PARAMETRIC STUDY OF PROGRESSIVE COLLAPSE ANALYSIS USING ALTERNATE PATH METHOD

Mittal Rathwa[1], Dr. V. R. Patel[2]

[1]PG Student, Applied Mechanics and Structural Engineering Department, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda, Gujarat, India
[2]Assistant Professor, Applied Mechanics and Structural Engineering Department, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda, Gujarat, India

***

Abstract - *Natural disasters such as hurricanes, earthquakes, and terrorist attacks on structures cause significant human and economic loss. Blast, Impact, Wind stresses, and Earthquake collapse of structural components is a highly dynamic phenomena. This type of event causes abnormal loading on the structure of the building. Typically, building members are unable to withstand this type of abnormal loading, resulting in failure. The term "Progressive Collapse" refers to one of the failure mechanisms that occurs during such an occurrence. When one or more vertical load-bearing elements, notably columns, are severely damaged or collapse during any abnormal occurrence, progressive collapse of building structures occurs. The purpose of this research is to determine whether a symmetrical reinforced concrete building constructed for seismic stress has the potential for gradual collapse. It is critical to reduce a building's vulnerability to progressive collapse if it has a high risk of progressive collapse. Three distinct solutions are investigated in this study to reduce the risk of gradual collapse.*

Key Words: GSA Guidelines, UFC (DoD) guidelines, Alternate path Method, Progressive Collapse, Time History Analysis, ETABS 17.

1. INTRODUCTION

The process of progressive collapse is a dynamic process. When one or more vertical load-bearing elements, notably columns, are severely damaged or collapse during any abnormal occurrence, progressive collapse of building structures occurs. When a column fails, the building's gravitational weight is transferred to surrounding members.

This portion of the structure will break if these members are not correctly constructed to resist and redistribute the extra weight. As a result, a significant portion of the building might collapse, causing more damage than the initial hit. As a result, it is critical to avoid the gradual collapse of major building structures. As a result, it is critical to avoid the gradual collapse of major building structures.
Structural experts are becoming increasingly interested in preventing the building's gradual collapse. Many government and commercial agencies worked together after the World Trade Center (WTC) Tower collapsed to create design recommendations for progressive collapse resistant constructions. The US General Service Administration (GSA) and Department of Defense (DoD) are the most commonly utilised rules among structural engineers. This paper discusses several factors to consider while performing progressive collapse analysis according to these standards.

Three analytical techniques are proposed in these guidelines: 1) Alternate load path method, 2) Tie force method, and 3) Local resistance method. To assess the risk of progressive collapse, four analytical techniques are recommended: linear static, linear dynamic, nonlinear static, and nonlinear dynamic. There is also a comparison of several guidelines.

The technique of determining the likelihood of a building's gradual collapse is known as progressive collapse analysis. G+12-storey The gradual collapse of a symmetrical reinforced concrete (RC) structure is investigated. Evaluation of progressive collapse potential of seismically designed building is carried out by following U.S. General Service Administration (GSA) and Department of Defense (DoD) guidelines.

The displacement at the column failure point calculated using static analysis is compared to the displacement calculated using linear dynamic analysis. Material and geometrical nonlinearities are taken into account in nonlinear dynamic analysis. The displacement acquired using nonlinear dynamic analysis under the column removal point is compared to the displacement obtained using linear dynamic analysis.

2. ANALYTICAL WORK:

a) Loading Data

G+12 storey Symmetrical Building is analyzed and designed by considering following loading parameters and material properties.

i) Gravity loading parameters :

- Dead load : Self weight of the structural elements
- Live load on roof : 1.5 kN/m^2
- Live load on floor : 3.0 kN/m^2
- Floor finish : 1.5 kN/m^2
- Super Imposed Dead Load : 1.5 kN/m^2
- Wall load : 11 kN/m

ii) Seismic loading parameters :

- Seismic Zone : III
- Soil type : II
- Importance factor : 1

iii) Material properties :

- Grade of concrete f_{ck} : M30
- Grade of steel f_y : Fe500

b) Preliminary Design of Building

The plan and elevation are used in the analysis and design of the building, as illustrated in Figures 1 and 2, respectively. The building is modelled in ETABS 17 with a slab thickness of 125 mm, beam sizes of 300x600 mm, and column sizes of 800x500 mm. The building's seismic design is carried out for the greatest number of load combinations as recommended by IS 1893 (part 1) : 2002.

- 1.5 (DL + LL)
- 1.2 (DL + LL ± EQ_x) and 1.2 (DL + LL ± EQ_y)
- 1.5 (DL ± EQ_x) and 1.5 (DL ± EQ_y)
- (0.9DL ± 1.5EQ_x) and (0.9DL ± 1.5EQ_z)

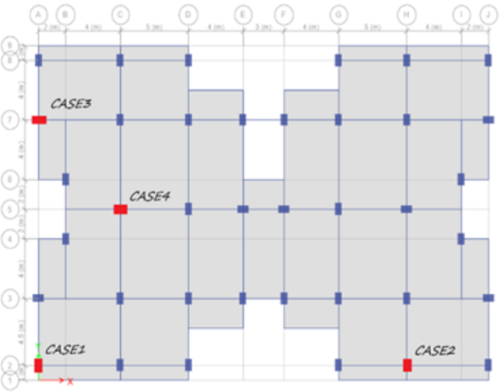


Figure 1: Plan of the G+12-storey Building

i) Linear Static Analysis

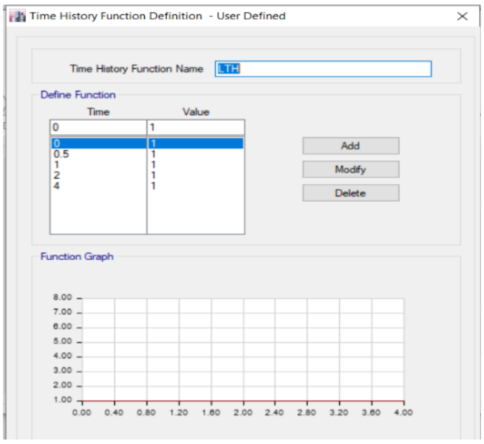
The column is removed from the site under consideration in linear static analysis, and the analysis is carried out for the subsequent vertical load that will be imposed downward on the structure.

As per GSA guideline, Load = 2(DL + 0.25LL)
As per UFC guideline, Load = 2(1.2DL + 0.5LL)
Where,
DL = dead load
LL = live load

ii) Linear Dynamic Analysis

The load applied in the linear dynamic method is half of the force applied in the static operation. Because the dynamic impacts are already taken into account in the time history analysis, there is a difference in load application. For the following vertical load that will be delivered downward on the structure, a linear dynamic analysis is performed.

As per GSA guideline, Load = DL + 0.25LL
As per UFC guideline, Load = 1.2DL + 0.5LL
Where,
DL = dead load
LL = live load



Time History Function Name: LTH

Time	Value
0	1
0	1
0.5	1
1	1
2	1
4	1

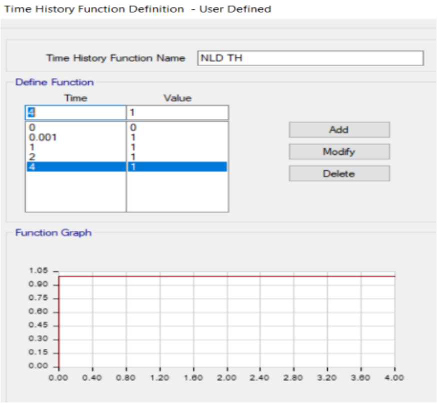
Figure 2: Time history function definition in ETABS 17 for linear dynamic analysis

iii) Nonlinear Dynamic Analysis

Rapid column loss is reflected in nonlinear time history analysis by removing the column from the model. Structures operate in a dynamic manner if a column is deleted. The time history function is used to mimic the dynamic effect of column removal. Figure 4 depicts the time history function defined in ETABS 17 for nonlinear dynamic analysis. This approach takes into account both material and geometrical nonlinearities. It is permissible for the material to deviate from the elastic limit. Geometrical nonlinearities are included via the P-effect and massive displacements. The vertical load that will be exerted downward on the structure is used in nonlinear dynamic analysis.

As per GSA guideline, Load = DL + 0.25LL

As per UFC guideline, Load = 1.2DL + 0.5LL
Where,
DL = dead load, LL = live load


Time History Function Definition - User Defined

Time History Function Name: NLD TH

Define Function

Time	Value
4	1
0	0
0.001	1
1	1
2	1
4	1

Figure 3: Time history function definition in ETABS 17 for nonlinear dynamic analysis

3. RESULT AND DISCUSSION :

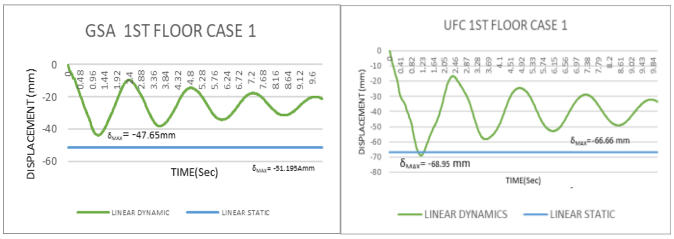


Figure 4: Displacement under column removal point At 1ST Floor for Case 1

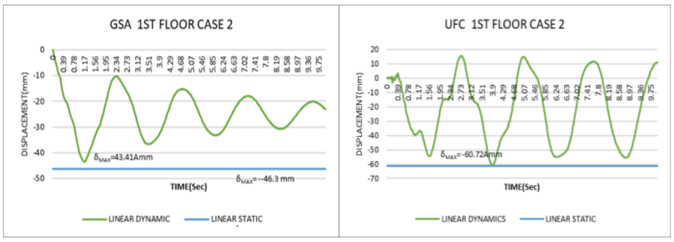


Figure 5: Displacement under column removal point At 1ST Floor for Case 2

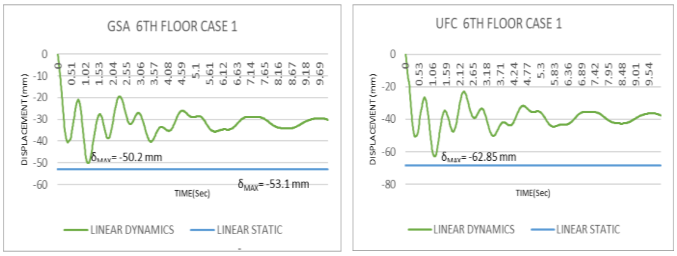


Figure 6,7: Displacement under column removal point At 1ST Floor for Case 3,4

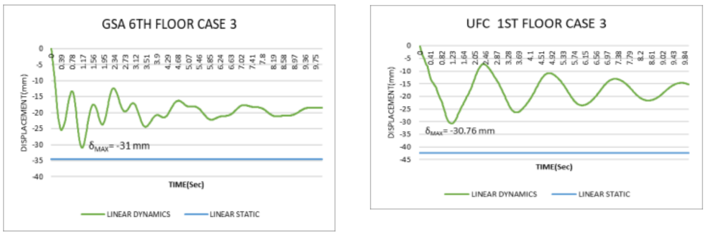


Figure 8: Displacement under column removal point At 6TH Floor for Case 1

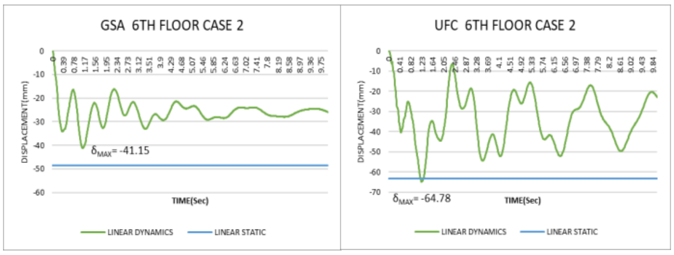


Figure 9: Displacement under column removal point At 6TH Floor for Case 2

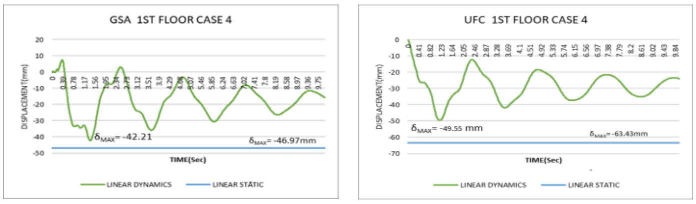


Figure 10: Displacement under column removal point At 6TH Floor for Case 3

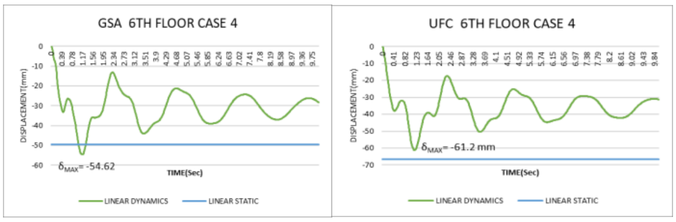


Figure 11: Displacement under column removal point At 6TH Floor for Case 4

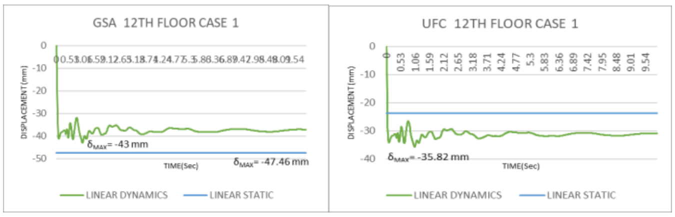


Figure 12: Displacement under column removal point At 12TH Floor for Case 1

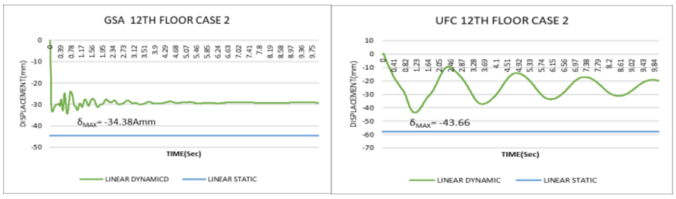


Figure 13: Displacement under column removal point at 12th Floor for Case 2

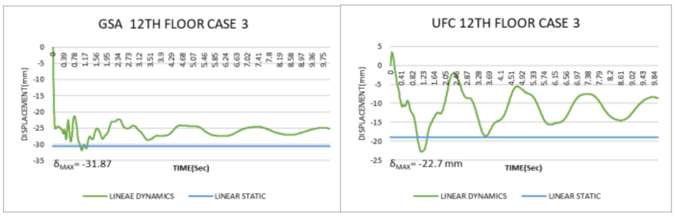


Figure 14: Displacement under column removal point At 12TH Floor for Case 3

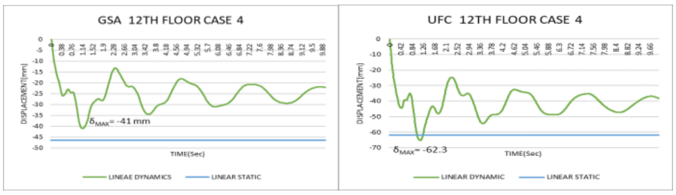


Figure 15: Displacement under column removal point At 12TH Floor for Case 4

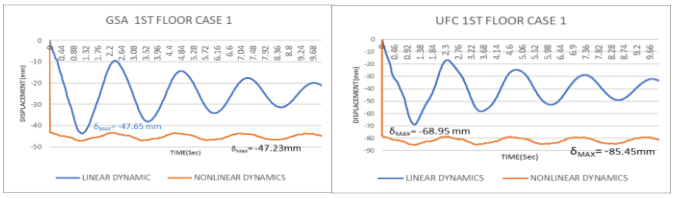


Figure 16: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 1st floor for case 1

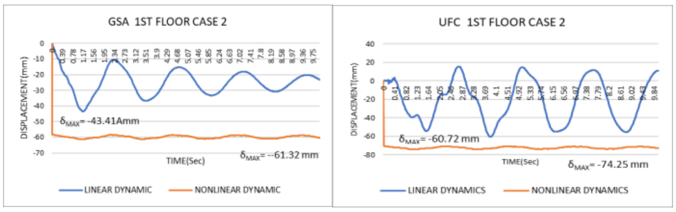


Figure 17: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 1st floor for case 2

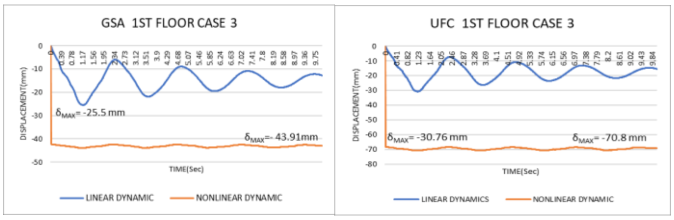
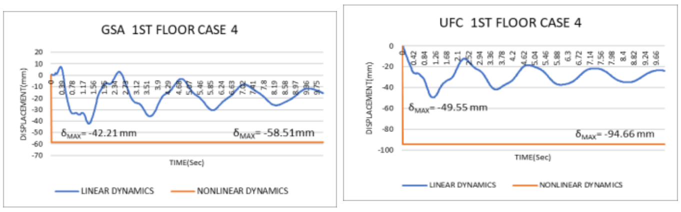


Figure 18: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 1st floor for case 3



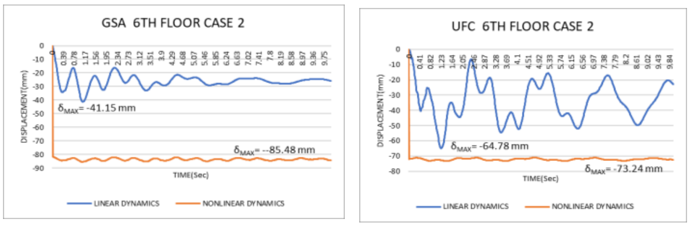


Figure 19: Comparison of Displacement bylinear and nonlinear dynamic analysis for column removal at 1st floor for case 4

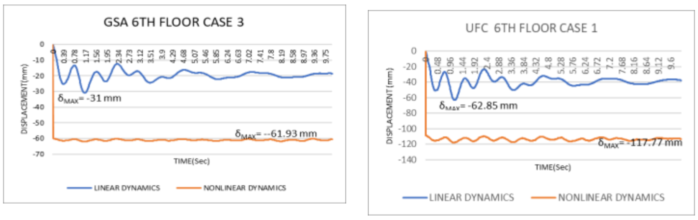


Figure 20: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 6th floor for case 1

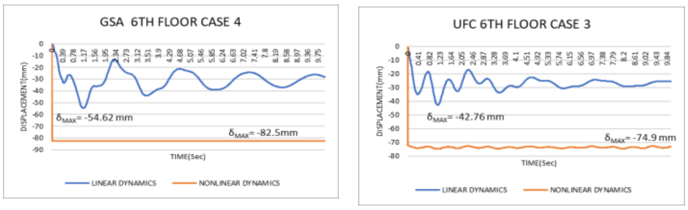


Figure 21: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 6th floor for case 2

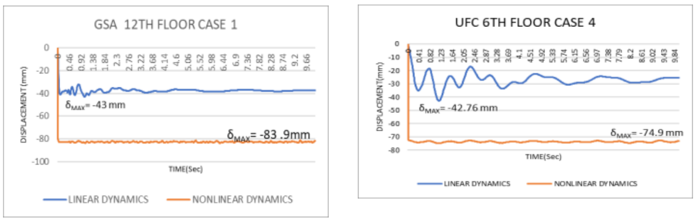


Figure 22: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 6th floor for case 3

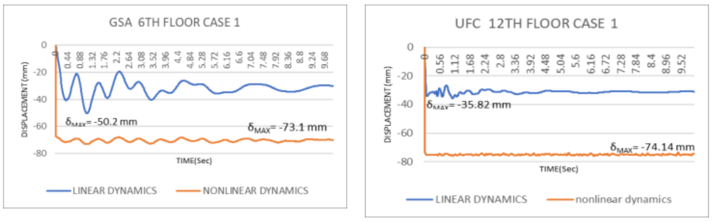


Figure 23: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 6th floor for case 4

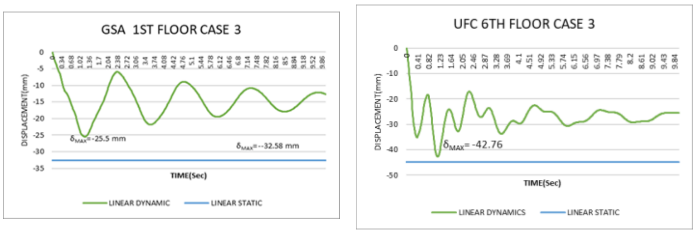


Figure 24: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 12th floor for case 1

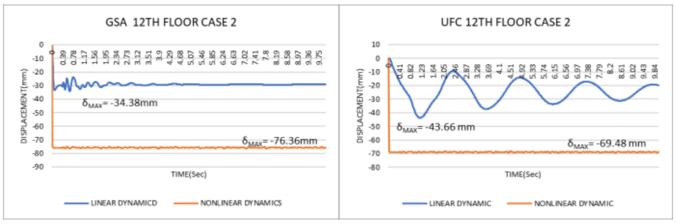


Figure 25: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 12th floor for case 2

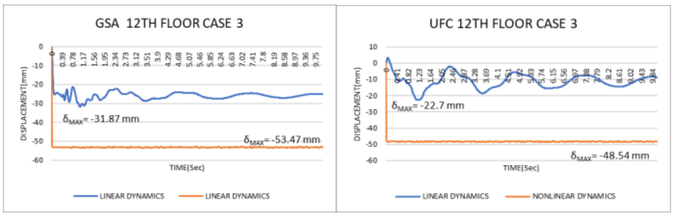


Figure 26: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 12th floor for case 3

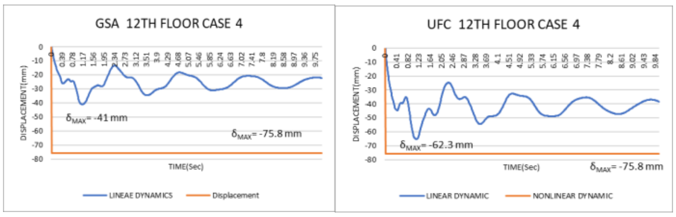


Figure 27: Comparison of Displacement by linear and nonlinear dynamic analysis for column removal at 12th floor for case 4

According to the research, case 4 of column removal had the most negative impact on the building structure among the four cases studied. For both static and dynamic analyses, displacements under the column removal point have been found for the GSA and UFC loads in all four cases. The displacements under the column removal point for all four column removal scenarios are shown in Figures 4 to 15. The maximum deflection achieved in dynamic analysis is about 5-10% lower than that obtained in static analysis, based on a comparison of maximum deflection at column removal point. When comparing the UFC and GSA load cases, the deflection under column removal point is higher for the UFC load scenario. Under the same basic conditions, removing a column from a higher level causes less vertical displacement than removing a column from the ground level. When a column is removed from the top storey level, the displacement under the column removal point is less than when a column is removed from the ground storey or intermediate storey level.

Nonlinear time history analysis is used to better understand how a structure behaves when material and geometrical nonlinearities are present. The results of a nonlinear dynamic analysis for case 4 of column removal, which has the greatest impact on the building structure, are provided. The displacement at the location where the column is removed is measured and compared to the displacement determined using linear dynamic analysis. The displacement comparison is shown in Figure 19. The column removal joint began vibrating and suddenly deflected 58.51 mm downward for the GSA load case and 94.66 mm downward for the UFC load case, according to the results. The displacement acquired by nonlinear dynamic analysis is 50-55 percent higher than the displacement produced by linear dynamic analysis, according to the comparison.

4. STRATEGIES TO PREVENT PROGRESSIVE COLLAPSE:

Here, three different solutions are used to reduce the risk of progressive collapse in symmetric reinforced concrete buildings G+12 stories. The following are the three options:

Alternative1: Install bracing at the top of the storey.

Alternative 2: Increase the size of frame members by a moderate amount at all storey levels.

Alternative 3: For a G+12-story building, a significant increase in the size of frame members at the bottom six storey level.

Member	**Original Size (mm)**	**Alternative-1 (mm)**	**Alternative-2 (mm)**	**Alternative-3 (mm)**
Beam	300×600	300×600	300×750	350×900
Column	800×500	800×500	900×550	900×550
Bracing Beam	—	300×350	—	—

Table 1: Member sizes for various alternative

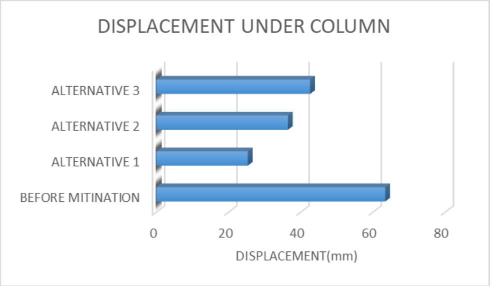


Figure 28 : Various mitigation alternatives symtems for RC building

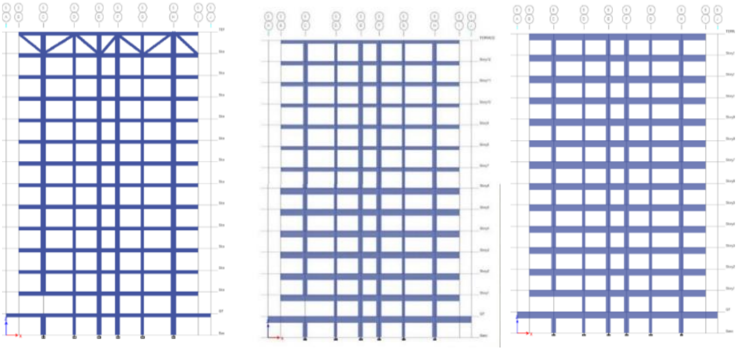


Figure 29 displacement beneath the column removal point

For each of the three mitigation approaches, the displacement beneath the column removal point is graphicalized and compared to the displacement obtained before mitigation. The findings demonstrate that using mitigation strategies on the building reduces displacement beneath the column removal point significantly. The displacement achieved after mitigation is roughly 50-60 percent lower than before mitigation for a G+12-story tower.

5. CONCLUSIONS:

The following conclusions may be taken from the research presented in this paper.

1) For static analysis methods, a dynamic amplification factor of 2 is a fair approximation since linear static and linear dynamic analysis processes produce almost identical maximum deflections.
2) In linear static analysis, displacements under the column removal point are predicted to be 5-10% higher than in linear dynamic analysis.
3) Under the same basic conditions, removing a column from a higher level causes less vertical displacement than removing a column from the ground level.
4) In comparison to linear static and dynamic analysis, nonlinear dynamic analysis indicates that when a building structure is examined using material nonlinearity and geometrical nonlinearity while considering the P- Δ effect, it results in significant displacement.
5) When compared to displacement produced by linear dynamic analysis under column removal point, the displacement obtained by nonlinear dynamic analysis is 50-55 percent greater.
6) Of the four situations of column removal indicated by the recommendations, case 4 has the most negative impact on the building structure.
7) Of the three mitigation options discussed, installing bracing in the building is the most cost-effective way to decrease the risk of progressive collapsing. The risk of progressive collapse can be successfully minimised by implementing two or more mitigation strategies in the building structure at the same time.

6. FUTURE SCOPE OF WORK:

This report's research is limited to a G+12-story symmetrical reinforced concrete building's progressive collapse analysis. The current research may be expanded to cover the following features.

- An examination of the progressive collapse of higher storeys By completing all four analytical procedures, an asymmetrical reinforced concrete structure may be created.
- Buildings with various structural configurations, such as shear walled buildings, braced frame buildings, and so on, should be studied for their progressive collapse potential.
- Important existing structures can be investigated to determine their risk of gradual collapse.
- A symmetrical and asymmetrical multi-story steel building can be subjected to a progressive collapse study.
- Other ways to prevent building progressive collapse, such as bracing, installing Vierendeel truss between floors, and upgrading shear connectors to completely restrained moment connections, can be further investigated.

- Dedicated computer software may be created to assess the likelihood for progressive collapse based on various criteria and to devise mitigation strategies to increase progressive collapse resistance.

7. REFERENCES

1) IS 1893:2002, Criteria for earthquake resistant design of structures, Bureau of Indian Standards, New Delhi.
2) IS 456:2000, Plain and Reinforced concrete code of practice, Bureau of Indian Standards, New Delhi.
3) SP:16, Design Aids for Reinforced Concrete to IS 456:1978, Bureau of Indian Standards, New Delhi.
4) Design of Buildings to Resist the Progressive Collapse, Unified Facilities Criteria (UFC 4-023-03) published by Department of Defense (DoD), July 2009.
5) Best Practices for Reducing the Potential for Progressive Collapse in Buildings, National Institute of Standards and Technology (NIST), June 2006.
6) Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects, U. S. General Service Administration (GSA), April 2003.