Study on Collapse Mechanism of Typical Rc Beam Against Progressive Collapse Under Column Removal Scenario

Divya T.H. and Nikhil R.

Abstract— This work investigates the response of typical RC beam under the column removal scenario and their potential resistance against progressive collapse. This paper analyses different span buildings with typical beam depth. Three different spans were chosen for this study such as 3, 4, 6 m and typical beam depth is 400 mm, obtained from L/D =15 in the case of 6m span. This study focuses buildings with aspect ratio L/B=B/H=L/H=1. Column removal locations are corner, intermediate and perimeter as per GSA and DoD. Load combination and beam reinforcement followed as per progressive collapse guidelines. Nonlinear dynamic analysis carried out in ETABS 17.0.1 software. The conducted study shows that maximum displacement is 50 mm, occurred in 6 m span at corner column removal scenario. Maximum DCR value was obtained for the 6m span building, intermediate ground column removal case.

Key words—.: alternative path method; aspect ratio; catenary action; DCR value; L/D ratio; plastic hinge; progressive collapse

1 Introduction

Progressive collapse is a dynamic event corresponding to structural failure mechanism triggered by the irreversible damage of one or more key structural elements which forces a redistribution of the loads and internal forces in the structure (Li et.al. [3]). Progressive collapse usually described as castrophic dynamic behavior influence by both material and geometric nonlinearities. In last few decades, several structures have taken place progressive collapse. More attention was given for progressive collapse since 1968.In 1968 the collapse of the Ronan building in East London took place because of gas explosion on the 18th floor of building. In 1995, the murrah federal office building in Oklahoma City collapsed because of a terrorist bomb explosion at the ground floor of building. The famous world trade center collapse was another example of progressive collapse. Reason of collapse plane impacting the upper level of the tower. In India, there are many structural damages caused due to progressive collapse. Unfortunately, there is only very little awareness about this phenomenon and therefore, many cases go unnoticed. Very few incidents are reported or detailed investigation is done to determine the cause of the failure and to make preventive measures for the same. Couple of cases are identified which are as below In 2008, Prestige Shantiniketan Township Collapse at Bangalore. At Bangalore, Tower C' of prestige shantiniketan, a town ship project on a 150acre campus. The project was a flat slab construction, Tower C came down crashing in Tuesday evening, October 23, 2008. Of all the 14 floors, a portion of the Tower C collapsed. Around 4.20pm, one side of corner roof started to fail. Six floor of the block crushed within the next 30 minutes as shown in figure 1

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In January 2014, Canacona Building Collapse at Goa Six storied structure named Ruby Residency located at Canacona, Goa. Failure occurred at the fourth floor on January 4, 2014 at 3pm. Construction of fourth floor was completed at the time of failure and the construction was going on at 5th floor. Reason for the failure is bad design of slab at fourth floor. This led to the overall failure of whole structure as shown figure 2

Progressive collapse in structure mainly occur due to abnormal loads, gas explosion, vehicle impact, fire, earthquake or other manmade or natural hazards. When major structural load carrying members are suddenly collapsed by abnormal loads, remaining structural elements cannot support the weight of the building or gravity loads. As an ultimate result of this event, substantial part of the structure may collapse, causing greater damage to the structure than the initial impact. Therefore, this study focuses arresting or eliminating progressive collapse by various guidelines. The U.S General Service Administration (GSA) and Department of Defense (DoD) provide detailed stepwise procedure regarding methodology to resist progressive collapse of building structure. This paper uses alternative path method shown figure 3. This method, transferring the forces through the loss of a load-bearing element. This approach does not determine threats or the reason of damaged condition; it restricts the acceptability of the abnormal loading conditions that would cause the provided level of damage. The advantage of ALP method is that it supports structural systems with ductility, continuity and energy consuming properties that are suitable in preventing the progressive collapse. Several theories, including beam action, catenary action etc can be used for calculating distribution of load after the loss of the column or another load bearing element of the construction. The beam action needs moment resistance from the horizontal member when the catenary action is based on the axial force of the membrane.

FIG. 1 SHANTINIKETAN TOWNSHIP COLLAPSE

FIG. 2 CANACONA BUILDING COLLAPSE

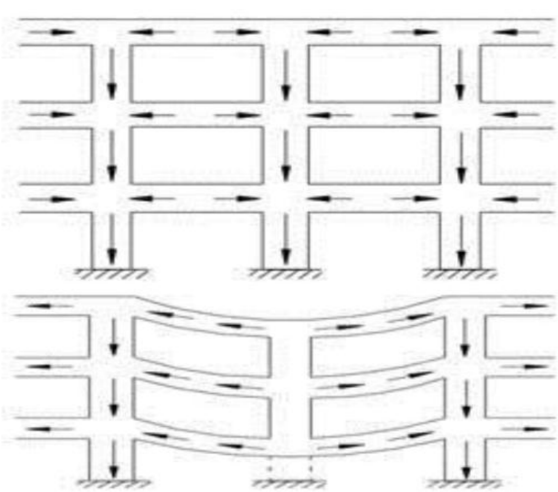


FIG. 3. ALTERNATIVE LOAD PATH METHOD

2 OBJECTIVE

The objective of this present study is to analyze the effect of typical beam in progressive collapse of multi-story RC buildings. It also includes the behaviour of the building under critical load bearing member loss. Buildings design as per the GSA [12] and UFC [13] guidelines in order to reduce the effect of progressive collapse.

3 CHARACTERISTICS OF BUILDING TO BE STUDIED

An 8-storey RC building with special moment resisting frame is designed. The building is assumed to be located on site class C, soft soil as per IS 1893:2016. Three different buildings are considered whose spans are 3, 4, and 6m with L/D ratio of beam 15. As obtained some results from post study says that L/D ratio 15 is a more versatile condition in 6m span building study. Thus, here all the spans were provided typical building beam depth 400mm. The minimum column size 400mmx400mm as per code IS 13920:2016. Live load of 3kN/m^2 except roof and 1.5 kN/m^2 were provided on roof as per IS 875 part 2. Provided all slabs with a floor finish 1 kN/m^2. Load combination as per GSA code, in static case 2 DL+0.5 LL and dynamic case DL+0.25 LL.

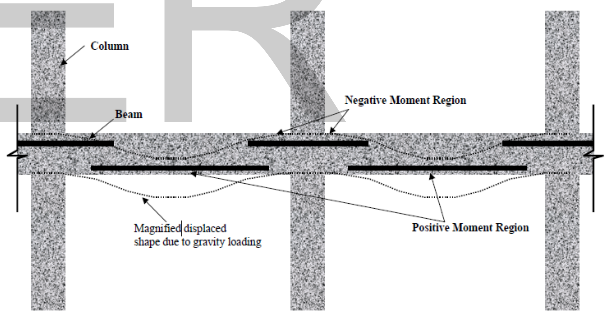
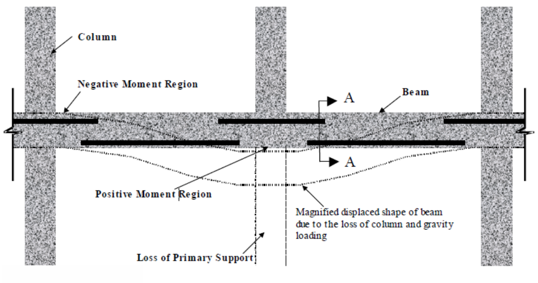
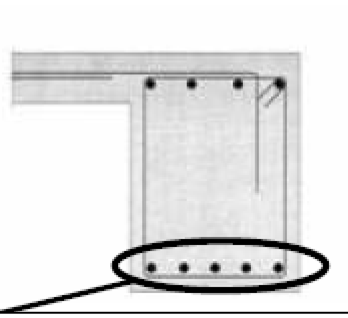


FIG. 4. SKETCH DEPICTING THE REINFORCEMENT SCHEME FOR A BEAM DESIGNED FOR GRAVITY LOADS ONLY

Column removal location as per GSA and DoD guidelines. GSA 2003 only consider first floor column removal cases but recently the guide lines were modified in 2013. The purpose of modification met the requirements of GSA and DoD guidelines. Recent guide lines consider all floor of column removal locations. The column removal location at corner indicated as C-G, C-M, and C-R are corner ground, corner medium and corner roof respectively. Similarly, INT-G, INT-M and INT-R for intermediate ground, intermediate medium and intermediate roof respectively. Finally, P-G, P-M and P-R for perimeter ground, perimeter medium and perimeter roof respectively. Building height, length and breadth were chosen as 24 m, to obtain a building with aspect ratio 1. Typical height of each floor 3m and base to plinth height 2.4m.



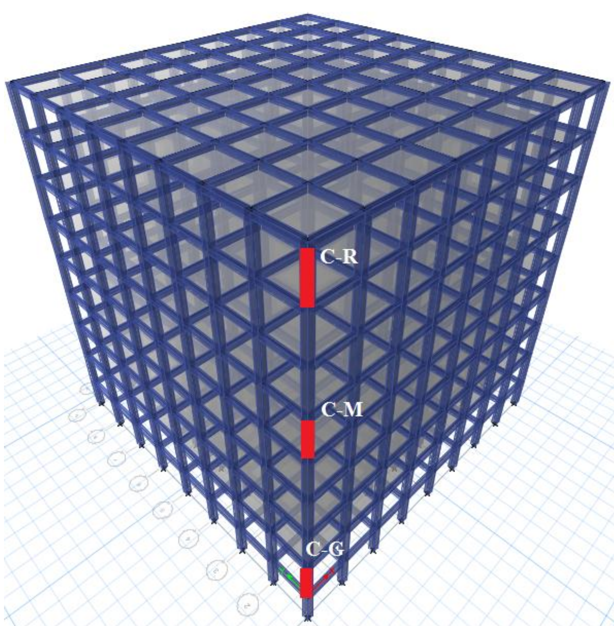
SECTION A-A



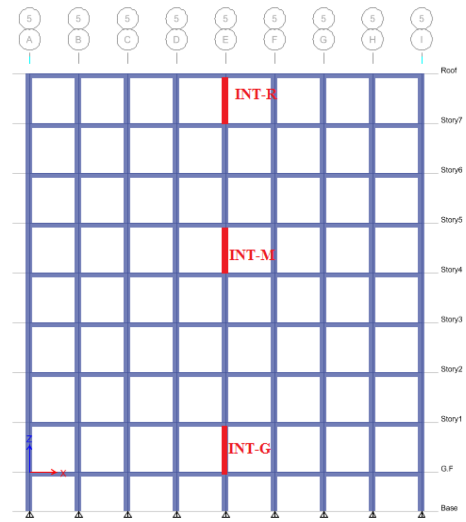
Note: Providing continuous bottom reinforcing steel across the connection is essential to accommodating the double-span condition

FIG. 5 RESPONSE OF THE BEAM SHOWN FIG. 4 AFTER LOSSES OF PRIMARY COLUMN SUPPORT, SHOWS THE INABILITY TO PROTECT AGAINST PROGRESSIVE COLLAPSE. [12]

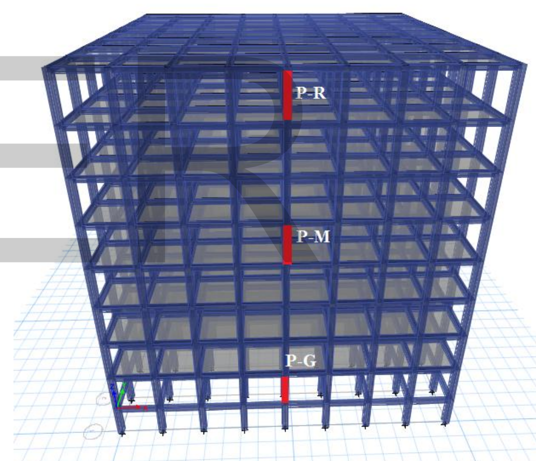
3.1 MODELS



(a) Corner column removal location @ 3m

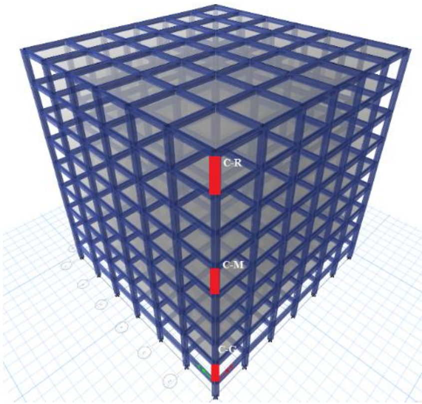


(b) Intermediate column removal location @ 3m

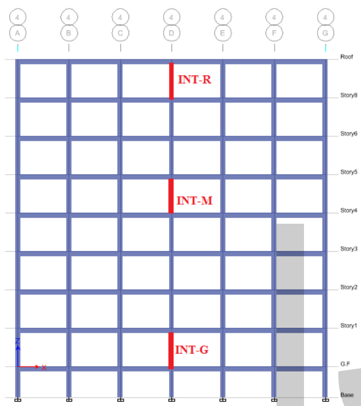


(c) Perimeter column removal location @ 3m

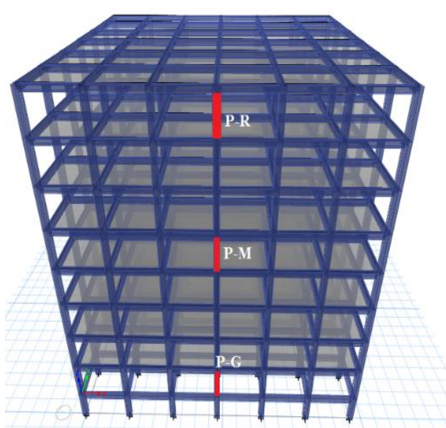
FIG. 6. a, b, c ARE COLUMN REMOVAL LOCATIONS OF TYPICAL 3 m SPAN BUILDING



(a) Corner column removal location @ 4 m

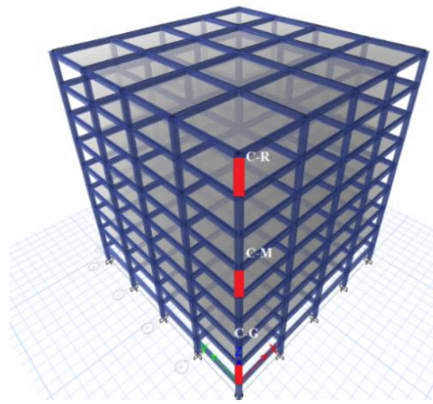


(b) Intermediate column removal location @ 4m

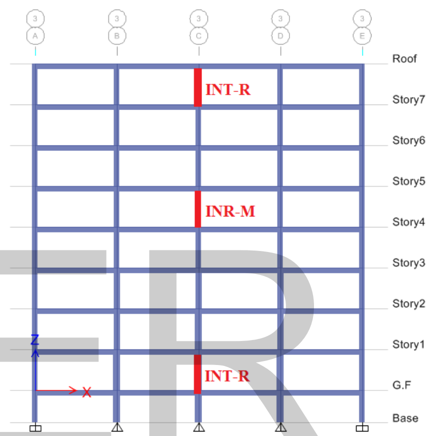


(c) Perimeter column removal location @ 4m

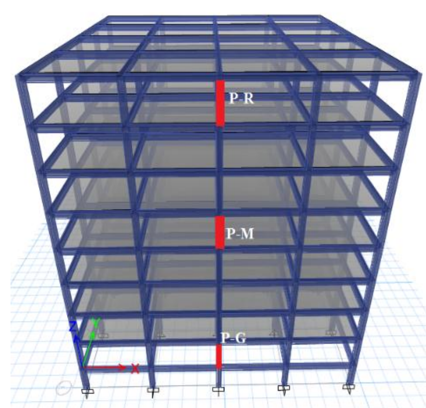
FIG. 7. a, b, c ARE COLUMN REMOVAL LOCATIONS OF TYPICAL 4 m SPAN BUILDING



(a) Corner column removal location @ 6 m



(b) Intermediate column removal location @ 6m



(c) Perimeter column removal location @ 6m

FIG. 8: a, b, c ARE COLUMN REMOVAL LOCATIONS OF TYPICAL 6m SPAN BUILDIN

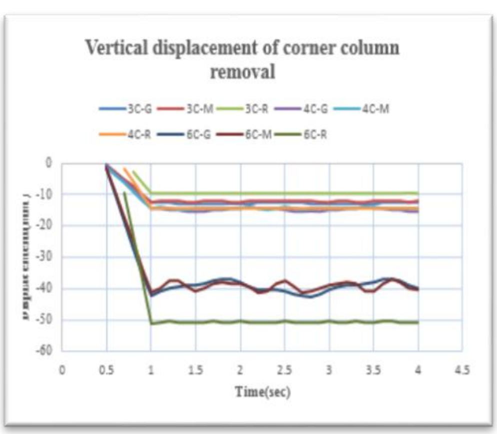
4 METHODOLOGY

The analysis was carried out for nonlinear dynamic analysis. It is an efficient method of analysis. Primary load bearing structural element is removed dynamically and the structural material is allowed to undergo nonlinear behavior. The main difference between nonlinear and linear dynamic analysis that in nonlinear dynamic case is that, the structural elements are allowed to enter in their inelastic range.

- Build a computer model by software ETABS
- Determine the forces present at equilibrium in each column to be removed.
- Static nonlinear analysis case are used as starting condition for column removals.
- For each column removal, the column member is deleted in the model and internal force determined from the equilibrium model are applied to the structure as load case to the joint or joints at each column end.
- Choose nonlinear parameter button
- When equilibrium is reached in the structure, remove the column by ramping down the column forces under a duration of less than one-tenth of the period associated with the structural response mode for column removal
- The analysis shall continue until the maximum displacement is reached.

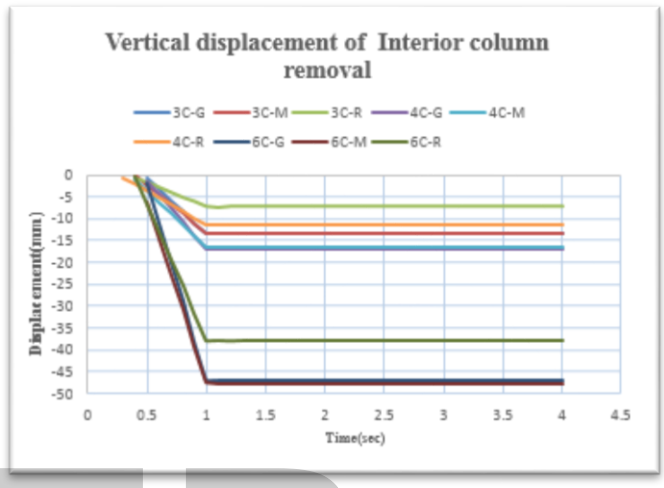
5 RESULT AND DISCUSSIONS

As per the graph results, the more versatile condition is the corner column removal case. More fluctuation occurs in this area due to lack of effective catenary action. When corner column is removed, beam at corner location act as cantilever causing more torsional effect. Maximum displacement occurs in the intermediate column removal scenario due to maximum axial force at this location but torsion effect is very less compared to other two locations. Perimeter column removal cases shown very less displacement compare to other two locations and higher torsion effect compared to intermediate case and lower compared to corner column removal scenario.

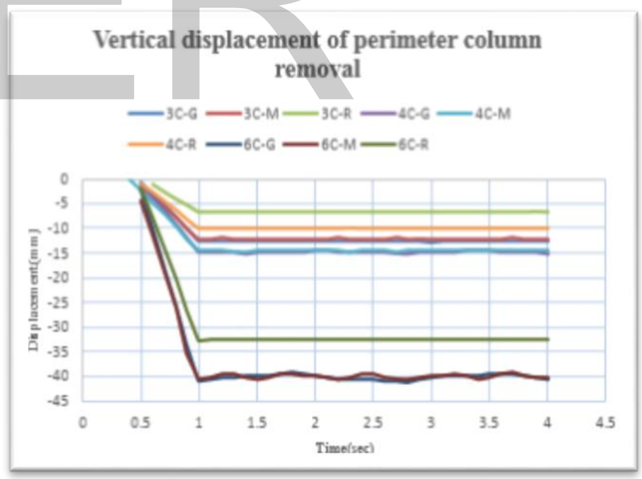


(a) CORNER

The analysis results show that maximum displacement occurred in corner case is 50.516 mm at roof, for intermediate column removal scenario displacement is 47.554 mm at middle floor and perimeter case displacement is 40.475 mm at ground level. DCR value obtained for the 6m span building is 2, for intermediate ground column removal case. Here it is clear that 400 mm depth is sufficient for 3 and 4m span buildings. Maximum displacement obtained for 6m span building is for corner column removal case at roof.



(b) INTERMEDIATE



(c) PERIMETER

FIG.9: VERTICAL DISPLACEMENT OF DIFFERENT SPAN IN DIFFERENT LOCATION BY COLUMN REMOVAL SCENARIO

6 CONCLUSIONS

This paper carried out analysis of three different spans RC building with typical beam with aspect ratio 1. For this study 3 different building with 8-storey were considered. The maximum displacement occurs in the 6m span building roof in corner column removal scenario. 3 and 4m span buildings have sufficient depth, which is provided with 400mm beam but it is not ideal for 6m span building. For 6m beam L/D ratio 15 is not suitable and it is better to avoid 6m beams at corners. The maximum displacement varies according to storey height, span of beam, beam depth, number of bays and column removal location. Maximum versatile condition is the corner column removal case due to lack of effective catenary action. Progressive collapse reduce rigidity of structure so span and L/D ratios are to be selected carefully. Provide load combinations and continuous bottom reinforcement as mentioned in GSA and DoD guide lines.

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REFERENCES

[1] H.M. Salem et al. (2011). "Toward An Economic Design of Reinforced Concrete Structures against Progressive Collapse." *J. of Structural Engg* 33 (2011) 3341–3350

[2] Kamal Alogla (2016). "A new mitigation scheme to resist progressive collapse of RC structures" *J. of structural engineering Engg* 125 (2016) 533-545

[3] Li et.al (2011) "An improved tie force method for progressive collapse resistance design of reinforced concrete frame strutures" *J. of Structural Engg* 33 (10): 2931-2942

[4] Niloufar Mashhadiali et al. (2016). "Dynamic Increase Factor for Investigation of Progressive Collapse Potential in Tall Tube – Type Buildings." *J. of Structural Engg* 10.1061 / (ASCE) CF.1943-5509

[5] Sasani, M. (2008). "Response of a reinforced concrete infilled-frame structure to removal of two adjacent columns." *J. of structural engineering Engg* 30 (10) : 248-2491

[6] Sasani, M., Bazan, M., and Sagiroglu, S. (2007). "Experimental and analytical Progressive collapse evaluation of an actual reinforced concrete Structure." *J. of structural engineering Engg* 104 (6): 731-739

[7] Sasani, M., Kazemi, A., Sagiroglu, S., and Forest, S. (2011). "Progressive Collapse resistance of an actual 11-story structure subjected to severe Initial damage." *J. of structural engineering Engg*10.1061/(ASCE)ST.1943-541X.0000418.

[8] Sasani, M., and Kropelnicki, J. (2008). "Progressive collapse analysis of an RC structure." The Structural Design of Tall and Special Buildings,17:1, 757-771

[9] Sasani, M., and Sagiroglu, S. (2008). "Progressive collapse resistance of Hotel San Diego." *J. of structural engineering Engg* 134(3), 478-488

[10] Sasani, M., and Sagiroglu, S. (2010). "Gravity load redistribution and Progressive collapse resistance of a 20-story RC structure following lossOf an interior column." *J. of structural engineering Engg ACI*

[11] Wei – jian Yi et al. (2018). "Experimemental Study on Progressive Collapse – Resistant Behavior of Reinforced Concrete Frame Structures " J. of structural engineering Engg ACI

[12] U.S General Service Administration, Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects

[13] Unified Facilities Criteria (UFC), Design of buildings to progressive collapse UFC 4-23-03June 2013