International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-4, November 2019

Effect of Steel Bracing in Progressive Collapse of Multi Storey RC Buildings

Ifteqhar Ahmed Khan, B. Narender

Abstract: Rapid increase in manmade and natural disasters can lead to structural instability which triggers the partial or complete collapse of the building. These manmade disasters include gas cylinder explosion or terrorist attack or instant removal of the primary structural element which leads to the progressive collapse of the building. To avoid the progressive collapse of building due to man-made disasters, incorporate the mechanism which resists the man-made disaster while the design for existing or newly constructing building. In this paper, an attempt is made to understand the effect of with and without providing steel bracing at various positions column removal in multi-storey building one at a time as per General Service Administration and Unified facilities criteria codes. The propagation of progressive collapse with and without the effect of steel bracing is studied in this paper. A seven-storey RC building is modelled and analysed for various column removal scenarios in SAP 2000 software. The Loads are applied according to General Service administration and Unified facilities criteria guidelines, column removal positions namely centre, edge and corner column removal at ground floor are also considered from guidelines. The three scenarios are then analysed individually as a bare frame, bare frame with steel bracing in the wall and bare frame with steel bracing in the slab. Push down analysis is carried out on models and results of mode shapes, time periods, force Vs displacement curves, plastic hinge deformation are discussed. From results, it is observed that wall bracings have better performance in all three and can help in arresting the progressive collapse from spreading throughout the building.

Keywords: Bare frame, Steel bracing, Pushdown analysis, Progressive collapse.

I. INTRODUCTION

Progressive Collapse is a series of collapses where the collapse of one or more primary structural member can grow in such huge proportions that it can lead to the collapse of the total structure. Instant removal or collapse of the primary structural element can removal of primary structural elements due to happen by many means, but the most common are Blast effects, Gas explosions and Improper loading or accidental manmade causes which are mainly columns.

Manuscript published on November 30, 2019.
* Correspondence Author
Ifteqhar Ahmed Khan*, Master's Student, Structural Engineering, Anurag Group of Institutions (An Autonomous Institution), Venkatapur, Hyderabad, Telangana, India.
Dr.B. Narender, Associate Professor, Structural Engineering, Anurag Group of Institutions (An Autonomous Institution), Venkatapur, Hyderabad, Telangana, India.

Structures today are not only designed for gravity, wind and seismic forces but also for impulse loads such blast, fire disasters and sometimes sudden removal or collapse of the column also takes places which leads to the progressive collapse of structures. Such type of sudden or impulsive loads come under the progressive collapse of the building. Many government structures and also public places are always under threat of terror attacks so taking precautions beforehand might protect structures and also innocent lives shall be a benchmark for future constructions. Progressive collapse is of the structure has been an important aspect of analysis but was neglected till the early 1990s till Ronon collapse and Michigan office blast which lead to one side collapse of the structure completely after that collapse happened this aspect of the analysis was deeply studied for further protection of structures. After the collapse of the world trade centre in 2011, research in this field was more emphasised. As the International terrorism and attacks on buildings have increased. It is good to be prepared for any such attack which can harm the strength of the structure and lead to collapse. In this analysis, the main aim is to arrest the collapse locally not letting it spread across structure and create large deformation and lead to the collapse of the entire structure. In many cases collapse is triggered due to improper loading pattern exerted on the column and the column not being designed to resist that load which leads to the collapse of column impulsively and progressive collapse is triggered in the structure. Sometimes due to improper building practices also lead to the non-uniformity of structure and cause the collapse of the column and initiate progressive collapse. In most of the progressive collapse cases, the main loads which are acting on the area where the column is removed are gravity load, but it acts which much larger impact than the normal as the column is removed impulsively and in most of the cases such mistakes go unnoticed. The performance of buildings during progressive collapse event depends on many factors, those factors include: the actual strength to the design strength, the level of redundancy in the structural system, the level of structural integrity of the individual members to form a whole system, and the types of structural details and the ductility existent in the system. Seismic design requirement adds strength and ductility to the system which are needed only during seismic events. This represents some additional redundancy when considering only gravity load since seismic events are rare and may exist one or two time during the lifespan of the structure and usually not coincident with blast event. S. M. Marjanishvili et al.

(2004) in his study of different methods of analysis of progressive collapse found that non-linear static analysis to be most realistic in results and feasible other methods of analysis of progressive collapse were found to be very complicated, unrealistic and sometimes over estimating or underestimating effect of progressive collapse [6]. Meng Hao Tsai et al. (2011) used non-structural elements such as different types of walls such as wing type wall, Parapet type wall and panel type wall to counter the effect of progressive collapse. In his study, the author found that non-structural elements are very helpful in resisting the effect of progressive collapse [5].D.A. Nethercota et al. (2011) in his study, found that combination of moment capacities, rotational stiffness and deformation capacity of structural members is helpful in progressive collapse event rather than the tying resistance. Composite type of structural elements has a greater ability to resist progressive collapse rather than that of homogeneous structural elements as it can provide extra stiffness against the effect of progressive collapse [1].

II. NEED OF STUDY

In many cases in old and new buildings, there is a high probability that progressive collapse may occur. This type of study which has steel bracings to resist the progressive collapse mitigation across the structure is very effective in both the cases of the building if new or old which has a great opportunity that it can be widely implied not changing any reinforcement details and structural arrangements of buildings.

III. OBJECTIVE OF WORK

The objective of the study is to understand the progressive collapse behaviour in midrise RC building with column removal scenarios. These scenarios are analysed as a bare frame, bare frame with steel bracing and bare frame with slab bracing.

IV. STRUCTURAL MODELLING

In this study, nine building models of seven storey reinforced concrete buildings with 30m×16m are modelled with various structural arrangements such as steel bracing bare frame and steel bracing in slab frame for three sceneries, i.e. centre column removal, corner column removal and edge column removals shown in figure 1. Building model consists of 6 bays along x-axis and 4 bays along y-axis with 5m and 4m width respectively. Height of the storey is considered as 3m and constant along the height of building. SAP 2000 software is used for modelling and analysis of building models. The geometry of all the models are same and mentioned in table I and loading details are shown in table III. An I –section of ISMB [3] steel member is used as steel bracing in wall and slab and properties of I-section as shown in table II.

Table I: Building model description

Building members	Dimensions
Total height of the building	21m
Each story height	3m
Total no. of stories	7
Size of beam	400mm x 450mm
Size of column	600mm x 650mm
Thickness of slab	150mm
Thickness of walls	230mm
Grade of beams and columns	M25
Grade of slab	M25
Grade of rebar	HYSD 415

Table II: ISMB 300

Details	m
Outside height [t_3]	0.3
Top flange width [t_f]	0.14
Top flange thickness[t_f]	0.0124
Web thickness[t_w]	0.0075
Bottom flange width[t_2b]	0.14
Bottom flange thickness [t_fb]	0.0124

Table III: Load Description

Load type	Load value
Live load	3 kN/m^2
Floor finish	1 kN/m^2
Exterior wall load	12 kN/m

Nine building models of 7 storey are considered for study, as mentioned in Table 4. Model-1, Model-2, Model-3 is for center column removal scenario, Model-4, Model-5, Model-6 is for edge column removal scenario, Model-7, Model-8, Model-9 is for corner column removal scenario cases. The steel bracing ISMB 300 is provided up to 3 stories in building model-2, model-3, model-5, model-6, model-8, model-9 adjacent to where column is removed. The column removal position for this study, as shown in fig.1.

Table IV: Model details

Building models	Descriptions
Model-1	Bare frame center column removal
Model -2	Bare frame with steel bracing centre column removal
Model -3	Bare frame with slab bracing centre column removal
Model -4	Bare frame edge column removal
Model -5	Bare frame with steel bracing edge column removal
Model -6	Bare frame with slab bracing edge column removal
Model -7	Bare frame corner column removal
Model -8	Bare frame with steel bracing corner column Removal
Model -9	Bare frame with Slab bracing corner column removal

All the building models are designed as per IS 456:2000 [4], and Pushdown analysis is done according to GSA [2] and UFC [7] guidelines. The increased gravity load is applied on all the slabs adjacent to column removed position and other slabs are loaded normally.

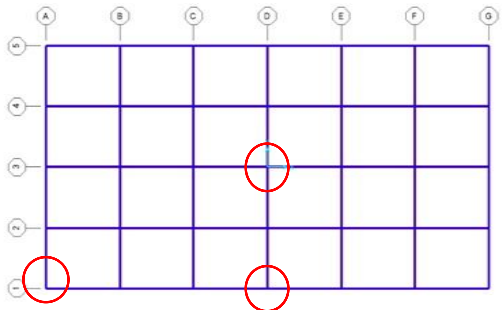


Fig. 1. Area in circle represents column removed positions in ground floor only one at a time.

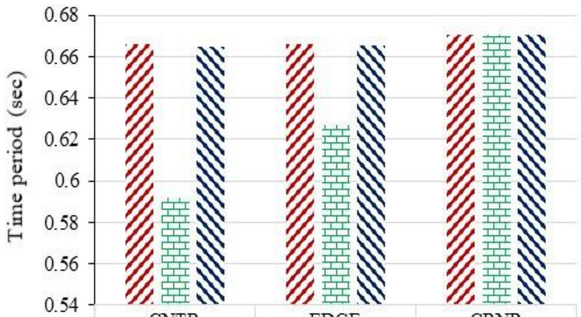
V. ANALYSIS

Modal analysis and Pushdown analysis are performed on considered building models. Modelling and analysis are carried out using SAP 2000. Load application for pushdown analysis is considered according to GSA [2] and UFC [7] guidelines. The default hinges M3 for beam and P-M2-M3 for the column are assigned at both ends of the member. The dynamic increased factor is taken 2.0 for nonlinear static analysis. The displacement control is applied where the column is removed in the pushdown analysis.

VI. RESULTS AND DISCUSSION

A. MODAL ANALYSIS

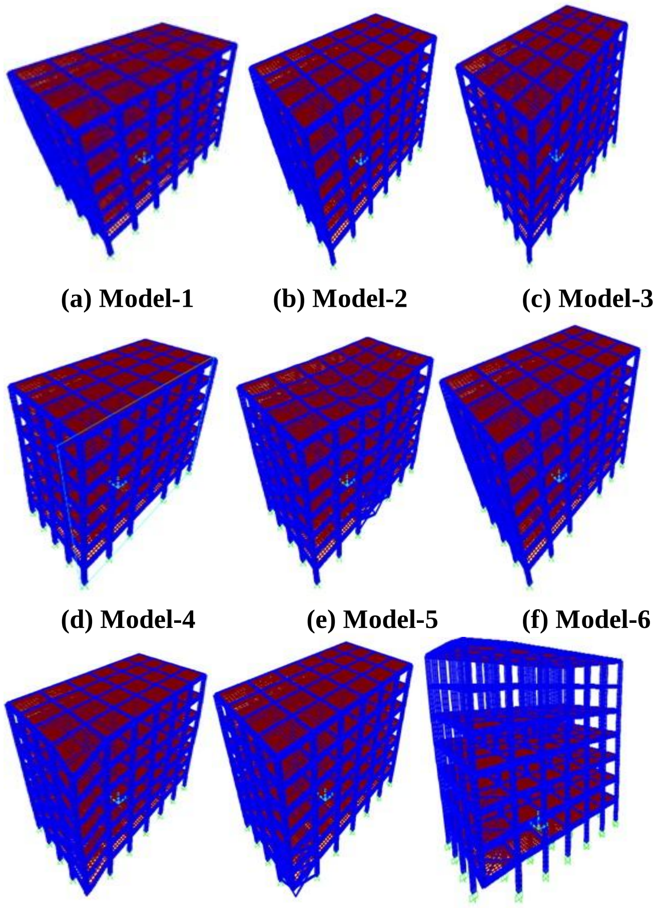
The time period for the first mode of different models is represented in fig.2.



	CNTR	EDGE	CRNR
BF	0.666139	0.666148	0.670593
STLB	0.591586	0.626725	0.670212
SLB	0.664414	0.665253	0.670272

Fig. 2. Time period of building models

In centre column removal, it observed that the time period for the bare frame, for steel bracing frame and for slab bracing frame is 0.666 sec, 0.591 sec and 0.664 sec respectively. The steel bracing frame is having less time period than that of bare frame and slab bracing frame. The steel bracing frame has 11.26% less time period than that of the bare frame. Whereas slab bracing has 0.30% less time period than that of the bare frame. And in edge column removal**,** the time period is 0.666 sec, 0.626 sec and 0.665 sec for the bare frame, for steel bracing frame and for slab bracing frame respectively. The steel bracing frame is having less time period than that of bare frame and slab bracing frame. The steel bracing frame has 6.26 % less time period than that of the bare frame. Whereas slab bracing has 0.15 % less time period than that of the bare frame. In corner column removal, the time period is 0.6705 sec, 0.6702 sec and 0.6702 sec for bare frame, steel bracing frame and slab bracing frame respectively. The steel bracing frame is having less time period than that of bare frame and slab bracing frame. The steel bracing frame has 0.05% less time period than that of the bare frame. Whereas slab bracing has 0.04% less time period than that of the bare frame. The time period does not change without bracing in column removal at the centre, corner and edge but adding bracing, the time period is reduced in the centre and edge column removal and almost same in corner column removal before and after adding the bracing. From Fig.3, it is observed that for the bare frame and bare frame with steel bracing in slab has the first mode as translation mode whereas for the bare frame with steel bracing has the first mode as rotation mode, it is due to addition of stiff elements in building models of bare frame with steel bracing.



(a) Model-1 (b) Model-2 (c) Model-3

(d) Model-4 (e) Model-5 (f) Model-6

(g) Model-7 (h) Model-8 (i) Model-9

Fig. 3. First mode shapes of building models

B. Pushdown analysis for Centre column removal:

After the design of the building, plastic hinges are assigned to each member, displacement control is applied and pushdown analysis is carried out for each column removal case. The pushdown curves of centre column removal in different cases are shown in fig.4. For bare frame model, the ultimate capacity of structure is found to be 203267.45 kN at a displacement of 0.00851 m, for bare frame with steel bracing the ultimate capacity of structure is found to be 226110.586 kN at a displacement of 0.009201 m and for bare frame with slab bracing ultimate capacity of structure is found to be 209963 kN at a displacement of 0.009299 m. For a bare frame with steel bracing force is 10.10% more than that of bare frame and displacement is 8.88 % less than that of the bare frame.

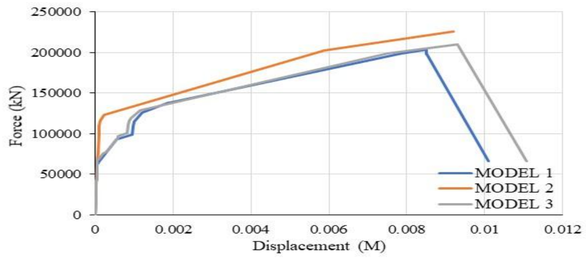
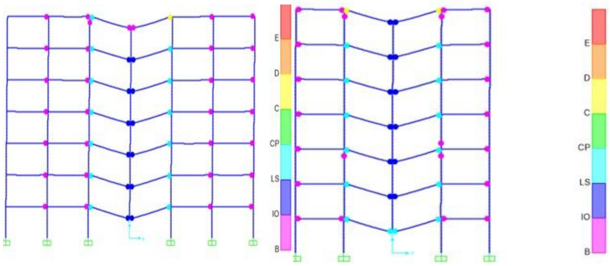


Fig. 4. Pushdown curves of centre column removal

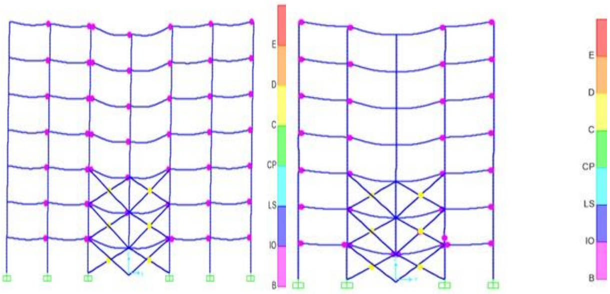
Table V: Plastic hinge deformation results

Hinge states	Model-1	Model-2	Model-3
A to B	881	886	884
B to IO	365	426	392
IO to LS	24	0	19
LS to CP	27	0	26
CP to C	0	0	0
C to D	3	12	3
D to E	0	0	0
Beyond E	0	0	0



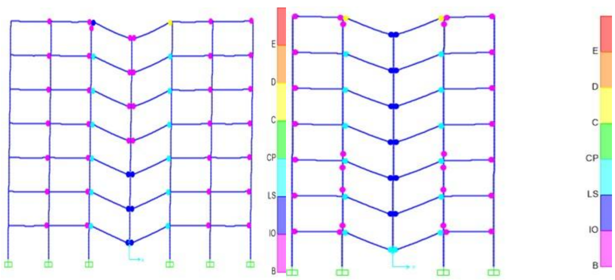
(a) (b)

Fig. 5. Plastic hinges of Model 1 at last step in (a) X-dir and (b) Y-dir



(a) (b)

Fig. 6. Plastic hinges of Model 2 at last step in (a) X-dir and (b) Y-dir



(a) (b)

Fig. 7. Plastic hinges of Model 3 at last step in (a) X-dir and (b) Y-dir

The plastic hinge deformation shown in table 5, it is observed that out 12 elements in C to D state in bare frame with steel bracing frame, all 12 hinges are formed in steel bracing doe, not in primary member. The effect of providing steel bracing in bare frame can be measured with percentage of members in IO to LS and LS to CP in bare frame was found to be 1.86% and 2.07% whereas for steel bracing frame it has come down to only 0 in IO to CP and 0.90% in C to D which are steel bracings provided to resist progressive collapse. From the last steps of Plastic hinge deformation in fig.5,6 and 7. It can be seen that in bare frame with slab bracing case the results are mostly the same as of the bare frame but is to be noted that reduction of member is in C to D state and but in bare frame with steel bracing case no primary structural member is in C to D state only steel bracings are in C to D. The members immediately adjacent to the column removed position in x-direction and y-direction are most affected. In the shorter direction as the length for the propagation of progressive collapse is shorter members the extreme ends are also affected in y-direction whereas in x-direction as the length for propagation is more the effect of progressive collapse doesn't affect the members on extreme edges. In adding the steel bracing in-wall strength and stiffness of building is increased and while adding the slab bracing, the response remains the same as that of bare frame building.

C. Pushdown analysis for Edge column removal:

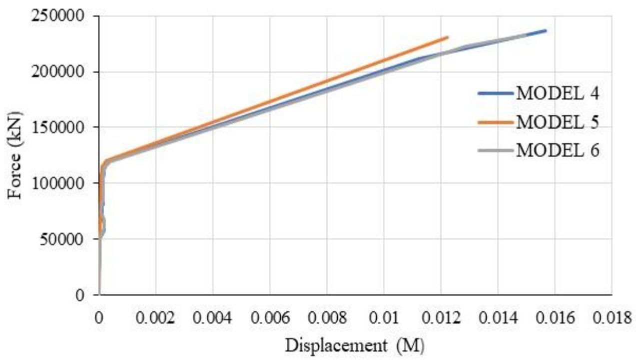
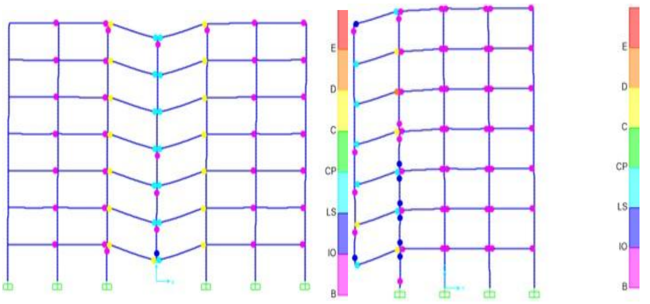


Fig. 8. Pushdown curves of edge column removal

Pushdown curves of edge column removal in different cases are shown in fig.8, for bare frame model, the ultimate capacity of structure is found to be 236644.279 kN at a displacement of 0.015676 m, for bare frame with steel bracing the ultimate capacity of structure is found to be 230378.667 kN at a displacement of 0.012232 m and for bare frame with slab bracing ultimate capacity of structure is found to be 232878.801 kN at a displacement of 0.014975 m. From the comparison of pushdown curves, it is seen that force in bare frame with steel bracing and bare frame with slab bracing are 2.64% and 1.59% less than bare frame respectively. The displacement for the bare frame with steel bracing is 21.96% less than that of the bare frame and for the bare frame with slab bracing displacement is 4.47% less than that of the bare frame.

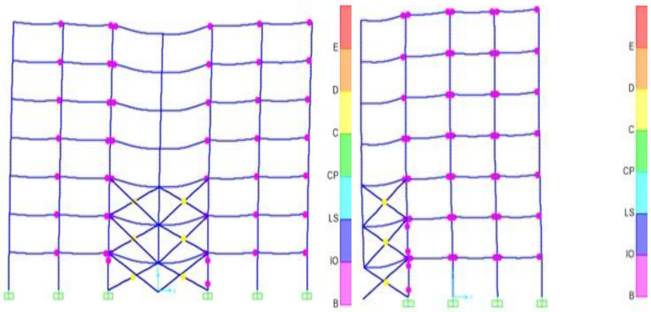
Table VI: Plastic hinge deformation results

Hinge states	Model-4	Model-5	Model-6
A to B	737	795	761
B to IO	510	514	502
IO to LS	12	0	23
LS to CP	21	0	18
CP to C	0	0	0
C to D	19	9	8
D to E	1	0	0
Beyond E	0	0	0



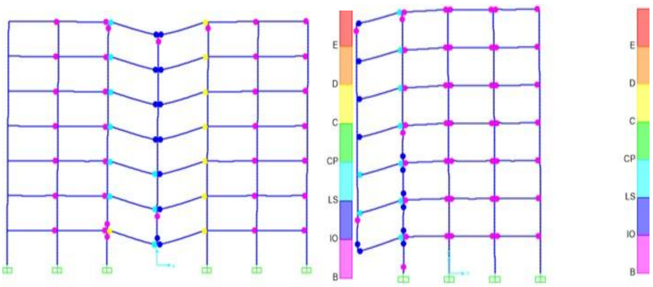
(a) (b)

Fig. 9. Plastic hinges of Model 4 at last step in (a) X-dir and (b) Y-dir



(a) (b)

Fig.10. Plastic hinges of Model 5 at last step in (a) X-dir and (b) Y-dir



(a) (b)

Fig.11. Plastic hinges of Model 6 at last step in (a) X-dir and (b) Y-dir

The Plastic hinge deformation is shown in table 6, and it is observed that for a bare frame 1.46% of members are in C to D state whereas less than 1% are in D to E state. For a bare frame with slab bracing reduction of members from C to D happens and no member is in D to E state which is good, but the complete arrest of progressive collapse is not possible with slab bracing. When a bare frame with slab bracing is compared with the bare frame with steel bracing is better than a bare frame with slab bracing. The percentage of members in C to D is 0.68% and when A to B and B to IO are compared steel bracing has 60.31% and 38.99%, for slab bracing it is 58.00% and 38.26%, it also has members in IO to LS and LS to CP making it up to 1.75% and 1.37%. From fig.9,10 and 11, it can be observed that columns above the column removed point are not affected due to progressive collapse in bare frame with steel bracing case where as in other two cases columns above column removed point are observed to be under the effect of progressive collapse. The effect of progressive collapse is seen to propagating to more primary structural elements.

D. Pushdown analysis for Corner column removal:

The pushdown curves of corner column removal in different cases are shown fig.12, for bare frame model, the ultimate capacity of structure is found to be 114903.129 kN at a displacement of 0.002786 m, for bare frame with steel bracing the ultimate capacity of structure is found to be 106209.126 kN at a displacement of 0.00098 m and for bare frame with slab bracing ultimate capacity of structure is found to be 104307.8 kN at a displacement of 0.002858 m. Form the comparison of curves it is noted that bare frame with steel bracing has 7.56 % reduction of force than that of the bare frame and the displacement is also reduced by 64.82 % .It is also observed that for the bare frame with steel bracing the curve is linear as steel bracing provided to bare frame resist the effect of progressive collapse.

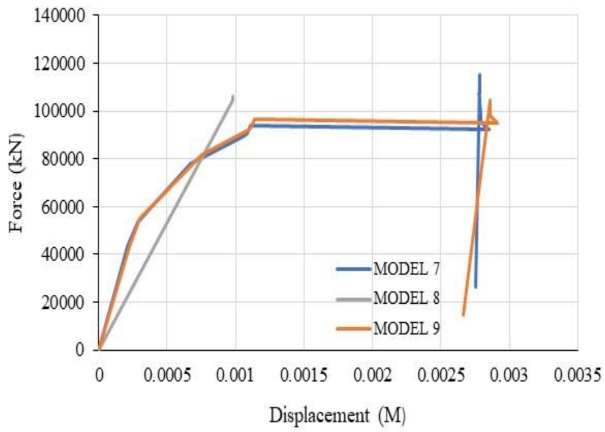
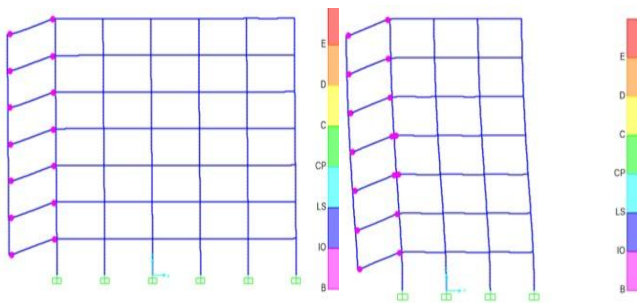


Fig. 12. Pushdown curves of Corner column removal

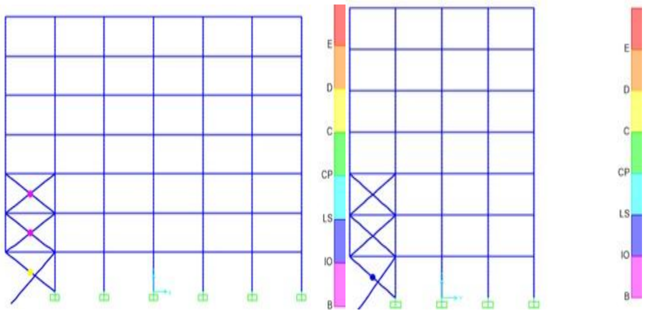
Table VII: Plastic hinge deformation results

Hinge states	Model-7	Model-8	Model-9
A to B	1205	1302	1240
B to IO	94	8	65
IO to LS	0	1	0
LS to CP	0	0	0
CP to C	0	0	0
C to D	1	1	1
D to E	0	0	0
Beyond E	0	0	0



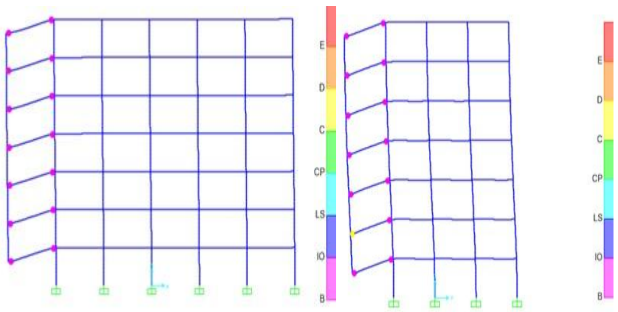
(a) (b)

Fig.13. Plastic hinges of Model 7 at last step in (a) X-dir and (b) Y-dir



(a) (b)

Fig.14. Plastic hinges of Model 8 at last step in (a) X-dir and (b) Y-dir



(a) (b)

Fig. 15. Plastic hinges of Model 9 at last step in (a) X-dir and (b) Y-dir

From table 7 it is observed that in corner column removal case for bare frame model 0.07% in C to D ,7.23% are in B to IO and 92.69% are in A to B whereas for slab bracing 0.07% of members are in C to D ,94.94% are in A to B ,4.97% are in B to IO. For steel bracing frame the values are better than slab bracing 99.23 % of members are A to B state whereas the 0.60 % in B to IO state, IO to LS is 0.07% and 0.07% in C to D which are steel bracings provided to resist progressive collapse. From figure 13,14and 15, it can be seen that primary structural elements in bare frame and bare frame with slab bracing are affected with progressive collapse in corner column removal case whereas when steel bracing is provided to the effect of progressive collapse doesn't propagate to primary structural elements, and none of primary structural element is effected in bare frame with steel bracing. As corner column is very distant from most of the primary structural members and the slab effected due to progressive collapse in also only one the effect of progressive collapse is less and this effect also doesn't propagate throughout the structure it only affects the area adjacent to column removed position and when steel bracing is provided total resistance from propagation of progressive collapse to primary structural elements can be seen.

VII. CONCLUSIONS

1. The time period of the bare frame with steel bracing is less than that of the bare frame and bare frame with slab bracing in the centre, edge and corner column removal. It concludes that the time period does not change without bracing in column removal at the centre, edge and corner but adding bracing, the time period is reduced in the centre and edge column removal and almost same in corner column removal before and after adding the bracing. In mode shapes, for the bare frame and bare frame with steel bracing in slab has the first mode as translation mode whereas for the bare frame with steel bracing has the first mode as rotation mode.
2. In the pushdown analysis, it can be concluded that bare frame with steel bracing has higher force carrying capacity in centre column removal scenario whereas less force carrying capacity in edge and corner column removal scenario compare to bare frame and steel bracing in slab frame. And Displacement is reduced in bare frame with steel bracing and increased in steel bracing in slab frame. In adding the steel bracing in-wall, stiffness and strength are increased all the column removal scenarios.
3. From plastic hinge deformation pattern, it concludes that the final collapse state, C to D state is found in steel bracing element only not in primary element whereas slab bracing and bare frame C to D state are in primary elements. It is observed that the bare frame with steel bracing performs better in resisting the effect of progressive collapse and reduces the propagation of progressive collapse force to other primary structural members.
4. Among all three scenarios, i.e. centre column, edge column and corner column removal, centre column removal has a larger impact on the building whereas corner column has less impact on the structure.

REFERENCES

1. D.A. Nethercot, Design of Building Structures to Improve their Resistance to Progressive Collapse, The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction, (2011) Published by Elsevier Ltd.
2. General service administration, Alternate Path Analysis and Design Guidelines for Progressive Collapse Resistance, January, (2016).
3. IS 800:2007: General construction in steel – code of practice (Third revision)
4. IS 456:2000, Plain and Reinforced Concrete-code of practice (fourth revision).
5. Meng-Hao Tsai, Tsuei-Chiang Huang, Progressive Collapse Analysis of an RC Building with Exterior Non-Structural Walls, The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction, Procedia Engineering 14 (2011) Pg.: 377–384.
6. S. M. Marjanishvili, Progressive Analysis Procedure for Progressive Collapse, Journal of Performance of Constructed facilities, (2004): Pg:79-85.
7. Unified Facilities Criteria (UFC), Design of Buildings to Resist Progressive Collapse, UFC 4-023-03, November (2016).

AUTHORS PROFILE

Ifteqhar Ahmed Khan, Master's Student, Structural Engineering, Anurag Group of Institutions (An Autonomous Institution), Venkatapur, Hyderabad, Telangana, India. (Mail: ifteqharahmedpathan@gmail.com)

Dr.B. Narender, Associate Professor, Structural Engineering, Anurag Group of Institutions (An Autonomous Institution), Venkatapur, Hyderabad, Telangana, India. (Mail: drnbodigece@cvsr.ac.in)