Study the Progressive Collapse Behavior of RC Structure under Gravity Loading

Reena B. Khadabadi[1] Kanchan Kanagali[2]
[1]P.G Student (Structural Engineering) [2]Assistant Professor
[1,2]Department of Civil Engineering
[1,2]Gogte Institute of Technology Belagavi, Karnataka, India

Abstract— Progressive collapse occurs when a primary structural component fails which results in the failure of adjacent components which in turn causes complete failure of structure. It might be man-made or natural hazards. In the present study the behavior of RC 12 storey RC frame structure are designed and evaluated as per U. S. General Services Administrative (GSA) guidelines. Structure considered consists of irregular geometry with a typical structural configuration of L-shaped block. Bay size is taken as 4m in X-direction and 3.5m in Y-direction and height of each storey is 3.6m. Progressive collapse was carried out using Linear Static Analysis in E-TABS version 13 software. The behavior of bending moment and axial forces variation are studied for the single column removal. It involves two case study i.e., exterior and interior column removal. It was observed that when exterior column was removed in the structure most of longitudinal beams and floors above the column will collapse. When ground floor interior column was removed there was no effect on the beams and floors and when upper floor interior column was removed the effect was observed on beams in short span.
Key words: E-TABS version 13 software, FEMA, GSA

I. INTRODUCTION

Progressive collapse of reinforced concrete structure can be defined as the failure of primary vertical load, results in the fall down of all or a huge part of a composition leading to additional collapse. It might be man-made or natural hazards. The structure may cause significant damage due to natural or man-made hazards such as gas explosion, bomb blast, vehicle impact, etc, in normal course of design any loading condition is not considered and the load may trigger to progressive collapse.

The nearest columns should be designed appropriately to defend against and restructure the supplementary loads, so that the structure will be safe next to collapse. When some members are loaded beyond their intended capacities its loading outline or limit conditions are changed in the construction and leads to progressive collapse. The other neighboring members surrounding this residual structure fail due to shedding some applied loads [4].

Progressive collapse system involves two special modes; the initial mode is exhibited by releasing sustain which leads to scattering fall down of the higher members. The next mode is exhibited by breakdown at higher levels which leads to rubble load which cause controlled mechanism. Investigations which have been carried out on the collapsed building beneath, results to earthquake have special modes of breakdown mechanism. The building could collapse by lateral sway in earthquake failure mechanism and collapses under its gravity loading. The results obtained in the first mode of spreading failure depends on geometry and beam span [1].

A. *Objectives*

1) Explains the term progressive collapse.
2) Bending moments and axial forces variation was studied.
3) To identity the progressive collapse pattern.

II. GENERAL SERVICES ADMINISTRATION

The most important purpose of the GSA guidelines in new and existing Federal Office Building is to help out in the assessment of the possibility of progressive collapse. In analysis method selection and evaluation of the results are concise and direct guidelines are provided in the document. Linear Static Analysis procedures applicability is limited to both GSA and FEMA guidelines [5].

GSA suggests the building with 10 above-ground stories and FEMA suggests not more than 100 feet in elevation. These 3 analyses can be performed for buildings taller than 10 stories with proper explanation and agreement. Based on the occupancy and functional use, the GSA guidelines permit definite buildings to be exempted from progressive collapse. A building is exempt can be determined by a comprehensive flow chart giving by GSA guidelines [5].

III. LINEAR STATIC ANALYSIS

Linear Static Analysis method is the most basic and easiest method of progressive collapse analysis in which most important structural components are detached statically. The analysis method is simple and is more fairly accurate, more conventional load circumstances are usually functional, with extremely conventional evaluation criteria [5].

The steps essential in performing the analysis are [5]:

1) Build 3-D model in ETABS version 13 software.
2) Perform concrete design and determine the provided reinforcement in the members.
3) Based on the provided reinforcement, calculate the capacity of the member in flexure and shear.
4) Removing the ground floor column as specified location one at a time suggested by GSA guidelines.
5) Perform Linear Static analysis.
6) Determine the bending moments and axial forces before and after removal.

GSA guidelines have specified the following load case for static analysis procedure [5].

$$\text{Load Case} = 2\,(DL + 0.25LL)$$

Where, DL = Dead Load and
LL = Live Load

To replicate the dynamic response in static analysis factor 2 is provided to purpose dynamic magnification factor [5].

IV. PROBLEM DEFINITION

To study the effect of column removal condition on the structure, hypothetical case of 12 storey RC building is considered. Progressive collapse analysis is based on the GSA guidelines. Structure measured consists of irregular geometry with a typical structural configuration with L-shaped block. Bay size is taken as 4m in X-direction and 3.5m in Y-direction. Height of base to plinth and plinth to ground floor is taken as 3.6m, height of typical floor as 3.6m. Beams are maintained uniform in size and columns sections are reduced towards top storey. The design of structure is made in order to comprise the geometric irregularity. The combination of loads taken into account is 2(DL + 0.25LL), where DL is dead load, LL is live load and 2 is the dynamic factor. The design is calculated using IS 456:2000 and analysis is done using ETABS v-13. The materials, sections, loadings used in the model are mentioned as below:

1) Material
   - Characteristic compressive strength of concrete (fck) : 25 N/mm^2
   - Yield strength of reinforcing steel (fy) : 415N/mm^2
2) Column Size
   - 300X600mm (Base to 3rd storey)
   - 300X500mm (4th to 7th storey)
   - 300X400mm (8th to 12th storey)
3) Beam Size: 230x400mm
4) Slab Thickness: 150mm
5) Wall Thickness: 230mm
6) Loads:
   - Dead Load :Self weight of structure
   - Floor Finish :1.5 kN/m^2
   - Wall Load :11.96 kN/m^2
   - Live Load :3 kN/m^2
   - Parapet Load: 5.52 kN/m^2

Bending Moment, Axial Forces are determined at column faces for each removal of column. To evaluate progressive collapse potential of a 12 storey unsymmetrical reinforced concrete building is considered. Building is designed in ETABS version 13 software and the structure is analyzed using Linear Static Analysis for two column removal cases. Then the analysis is performed for column removal of C16 and C11. Bending moments and axial forces of columns and beams variation are studied for all the column removal.

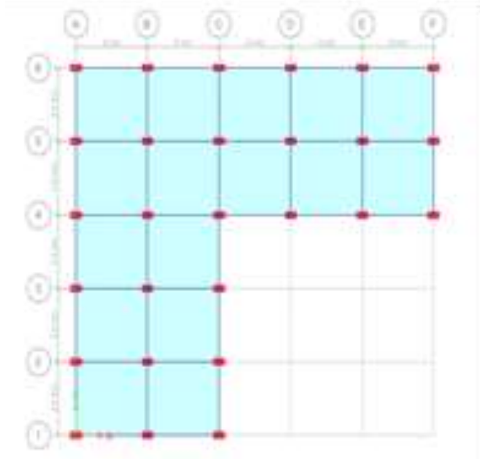


Fig. 1: Plan before Removal

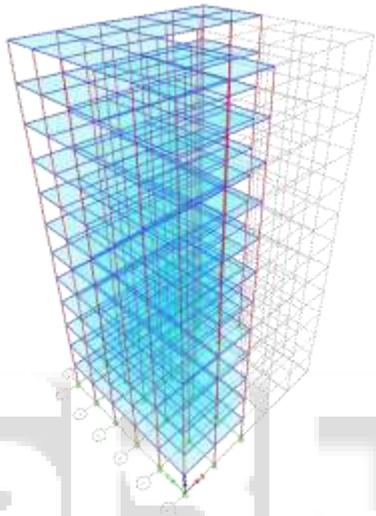


Fig. 2: Elevation before Removal

V. RESULTS

A. *Case 1: Removal of Exterior Column at Storey1*

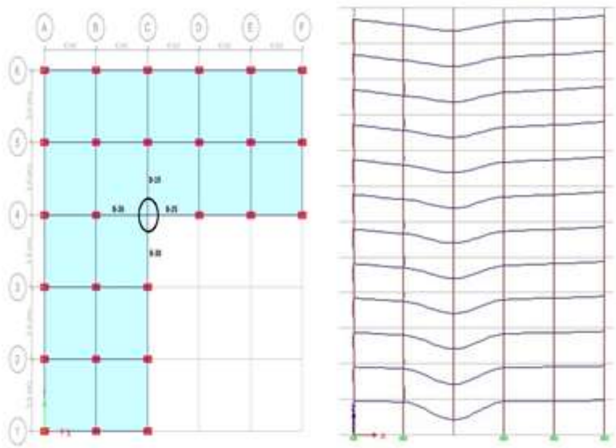


Fig. 3: Plan and Elevation after Removal of Column C16

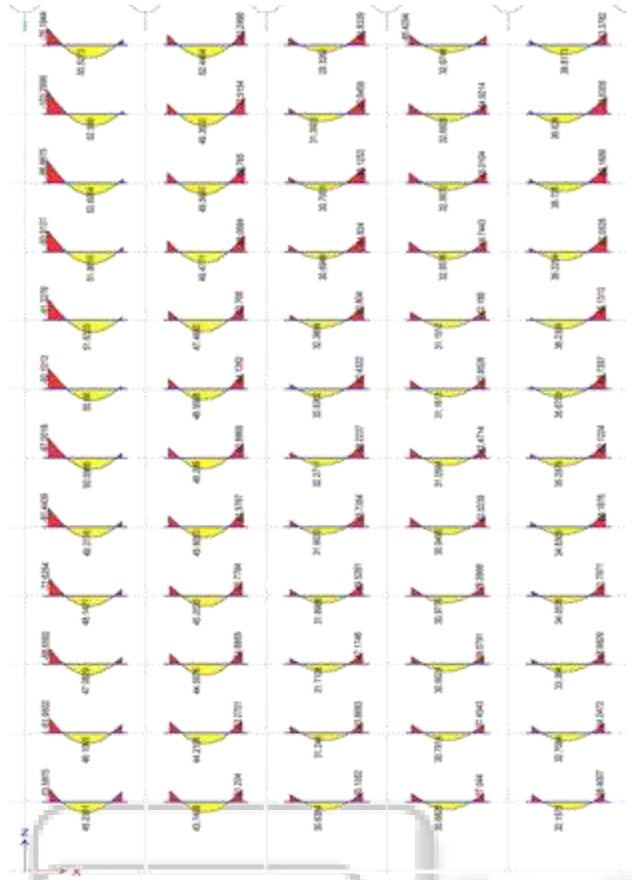


Fig. 4: Bending Moment before Removal Elevation4

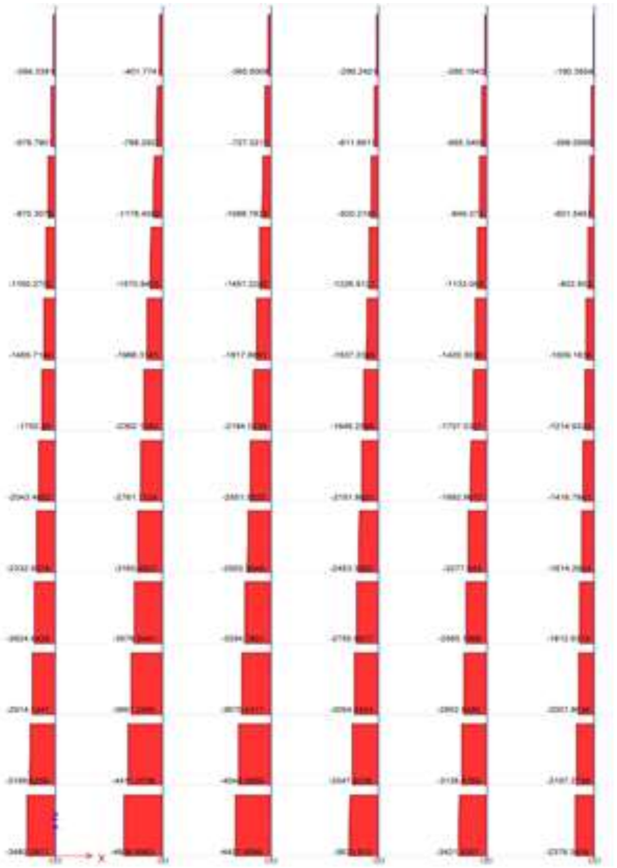


Fig. 6: Axial Force before Removal Elevation 4

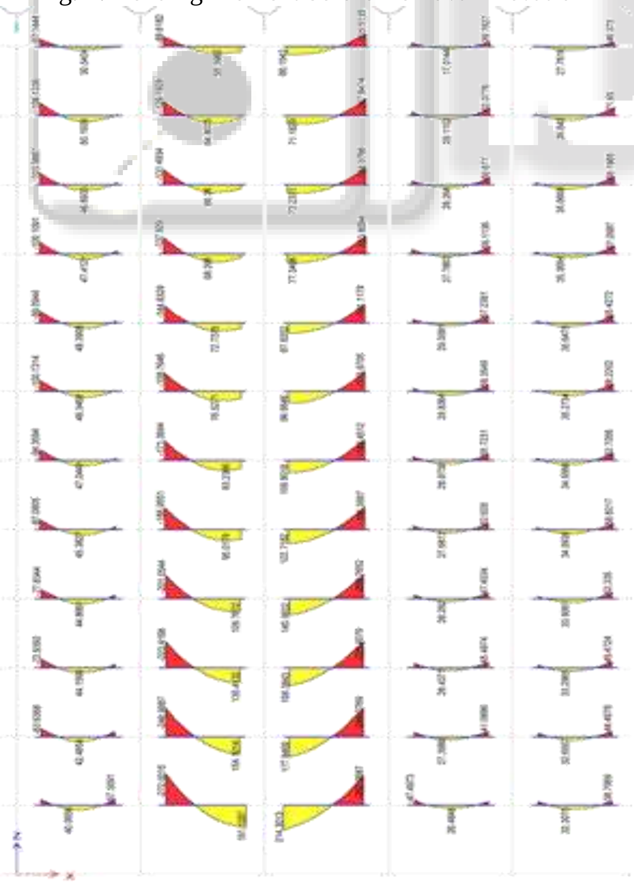
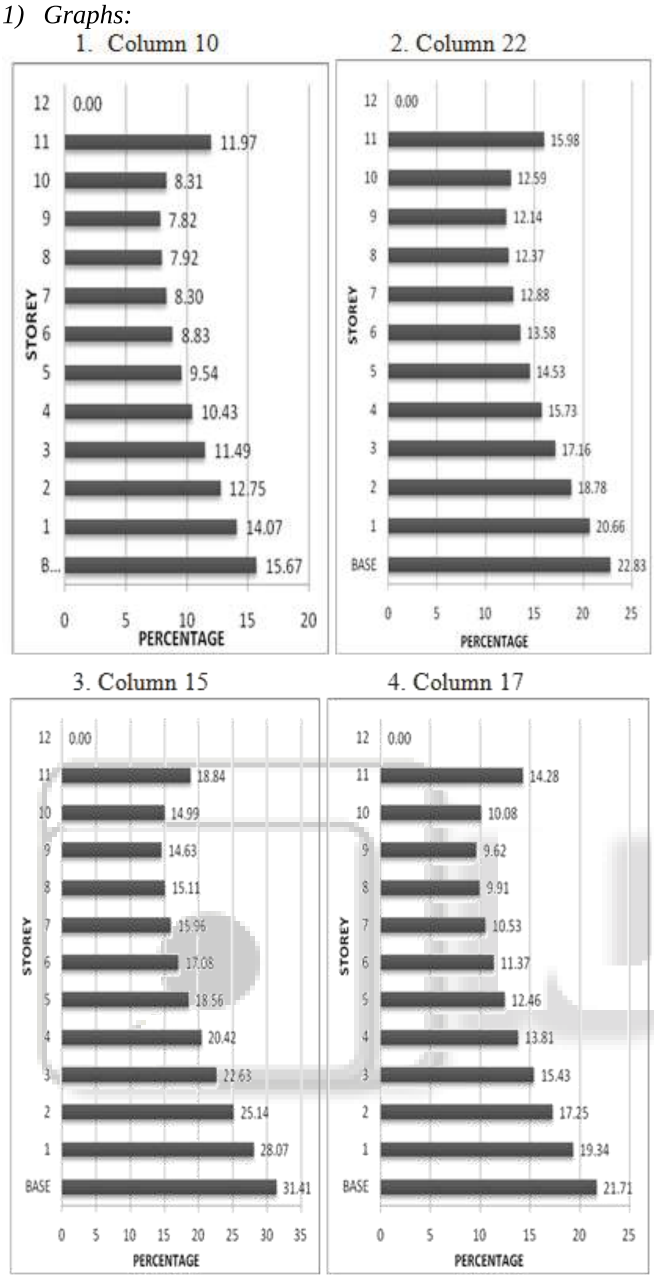


Fig. 5: Axial Force after Removal Elevation 4

Fig. 7: Axial Force after Removal Elevation 4

B. Percentage Variation in Axial Forces

1) Graphs:



C. Case 2: Removal of Interior Column at Storey 1

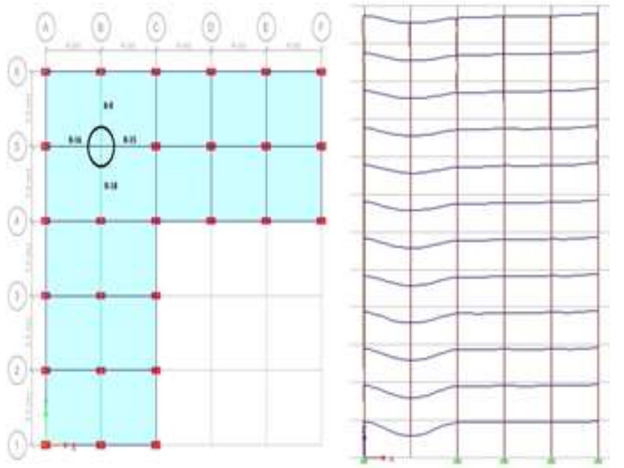


Fig. 8: Plan and Elevation after Removal of Column C11

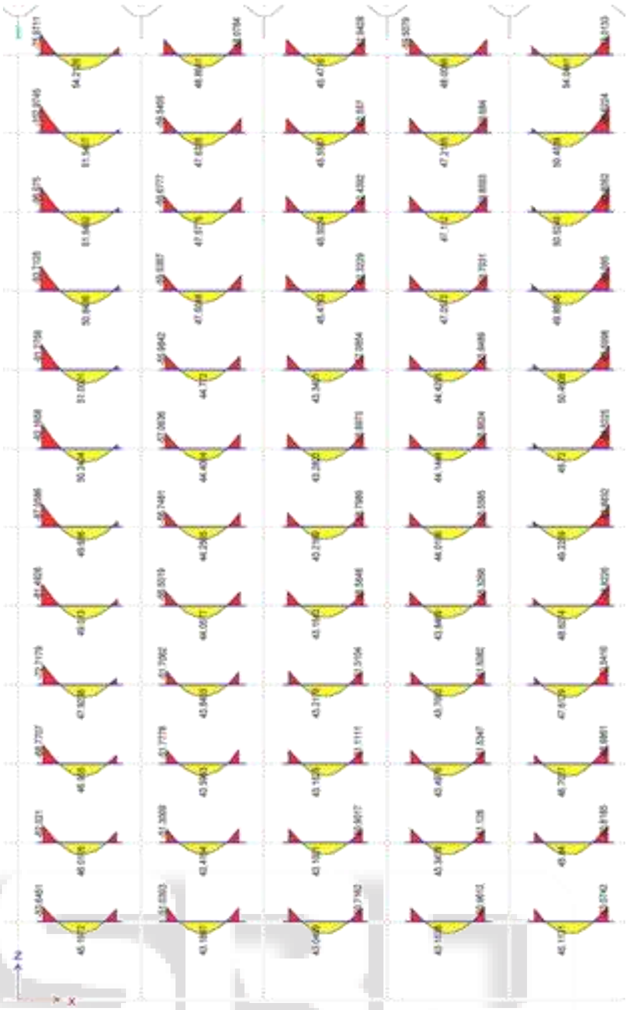


Fig. 9: Bending Moment before Removal Elevation 5

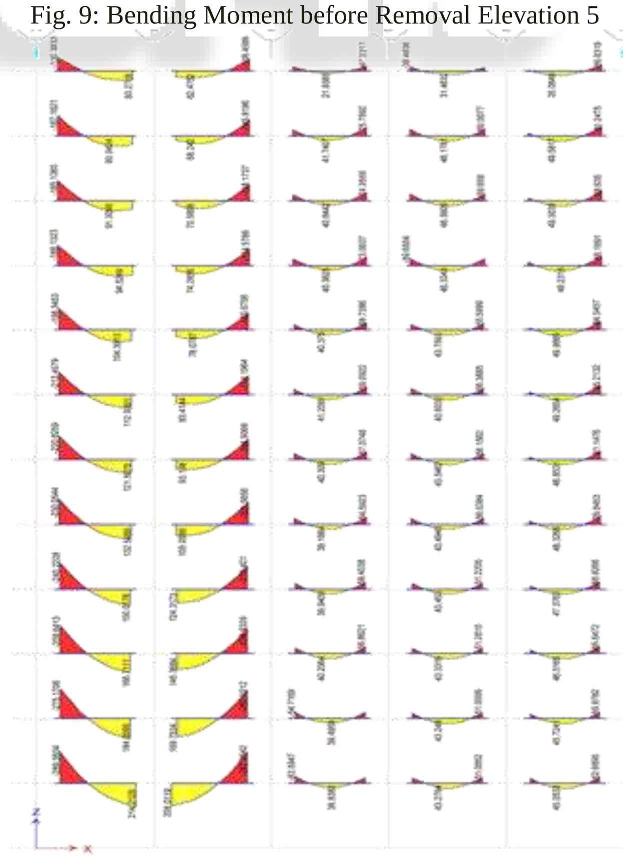


Fig. 10: Bending Moment after Removal Elevation 5

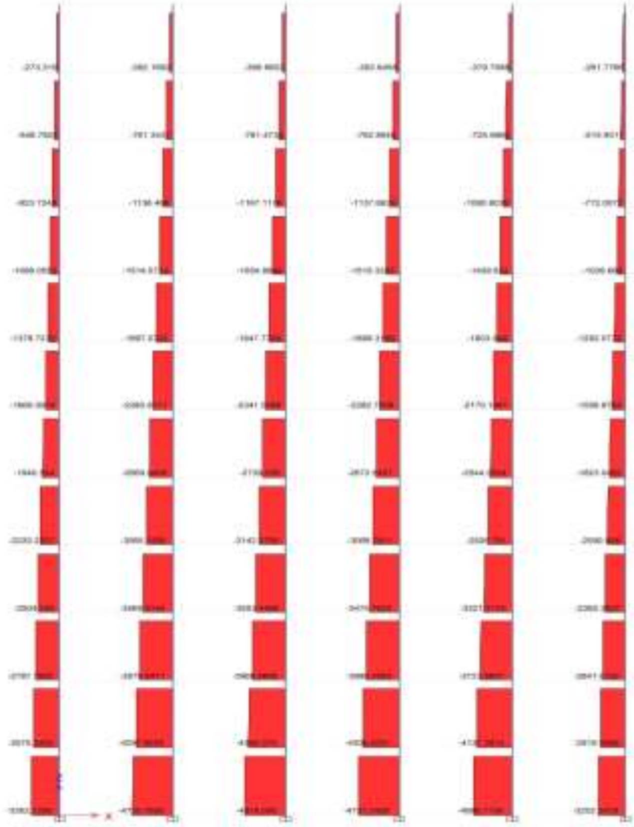


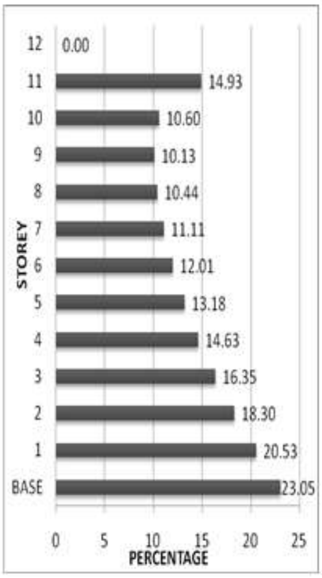
Fig. 11: Axial Force before Removal Elevation 5

Fig. 12: Axial Force after Removal Elevation 5

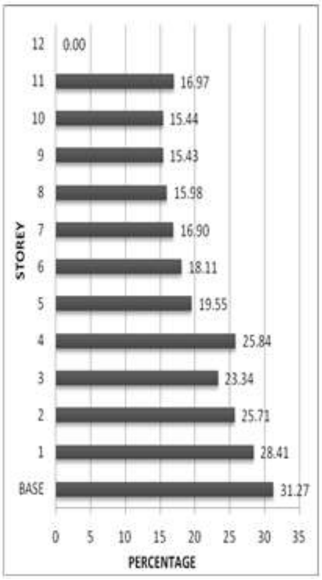
D. *Percentage Variation in Axial Forces*

1) *Graphs:*

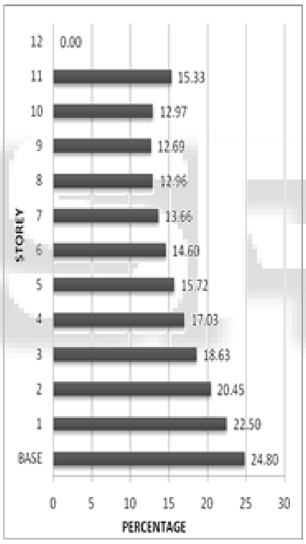
1. Column 10



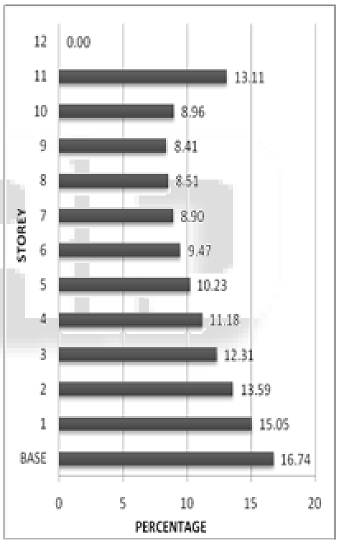
2. Column 12



3. Column 5



4. Column 17



VI. DISCUSSIONS

A. *Elimination of Interior and Exterior Column*

In this segment of study a single column is eliminated and gravity load is applied, the frame tries to behave as vertical cantilever and columns above the column which has been eliminated behave as a floating column. The load distribution path suddenly gets disturbed and floating column loads get transferred to the beam on either side of eliminated column.

1) Two segments of the beam [on the either side of the eliminated column] act as a single beam element. Thus the loads from floating column get transferred to the adjacent column through the single beam element action.
2) It is observed that maximum sagging bending moment is at the centre of the beam in Interior Column Removal case.

3) It is observed that maximum hogging bending moment is at the ends of the beam in Exterior Column Removal case.
4) When the centre column is eliminated load is transferred to the four adjacent beams and it is observed that maximum sagging bending moment is at the centre and it is observed that maximum hogging bending moment is at the support opposite to the eliminated column.
5) The amount of load transferred on the single beam element is observed to be highest on the eliminated story and it goes on reducing on the above stories as seen in the graph.

VII. CONCLUSION

Shorter bays are more affected in all collapse regions, the reason is shorter bay tries to acts as a cantilever and heavy point load from longer bay acts on the shorter bay. Bending moment variation is similar throughout the building after the elimination of column, i.e., it decreases as the storey increases. Axial force variation is similar throughout the building after the elimination of column, i.e., it decreases as the storey increases. Interior column elimination leads to Domino Type Collapse and Pancake Type Collapse. When interior column was removed maximum number of beams and columns failed and there was maximum effect to the structure. It is localized failure where the effect reduces as we move away from the collapse area. Mass of the structure gets transferred to adjoining columns, leading the failure of adjoining members and ultimately the failure of partial or total collapse of the structure. Thus the frame is less susceptible to progressive collapse.

VIII. SCOPE FOR FURTHER STUDY

1) Building can be design for higher storey's.
2) Analysis can be carried out including wind loads and seismic loads
3) The effect of building can be analyzed and checked by including Shear Wall and Bracing Frames.
4) Infill walls can be included and comparison study can be done between infill walls and without infill walls
5) Building can be analyzed for different analysis method and comparison study can be conducted.

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