Linear Static Analysis of An Irregular (L Shaped) Flat Slab Building For Progressive Collapse

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Abstract- *Progressive collapse of building is initiated when one or more vertical load carrying members particularly columns are seriously damaged or collapsed during any of the abnormal event. Once a column is failed the building's gravity load transfers to the neighboring members in the structure. If those members are not properly designed to resist and redistribute the additional load that part of the structure will fails. As a result, a substantial part of the structure may collapse, causing greater damage to the structure than the initial impact. Different approaches for evaluating progressive collapse potential and a few related works on progressive collapse analysis are discussed in thispaper. 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 III and zone IV.*

Keywords**-** Progressive collapse, demand capacity ratio, Column removal, ETABS.

I. INTRODUCTION

Progressive collapse may be explained as a situation originated from the failure of one or more structural load bearing elements following an extreme abnormal loading or accidental loading. It is one of the most important types of building failures, most often leading to damages, multiple injuries, and possible loss of life too. Factors contribute to progressive collapse of the structures includes design mistakes, construction errors, faulty constructions, miscommunication, poor inspections, abnormal load events. The local failure occurred in the structure leads to load redistribution in the entire structure and which may result in an overall damage of the structure. The General Service Administration (GSA) of the United States define progressive collapse as "a situation where local failure of a primary structural members leads to the collapse of adjoining members which, in turn, leads to additional collapse. Hence, the total damage is disproportionate to the original cause".

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 III, IV.
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.

III. METHODOLOGY

i. Design Approaches for the Progressive Collapse

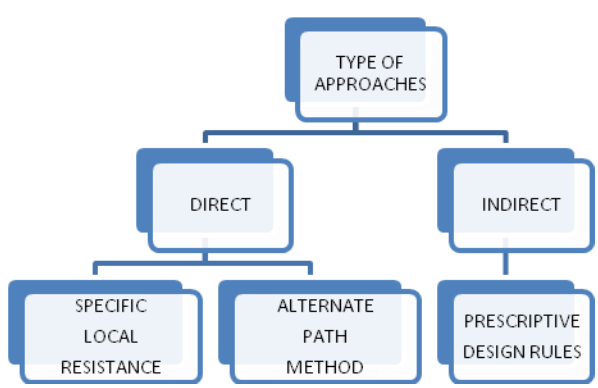
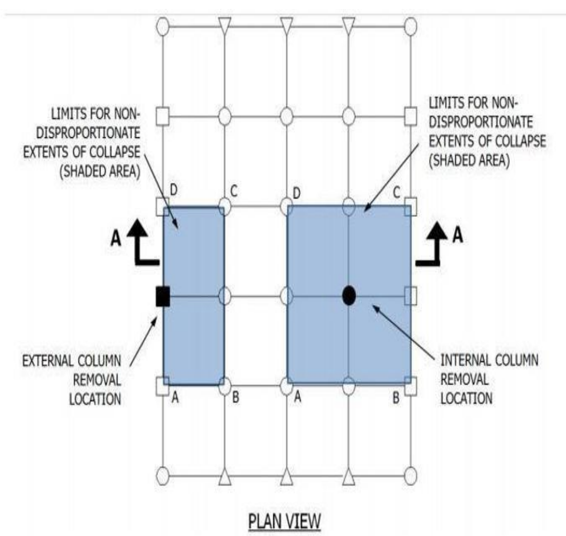


Fig 1. Flow Diagram of Design Approaches

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 foundation's.

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.



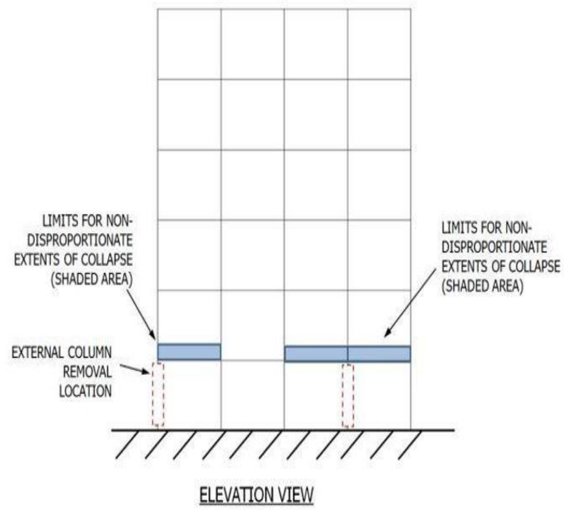


Fig 2- GSA guidelines for removing the columns

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

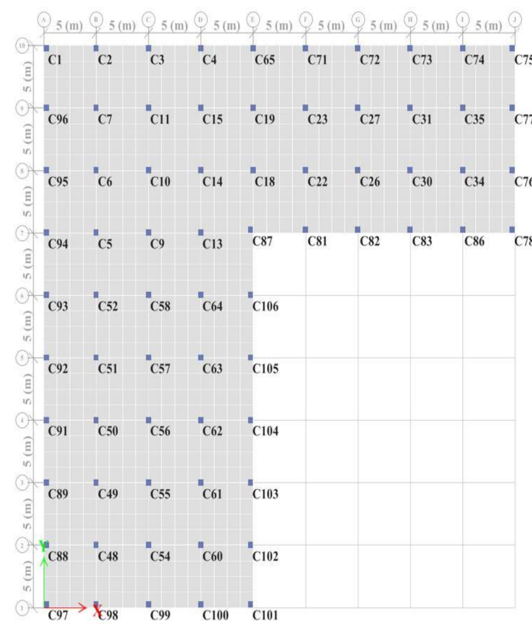


Fig 3-Plan of the building and column labels

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 analyzed 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

$$G = 1.2\ DL + (0.5\ LL \text{ or } 0.2\ SL)$$

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.

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

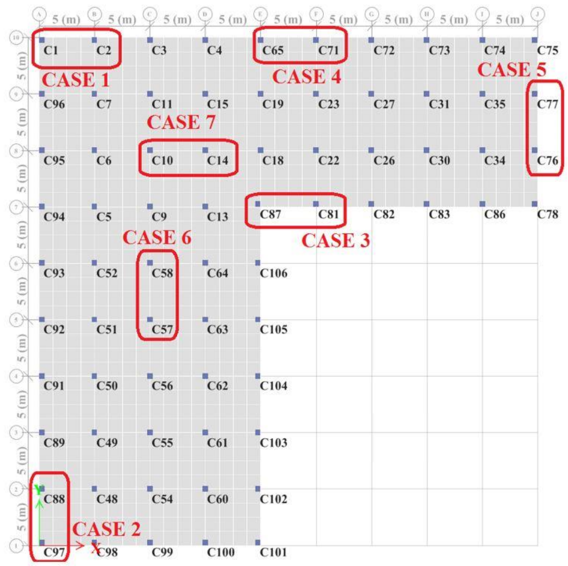


Fig 4 – Column removed in respective cases

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.

$$\mathbf{DCR = Q_{ud} / Q_{ue}}$$

where,

Q_{ud} - Acting force (demand) observed in member or connection (axial force, bending momentfor 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.

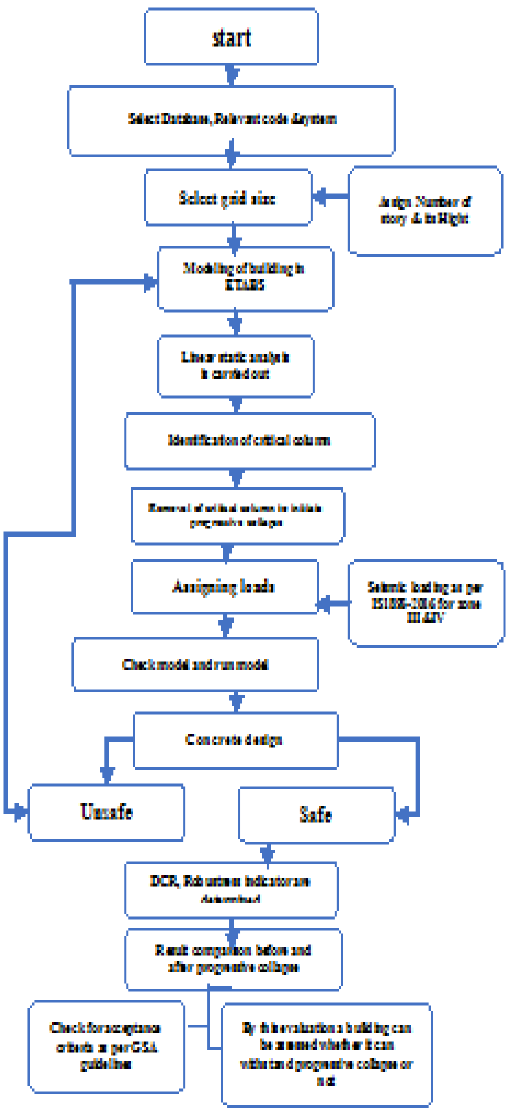


Fig 5-Flow Diagram of Methodology

VI. 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 dead load
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	$f$ck= 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 III and zone IV 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-III and IV is considered.

i. Dead Loads

a) Self-weight of slab =
=(Thickness of slab) X (Density of Concrete)
= 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-III And IV, Z= program calculated
Response Reduction Factor (R) = 3
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

i. Plan and 3D Views of Building

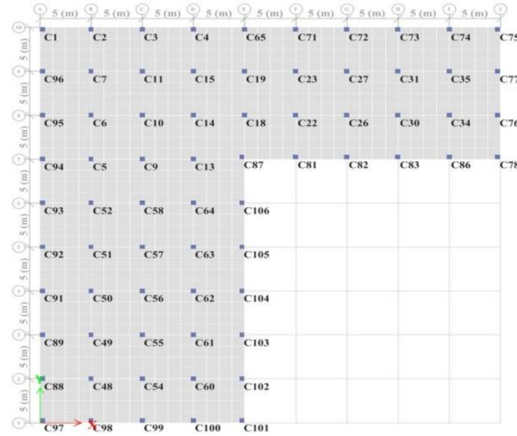


fig 6- plan of the building and column labels

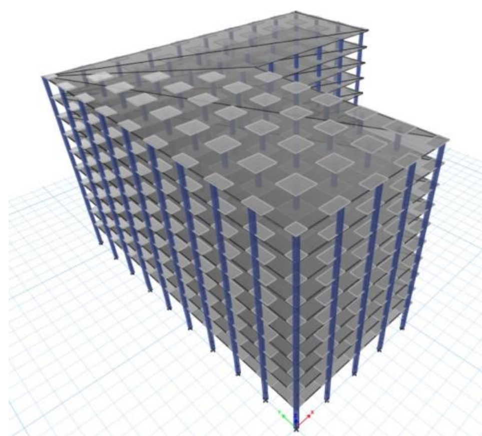


Fig 7- Building Modelled in ETABS

VII. RESULTS, OBSERVATIONS AND DISCUSSIONS

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.

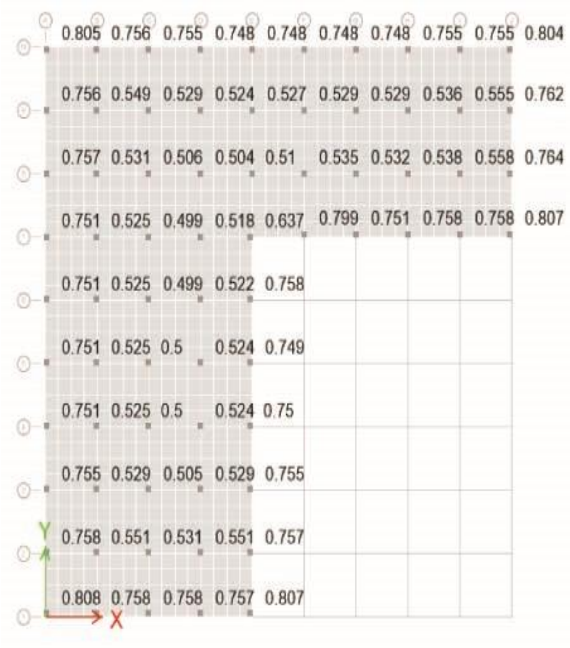
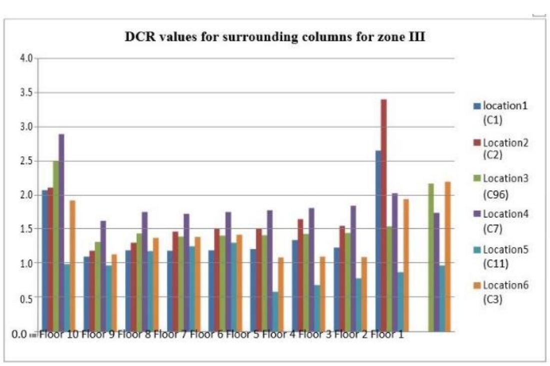


Fig 8 - Punching Shear Ratio check in ETABS 16

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 IV, 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 III should be less than DCR for zone IV. Those comparison is shown in the upcoming figures.

ii. COMPARISON OF DCR VALUES FOR ZONES III AND ZONE IV CASE-WISE USING GRAPH.

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



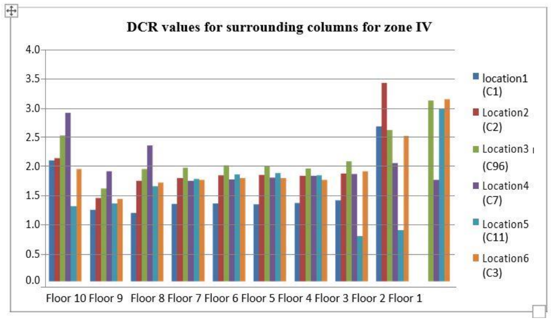


Fig 9 – Case 1 DCR values for surrounding columns for zone III and IV

b) CASE 2: Removal of columns C97 and C88

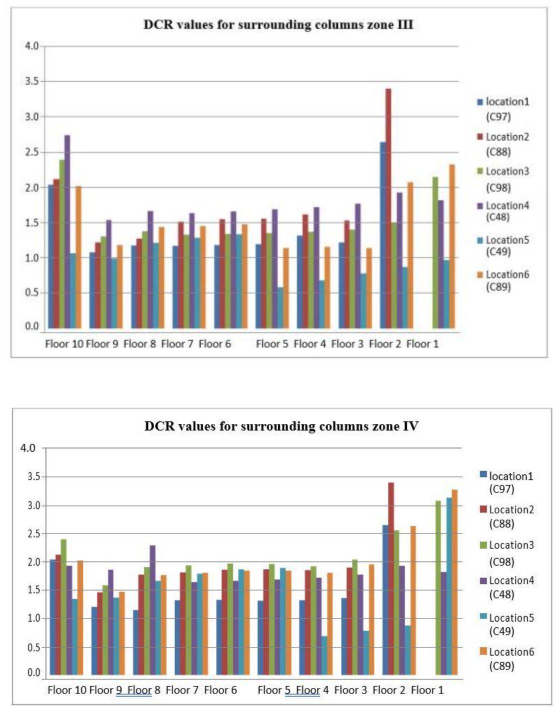
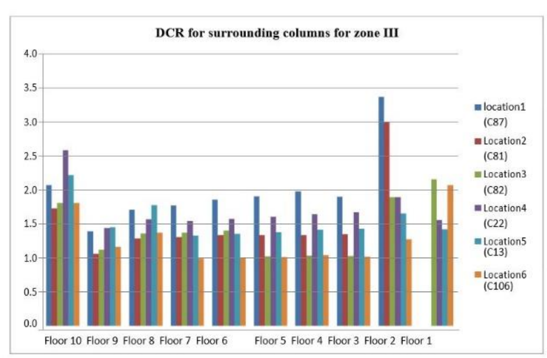


Fig 10 – Case 2 DCR values for surrounding columns for zone III and IV

c) CASE 3: Removal of columns C87 and C81



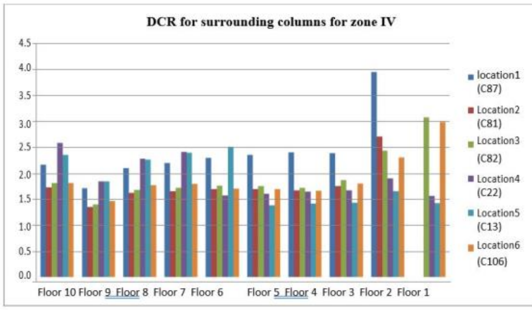
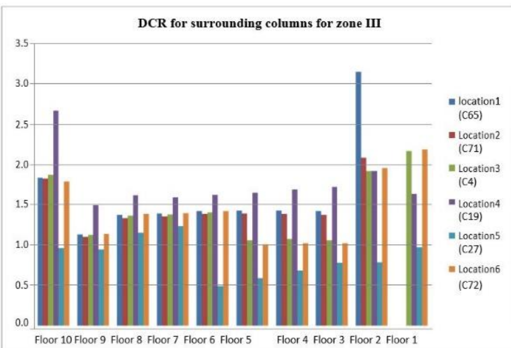


Fig 11 – Case 3 DCR values for surrounding columns for zone III and IV

d)CASE 4: Removal of columns C65 and C71



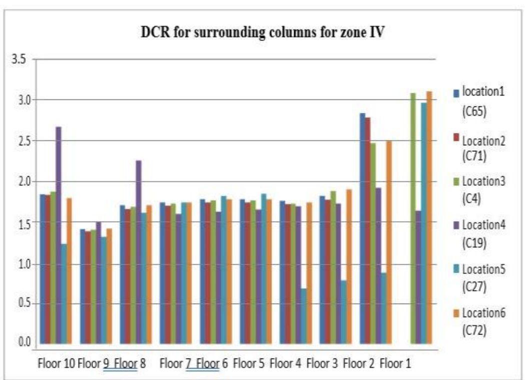
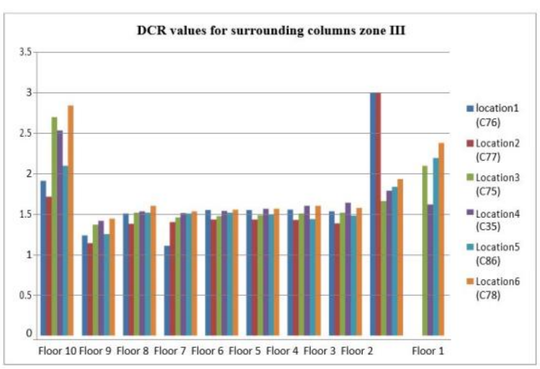


Fig 12– Case 4 DCR values for surrounding columns for zone III and IV

e) CASE 5: Removal of columns C76 and C77



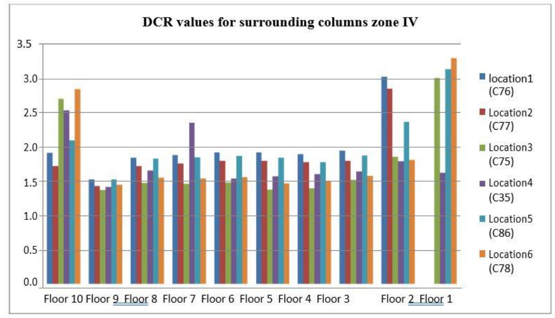
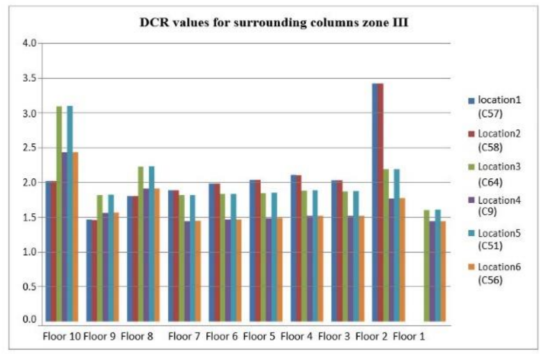


Fig 13 – Case 5 DCR values for surrounding columns for zone III and IV

f) CASE 6: Removal of columns C57 and C58



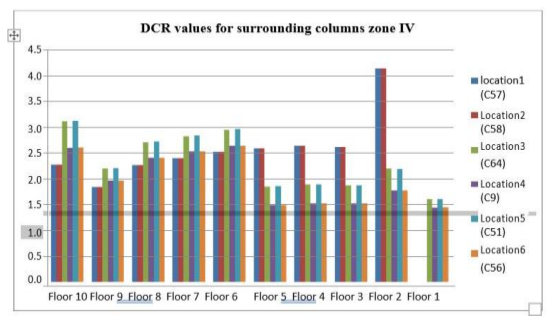
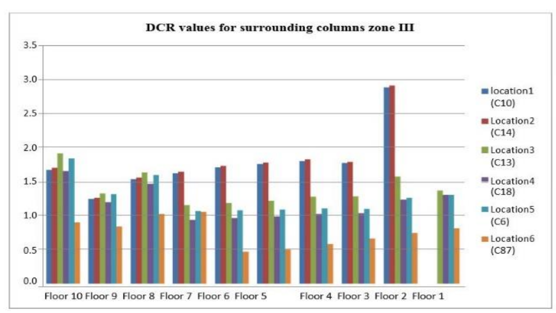


Fig 14 – Case 6 DCR values for surrounding columns for zone III and IV

g) CASE 7: Removal of columns C10 and C14



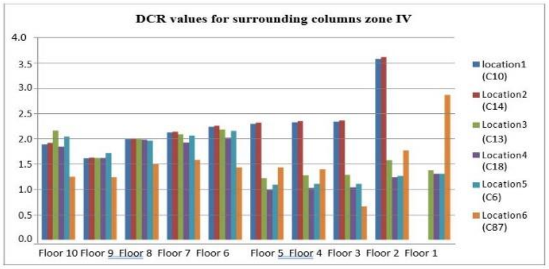


Fig 15 -Case 7 DCR values for surrounding columns for zone III and IV

It is observed from the above figures that the column C10 is the removed columnand 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

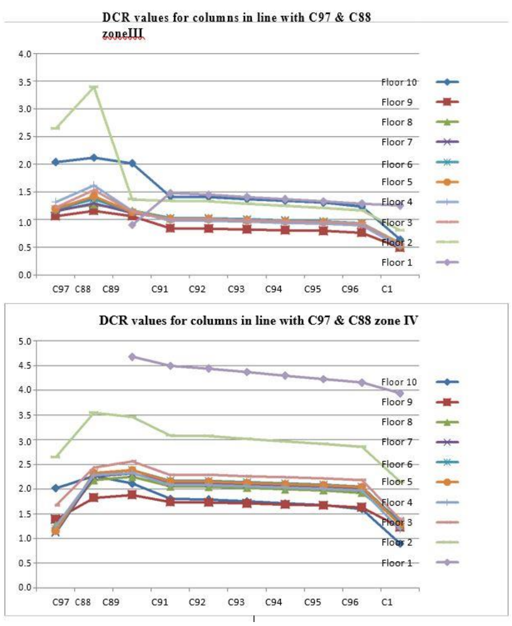


Fig 16 - DCR values for columns in-line with C97 and C88 (↑)

DISCUSSION: From the Fig 16, we can see that C97 and C88 in the floor 2 has greater DCR values than any other column in-line with them in zone III. But in zone IV, 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 3.

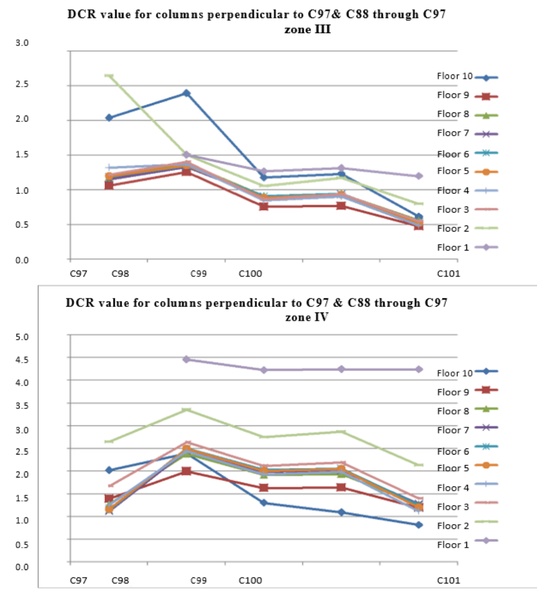


Fig 17 -DCR value for columns perpendicular to C97& C88 through C97 (→)

DISCUSSION: From the Fig 17, we can see that C97 in the floor 2 has highest DCR value compared to columns perpendicular to it in zone III. But in zone IV, the all columns which are perpendicular to C97 have the DCR lying between 4 and 4.5 in floor 1 and in floor 2 it is more than 2 but not as high as floor 1 values

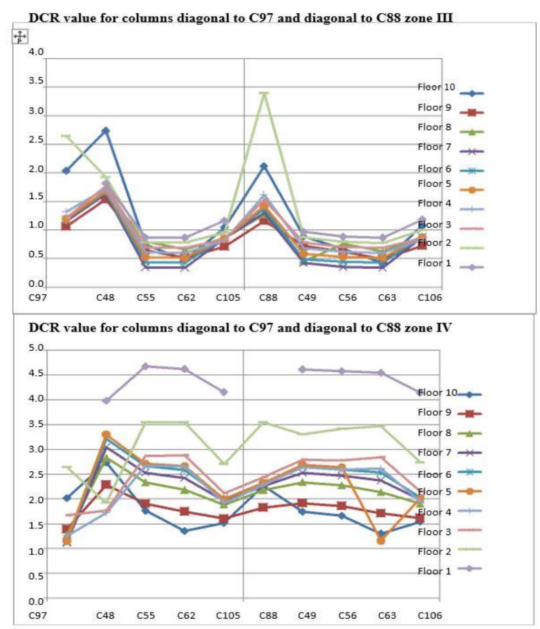


Fig 18 - DCR value for columns diagonal to C97 (↗) and diagonal to C88 (↗)

DISCUSSION: A major grid line at the middle of the graph indicates that one left side are the columns diagonal to one of the removed columns and right-side columns are diagonal to another removed column. To check the columns side by side; refer the page no. 77. From the above figures, C97 has high value in zone III and in zone IV 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 1,3,4,5,6,7.

iv. Observations And Discussions

From the overall observations of results of different cases it can beconcluded 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 removedsimultaneously 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 III whereas the same columns have very high DCR values for zone IV.
- 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 III whereas the first and the second floors will have the DCR values highest in zone IV 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 theabove 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 IV, 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 IV) and due to the mass of the structure.

VIII. CONCLUSION

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

1. The performance of the Reinforced Concrete flat slab structure is completely dependent on the capability of slab-column connections to with stand extreme or abnormal loading.
2. Reinforced Concrete Flats lab structures are very strong so 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. For both Zones, 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. By providing the additional reinforcement in the columns will be more effective in avoiding or delaying collapse of the structure.
8. 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.

9. Finally, it can be concluded that, the location of building where the building located, position of the column removed will matter.

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