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Progressive Collapse of Reinforced Concrete Building

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Abstract: *In this project it is proposed to carry out progressive collapse analysis of 13 storey RC frame building by removing different column one at a time as per the GSA guidelines. Building consists of 5 X 5 bay 5 m in both direction and designed by Indian code as a special moment resistant frame. Structural model of building has been created in ETABS and loads are applied as per GSA guidelines, for evaluation of progressive collapse linear static method of analysis and nonlinear static method of analysis has been used. As per GSA guidelines three column removal case one at a time has studied, namely Corner column removal at ground floor, Exterior column at ground floor and interior column at ground floor. For all three cases both linear and nonlinear analysis has done and DCR ratios are evaluated. Member having DCR ratio greater than 2 will going to fail for corresponding column removal case. It is obtained that shear in beam is not critical in any case, Columns are also not critical in Progressive collapse. But by Linear static analysis and nonlinear static it is obtained that beams are going to fail in flexure.*
Keywords: *Progressive Collapse Analysis, Nonlinear Static Analysis, DCR ratio, Linear Static Analysis etc.*

I. Introduction

1.1 General

A normal structural design of building consist of designing structural members for Dead load, Live load, Wind Load, Earthquake load etc. and there combination. Though the structural member will be safe for above mentioned loads and there combination, building will be collapse one of the important structural members gets fail. Due to failure of one Structural member (Local failure) load on the other members in the vicinity of it increases, that member is going to fail if an increased load goes beyond the capacity of member. Likewise failure will transfer from one member to another which leads to collapse of whole structure. Such type of failure of structure in known as progressive collapse or Cascade failure.The design for mitigation of progressive collapse has been a hot topic in structural engineering due to a heightened awareness of blast and terrorist hazards. Many alternatives and suggestions have been proposed by numerous structural engineers and blast experts, and with continued research more alternatives are to be expected in the near future. The challenge exists in making decisions about the best solutions because of the inherent uniqueness that are to be encountered for each project. Also, there is little to no official design standards or guidelines available for engineers to follow to aide their decisions. Instead, the engineer must be well-versed in blast resistance and progressive collapse research in order to have a good understanding of what it takes to build or retrofit a robust structure.

1.2 Objectives of work

Following are the objectives of work:

- To understand the process of progressive collapse of 13 storey RC in sudden column loss scenario
- To understand progressive collapse analysis of building by Linear static analysis
- To understand progressive collapse analysis of building by Nonlinear static analysis
- To check 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.

II. Introduction to Progressive Collapse and Gsa Guidelines

Structural engineers are facing new challenges in designing safe structures due to the increase in terrorist actions carried out on landmark buildings which has the potential to cause great destruction, damage, and danger to people. Up to now a day designer considers all the possible load in the form of Dead, Live, Wind, Temperature, earthquake loads etc and there combinations for assuring safety of structure and the people using structure. We never considered in past any abnormal loading like Blast or we never designed a whole by considering one member is removed, but now it is necessary to design some important structure which are important and having more probability of terrorist attack. It is virtually impossible to predict what exact extreme load may be induced on a building, therefore when designing for structural integrity the most important consideration is progressive collapse. Progressive collapse results when a localized failure spreads to a larger portion of the structure. Exactly how progressive collapse occurs? When one of the major load carrying element failed due to some reason such as blast of cylinder or terrorist attack, due to failure of major element load carried by major element is distributed to adjacent elements which increases load on adjacent member more than its capacity and due to which adjacent member also get failed and transfers loads to its adjacent member. The process is continuing until all the structure gets failed.

2.1 Need of Progressive collapse Resistance

There is a need to design against progressive collapse due to an increasing trend of terrorist action against important facilities such as loss of those leads to heavy loss of life and property. Now a day Probability of terrorist attack is increased and they can target any Facility which are important. Sometimes a small explosion of cylinder in kitchen will also leads to progressive collapse, or hitting of a heavy vehicle at ground level will also leads to progressive collapse. There is also probability of Striking of Airplane on building which may leads to progressive collapse.

Due to all of above reasons it is necessary to consider Progressive collapse failure of Structures while designing.

2.2 Guidelines of GSA

2.2.1 Facility security levels (FSL)

The facility security level determinations defines the criteria and process for determining the FSL of a federal facility, which categorizes facilities based on the analysis of several security-related facility factors, including its target attractiveness, as well as its value or criticality.

FSL I & II

Given the low occupancy and risk level associated with these types of facilities, progressive collapse design is not required for FSL I and II, regardless of the number of floors.

FSL III & IV

These Guidelines are applicable to FSL III and IV buildings with four stories or more measured from the lowest point of exterior grade to the highest point of elevation. Unoccupied floors such as mechanical penthouses or parking shall not be considered a story. FSL III and IV facilities shall implement both the Alternate Path and Redundancy design procedures. The Alternate Path method shall be applied based on vertical load bearing element removal locations.

FSL V

These Guidelines are applicable to all FSL V buildings regardless of number of floors. FSL V facilities shall implement the Alternate Path method based on vertical load bearing element removal locations identified. Redundancy design procedures do not need to be applied to FSL V facilities.

III. Progressive Collapse Analysis of Reinforced Concrete G+12 Building

In this chapter progressive collapse analysis of reinforced concrete building of G+12 floors is carried out. The proposed building plan and elevation is as shown in figure. First building is analysed and design in ETABS 2015. The geometric and loading details of building are mentioned as below.

Table No. 3.1: Geometric and loading data for building

1.	Span in both direction	25m
2.	No. of bays	5 in both direction
3.	Height of each floor	3m
4.	Live load	3 kN/m^2
5.	Floor finish load	1.5 kN/m^2
6.	Zone factor	0.16
7.	Soil type	II
8.	Importance factor	1.0
9.	Type of frame	SMRF
10.	Response reduction factor	5.0
11.	Slab thikcness	175mm
12	Concerte and steel	M30 and Fe500

Progressive Collapse Analysis: Linear Static

Progressive collapse analysis by Linear Static is carried out as per General Service Administration (GSA) guidelines. Columns are removed one at one time and static linear analysis is carried out. Here 3 case of column removal (Corner column, Edge column and interior column) are studied. DCR ratios are evaluated for critical section in the line of column removal. DCR ratio evaluation for Shear of beam is not done because shear capacity of beam is too high (378.97 KN) and in no case DCR of shear of beam will exceed more than one.

Load combination as per GSA G_{LD} = 2 (1.2DL + 0.5LL)……..for column removal region
Combination G = 1.2DL + 0.5LL …….for other region.

Corner Column Removal

Flexure in beams: For corner column removal case load G_{LD} should be applied in vicinity of removed column (Shaded area in figure) and in remaining area G load is applied. Bending moment of beams of Grid A and Grid 6 are noted and dividing the Bending moment by respective capacity of beam gives the DCR for beam. Following figure shows bending moment and DCR ratio.

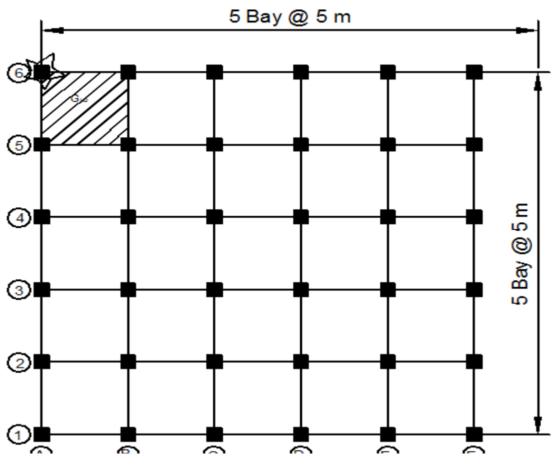


Fig 3.1: Corner Column Removal

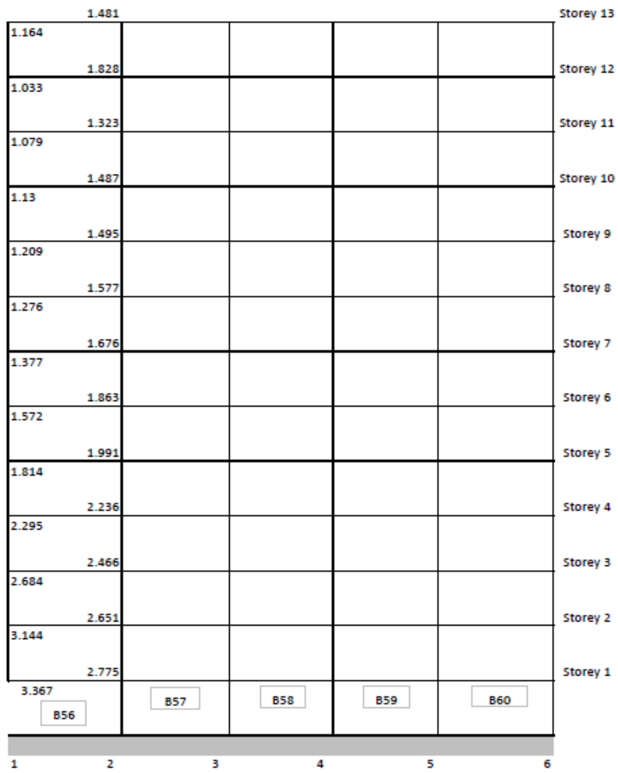


Fig.3.2 DCR for Beams (Flexural) A-6 Removal case

Exterior Edge Column Removal: (C-1)

For exterior edge column removal case load G_{LD} should be applied in vicinity of removed column (Shaded area in figure) and in remaining area G load is applied. Bending moment for beams of Grid C and Grid 1 are noted and dividing the Bending moment by respective capacity of beam gives the DCR for beam. Following figure shows bending moment and DCR ratio.

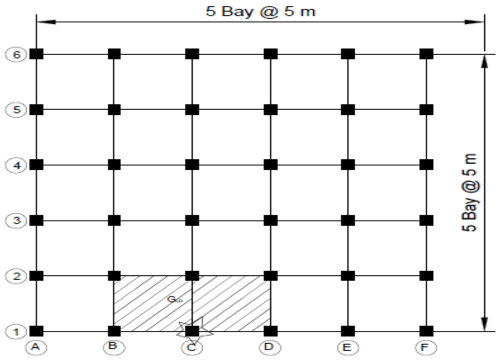


Fig.3.3 Exterior Column Removal Location

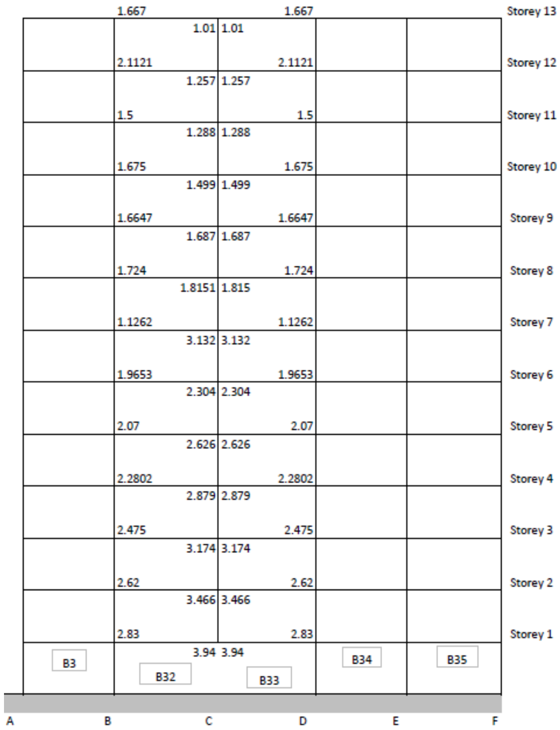


Fig.3.4 DCRs for beam (Flexural) for edge column removal

Interior Column Removal: (C-3)

For interior column removal case load G_{LD} should be applied in vicinity of removed column (Shaded area in figure) and in remaining area G load is applied. Bending moment for beams of Grid C and Grid 3 are noted and dividing the Bending moment by respective capacity of beam gives the DCR for beam. Following figure shows bending moment and DCR ratio.

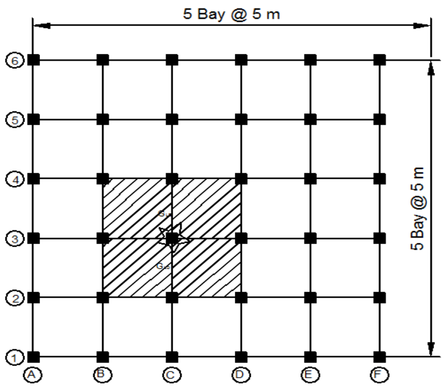


Fig.3.5 Interior column removal case

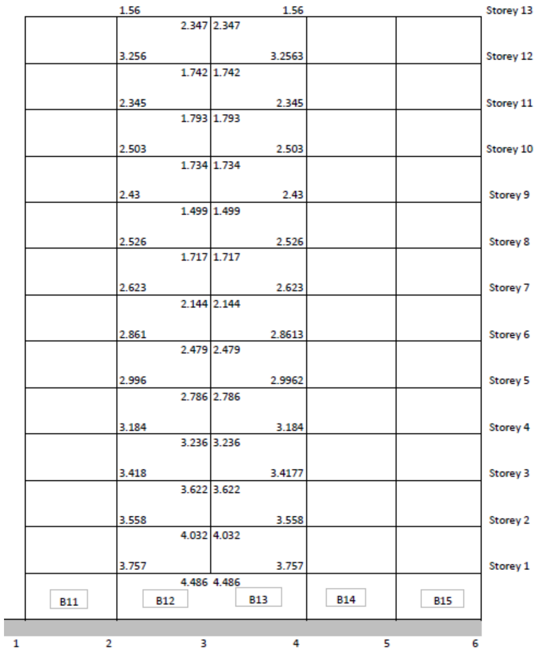
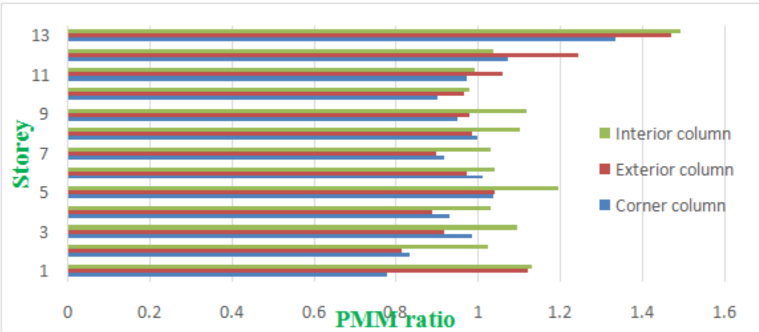


Fig.3.6 DCRs for beam (Flexural) for interior column removal case

Dcr/Pmm Ratio Of Columns

PMM ratio of columns has been obtained by running design after loss of corner column, exterior column and \interior column. PMM ratio of columns which are critical and in vicinity of removed column has been obtained for all storeys. PMM ratio is also plotted in the form of Bar chart for all three column removal cases. Finally critical columns are selected from each case of column removal and bar chart of those columns has been plotted in fig

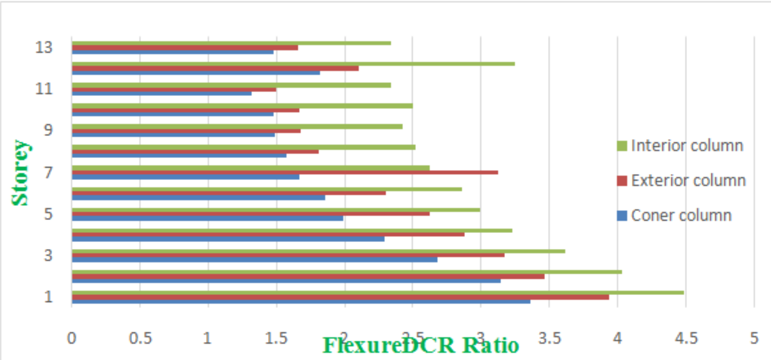


IV. Result and Discussion on Linear Static Analysis

Linear static analysis of 3 column removal cases at ground floor one at a time has been done to evaluated progressive collapse resistance of building. DCR ratio of beams for flexure and shear (one case only) has been evaluated for beams. While for column PMM ratio are taken as DCR ratio. DCR ratios are presented in the form of bar charts for each case. As per ASCE 41 [10] the frame members will fail when DCR ratio exceeds 2. That means column and beams are going to fail when DCR of member increases beyond the value 2.0.

Beams in Flexure: DCR ratio of critical beams for flexure for each case of column removal has been plotted in bar chart form. And after ward one critical beam from each column (whose DCR is higher) removal case has been selected. For all such four critical beams one from each case a combine bar chart has plotted it has been observed that beams B5 and B56 of lower four storeys will be going to fail as DCR > 2. This indicates that lower storey beams are more critical than upper storey beams. For exterior column removal case it can be seen that all beam vicinity of removed column namely B11, B32 and B33are going to fail on all storey except storey 8-11. While beam B32 and B33are more critical than B11. Again here in exterior column removal case lower storey beams are more critical than upper storey beams. While in interior column removal case it can be seen that, all beams will be going to fail in case of loss of interior column and lower storey beams are more critical than upper storey beams.

By observing it can be seen that the most critical case of column loss is interior column loss and least critical is corner column loss case among the three column removal case. For all thr cases of column loss lower storey beams are more critical than upper storey, the reason for this is that in case of column loss lower beams have to carry load of loss column.



Progressive Collapse Analysis: Nonlinear Static Analysis

Nonlinear static analysis is carried out here by using ETABS software. A 3D modeling of building is done first and loads are applied as per GSA guidelines. Nonlinear hinges are provided at the end of beams and columns. Default nonlinear hinges M3 in ETABS are provided to beams and for column P-M-M hinges are provided to columns. After that structure is pushed down and vertical displacement at column removed location are monitored

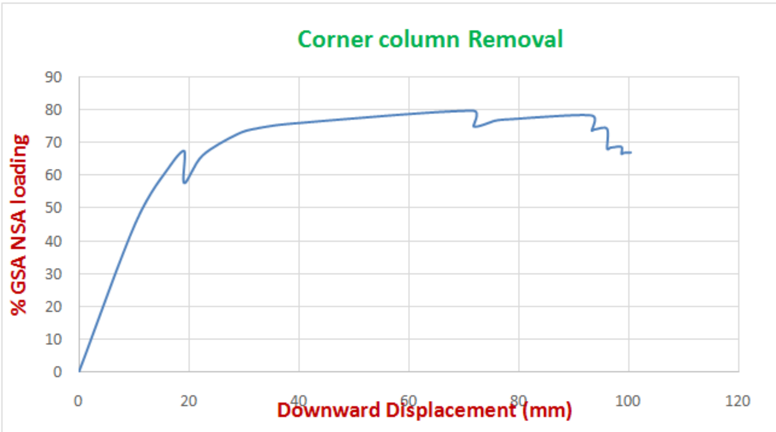


Fig.3.7 % GSA loading vs Monitored deflection at column removed point

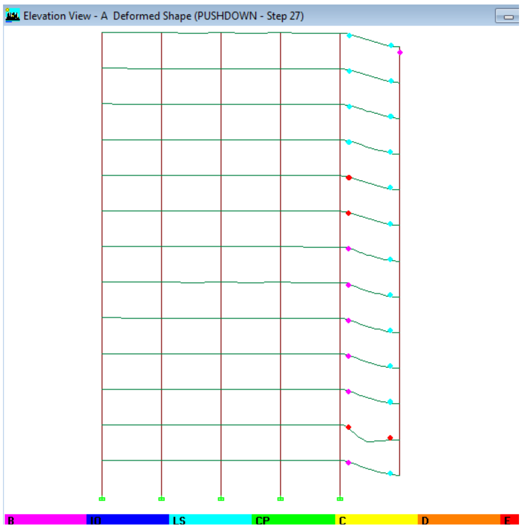


Fig.3.8 Hinge formation for elevation a corner column removal case

By observing the % load vs. displacement graph, pushdown and hinge formation sequence, following conclusions of pushdown of corner removal case can be made:

- Before collapse structure carries 80% of GSA loads and a maximum deflection of 99 mm was observed.
- Hinge formation sequence shows that the most critical beam is the second storey beam in which hinge goes beyond E state.
- Almost no hinges are formed in column therefore columns are not too much critical as beams in this case (In earthquake resistance structure).

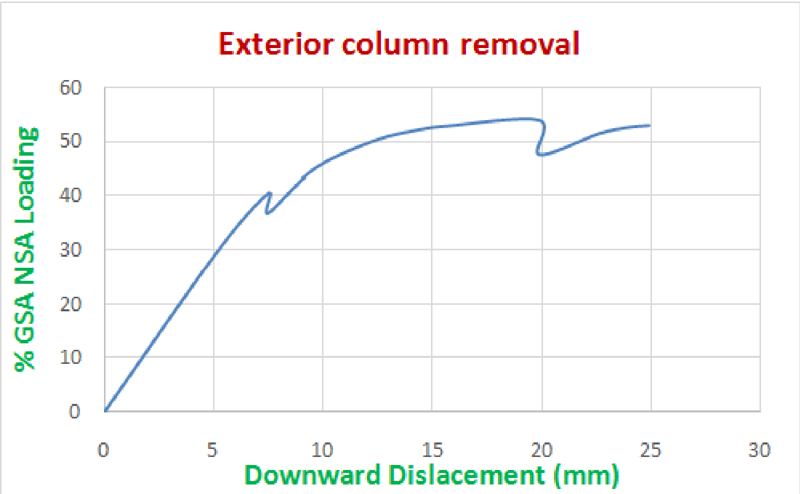


Fig.3.9 % GSA loading vs Monitored deflection at Exterior column removed

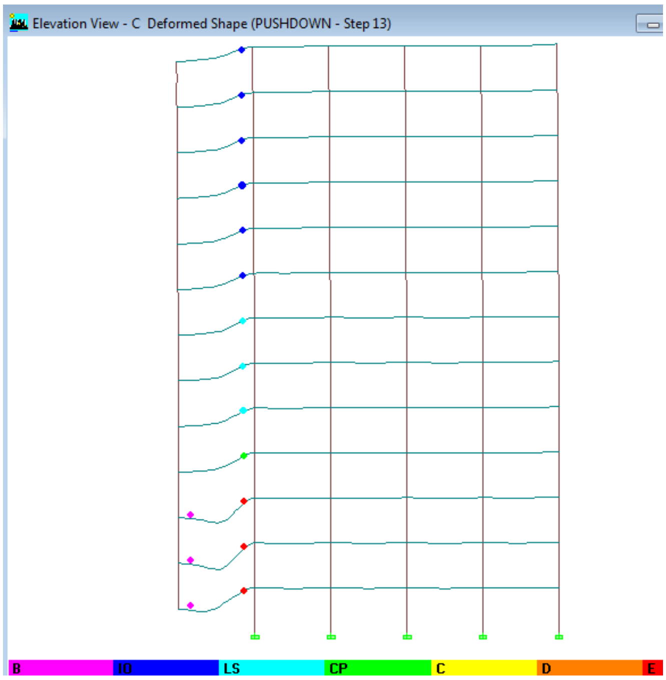


Fig.3.10 Hinge formation for elevation C exterior column removal

By observing the % load vs displacement graph, pushdown table and hinge formation sequence, following conclusions of pushdown of corner removal case can be made:

- Before collapse structure carries 53 % of GSA loads and a maximum deflection of 25 mm was observed.
- Hinge formation sequence shows that the most critical beams are the first, second third and fourth storey beams in elevation C below which column is removed in these beams hinges goes beyond E state.
- Almost no hinges are formed in column therefore columns are not too much critical as beams in this case (In earthquake resistance structure).

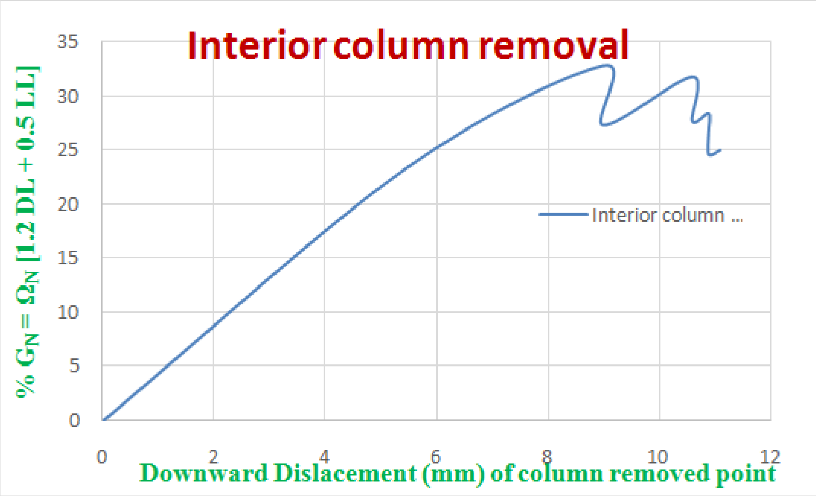


Fig.3.11 % GSA loading vs. Monitored deflection at Interior column removed

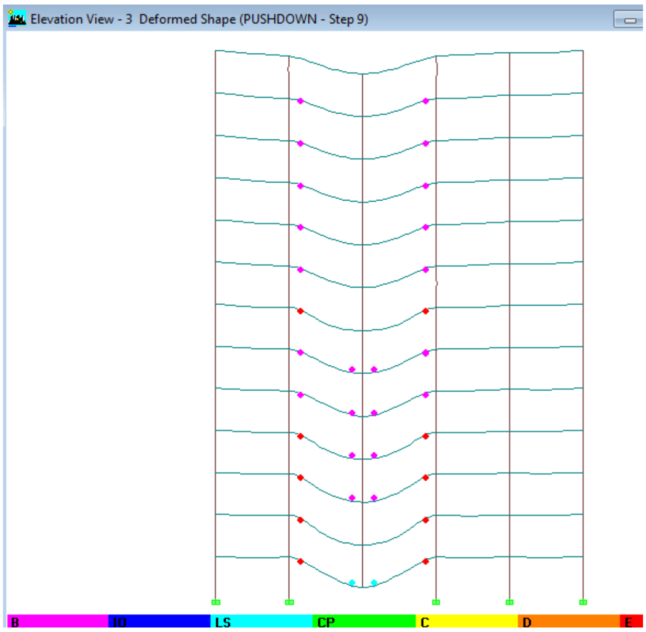


Fig.3.12 Hinge formation for elevation 3 Interior column removal

By observing the % load vs. displacement graph, pushdown table and hinge formation sequence, following conclusions of pushdown of corner removal case can be made:

- Before collapse structure carries 36 % of GSA loads and a maximum deflection of 11.1 mm was observed. This is the least resistance to progressive collapse among three removal case. As soon as the column is removed and structure is pushed down structure loss its stability.
- Hinge formation sequence shows that the most critical beams are the first, second third and fourth storey beams in elevation C and 3 below which column is removed in these beams hinges goes beyond E-state.
- Almost no hinges are formed in column therefore columns are not too much critical as beams in this case (In earthquake resistance structure).

V. Conclusion

1. As the shear capacity of beams is high none of the beam in any column removal case is going to fails in shear, i.e. shear in beam is not critical in progressive collapse.
2. By linear static method it is observed that in case of column loss scenario Lower storey beams are critical than upper storey beams.
3. Columns which are in vicinity of removed column has PMM ratio higher than other column this is due to fact that when one column has lost adjacent column have to share load of it. In no case column PMM ratio exceeds than 2, this means that columns are not critical in this case of progressive collapse.

4. By linear static analysis for most of the beams DCR ratio for bending has value greater than 2 which shows that they are going to fail under sudden column loss conditions, these beams needs to redesign to arrest progressive collapse.
5. In Nonlinear static analysis for corner, exterior and interior removal case building carries 80%, 53% and 36% of GSA load respectively before failure, which shows that most dangerous case is interior column removal and least dangerous is corner removal case.
6. Observing hinge formation pattern in all the three cases of column removal of nonlinear static analysis it has found that Nonlinear hinge in lower storey beams has gone beyond E-state (failure) which means that lower storey beams are more critical than upper storey beams.
7. A Special moment resistance frame designed by IS 456 and detailed by IS 13920 does not provide resistance to progressive collapse this is because of that SMRF is designed for lateral loads and in progressive collapse the failure loads are gravity loads.

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