

# Seismic Performance Evaluation of RC Structure against Progressive Collapse under Different Column Removal Scenario

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**ABSTRACT:** Progressive collapse is a nonlinear dynamic event which occurs when load carrying members are removed. In the present study, a progressive collapse assessment according to GSA and DoD guidelines are carried out for a G+7 RCC building. Using nonlinear dynamic analysis with joshua earthquake data. This dynamic phenomena created due to various human activities and natural phenomena adversely affect buildings, its occupants and human life. Aim of this study is to understand performance of RC building under the column removal scenario during an earthquake data. Nonlinear direct integration analysis is performed using ETABS 17.0.1 to understand response of a structure during seismic action. For this study column removal locations considered are corner, intermediate and perimeter of the plans. Beams are considered for this study optimum. L/D ratio of Beam is obtained as per IS 456 - 2000, for 3m and 4m span L/D ratio 12 is considered and L/D ratio 10 is considered for 6m span beam. DCR value is less than 2.

**KEYWORDS:** progressive collapse; catenary action; aspect ratio; L/D ratio; DCR value; plastic hinge.

## I. INTRODUCTION

Progressive collapse is described as the spread of an initial local failure from element to element due to lack of structural continuity, ductility and redundancy that leads to partial or total collapse of a structure. Department of defense (DoD) and general service administration (GSA) issue guidelines for design of structures (both RC and steel) to resist progressive collapse. Both documents (GSA 2003, DoD 2005) are recommended to be applied to, low to medium rise structure with common structural system. Abnormal loads such as earthquake, gas explosions and vehicle collision tend to lead local failure in structures. If local failures are uncontrolled, they can lead to partial or full progressive collapse of structure.

In 1968, the partial collapse of the Ronan point Apartment building in London, England generated a wide spread concern for progressive collapse of buildings in chain reaction mode, triggered by local failure. The Ronan point collapse occurred due to the gas explosion in an apartment on 18<sup>th</sup> floor of a 22 storey precast concrete building. By the gas explosion below out the exterior bearing wall of the apartment that caused the upper floor triggered the collapse of one corner of the building almost to the ground take place as shown in figure 1(a) Since the Ronan point apartment building collapse was considered as “progressive collapse” both in the vertical and horizontal direction, that led to a total or a disproportionately large failure relative to an initiating local failure. The Alfred .P. Murrah building, located in Okalahoma city, Okalahoma was an office facility for U.S. government and it was constructed between 1970 and 1976. It was composed of nine-storey, and was a reinforced concrete ordinary moment resisting frame. On April 19, 1995 the Murrah federal building was the target of terrorist’s attack in which a truck bomb was denoted in front of its northside of murrah building. By the explosion, extensive structural damage was caused to the building. Most of the north half of the building was damaged as the north side of the murrah building, which was exposed directly to the blast. In the third

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floor, three columns that supported the transfer girder were immediately destroyed by the blast, triggering progressive collapse of the upper stories as shown in figure 1 (b)

Several other notable events for progressive collapse of structures which are:-

- L'Ambiance Plaza at Bridgeport, Connecticut
- U.S. Marine Barracks Lebanon
- Kansas City Hyatt Regency Hotel Walk Way Collapse
- Skyline Plaza – premature formwork removal
- Civic Arena Roof collapse
- World Trade Centre
- Khobar Towers
- Jackson Landing Skating Ring – Excessive ice load



(a)



(b)

Fig. 1 Collapse of (a) Ronan Point Apartment Building (b) Alfred. P.Murrah building

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(a)



(b)

Fig. 2 Collapse of (a) U.S Marine Barracks (b) Skyline Plaza

## II. GENESIS OF PROGRESSIVE COLLAPSE

Progressive collapse occurs in the building structure under the abnormal loads. Abnormal load resistance criteria is not considered in the normal building design. Therefore, when buildings are subjected to such type of loads, progressive collapse may take place. The potential of abnormal loads that can trigger the progressive collapse are classified as follows:-

### ➤ PRESSURE LOADS

- Internal gas explosion
- Blast loads
- Extreme value of wind pressure

### ➤ IMPACT LOADS

- Aircraft impact
- Vehicular collision
- Earthquake

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### III.OBJECTIVES

The objective of the present study is to analyse the effect of span length and beam depth in progressive collapse of multistory RC buildings. It also includes the behavior of building under critical member loss using Joshua earthquake data.

### IV. DETAILS OF HYPOTHETICAL CASES

To study the effect of column removal condition on the structure, hypothetical case of G+7, storied reinforced concrete building with special moment resisting frame is considered. Total height of building is 24 m and all floor height are 3m. Height of base to plinth is taken as 2.4 m. Aspect ratio L/B= 1. (Length and breadth of building 22 m). Building is to be located in seismic zone 5, as per IS: 1893-2016. Hypothetical buildings are designed as per IS 456-2000, IS 1893-2016, IS 875 -2000, IS 13920-2016, SP 34, GSA (2013), and DoD (2010).

Table 1 Details of Properties in Hypothetical Building

MATERIAL PROPERTIES	
Grade of concrete	M 34.5 (MPa)
Unit weight of concrete	23.5 kN/m <sup>3</sup>
Modulus of elasticity	29600 MPa
Grade of steel	Fe 413 (MPa)
Density of concrete	25 kN/m <sup>3</sup>
Wall thickness	200 mm
LOADS IS 875 PART 2	
Live load on all floor	3 kN/m <sup>2</sup>
Live load on roof	1.5 kN/m <sup>2</sup>
Floor finish	1 kN/m <sup>2</sup>
SEISMIC DETAILS IS 1893-2016	
Zone factor Z	0.36
Site type	III (soft soil)
Importance factor	1.5
Reduction factor R	5

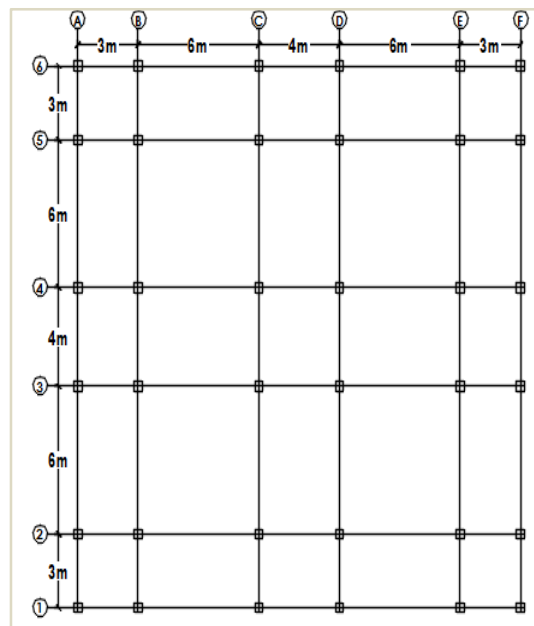


Fig. 3 Plan of Hypothetical Case Study Building

Column removal locations as per guidelines where corner, intermediate and perimeter of the building. Column removal stories are ground, middle (4<sup>th</sup> floor) and roof are considered for this study. Progressive collapse analysis is based on the GSA and UFC guidelines. As per IS 1893 – 2016 Earthquake Load along X direction (EQX) and Earthquake Load along Y direction (EQY) acting and load combinations are considered for design of structural elements 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 and 0.9 DL ± 1.5 EQY. The earthquake data selected should have higher magnitude; it should have the ability to cause high structural destruction and damage. Selected earthquake data name is Landers in 1992 station at Joshua with magnitude 7.28 and PGA was 0.3629.

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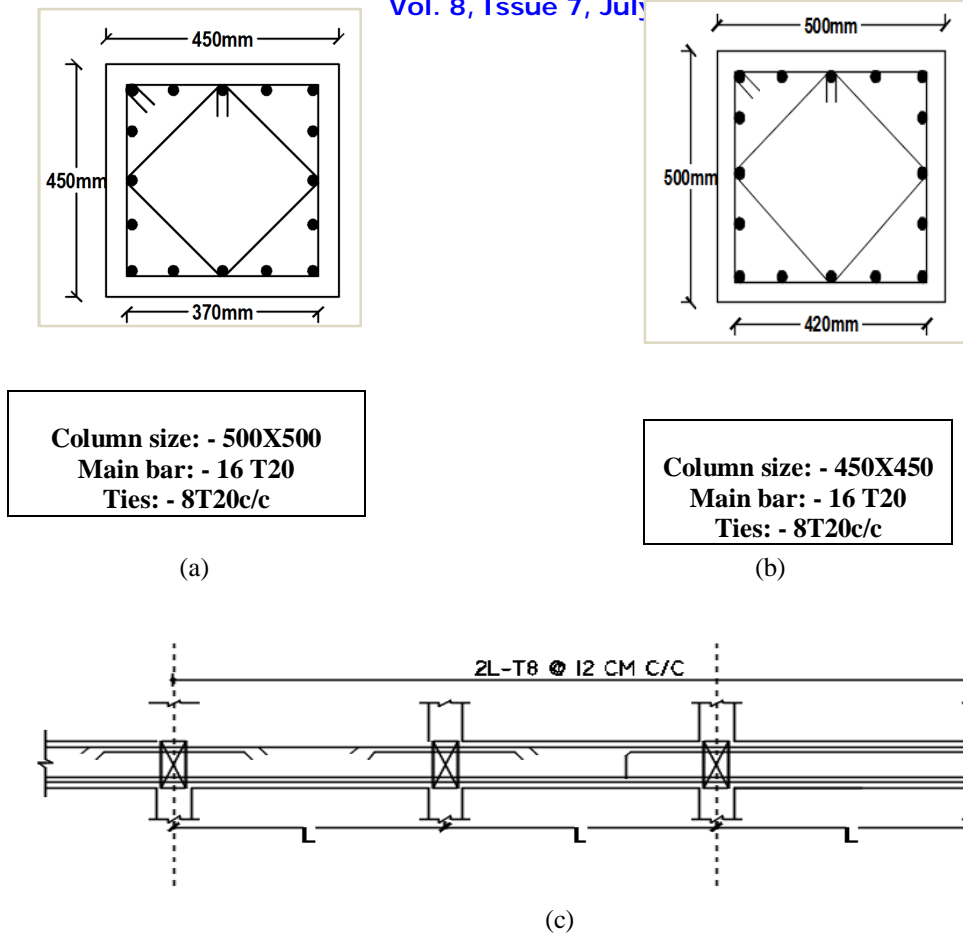


Fig. 4 Reinforcement details of columns(a)500 x 500 mm and (b) 450 x450 mm and (c) Beam as per GSA guidelines

Table 2 Building Details

SPAN (m)	COLUMN (mm)	BEAM (mm)	SLAB (mm)	WALL LOAD (kN/m <sup>2</sup> )
3	GF - 4 <sup>th</sup> : 450 x 450 (interior column) & 400 x 400 (exterior column)	300x250	100	11
4	5 <sup>th</sup> - ROOF : 400X400 (Exterior & interior column)	300x350	110	9.6
6		300x600	170	10.6

Column Section definition cover provide 25mm and grade beam cover 60mm. Column cover provide 40 mm and 20 mm diameter of bars. The minimum 2 % steels are used for this study. The analysed case building composed three different span with different beam depth are shown in table 2. The material properties and IS 1893 -2016 conditions are same as the other building shown in table 1. This case sociality that consider Pacific Earthquake Engineering Research (PEER) Centre. PEER provides information of very large set of earthquake motion recorded worldwide. Database

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obtained from PEER contain detailed set of earthquake details such as magnitude of earthquake, source details, fault details, local site conditions of earthquake recording station, other important and relevant engineering parameters. Earthquake is a probability case of progressive collapse. Seismic analysis provided in FEMA 356 consist of four different type of analysis procedures for seismic performance based evaluation is same progressive collapse analysis are

- **NON LINEAR ANALYSIS**
  1. NON LINEAR DYNAMIC ANALYSIS
  2. NONLINEAR STATIC ANALYSIS
- **LINEAR ANALYSIS**
  1. LINEAR DYNAMIC ANALYSIS
  2. LINEAR STATIC ANALYSIS

## V. MODELS AND COLUMN REMOVAL LOCATIONS

The column removal location at (a) corner indicated as C-G, C-M, and C-R are corner ground, corner medium and corner roof respectively (b) INT-G, INT-M and INT-R for intermediate ground, intermediate medium and intermediate roof respectively. (c) P-G, P-M and P-R for perimeter ground, perimeter medium and perimeter roof respectively as shown in figure 5. Column removal locations considered as per General Service Administration and Department of Defense guidelines.

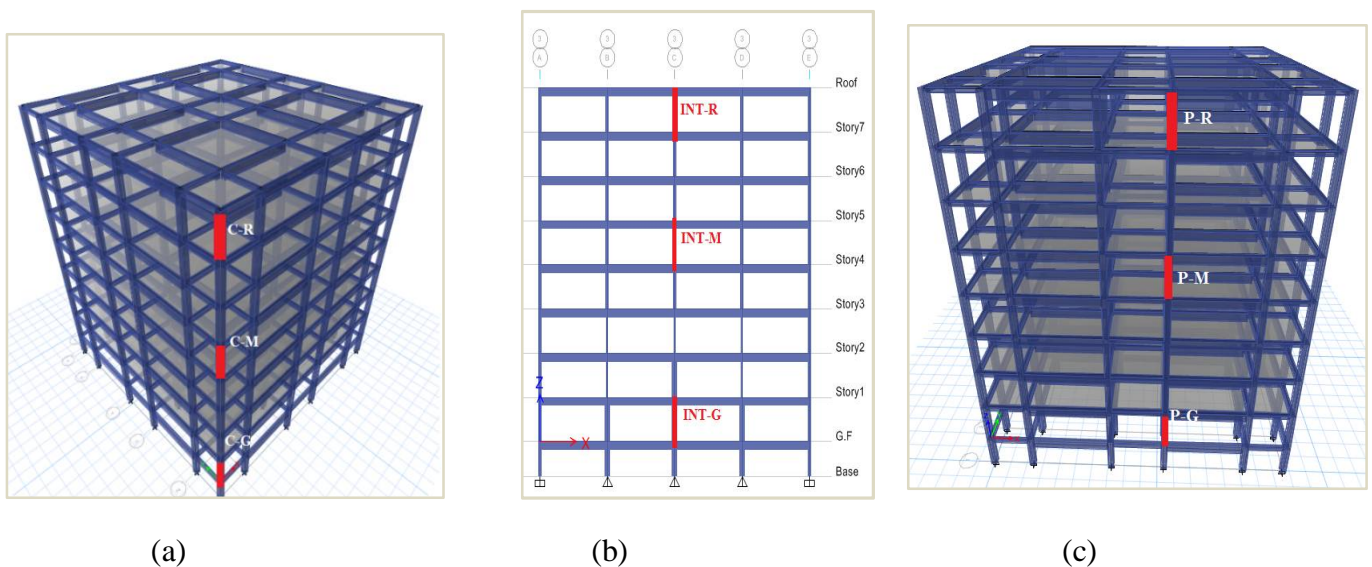


Fig. 5 Column Removal Locations of Hypothetical Case Study Building (a) Corner column ,(b) Intermediate column and (c) Perimeter column

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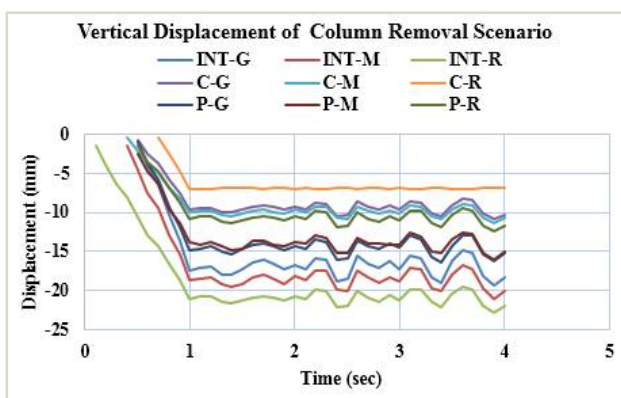
## VI.METHODOLOGY

As per guidelines following three procedures are used for analysing structures subjected to progressive collapse: first one, Linear static procedure also called LSP which is simplest method in this method material is assumed to be linearly elastic; no geometric nonlinearity is considered; and structure is supposed to experience small deformation. Second one is nonlinear static analysis also called NSP, in which both geometric and material nonlinearities are considered; third case is nonlinear dynamic procedure also called NDP which involves inertia and damping effects and it gives most accurate results. In the current study the method used is nonlinear dynamic procedure. The main difference between nonlinear and linear dynamic analysis is that in nonlinear dynamic case, the structural elements are allowed to enter the inelastic range.

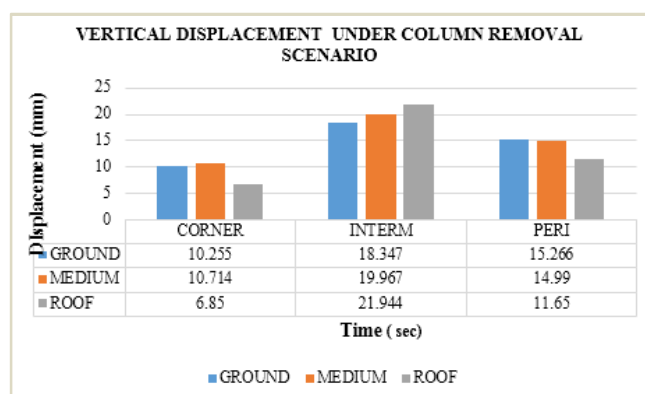
Following procedure were carried out for this study:

- ETABS 17.0.1 software used for modelling
- Apply load combination as per progressive collapse guidelines
- Determine the forces present at equilibrium in each column to be removed.
- Static nonlinear analysis case are used as starting condition for column removals
- Find the gravity load carrying capacity of vertical members (i.e. column) to be removed
- Remove the column and corresponding axial force of removed columns to be provided as point load
- Remove the point load using time history ramp function
- Evaluate the result based on demand capacity ratio (DCR) for beams

## VII. RESULT AND DISCUSSION



(a)



(b)

FIG. 6 Vertical Displacement Graph (a) Column Removal Conditions in each Locations (b) Maximum Displacement Value in each Locations

The analysis results show that maximum displacement occurred in intermediate case is 21.944 mm at roof, for corner column removal scenario displacement is 10.714 mm at middle floor and perimeter case displacement is 15.266 mm at ground level.

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## VII. DEMAND CAPACITY RATIO

According to GSA (20013) guidelines the DCR, of the member force and the member strength, is a measure to determine the failure of main structural member by linear dynamic procedure. Figure shown the maximum bending moment diagram

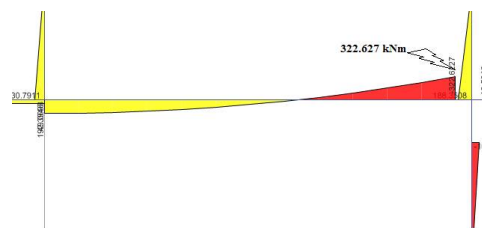


FIG. 7 Maximum Bending Moment under Column Removal Scenario

$$D.C.R = QUD / QCE$$

Where, QUD = Acting force or demand determine (shear, axial force, bending moment, and possible combined forces

QCE = Apparent ultimate capacity (shear, axial force, bending moment, and possible combined forces

DCR < 2.0 for typical structural configurations and DCR < 1.5 for atypical structural configurations. The current study model is typical

Where, QUD = 322. 627 kNm from the software

$$QCE \Rightarrow Mu_{limit} = 0.138 \times f_{ck} \times b \times d^2$$

$$= 0.138 \times 34.5 \times 300 \times 565^2$$

$$= 455.9 \text{ kNm}$$

$$DCR < 2$$

The maximum DCR value obtained from column removal of intermediate case at ground floor level. The value of demand moment is 322.627 kNm obtained since 5 sec. For the case study a maximum time of 5 second is considered, the number of output time steps were taken as 50 and output time step size 0.1 second. DCR value is less than 2, building is safe condition occur.

## VIII. CONCLUSION

This paper conducts analytical study of RC structure for progressive collapse and economic beam design. Progressive collapse resistance of 8-storey RC structure with 24 m height and aspect ratio 1. Span to depth ratio have a significant effect on the performance of RC frame to arrest progressive collapse, among the cases of column removal, most damage occurs when interior column is lost. Catenary action helps to resist progressive collapse but in corner column removal case catenary action is absent. Roof displacement is higher, when same load is provided in all the floors because that sharing members is less compare to other floors. In practical case roof displacement depends the depth of beam, span length and column removal location. Corner column removal is severe due to cantilever action. This paper also consider the earthquake data so that displacement also depends its magnitude. Variation of displacement is non uniform through the height of the structure, span, depth of beam, moment of inertia, deflection. In the study, DCR value is less



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than 2, in the case of 3m and 4m span are found ideal and L/D ratio may vary from 10 to 12, remaining range is not safe. For 6 m span, only L/D=10 is found safe. In seismic zone it is better not to consider L/D above 10. Progressive collapse reduce the rigidity of the structure. Provide adequate joint and adequate reinforcement detailing. Span of the structural element should be adequate as per the guidelines given by the standard codes. For future studies all spans may be given same depth i.e. here the versatile condition is L/D=15 in 6m span.

## IX. FUTURE WORK SUGGESTIONS

- Study on typical 8 m span building with L/D ratio of beam 10,12 and 15
- Study the same case in steel building
- Study on irregular structure may be a good option for future work. But for this case rather than span and depth, flanged or doubly reinforced sections may be considered for effective results.

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