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Seismic Analysis and Progressive Collapse of RCC Building Due To Seismic Load

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Abstract - *This study aims to understand the effect of the earthquake and progressive Collapse on Structures of regular and irregular buildings. The main objective of the study is to understand the behavior of structure with respect to time period, story drift, story shear and story displacement. The G+15 storied Structure is acquired for dynamic analysis. Method adopted was Response spectrum technique to analyse the both regular and Irregular Building. For the purposes of analysis software used is ETAB'S. After analysis the results are compared between two buildings. And the notional method used to study the progressive collapse. And the DCR values are noted down and the failure of beams in tension are checked after removal of column one at a time. And to strengthen the building and increase the robustness of building redesign the failed members and the study has been validated with the help of manual Calculations.*
Key Words: Dynamic analysis (response spectrum), DCR ratio, ETABS software, Building construction, Earthquake.

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I. INTRODUCTION

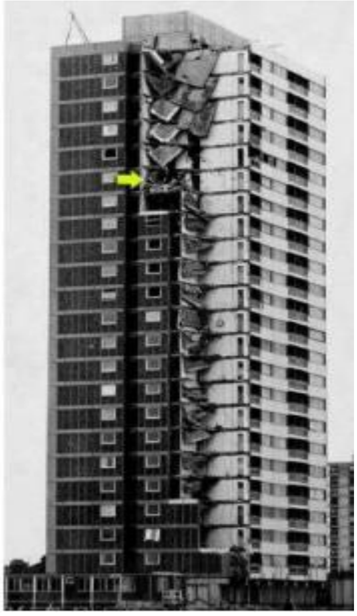
Progressive collapse happens when local failure of a primary structural component leads to the failure of adjoining members and finally to the failure of partial or whole structure system. Progressive collapse IS an instantaneous removal of a column due to unexpected impact, explosion or earthquake has occurred. The present study addresses progressive collapse in RC structures resulting from both instantaneous and gradual removal of columns due to earthquake load.

The Ronan Point failure was the classic example of progressive collapse; that is the failure of one member which set off a chain reaction of other collapses such that the totality of damage was quite disproportionate to the initiating event. No engineer can prevent total collapse if the event is big enough.

To study the structural behavior, the nonlinear dynamic method was used. ETABS 18 VS software was used for nonlinear analysis of structure. At the end of the paper results of instantaneous and gradual removal were compared.

1.1 Progressive collapse:

Progressive collapse is a situation in which a local failure in a structure leads to load redistribution, resulting in an overall damage to an extent disproportionate to the initial triggering event. While the disproportionate collapse is associated with local failure of a structural component leading to the total failure of the entire structure or a significant portion of the structure, that is, the extent of final failure is not proportional to the original local failure. An example for this sort of collapse, the failure of a single column in a frame system due to an abnormal event leads to a chain reaction of subsequent failures for the adjoining components resulting in the entire collapse of the building. The collapse of the Ronan Point apartment could be considered as the first well-known and the most publicized example of progressive collapse. The Ronan Point tower was a multi-story residential building consisted of 22 stories located in Newham, East London, United Kingdom constructed between July, 1966 and March, 1968. The overall dimensions of the plan were 24.4m by 18.3m and the total height of the apartment was 64m. It was easy to be built since the structural flat plate floor system contained precast concrete for the walls, floors and staircases. The walls and floors were bolted together and the connections were filled with dry packed mortar. This means that the floors did not have a high potential to withstand bending, especially if overhanged, so that each floor was supported directly by the walls in the lower story.



It is obvious in (Fig. 1.2) that the eventual result of the very moderate gas explosion was the collapse of the corner bay for the full height of the tower (entire collapse of the southwest corner). The consequences of the partial collapse of the 22-storey precast Ronan Point apartment were a building bereft of one of its corners besides four dead residents and seventeen injured but the tenant of the flat number eighteen Mrs. Hodge who triggered the incident survived. Despite the truth that the partial collapse of the Ronan Point tower in London, England in 1968 was not categorized as one of the biggest buildings disasters of recent years, it was such a shocking accident because the extent of the failure was absolutely out of case was of the order of 20.

It should be stated that the wall system was designed only to withstand the extreme wind pressure; hence the continuity in the vertical load path was lost for the upper floors. The collapse was attributed to the lack of structural integrity, mainly in terms of redundancy and local resistance. In other words, the structural system was not designed to provide alternate load path to redistribute the stresses. Another reason of this disproportionate collapse was the building had been constructed with very poor workmanship, and thus its overall structural robustness was considerably compromised. Further investigations in this collapse reported that stronger interconnection amongst the structural elements is the key for such kind of facilities where this improvement in the connections between the wall panels and floors is likely to have great reduction in the damage scale of the Ronan Point apartment. Ultimately, the building was demolished in 1986 in the last century due to safety concern.

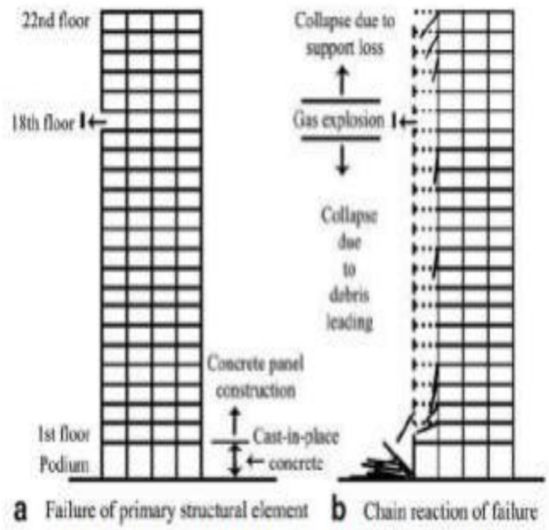


Fig. 1.2: Progressive Collapse of Ronan Apartment

II. METHODOLOGY

A high-rise building of G+15 stories with regular and irregular geometry considered for analysis. Modal analysis and response spectrum analysis is carried out using the ETABS 2018 FEM-based software. Seismic analysis of a regular building with and without removal of column is considered for study.

2.1 Response spectrum analysis:

Response spectrum analysis is most widely used in seismic analysis of a structure. A response spectrum is a graphical representation of the peak or steady-state response (displacement, velocity or acceleration) of a series of oscillators of varying natural frequency. Response spectrum analysis is more optimistic for design purpose compared to static analysis. Typical Response spectrum curve as shown below.

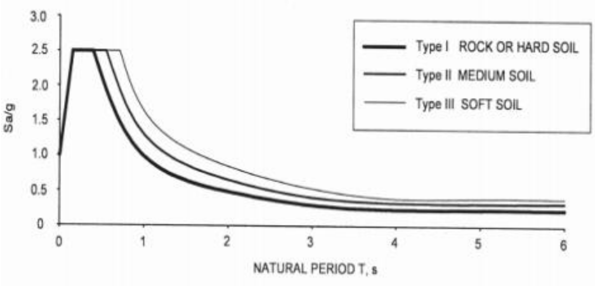


Fig:1.1.Response Spectrum analysis

2.2. BUILDING SPECIFICATIONS

2.2.1. Plan details

- (G+15) story building
- No. of bays along x direction - 6
- No. of bays along y direction - 5
- Spacing between two bays - 10m
- Story height - 3.35m
- Soil type - II (medium)
- Location - Zone: - IV
- Grade of concrete - M30
- Grade of steel - Fe500
- Response reduction factor – 5
- Impedance factor - 1.2

2.3. Modelling:

A high-rise building of G+15 story with and without removal of column is analysed using ETABS software. Model consists of G+ 15 story with a typical floor height of 3.35 m. The building plan consists of 6 bays along the direction x and 5 bays along the direction y. Figure 3.1 shows the plan of the building, fig shows the elevation of the building, and fig shows the 3D view of the building.

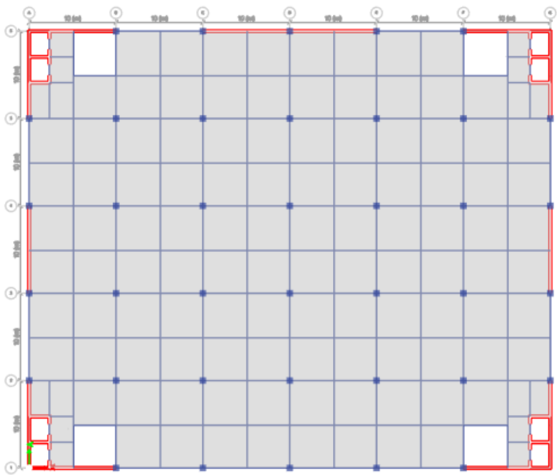


Fig: 1.2. Plan of a building

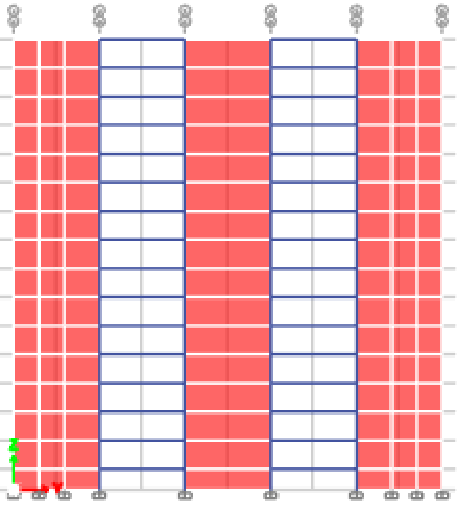


Fig: 1.3.Elevation of regular building.

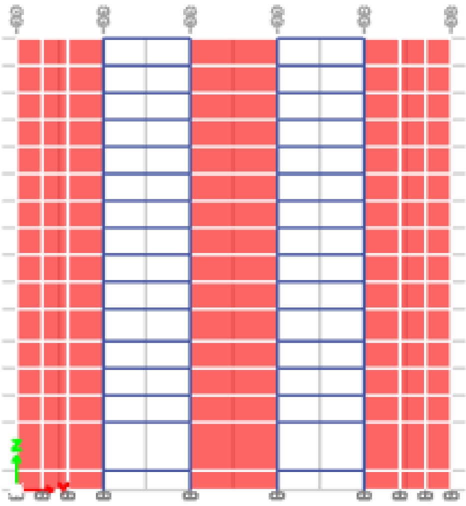


Fig: 1.3.Elevation of Irregular building.

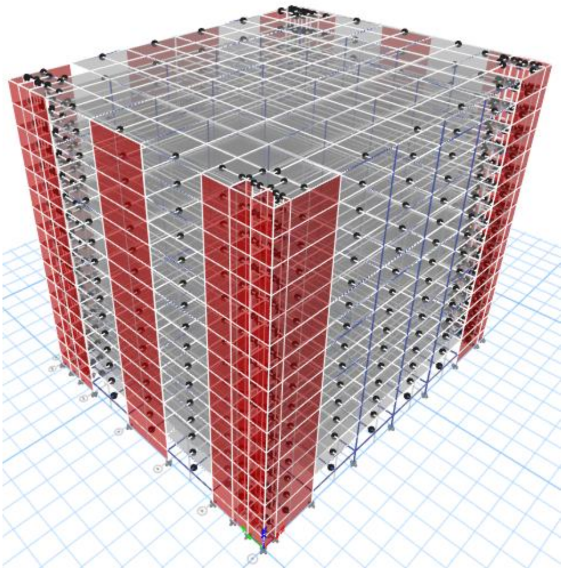


Fig:1.4.3D view of a building

2.4. Loads and dynamic parameters considered for study:

Dead loads and live loads are considered as per IS 875 Part II and the details are shown in Table 3.1. The structural elements were designed in compliance with IS 456-2000 and IS 1893-2016, with regard to grades M 30 of concrete and Fe 500 of steel. The complex parameters considered for the study of the response spectrum are shown in Table 3.2. Designed building dimensions are shown in Table.

Table-1. Details of Load

Dead load	Self Weight of Building
Live load	4 KN/m^2
Floor Finish	1.5 KN/m^2
Wall Load	5 KN/m^2
Partirion Load	1 KN/m^2
Glass Load	1 KN/m^2
False Ceiling	0.5 KN/m^2
Roof Live load	3 KN/m^2

Dynamic parameters considered as per code IS 1893:2016 for analysis is shown below table 3.2. Seismic zone consider as IV. Soil type considered as type 2 (it's a medium soil). Importance factor considered as 1.2 (commercial building). Response reduction factor is 5.

Table-2: Details of dynamic parameters.

Seimic zone	**IV**
Soil type	**II**
Importance Factor	**1.2**
Response reduction factor	**5**

Table-3: Dimensions of Building Components

Column	1200mmX1200mm 1050mmX1050mm 800mmX8000mm	M35
Beam	450mmX700mm 450mmX500mm	M30 M25
Slab	150mm thick	M25
Shear Wall	300mm thick	M30

III. PROPOSED CASE STUDY:

In the present study two buildings are considered for dynamic analysis using ETABS software. They are regular and Irregular building with and without Removal of column. Response spectrum analysis is carried out for this building.

3.1. Structural details of above building configuration as shown in table

Table-4:

Building configuration	**Description**
Regular building	Building dimension - 60mX50m Height of building - 52.65m Typical story height - 3.35m Number of columns - 38 Typical story height - 3.35m
Irregular Building	Building dimension - 60mX50m Height of building - 56m Typical story height - 3.35m Number of columns - 38 Soft story height - 6.7m

IV. MODELLING PROCEDURE OF RESPONSE SPECTRUM ANALYSIS:

Step 1:

Defining a response spectrum function

Define – function – Response spectrum functions – select code **-** add new function

Step 2: Defining the load cases of RSA
Define – load cases - Add new case
Load case 1 – RSX
Load case 2 – RSY
scale factor = Ig /2R
Step 3: Run analysis
Step 4: Scaling up of base reactions of seismic analysis and response spectrum analysis After analysis, the base reaction of EQX and RSX load case are not same, by using below formula can make base reaction same.
Scale factor = BASE REACTION OF EQX/ BASE REACTION OF RSX x I_g /2R

4.1. Base reactions of both seismic analysis and RSA before scaling
EQX – 42139.2881
EQY – 38428.521 kN
RSX – 2147.3598 kN
RSY – 2112.7585 KN

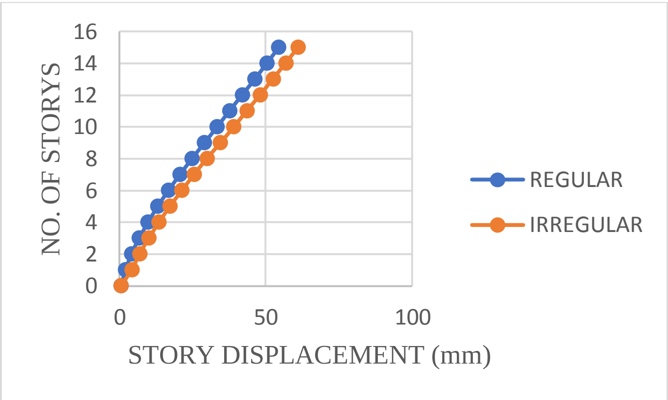
4.1.1 **Scale factor for response spectrum analysis**
Scale factor for RSX= $Ig/2*R$ x EQX /RSX = 1.2∗9810 /2∗5 x (42139.2881 /2147.3598) = 23101.09
Scale factor for RSY= $Ig/2*R$ x EQY /RSY = 1.2∗9810/ 2∗5 x (38428.521 /2112.7585) = 21411.843
4.1.2.Base reaction of both seismic and response spectrum cases after scaling as shown below
EQX – 42139.2881 kN
EQY – 38428.521 kN
RSX – 42139.272 kN
RSY – 38428.5188 kN

V. RESULTS AND DISCUSSION

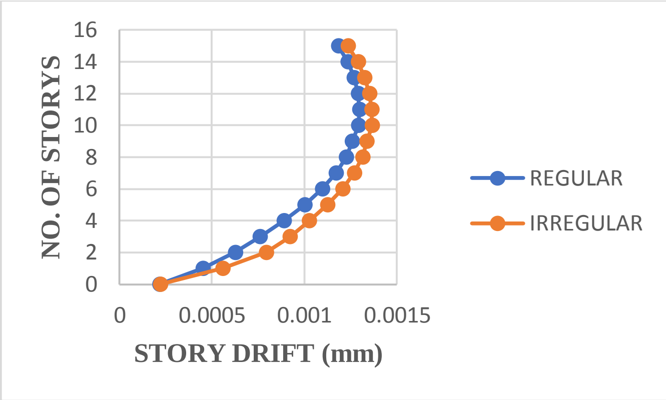
General:
After modeling and analysis by using Etabs, the results of both regular and Irregular building configuration are shown below in terms of modal frequency, story displacement, story drift and story shear. The results of each building configuration are discussed below.

5.1.Regular building
Fig refers to plan of regular building; distance between two columns is 10m and they connected by main beam. Secondary beams are provided in between two columns. Red colour in plan image indicates shear wall distribution. In plan free left places indicates stair case position.

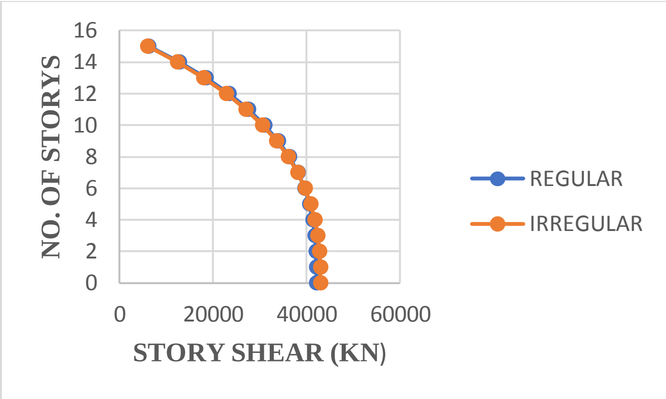
- **The variation in story displacement for building configuration are noted below for response spectrum analysis.**



From the chart1 it is observed that maximum story displacement is occurs to Irregular building for response spectrum analysis. In comparison with regular building has maximum displacement due to irregularity of building.The variation in story drift for building configuration are noted below for response spectrum analysis.



Story drift v/s number of story for Regular and Irregular Building
From the chart 2 it is observed that maximum story drift obtained for Irregular building for response spectrum analysis In comparison with regular building.



From the chart 3 it is observed that maximum story shear obtained for Irregular building for response spectrum analysis compare to regular building.

5.2.Study of Progressive Collapse of Regular and Irregular Building:
5.2.1.Structural concept:
Building a structural framework would have a major effect on the performance of the structure. There are two types of construction structures, i.e. load bearing structure and framed structure. The load bearing structure is more robust than the frame structure. In case of load bearing structure failure of any wall may not lead major collapse. Where as in the case of framed structure, failure one column can lead to more damage compared to the load bearing structure. Structure robustness can be accomplished by creating consistent paths for horizontal and vertical loads to the foundation. Robustness con also improved by preventing wide area collapse due to limited area or single item failure.

5.2.2.Determination of building class
Building can classified based on British code book shown in below.

Table -5:

Building Classification	**Criteria**
Class 1	Less than three storys
Class 2A	3 Story over basement
Class 2B	4 to 15 story over basement
Class 3	16 Story above Basement

Based on above details the structure belongs to class 2B

5.3. GSA Progressive Collapse Analysis and Design Guidelines:

Progressive collapse is a situation where local failure of a primary structural component leads to the collapse of adjoining members which, in turn, leads to additional collapse. Hence, the total damage is disproportionate to the original cause."

To allow the use of simplified analysis, the Design Guidelines make use of the demand-capacity ratio (DCR) defined as

$$DCR = Q_{UD/} Q_{CE}$$

Where,

QUD = acting force on structural member or joint, and

QCE = expected ultimate capacity.

The Design Guidelines limit the DCR to 2 or less for typical structural configurations, and to 1.5 or less for atypical structural configurations. If the DCR cannot be limited to these values, then the structural member or connection in question is considered to have failed.

The GSA Design Guidelines also consider the dynamic effects due to instantaneous removal and removal is of the vertical element only, not of the connection to any horizontal member.

5.4. Failure analysis of structural components:

1. Regular Building:

In this building the study is carried out by removal of Column at center, corner and middle adjacent of the column at ground floor, story 5 and story 10 and monitoring in which story the removal of column effects more damage compare to other story's by taking their respective DCR ratios and checking the tension failure in failed beams.

CASE 1:

Ground Floor:

1. Removal of column at Centre
2. Removal of column at corner
3. Removal of column at middle adjacent

DCR ratio of columns:

Regular Building

Before removal of column

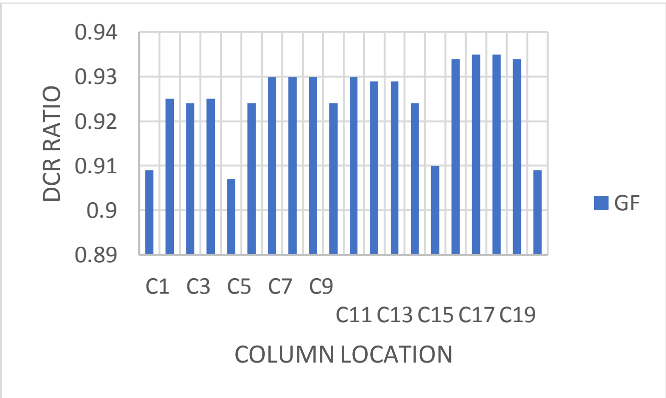


Chart 4:DCR ratio of column at Ground Floor

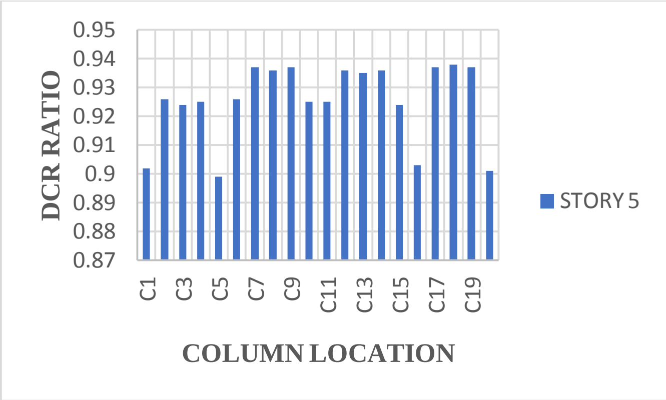


Chart 5 : DCR ratio of column at Story 5

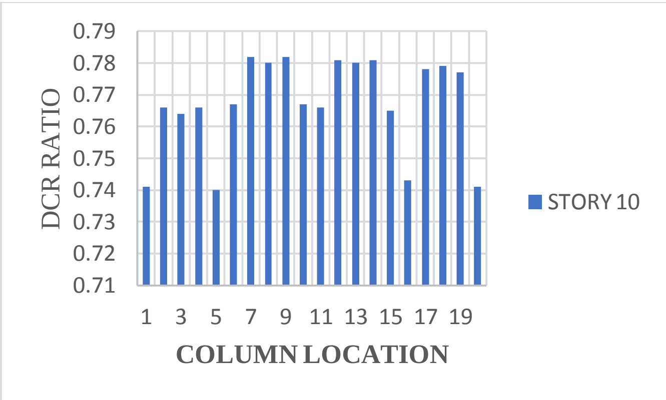


Chart 6: DCR ratio of column at Story 10

Comparative Study of DCR ratio between respective Story of Ground Floor, Story 5 and Story 10.

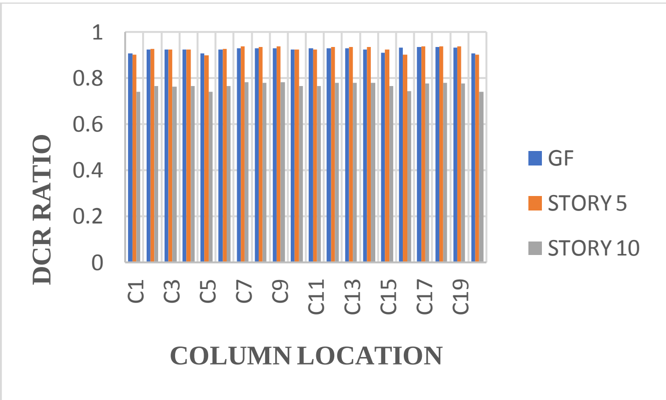


Chart 7: Before removal of column the DCR value of all the columns in each storys are within the limit of 2. hence as per GSA guidelines the columns are safe.

After removal of column

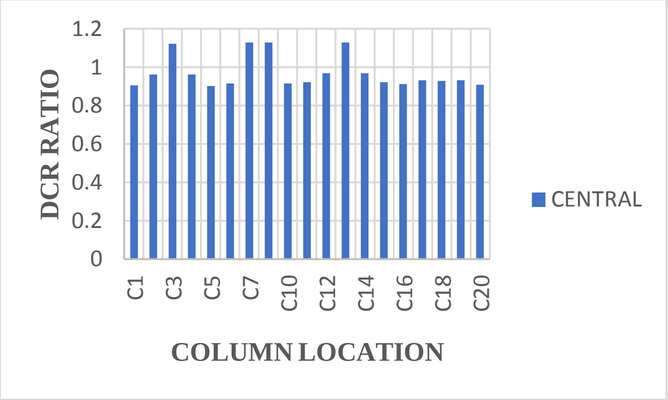


Chart 8: DCR ratio of column at Ground Floor

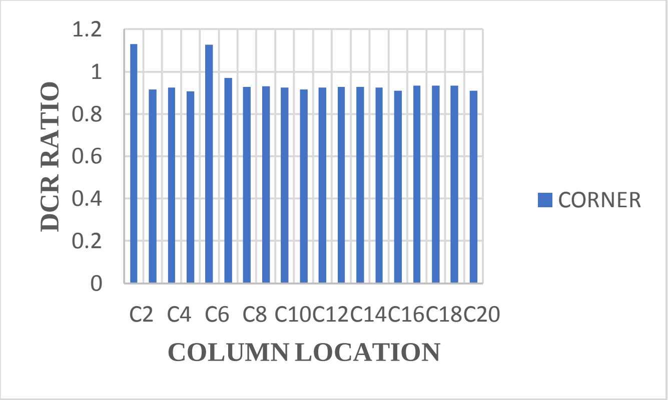


Chart 9: DCR ratio of column at Story 5

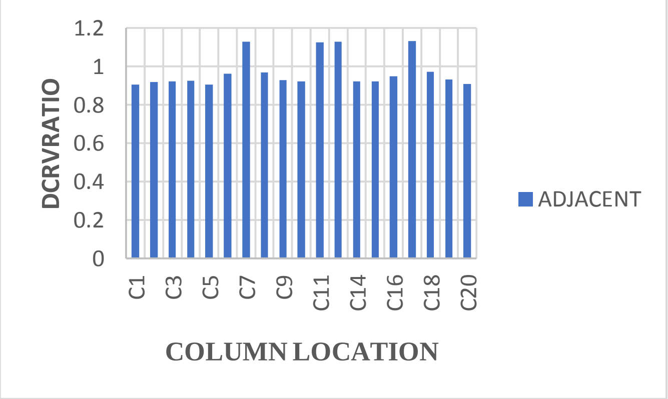


Chart 10: DCR ratio of column at Story 10

Comparative Study of DCR ratio between respective Story of Ground Floor, Story 5 and Story 10.

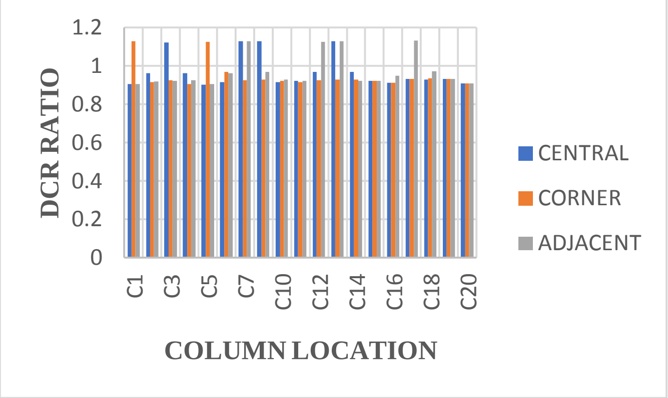


Chart 11: After removal of column also the DCR value of all the columns in each storys are within the limit of 2. hence as per GSA guidelines the columns are safe against progressive collapse. And the building has more robustness.

2. IRREGULAR BUILDING:

Before removal of Column:

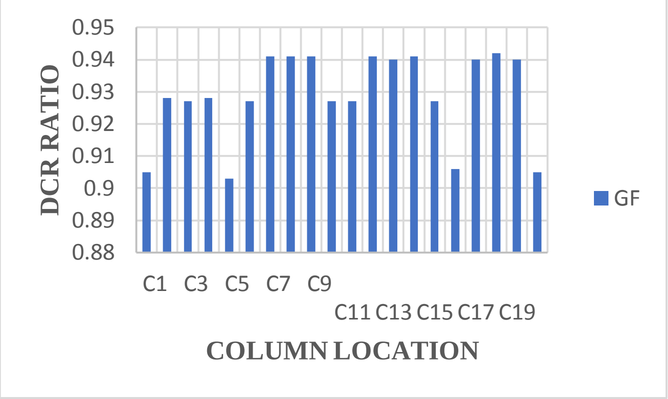


Chart 12: DCR ratio of column at Ground Floor

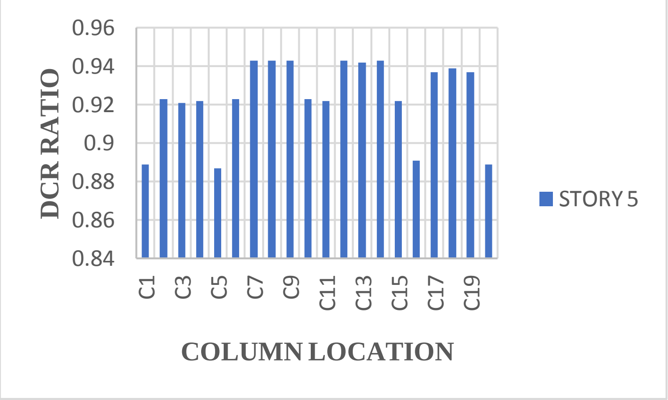


Chart 13: DCR ratio of column at Story

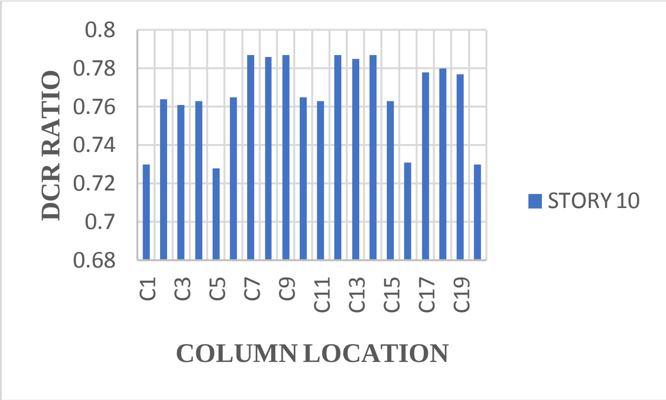


Chart 14: DCR ratio of column at Story 10

Comparative Study of DCR ratio between respective Story of Ground Floor, Story 5 and Story 10.

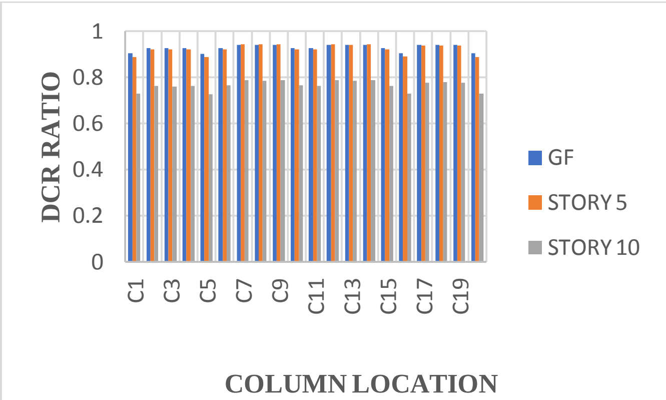


Chart 15:Before removal of column the DCR value of all the columns in each storys are within the limit of 2. hence as per GSA guidelines the columns are safe.

After removal of column:

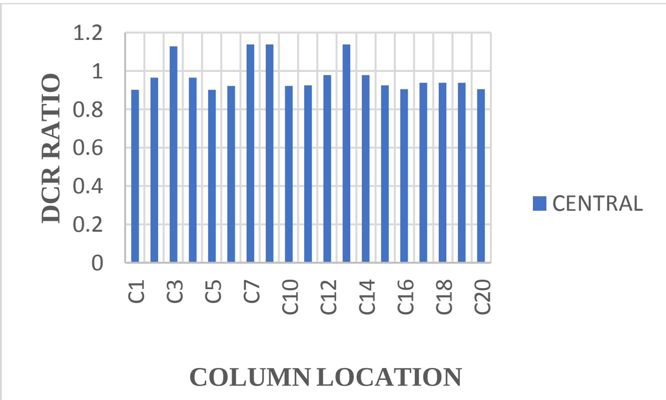


Chart16: DCR ratio of column at Ground Floor

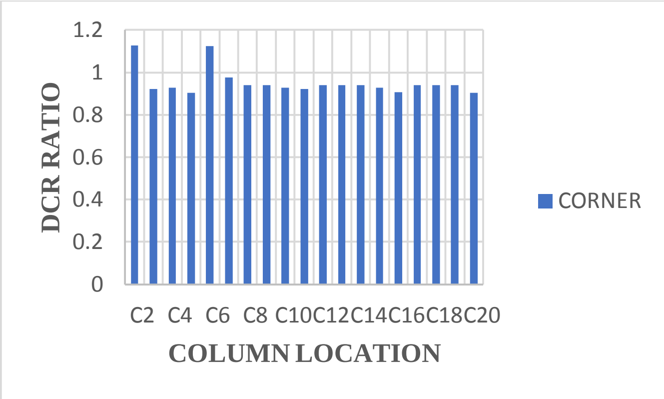


Chart 17: DCR ratio of column at Story 5

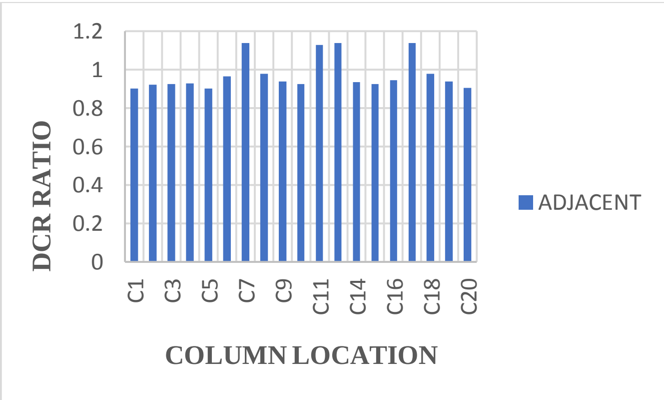


Chart 18: DCR ratio of column at Story 10

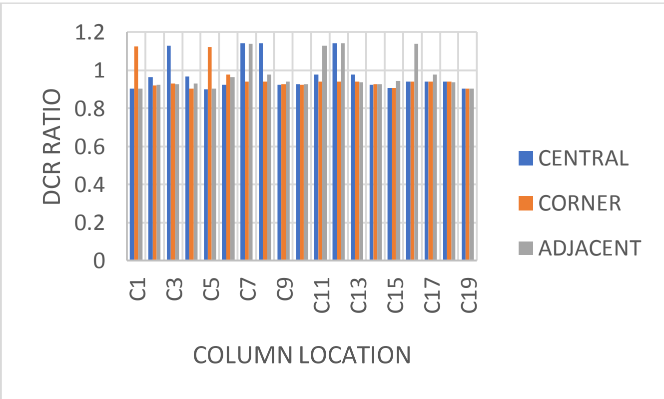


Chart 19: After removal of column also the DCR value of all the columns in each storys are within the limit of 2. hence as per GSA guidelines the columns are safe against progressive collapse. And the building has more robustness.

5.5. Failure check in beams:
strain value calculations :
Regular Building:
Ground floor:

Calculation of strain values before column removal:
Mx = 0.272kN/m and My = 0.273kN/m
R= $Mu/Bd2$ = 0.272∗10^6 /1000∗625*625 =0.000696 &
Ry =0.456∗$10^{6/}$1000∗625*625 =0.000698
$Pt/100 = fck/2fy$ x[1 − √1 − 4.598R/fck]
= 30/ 2∗500 x[1 − √1 − 4.598∗0.000696/30]
= 1.6*10^{-6}………..x direction
$Pt/100 = fck/2fy$ x[1 − √1 − 4.598R/fck]

= 30/ 2∗500 x[1 − √1 − 4.598∗0.000698/30]
= $1.6*10^{-6}$ ………..y direction

Ast x = 0.000696 * 1000* 625 = 435 $mm2$
Ast y = 0.000698 * 1000* 625 = 436.25 $mm2$
fy = 500kN/$m2$ &
strain = 500 /200∗10^3= 0.0025mm

After column removal:
Mx = 2.55kN/m and My = 1.09kN/m
Rx= Mu /$Bd2$ = 2.55∗10^6 /1000∗625*625 =0.00652 &Ry =1.09∗$10^{6/}$1000∗625*625 =0.00279
f_y = fck /2*P_t /100*[1 − √1 − 4.598R /fck]
= 30/ 2∗$1.6*10^{-6}$ *[1 − √1 − 4.598∗0.00652/30]
= 4688.63 ………..x direction
f_y = fck /2* P_t /100 x[1 − √1 − 4.598R /fck]
= 30/ 2∗$1.6*10^{-6}$ *[1 − √1 − 4.598∗0.00279 /30]
= 2003.58………..y direction
Strain X = (fy) E & strain Y = $stre$(fy) E
Strain X = 4688.63 / 200∗10^3 = 0.023 &
strain Y = 2003.58/ 200∗10^3 = 0.01
Strain ≥ 0.0045 member fails under tension zone.
Strain along x & y direction greater than 0.0045, then it represents member failed. Same procedure followed to identify failure plate after column removal with excel sheet.

Irregular Building:
Ground floor
Calculation of strain values before column removal:
Mx = 0.295kN/m and My = 0.296kN/m
R= Mu /$Bd2$ = 0.295∗10^6 /1000∗625*625 =0.000755 &
Ry =0.296∗$10^{6/}$1000∗625*625 =0.000757
Pt /100 = fck /2fy x[1 − √1 − 4.598R /fck]
= 30/ 2∗500 x[1 − √1 − 4.598∗0.000755/30]
= $1.736*10^{-6}$………..x direction
Pt /100 = fck /2fy x[1 − √1 − 4.598R /fck]
= 30/ 2∗500 x[1 − √1 − 4.598∗0.000757/30]
= $1.74*10^{-6}$ ………..y direction

Ast x = 0.000755* 1000* 625 = 472 $mm2$
Ast y = 0.000757 * 1000* 625 = 473.12 $mm2$
fy = 500kN/$m2$ &
strain = 500 /200∗10^3= 0.0025mm

After column removal:
Mx = 2.922kN/m and My = 2.765kN/m
Rx= Mu /$Bd2$ = 2.922∗10^6 /1000∗625*625 =0.00748 &Ry =2.765∗$10^{6/}$1000∗625*625 =0.007078
f_y = fck /2*P_t /100*[1 − √1 − 4.598R /fck]
= 30/ 2∗$1.6*10^{-6}$ *[1 − √1 − 4.598∗0.00748/30]
= 4954 ………..x direction
f_y = fck /2* P_t /100 x[1 − √1 − 4.598R /fck]
= 30/ 2∗$1.6*10^{-6}$ *[1 − √1 − 4.598∗0.007078 /30]
= 4676.84………..y direction
Strain X = (fy) E & strain Y = $stre$(fy) E
Strain X = 4954 / 200∗10^3 = 0.024 &
strain Y = 4676.84/ 200∗10^3 = 0.023
Strain ≥ 0.0045 member fails under tension zone.
Strain along x & y direction greater than 0.0045, then it represents member failed. Same procedure followed to identify failure plate after column removal with excel sheet.

VI. CONCLUSION:

1. From response Spectrum Analysis it is observed that the time period for first mode of vibration is more for Irregular Building. As the time period increases the Frequency decreases.
2. The story displacement, Story Shear and Story Drift is maximum for Irregular Building compared to Regular Building.
3. After removal of column the beams are failed in tension zone. And In frame structures, Large column spacing decreases the ability of structure to redistribute load in the event of column failure.
4. The DCR ratio's are within the limit of 2 for both regular & irregular building before and after removal of column. It means the columns are safe against Progressive Collapse.
5. To prevent the progressive collapse and Increase the Robustness of Structure redesign the Respective failed Beams to withstand the additional load carrying capacity.

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