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Comparative Study on Progressive Collapse of An Irregular (Lshaped) Flat Slab Building by Linear Static Analysis using ETABS

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***Abstract:** Concrete and steel structures influences the construction of multi-storey structures. The aid of progressive collapse increases when there is a failure of one or more load bearing structural elements. Thereafter, this case study is carried out to determine the prospective of the progressive collapse of an irregular (L shaped) building due to the failure or removal of two adjacent columns at a time present in the ground floor. Failure may occur because of the natural or manmade accidental loads like explosion or seismic loads, collision of vehicles, etc. Columns at different locations were removed and the slab loads had been increased as per the General Services Administration (GSA) guidelines and the results in terms of Demand Capacity Ratios (DCR) are compared for all the cases. The Demand to Capacity Ratios were calculated for the interested columns. It is observed that when the interior columns were removed then the possibility of progressive collapse is more. This study has been made for the case or earthquake forces for corresponding zone II and zone V.*

***Key words:** Progressive collapse, demand capacity ratio, Column removal, ETABS.*

I. INTRODUCTION

Progressive collapse is initiated by a local failure, where only some part of the building fails and if that failure progresses across the whole building; then it may cause the complete building to come down and it is known as the progressive collapse. If the building undergoes progressive collapse, then not only the building collapses but also there will be loss of lives, so as per the American Society of Civil Engineers (ASCE) the progressive collapse should be taken into design consideration with the possible loss of structural elements. There are many researchers studying the resistance of the buildings against progressive collapse, so that even if the building is susceptible to local failure then that local failure should not cause the entire building's failure.

II. OBJECTIVES

A. Designing the flat slab and check for punching shear failure.
B. To understand the impact of seismic forces on the structure during the progressive collapse. Due to earthquake in zone II, V.
C. To study the effect on a particular column by removing columns at different locations due to load transfer.
D. Analyzing the load transfer by using Demand Capacity Ratio (DCR) values of the columns.
E. To locate the critical column positions.
F. To study the progressive collapse and Demand Capacity Ratio (DCR) values at different stories location and for different zone.

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III. METHODOLOGY

i. Design Approaches for the Progressive Collapse

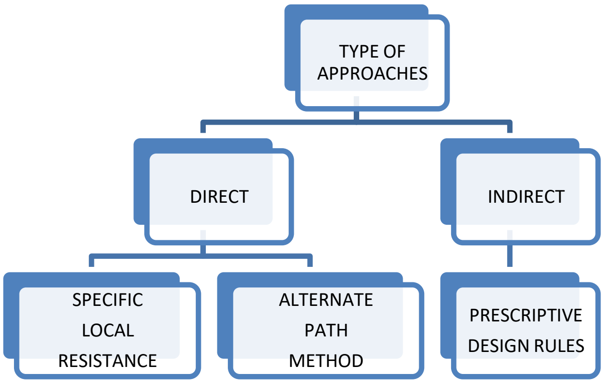

Fig 1. Flow Diagram of Design Approaches

The specific local resistance method will tries to sustain the progressive collapse by the local members, which are intact surrounding the removed structural elements, whereas in the Alternate load path method, allows the loads to pass through the structural elements to the earth by alternate path when there is a failure in a structural elements. Hence Alternate load path method is more relevant to the real world, wherein if a structural element has failed, say a column has failed, then surely the loads that were carried by that column will try to go to foundation by alternative paths like transferring to the surrounding slabs, beams, columns and to the foundations.

ii. Guidelines for progressive collapse

One of the simple scenarios from the GSA guidelines is as shown below, where the exterior column and an interior column had been removed and the figure shows the slab area, in which the loads should be increased as per the formula provided by the GSA guidelines. In general, it says that, the loads on the floors present above the removed columns should be increased. For illustration, if any corner column is removed then only loads on that corresponding corner column floors throughout the height of the building need to be increased. Similarly, if an exterior column is removed then there will be two slabs, which get affected as shown in the Fig 2.

Those two corresponding slabs should get the increased loads, whereas when an interior column is removed then that particular column will be surrounded by slab in all four directions in most of the cases. Therefore, the load should be increased on the all the four slab that surrounded the interior column surrounds. It is as shown in Fig 2.

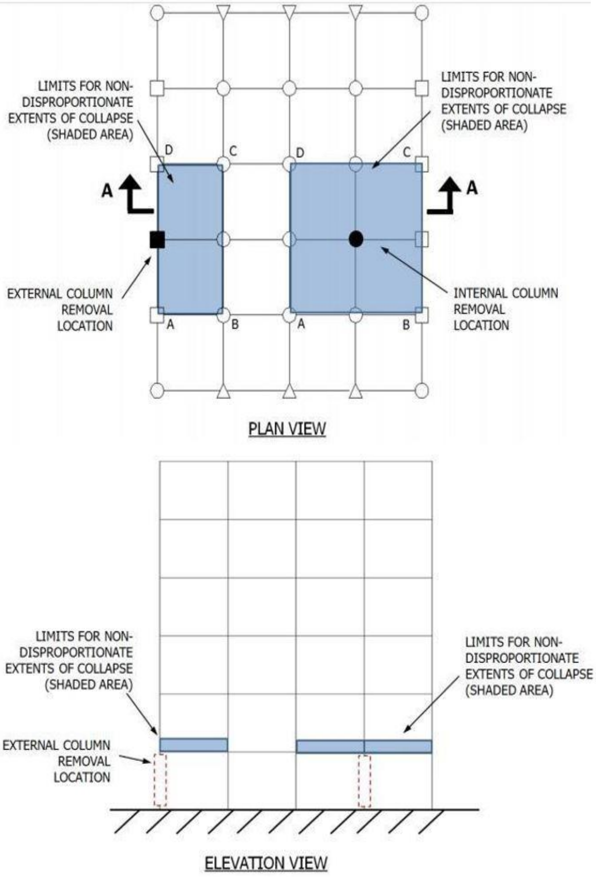

Fig 2- GSA guidelines for removing the columns

A. In this study the structure selected is of L shape flat slab with drops and it is a G+10 storey building. Along the x-direction it has 4 bays and along the y-direction it has 3 bays. Column to column distance is 5m. The building characteristics are as listed in fig 2 The model is analyzed in ETABS version 16. The punching shear is checked first for the flat slab, which is the basic check to be done in the flat slab to withstand the gravity loads

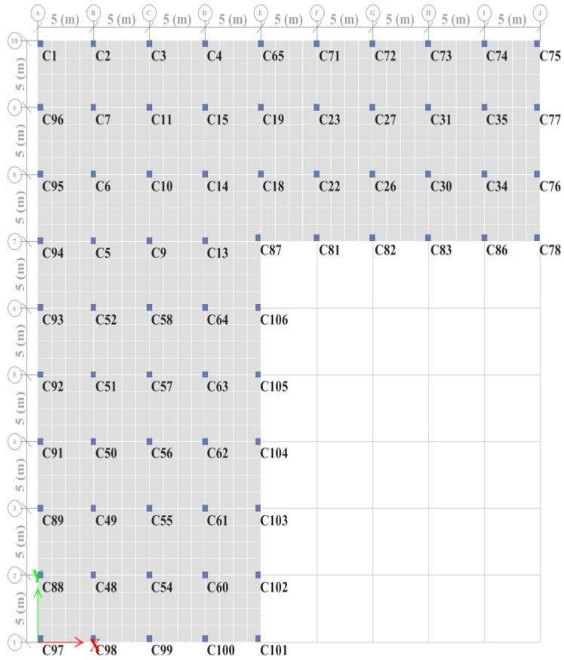

Fig 3-Plan of the building and column labels

iii. Procedure for Analysis for Progressive Collapse.

The steps mentioned below are followed for analysis of the model in ETABS.

Step - 1: The structure is modelled in ETABS as per the description. And the loads are applied to the model including the seismic loads. The model is analysed under linear static condition.

Step - 2: The punching shear is checked for the entire structure. The results are shown in the Fig 5.1. Also, the DCR's are found out for the columns that are to be removed.

Step - 3: Case-wise 2 columns are removed simultaneously in the ground floor and the loads are applied as per the GSA guidelines to simulate the actual condition.

Floor load on the slabs above the removed column in all floors

$G_{LF} = 2\,[\,1.2\,DL + (0.5\,LL \text{ or } 0.2\,SL)]$

Floor load on the all slabs except the slabs present above the removed column in all floors

G = 1.2 DL + (0.5 LL or 0.2 SL)

Where DL - Dead Load

LL - Live Load

SL - Snow Load (zero for my study)

Step - 4: The results of the analysis are extracted to excel sheet or the spreadsheets. The DCR values for the columns of interest are found out with the help of the formula provided in chapter 4.5 in the page no19. A table is generated to represent the DCRs of these columns. Graphical representations are made to analyse the results easily.

Step - 5: As per the GSA guidelines, the columns which have DCR less than 2are safe and resist the progressive collapse. But in general, if the DCR > 1, that means the demand is more than the capacity of the column; so DCR>1 is simply means that the column has failed. If and only if the DCR is more than 2 then there will be progressive collapse.

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iv. Cases Considered

1. Removal of Corner Columns

- **Case 1**: Column C1 and C2 - Position A10 and B10
- **Case 2**: Column C97 and C88 - Position A1 and A2
- **Case 3**: Column C87 and C81 - Position E7 and F7

2. Removal of Exterior Columns

- **Case 4:** Column C65 and C71 - Position E10 and F10
- **Case 5:** Column C76 and C77 - Position J8 and J9

3. Removal of Interior Columns

- **Case 6:** Column C57 and C58 - Position C5 and C6
- **Case 7:** Column C10 and C14 - Position C8 and D8

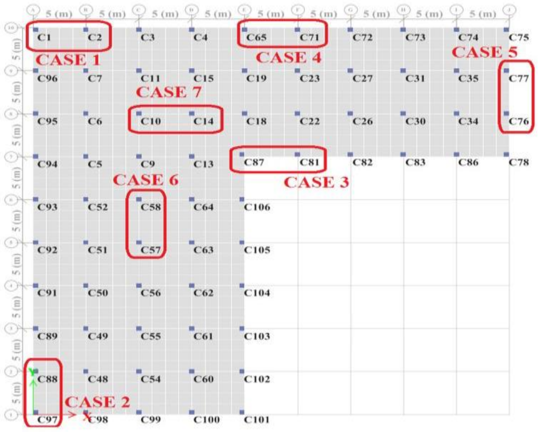


Fig 4 – Column removed in respective cases

v. Permissible Limits

The GSA has its own set of rules for the linear static analysis. GSA provides the formula to find out the DCR values for the members.

DCR = Q_{ud} / Q_{ue}

where,

Q_{ud} - Acting force (demand) observed in member or connection (axial force, bending moment for the combined forces)

Q_{ue}- Expected ultimate, nonfractured capacity of the member or connection (axial forces, bending moment for the combined forces)

As per the GSA guidelines DCR values have the limits as shown below

- Demand Capacity Ratio for failure of members in flexure >= 2
- Demand Capacity Ratio for failure of members in shear >= 1.5

process of Analysis of structure is performed on ETABS 2016 in accordance with IS 456-2000 and IS 1893-2016 (part I). Figure shows Flow of work in ETABS.

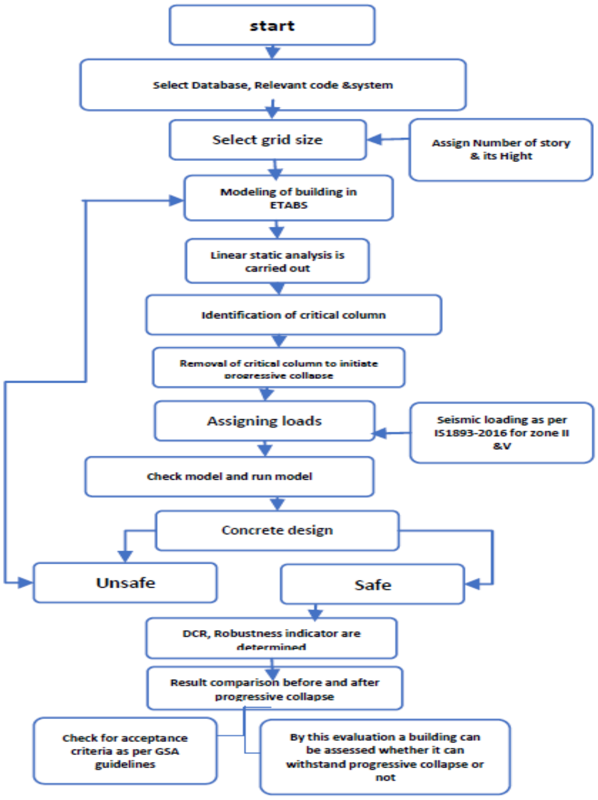


Fig 5-Flow Diagram of Methodology

IV. MODELING AND PROBLEMFORMULATION

To model a building in ETABS 2016, we require some preliminary data to input such as codes for design, material specifications, building specification with the dimensions of each structural component, load case, load patterns & load combination. However, the building modelling may differ from case to case

A. Codes for Design

i.IS456-2000 code for plain and reinforce concrete design
ii.IS1893-2016 (part I) code for earthquake loading
iii.IS875-1987 (part I) code for deadload
iv.IS875-1987 (part II) code for live load

B. Material Specification Table

I. Material Specification.

Sl No.	Material specification	
1	Grade of Concrete – M25	fck= 25 N/mm2
2	Grade of Steel – Fe-500	fy= 500 N/mm2
3	Density of Concrete	Dc = 25 KN/m^3
4	Density of Steel	Ds = 77 KN/m^3
5	Partial safety factor for Concrete	γm = 1.5
6	Partial safety factor for Steel	γm = 1.15

C. Building Specification

The details of the building analyzed are mentioned below:
Number of cases analyzed: 7 cases for each zone
Loads on the building:

Super Imposed Load = 1.5 kN/m2
Live Load = 3 kN/m2
Seismic Loads: based on the zones as per the IS 1893:2002
The structural details are:
Floor to floor height = 3 m (constant)
Column size = 500 mm x 500 mm
Column spacing = 5 m
Slab depth = 150 mm
Drop panel = 75 mm (total drop = 225 mm for all columns)
Seismic zones: zone II and zone V as per the IS1893:2002
Soil type II
Response Reduction Factor (R) = 3
Importance Factor (I) = 1 (as per the Clause 6.4.2 of IS 1893:2002)
Fundamental Period (Ta): as per the IS 1893:2002

D. Load Patterns

In ETABS 2016 Load Patterns are the types of load considered. Here for this project, Dead Load, Live Load & Earthquake Load for Zone-II and V is considered.

i. Dead Loads

a) Self-weight of slab =
=(Thicknessofslab)X(DensityofConcrete)
= 0.15 X 25 = 3.75 KN/m2
However, the self-weight of each structural component is calculated automatically on the basis of input data by ETABS 2016 & hence the above value is only for illustration purpose.

b) Floor finish load= 1.2 KN/m2
(To be imposed in addition to the dead load)

ii. Live Load

Live load on floor = 3 KN/m2

iii. Earthquake Loads

Seismic Definition: Response Spectrum Analysis
(linear Static Analysis) Earthquake Zone-II And V,
Z= Programmed calculated.
Response Reduction Factor (R) = 3 (S.M.R.F.)
Importance Factor (I) = 1
Soil Type = II (Medium Soil)
Type of Structure = I,
Natural Time Period = Program Calculated

E. Load Cases

Load cases here in ETABS 2016 is referred as the type of analysis carried out for a particular load pattern. The Dead Load (D.L), Live Load (L.L) and the equivalent earthquake loads (earthquake load in X-direction (EQ-X) & earthquake load in Y-direction (EQ-Y)) are consider as linear static load.

F. Load Combinations

As per IS 456-2000, the following are the various possible load combinations for the given loading cases. Also, due to plan Irregularity the ground motion due earthquake load is considered in both the direction:
1) 1.5(D.L)
2) 1.5(D.L + L.L)
3) 1.2(D.L + L.L + EQX)
4) 1.2(D.L + L.L - EQX)
5) 1.2(D.L + L.L + EQY)
6) 1.2(D.L + L.L - EQY)
7) 1.5(D.L + EQX)
8) 1.5(D.L - EQX)
9) 1.5(D.L + EQY)
10) 1.5(D.L - EQY)
11) 0.9D.L + 1.5EQX*
12) 0.9D.L - 1.5EQX*
13) 0.9D.L + 1.5EQY*
14) 0.9D.L - 1.5EQY

G. Plan and 3D Views of Building

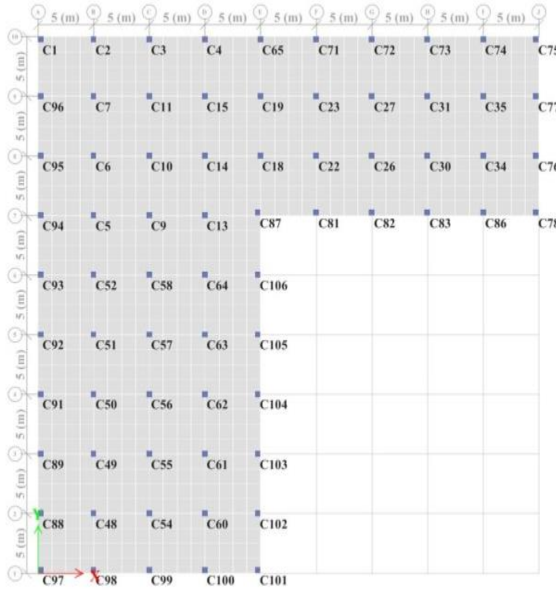


fig 6- plan of the building and column labels

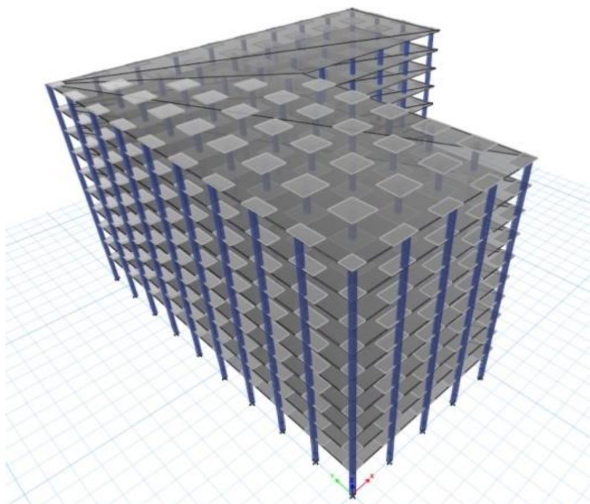


Fig 7- Building Modelled in ETABS

V. RESULTS, OBSERVATIONS ANDDISCUSSIONS

i. Punching Shear Check

Before removing the columns, the basic check for flat slabs is to be done. The punching shear check is found out to know, whether the slab is safe against punching shear or not. From the history also we can see many failures because of the punching of column through slab.

Therefore, when it had been checked in this study, the model is safe under punching shear. And the DCR values for the punching shear are as shown in the below figure. The ETABS version 16 shows the punching shear values directly in terms of DCR, which means if the value is lesser than 1, then it safe in punching shear. In case if it is more than 1 then we have to go for either increasing the slab depth or drop depth or the column sizes.

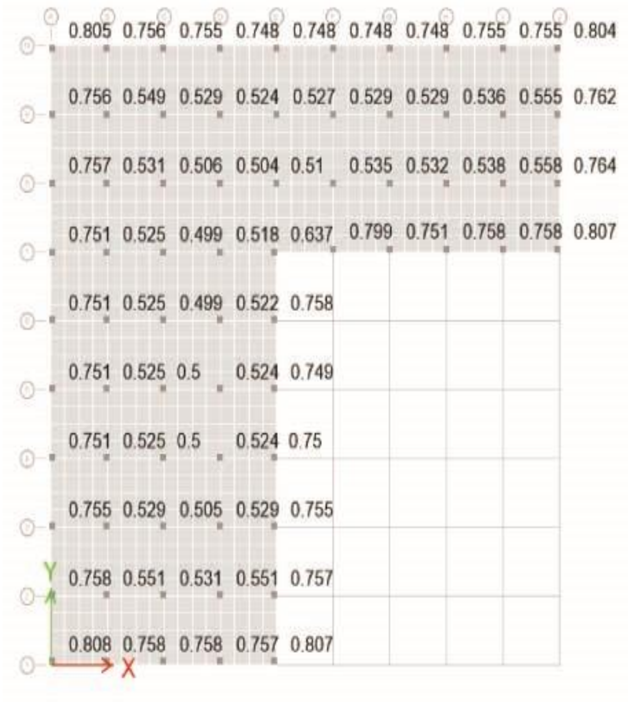


Fig 8 - Punching Shear Ratio check in ETABS 16

Before analysing the results, in the present study, a comparison of DCR values of columns to be removed for different zones has been done. Therefore, in general it is known that for lower zones like zone II and zone III, the base shear and storey drift are minimum. Therefore, whenever the columns are removed then the moments are less and thereby the DCR will be small. Similarly, in case of zone V, which is the severe earthquake prone area will get higher magnitude of seismic force, thereby the base shear and story drift are more and for the columns to be removed columns, the moment generated will be more, thereby increasing the DCR values. In general, DCR for zone II should be less than DCR for zone V. Those comparison is shown in the upcoming figures.

ii. Comparison of DCR Values for Zones II and Zone V Case-Wise Using Graph.

a) **CASE 1: Removal of columns C1 and C2**

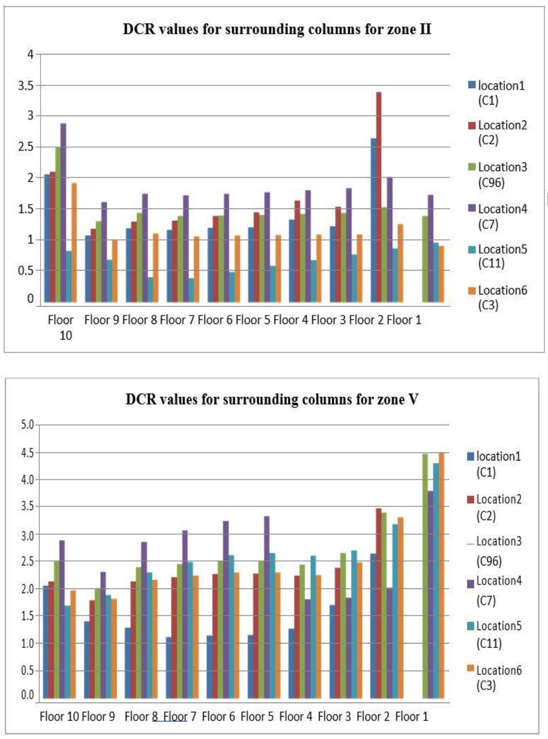


Fig 9 – Case 1 DCR values for surrounding columns for zone II and V

b) CASE 2: Removal of columns C97 and C88

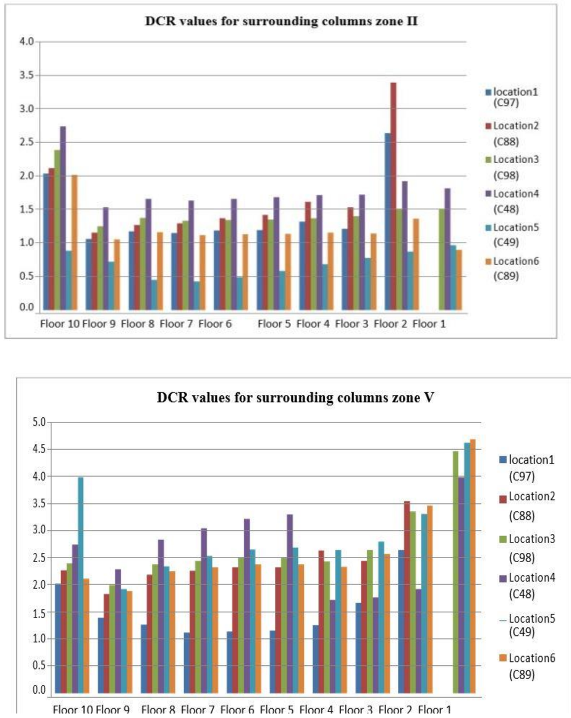
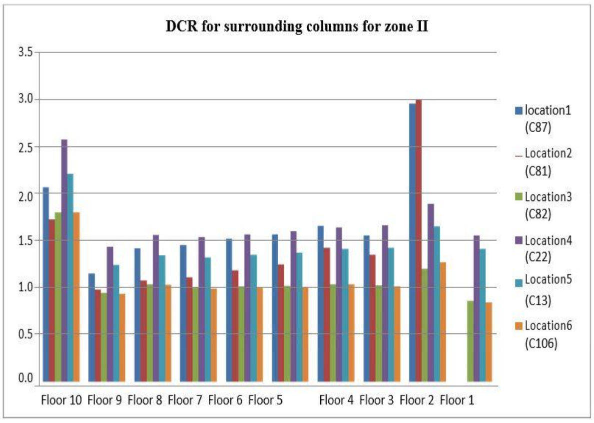


Fig 10 – Case 2 DCR values for surrounding columns for zone II and V

c) CASE 3: Removal of columns C87 and C81



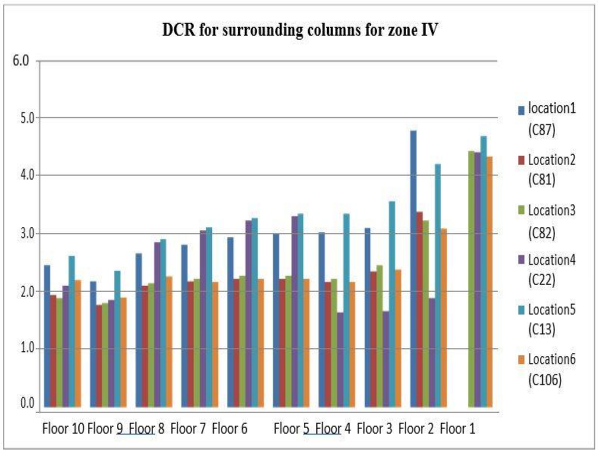
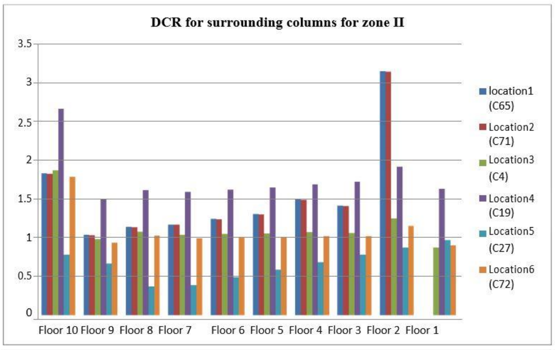


Fig 11 – Case 3 DCR values for surrounding columns for zone II and V

d)CASE 4: Removal of columns C65 and C71



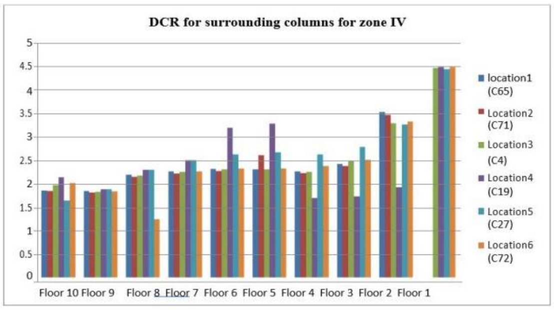
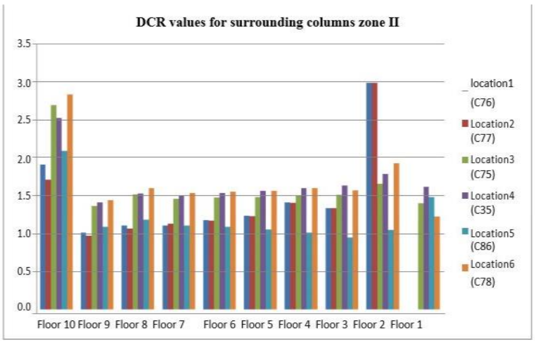


Fig 12– Case 4 DCR values for surrounding columns for zone II and V

e) CASE 5: Removal of columns C76 and C77



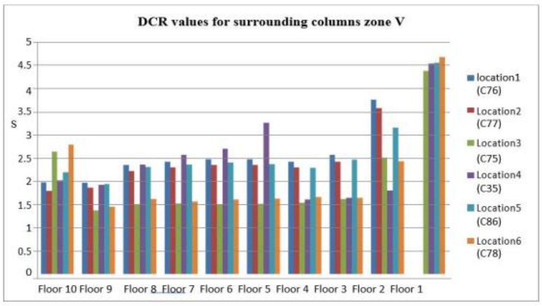
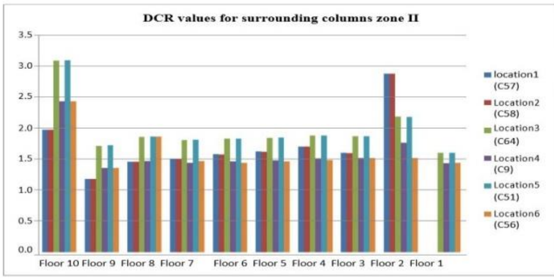


Fig 13 – Case 5 DCR values for surrounding columns for zone II and V

f) CASE 6: Removal of columns C57 and C58



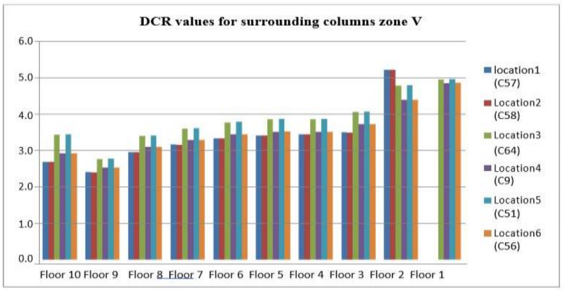
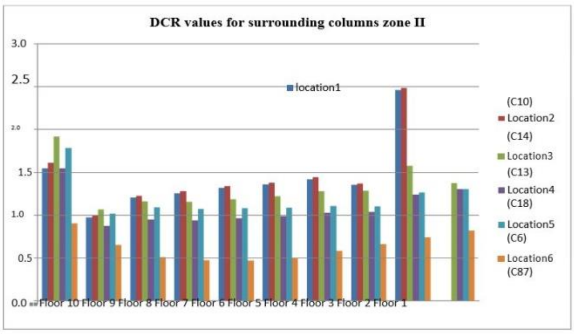


Fig 14 – Case 6 DCR values for surrounding columns for zone II and V

g) CASE 7: Removal of columns C10 and C14



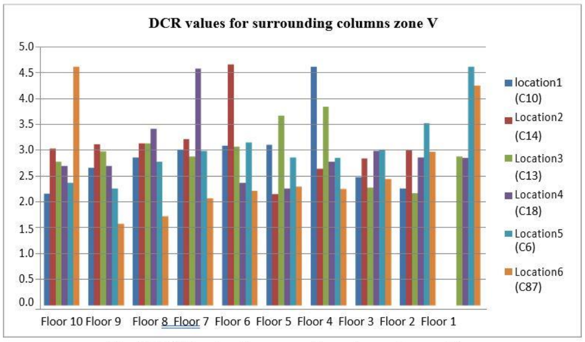


Fig 15 -Case 7 DCR values for surrounding columns for zone II and V

It is observed from the above figures that the column C10 is the removed column and the column C15, both are undergoing higher flexural moment, whereas in both zones the column C5 has lower DCR even though it is next to the removed column C10 and show that it is subjected to lesser flexural moment.

iii. Graphical Representation Of The DCR Values

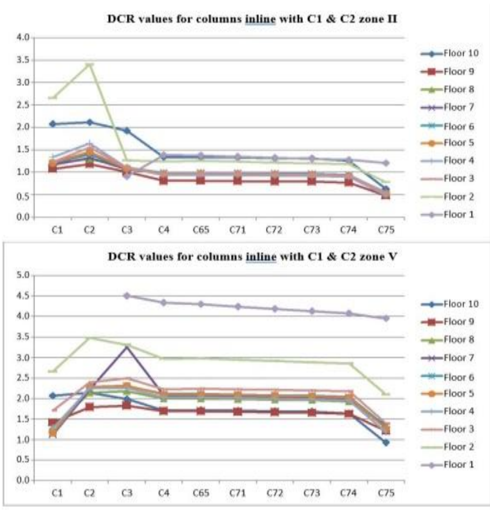


Fig 16 - DCR for columns in line with C1 and C2 (→)

DISCUSSION: From the Fig 16, we can see that C1 and C2 in the floor 2 has greater DCRvalues than any other column in-line with them in zone II. But in zone V, the same columns which are in-line with the removed columns are highly vulnerable to progressive collapse because DCR values of all columns are more than 2.

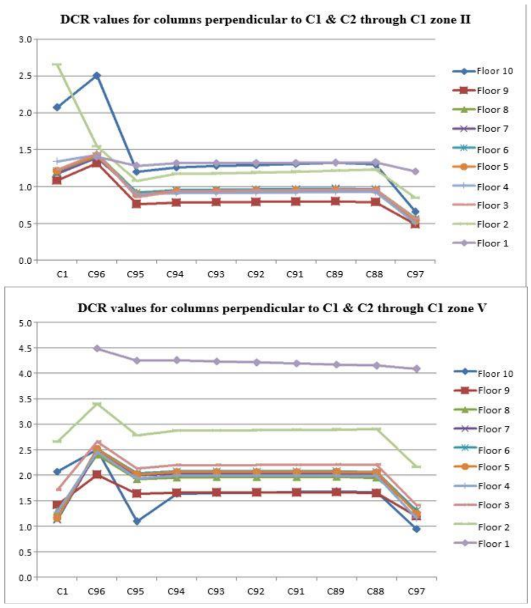


Fig 17 - DCR value for columns perpendicular to C1 & C2 through C1 (↓)

DISCUSSION: From the Fig 17, we can see that C1 in the floor 2 has highest DCR value compared to columns perpendicular to it in zone II. But in zone V, the all columns which are perpendicular to C1 have the DCR more than 4 in floor 1.

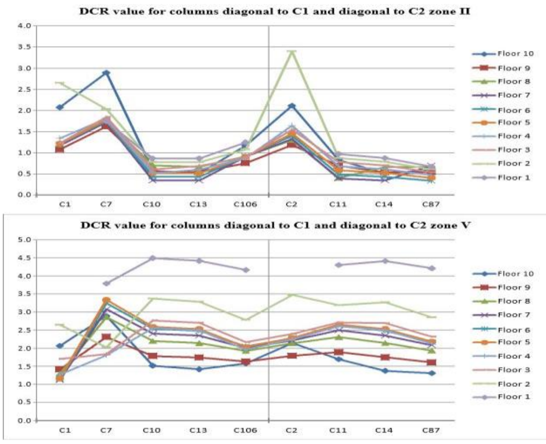


Fig 18 - DCR value for columns diagonal to C1 (↘) and diagonal to C2 (↘)

DISCUSSION: In the above figures, the arrows indicates the direction of diagonal columns consider. To check the columns side by side; which is a folded page of column labels. From the above figures C1 and C2 have high values in zone II and in zone V the columns in diagonal direction have variable values from floor to floor.

Note: The Same Trend was observed for all other cases. i.e fore case 2,3,4,5,6,7.

iv. Observations and Discussions

From the overall observations of results of different cases it can be concluded that, the surrounding columns will have higher DCR values and there is a more possibility for the progressive collapse when the intermediate columns were removed.

And the columns surrounding to the removed columns and the exterior columns will have higher DCR values compared to the other intermediate columns.

- In the present study two columns are removed simultaneously and it is seen that a greater number of columns fail in the for higher zones. We can say that when more number of adjacent columns are removed then stiffness gets reduced drastically, which will put the remaining columns in danger. It means the other columns may get failed or even progressive collapse could take place.
- It is seen that, in the floor 2 the columns surrounding to the removed columns have the DCR values more than 2 as shown in fig 9 to fig 15. But in almost all the cases, the removed columns have the DCR values very high in the floor just above the removed columns in zone II and in zone III.
- From the graphs as shown in fig 9 to 15. It is observed that the columns are more tentative to cause progressive collapse from lower zones to the higher zones. It means, that the columns have the lesser DCR values for zone II whereas the same columns have very high DCR values for zone V.
- It can be concluded from the graphs as shown in fig 9 to 15,that the top floor will have the higher DCR values in zone II whereas the first and the second floors will have the DCR values highest in zone V compared to any other zones. Also, it is observed that for the Case 6, when C57 and C58 are removed; all the columns in most of the floors have the DCR values more than 2. It means, building will undergo progressive collapse.
- In general, as it is already known from the above points from fig 13 to 15 here in fig graphs also the columns which are removed have the higher DCR in the second floor, when the columns are removed in the first floor.
- When theDCRs of the columns, which are in line with the removed columns as show are considered, the graphs fig 13 clearly shows that in most of the cases the DCR values are decreasing from the removed column to the last or far columns. But the far most or last columns will have slightly higher DCRs compared to the last but one adjacent column.
- Considering the columns perpendicular to the removed columns as shown in fig 14Herealso it is very much similar to the columns in line action. For the removed columns the DCR will be more and for other adjacent columns, DCR goes on decreases.
- Considering the columns diagonal to the removed columns as shown in fig 15 In this casefrom the observations; the columns in diagonal to the removed columns will have variable DCRs alternatively.
- It is also concluded from fig 12 to 15 that for lower zones the DCRs for all columns are less and for zone V, DCRs are very high. It is because when the columns are removed, the stiffness reduces and thereby stability reduces. Also, the base shear increases for the due to the zone (zone V) and due to the mass of the structure.

VI. CONCLUSION

Based on the comparative study of progressive collapse on reinforced framed structure the following conclusions can be made.

1. The performance of the RC flat slab structure is completely dependent on the capability of slab-column connections to with stand extreme or abnormal loading.
2. Reinforced Concrete Flat slab structures are very strongso there is no brittle failure and punching shear failure. Hence it can prevent progressive collapse.
3. The surrounding columns will have higher DCR values and there is a more possibility for the progressive collapse when the intermediate column were removed.
4. ForallZones, corner column removal case is critical in the event of progressive collapse when compared to interior and exterior column removal.
5. It can be concluded that the columns are more tentative to cause progressive collapse from lower zones to the higher zones.
6. The columns adjacent to the removed column experienced more damage to the column which are away from the removed column.
7. Higher the number of floors, there is a high risk of progressive collapse.
8. 8By providing the additional reinforcement in the columns will be more effective in avoiding or delaying collapse of the structure.
9. The adequate reinforcement should be provided to slab or column which are unsafe can develop alternative load paths and prevent progressive collapse due to the loss of an indusial local members.
10. Finally, it can be concluded that, the location of building where the building located, position of the column removed, and the number of floors will matter.

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