ASSESSMENT OF PROGRESSIVE COLLAPSE OF RC BUILDING UNDER DIFFERENT COLUMN REMOVAL SCENARIO

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 - *Hurricanes, earthquakes, and terrorist attacks on infrastructure are all natural catastrophes that cause substantial human and economic devastation. The collapse of structural components due to blast, impact, wind pressures, and earthquakes is a highly dynamic phenomenon. The structure of the building is subjected to anomalous loading as a result of this type of incident. Building members are typically unable to sustain this type of anomalous loading and fail as a result. One of the failure processes that occurs during such an occurrence is known as "Progressive Collapse. Progressive collapse of building structures happens when one or more vertical load-bearing elements, typically columns, are badly damaged or collapse during any abnormal occurrence. The goal of this study is to see if a symmetrical reinforced concrete building designed for seismic stress has the ability to collapse gradually. If a building is at high danger of progressive collapse, it is vital to lessen its vulnerability to progressive collapse. This study looks into three different solutions for reducing the risk of progressive collapse."*

Key Words: GSA Guidelines, UFC (DoD) guidelines, Alternate path Method, Progressive Collapse, Damage to capacity Ratio(DCR), Pushover Analysis, ETABS 17.

1. INTRODUCTION

Experts in structural engineering are becoming increasingly concerned about the building's inevitable collapse. Following the fall of the World Trade Center (WTC) Tower, a number of government and commercial agencies collaborated to develop design suggestions for progressive collapse resistant structures. The most often used rules among structural engineers are those of the US General Service Administration (GSA) and the Department of Defense (DoD). Several considerations to consider when performing progressive collapse analysis in accordance with these criteria are discussed in this study.

These guidelines suggest three analytical techniques: 1) Alternate load path method, 2) Tie force method, and 3) Local resistance method. Four analytical methodologies are advised to estimate the risk of progressive collapse: linear static, linear dynamic, nonlinear static, and nonlinear dynamic. A comparison of many guidelines is also included.

Following US General Service Administration (GSA) and Department of Defense (DoD) requirements, the progressive collapse potential of seismically constructed buildings is assessed.

Linear static and dynamic analysis utilising the structural analysis tool ETABS 17 and the alternate load path technique are used to obtain the Demand Capacity Ratio (DCR). The DCR derived using linear static analysis is compared to the DCR calculated using linear dynamic analysis at various floors.

To better understand the nonlinear behaviour of building structures, nonlinear static and dynamic analyses are performed. The hinge pattern is created using nonlinear static analysis. The DCR obtained by linear static analysis is compared to the hinge formation pattern acquired from nonlinear static analysis.

2. OBJECTIVE OF STUDY

The objective of this study is to understand the analysis and design of framed building structure to reduce the potential of progressive collapse.

The key objectives of study are as follows:

- To study the various causes and types of progressive collapse.
- To study and compare the various guidelines for progressive collapse analysis.
- To study the various analysis approaches for evaluation of potential of progressive collapse of symmetrical building by considering various guidelines.
- To study the mitigation measures of progressive collapse and various techniques to improve the capacity of building to resist progressive collapse

3. METHODOLOGY:

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)

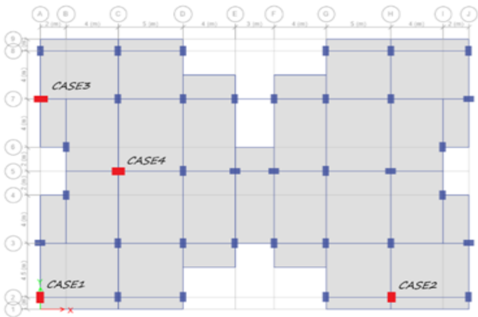


Figure 1: Plan of the G+12-storey Building

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.

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

iii) NonLinear Static Analysis

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). The hinge properties are calculated by the program for the cross section and reinforcement details provided.

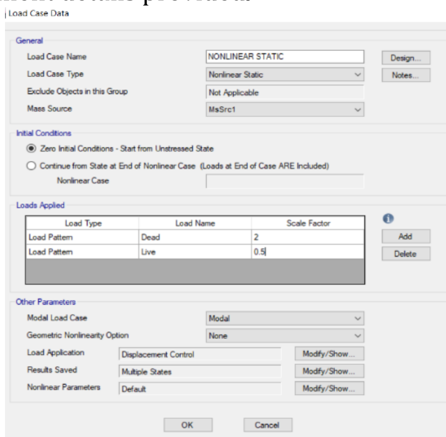


Figure 2 : Nonlinear Static Case definition in ETABS 17

iv) Acceptance criteria

The magnitudes and distribution of possible demands on both the major and secondary structural elements must be determined using the findings of the linear elastic analysis in order to assess the potential collapse reaction. Demand Capacity Ratios will show the magnitude and distribution of these demands (DCR).

$$DCR = \frac{Q_{UD}}{Q_{UC}}$$

Where,
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
Q_{UD} = Acting force (demand) determined in member or connection (moment, axial force, shear, and possible combined forces)
Q_{CE} = Expected ultimate, un-factored capacity of the member and connection (moment, axial force, shear and possible combined forces)

Structural components and connections with DCR values that exceed the following allowed values are deemed badly damaged or collapsed, according to the DCR criteria of the linear elastic method.
The following are the DCR values that are permissible for primary and secondary structural elements:

- DCR < 2.0 for symmetrical structural configurations
- DCR < 1.5 for Asymmetrical structural configurations

4. RESULT AND DISCUSSION :

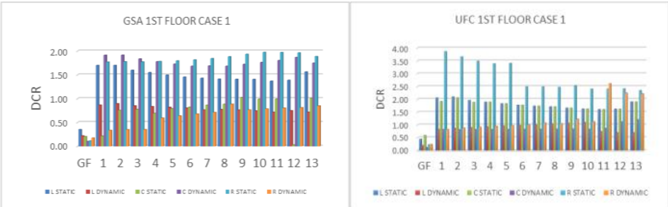


Figure 3: DCR for flexure for column removal at 1st storey case 1

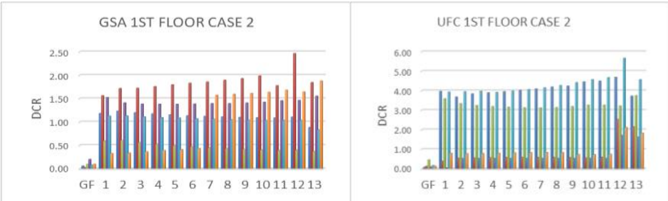


Figure 4: DCR for flexure for column removal at 1st storey case 2

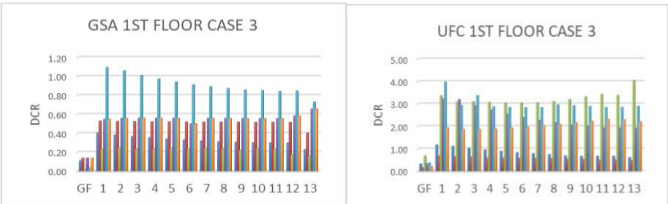


Figure 5: DCR for flexure for column removal at 1st storey case 3

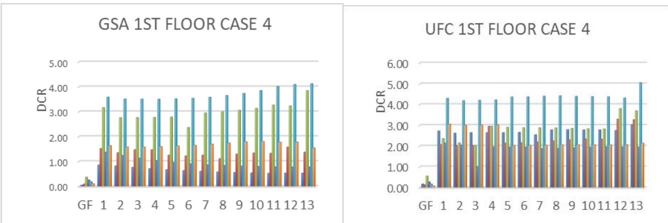


Figure 6: DCR for flexure for column removal at 1st storey case 4

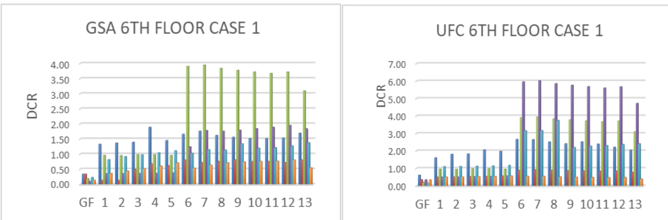


Figure 7: DCR for flexure for column removal at 6th storey case 1

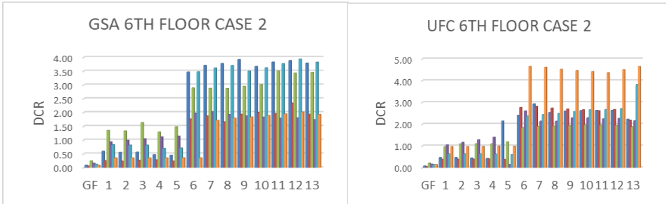


Figure 8: DCR for flexure for column removal at 6th storey case 2

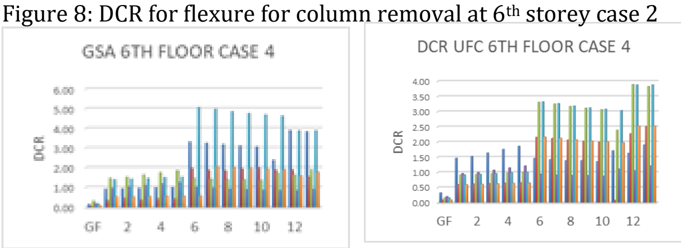


Figure 9: DCR for flexure for column removal at 6th storey case 3

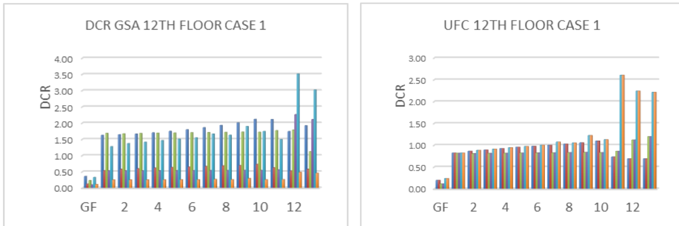


Figure 10: DCR for flexure for column removal at 6th storey case 4

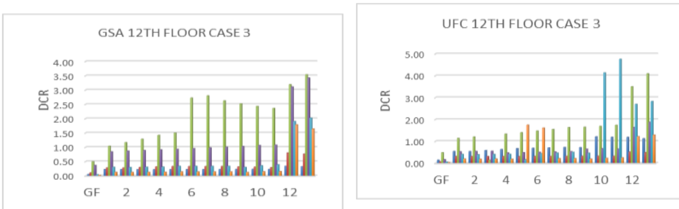


Figure 11: DCR for flexure for column removal at 12th storey case 1

Figure 12: DCR for flexure for column removal at 12th storey case 2

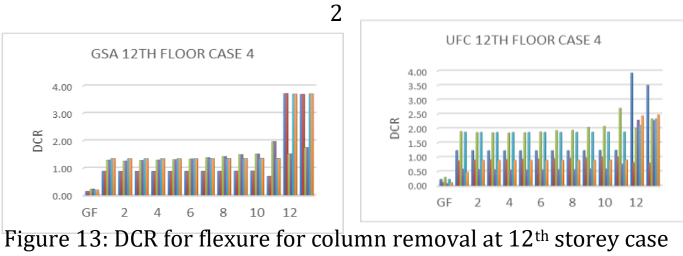


Figure 13: DCR for flexure for column removal at 12th storey case 3

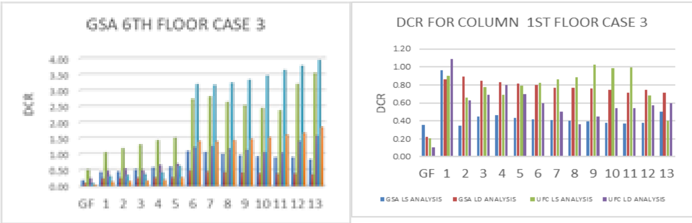


Figure 14: DCR for flexure for column removal at 12th storey case 4

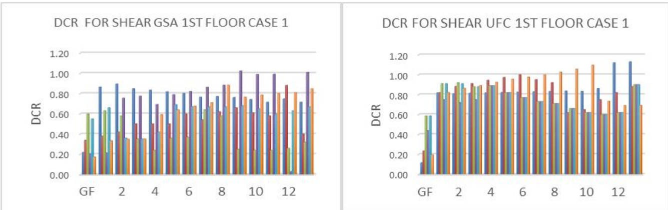


Figure 15 : DCR for shear for column removal at 1st storey case 1

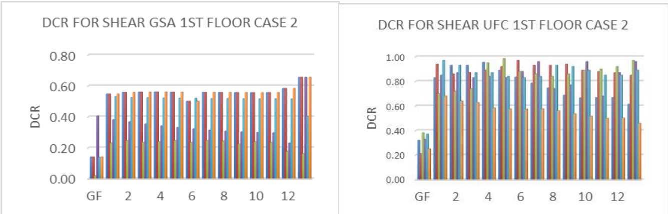


Figure 16 : DCR for shear for column removal at 1st storey case 2

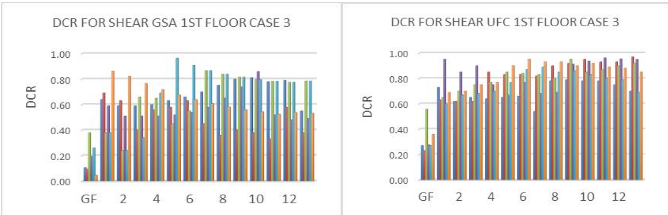


Figure 17 : DCR for shear for column removal at 1st storey case 3

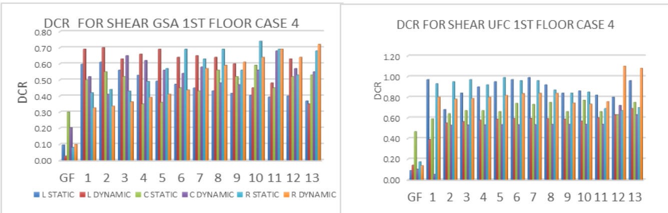


Figure 18 : DCR for shear for column removal at 1st storey case 4

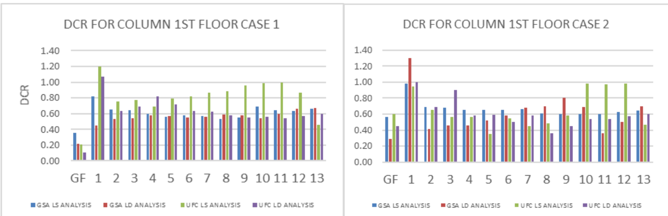


Figure 19 : DCR for column fo column removal at 1st storey case 1&2

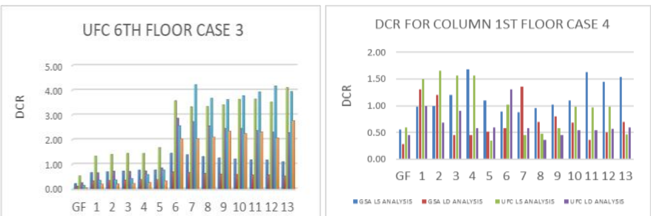


Figure 20 : DCR for column fo column removal at 1st storey case 3&4

Figures 3 to 14 show the DCR for flexure in each of the four column removal instances. The DCR in flexure in beam exceeds the allowable limit of 2 in all storeys of the building for both GSA and UFC Load cases, according to the results. In comparison to DCR calculated using GSA rules, DCR calculated using UFC criteria has greater values. For beams by line, DCR is calculated in flexure. While linear dynamic analysis yields greater DCR values for the uppermost six levels. For all cases, the DCR derived by linear static analysis is higher toward the centre.

According to the research, case 4 of column removal had the most negative impact on the building structure among the five cases studied. As a result, for Case 4, DCR is determined by deleting columns at the intermediate and top storey levels, as specified by UFC rules. When a column is removed from the intermediate and top storey levels, the DCR values are shown in Figures 7 to 14. DCR is calculated by deleting columns from the 6th and 12th storeys. DCR exceeds the allowable maximum of 2 for those beams above the column removal point when a column is removed from the 6th storey level. DCR exceeds the permitted limits for beams positioned above the 6th storey level when a column is removed from the 6th storey level. In this situation, the DCR for beams below the 6th floor level does not exceed the allowed limit. Only at the top storey level does DCR exceed the allowed limit when a column is removed.

Following GSA and UFC requirements, DCR for shear for beam is computed at the left, centre, and right side of column removal position. Figures 15 to 18 show the DCR for shear for each of the four column removal situations. DCR for shear is within allowed limits for both GSA and UFC loadings, according to the data.

The Demand Capacity Ratio (DCR) is calculated for one neighbouring column that is subjected to maximum redistributed forces in each of the four situations. When the UFC linear static analysis load case is analysed, the DCR for column has the highest value at the first 3-4 storeys. DCR exceeds the legal maximum at the first 3-4 storey levels, however it is within the allowable limit at the top storey levels. At higher stories, dynamic analysis produces a greater DCR value for the column than static analysis. When compared to GSA criterion, the DCR produced by UFC criteria is greater. When a column is removed from the intermediate and top storey levels, only the uppermost storey's DCR value exceeds the permitted limit.

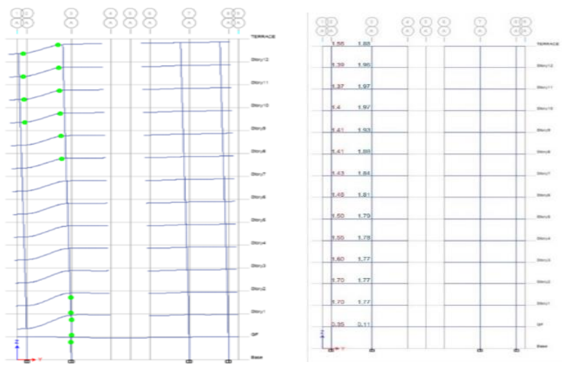


Figure 21: Comparison of DCR by LS Analysis & hinge formation pattern For column removal point At 1st Floor for Case 1&2

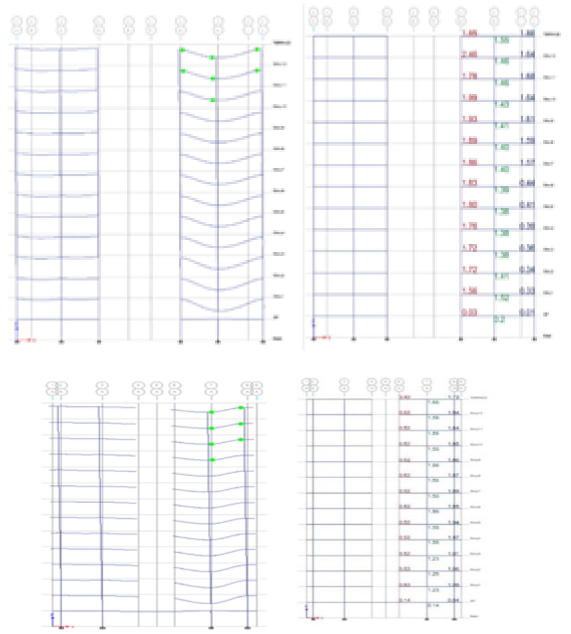


Figure 22: Comparison of DCR by LS Analysis & hinge formation pattern for column removal point At 1st Floor for Case3& 4

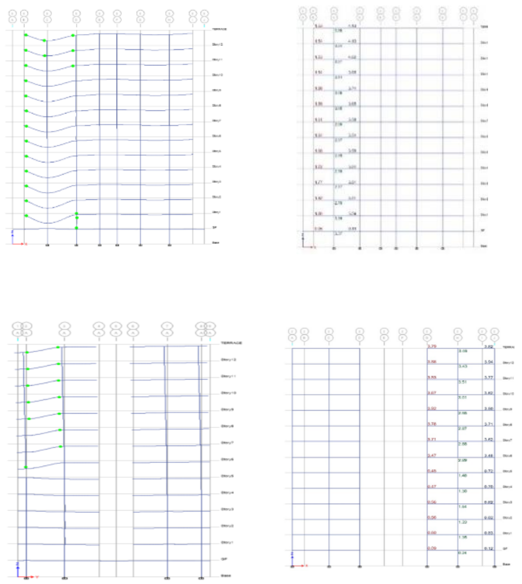


Figure 23: Comparison of DCR by LS Analysis & hinge formation pattern for column removal point At 6th Floor for Case1&2

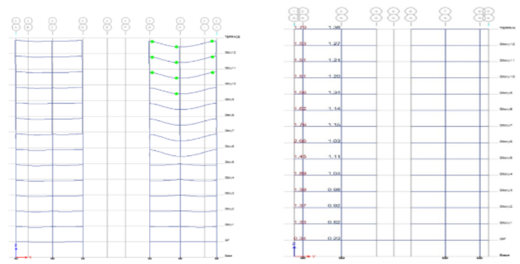


Figure 24: Comparison of DCR by LS Analysis & hinge formation pattern for column removal point At 6th Floor for Case3&4

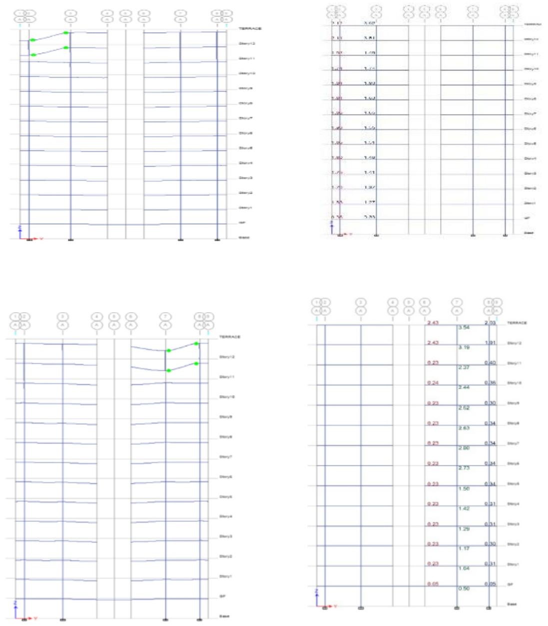
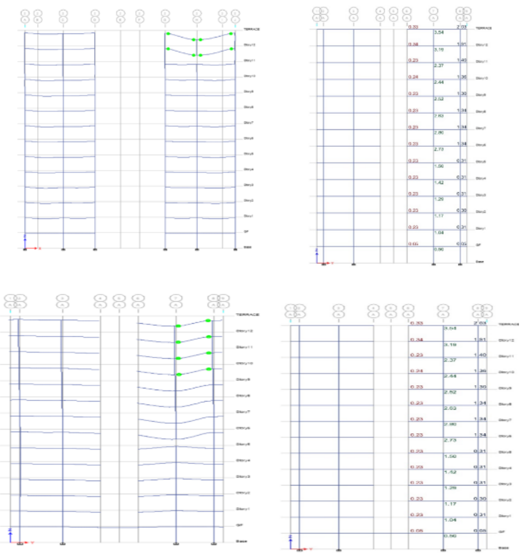


Figure 25: Comparison of DCR by LS Analysis & hinge formation pattern for column removal point At 12th Floor for Case1&2



International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 08 | Aug 2021 www.irjet.net p-ISSN: 2395-0072

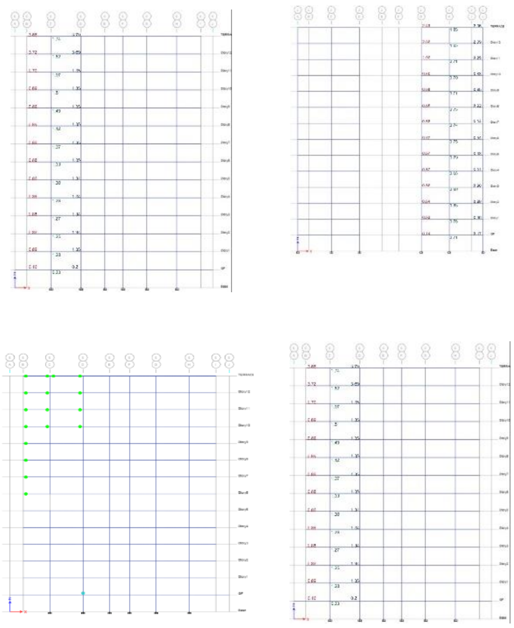


Figure 26: Comparison of DCR by LS Analysis & hinge formation pattern for column removal point At 12th Floor for Case3&4

Nonlinear static analysis. After the analysis, the hinge formation pattern for various displacement levels in the structure intended for seismic loading is noticed for all four cases of column removal in the building. The DCR produced from linear static analysis is compared to the hinge formation. Figures 21 to 26 depict the creation of hinges at various displacement levels. It has been discovered that the hinge forms at the point when the demand capacity ratio is highest. In the following stage, portions with greater demand capacity ratio values demonstrate hinge creation.

4. MITIGATION OF PROGRESSIVE COLLAPSE:

To lessen the risk of progressive collapse in symmetric reinforced concrete buildings with G+12 stories, three distinct techniques are applied. The three alternatives are as follows:
Install bracing at the top of the storey as an alternative.
Alternative 2: At all storey levels, increase the size of frame members by a considerable amount.
Alternative 3: A major increase in the size of frame members at the bottom six storey level for a G+12-story building.

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

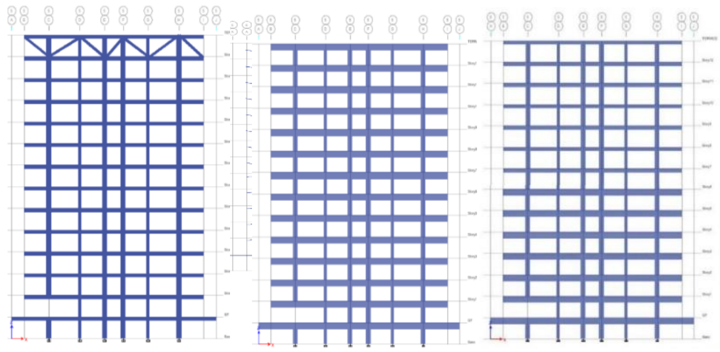


Figure 27 : Various mitigation alternatives symtems for RC building

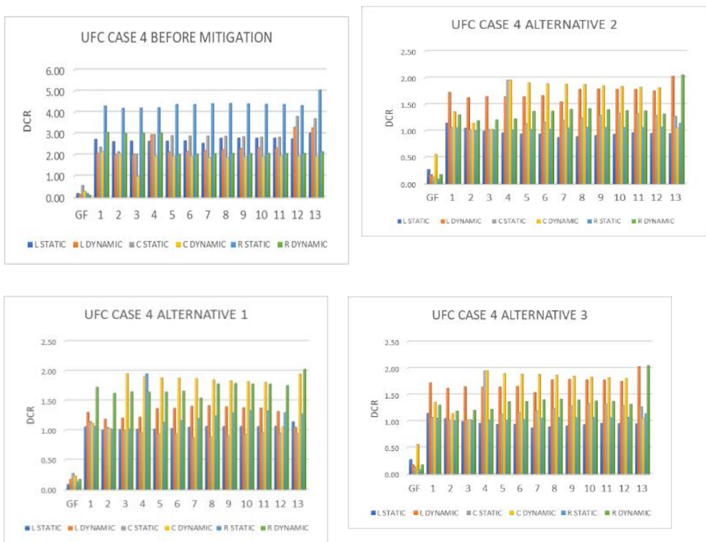
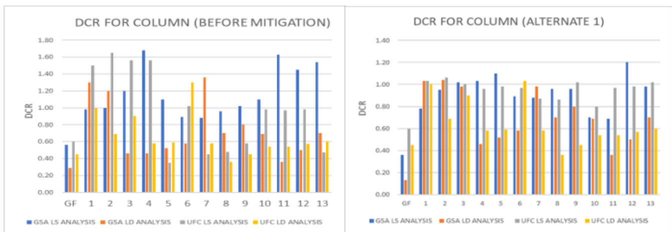


Figure 28: DCR for flexure before and after mitigation



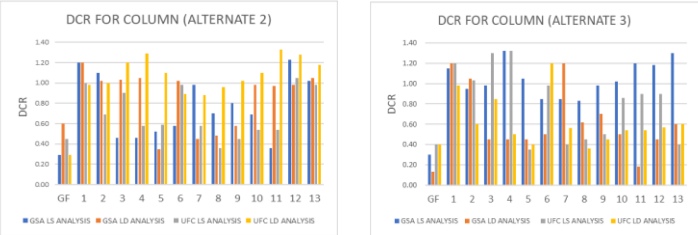


Figure 29 : DCR for Column for case 4 of G+12-storey building before and after mitigation

In accordance with US General Services Administration (GSA) and Department of Defense (DoD) standards, a linear static and dynamic analysis is performed for a G+12-story symmetric reinforced concrete building. DCR is calculated at critical points for four different column removal situations using the member loss scenario. Under the UFC static analysis load scenario 2(1.2DL + 0.5LL), case 4 of column removal had the worst effect on the building structure of all four cases. As a result, following the UFC static load example, the mitigation approach conclusion for case 4 of column removal is provided.
For all three mitigation approaches, DCR for the beam in flexure and column is determined at a crucial point and compared to DCR acquired before to mitigation at the same position. DCR is dropped within acceptable limits for all three mitigating methods for G+12-story buildings, according to the data presented.

5. CONCLUSIONS:

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

1) For both linear static and dynamic analyses for both load cases, DCR for flexure exceeds the permissible limit of 2 in the event of a beam exceeding the allowable limit of 2.
   a) For all four column removal cases, the DCR produced by the Department of Defense (DoD) Unified Facilities Criteria (UFC) has greater values than those obtained by the US General Service Administration (GSA) standards.
   b) For case 2 and case 3 of column removal alone, linear static analysis dictated the value of DCR at the left and right sides of the column removal location. Linear static analysis regulates the value of DCR at the left and right sides of the column removal location up to the lowest five floors only in other situations of column removal. The linear dynamic analysis shows a larger value of DCR than the linear static analysis in the middle and upper five floors on the left and right side of the column removal point.

2) DCR in beam for flexure exceeds the allowed limit of 2 only in those beams located above the column removal level when column is removed from intermediate storey level and top storey level.
   a) When a column is removed from a 6th storey level in a G+12-story structure, the DCR for beams situated above that level exceeds the allowed limit 2. As a result, beams at lower floor levels are safe in this situation. If such beams break, it will be owing to the impact pressures of falling debris

3) In the event of shear, DCR exceeds the allowed limit of 1.0 in the UFC load case, indicating that beams are acceptable in shear according to GSA rules but fail if UFC criteria.
   a) For the left and right sides of the column removal position, linear static analysis rules the value of DCR as opposed to linear dynamic analysis, whereas for the centre point of the column removal position, linear dynamic analysis governs the value of DCR in most circumstances.

4) In most situations, the DCR for a column exceeds the allowed limit of 1.0 at the lowest four to five storeys and at the top storey.

   a) For a linear dynamic analysis, the column values of DCR are greater than for a linear static analysis.
   b) The DCR achieved by UFC loading is greater than the DCR obtained through GSA loading.
   c) DCR values produced using UFC criteria are greater than those obtained using GSA criteria.

5) When a column is removed from the intermediate and top storey levels, the DCR value exceeds the allowed limit of 1.0 only at the uppermost floor.
6) 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.
   a) In linear static analysis, displacements under the column removal point are predicted to be 5-10% higher than in linear dynamic analysis.

7) Of the four situations of column removal indicated by the recommendations, case 4 has the most negative impact on the building structure.
8) 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. 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.