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Progressive Collapse Analysis with Various Lateral Load Resisting Systems

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Abstract - *In this study, the progressive collapse potential of 10 storey reinforced concrete building with lateral load resisting systems are investigated. Two lateral load resisting system is considered named as bracing, and shear wall and their performance are compared with those of reinforced concrete building without lateral load resisting system with the same design load and seismic parameters. Linear static analysis and nonlinear static analysis (pushdown analysis) are carried out for different ground-story column removal cases. According to the linear static analysis result, members of both lateral load resisting systems have Demand Capacity Ratio values under permissible limit except RC building with the shear wall has not under the permissible limit of 2 for two cases. Pushdown analysis results show that all three types of structure have sufficient strength to resist progressive collapse. RC building with Bracing gives the better result as compared to the shear wall with reduced size of column for all cases.*

Keywords — *Progressive collapse, Alternate path method, Demand Capacity Ratio, Lateral Load Resisting System.*

I. INTRODUCTION

The term "progressive collapse" is used in structural engineering to describe the spread of an initial local failure in a similar manner to a chain reaction from local damage to one or more structural elements that leads to the partial or total collapse of a building. General Service Administration (GSA) defined progressive collapse as "an extent of damage or collapse that is disproportionate to the magnitude of the initiating event." The progressive collapse might happen in a building when the structure is exposed to unexpected loadings beyond the design constraints of the building and occurred due to hurricanes, tsunamis, earthquakes, explosions, vehicle impacts, fires, and human errors or even terrorist attacks. In recent years, a number of notorious progressive collapses occurred. It Includes the classics Ronan Point (London, 1968), the A.P. Murrah Federal Building (Oklahoma, 1995), and the buildings of the World Trade Center (New York, 2001). From a series of catastrophes, it has been observed that a structure should have sufficient continuity to offer an alternative path to the stability of the structure, even if an element of a vertical load-resisting system is removed in order to prevent progressive collapse.

There are no common rules to design against progressive collapse. However, there are some groups of design methods that can be easily identified across the different international codes; there are three widely recognized approaches, (1) tying force prescriptive rules, (2) alternative load path (ALP) methods, and (3) key element design methods. Recent comprehensive reviews in this field identified a fourth group, (4) risk-based methods. The tying force and ALP methods consider local failure, whereas the key element design method prevents local failure of critical elements. ALP approaches that supported the notional member removal concept are deterministic instead of prescriptive and are widely accepted by all codes.

Many studies have been carried out to evaluate the behavior and resistance of different structural systems during the progressive collapse, either experimentally or numerically. Tsai and Huang (2011) investigated by linear and nonlinear static analysis that without consideration of the non-structural walls, the moment demands of beams may be overestimated while the shear demand may be underestimated. Khandelwal and Tawil (2011) investigated that the frame designed for moderate seismic risk is less robust than the corresponding one designed for high seismic risk by pushdown analysis. Mashhadiali et al. (2016) compared steel plate shear wall with x-braced frame and investigated that steel plate shear wall system has more progressive collapse resisting potential than X-braced and moment frame structure. Salmasi and Sheidaii (2017) carried out a nonlinear static analysis and found that changes in the type of bracing resulted in significant changes in the system capacity in the progressive collapse, and also chevron type eccentrically brace showed higher strength against progressive collapse. Naji and Ommetalab (2019) obtained capacity curves for each case, and their results indicate that horizontal bracing would increase the resistance of moment frames against progressive collapse. Naji and Zadeh (2019) studied the behavior of concentrically braced frames (CBF) and eccentrically braced frames (EBF) under progressive collapse scenarios and concluded that both systems could withstand the progressive collapse. In the CBF system, the ductility of the CBF structure increases with a decrease in the cross-sections of braces. Mashhadiali and Kheyroddin (2014) investigated that the new system had high resistance to progressive collapse than diagrids in similar conditions. Kim et al. (2011) observed that the inverted-V type braced frames showed superior ductile behavior among all considered braced frames during the progressive collapse, and deflections of all braced structures were less than that of the moment-resisting frame. Shayanfar and Javidan (2017) observed that partially damaged shear walls could redistribute the loads and withstand progressive collapse.

In this paper, progressive collapse analysis is carried out for reinforced concrete (RC) structures, RC structure with bracings, and RC structure with the shear wall by different column removal scenarios. The specific objectives of the study are: (1) To perform the progressive collapse analysis of RC structure with various lateral load resisting system, (2) To study the comparative performance of lateral load resisting systems like Shear wall system and Bracing system, and (3) To compare various parameters like Demand Capacity Ratio, vertical displacement, base shear and to study the behaviour of hinge.

II. PROCEDURE FOR PROGRESSIVE COLLAPSE ANALYSIS

An alternative path approach assumes a critical element is removed from the structure due to abnormal loading, and therefore the structure is required to redistribute the gravity loads to the remaining undamaged structural elements. An advantage of this approach is that it promotes structural systems with ductility, continuity, and energy-absorbing properties, which is desirable in preventing progressive collapse. An alternate load path analysis may be performed using one among three procedures: nonlinear dynamic, nonlinear static, or linear static.

A. Linear Static Analysis

In linear static analysis, the column is removed from the location being considered, and linear static analysis has been carried out with the gravity load imposed on the structure. For all sections, provided reinforcement detail are obtained from the originally seismically designed section. Based on provided reinforcement, the capacity of the member is calculated. From the results of linear static analysis for different column removal scenarios, demands at critical locations are obtained. Check for the Demand Capacity Ratio (DCR) is carried out in each structural member. The member is taken into account as failed if the DCR of a member exceeds the acceptance criteria in flexure and shear. The DCR calculated from linear static analysis helps to Fig. out the potential for progressive collapse of the building. For linear static analysis purpose, the following vertical load shall be applied downward to the structure under investigation:

Load = 2(DL + 0.25 LL)

where,

DL = Dead Load, LL = Live Load

For static analysis, the GSA (2003) recommends the use of a dynamic amplification factor of 2.0 in load combination. This factor is used to account for the dynamic effects of column or wall removal to assess the potential for progressive collapse analysis.

The acceptance criterion for progressive collapse:

The GSA proposed the use of the Demand–Capacity Ratio (DCR), the ratio of the member force and the member strength, as a criterion to determine the failure of main structural members by the linear analysis procedure.

D.C.R. = Q_{UD} / Q_{CE}

Q_{UD} = Acting Force (demand) determined in component or connection/joint (moment, axial force, shear, and possible combine forces)

Q_{CE} = Expected ultimate, unfactored capacity of the component and/or connection/joint (moment, axial force, shear, and possible combine forces)

The capacity of members calculated as per IS 456:2000 at critical section using increased material strength.

The allowable limit of DCR values for primary and secondary structural elements are:

DCR< 2.0 (Typical structural configurations)

DCR< 1.5 (A-typical structural configurations)

B. Nonlinear Static Analysis

The nonlinear static pushdown analysis method is carried out to investigate the structural performance of buildings against progressive collapse by gradually increasing the vertical displacement in the location of the removed column. A non-linear static procedure that is popular in seismic assessment of structures is ‘‘pushover analysis’’ wherein a structure is subjected to a monotonically increasing lateral load pattern till a failure mechanism is formed. This analysis provides valuable information in which sequence plastic hinges form in the elements and strength and deformation reserves, if any, in the system beyond the required seismic demands. Similarly, in several studies, the concept of a ‘‘pushdown’’ analysis has been utilized in the case of progressive collapse simulations. A pushdown analysis is an incremental non-linear static procedure in which a downward distributed or concentrated load of increasing intensity is applied to the structure till a collapse condition occurs.

The pushdown analysis is used to investigate the robustness of building system residual by computing residual capacity and establishing collapse modes of a damaged structure. In the Nonlinear static analysis, define and assign plastic hinges to beams and columns. Load case defined for nonlinear static analysis is the same as static linear analysis as per GSA, which is

2 (DL + 0.25 LL),

Where DL= Dead Load and LL = Live Load

Nonlinear static analysis with the load case imposed on the structure has been carried out for all column removal scenarios. In pushdown analysis, a maximum load factor less than 1 implies that the structure cannot resist the progressive collapse under the load combination of 2(DL+0.25LL) as per GSA guidelines, where load factor is referred to as the ratio of applied load and the GSA specified load.

III. MODELING OF STRICTURE

In this study, the performance of RC structure with bracings and with shear wall subjected to the sudden removal of a column was investigated by linear static and nonlinear static analysis using the software SAP2000.

The analyzed structural models are basically 10-storeys structures with 5 bays width of 4m in both directions subjected to the loss of the ground storey column from different locations one at a time. The plan dimension of the building is 20m x20m. The height of the building is 30m with 3m of each floor height. Fig. 1 shows 3D and plan view of the RC building. Fig. 2 shows the configurations of G+ 9 storey with bracing and with shear wall to be analyzed.

Four-column removal cases are considered for progressive collapse analysis as mentioned below:

1) The corner column is removed (C1)
2) Internal Column is removed (C201)
3) An exterior column near the middle of the Building in the X direction (C181)
4) An exterior column beside the corner column of the Building in Y direction (C11)

Construction Material	Strength Increase Factor
Concrete (compressive Strength)	1.25
Reinforcing Bar (tensile strength)	1.25

Fig. 1b shows the location of four-column removal cases for progressive collapse analysis. In Fig. 1b, the dotted line is showing the affected area due to the removal of the column.

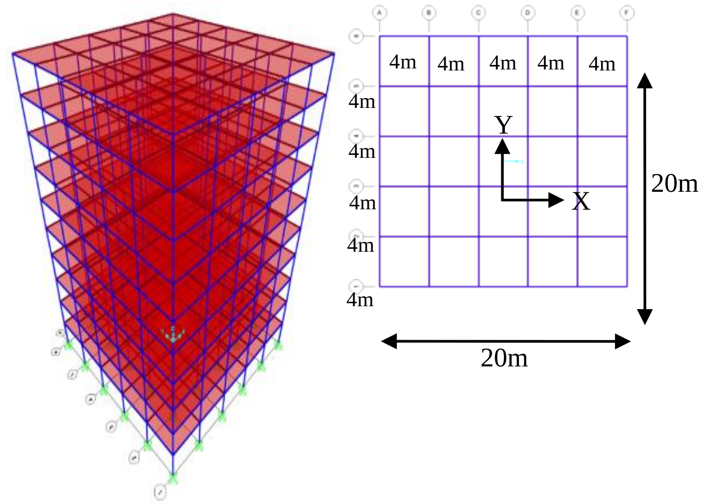

Fig. 1a: 3D and Plan View of Building

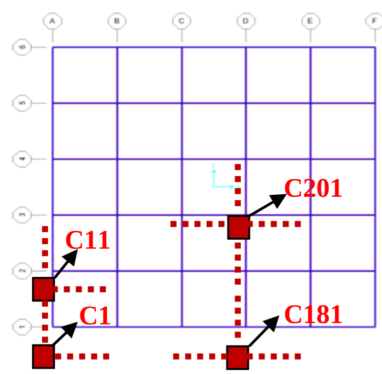

Fig. 1b: Column Removal Locations

Fig. 1: Configuration and Consideration for Building

IV. NUMERICAL STUDY

A 10 storey building is designed for seismic loading in SAP2000 according to IS456:2000. After that, progressive collapse analysis is carried out. All supports are modeled as fixed supports. Data considered for all 3 types of buildings are listed below in Table I.

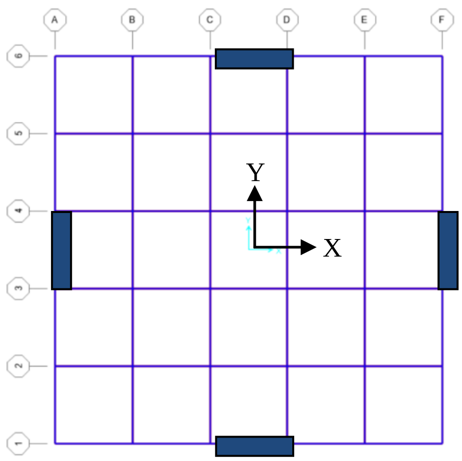

Fig. 2a: Position of Lateral Load

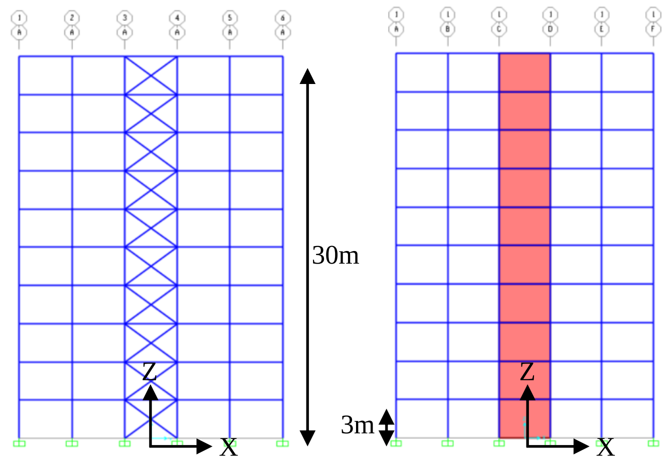

Fig. 2b: Elevation view of Building with X-Braces and with Shear wall

Fig. 2: Configuration of G+9 storey RC building with lateral load resisting system

Table I: Data Considered for Analysis

Parameters	**Values**
Beam Size	350mm X 550mm
Column Size (RC Building)	600mm X 600mm
Column Size (RC Building with bracing and Shear Wall)	450mm X 450mm
Thickness of Slab	150mm
The thickness of Outer Wall	230mm
Thickness of Inner and Parapet Wall	115mm
Bracing Size	350mm x 350mm
The thickness of shear Wall	230 mm
Material Properties	
Characteristic compressive strength of concrete (**f_{ck}**)	30 N/mm^2
Yield strength of reinforcing steel (**f_y**)	500 N/mm^2

Loading Data		
Dead Load	Self Weight of Structural Elements	
	Outer Wall Load	13.8 kN/m
	Inner Wall Load	6.9 kN/m
	Parapet Wall Load	2.3 kN/m
	Floor Finish	1 kN/m^2
Live Load		3 kN/m^2

Seismic Parameter (Seismic Code: IS1893 (I): 2016)	
Seismic Zone	V
Response Reduction Factor	5
Importance Factor	1
Type of Soil	Medium

Analysis and Result

A. Linear Static analysis

Linear static analyses are carried out by removing columns at the ground storey for specified locations and calculate Demand Capacity Ratio (DCR) from the demand of members who are affected because of the removal column. Member is considered failed under gravity load (2(DL+0.25LL)) if DCR is greater than 2 as per GSA guidelines.

Fig. 3 shows the DCR value of beams and columns after removal of corner Columns. Fig. 3a shows the DCR value of RC building without lateral load resisting system, and all the values are less than permissible value 2, so all members have sufficient capacity to resist progressive collapse. From DCR values, it is observed that the effect of progressive collapse is more near to the location of the removal column and then decreases with the storey's level. Similarly, for RC building with bracings, as shown in Fig. 3b, DCR values are less than 2, which show all members are safe. For RC building with the shear wall (Fig. 3c), DCR value of beam near to column removal location exceeds the permissible limit of 2, so the member is considered to fail under gravity load. Beam where DCR>2 needs to be strengthened by providing additional reinforcement to prevent progressive collapse.

Similarly, the DCR value is less than 2 after removal of the internal column for RC building and RC building with bracings (Fig. 4a and Fig. 4b); hence all members are safe against progressive collapse. Whereas RC building with the shear wall has DCR value greater than 2 for beam near to removal column (Fig. 4c). So provide adequate reinforcement to limit the DCR within the acceptance criteria.

DCR values after removal of exterior column (C181) are shown in Fig. 5. In this case, all members have DCR value within the permissible limit for all three types of buildings. RC building with the Shear wall has lesser value as compared to another two and will give better result in this case due to shear wall at the location of column removal.

B. Nonlinear Static Analysis (Pushdown Analysis)

A nonlinear static analysis is carried out by removing the column from specified locations and applies Nonlinear Gravity Load case 2(DL+0.25LL) with gradually increase displacement to the target displacement. In nonlinear static analysis, nonlinearity is explicitly included in the model by the use of plastic hinges.

Hinge Formation

Fig. 7 shows the force deformation curve. 5 points marked as A, B, C, D, and E are used to define the force-deflection behavior of the hinge. The hinge is in an elastic state if the hinge is formed in between A to B. The structure remains elastic from A to B. If the hinge formation is occurred in between B to IO, then it is below immediate occupancy state. The structure is often occupied

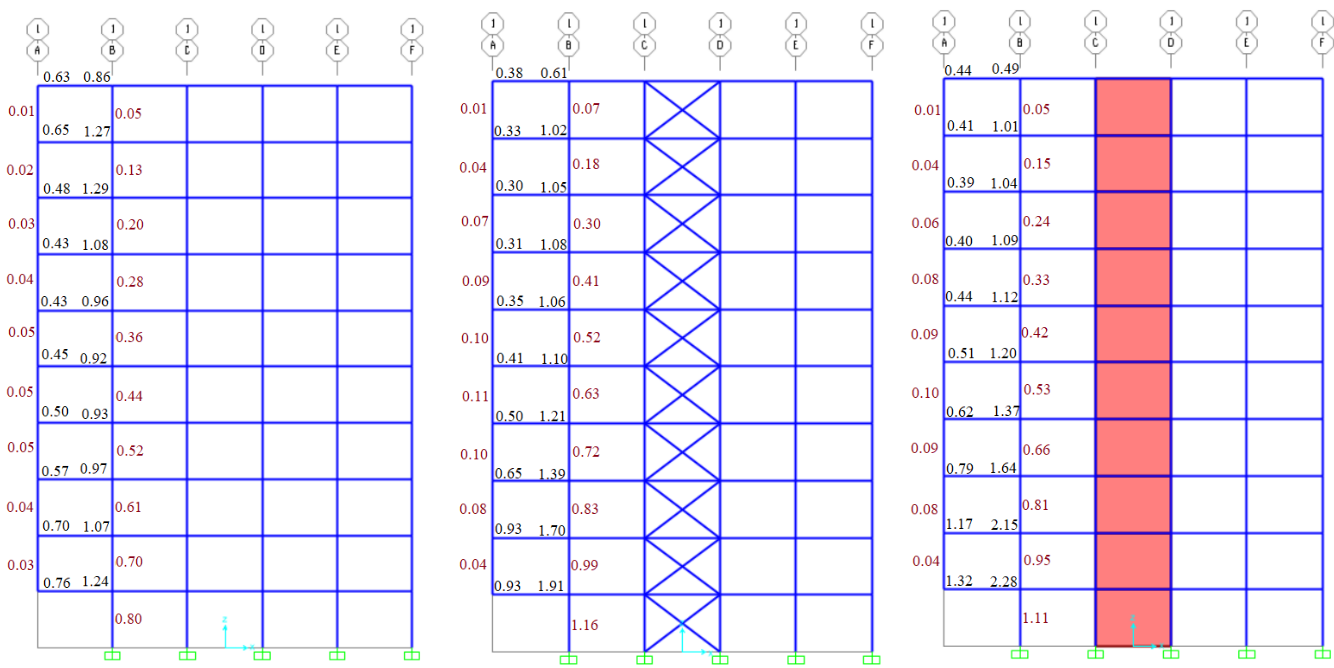

Fig. 3a: G+9 RC Building ***Fig. 3b: G+9 RC Building with Bracings*** ***Fig. 3c: G+9 RC Building with Shear Wall***

Fig. 3: DCR values of members for Corner Column Removal

DCR values are less than 2 for all members in the case of exterior column (C11) removal case for all three types of building. As shown in Fig. 6c, DCR values of column adjacent to the shear wall (grid 3A) are less as compared to members away from the lateral load resisting system; hence members adjacent to the shear wall have less demand. While RC building and RC building with bracings (Fig. 6a and Fig. 6b) have nearly the same DCR value for the column so as to demand.

immediately with minor non-structural element repair works. If hinge formation is occurred in between IO (Immediate Occupancy) to LS (Life Safety) then the lifetime of the structure is safe but repair works are to be done. If the hinge is formed in between LS (Life Safety) to CP (Collapse Prevention) and therefore the structural elements are damaged but structure won't collapse. If the hinge formation is occurred in between CP (Collapse Prevention) to C (Ultimate Capacity) then the structure crosses its ultimate strength. If hinge is in between C (ultimate capacity) to D (residual strength) then the structural elements drop the load and there is reduction in load carrying capacity.

increase in load-carrying capacity. The structure will collapse if the hinges are formed beyond the E.

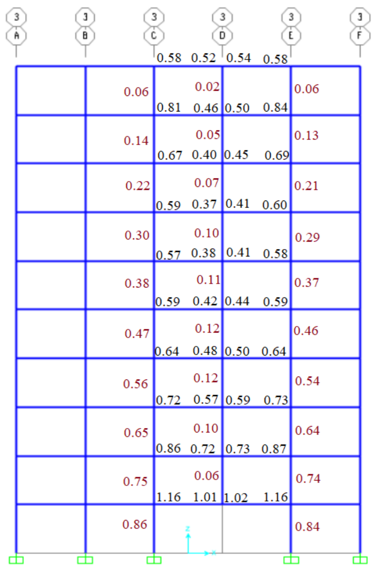

Fig. 4a: G+9 RC Building

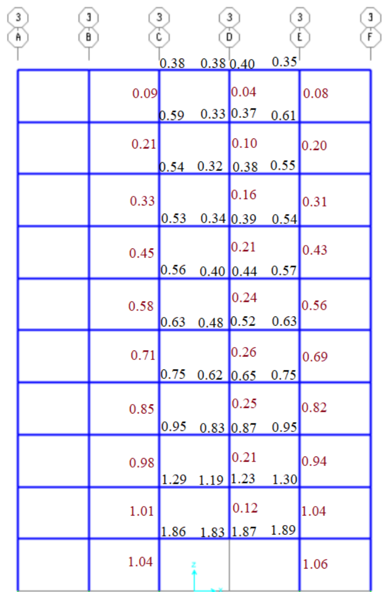

Fig. 4b: G+9 RC Building with Bracings

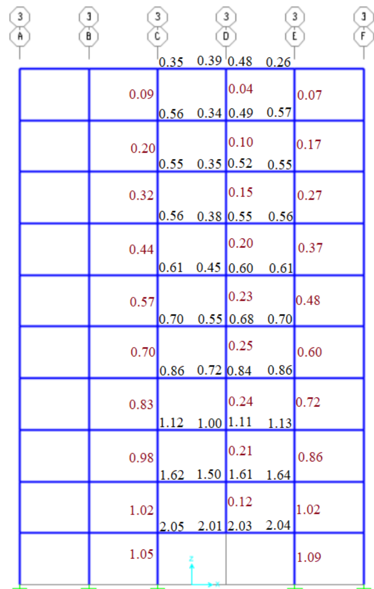

Fig. 4c: G+9 RC Building with Shear Wall

Fig. 4: DCR values of members for Internal Column Removal

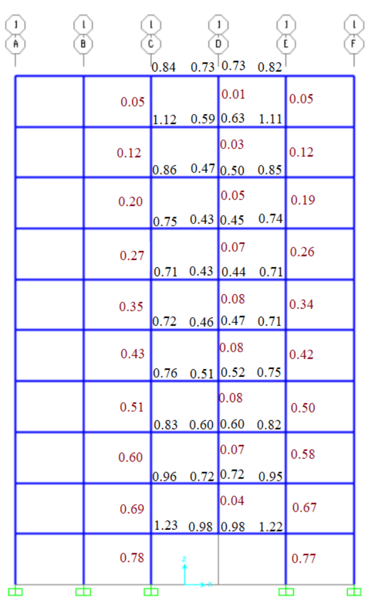

Fig. 5a: G+9 RC Building

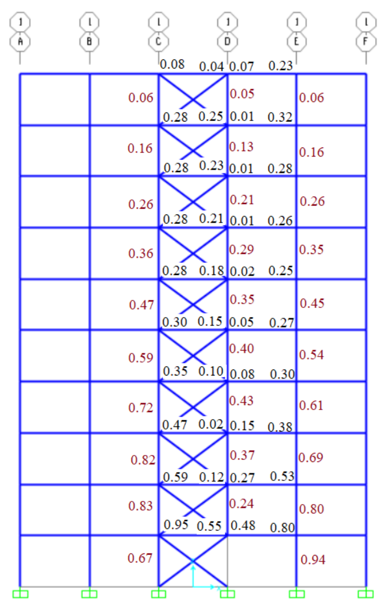

Fig. 5b: G+9 RC Building with Bracings

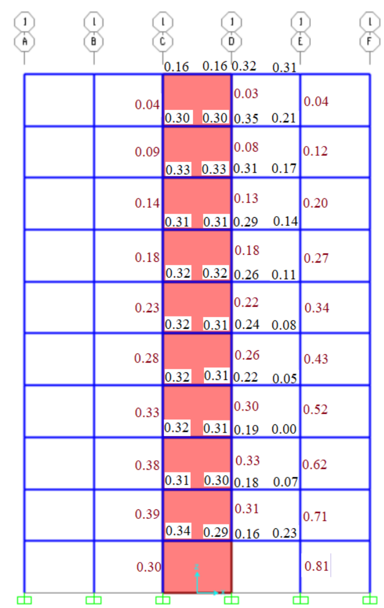

Fig. 5c: G+9 RC Building with Shear Wall

Fig. 5: DCR values of members for Exterior Column Removal (C181)

If the hinge drops at D or beyond D, then there will be no

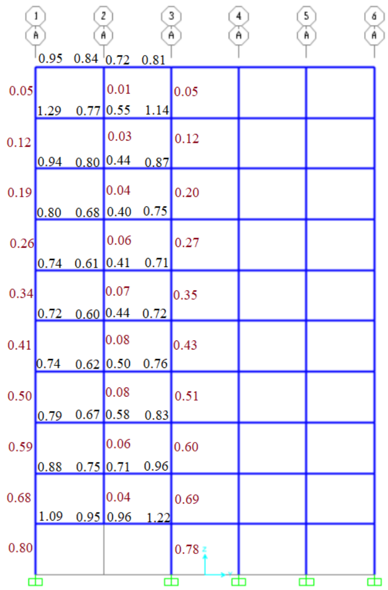

Fig. 6a: G+9 RC Building

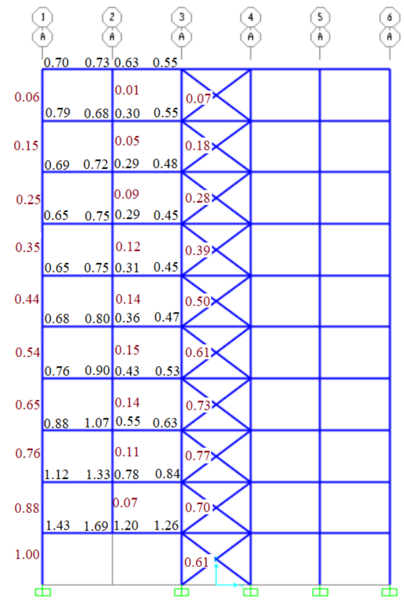

Fig. 6b: G+9 RC Building with Bracings

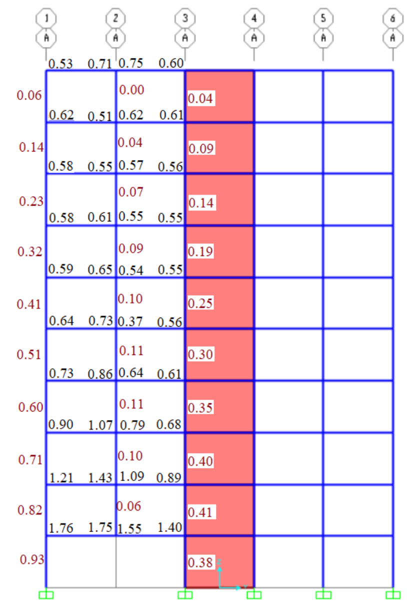

Fig. 6c: G+9 RC Building with Shear Wall

Fig. 6: DCR values of members for Exterior Column Removal (C11)

Hinge formations for all cases are shown in Fig. 8, 9, and 10. Hinges are started to form near the column removal location and moving forward towards the upper storey. In the RC building (Fig. 8), the performance of the building is in between immediate occupancy to life safety level for all 4 cases, so the life of the structure is safe, but there may be repair works that need to be done. Performance of RC building with bracing (Fig. 9) is in between IO to LS for corner and exterior column (C11) cases while for internal and exterior (C181) column removal case, performance is in between B to IO, so there will be minor repair work in the non-structural element. Similarly, hinge formation for RC buildings with shear walls is shown in Fig. 10. A number of hinges form for all cases are listed according to a different state in Table 2.

Vertical displacements are obtained corresponding to respective load for several steps after performing pushdown analysis. Table II shows the maximum vertical displacements for all considered cases. Vertical displacement is more for RC buildings as compared to RC buildings with bracings and with the shear wall for all cases. For the corner column removal case, vertical displacement decreased by 37.5 % for RC building with bracing and decreased by 27.9 % for RC building with the shear wall in comparison with RC building. Whereas for internal column remove the case, vertical displacement decreased by 21% for RC building with bracing and increased by 15.6 % for RC building with the shear wall. In the other two cases of exterior column removal C181 and C11, vertical displacement decreased by 73.91%, 96.7%, and 37.44%, 43% accordingly for RC building with bracing and RC building with the shear wall, respectively. Base shear force is less for RC building with bracings; RC building with the shear wall has more than that.

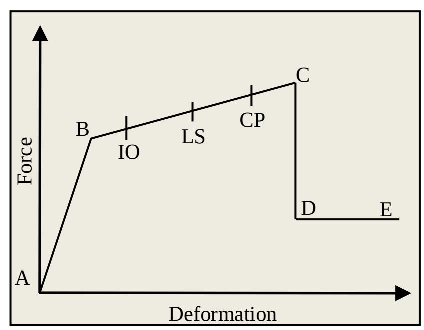

Fig. 7: Force Deformation curve

Fig. 11 shows the load factor versus displacement graph of all four cases. For all 3 types of buildings, the maximum load factor reaches up to 1, as shown in Fig. 11a, so the structure has enough strength to resist progressive collapse by loss of a corner column. However, after the maximum strength is reached, the strength drops abruptly with a further decrease in displacement for RC buildings with the shear wall. As shown in Fig. 11c, the maximum load factor reaches up to 1, so the building has the capacity to resist progressive collapse and strength decrease with a decrease in displacement after reached to maximum strength for RC building and RC building with a shear wall. Similar results are obtained for the exterior column (C11) removal case (Fig. 11d).

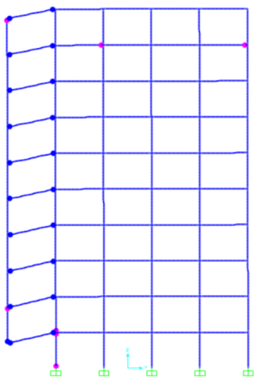

Fig. 8a: Corner Column Removal

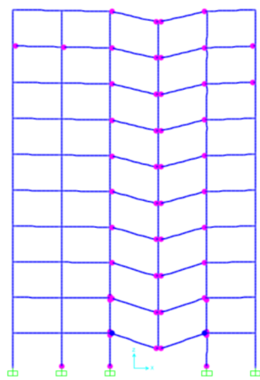

Fig. 8b: Internal Column Removal

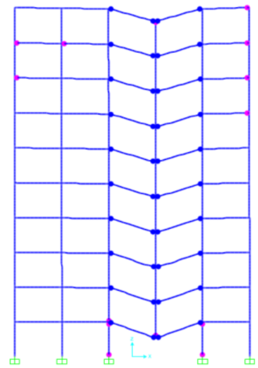

Fig. 8c: Exterior C181 Column

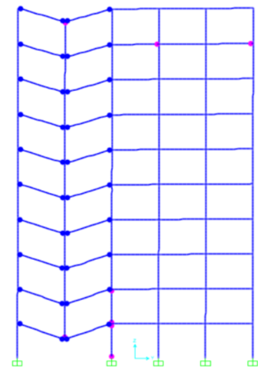

Fig. 8d: Exterior C11 Column Removal

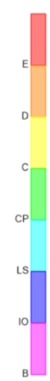

Fig. 8: Hinge Formation for G+9 Storey RC building

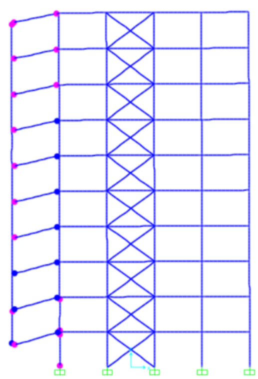

Fig. 9a: Corner Column Removal

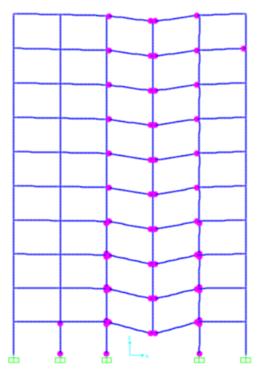

Fig. 9b: Internal Column Removal

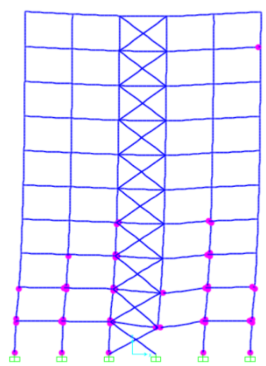

Fig. 9c: Exterior C181 Column *Removal*

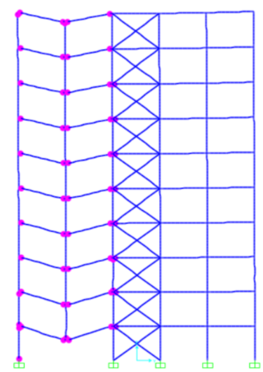

Fig. 9d: Exterior C11 Column Removal

Fig. 9: Hinge Formation for G+9 Storey RC building with Bracings

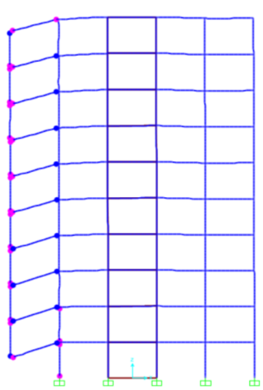

Fig. 10a: Corner Column Removal

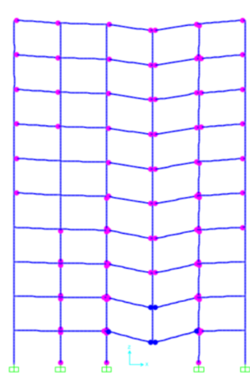

Fig. 10b: Internal Column Removal

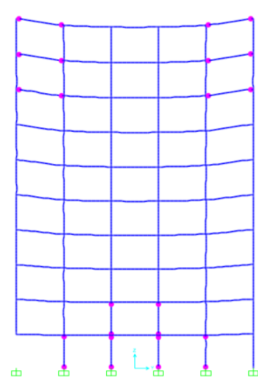

Fig. 10c: Exterior C181 Column

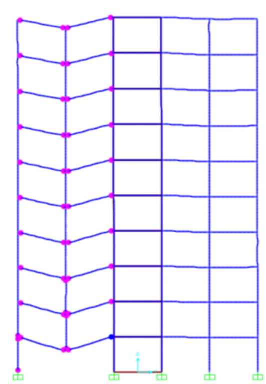

Fig. 10d: Exterior C11 Column

Fig. 10: Hinge Formation for G+9 Storey RC building with Shear Wall

TABLE II: Pushdown Analysis Result (Base force, Displacement, Hinge result)

Column removal location	Type of Building	Base Force (kN)	Displacement(mm)	Hinge Results			
				Total	A to B	B to IO	IO to LS
Corner Column Removal	RC Building	314134.18	90.4	1918	1851	26	41
	With Bracings	192442.28	56.5		1865	34	19
	With Shear Wall	214318.48	65.2		1820	72	26
Internal Column Removal	RC Building	334303.49	45.6	1918	1780	134	4
	With Bracings	217145.22	36.0		1768	150	0
	With Shear Wall	296862.83	52.7		1562	344	12
Exterior Column Removal (C181)	RC Building	331301.15	66.7	1918	1803	57	58
	With Bracings	296504.96	17.4		1670	248	0
	With Shear Wall	234246.75	2.2		1831	87	0
Exterior Column Removal (C11)	RC Building	331761.96	66.5	1918	1810	50	58
	With Bracings	223473.02	41.6		1794	124	36
	With Shear Wall	234290.43	37.9		1760	157	1

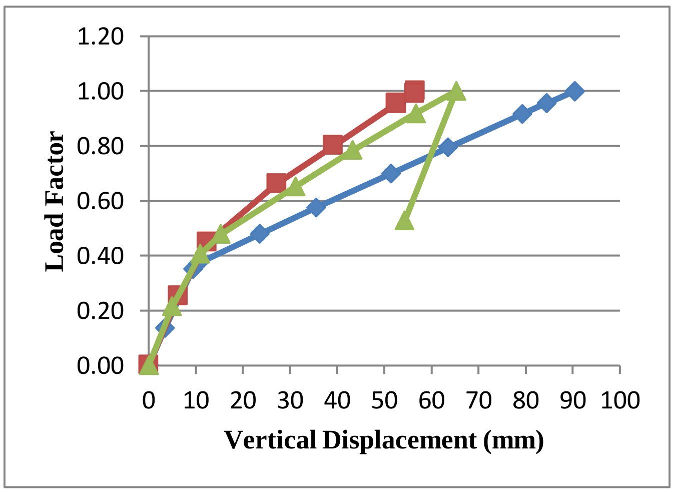

Fig. 11a: Corner Column Removal

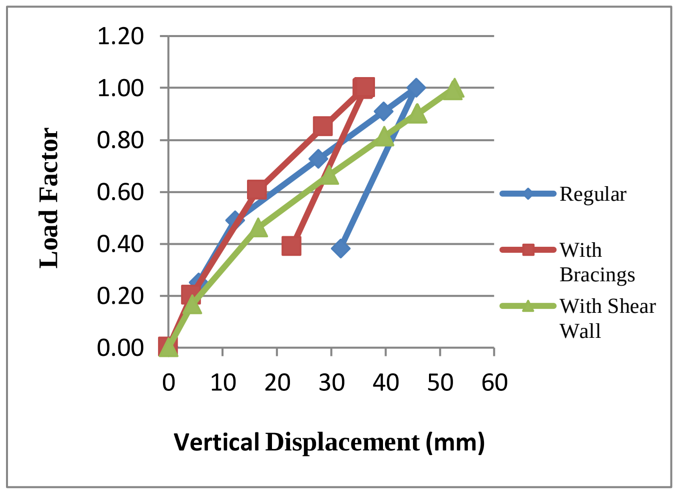

Fig. 11b: internal Column Removal

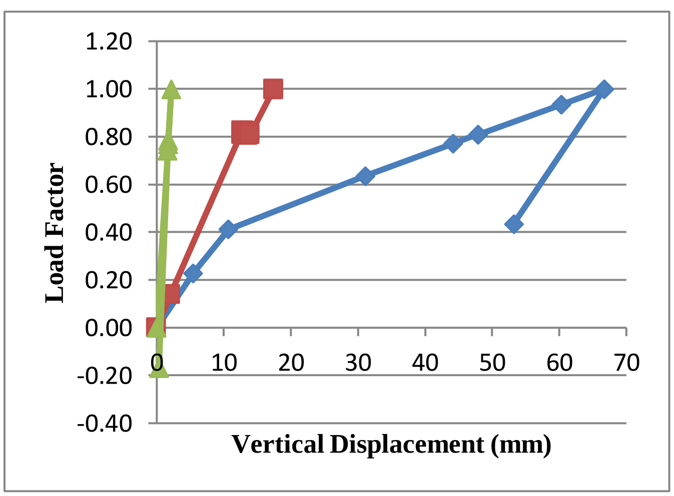

Fig. 11c: Exterior C181 Column Removal

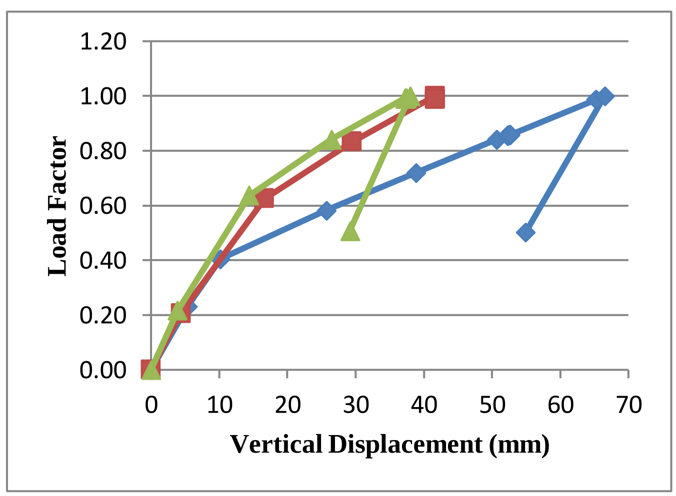

Fig. 11d: Exterior C11 Column Removal

Fig. 11: Load Factor Vs Displacement

V. CONCLUSIONS

This study investigated the progressive collapse potential of RC building, RC building with bracings, and RC building with shear wall with 10 storeys, subject to loss of column at the ground storey. Four cases are considered for progressive collapse analysis by two methods of alternate path approach named linear static analysis and nonlinear static analysis. The parameters considered are Demand capacity ratio, Hinge formation, Base force, Vertical displacement, load factor. After obtained the results of the present studies, the following conclusions can be drawn:

- DCR values meet permissible limit as per GSA guideline for RC building and RC building with bracing, so member have sufficient capacity to resist progressive collapse. For RC building with shear wall, DCR greater than 2 for corner and internal removal cases hence need to provide additional reinforcement to strengthened member. DCR values are higher for corner removal cases as compared to other three.
- Performance of three type of building is in between immediate occupancy to life safety level for all cases except performance of RC building with bracing in internal column removal case and RC building with bracing and shear wall in exterior column (C181) are below immediate occupancy level.
- Vertical Displacement of RC building with bracing is less as compared to shear wall for all cases except exterior column (C181) removal case. In this case, vertical displacement is very small for RC building with shear wall.
- The nonlinear static pushdown analysis results showed that the model structures had enough strength as the strength required by the GSA guideline for all column removal case. However, after the maximum values were reached, the strengths sharply dropped for some case.
- According to all results, it is observed that RC building with bracing gives better result for all cases as compared to two others.

REFERENCES

[1] A. Ch. Salmasi and M. R. Sheidaii, Assessment of eccentrically braced frames strength against progressive collapse, International Journal of Steel Structures, 17(2) (2017) 543-551.

[2] A. Naji and M. K. Zadeh, Progressive collapse analysis of steel braced frames, Pract. Period. Struct. Des. Constr., 24(2) (2019) 04019004-(1-9).

[3] A. Naji and M. R. Ommetalab, Horizontal bracing to enhance progressive collapse resistance of steel moment frames, The Structural Design of Tall and Special Buildings, 28(7) (2019) 1-15.

[4] D. D. Joshi, P. V. Patel and S. J. Tank, Linear and nonlinear static analysis for assessment of progressive collapse potential of multistoried building, Structure Congress, April 2012.

[5] General Services Administration (GSA), (2003), Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects, The U.S. General Services Administration.

[6] IS 456: 2000, Plain and reinforced concrete- code of practice, Bureau of Indian Standards.

[7] IS 1893 (Part 1): 2016, Criteria for earthquake resistant design of structures, Bureau of Indian Standards.

[8] J. Kim, Y. Lee and H. Choi, Progressive collapse resisting capacity of braced frames, Struct. Design Tall Spec. Build., 20 (2011) 257–270.

[9] K. Khandelwal and S. EI-Tawil, Pushdown resistance as a measure of robustness in progressive collapse analysis, Engineering Structures, 33(9) (2011) 2653-2661.

[10] M. A. Shayanfar and M. M. Javidan, Progressive collapse-resisting mechanisms and robustness of RC frame–shear wall structures, Journal of Performance of Constructed Facilities, 31(5) (2017) 04017045-(1-12).

[11] M. Tsai and T. Huang, Progressive collapse analysis of an RC building with exterior non-structural walls, Procedia Engineering, 14 (2011) 377-384.

[12] N. Mashhadiali and A. Kheyroddin, Progressive collapse assessment of new hexagrid structural system for tall buildings, The Structural Design of Tall and Special Buildings, 23(12) (2014) 947-961.

[13] N. Mashhadiali, M. Gholhaki, A. Kheyroddin and R. Zahiri-Hashemi, Technical note: Analytical evaluation of the vulnerability of framed tall buildings with steel plate shear wall to progressive collapse, Int J Civ Eng, 14 (2016) 595-608.