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Assessment of Progressive Collapse Resistance of a Symmetrical Reinforced Concrete Framed Structure

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Abstract: Progressive collapse of buildings is occurs when one or more vertical load carrying members particularly columns are seriously damaged or collapsed during any abnormal event. Once a column is damaged the building's gravity load transfers to the neighbouring members in the structure. If those members are not properly designed to resist and redistribute the additional load received that part of the structure will fails. As a result, a considerable part of the structure may collapse, causing greater damage to the structure than the initial impact. In this study progressive collapse resistance of a 10-storey symmetric concrete framed building is analysed using linear static and nonlinear static analysis methods by following the General Service Administration guidelines. Modelling, analysis and design of the buildings are performed using SAP 2000 software. The results obtained include calculation of demand capacity ratios (DCR), hinge properties and % load taken by the structure. It is observed that building considered for the study is having high potential of progressive collapse since DCR in beams exceeds the allowable limit in all the cases. Bracings are provided at the top storey level as an alternative for reducing the risk of progressive collapse and it emerges out as an effective method for resisting progressive collapse in structures.
Keywords: Progressive Collapse; Demand Capacity Ratio; Linear Static Method; Nonlinear Static Method; Sap2000

I. INTRODUCTION

Progressive collapse can be described as a situation emerges out from the failure of one or more load carrying members following an abnormal loading event. It is one of the most significant types of building failures, most often leading to costly damages, multiple injuries, and possible loss of life. Factors lead to progressive collapse of the structures includes construction errors, miscommunication, poor inspections, or design faults. The local failure occurred in the structure lead to load redistribution in the entire structure and which may results in an overall damage of the structure. Although a number of different definitions of progressive collapse coexist, the concept of disproportionality is general to all of them. Progressive collapse of a structure occurs when loading pattern or boundary conditions of a structure is distorted and some members are loaded beyond their ultimate capacities. Once a column is damaged due to some accidental loading like; fires, vehicle impact and bomb blasting, the building’s weight transfers to the neighbouring members in the structure. During progressive collapse large deformations occur, in which the collapsing system continually search for alternative load paths in order to survive. One unique property of progressive collapse is that the final damage is not proportional to the initial damage.

II. BUILDING CONFIGURATION

The building considered for performing progressive collapse analysis is a ten storey symmetrical reinforced concrete framed building. The structure consists of five bays of 5 m in the longitudinal direction and five bays of 4 m in the transverse direction. Height of base to plinth is taken as 1.5 m, Plinth to ground floor as 3.5 m, which is considered as hollow plinth and height of typical floor as 3 m. Beam size: 300 x 400 mm. Column size: 550 x 550 mm. The columns are assumed to be hinged to the foundations. Slab of thickness 150 mm is provided. Wall having 230 mm thickness is considered on all the beams. M25 grade concrete and Fe415 grade reinforcing bars are used in this building. The structures were modelled using powerful finite element software, SAP 2000 version 18. Fig. 1 shows typical floor plan and three dimensional view of the building.

A. Loading Data

Self weight of structural members

Floor finish on typical floor and roof = 1.5 kN/m^2
Wall load on typical floors = 13.8 kN/m
Parapet wall load on roof = 4.5 kN/m
Live load on typical floors = 3 kN/m^2
Live load on roof =1.5 kN/m^2

B. Seismic Loading Parameters

Seismic Zone = 3
Zone factor = 0.16
Soil Type = Type II
Importance Factor = 1
Response reduction factor = 5

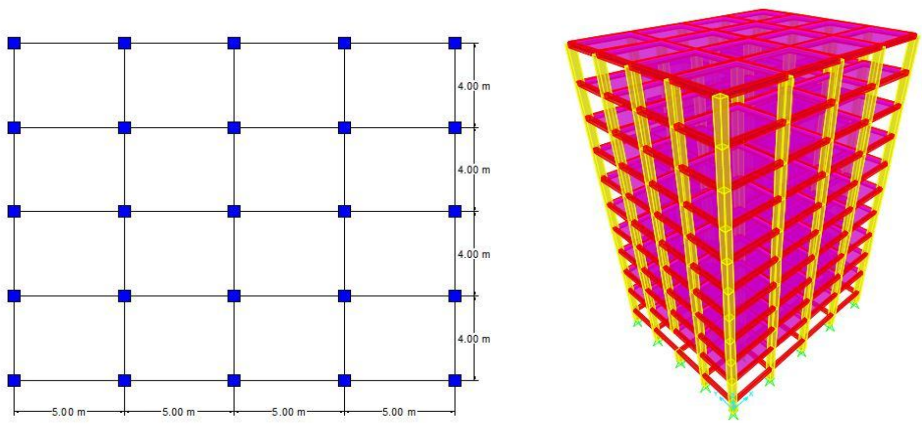

Fig. 1 Typical floor plan and three dimensional view of building

C. 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 (WL)
5) Earthquake Load along X direction (EQX)
6) Earthquake Load along Y direction (EQY)

Along with the primary cases, following load combinations are considered for design of structural elements as per IS 1893:2002.1. 1.5 (DL+LL)
1.2 (DL+LL±EQX)
1.2 (DL+LL±EQY)
1.5 (DL±EQX)
1.5 (DL±EQY)
0.9 DL ± 1.5 EQX
0.9 DL ± 1.5 EQY

Reinforced concrete design is carried out by taking the envelope of the above given combinations and percentage steel is provided accordingly.

III. PROGRESSIVE COLLAPSE ANALYSIS

Progressive collapse analysis is carried out by instantly removing one column from particular location at a time and analyzing remaining capacity of the building to absorb the damage. In order to inspect the response of the structures during progressive collapse, there are several analytical methods namely; linear static, linear dynamic, nonlinear static and nonlinear dynamic analysis.

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In this study, progressive collapse resistance of the selected reinforced concrete framed structure was determined using the following analysis procedures.

Load case as per GSA guidelines for linear static analysis and nonlinear static analysis are same, which is 2(DL+0.25LL), Where DL= Ded Load and LL = Live Load. Using SAP2000 software, removal of columns and their consequences were modelled. The column removal locations are provided in GSA guideline. Fig. 2 shows the column removal scenarios created for progressive collapse analysis in the present study.

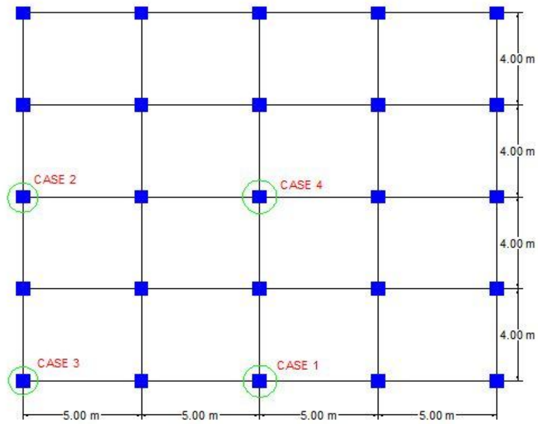

Fig. 2 Column removal scenarios

A. Linear Static Analysis Method

Linear static method is the simplest and fundamental method for progressive collapse analysis. This method doesn't consider geometric and material nonlinearity. Since this method doesn‘t include dynamic behaviour, dynamic increase factor is used to introduce the dynamic effect in the static analysis. It is difficult to perfectly foretell the structural behaviour of the buildings particularly under blast or progressive collapse scenarios. For this reason, the execution of this analysis method has some errors when compare with more complicated approaches. In spite of these disadvantages, the linear static procedure is a well accepted method for analysis of the structures since it is quick, easy, and economic analysis approach.

GSA illustrates the use of DCR (Demand Capacity Ratio), the ratio of the member force and member strength, as a reference to define the failure of structural members by the linear static analysis method. DCR values are calculated with the following equation:

$$DCR = Demand / Capacity$$

Where,

Demand is the bending moment obtained from linear static analysis after removal of the specified columns.

Capacity of the member at any section can be calculated as per IS 456:2000.

DCR values should not exceed 2 for regular structures and 1.5 for irregular structures or else they are considered as severely damaged or collapsed. The following stepwise procedure was used to carry out linear static analysis.

Step 1: Three dimensional model of the building was prepared in SAP2000. Reinforced concrete design was performed and the reinforcement to be provided in members was determined.

Step 2: Based on the area of reinforcement provided, capacity of the member in flexure was calculated as per IS 456:2000.

Step 3: Column loss scenarios were created by removing one column at a time as mentioned in GSA guidelines.

Step 4: Linear static analysis was performed by applying the GSA load combination and the demand for specific column removal case was determined.

Step 5: DCR was calculated in all stories at 3 points; left, right and centre of the column removal location. The results were evaluated as per the acceptance criteria provided in GSA guidelines.

B. Nonlinear Static Analysis Method

Nonlinear static method is more precise than the linear static method since it includes both geometric and material nonlinearity. Since dynamic effects are neglected, dynamic increase factor of "2" is introduced in the load combination. In this method the structural performance is evaluated by applying a stepwise increment of vertical loads until structure collapse or maximum loads are

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attained. In the present study, nonlinear analysis is carried out in SAP 2000 software. For this M3 and V2 hinges were assigned to beams and P-M2-M3 hinges for columns at both the ends. Fig. 3 shows the force-displacement (moment-rotation) curve.

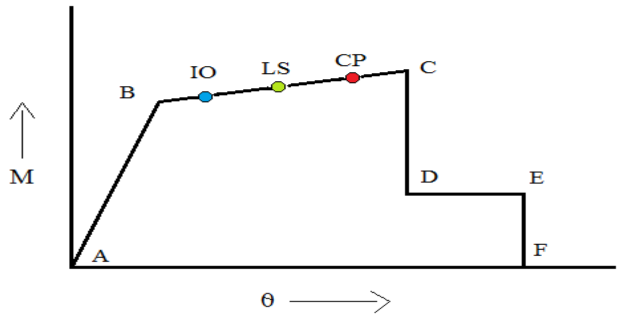

Fig. 3: Force-displacement (moment-rotation) curve

In the curve, point A is the origin point. Point B represents yield condition. Point C represents the ultimate capacity for pushover analysis. After reaching ultimate capacity at point C, strength suddenly decreases and reaches to point D having some residual strength. Point E is the final deformation under residual strength. Additional deformation measures at points IO (immediate occupancy), LS (Life safety), and CP (Collapse prevention) shows capacity at 20%, 50% and 90% of ultimate capacity. The following stepwise procedure was used to carry out nonlinear static analysis.

Step 1: Three dimensional model of the building was prepared in SAP2000. Reinforced concrete design was performed and the reinforcement to be provided in members was determined.

Step 2: Plastic hinges were defined and assigned for beams and columns at both the ends.

Step 3: As per GSA guidelines the nonlinear load combination was defined.

Step 4: Column loss scenarios were created by removing one column at a time as mentioned in GSA guidelines and nonlinear static analysis was performed.

Step 5: Observe hinge formation pattern. % load taken by the structure was calculated in all the column removal cases.

IV. RESULTS AND DISCUSSIONS

A. Calculation of Demand Capacity Ratio

Column damage scenario was created by removing columns from the specified locations one at a time as shown in Fig. 2 and linear static analysis was performed. After performing the analysis, flexure demand of the beams are found. DCR values at left, right and centre of the column removal points along the height of the building were found out in all the column removal cases. Here, DCR calculation of case 1 column removal is depicted. Fig. 4 shows the bending moment diagram of case 1 column removal after performing linear static analysis. DCR values of long bay middle column removal case (case 1) along longitudinal and transverse direction are depicted in Table I.

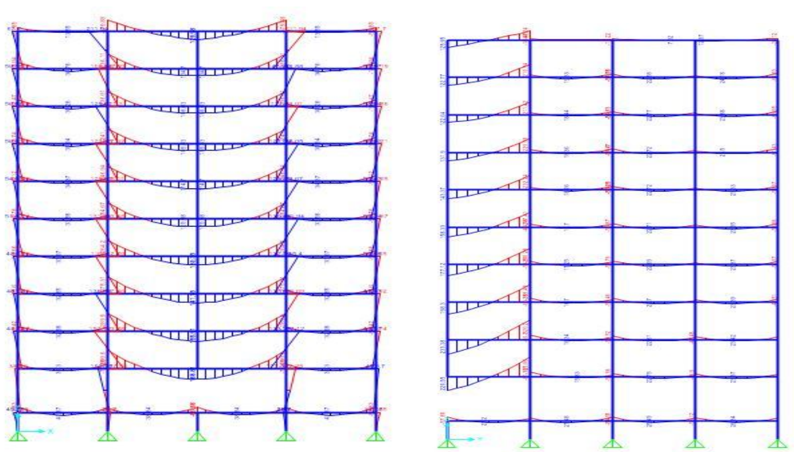

Fig. 4 Bending moment diagram of long bay middle column removal case

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TABLE I
DCR VALUES OF LONG BAY MIDDLE COLUMN REMOVAL

	Longitudinal Direction			Transverse Direction	
Storey	Left	Centre	Right	Centre	Right
1	1.95	1.1	1.95	1.48	2.18
2	1.93	1.04	1.93	1.56	2.14
3	1.86	0.96	1.86	1.32	1.91
4	1.83	0.9	1.83	1.18	1.77
5	1.82	0.86	1.82	1.07	1.67
6	1.85	0.85	1.85	1	1.62
7	1.93	0.86	1.93	0.97	1.63
8	2.08	0.9	2.08	0.98	1.7
9	2.32	0.99	2.32	1.1	1.89
10	3.09	2.23	3.09	2.39	2.74

After performing linear static analysis in all column removal cases it can be seen that DCR values for beams is higher on left and right side of column removal points, but the severity varies from each column removal cases. DCR values in stories that are near to column removal points and roof are higher. Shorter bays are more vulnerable to progressive collapse in all column removal cases it act as cantilever and heavy load from the longer bays act on shorter bay. In all the column removal cases DCR value exceeded permissible value. This indicates that the building considered for study is having high potential of progressive collapse. In order to limit DCR value within the acceptable limit provision of bracing at top storey level is implemented as an alternative to minimize the potential of progressive collapse of the building. The original and proposed sizes of structural members for the building are shown in Table II. Fig. 5 shows the three dimensional view of the braced structure.

TABLE II
MEMBER SIZES OF THE STRUCTURES

Member	Original Size (mm)	Proposed Size (mm)
Beam	300 x 400	300 x 400
Column	550 x 550	550 x 550
Bracing	-----	200 x 200

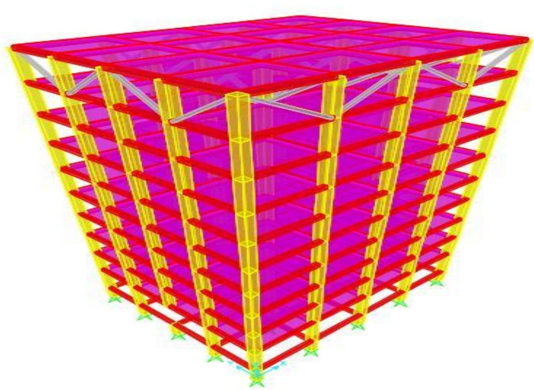

Fig. 5 Three dimensional view of braced structure

Linear static analysis was performed in the braced structure and DCR values were calculated for all the column removal cases as depicted in Fig. 2. Table III shows DCR value of the braced structure for the long bay middle column removal case along both longitudinal and transverse direction.

TABLE III

DCR VALUE OF LONG BAY MIDDLE COLUMN REMOVAL OF BRACED STRUCTURE

	Longer Direction			Shorter Direction	
Storey	Left	Centre	Right	Centre	Right
1	1.65	0.77	1.65	1.09	1.77
2	1.61	0.69	1.61	1.11	1.71
3	1.53	0.59	1.53	0.89	1.49
4	1.47	0.51	1.47	0.75	1.35
5	1.44	0.44	1.44	0.62	1.24
6	1.43	0.38	1.43	0.53	1.17
7	1.46	0.33	1.46	0.45	1.14
8	1.55	0.29	1.55	0.4	1.18
9	1.8	0.28	1.8	0.43	1.41
10	1.96	1.01	1.96	1.02	1.34

Similarly, DCR values of all four column removal cases were found out and It can be seen that in all the cases DCR values are within the allowable limit provided in GSA guidelines and hence the structure becomes enough resistant against progressive collapse.

B. Plastic Hinge Formation

Nonlinear static analysis was performed in the structure before and after mitigation for all specified column removal cases. Plastic hinge formation patterns were studied for various column removal cases before and after mitigation in both longitudinal and transverse directions. When the hinges go beyond the CP state, hinges are considered to be collapsed. In all the cases, the first hinge was formed at the top most storey (terrace level beams). This is because the beams at the top most level are having least amount of reinforcement. Therefore the capacity of beams at top level is considerably less compared to beams at ground floor level from where the column is being removed. Thus it is clear that the hinge forms first at top level. In consecutive steps, the hinge started forming at the bottom stories from where the column is removed. And from thereon, the hinges started propagating in the upward direction. One of the important points to be noted from this analysis is that for the braced structure hinges in the beams are yielding and no hinges in the beams are collapsing. Hinge formations in long bay middle column removal case before and after mitigation are depicted in Fig. 6 and Fig. 7 respectively.

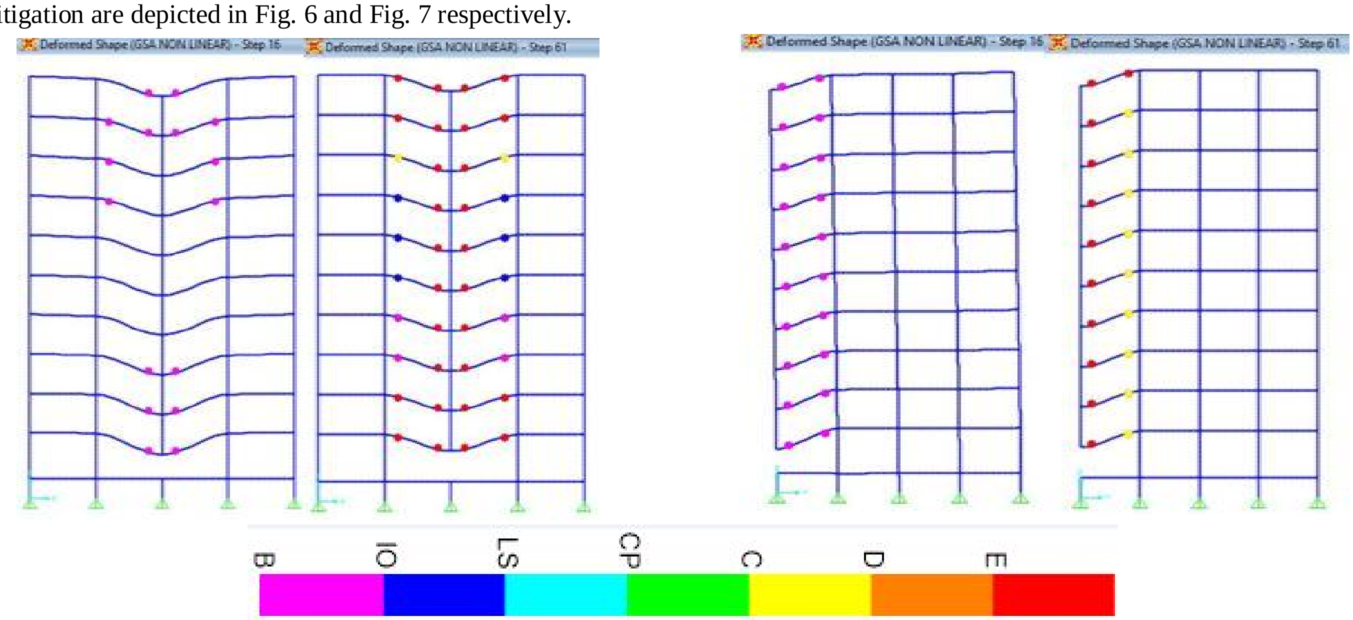

Fig. 6 Hinge formation in long bay middle column removal case before mitigation

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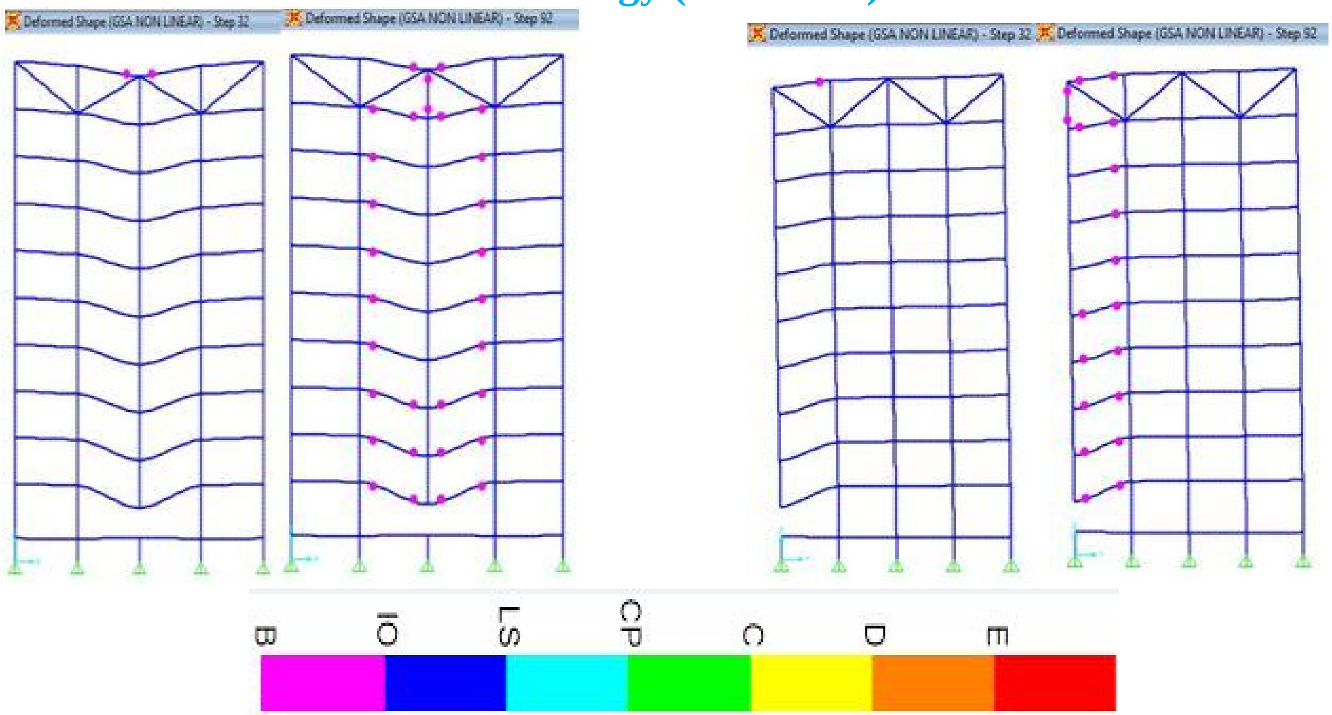

Fig. 7 Hinge formation in long bay middle column removal case after mitigation

C. Percentage Load Taken by the Structure

After performing nonlinear static analysis percentage load taken by the structure after loss of column were found out. The percentage load is calculated as the ratio of load taken by the structure after column removal to the total load applied on the structure. The total applied load, i.e. 2(DL+0.25LL), was calculated in each case before column removal. Table IV shows the percentage load taken by the structure before and after mitigation in all four column removal scenarios.

TABLE IV
PERCENTAGE LOAD TAKEN BY THE STRUCTURE

Column Removal Case	GSA Loading	% Load Taken	
		Original structure	Braced structure
Longer	2(D.L+0.25L.L)	64.05	91.8
Shorter	2(D.L+0.25L.L)	71.62	95.3
Corner	2(D.L+0.25L.L)	62.83	88.5
Interior	2(D.L+0.25L.L)	60.71	84.9

Clearly, we can see that by providing bracing in the top storey level percentage load taken by the structure is increased substantially in all the column removal cases. In both the cases we can notice that interior column removal case shows the least capacity. Corner column and long bay middle column removal cases are capable of absorbing more loads compared to interior column removal case. Short bay middle column removal case shows the highest percentage of load taken than the other column removal cases.

D. Displacement under Column Removal Point

After performing linear static analysis in all the four column removal cases, displacement under the column removal position was noted down for both original and braced structure. Table V shows the values of displacement under the column removal point before and after mitigation. Comparison of displacement under the column removal point before and after mitigation in the form of a bar chart is depicted in Fig. 8.

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TABLE V

DISPLACEMENT UNDER COLUMN REMOVAL POINT BEFORE AND AFTER MITIGATION

Column Removal Cases	Displacement (mm)	
	Original structure	Braced structure
Longer	29.6	23.6
Shorter	23.9	19.8
Corner	28.3	22.2
Interior	26.5	22.5

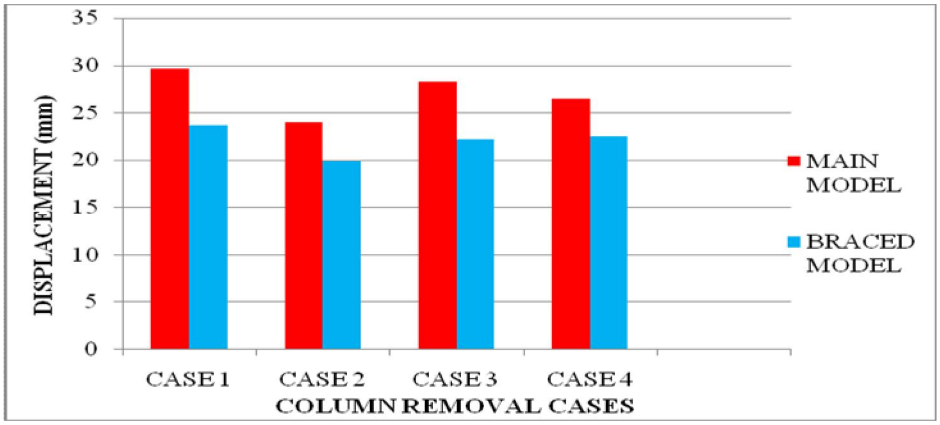

Fig. 8 Graphical representation of displacement under column removal point

From the chart it is clear that by providing bracing at the top floor, the vertical displacement under the column removal points are greatly reduced in all column removal cases.

V. CONCLUSIONS

In this study, progressive collapse resistance of a 10 storey symmetric reinforced concrete framed building was analysed by performing linear static and nonlinear static analyses. DCR values are determined for beams at 3 locations and it is found that DCR values exceed the acceptable limit near to column removal position and roof for all column removal cases. Provision of bracing at the top storey level brought the DCR values within the acceptable limits in all the column removal cases. Nonlinear static analysis was carried out to understand the hinge formations at yield and at collapse. Short bay middle column removal case take the maximum percentage load and interior column removal case take the least percentage load. By providing bracings percentage load taken by the structure in all column removal scenarios was increased. It also reduced the displacement under the column removal points. It can be concluded that provision of bracings in the structures emerges out as an effective alternative for reducing the risk of progressive collapse.

VI. ACKNOWLEDGMENT

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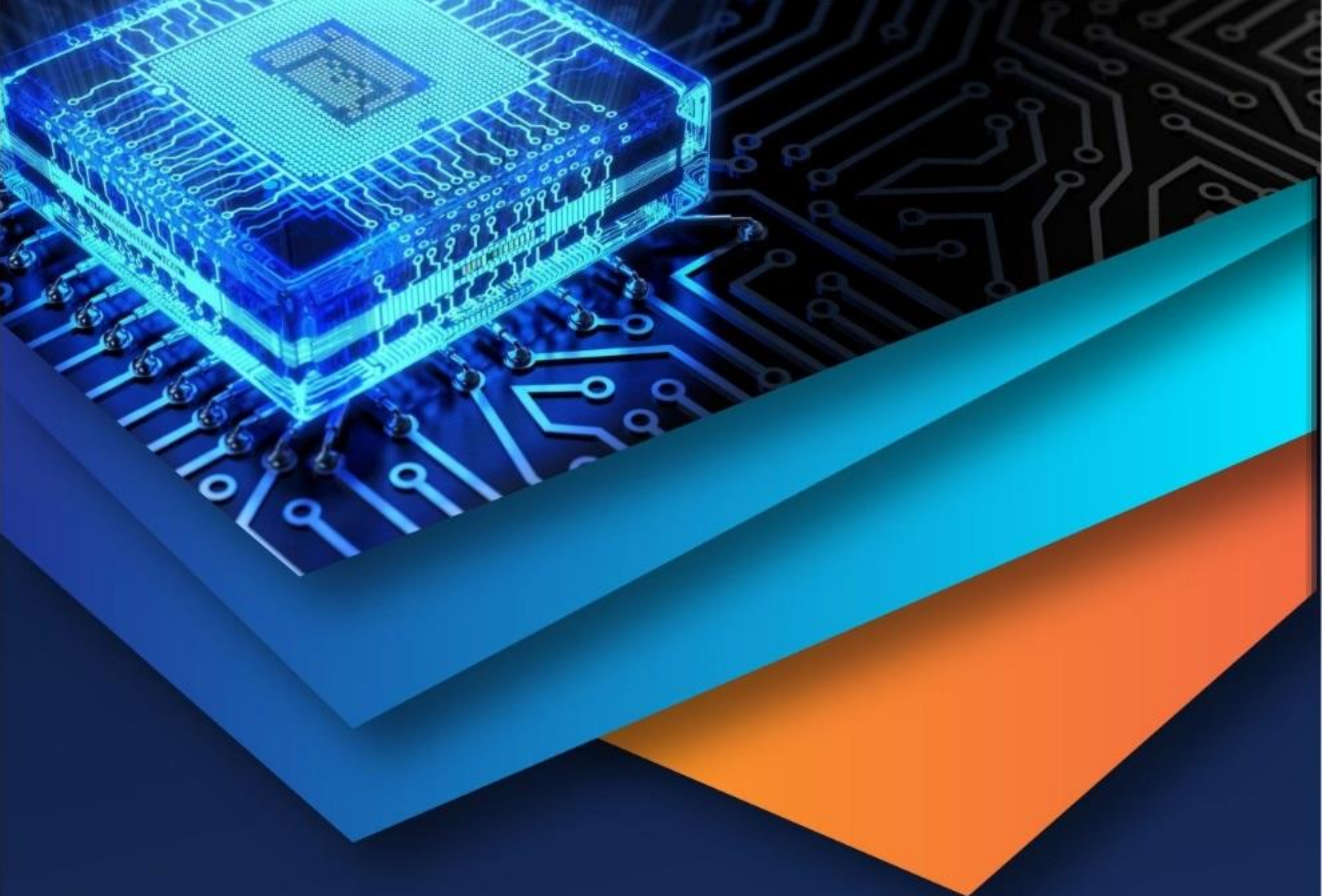
REFERENCES

[1] Ali Kazemi and Mehrdad Sasani, "Progressive Collapse Analysis of RC Structures including Beam Axial Deformation", ASCE, pp 3132-3140, 2011.
[2] Digesh D. Joshi, Paresh V. Patel and Saumil J. Tank, "Linear and Nonlinear Static Analysis for Assessment of Progressive Collapse Potential of Multistoried Building", ASCE, pp 3578-3589, 2010.
[3] H. Sezen, "Collapse Performance of Existing Buildings after Loss of Load-Bearing Walls and Columns", ASCE, pp 1966-1975, 2016.
[4] Harinadha Babu Raparla and Pradeep Kumar Ramancharla, "Progressive collapse analysis of RC buildings subjected to seismic loads", The Indian concrete journal, vol. 89, 2015.

[5] Huda Helmy, Hamed Salem and Sherif Mourad, "Progressive collapse assessment of framed reinforced concrete structures according to UFC guidelines for alternative path method", Engineering Structures, Elsevier, Vol. 42, pp 127-141, 2012.
[6] Hyun-Su Kim, Jinkoo Kim and Da-Woon, "An Development of integrated system for progressive collapse analysis of building structures considering dynamic effects", Advances in Engineering Software, Elsevier, Vol. 40, pp 1-8, 2009.
[7] Massimiliano Ferraioli, Alberto Maria Avossa and Alberto Mandara "Assessment of Progressive Collapse Capacity of Earthquake-Resistant Steel Moment Frames Using Pushdown Analysis", The Open Construction and Building Technology Journal, Vol. 8, pp 324-336, 2014.
[8] Nabil A. Rahman, Ayman Elfouly and Michael Booth, "Alternate Path Progressive Collapse Analysis of Steel Stud Bearing Wall Structures", ASCE, pp 2840- 2851, 2011.
[9] Paresh V. Patel and Digesh D. Joshi, "Various Approaches for Mitigating Progressive Collapse of Asymmetrical RC Building", ASCE, pp 2084-2094, 2012.
[10] S. M. Marjanishvili, P.E, "Progressive Analysis Procedure for Progressive Collapse", Journal of Performance of Constructed Facilities, ASCE, vol. 18, pp 79-85, 2004.
[11] Shalva Marjanishvili and Elizabeth Agnew, "Comparison of Various Procedures for Progressive Collapse Analysis", Journal of Performance of Constructed Facilities, ASCE, Vol. 20, pp 365-374, 2006.
[12] Steven W. Kirkpatrick, Robert MacNeill, Joseph L. Smith, Kenneth Herrle, and Mikhael Erekson, "Methodologies for Progressive Collapse Analysis", ASCE, pp 1126-1135, 2009.
[13] U. S. General Service Administration, "Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects", 2003.
[14] Department of Defense, "Design of Buildings to Resist the Progressive Collapse", 2013.



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