Effects of Irregularity on Progressive Collapse of RCC Building

Patel Kevins J¹ & Patel Tushar N²

¹P.G.Student, Department of civil engineering, Sardar Vallabhbhai Patel Institute of Technology, Vasad-388306
²Assistant professor, Department of civil engineering, Sardar Vallabhbhai Patel Institute of Technology, Vasad-388306

Abstract: Progressive collapse of a structure is caused due to the removal of vertically load carrying member (typically columns). In the present study, a progressive collapse assessment according to the GSA guideline is carried out for a G+10, G+15, G+20, G+25, G+30 storey RCC building considering irregularity of different height of building, G+15 and G+20 storey RCC building considering mass irregularity, G+15 storey RCC building considering various sloping ground angle 10° and 15° using linear dynamic analysis. Linear dynamic analysis is carried out by ETABS 15.0.0 for without longer side column removal, corner side column removal, short side column removal, center column removal. And parameters such as Demand capacity ratio checked for the acceptance criteria provided in GSA 2003 which show that members are safe or unsafe.

Keywords: Progressive Collapse, DCR, U. S. General services administration (GSA) Guidelines, Mass irregularity, height irregularity, various sloping ground angle, Linear Dynamic Analysis, ETABS 15.0.0.

1. Introduction

The collapse of building is started when one or more columns are removed. When a column is removed, the building’s weight (gravity load) transport to adjacent columns. If adjacent columns are not properly designed to resist and redistribute the additional load that part of the structure fails. The columns continue to fail until the additional loading is stabilize. As a result, a large part of the structure may collapse, causing greater damage to the structure than the initial impact. The collapse occurs when a structure has its loading pattern or boundary conditions changed such that some members are loaded beyond their proposed capacities. The remaining structure is then forced to look for alternate load paths method (AP method) to redistribute the outside balance loads from damaged members. As a result, other adjacent members surrounding the remaining structure may also fail coming off some applied loads. The redistribution of loads is a dynamic process and will continue until a new equilibrium position is reached by the remaining structure, either through finding a stable alternate load path or through extra coming off of loads as a result of collapsed members.

1.1 Objectives

- To find Demand Capacity Ratio after column removal condition considering irregularity of different height of building, mass irregularity in multi storey building, various sloping angle 10° and 15° uses linear dynamic analysis.
- To evaluate by progressive collapse results such as lateral displacements values various column failure cases comparing with dynamic analysis.
- To compare various results such as vertical deflection and storey drift for bare frame model and model with removal of column in different cases.

1.2 Modelling and analysis method

- For the study of G+10, G+15, G+20, G+25, G+30 storey reinforced concrete structure is considered. The progressive collapse is initiated by removing verticals load carrying members.
- To evaluate the potential for progressive collapse of various irregularity in multi-storey building using the linear dynamic analysis by column removal condition.
- Using ETABS 15 software and analyzed for progressive collapse using GSA guidelines.
- The building is designed as per IS 456-2000, IS 1893-2002.

2. Literature Review

Marjanishvili and Agnew (2006) studied the three dimensional simulation of a nine-storey six-bay by three bay steel moment-resistant frame building was adopted in the comparison examination. All linear static, linear dynamic, nonlinear static and nonlinear dynamic analyses were conducted the alternate path method suggested by GSA (2003) guidelines. The analysis results of the numerical examination show...
that the nonlinear dynamic analysis is easy to conduct as well as providing the most precise solution.

Ruth et. al. (2006) studied eleven storey steel building frames were measured to capture the effect of different parameters on the value of dynamic amplification factor. The building models included 2-dimensional and 3-dimensional models with varying bay dimensions, foundation constraints, number of bays, number of storey, members dimensions and the height of storey. The analysis results show that there were no significant effects of any parameter measured in that analysis on the dynamic amplification factor. Also the results show that the dynamic amplification factor equal to 2 which is suggested by both GSA (2003) and Department of Defense(DoD) (2005) were conventional in which all results showed that the maximum measured amplification factor was 1.41. They suggested using amplification factor equal to 1.5 rather than 2.

Tsai and lin (2008) studied linear static, nonlinear static and nonlinear dynamic analyses considering three dimensional finite element modeling of an eleven storey RC building. Different failure scenarios of ground floor columns were measured in the analysis. The analysis results show that the dynamic amplification factor is in line with the specified value (2) by the GSA (2003) when the building responses are in the elastic range. The results showed that amplification factor would become less than the specified value (two) when the building responses in the inelastic range. Also, it was establish that the dynamic amplification factor decreases with increases in the ductility demand of the building’s response.

Tank et al. (2010) analysis the DCR of RC 4 storey and 10 storey frame structure are evaluate as per GSA guidelines. The linear static and nonlinear static analyses are carried out using software SAP2000. The DCR found using linear static analysis at important locations are compared with the hinge formation obtained from nonlinear static analysis. Comparison of linear static and nonlinear static analysis reveal that hinge formation starts from the location having maximum DCR considered from static analysis. From this analysis it is observed that to avoid the progressive failure of beams and columns, after failure of particular column due to extreme loading from blast, adequate reinforcement to limit the DCR within the acceptance criteria and adequate detailing can be useful.

Pachenari et al. (2010) analysis that 5 storey building some external and corner column removal are evaluate by nonlinear procedures in all storey of a regular structure. They considers the acceptance criteria of nonlinear dynamic analyses, nonlinear static analyses require additional reinforcement in beam supports in the top two storey. Compared to dynamic analyses, it is also concluded that static analyses are more conventional in the estimation of maximum vertical displacement and shear force in beams.

Kima and Kimb (2008) studied that 15 storey steel moment resisting frames was investigate using the linear static, linear dynamic, and nonlinear dynamic analysis procedures suggested in the GSA 2003 and the DoD 2005 guidelines. It was also observed that the potential for progressive collapse was highest when a corner column was suddenly removed, and that the progressive collapse potential decreased as the number of storey increased. The analysis conducted by that the vertical displacements at the top of failed column considered by linear static analysis are smaller than those considered using nonlinear dynamic analysis. They concluded that the use of nonlinear dynamic analysis is more precise and practical than the other analysis methods in considering the potential of progressive collapse of buildings.

Ren et al. (2014) analyses the progressive collapse resistance of high-rise RC frame shear wall structures, two typical 15-storey building models are designed with equivalent lateral resistance to seismic actions. The structural layouts in resisting the lateral forces are different two buildings. Building A is a weak wall-strong frame structure while Building B is a strong wall-weak frame system. The collapse resistances of the frames and the shear walls in both buildings are evaluating under various column removal scenarios. After analysis the collapse resistance tends to be inadequate for the strong wall-weak frame system. Such a system is after re-designed using the linear static AP method proposed in GSA guidelines. The design and analysis outcomes also confirm that the linear static AP method specified in GSA guidelines is reliable and efficient for progressive collapse prevention designs of typical and representative high-rise RC frame shear wall structures.

3. Methodology

3.1 General Service Administration Guidelines

The aim of GSA guidelines is to help in evaluate the potential of progressive collapse for existing RC and steel framed buildings. This guideline is based on AP method and removal of vertical load carrying members. GSA (2003) factors the loading condition using equation:
For linear static analysis: \(2 \times (D.L. + 0.25 \times L.L.)\)
For linear dynamic analysis: \( (D.L. + 0.25 \times L.L.)\)

Where, \(D.L.\) = Dead load, and \(L.L.\) = Live load.

The following are the consideration for the analysis as per guidelines:

1. An external column near the centre of the long side of building.
2. An external column near the centre of the short side of building.
3. A column located at the corner of building.
4. A column centre to the edge column lines for facilities that have underground parking and/or uncontrolled public ground floor areas.

### 3.2 Demand Capacity Ratio

As per GSA (2003) guidelines the DCR, of the member force and the member strength, as a measure to determine the failure of main structural member by linear dynamic procedure.

\[
D.C.R = \frac{Q_{UD}}{Q_{CE}}
\]

Where,
- \(Q_{UD}\) = Acting force determined
- \(Q_{CE}\) = Apparent ultimate capacity

\(D.C.R < 2.0\) for typical structural configurations
\(D.C.R < 1.5\) for atypical structural configurations

### 3.3 Linear Dynamic analysis procedure

Loading: As per GSA guideline, Load = \((D.L. + 0.25 \times L.L.)\)

**Step 1:** Build a computer model
**Step 2:** Apply analysis loading as per GSA guidelines
**Step 3:** Run analysis with all column present
**Step 4:** Find the load carrying capacity of column to be removed
**Step 5:** Remove the column and apply the load carrying capacity of the column as point load.

**Step 6:** Remove the point load suddenly from the linear dynamic analysis case using time-history function to achieve actual dynamic behaviour.
**Step 7:** Perform linear dynamic analysis using time-history.
**Step 8:** Evaluate the results based on DCR for beams and columns.

Linear dynamic analysis case has been defined in ETABS 2015 for GSA is shown in Figure:
4. Model Description

To study the effect of column removal condition on the structure, case of G+10, G+15, G+20, G+25, G+30 storeys RCC building is considered. Progressive collapse analysis is based on the GSA guidelines. Bay size is taken as 6m in one direction and 4m in other direction. Building size in plan is 36m x 24m. Height of base to plinth is taken as 2m, Plinth to ground floor as 4m, which is considered as hollow plinth and height of typical floor as 3.5m. 230mm thick walls are assumed to be on all beams. Figure shows typical floor plan of regular building.

Figure 5: Column removal locations are shown by circles

Loading Data:
- Live load at typical floor = 2 kN/m²
- Live load at roof = 1.5 kN/m²
- Floor finish at typical floor = 1 kN/m²
- Parapet wall load at terrace (230mm thick) = 4.6 kN/m
- Water proofing roof = 1 kN/m²
- Wall load at typical floor (230mm thick) = 13.685 kN/m
- Self weight of slab (150mm thick slab) = 3.75 kN/m²

Table 1: Structural element characteristics

<table>
<thead>
<tr>
<th>Type</th>
<th>Dimension</th>
<th>Longitudinal reinforcement</th>
<th>Confinement bars</th>
<th>Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column</td>
<td>0.8x0.8</td>
<td>8-20ø evenly distributed</td>
<td>16-10ø, 15cm spacing</td>
<td>0.05</td>
</tr>
<tr>
<td>Beam</td>
<td>0.3x0.6</td>
<td>4-20ø (Bottom) 3-16ø(Top)</td>
<td>12-8ø, 15cm spacing</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Seismic loading as per IS: 1893-2002.
Zone: III
Soil type: II
Response Reduction Factor, R=5
Importance Factor, I=1

Following load combinations are considered for design of structural elements as per IS 1893-2002.

1. 1.5 (DL+LL)
2. 1.2 (DL+LL±EQX)
3. 1.2 (DL+LL±EQZ)
4. 1.5 (DL±EQX)
5. 1.5 (DL±EQZ)
6. 0.9 DL ± 1.5 EQX
7. 0.9 DL ± 1.5 EQZ

4.1 Description of Various Building Models

For the particular study, the plan of the building is kept same for all types of buildings. For each model, take four column removal conditions.

4.1.1 Irregularity of different height of building models
Model 1: G+10 Storey RCC building
Model 2: G+15 Storey RCC building
Model 3: G+20 Storey RCC building
Model 4: G+25 Storey RCC building
Model 5: G+30 Storey RCC building

4.1.2 Mass irregularity of different height of building models
Two RCC frames of G+15, G+20 storeys have been considered. To making building irregular providing extra load at the storey level 20kN/m². Slab thickness of these heavier floors is taken as 300mm. In this way, the effective mass of heavier storey is made greater than 200% of effective mass of an adjacent storey (as per IS 1893-Part I: 2002).

Model 6: Two frames carries heavier loading on the roof level, hence the building irregular.
Model 7: Two frames carries heavier loading 7th storey, hence making the building irregular.
Model 8: Two frames with heavy loading on the 7th and 11th storey, e.g., in this storey extra load has been introduced hence making the storey heavy, and the building becomes irregular.
Model 9: Two frames with heavy loading on middle storey, e.g., 7th and 10th storey, in this storey extra load has been introduced hence making the storey heavy, and the building becomes irregular.

4.1.3 Various sloping ground angle 10⁰ and 15⁰ of building models
Model 10: G+15 Storey sloping ground at 10⁰ RCC building
Model 11: G+15 Storey sloping ground at 15⁰ of RCC building
5. Analysis and Result

5.1 Irregularity of different height of building models

5.1.1 DCR value of Irregularity of different height of building models

Figure 6: DCR value of G+10 storeys

Figure 7: DCR value of G+15 storeys

Figure 8: DCR value of G+20 storeys

Figure 9: DCR value of G+25 storeys

Figure 10: DCR value of G+30 storeys

Figure 11: Storey vs. beam failure graph
5.1.2 Limit deflection of Irregularity of different height of building models

Figure 12: Vertical deflection as per case GSA DL+0.25LL

Figure 13: Vertical deflection of different height of building models

5.2 Mass irregularity of different height of building models

5.2.1 G+15 Storey DCR value of mass Irregularity of building models

Figure 14: G+15 Storey mass irregularities at roof

Figure 15: G+15 Storey mass irregularities at roof

Figure 16: G+15 Storey mass irregularities at 7th and 11th floor

Figure 17: Compare of various irregularity in terms of no. beam failure
5.2.1 G+20 Storey DCR value of mass irregularity of building models

Figure 18: Compare of various irregularity in terms of vertical deflection

Figure 19: Lateral displacement of X direction

Figure 20: Lateral displacement of Y direction

Figure 21: Storey Drift of X direction

Figure 22: Storey Drift of Y direction

Figure 23: G+20 Storey Mass irregularities at roof
Imperial Journal of Interdisciplinary Research (IJIR)
Vol-3, Issue-4, 2017
ISSN: 2454-1362, http://www.onlinejournal.in

Figure 24: G+20 Storey Mass irregularities at 7th floor

Figure 25: G+20 Storey Mass irregularities at 7th and 11th floor

Figure 26: G+20 Storey Mass irregularities at 10th floor

Figure 27: Compare of various irregularity in terms of no. beam failure

Figure 28: Compare of various irregularity in terms of vertical deflection

Figure 29: Lateral displacement of X direction

Figure 30: Lateral displacement of Y direction
5.3 Various sloping ground angle $10^\circ$ and $15^\circ$ of G+15 RCC Storey building models

![Figure 31: Storey Drift of X direction](image)

![Figure 32: Storey Drift of Y direction](image)

Figure 33: $10^\circ$ slope angle of G+15 Storey

Figure 34: $10^\circ$ slope angle of G+15 Storey

Figure 35: $15^\circ$ slope angle of G+15 Storey

Figure 36: Compare of $10^\circ$ and $15^\circ$ slope angles of G+15 storey in terms of no. beam failure
6. Conclusion

- The height of multi storey building increases as the progressive collapse potential decreased since more structural members participate in resisting progressive collapse.

- Considering mass irregularity on building, the generalized behaviour is observed when mass irregularity present at same position, G+ 15 storeys is more critical than G+ 20 storeys in terms of no. of member failure.

- When mass irregularities apply on more height of building is less affected of progressive collapse.

- Vertical deflection is more when height of building increases at column removal location more than permissible limit.

- In both cases, mass irregularity apply at roof level is more storey displacement, storey drift more than other cases.

- When sloping ground angle increases is more critical for progressive collapse, but storey displacement and storey drift less.
7. References


6. Peiqi Ren, Yi Li, Hong Guan, Xinzheng Lu “ Progressive collapse resistance of two typical high-rise RC frame shear wall structures” ASCE 2014


