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Progressive Collapse Analysis of Reinforced Concrete Multistoried Frame Structure

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Abstract: The objective of this project is to analyze the progressive collapse behavior of 10 story reinforced concrete frame structures by removing column suddenly from different locations, as per the GSA guidelines. To achieve this, a structural model of the building has been developed in ETABS version 18.1.1 and loads are applied as per GSA guidelines. The design and detailing of the structure are done in accordance with IS codes, using the special moment-resistant frame linear static analysis method. In accordance with GSA guidelines, three-column removal scenarios have been studied on the ground floor, including the removal of a Corner column, Middle column of longer and Middle column of shorter side. The Demand/Capacity ratios (DCR) for each member have been calculated using the linear static analysis method. Members with a DCR ratio greater than 2 are expected to fail in a similar column removal case. Past studies have revealed that shear in a beam and columns are not crucial in progressive collapse. However, the linear static analysis method has demonstrated that beams are prone to fail in flexure.
Keywords: Progressive collapse analysis, RC frame shear wall structure, ETABS, Linear Static Analysis, GSA guidelines 2016, Demand/Capacity Ratio

I. INTRODUCTION

Progressive collapse, a critical concern in building safety since the 1968 collapse of the Ronan Point apartment building in Canning Town, East London fig. 1.1, refers to a sequence of failure, also known as disproportionate failure. This sequence connects localized damage caused by a single structural element to the eventual collapse of an entire structure. Local failure can be understood as the loss of load-bearing capacity in one or more structural components that make up the overall structural system. Ideally, when a structural member fails, the building should have mechanisms in place to redirect the load through alternative paths. As the load redistributes within the structure, each structural element takes on new loads. However, if any load surpasses the load-carrying capacity of a component, it can trigger another local failure. Sequential failures can spread throughout the structure. When a greater number of structural components fail, it can lead to either a partial or complete collapse. The latest known example is the Twin Towers of the World Trade Center in New York, USA, fig. 1.2. The world experienced horror on September 11, 2001, as both of the Twin Towers at the World Trade Center in New York City, USA, fell down in this order: First, a Boeing 767 airplane crashed into one of the towers at high speed. This impact caused serious damage to the structure around the point of impact and set off a massive fire inside the buildings. The area around the impact, including the floors above it, lost its ability to support the weight of the floors above. As a result, the part of the tower above the impact zone collapsed. When it lost support, the heavy upper part of the tower fell, causing a chain reaction of collapses all the way down to the ground. This tragic event is an example of a complete or total collapse.

Fig. 1.1: Ronan point building after 1968

Fig. 1.2: World Trade Centre after attack

II. OBJECTIVES

1) To understand the process of progressive collapse of 10 story RC Structure in column removal scenario.
2) The objective of this study is to understand the analysis and design methodology of RC framed building structure using ETABS.
3) To find critical structural components in building which causes maximum damage or collapse after the removal of the column.
4) To perform Linear Static Analysis for the RC framed structure with and without removal of the column from different positions such as corner column, middle of long side and short side column under consideration of GSA guidelines.
5) To know whether a RC building (Special Moment Resistance Frame) designed and detailed by Indian Codes for seismic loads provides any resistance to progressive collapse or not.

III.MODEL DESCRIPTION

ETABS 2018 software is used to create a model and fixed the cross-sections for columns, beams, slabs based on preliminary analysis and study 10-story buildings model made of reinforced concrete (RC). All the supports in the models were set as fixed supports. A model is designed to withstand Dead Loads, Live Loads, Wind Loads, Seismic Loads. To account for the weight of the structure (i.e. DL), we followed the guidelines of IS 875 Part 1 and IS 875 Part 2. For seismic loading, we followed the standards specified in IS: 1893:2016.

Table 3.1: Specifications of the structures

1	Type of frame	SMRF
2	Seismic Zone (Z)	III
3	Span in X direction (5m x 6bays)	30m
4	Span in Y direction (4m x 4bays)	16m
5	Height of each floor	3.5 m
6	Zone factor	0.16
7	Soil type	II
8	Importance factor (I)	1.5
9	Response reduction factor	5.0
10	Slab thickness	120mm
11	Beam Dimensions	230mmx530mm
12	Column dimensions	300mmx750mm
13	Grade of Concrete and Grade of Steel	M25, Fe415

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IV. METHODOLOGY

Although there are several methods available for analyzing structures to assess the risk of progressive collapse, the alternate path method has become widely favoured in the scientific and engineering community. This is mainly because of its simplicity in application. In the alternate path method, critical structural elements, often a single column, are intentionally removed, and then the structure is analyzed to see if it can still 'bridge' across the gap left by the missing member. For this study, we are using the GSA 2016 guidelines to simulate progressive collapse behaviour using the linear static analysis procedure.

A. Linear Static Analysis Procedure (LSA)

Linear Static Analysis (LSA) proves to be effective for structures with a height of up to 10 stories. To determine force-controlled actions, simultaneously calculate the combination of gravity loads as per equation {4.1}. These loads are then applied to the bays directly adjacent to the removed element and to all floors located above the removed element.

G_{LF} or $G_{LD} = \Omega_{LF}$ [1.2 D + (0.5 L or 0.2 S)] …………………………………… eq. (4.1)

Where G_{LF} and G_{LD} = Increased gravity loads for force-controlled actions

Ω_{LF} = Load increase factor for linear Static analysis = 2

For floor areas that are not directly above the removed column, use the gravity load combination given in equation 4.2

G = 1.2 D + (0.5 L or 0.2 S)……………………………………………………eq.(4.2)

Where G = Gravity loads, D = Dead loads, L = Live loads and S= Snow loads

B. Acceptance Criteria as per GSA Guidelines

The objective of the 2016 GSA guidelines (General Services Administration) is to provide guidance for the reduction and evaluation of the potential for progressive collapse in Federal buildings, regardless of whether they are newly constructed or old/existing.

Demand Capacity Ratio: The Demand Capacity Ratio (DCR) is the ratio of the internal force or moment (Q_{udlim}) to the expected strength of the component (Q_{CE}).

DCR = Q_{udlim} / Q_{CE}

Allowable values of DCR:

DCR< 2, for typical structural configuration,

DCR < 1.5, for atypical structural configuration.

C. Location of Column Removal

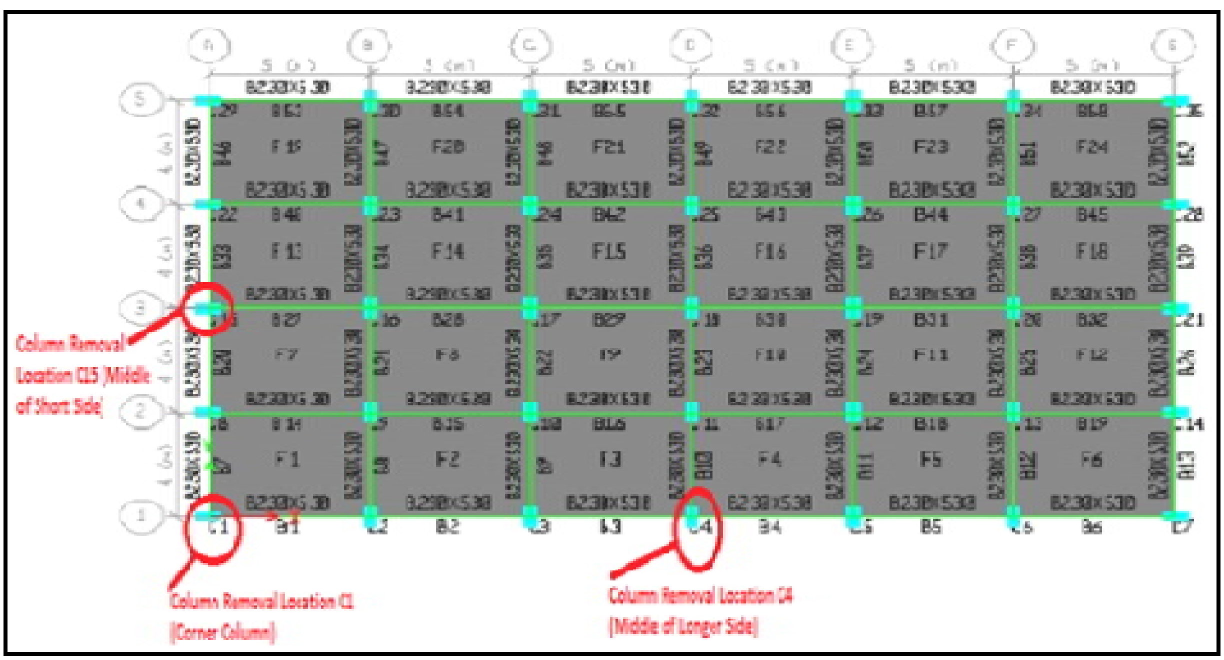

Fig. 4.1: Plan view of model without removal of column

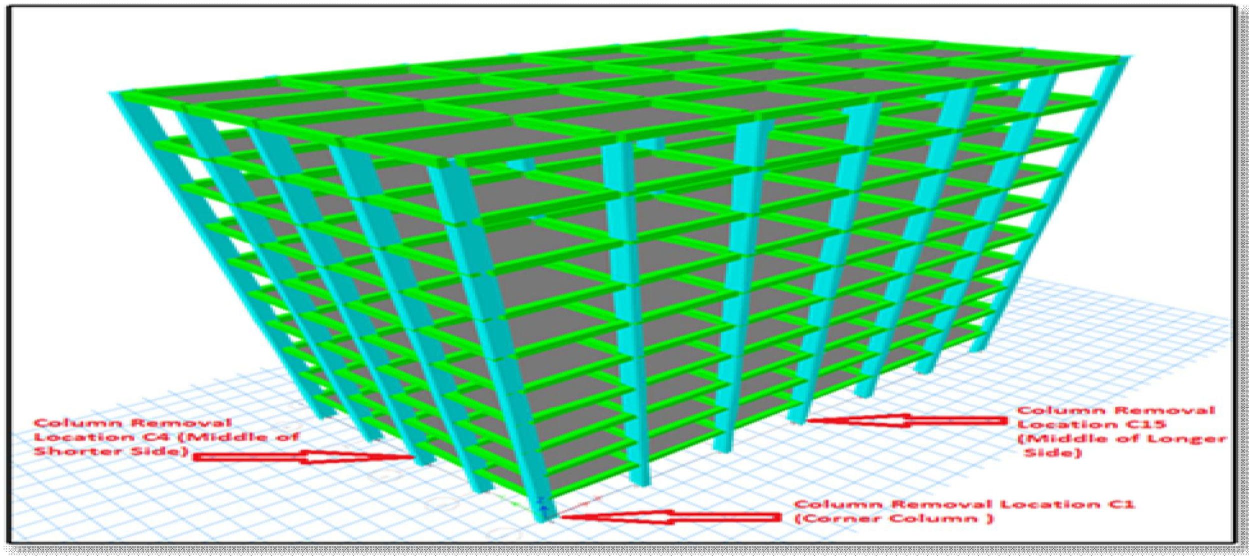

Fig. 4.2: 3D view of model with removal of column

V. RESULTS AND DISCUSSION

1) After removal of column C1 (Corner column), beam B1, B7 fails in all stories. Beam B7 of story 1 to 4 are most critical. They not only fail in shear but also in flexure.
2) After removal of column C4 (Middle of Longer side column), beams B3, B4, (except Story No.10) and B10are failed on all stories. Beam B10 of Story 1 to 7 is most critical. They fail in both shear as well as in flexure.
3) After removal of column C15 (Middle of Shorter side column), beams B14, (except Story No.10), B20 and B33 are failed on all stories. Beam B20 & B33 of Story 1 & 2 are most critical. They fail in both shear as well as in flexure.
4) In the case of Corner Column Removal, as depicted in the pie chart of Figure 6.97 below, the percentage of structural members failing without an earthquake load is equal to those failing with an earthquake load in both zone 2 and zone 3. Additionally, the percentage of members failing in earthquake zone 5 is higher than in zone 4, which, in turn, is lower than zone 3.
5) In the case of all three Column Removal Scenario, as depicted in the bar chart of Figure 6.100 and Table 6.7 below, the number of structural members failing without an earthquake load is almost equal to those failing with an earthquake load in both zone 2 and zone 3. Additionally, when move from zone 2 to zone 5, more members fail as the earthquake intensity increases.

The following bending moment diagram (BMD) shows reversal of stresses after removal of column above the removed column.

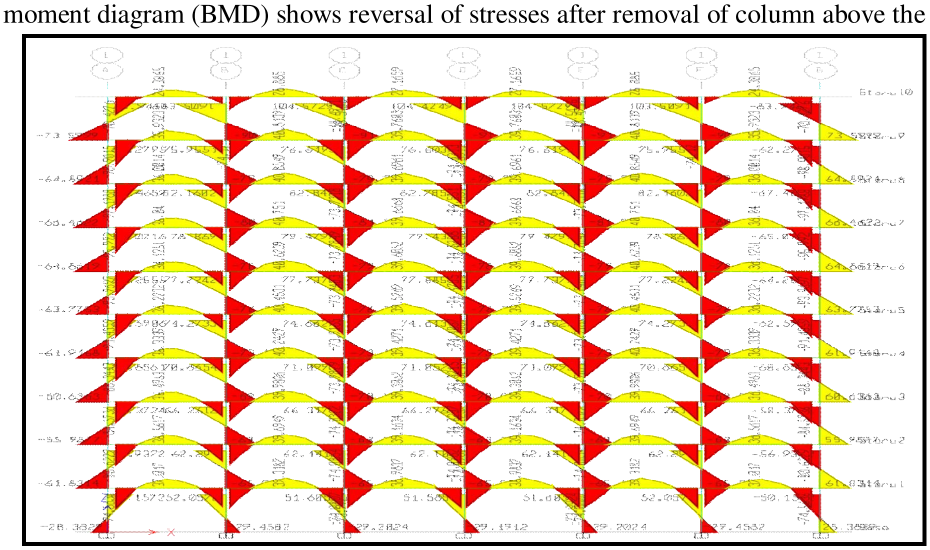

Fig. 5.1: BMD before removal of column C1

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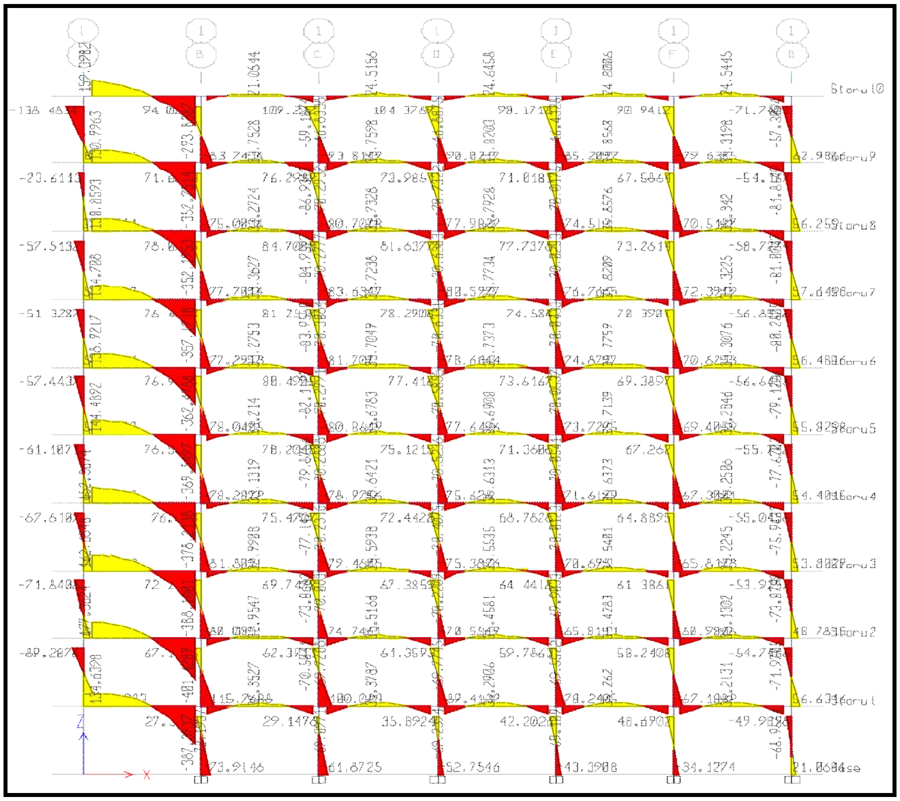

Fig. 5.2: BMD after removal of column C1

The following shear force diagram (SFD) shows reversal of stresses after removal of column above the removed column.

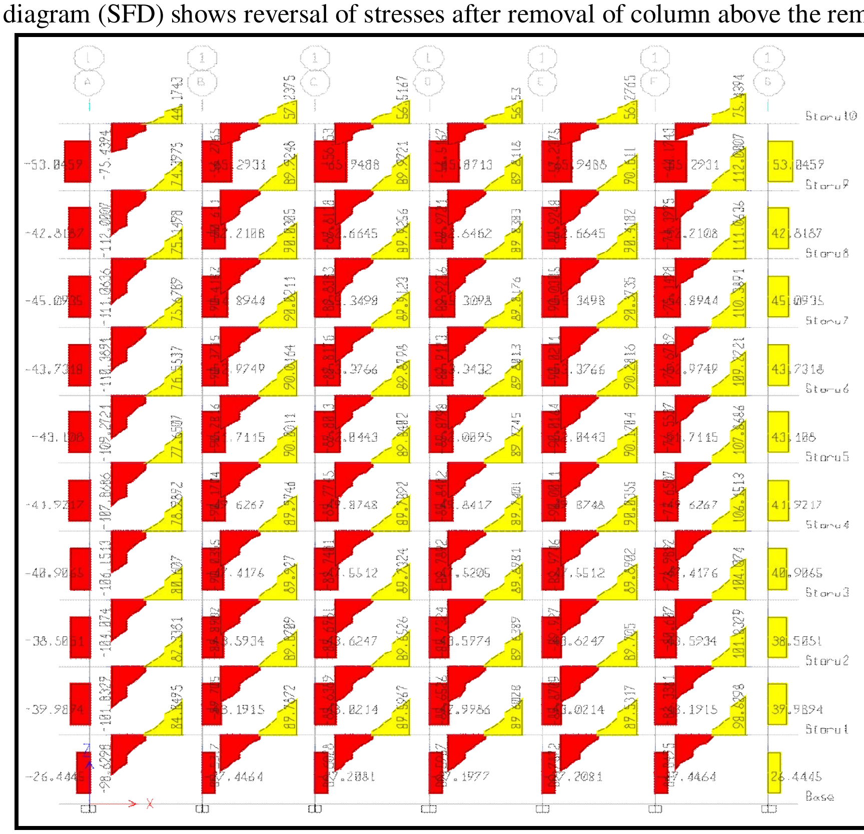

Fig. 5.3: SFD before removal of column C1

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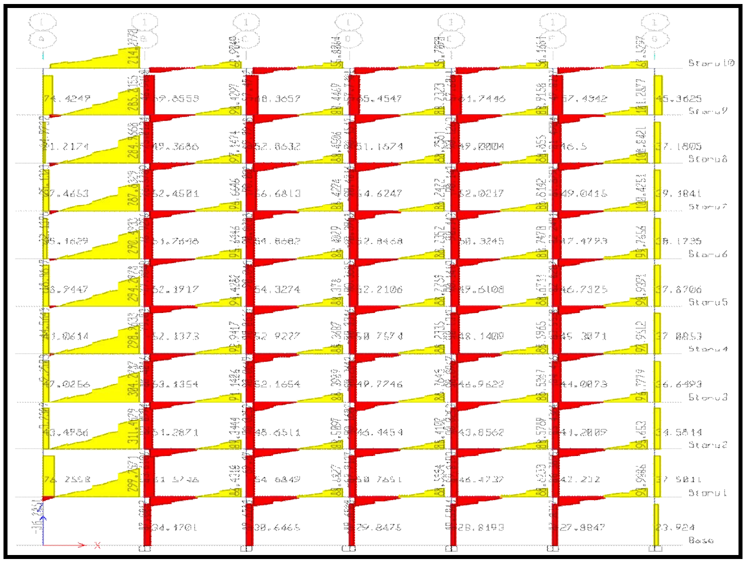

Fig. 5.4: SFD after removal of column C1

The following AFD shows diminishes of stresses after removal of column above the removed column and after removal of column axial force in column transfers to the adjacent structure.

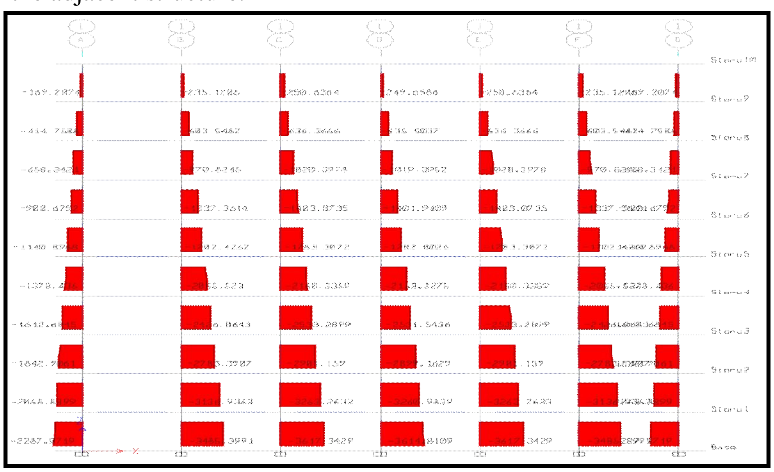

Fig. 5.5: AFD before removal of column C1

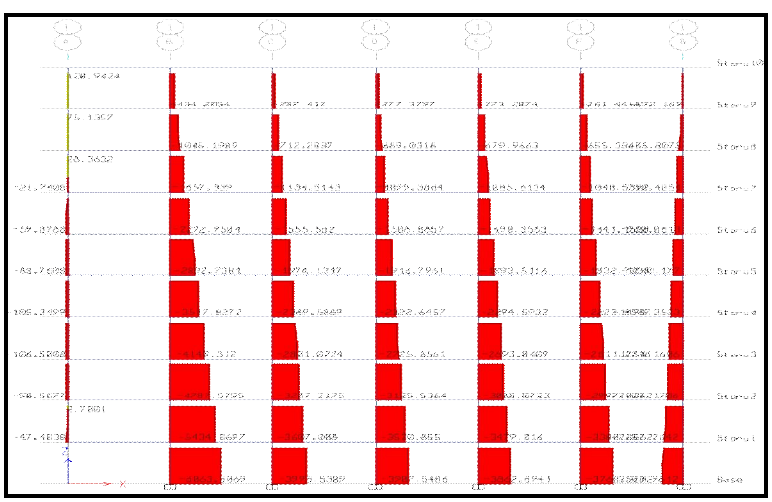

Fig. 5.6: AFD after removal of column C1

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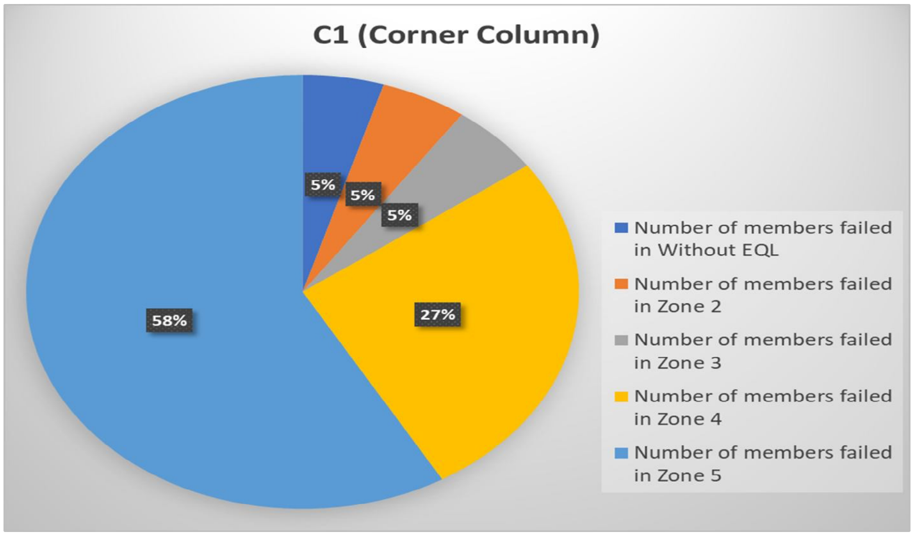

Fig. 5.7: Number of members failed in different earthquake zones in C1 removal scenario

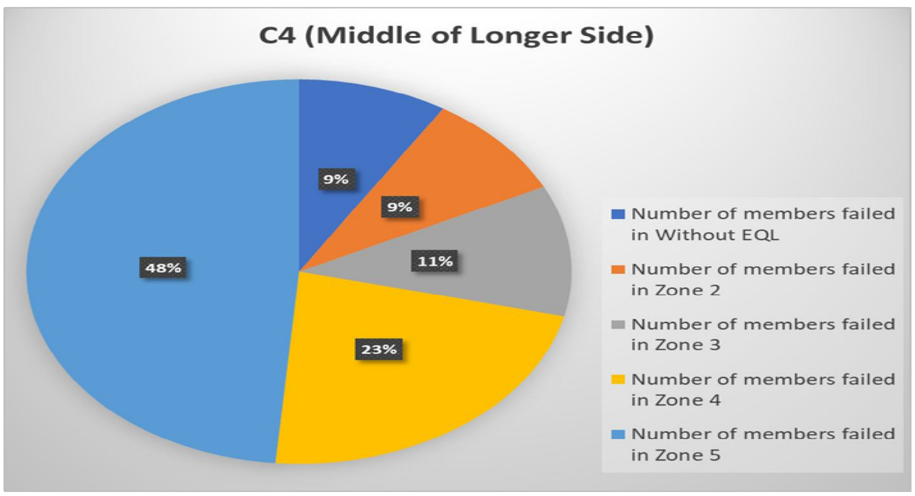

Fig. 5.8: Number of members failed in diffrent earthquake zones in C4 removal scenario

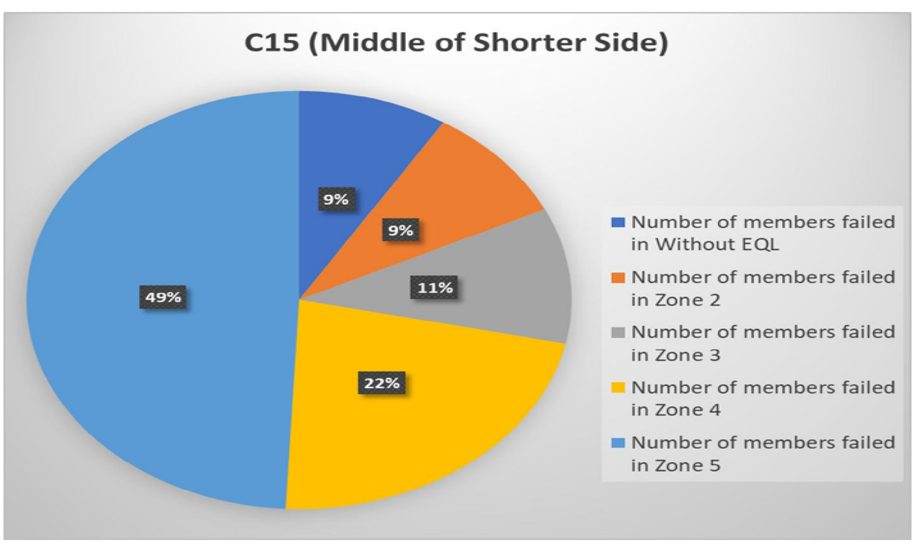

Fig. 5.9: Number of members failed in different. earthquake zones in C15 removal scenario

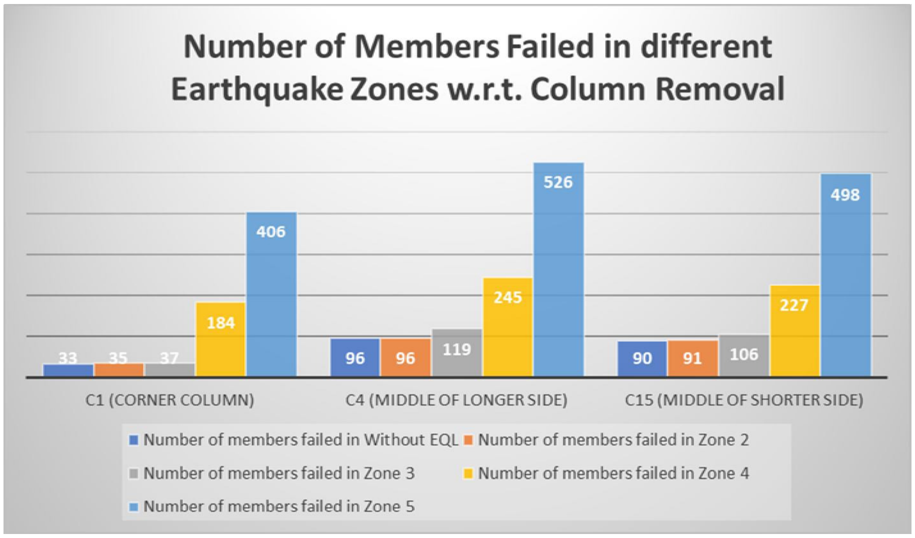

Fig. 5.10: Number of members failed in different earthquake zones in C1,C4.C15 removal scenarios

VI. CONCLUSION

1) The collapse pattern is such that the demand capacity ratio of the beam increases when beams are closer to the removed column and decreases as beams are farther from it.
2) The beams situated both adjacent to and directly above the removed column are subjected to the greatest bending moments in comparison to beams positioned at a greater distance from the removed column.
3) The members above the removed column experience reversal of stresses in both bending and shear. To counter this, these members should be redesigned by either increasing the section size or adding more reinforcement.
4) At the lowest story, beams connected to the removed column experience failure. Similarly, beams of the same type connected to columns above the removed column at various stories also undergo failures, involving both shear and flexure failure.
5) Out of the three cases of column removal, the most severe collapse happens when the middle column of the longer side is taken out. The second most damaging scenario is when the middle column of the shorter side is removed, while the least detrimental situation occurs when the corner column is removed. Hence middle column removal case is the most critical one. In general, the RCC building under consideration exhibits a lower potential for progressive collapse when a corner column is removed compared to the removal of a middle column.
6) After the removal of a column, the axial force in the columns above it gradually diminishes and is subsequently transferred to the adjacent columns through the interconnected beams.
7) Columns located in the vicinity of the removed columns exhibit a higher PMM ratio compared to columns situated farther away from the column removal locations. The reason behind this is that when one column is lost, the neighbouring columns are burdened with carrying its load. In all three cases, the PMM ratio exceeds 2, indicating that the columns supporting adjacent bays are critical in this progressive collapse scenario.
8) A structure designed with Special Moment-Resisting Frames (SMRF) according to IS 456:2000 and detailed according to IS 13920 may not inherently resist progressive collapse. This is because SMRF design primarily resists lateral loads, while progressive collapse involves the failure of structural elements under gravity loads.

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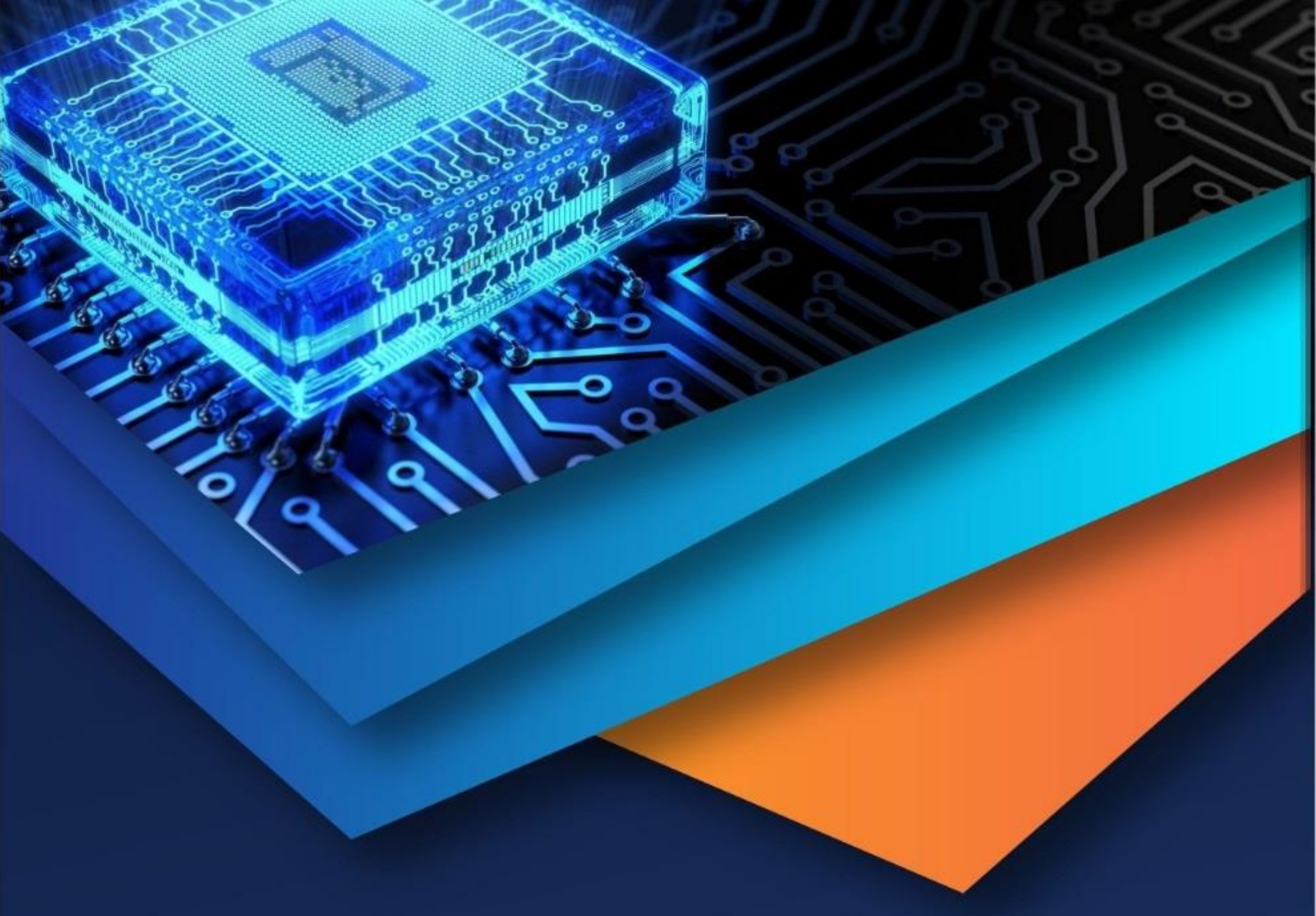

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