BILINGUAL PUBLISHING CO. Pioneer of Global Academics Since 1984

**Journal of Smart Buildings and Construction Technology**

https://ojs.bilpublishing.com/index.php/jsbct

ARTICLE

# Control of Progressive Collapse of the Structure Using Shear Wall

**Pruthviraj S R*** **Shivukumarnaika M** **Prabhakara H R**

Department of Studies in Civil Engineering, University B.D.T College of Engineering, Davangere, Karnataka, 577004, India

ARTICLE INFO

*Article history*
Received: 21 July 2022
Revised: 20 September 2022
Accepted: 29 September 2022
Published Online: 8 October 2022

*Keywords*:
Progressive collapse analysis
General Service Administration (GAS) Guidelines
Demand capacity ratio (DCR)
Column removal
ETABS
Shear wall

ABSTRACT

The vulnerability of reinforced concrete (RC) building systems to progressive collapse has turned out to be a challenging trouble for professional structural engineers so as to prevent total failure on account of nearby damage. The goal of this paper is to enhance the knowledge of such buildings' behavior underneath several scenarios of misplaced columns at different floor stages, and their capacity for progressive collapse. The homes had been analyzed following the guidelines for progressive collapse evaluation and design organized by means of the general services administration guidelines (GSA). The progressive collapse of a ten story structure subjected to a simplest gravity load is taken into consideration and the column has been eliminated at one place and the spread damage is evaluated. The progressive collapse study has been carried out by way of removing the column at a diagnosed crucial locations (at corner, middle and at interior) as in line with GSA guidelines. Static analysis is done using analysis program ETABS. For each case, the consequences were taken in terms of demand capacity ratio (DCR) at critical section, and as a result the structure has been assessed for it's susceptible to progressive collapse. The availability of shear wall is made on the component wherein collapse occurred and DCR values are mentioned. After imparting the shear wall to the structure, the progressive collapse of the structure because of accidental load may be controlled in order that the GSA guidelines recommended DCR value would be within the range.

## 1. Introduction

One or a couple of vertically load carrying members such as columns are eliminated or made the complete shape begins to collapse progressively [1]. While the vertical member is knocked down either because of natural or man-made destruction like vehicular impact or because of fireplace threat or may be because of seismic the load of the shape about that vertical member could be transferred to the close by column of that shape. Whilst collapse of column due to unintended loading, the loads are dispensed to adjoining member. Consequently the DCR value of individuals adjustments. Criteria for treating the adjacent members as safe, the DCR value must be less than 1.5 as prescribed in GAS guidelines. As attempted is made to

*Corresponding Author:
Pruthviraj S R,
Department of Studies in Civil Engineering, University B.D.T College of Engineering, Davangere, Karnataka, 577004, India;
*Email: pruthvi960637@gmail.com*

DOI: https://doi.org/10.30564/jsbct.v4i2.4910

manipulate progressive fall apart by offering shear wall the closest the unintentional collapsed column [2]. The seismic kind of failure mechanism involves the lateral sway of the constructing or the shape after which the shape may also begin collapsing and its own gravitation notes. Distribution of failure in first sort of failure mechanism will depend on the geometrical shape of the building and also the span among the columns [3]. To carry out the progressive collapse of the structure by referring the GSA guidelines where the reinforcement required to keep the DCR value within the acceptable limit is must [4,5]. Some of the examples supporting to the progressive collapse of the structure due to the accidental load are discussed below.

### Progressive collapse OF WTC-7 & twin TOWERS

On November 9th, 2001, the WTC7 block's dual towers fell when a plane hit the tower as shown in Figure 1. Because the entire centre of the shape was constructed of metal, the structure could endure the colloid for a long period. This period became equal to the amount of time the steel could tolerate the heat before melting. When a number of the steel persons began melting on the floor where the plane crashed, those contributions began melting as well, and they rained down on other contributors. This reduced the strain on the entire floor, which was under pressure to fail on its lower floor. This unexpected increase in strain on this deteriorating ground exacerbated the breakdown. This method was continued, and after a period of time, the entire structure collapsed. The load approaching the subsequent contributors exceeded their load sporting potential, causing the revolution to fall apart. This led in a lack of property and a large number of deaths. In both towers, the temperature was over the melting point of metal. The Events of Significant progressive collapse & the time of design code are shown in Figure 2.

**Figure 1.** Failure of WTC-7 & Twin Tower

## 2. Objectives

The progressive collapse of a 10 story structure subjected to a simplest gravity load is studies with following objectives.

- To model the multi-storey shape with plan irregularity in ETABS software.
- To study the revolutionary progressive collapse of structure when the columns of different locations are at collapse state.
- To control the progressive collapse of the structure the usage of shear wall at exceptional region.

## 3. Literature Review

**Anu Thampy [5]:** They're being researched in recent years, terrorism, accidents, fire explosions, and other threats have made structures more vulnerable. When a local structural load bearing part fails, the additional load is passed to surrounding structural members, potentially resulting in global failure due to overloading. For the sake of human life and the societal economic impact, the likelihood of slow collapse must be evaluated. The progressive

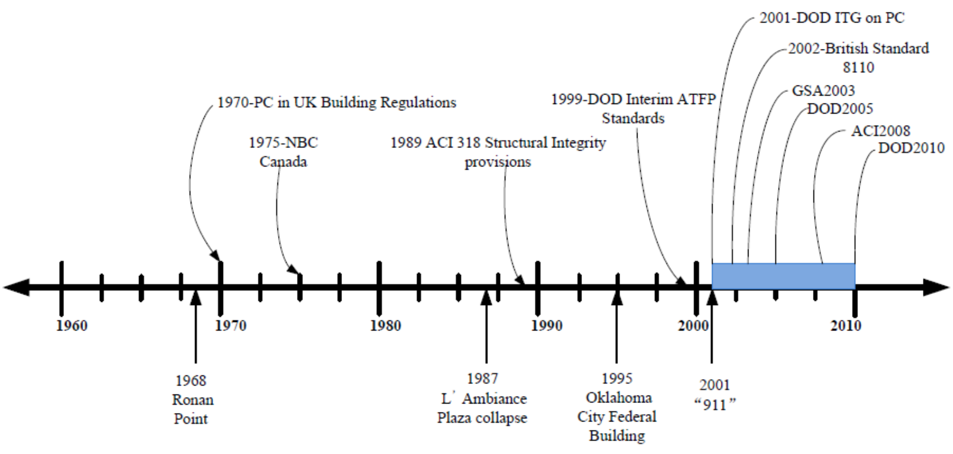


**Figure 2.** Events of Significant progressive collapse & the time of design code

collapse potential of multistory typical and atypical buildings with a c shape is assessed using numerical methods of analysis. Terrorism, accidents, fire explosions, and other events are examined. The impacts of different column situations on the linear static loading response of a building were explored. The evaluation comes after a negative assessment of the US General Services Administration (GSA). The DCR values are proportional to the BM and consequently the amount of steel. As a result, sufficient reinforcement is necessary to keep the DCR within acceptable bounds.

**Ms. Vidya V Mhaske** [4]: In a progressive collapse research, the amount of injury or collapse is disproportionate to the scale of the initial incident. When a critical structural element fails, it causes nearby structural parts to fail as well, resulting in structural failure. This study looks at the performance of an existing three-story RC framed building in seismic zone III. GAS guidelines were utilised to examine the demand capacity ratio of the existing RC building, and IS codes were applied to define building modelling and loads. When the vertical weight bearing components of a building are removed, the structure progressively collapses.

**B. Gururaja and R. Sridhar** [6]: When a column is removed due to a vertical impact exploration earthquake or any other man-made or natural disaster, the weight of the building is transferred to adjacent columns in the structure. The current research examines the gradual collapse susceptibility of midrise RC framed structures with complicated structural configurations. The possibility for progressive collapse of a structure is assessed using the linear static analysis approach in accordance with GSA (2003) gridlines, based on the so-called missing columns issue. The linear static analysis is carried out using software ETABS V9.6 for buildings designed for ductile standards to resist earthquakes in zone II.

**R Jeyanthi** [7]**:** The final collapse of a component of a structure or the proportionately huge failure of a portion of a building as a result of a local failure spreading from element to element across the structure is referred to as progressive collapse. The study focused on progressive collapse analysis of reinforced concrete framed structures under column removal consideration using the widely available computer software ETABS. A G+8 RCC educational building that was examined and developed according to Indian building code was subjected to a pushover study. Essential columns were then identified and deleted to begin the steady collapse. The approval criteria were first published in GSA 2003, where they were reviewed for factors such as demand capacity ration and robustness indicator. For these reasons, the building has been gradually collapsing. Finally, the impact of the crucial component that was removed was investigated.

### Concept of Shear Wall

A shear wall is a structural component in a given RC construction that provides resistance to forces acting in the horizontal axis, such as wind or seismic. In most circumstances, shear walls are utilized in tall buildings, yet in rare exceptional cases, they are used in small buildings. These are typically utilized in tall constructions because they are frequently subjected to lateral forces. As a result, shear walls are employed or inserted to impart greater rigidity to the structure represented in Figure 3. The effect of forces acting in the horizontal axis grows as the height of a tall structure increases. Because the rules have set limits on lateral sway, it's critical to keep the structure's sway within those limits. Increased stiffness as a result of the addition of a shear wall is one of the approaches to do this.

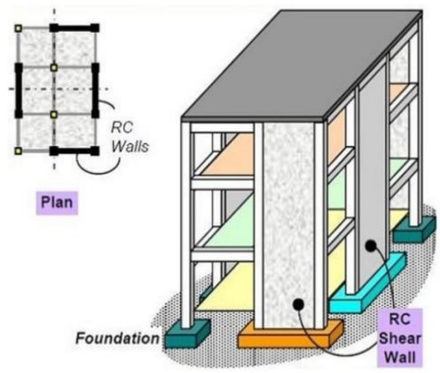


**Figure 3.** Typical Placement of shear wall

Restriction on how the structure can be used. Unfavorable impacts on the performance of any non-load bearing or nonstructural elements, deprivation in the structure's appearance, and psychological discomfort in end users using the structure In general, a floor's relative horizontal sway/deflection should not exceed the height of the floor. The profile of deflection for both a shear wall and a rigid frame is shown in the diagram above.

## 4. Methodology

Collect the data like dimensions of the building, dimensions of the rooms and the wall thickness etc from the plan and then launch ETAB software. Then the below steps are followed to obtain the desired results.

**Step-1:** Go to define menu → under materials define concrete grade of M40 and reinforce steel as Fe500

**Step-2:** Go to define menu → under section property define beam of 300 x 600, 400 x 600, column of 400 x

400, slab thickness 175 mm and shear wall of 150 mm thickness.

**Step-3:** Using above material & sectional properties generate the model/frame structure which will be in line with the provided architectural plan.

**Step-4:** Assign all the loads like wall loads, live loads, floor finishes, ceiling suspended loads, terrace finishes etc. by following IS 875- Part1 & 2.

**Step-5:** Define various load patterns, like DL, LL, and earthquake load etc. By using these primary load patterns generate load combinations as per IS code.

**Step-6:** Carry out linear static Analysis & then unlock the structural model.

**Step-7:** Carry out the design the give model by following the codal standard**.** Ensure that all the members are safe.

**Step-8:** Unlock the model once the design is performed successfully.

**Setp-9**: Now as per the 3 cases defined in subsequent pages remove a pair of columns and note down the DCR values of the columns before remove the selected columns as one set, another set after removing the columns and third set after providing the shear wall. It has to be noted that when the pre-defined columns are removed the DCR values of the columns around the removed columns are also be noted. Tabulate the DCR values. Check for the values of DCR values from the table to observe if the progressive collapse will occur or not for the chosen building.

## GSA Guidelines

General Service Administration (GSA 2003) has listed out a set of guidelines in order ascertain the possible progressive collapse situation. GSA spells out localities of the columns to be taken out as listed below. Removing the corner column, removing the exterior middle column removal in the structure and removing the interior column.

## Load Combination as per GSA Guidelines

The progressive collapse is initiated by removing a column at selected location of the structure as per GSA (General Service Administration) guideline the structure is analyzed for load combination.

$$\text{Load} = 2(DL + 0.25LL)$$

where, DL = Dead Load & LL = Live load.

## Acceptance Criteria

For both primary & secondary structural elements the acceptance criteria can be established as DCR - Demand Capacity Ratio as shown in the equation below

$$DCR = QUD/QCE$$

where, QUD = Acting force also called as the demand obtained as the component or joint (moments, shear forces, axial forces and probable combined forces) obtained using linear elastic analysis. QCE = Expected an ultimate & un-factored capacity of an element or a joint (moments, shear forces, axial forces and probable combined forces).

Permissible DCR values suggested by GSA are:

DCR lower than 2.0 for a typical structural configuration;

DCR lower than 1.5 for an untypical structural configuration;

DCR value which exceeds the permissible value will be treated as collapsed or severely damaged. While calculating the capacity of a component or a connection, GSA guidelines suggest enhancing the strength of the design material by a factor called strength-increase in order to obtain the material strength as per the expectation.

## Load Considered

The followings are the loads which are considered for the analysis of the building.

- Floor Finish: 2.5 kN/m$^2$
- Live Load: 4 kN/m$^2$ (upto 9$^{th}$ floor)
- live load for roof is –1.5 kN/m$^2$ (terrace floor)
- Wall load 0.23 m thick BBM = 11.6 kN/m and 0.115 m thick BBM = 5.8 kN/m.

## Progressive Collapse of the Structure

For an analysis of progressive collapse of the structure, the necessary details which are taken are discussed below.

## Plan

A public building is consisting of structural dimensions having total length in X direction of about 39.4 m and the total length in Y direction of about 33 m and height of each floor is considered as 3.5 m. Material details: M40 grade concrete (Concrete density = 25 KN/m$^3$) and Fe550 grade steel. Section details: the size of about Beam = 300 mm x 600 mm, & 400 mm x 600 mm, and the size of about Column = 400 mm x 400 mm, and the thickness of Slab about = 175 mm.

## Column Positioning

As per figure shown below the columns are positioned in grid wise where every column is oriented in Y direction and respective column position are taken for the analysis.

## Beam Drawing Details

Based on the position of the main and partition walls beams are placed so that the loads coming from these walls are directly transferred on to the beams and from beams to the columns.

Figure 4, Figure 5 and Figure 6 show the plan, column location and beam layout of the RC framed structure which is used as a building model for the analysis and design of the structure for progressive collapse by considering cases for the failure of the column as disused in below cases.

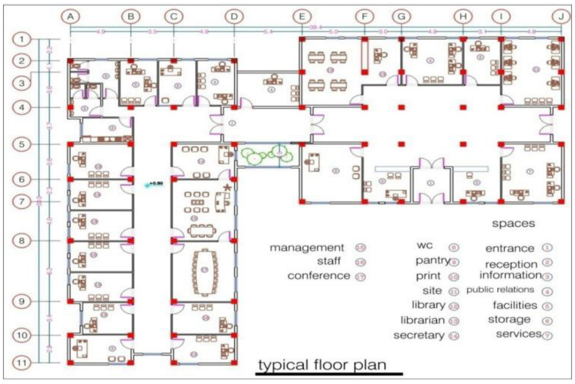


**Figure 4.** Typical floor plan

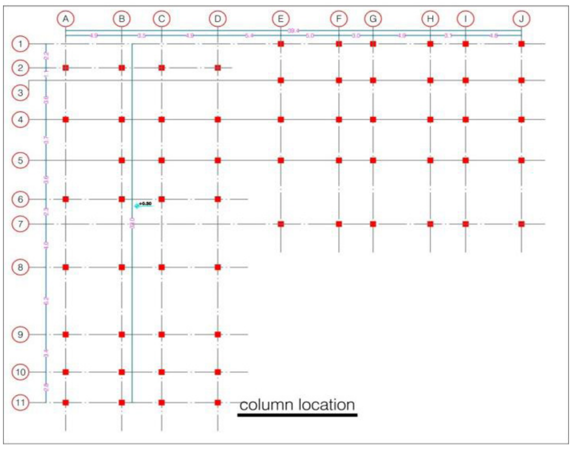


**Figure 5.** Column Location

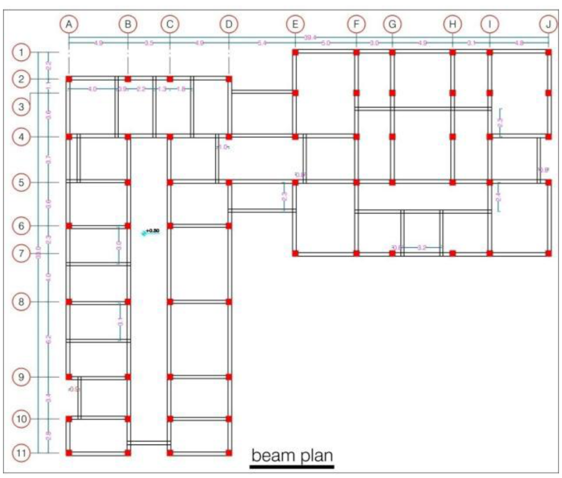


**Figure 6.** Beam Plan

### Cases Considered

To assess the potential progressive collapse of a ten story unsymmetrical structure by static investigation (as per GSA guideline), majorly, the structural system is classified into two categories, they are exterior and interior considerations. In this study, three cases are taken in which case I and case II are under exterior consideration and case III is taken under interior consideration shown in Figure 7.

*CASE-I: At Corner*

As per case-1, corner columns of C31 & C32 are considered for the analysis as shown in figure:

*CASE II: At Middle*

As per case-2, exterior middle Columns of C26 & C27 are considered for the analysis as shown in figure:

*CASE-3: At Interior*

As per case-3, interior Columns of C36 & C37 are considered for the analysis as shown in figure:

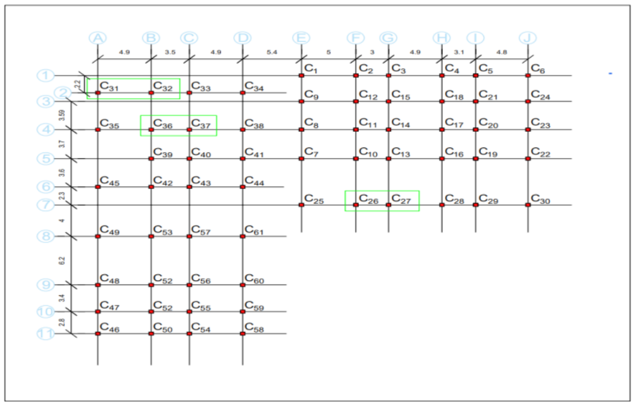

**Figure 7.** Three Cases defined

## 5. Results and Discussions

Only gravity loads are taken into account in the progressive collapse of a ten-story structure. Before removing the columns, the structure is inspected to see if it is safe. The column fails after an inadvertent load acts on it, and the column is eliminated. The DCR value is calculated using the ETABS programme. The structure is secure if the DCR value is less than 1.5. If the DCR value is greater than 1.5, the structure is considered as dangerous. The Shear wall was used in this situation to control the structure collapse.

### Results of Case-1:

In this case, the corner columns fail due to an accidental load (vehicular impact or fire hazard). The load is transferred to the surrounding columns. It will initiate the progressive collapse for the surrounding columns. And if the DCR value in Table 1 is greater than 1.5, the structure is considered unsafe. In such cases, the present study recommending to provide shear wall at the collapsed part of the structures.

As for as the columns C31 and 32 are fails due to the damage caused (as discussed in case-I), surrounding columns such as C33, C35, C36, and C37 are prior to take the load from ground floor till third floor as shown in the Table 1. The corner columns C31 and C32 have been removed and are replaced by shear wall as shown in the Figure 8.

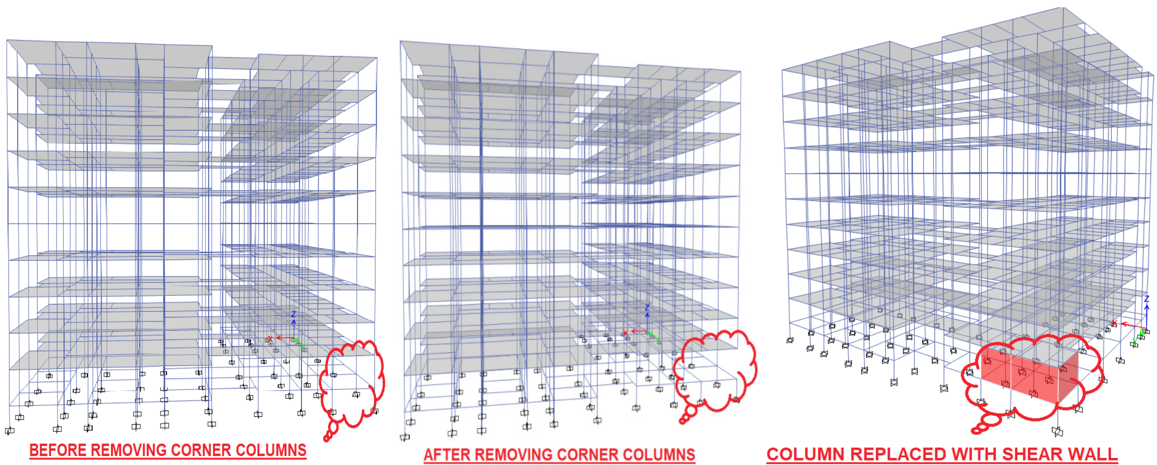


**Figure 8.** Possible considerations for Case-1

**Table 1.** DCR value results of Corner columns

| DCR VALUE OF CORNER COLUMN | | | | | | | |
|---|---|---|---|---|---|---|---|
| **STORY** | **COL REMOVED** | **C31** | **C32** | **C33** | **C35** | **C36** | **C37** |
| Terrace | With all Columns | 0.268 | 0.076 | 0.072 | 0.345 | 0.09 | 0.061 |
| | Corner columns **(C31&C32)** Removed | 0.805 | 1.005 | 0.918 | 0.731 | 0.340 | 0.125 |
| | Portion Replaced with Shear wall | 0.441 | 0.128 | 0.139 | 0.601 | 0.141 | 0.107 |
| $9^{th}$ Story | With all Columns | 0.237 | 0.106 | 0.102 | 0.333 | 0.152 | 0.131 |
| | Corner columns **(C31&C32)** Removed | 0.674 | 1.145 | 0.837 | 0.705 | 0.404 | 0.276 |
| | Portion Replaced with Shear wall | 0.397 | 0.181 | 0.184 | 0.589 | 0.248 | 0.226 |
| $8^{th}$ Story | With all Columns | 0.252 | 0.147 | 0.144 | 0.355 | 0.221 | 0.204 |
| | Corner columns **(C31&C32)** Removed | 0.718 | 1.168 | 0.975 | 0.849 | 0.546 | 0.431 |
| | Portion Replaced with Shear wall | 0.425 | 0.252 | 0.255 | 0.632 | 0.369 | 0.35 |
| $7^{th}$ Story | With all Columns | 0.265 | 0.194 | 0.192 | 0.393 | 0.295 | 0.278 |
| | Corner columns **(C31&C32)** Removed | 0.748 | 1.192 | 1.12 | 1.002 | 0.7 | 0.589 |
| | Portion Replaced with Shear wall | 0.449 | 0.334 | 0.337 | 0.699 | 0.496 | 0.476 |
| $6^{th}$ Story | With all Columns | 0.283 | 0.243 | 0.241 | 0.43 | 0.369 | 0.356 |
| | Corner columns **(C31&C32)** Removed | 0.799 | 1.238 | 1.069 | 1.05 | 0.867 | 0.756 |
| | Portion Replaced with Shear wall | 0.481 | 0.419 | 0.422 | 0.768 | 0.628 | 0.613 |
| $5^{th}$ Story | With all Columns | 0.302 | 0.294 | 0.293 | 0.482 | 0.449 | 0.435 |
| | Corner columns **(C31&C32)** Removed | 0.860 | 1.303 | 1.255 | 1.269 | 1.007 | 0.923 |
| | Portion Replaced with Shear wall | 0.514 | 0.511 | 0.508 | 0.858 | 0.767 | 0.75 |
| $4^{th}$ Story | With all Columns | 0.326 | 0.348 | 0.345 | 0.535 | 0.531 | 0.515 |
| | Corner columns **(C31&C32)** Removed | 0.973 | 1.414 | 1.456 | 1.496 | 1.198 | 1.083 |
| | Portion Replaced with Shear wall | 0.553 | 0.602 | 0.597 | 0.948 | 0.908 | 0.887 |
| $3^{rd}$ Story | With all Columns | 0.348 | 0.401 | 0.397 | 0.586 | 0.614 | 0.595 |
| | Corner columns **(C31&C32)** Removed | 0.921 | 1.433 | **1.671** | **1.731** | 1.393 | 1.250 |
| | Portion Replaced with Shear wall | 0.599 | 0.697 | 0.692 | 1.048 | 1.042 | 1.02 |

Table 1 continued

| DCR VALUE OF CORNER COLUMN | | | | | | | |
|---|---|---|---|---|---|---|---|
| **STORY** | **COL REMOVED** | **C31** | **C32** | **C33** | **C35** | **C36** | **C37** |
| 2nd Story | With all Columns | 0.376 | 0.454 | 0.448 | 0.664 | 0.697 | 0.675 |
| | Corner columns **(C31&C32)** Removed | **1.888** | 1.158 | **1.923** | **1.984** | **1.592** | 1.416 |
| | Portion Replaced with Shear wall | 0.617 | 0.834 | 0.783 | 1.113 | 1.185 | 1.16 |
| 1st Story | With all Columns | 0.395 | 0.511 | 0.502 | 0.699 | 0.778 | 0.755 |
| | Corner columns **(C31&C32)** Removed | -- | -- | **2.072** | **2.173** | **1.785** | **1.600** |
| | Portion Replaced with Shear wall | -- | -- | 0.39 | 0.545 | 1.315 | 1.3 |
| Ground | With all Columns | 0.418 | 0.529 | 0.521 | 0.745 | 0.793 | 0.769 |
| | Corner columns **(C31&C32)** Removed | 0.151 | 0.150 | **2.047** | **2.243** | **1.827** | **1.619** |
| | Portion Replaced with Shear wall | 0.769 | 0.902 | 0.933 | 1.283 | 1.328 | 1.322 |

Figure 9 shows the graphical representation (as per case-I). In this graph the X axis represents the number of story and Y axis represents DCR values of the columns. And the DCR values are within the limits (1.5) in all story. The removing C31 and C32 corner columns. And take The DCR value for corner column and surrounding columns of the structure are tabulated in Table 1 it shown value is not within the limit (1.5).

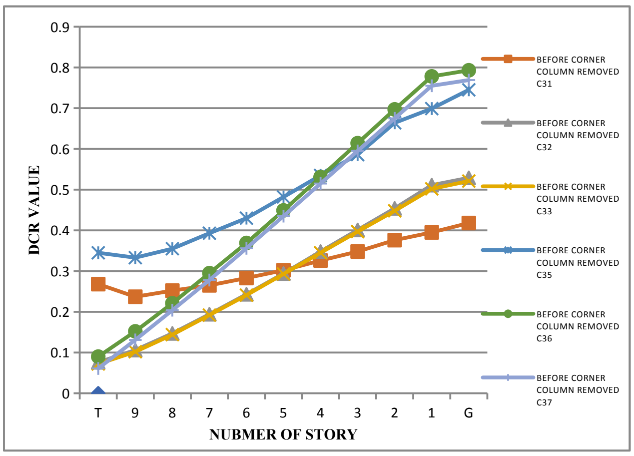


**Figure 9.** Before corner column removed DCR value v/s number of story

Figure 10 shows the graphical representation (as per case-I corner column removed). In this graph the X axis represents the number of story and Y axis represents DCR values of the columns. And the DCR values are not within the limits (1.5). The shear wall is replaced by collapse column location. And take the DCR value for corner column and surrounding columns of the structure are tabulated in Table 1 it shown value is within the limit (1.5) and the structure is safe.

Figure 11 shows the graphical representation (as per case-I shear wall provided by corner collapsed column). In this graph the X-axis represents the number of story and Y axis represents DCR values of the columns.

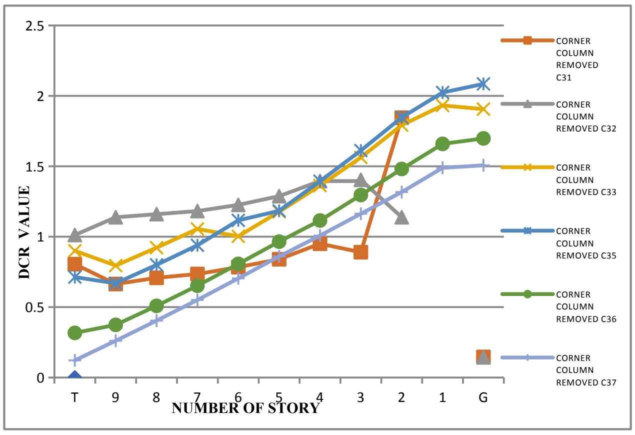


**Figure 10.** After corner column removed DCR value v/s number of story

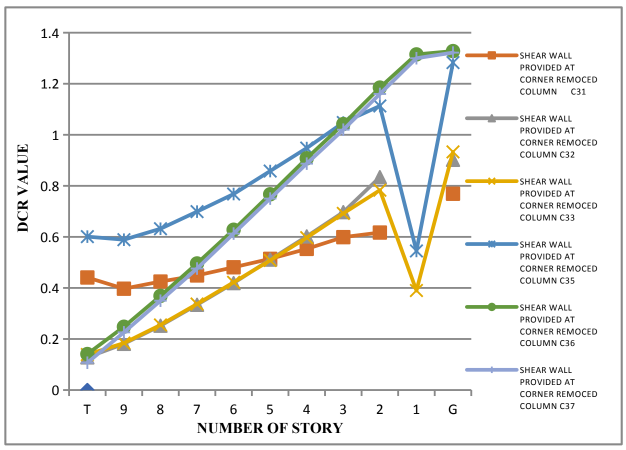


**Figure 11.** Shear wall provided at corner column DCR value v/s number of story

DCR values for Corner column and surrounding columns are tabulated in Table 1 and it shows that all columns are in safe condition before the application of collapse to the structure.

## Case-1: Summary

As for as the Column C31 & C32 are failed (as per

Case-I) and are removed, load contributes to surrounding column suffers due to excess load as discussed. To overcome from this situation, a shear wall of thickness 150 mm would be connected to the respective floor where structure showing failure and DCR values were compared and tabulated. Providing shear wall contributes to take load which is causing failure at C31 and C32 and also avoids excessive load transfer to the surrounding columns. Thereby decrease in the DCR values (within the limit) were discussed.

## Results of Case-2:

In this case, the exterior middle column fails due to an accidental load (vehicular impact or fire hazard). The load is transferred to the adjacent column after the damage. It will be initiated by the progressive collapse of nearby columns. And if the DCR value in Table 2, is greater than the limit (1.5), the structure is considered unsafe. In such case, the present study recommended to provide shear wall at the collapsed part of the structure.

**Table 2.** DCR value results of exterior middle column

| DCR VALUES OF EXTERIOR MIDDLE COLUMN | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **STORY** | **COL REMOVED** | **C25** | **C26** | **C27** | **C28** | **C07** | **C10** | **C13** | **C16** |
| Terrace | With all Columns | 0.339 | 0.333 | 0.122 | 0.095 | 0.226 | 0.247 | 0.201 | 0.163 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.397 | 1.058 | 0.863 | 1.021 | 0.693 | 1.285 | 0.394 | 0.361 |
| | Portion Replaced with Shear wall | 0.601 | 0.595 | 0.224 | 0.158 | 0.376 | 0.416 | 0.352 | 0.293 |
| 9th Story | With all Columns | 0.296 | 0.288 | 0.124 | 0.112 | 0.236 | 0.246 | 0.202 | 0.177 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.384 | 1.055 | 0.742 | 1.081 | 0.614 | 1.103 | 0.425 | 0.386 |
| | Portion Replaced with Shear wall | 0.542 | 0.535 | 0.23 | 0.208 | 0.415 | 0.435 | 0.367 | 0.323 |
| 8th Story | With all Columns | 0.316 | 0.312 | 0.156 | 0.149 | 0.28 | 0.283 | 0.237 | 0.219 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.033 | 1.055 | 0.774 | 1.163 | 0.692 | 1.175 | 0.52 | 0.473 |
| | Portion Replaced with Shear wall | 0.585 | 0.586 | 0.29 | 0.28 | 0.499 | 0.507 | 0.434 | 0.403 |
| 7th Story | With all Columns | 0.329 | 0.337 | 0.196 | 0.193 | 0.331 | 0.327 | 0.287 | 0.27 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.069 | 1.072 | 0.78 | 1.273 | 0.784 | 1.254 | 0.647 | 0.583 |
| | Portion Replaced with Shear wall | 0.616 | 0.639 | 0.363 | 0.365 | 0.598 | 0.594 | 0.529 | 0.5 |
| 6th Story | With all Columns | 0.354 | 0.369 | 0.236 | 0.237 | 0.395 | 0.379 | 0.337 | 0.328 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.181 | 1.109 | 0.813 | 1.09 | 0.9 | 1.091 | 0.779 | 0.709 |
| | Portion Replaced with Shear wall | 0.664 | 0.705 | 0.437 | 0.451 | 0.718 | 0.692 | 0.624 | 0.609 |
| 5th Story | With all Columns | 0.378 | 0.407 | 0.281 | 0.282 | 0.462 | 0.44 | 0.397 | 0.393 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.295 | 1.157 | 0.853 | 1.228 | 1.026 | 1.294 | 0.92 | 0.847 |
| | Portion Replaced with Shear wall | 0.71 | 0.777 | 0.52 | 0.537 | 0.841 | 0.805 | 0.737 | 0.729 |
| 4th Story | With all Columns | 0.408 | 0.451 | 0.326 | 0.328 | 0.502 | 0.505 | 0.462 | 0.459 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.427 | 1.244 | 0.92 | 1.383 | 1.099 | 1.414 | 1.034 | 0.987 |
| | Portion Replaced with Shear wall | 0.764 | 0.862 | 0.602 | 0.63 | 0.97 | 0.928 | 0.856 | 0.854 |
| 3rd Story | With all Columns | 0.435 | 0.491 | 0.37 | 0.375 | 0.575 | 0.552 | 0.512 | 0.514 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.586 | 1.211 | 0.906 | 1.546 | 1.252 | 1.587 | 1.179 | 1.102 |
| | Portion Replaced with Shear wall | 0.82 | 0.933 | 0.688 | 0.721 | 1.054 | 1.015 | 0.976 | 0.987 |
| 2nd Story | With all Columns | 0.483 | 0.498 | 0.416 | 0.423 | 0.65 | 0.623 | 0.579 | 0.587 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.77 | 2.085 | 1.575 | 1.729 | 1.407 | 1.782 | 1.329 | 1.259 |
| | Portion Replaced with Shear wall | 0.915 | 1.088 | 0.934 | 0.932 | 1.194 | 1.148 | 1.076 | 1.093 |
| 1st Story | With all Columns | 0.476 | 0.542 | 0.463 | 0.467 | 0.721 | 0.693 | 0.653 | 0.662 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.828 | - | - | 1.806 | 1.556 | 1.919 | 1.49 | 1.411 |
| | Portion Replaced with Shear wall | 0.384 | - | - | 0.443 | 1.325 | 1.278 | 1.21 | 1.227 |
| Ground | With all Columns | 0.493 | 0.552 | 0.484 | 0.489 | 0.751 | 0.72 | 0.676 | 0.683 |
| | Exterior Middle columns **(C26&C27)** Removed | 1.67 | 0.043 | 0.111 | 1.743 | 1.611 | 1.846 | 1.552 | 1.463 |
| | Portion Replaced with Shear wall | 0.935 | 1.007 | 0.998 | 0.933 | 1.383 | 1.327 | 1.245 | 1.262 |

Figure 12 shows the removal of the exterior middle columns C26 and C27 from the first floor structure. The load is transferred to the surrounding columns C25, C28, C07, C10, C13 and C16. The effect columns from ground floor to the third floor of the structure as shown in Table 2. The exterior middle columns C26 and C27 are removed, and at the same time shear wall is replaced at the first floor of the structure, as shown in Figure 13 DCR values for exterior column and surrounding columns are tabulated in Table 2 the values is within the limits (1.5) and it shows that all columns are in safe condition before the application of collapse to the structure.

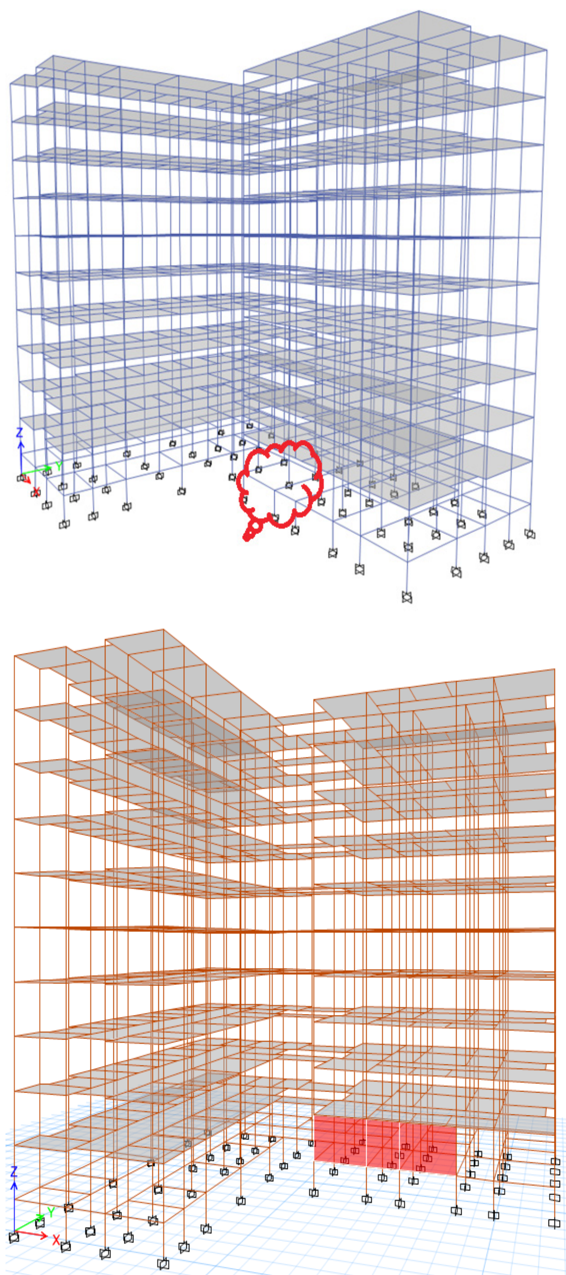

**Figure 12.** Middle column removed

Figure 13 shows the graphical representation (as per case-II). In this graph the X axis represents the number of story and Y axis represents DCR values of the columns.

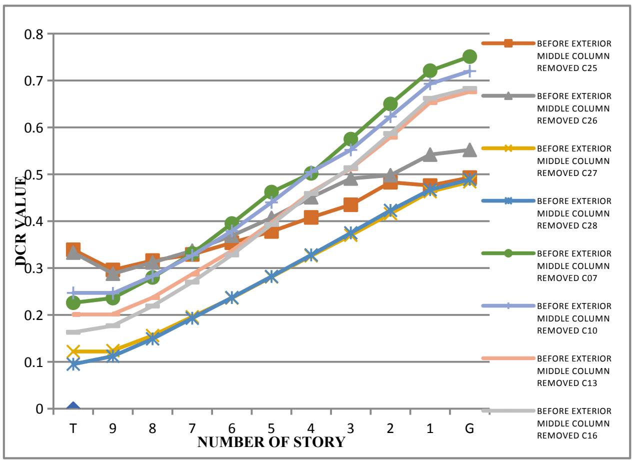


**Figure 13.** Before exterior column removed DCR value v/s number of story

The exterior middle columns C26 and C27 are removed. And the DCR value for middle column and surrounding columns of the structure are tabulated in Table 2 it shown value is not within the limit (1.5).

Figure 14 shows the graphical representation (as per case-II exterior column removed). In this graph the X axis represents the number of story and Y axis represents DCR values of the columns.

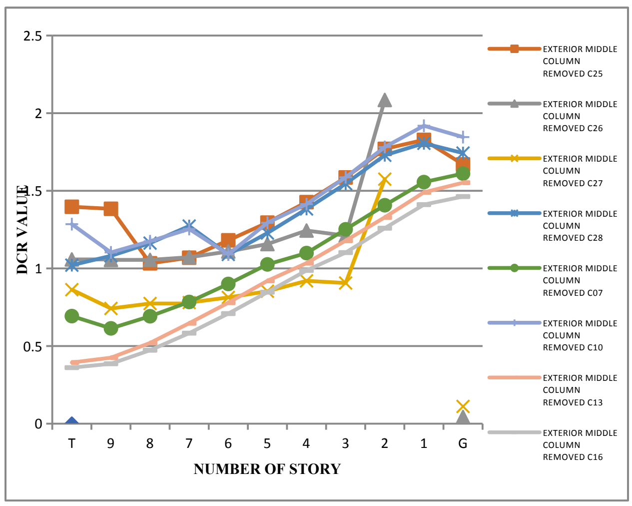


**Figure 14.** After exterior column removed DCR value v/s number of story

The shear wall is replaced at collapse column location and the DCR value for middle column and surrounding columns of the structure are tabulated in Table 2 it shown value is within the limit (1.5) and the structure is safe.

Figure 15 shows the graphical representation (as per case-II shear wall provided by corner collapsed column).

In this graph the X axis represents the number of story and Y axis represents DCR values of the columns.

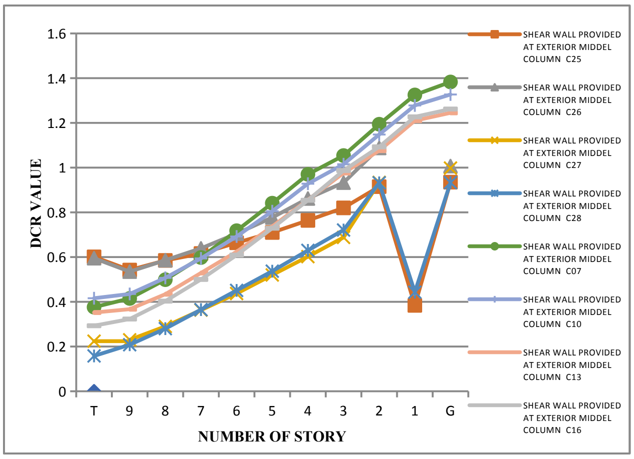


**Figure 15.** Shear wall provided at exterior column removed DCR value v/s number of story

## Case-2: Summary

As for as the exterior middle column C26 and C27 are failed (as per Case-II) and are removed, load contributes to surrounding column suffers due to excess load as discussed. To overcome from this situation, a shear wall of thickness 150 mm would be connected to the respective floor where structure showing failure and DCR values were compared and tabulated. Providing shear wall contributes to take load which is causing failure at C26 and C27 and also avoids excessive load transfer to the surrounding columns. Thereby decrease in the DCR values (within the limit) were discussed.

## Results of Case-3:

In this case, interior column fails due to an accidental load (fire hazard or gas explosion). The load is transferred to the adjacent column after the damage. It will initiate the progressive collapse for the surrounding columns. And if the DCR value shown in Table 3, it is more than limits (1.5). It denotes the unsafe structure. In this situation, the present study recommending to provide shear wall at the collapsed part of the structure.

Figure 16 shows the removal of an interior column (C36 and C37) on the first floor. The load is moved to a nearby column. It affects the structure from the ground floor to the third floor as shown in Table 3.

The interior column is removed, and replaced by a shear wall on the first floor structure, as shown in Figure 16. The shear wall is reduced load in surrounding columns. DCR values for exterior column and surrounding columns are tabulated in Table 3 the values is within the limits (1.5) and it shows that all columns are in safe condition before the application of collapse to the structure.

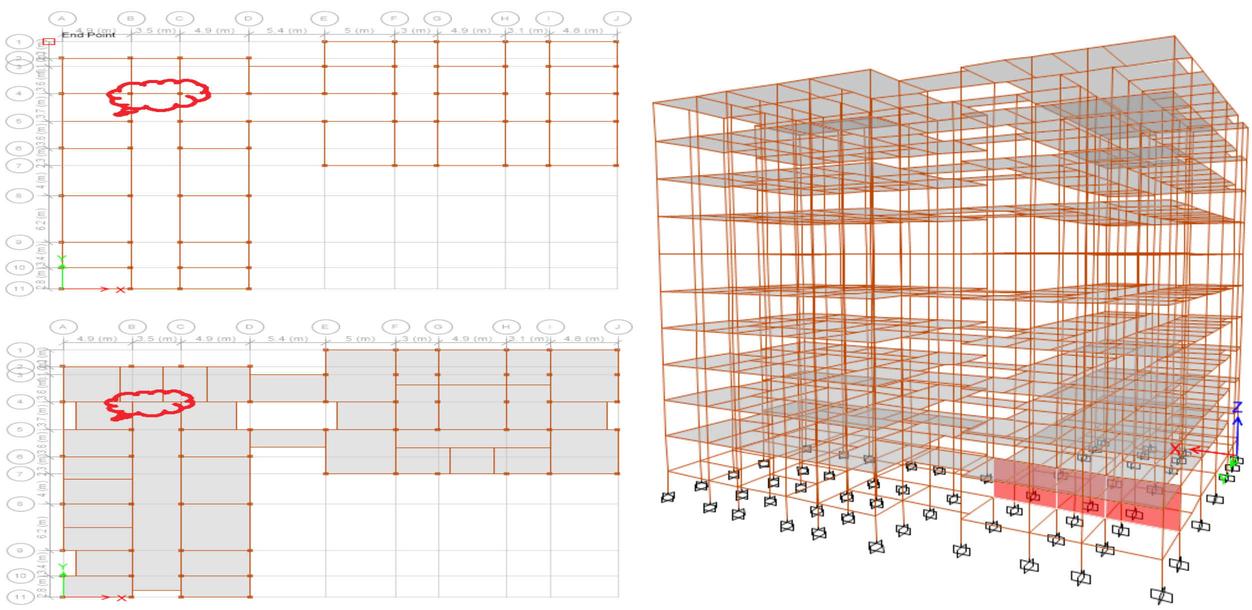

**Figure 16.** Interior plan removed

**Table 3.** DCR value results of Interior columns

| DCR VALUES OF INTERIOR COLUMN | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **STORY** | **COL REMOVED** | **C35** | **C36** | **C37** | **C38** | **C32** | **C33** | **C39** | **C40** |
| Terrace | With all Columns | 0.286 | 0.077 | 0.053 | 0.133 | 0.065 | 0.061 | 0.153 | 0.089 |
| | Interior columns **(C36&C37)** Removed | 1.199 | 0.758 | 0.885 | 0.727 | 0.217 | 0.172 | 0.827 | 0.693 |
| | Portion Replaced with Shear wall | 0.559 | 0.174 | 0.12 | 0.27 | 0.124 | 0.116 | 0.329 | 0.2 |
| 9th Story | With all Columns | 0.282 | 0.13 | 0.113 | 0.169 | 0.09 | 0.086 | 0.187 | 0.133 |
| | Interior columns **(C36&C37)** Removed | 1.054 | 0.643 | 0.747 | 0.719 | 0.248 | 0.217 | 0.795 | 0.694 |
| | Portion Replaced with Shear wall | 0.557 | 0.268 | 0.234 | 0.342 | 0.178 | 0.169 | 0.372 | 0.266 |
| 8th Story | With all Columns | 0.301 | 0.188 | 0.174 | 0.204 | 0.125 | 0.122 | 0.231 | 0.183 |
| | Interior columns **(C36&C37)** Removed | 1.135 | 0.688 | 0.793 | 0.827 | 0.323 | 0.307 | 0.897 | 0.823 |
| | Portion Replaced with Shear wall | 0.601 | 0.391 | 0.362 | 0.416 | 0.248 | 0.242 | 0.458 | 0.366 |
| 7th Story | With all Columns | 0.333 | 0.25 | 0.236 | 0.241 | 0.164 | 0.162 | 0.282 | 0.235 |
| | Interior columns **(C36&C37)** Removed | 1.201 | 0.727 | 0.83 | 0.922 | 0.402 | 0.395 | 1.027 | 0.961 |
| | Portion Replaced with Shear wall | 0.672 | 0.523 | 0.493 | 0.497 | 0.329 | 0.325 | 0.56 | 0.469 |
| 6th Story | With all Columns | 0.365 | 0.313 | 0.302 | 0.284 | 0.206 | 0.204 | 0.333 | 0.289 |
| | Interior columns **(C36&C37)** Removed | 1.284 | 0.787 | 0.888 | 1.031 | 0.495 | 0.49 | 1.168 | 1.114 |
| | Portion Replaced with Shear wall | 0.746 | 0.658 | 0.632 | 0.583 | 0.414 | 0.41 | 0.665 | 0.578 |
| 5th Story | With all Columns | 0.409 | 0.38 | 0.362 | 0.331 | 0.249 | 0.248 | 0.386 | 0.344 |
| | Interior columns **(C36&C37)** Removed | 1.102 | 0.86 | 0.959 | 1.146 | 0.591 | 0.585 | 1.178 | 1.128 |
| | Portion Replaced with Shear wall | 0.838 | 0.798 | 0.774 | 0.682 | 0.502 | 0.499 | 0.769 | 0.686 |
| 4th Story | With all Columns | 0.454 | 0.45 | 0.436 | 0.38 | 0.294 | 0.292 | 0.441 | 0.398 |
| | Interior columns **(C36&C37)** Removed | 1.236 | 0.973 | 1.069 | 1.1 | 0.692 | 0.684 | 1.377 | 1.316 |
| | Portion Replaced with Shear wall | 0.925 | 0.946 | 0.917 | 0.784 | 0.593 | 0.588 | 0.877 | 0.794 |
| 3rd Story | With all Columns | 0.497 | 0.517 | 0.501 | 0.428 | 0.339 | 0.336 | 0.495 | 0.455 |
| | Interior columns **(C36&C37)** Removed | 1.387 | 0.988 | 1.076 | 1.239 | 0.785 | 0.784 | **1.595** | **1.517** |
| | Portion Replaced with Shear wall | 1.039 | 1.081 | 1.048 | 0.893 | 0.683 | 0.676 | 0.985 | 0.902 |
| 2nd Story | With all Columns | 0.536 | 0.587 | 0.507 | 0.484 | 0.384 | 0.379 | 0.538 | 0.509 |
| | Interior columns **(C36&C37)** Removed | **1.567** | **1.799** | **1.91** | 1.395 | 0.917 | 0.902 | **1.843** | **1.753** |
| | Portion Replaced with Shear wall | 1.106 | 1.235 | 1.197 | 0.997 | 0.778 | 0.768 | 1.056 | 1.003 |
| 1st Story | With all Columns | 0.592 | 0.66 | 0.64 | 0.517 | 0.432 | 0.425 | 0.595 | 0.563 |
| | Interior columns **(C36&C37)** Removed | **1.671** | - | - | 1.49 | 1.011 | 0.999 | **2.044** | **1.941** |
| | Portion Replaced with Shear wall | 0.435 | - | - | 0.371 | 0.861 | 0.846 | 1.164 | 1.105 |
| Ground | With all Columns | 0.631 | 0.672 | 0.652 | 0.552 | 0.447 | 0.44 | 0.606 | 0.574 |
| | Interior columns **(C36&C37)** Removed | **1.61** | 0.031 | 0.046 | 1.464 | 1.028 | 1.014 | **2.007** | **1.894** |
| | Portion Replaced with Shear wall | 1.334 | 1.44 | 1.397 | 1.186 | 0.891 | 0.878 | 1.192 | 1.132 |

Figure 17 shows the graphical representation (as per case-III). In this graph the X axis represents the number of story and Y axis represents DCR values of the columns.

The interior columns C36 and C37 are removed. And take The DCR value for interior column and surrounding columns of the structure are tabulated in Table 3. The shown value is not within the limit (1.5).

Figure 18 shows the graphical representation (as per case-III interior column removed). In this graph the X axis represents the number of story and Y axis represents DCR values of the columns. The shear wall is replaced by collapse column location and take the DCR value for interior column and surrounding columns of the structure are tabulated in Table 3. The shown value is within the limit (1.5) and the structure is safe.

Figure 19 shows the graphical representation (as per case-III shear wall provided by corner collapsed column). In this graph the X axis represents the number of story and Y axis represents DCR values of the columns.

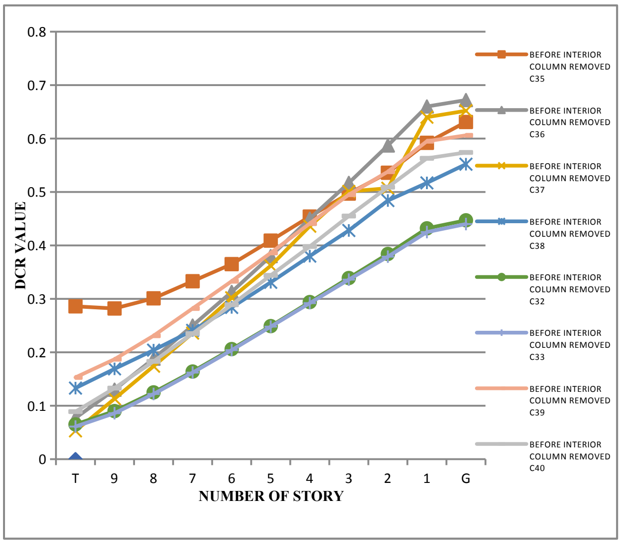


**Figure 17.** Before interior column removed DCR value v/s number of story

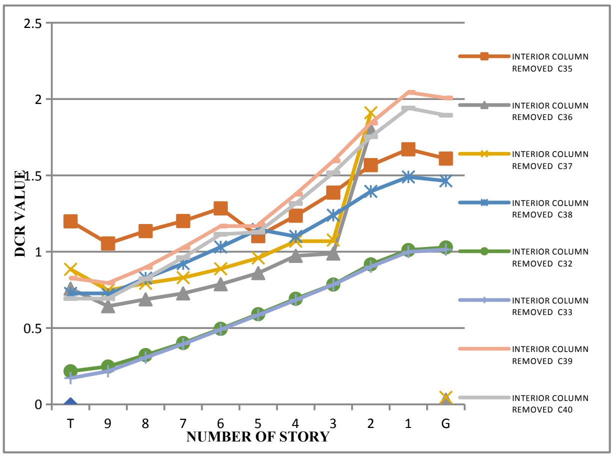


**Figure 18.** After interior column removed DCR value v/s number of story

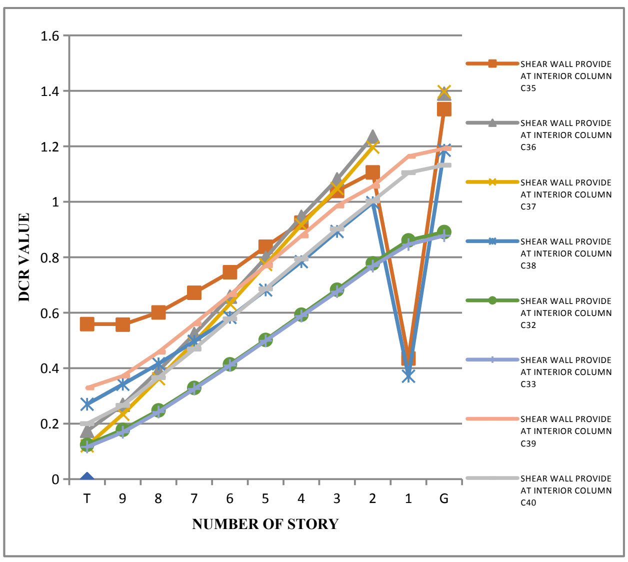


**Figure 19.** Shear wall provided at interior column DCR value v/s number of story

### Case-3: Summary

As for as the interior column C36 & C37 are failed (as per Case-III) and are removed, load contributes to surrounding column suffers due to excess load as discussed. To overcome from this situation, a shear wall of thickness 150 mm would be connected to the respective floor where structure showing failure and DCR values were compared and tabulated. Providing shear wall contributes to take load which is causing failure at C36 and C37 and also avoids excessive load transfer to the surrounding columns. Thereby decrease in the DCR values (within the limit) were discussed.

## 6. Conclusions

The study was conducted on the columns were removed for progressive collapse and analysis was performed. The DCR values should be taken. The following major finding can be obtained from a study of a 10 story structure for progressive collapse.

- Columns 31 and 32 of Case-1, columns 26 and 27 of case-2 and columns 36 and 37 of case-3 are removed and are replaced by shear wall to enhance the load carrying capacity and to limit the DCR value within 1.5.
- Since, collapse of the column exerted in first floor, the DCR values for the failure also increased more than 1.5 in ground, first, second and third floor before the provision of shear wall.
- After providing the shear wall in respective portion where collapse occurred, the DCR value gets decreased and the values are within the acceptable range. So the DCR value for any member decreases in respective floors by providing shear wall.
- The progressive collapse of the structure due to accidental load can be controlled by providing shear wall so that the GSA guidelines recommended DCR value would be within the range.

## Future Scope

- In present study we have introduced concrete shear walls in place of removed columns. However, it is possible to introduce other forms of shear walls like steel shear wall, hollow cement concrete block shear wall with reinforcement in hollow places etc.
- In place of shear wall we can also introduce bracings and understand the performance and contribution of these bracings during the progressive collapses.

## Acknowledgements

We herewith thank our beloved Principal Dr. Mallikarjun S Holi, who always supports the excellence, facilities, and student welfare that a student desires. We also thank our Chairman Dr. H Eramma for their moral support and encouragement.

## Conflict of Interest

There is no conflict of interest.

## References

[1] Singh, R.S., Jamal, Y., Khan, M.A., 2015. Progressive Collapse Analysis of Reinforced Concrete Symmetrical and Unsymmetrical Framed Structures by Etabs. International Journal of Innovative Research in Advanced Engineering. 12(2).

[2] Sezen, H., Song, B.I., Giriunas, K.A., 2010. Progressive Collapse Testing and Analysis of a Steel Frame Building. International Journal of Engineering Research Structures. 2(4).

[3] Kim, J., Hong, S., 2011. Progressive collapse performance of irregular buildings. International Journal of Engineering Research Structures. 20, 721-734.

[4] Vidya, V., 2016. Progressive Collapse Analysis of Existing Rc Buildings Using Linear Static Analysis. International Journal for Research in Engineering. 2(5).

[5] Thampy, A., Paulose, H., 2017. Assessment Of Progressive Collapse Potential In Regular And Irregular RC Structures Using Linear Static Analysis. International Journal of Advance Engineering and Research Development (IJAERD). 4(6).

[6] Gururaja, B., Sridhar, R., 2015. Progressive Collapse Potential of Irregular Concrete Building. IOSR Journal of Mechanical and Civil Engineering. pp. 67-70.

[7] Jeyanthi, R., Mohan Kumar, S., 2016. Progressive Collapse Analysis of a Multi-storey RCC building using Pushover Analysis. International Journal of Engineering Research & Technology.