International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 08 | August 2022 www.irjet.net p-ISSN: 2395-0072

# Analysis and study of progressive collapse behaviour of reinforced concrete structure with outrigger beams

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**Abstract -** *Progressive collapse of a building or structure can be defined as the spread of a primary local structural element failure that ultimately causes the collapse of the whole structure or a significant component of it. In order to reduce the potential for collapse associated with the loss of primary structural member such as perimeter column, outrigger systems can be used. Outriggers are horizontal structural systems inserted into the building to connect the core structure to the exterior structural elements. In this paper, A typical reinforced concrete framed building of 20 storey is modelled in ETABS. This is a rectangular RC building containing 6 bays in X-direction and 8 bays in Y-direction each of 6m in both directions. In addition, the structure consists of a core and outrigger beams. The analysis is done using linear static analysis method. This study considers two different cases of column removal as specified by GSA guidelines. The percentage variations of axial force in critically affected columns and demand capacity ratios of critically affected beams are calculated. The results of the structure with outrigger beams are compared to structure without outrigger beams.*

***Key Words*: Progressive collapse, Outrigger beams, General Services Administration (GSA), Linear static analysis, Alternate load path, Axial force variations, Demand Capacity Ratio (DCR).**

## 1. INTRODUCTION

Progressive collapse of a structure takes place when a particular structural member fails leading to the failure of neighboring structural members in a progressive way. Initially, the primary structural member fails, which causes the failure of adjacent structural members, resulting in the structural collapse. Progressive collapse may be caused due to mishaps such as gas explosions, bomb attacks, fire; actions of overload, material failure, or natural phenomena. The ability to transfer loads from the collapsed columns to columns that are properly designed and properly attached to the foundation can be achieved to mitigate this failure by means of outriggers. Outriggers are interior lateral structural members equipped to increase strength and enhance the overturning stiffness of high-rise buildings. The entire system includes a central core structure linked to the outer columns of the structure with the help of structural members termed as outriggers. The outriggers may be equipped as walls, trusses, or horizontal beams. The core system and perimeter columns together with the outriggers regulate the performance of the entire building. Reference [3] uses DCR values to investigate the progressive collapse resisting ability of the structure. Reference [2] discusses how outrigger systems may mitigate toppling and disproportionate collapse of building structures and concludes that redistribution of gravity forces results in reducing the axial compressive stress, compared to the system without outriggers. Reference [4] shows that the use of outrigger and built system adds to different load paths to the building that contributes to its resistance to progressive collapse.

## 2. GSA GUIDELINES

The U.S. General Services Administration (GSA) established the "Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects" to make sure that the possibility of progressive collapse is addressed in the design, planning and construction of new buildings and major renovation projects.

### 2.1 Analysis techniques

The methods for progressive collapse analysis include linear static analysis, nonlinear static analysis, linear dynamic analysis and nonlinear dynamic analysis. A Linear Procedure is a simplistic analysis approach, and suggests the usage of either a static or dynamic linear elastic finite element analysis. A Nonlinear Procedure is a more sophisticated analysis approach, and implies the use of either static or dynamic elasto-plastic finite element analysis methods that capture both material and geometric nonlinearity.

1) Linear Static Analysis Method

Linear Static Analysis method is the most basic and easiest method for progressive collapse analysis in which one of the most important structural components are detached statically.

Steps to perform the analysis:

1. Build a 3D model in ETABS.
2. Assign the necessary material properties, section properties, loads, load combinations as per GSA guidelines.

3. Remove the column at the location specified in GSA guidelines separately for each considered case.
4. Perform the linear static analysis for the specified static load combination.
5. Calculate the Demand Capacity Ratio (DCR) for the critically affected adjoining structural members.

2) Nonlinear Static Analysis Method

Nonlinear static analysis also known as pushover analysis is used to evaluate the deflection capability and ultimate load of a structure. Until higher load or higher displacement is attained, nonlinear static analysis increases practical loads step by step while allowing structural components to undergo nonlinear performance.

It is recommended that the following downward loads be applied when assessing the possibility for progressive collapse as presented in the GSA Guideline.

Static Analysis Loading

For static analysis purposes the following vertical load shall be applied downward to the structure under consideration:

$$\text{Load} = 2(DL + 0.25L) \qquad (1)$$

Where,

DL is Dead Load, LL is Live Load, 2 is dynamic factor

3) Linear Dynamic Analysis Method

Linear dynamic analysis is also known as time history analysis. This method involves real-time elimination of one of the most important bearing structural members resulting in real-time linear elastic motions.

4) Nonlinear Dynamic Analysis Method

Stepwise collapse analysis using the nonlinear dynamic analysis approach is particularly precise and effective. It involves removal of the vertical bearing structure which affects the material by nonlinear behavior.

It is recommended that the following downward loads be applied when assessing the possibility for progressive collapse as presented in the GSA Guideline.

Dynamic Analysis Loading

For dynamic analysis purposes the following vertical load shall be applied downward to the structure under consideration:

$$\text{Load} = DL + 0.25L \qquad (2)$$

Where,

DL is Dead Load, LL is Live Load

## 2.2 Vertical Element Removal as per GSA

1) Exterior Considerations

a. Analyse for the sudden loss of a column for one floor above grade (1 story) located at or near the middle of the short side of the structure.
b. Analyse for the sudden loss of a column for one floor above grade (1 story) located at or near the middle of the long side of the structure.
c. Analyse for the sudden loss of a column for one floor above grade (1 story) located at the corner of the structure.

2) Interior Considerations

a. Analyse for the sudden loss of 1 column that extends from the floor of the underground parking area or uncontrolled public ground floor area to the next floor (1 story). The column considered should be interior to the perimeter column lines.

## 3. PROBLEM DESCRIPTION

A typical reinforced concrete framed building of 20 storey is modelled in ETABS. This is a rectangular RC building containing 6 bays, each of 6m in X-direction and 8 bays, each of 6m in Y-direction. The typical storey height is 3m and the base supports are fixed. In addition, the structure consists of a core and outrigger beams. The outrigger beams extend from the core to perimeter columns in horizontal grids 4 & 6 and vertical grids C & E as shown in the figure. Connection is formed between perimeter columns by means of outrigger perimeter beams.

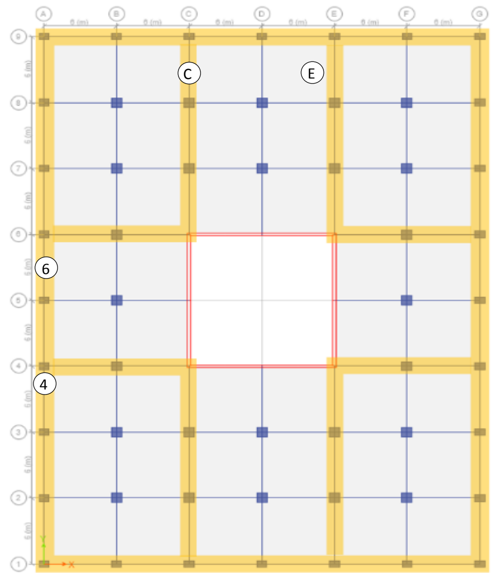


**Fig -1**: Plan view (outrigger beams highlighted)

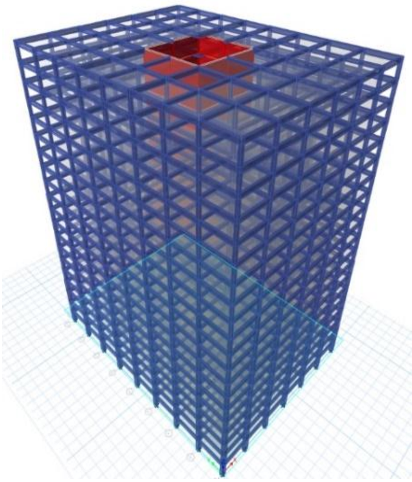

**Fig -2**: 3D view

The analysis is done using linear static analysis method. The design of structural members is done as per IS 456:2000.

Details of the building structure are given below:

1) Material Properties

Characteristic compressive strength of concrete ($f_{ck}$): 30 N/mm²
Yield Strength of reinforcing steel ($f_y$): 500 N/mm²

2) Section Properties

Beam size: 300x500mm
Outrigger beam size: 300x750mm
Slab thickness: 150mm
Shear wall thickness: 250mm
Wall thickness: Exterior walls 230mm
Interior walls 150mm
Interior Columns sizes:

850x850 (Base floor)

800x800 (2nd to 4th floor)

600x800 (5th to 9th floor)

600x600 (10th to 14th floor)

450x600 (15th to 20th floor)

Exterior Column sizes

600x800 (Base to 4th floor)

600x600 (5th to 9th floor)

450x600 (10th to 14th floor)

450x450 (15th to 20th floor)

3) Loads

Dead load: Self weight of the structure
Live load: 2 kN/m²
Floor finish: 1.5 kN/m²
Wall load: Exterior wall= 13.8 kN/m
Interior wall= 9 kN/m

4) Load Combinations

The combination of load taken into account is

Load = 2(DL+0.25LL)

Where, DL is Dead Load, LL is Live Load, 2 is dynamic factor

5) Demand Capacity Ratio (DCR)

Demand Capacity Ratio is the ratio between structural member force after removal of column to the member's ultimate strength or capacity of the member.

DCR = Mu/Mulimit

Mu = demanding or acting force in member or connection.

Mulimit = Unfactored capacity of the member or expected ultimate strength of member.

DCR acceptance criteria are as follows,

Demand Capacity Ratio <2.0 for regular structures.

Demand Capacity Ratio<1.5 for irregular structures.

Demand Capacity Ratio<3.0 for steel structures.

Calculation of Mulimit to determine DCR for the structural members are given below.

DCR= Mu/Mulimit

Outrigger beam:

Breadth, b = 300 mm, Depth, D = 750 mm

Cover, d’ = 60 mm

Effective depth, = D- d' =750-60 =690 mm

fck = 30 N/mm², fy = 500 N/mm²

Calculation of ultimate moment:

Mulimit = 0.133*fck*b*d*d

= 0.133*30*300*690*690

= 569.81 kN-m

Beam:

Breadth, b = 300 mm, Depth, D = 500 mm

Cover, d' = 30 mm

Effective depth, = D- d' =500-30 =470 mm

fck = 30 N/mm$^2$, fy = 500 N/mm$^2$

Calculation of ultimate moment:

Mulimit = 0.133*fck*b*d*d

= 0.133*30*300*470*470

= 264.42 kN-m

## 4. ANALYSIS AND RESULT

Reinforced concrete building is modelled in ETABS and is analyzed using linear static analysis method. Progressive collapse potential of a building is analyzed for two different cases of column removal.

### 4.1 Load Paths

Case 1: Exterior column (C18) situated at the middle of the short side of the structure at storey 1

When Column C18 is removed at storey 1, most critically affected columns are: Columns: C46, C48, C15

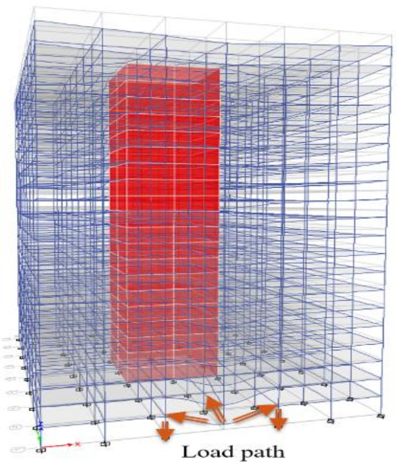


**Fig -3**: Load path distribution when exterior column situated at middle of short side of the structure is removed.

Case 2: Exterior column (C36) situated at the corner of the structure at storey 1

When Column C36 is removed at storey 1, most critically affected columns are: Columns: C37, C45

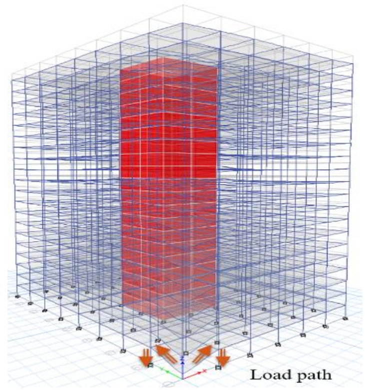


**Fig -4**: Load path distribution when exterior column situated at corner of the structure is removed.

### 4.2 Demand Capacity Ratios

Case 1: Exterior column (C18) situated at the middle of the short side of the structure.

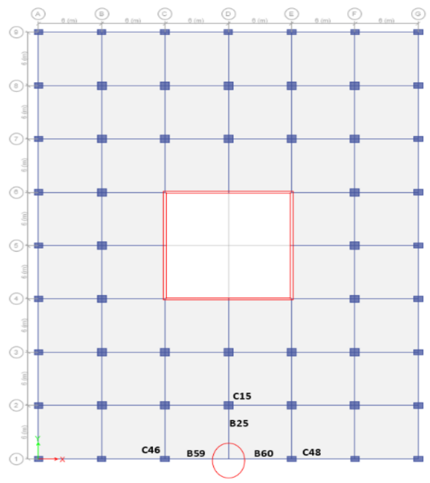


**Fig -5**: Case 1: Exterior column (C18) situated at the middle of the short side of the structure

When Column C18 is removed at story 1, most critically affected beams are: Beams: B59, B60, B25

Variations in DCR values for the beams B59 and B60

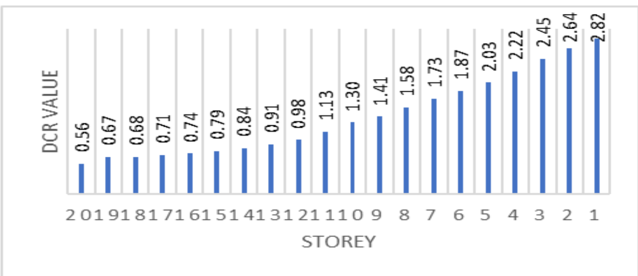


**Chart -1**: Demand Capacity Ratio V/S storey of beam B59 & B60

Variations in DCR values for the beam B25

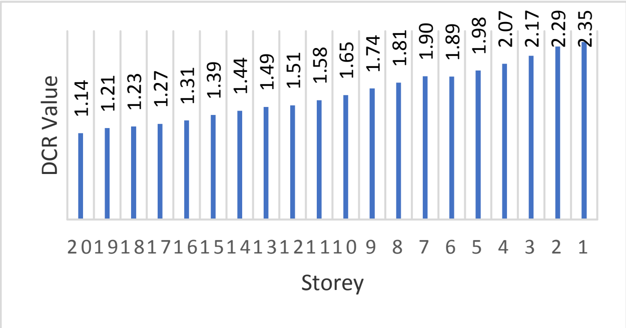


**Chart -2**: Demand Capacity Ratio V/S storey of beam B25

Case 2: Exterior column (C36) situated at the corner of the structure.

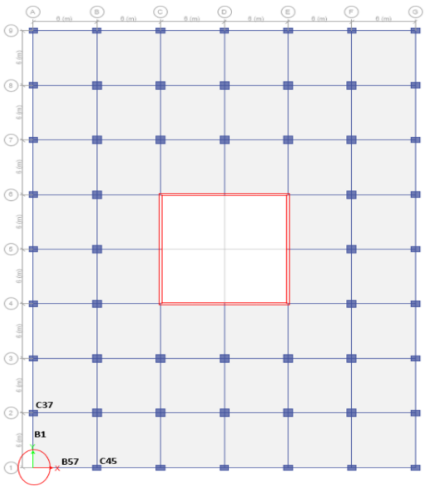


**Fig -6**: Case 2: Exterior column (C36) situated at the corner of the structure

When Column C36 is removed at story 1, most critically affected beams are: Beams: B1, B57

Variations in DCR values for the beam B1

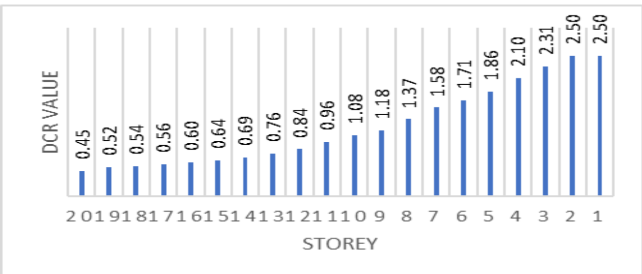


**Chart -3**: Demand Capacity Ratio V/S storey of beam B1

Variations in DCR values for the beam B57

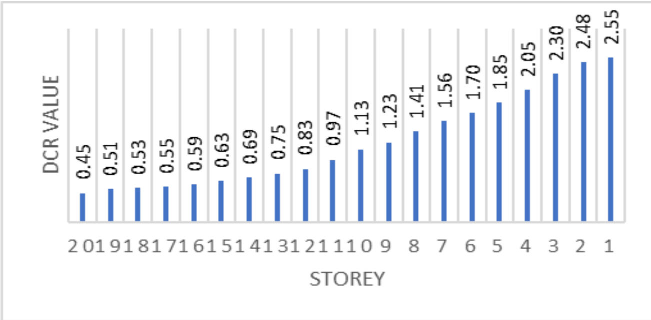


**Chart -4**: Demand Capacity Ratio V/S storey of beam B57

**4.3 Comparison of DCR between structures with and without outrigger beams.**

Case 1: Exterior column located at the middle of the short side of the building:

Variations in DCR values for the beams B59 and B60

Structure with outrigger beams

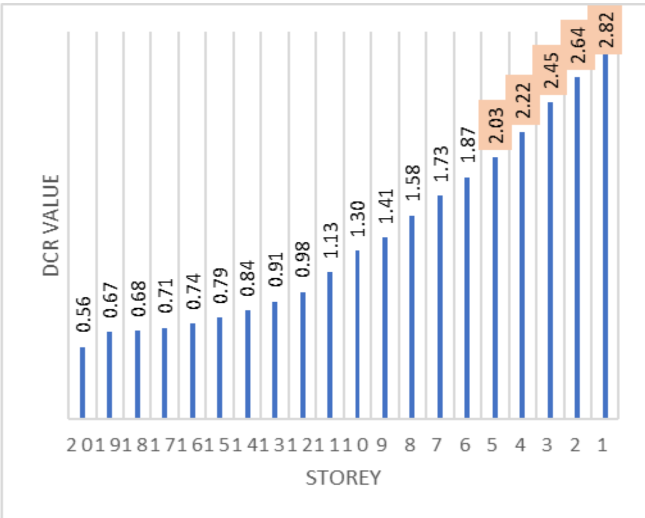


**Chart -5**: Demand Capacity Ratio V/S storey of beam B59 & B60

Variations in DCR values for the beams B25

Structure without outrigger beams

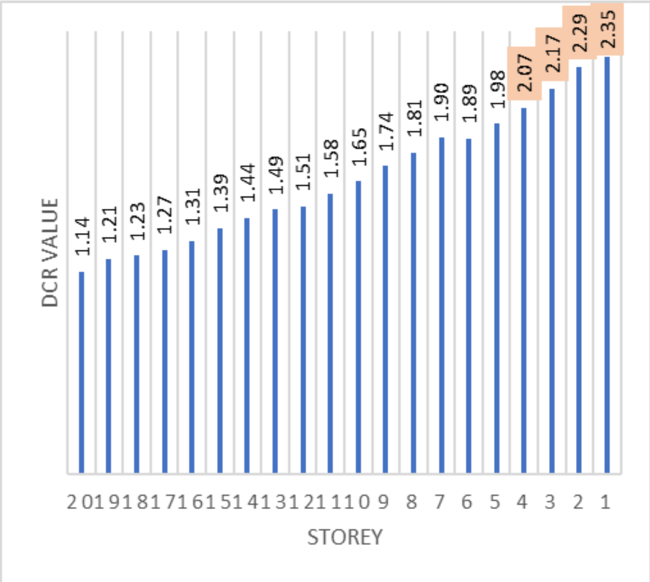


**Chart -7**: Demand Capacity Ratio V/S storey of beam B25

Variations in DCR values for the beams B59 and B60

Structure without outrigger beams

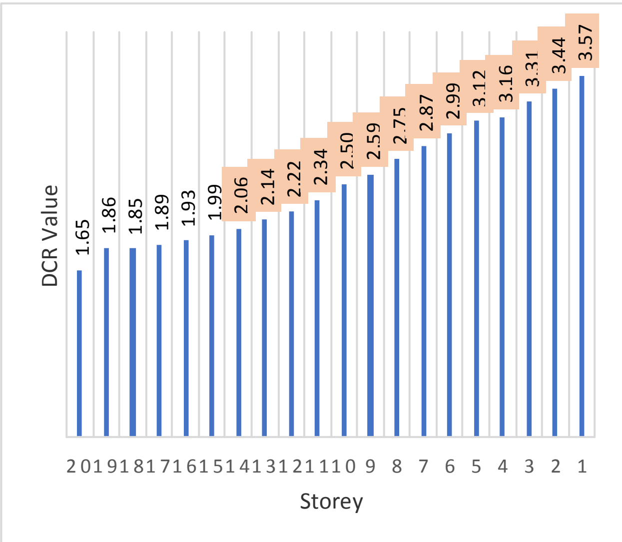


**Chart -6**: Demand Capacity Ratio V/S storey of beam B59 & B60

Variations in DCR values for the beams B25

Structure without outrigger beams

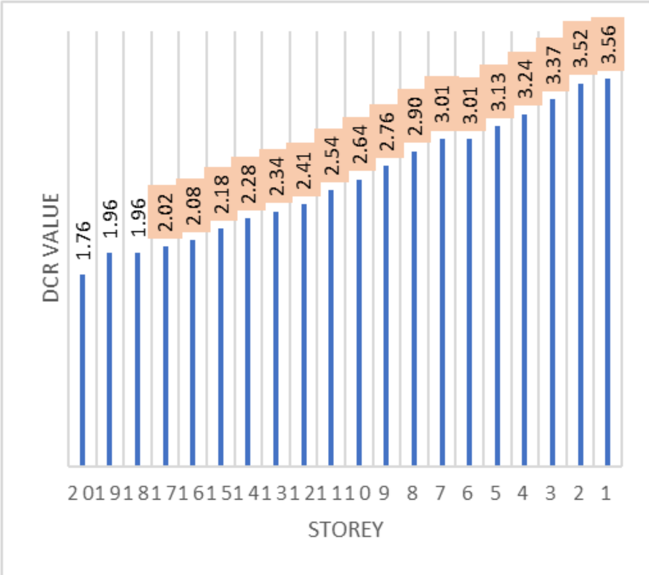


**Chart -8**: Demand Capacity Ratio V/S storey of beam B25

Case 2: Exterior column located at the corner of the building:

Variations in DCR values for the beams Beam B1

Structure with outrigger beams

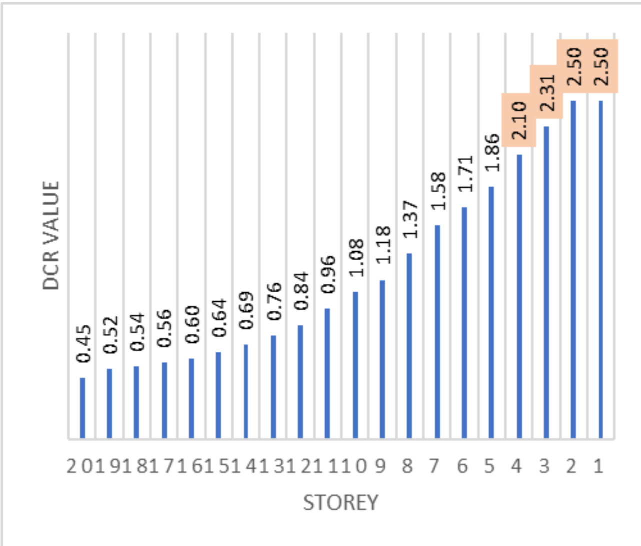


**Chart -9**: Demand Capacity Ratio V/S storey of beam B1

Variations in DCR values for the beams Beam B57

Structure with outrigger beams

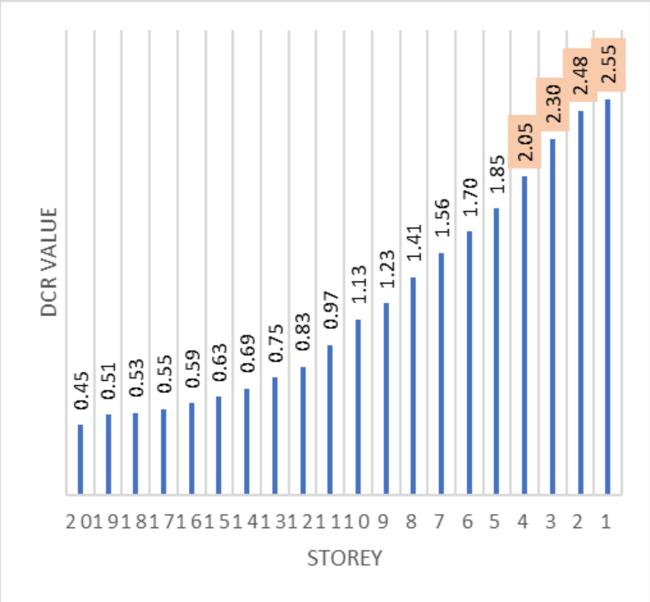


**Chart -11**: Demand Capacity Ratio V/S storey of beam B57

Variations in DCR values for the beams Beam B1

Structure without outrigger beams

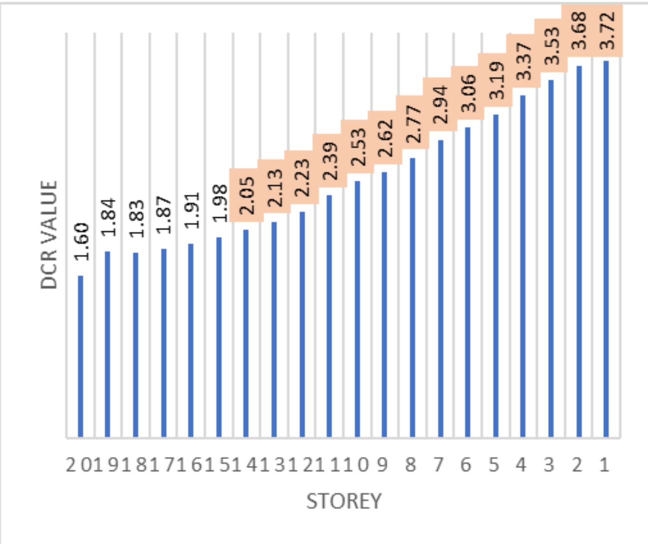


**Chart -10**: Demand Capacity Ratio V/S storey of beam B1

Variations in DCR values for the beams Beam B57

Structure without outrigger beams

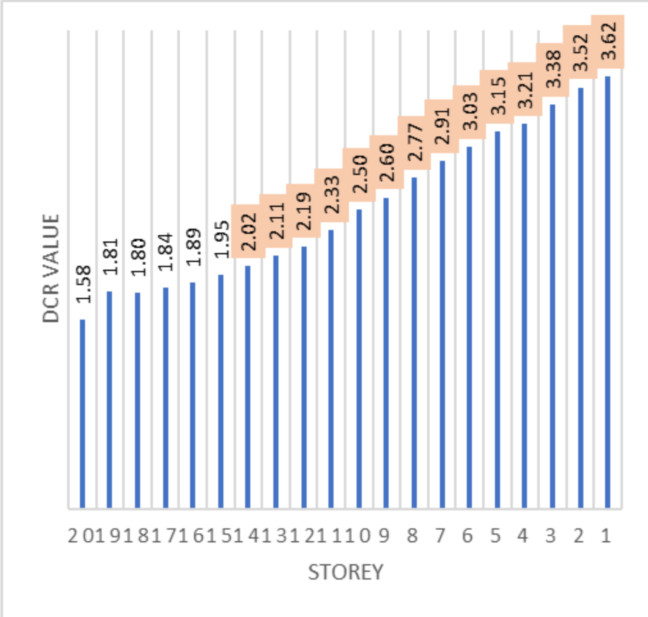


**Chart -12**: Demand Capacity Ratio V/S storey of beam B57

## 5. CONCLUSIONS

1. Case 1: Exterior column situated at the middle of the short side of the structure.

    i. Column removal at storey 1 has led to the failure of adjacent beams B59 & B60 from storeys 1 to 5 and failure of beam B25 from storeys 1 to 4 in case of structure with outrigger beams whereas in case of structure without outrigger beams, failure of adjacent beams B59 & B60 is from storeys 1 to 14 and failure of beam B25 from 1 to 17.

    ii. Axial forces before and after column removal are compared for adjoining columns C46 & C48 and the percentage increase is found to be 33.12% at storey 1 and 6.47% at storey 20 after column removal.

    iii. Axial forces before and after column removal are compared for adjoining column C15 and the percentage increase is found to be 9.8% at storey 1 and 3.87% at storey 20 after column removal.

    iv. In this case, when column is removed the length of beams in that bay is doubled on either sides and hogging bending moment is increased in tension zone resulting in increasing positive reinforcement.

2. Case 2: Exterior column situated at the corner of the structure.

    i. Column removal at storey 1 has led to the failure of adjacent beams B1 & B57 from storeys 1 to 4 in case of structure with outrigger beams whereas in case of structure without outrigger beams, failure of adjacent beams B1 & B57 is from storeys 1 to 14.

    ii. Axial forces before and after column removal are compared for adjoining column C37 and the percentage increase is found to be 34.5% at storey 1 and 6.47% at storey 20 after column removal.

    iii. Axial forces before and after column removal are compared for adjoining column C45 and the percentage increase is found to be 35.16% at storey 1 and 6.12% at storey 20 after column removal.

    iv. The beam members in both directions at the junction where column is removed acts as an overhanging cantilever beam where load is transferred to adjacent structural members.

3. According to GSA the beams whose DCR values are more than acceptance criteria i.e., 2, then the failure of beams and columns will occur and is unsafe. If the DCR values are less than 2, it suggests that beams and columns are safe as per GSA.

4. When a column is removed, the column above this column becomes a floating column and the moments & axial forces are transferred to adjacent beams and columns for the above storeys.

5. It is observed that the axial forces and bending moments are increased in load carrying elements adjacent to removed column therefore to overcome this, sizes of elements should be increased and bracings can be provided.

6. Localized failure is observed up to certain number of storeys and failure at remaining stories is arrested due to the presence of outriggers.

7. It was observed that progressive collapse resisting capacity of structure with outrigger beams is higher compared to structure without outrigger beams.

8. It is seen that use of outrigger beams provides an alternate load path to the structure to compensate the immediate loss of column, this contributes to its resistance to progressive collapse and provides time for remedial measures.

## ACKNOWLEDGEMENT

I would like to thank K.L.S. Gogte Institute of Technology, Belagavi, Karnataka for providing all the required facilities and special thanks to faculty for guidance. I would also like to thank all the referees cited in this paper.

## REFERENCES

[1] General Services Administration (GSA), "Progressive collapse design guidelines for New Federal Office Buildings and Major Modernization Projects June 2003"

[2] Osama Ahmed Mohamed and Omar Najm, "Outrigger Systems to Mitigate Disproportionate Collapse in Building Structures", ELSEVIER, World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium, pp. 839-844, 2016

[3] ZHANG Peng, CHEN Baoxu, "Progressive Collapse Analysis of Reinforced Concrete Frame Structures in Linear Static Analysis Based on GSA", IEEE, Third International Conference on Intelligent System Design and Engineering Applications, pp. 1074-1078, 2012

[4] J. M. Mirhom, H.T. Hafez, K.N. Ibrahim, J.R. Shaker, M. Abdel-Mooty, "Progressive collapse analysis of a high-rise building considering the effect of an outrigger belt lateral load resisting system", WIT Press, Structures Under Shock and Impact XII, pp. 293-302, 2012

[5] Jinkoo Kim, Junhee Park, "Progressive collapse resisting capacity of building structures with outrigger trusses", Wiley, The structural design of tall and special buildings, pp. 566-577, 2010

[6] Huda Helmy, Hamed Salem, Sherif Mourad, "Computer-Aided Assessment of Progressive Collapse of Reinforced Concrete Structures according to GSA Code", ASCE, Journal of performance of constructed facilities, pp. 529-539, 2013

[7] S. M. Marjanishvili, "Progressive Analysis Procedure for Progressive Collapse", ASCE, Journal of performance of constructed facilities, pp. 79-85, 2004

[8] Tae-Sung Eom, Hiubalt Murmu, Weijian Yi, "Behaviour and Design of Distributed Belt Walls as Virtual Outriggers for Concrete High-Rise Buildings", Springer, Int J Concr Struct Mater, pp. 1-13, 2019

[9] Han-Soo Kim, "Optimum Locations of Outriggers in a Concrete Tall Building to Reduce Differential Axial Shortening", Springer, Kim Int J Concr Struct Mater, pp. 1-12, 2018

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