analysis by GSA guideline in SAP2000

For nonlinear analysis automatic hinge properties and user-defined hinge properties can be assigned to frame elements. When automatic or user-defined hinge properties are assigned to a frame element, the program automatically creates a generated hinge property for each and every hinge. Five default hinge options are available, Axial (P), Torsion (T), Moment (M2 or M3), Shear (V2 or V3), and Coupled (P-M2-M3). For default moment hinges, SAP2000 uses Tables 6-7 and 6-8 of FEMA 356. Agraphical representation of the moment hinge property is shown in Figure 4.

olacement I	Control Parameters-		
Point	Moment/SF	Rotation/SF	
E-	-0.2	-0.025	
D-	-0.2	-0.015	
C-	-1.1	-0.015	
B-	-1	0	
A	0	0	
B	1.	0.	
С	1.1	0.015	
D	0.2	0.015	Symmetric
ΞĘ. Š	0.2	0.025	

Figure-4: Moment (M3) Hinge Property





CALCULATION OF DCR (DEMAND CAPACITY RATIO)

Demand Capacity Ratio (DCR) for Flexure= Demand Moments / Flexure Capacity of Member

Demand Capacity Ratio (DCR) for Shear= Demand Shear Force / Shear Capacity of Member

The Demand Capacity Ratios (DCR) is calculated at each storey for static analysis. DCR is calculated at three points left, center and right side of the column removal position show in fig 4. L static, C static and R static indicates the value of DCR at left, center and right side from the position of removed column respectively for static analysis. According to the guidelines structural

elements having Demand Capacity Ratio (DCR) values exceeding 2 for flexure and 1.0 for shear are considered as severely damaged or collapsed.









Figure-9: DCR for flexure for case 1, 2, 3 Of G+10 Building



Figure-10: steps of hinge formation for case-1, 2 of G+4 Building



Figure-11: steps of hinge formation for case-3 of G+4 Building



Figure-12: steps of hinge formation for case-1, 2 of G+8 Building



Figure-13: steps of hinge formation for case-3 of G+8 Building



Figure-14: steps of hinge formation for case-1,2 of G+10 Building



Figure-15: steps of hinge formation for case-3 of G+10 Building

A nonlinear static analysis is performed for each case of column failure. After analysis has been performed the hinge formation pattern for various displacement levels are observed for all the three cases of column removal in the building designed for seismic loading. Steps of the hinges formation at some of the displacement levels are shown in the Figure.

CONCLUSION

- The Selected R.C. building has high potential for progressive collapse analysis when column is considered as totally damage.
- The beams adjacent to the damaged column joint experienced additional damage as compared to the beams which are away from the damaged column joint.
- Comparison of flexural DCR values for individual column position shows that interior column removal condition has least effect amongst all cases.
- Results of Upper storey beams shows higher flexural DCR values than the lower storey.
- Upper storey beams fails in progressive collapse situations, the DCR of lower storey beams are still within permissible limit for regular building which shows that the lower storey floors are capable to resist the failure of upper storey.
- Form Observation for all Column removal Cases Shorter bays in all Column cases are most affected for collapse.
- DCR values for flexure, shear increase as the height of the building increase. So potential for progressive collapse of the building increases as the height of the building increases.
- Increasing beam dimension will be more effective in avoiding collapse. Changing of the beam dimension results
 increase of cost of the structure, but negligible when compared to loss of life and property. so it may be useful for
 important structures.
- It is clearly observed that first hinge forms at the location where demand capacity ratio is maximum. Further in next step sections having higher values of demand capacity ratio shows hinge formation.

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