# Progressive Collapse Performance of Step Back-Set Back Building Provided With Secondary Columns

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**Abstract –** *A building undergoes progressive collapse when a primary structural elements fails, leading to failure of adjoining elements, which successfully causes further structural failure. Progressive collapses could be accidental, because of the results of design deficiencies, fire, unintentional overload, material failure or phenomenon (e.g. erosion, wind or earthquakes). They can even be induced deliberately as a demolition method, specifically that of building implosion, or caused by acts of terrorism or war.*

*In this article, we conduct a linear static analysis and push-down analysis of step back-set back building with exterior corner column removal scenario following GSA guidelines. Analysis is done by using ETABS. After analysis of the building, we provide secondary columns to study the improvement in its performance against progressive collapse. The DCR values obtained from the analysis of both the buildings are compared to assess the improvement of progressive collapse performance of the step back-set back building.*

***Key Words*: Progressive Collapse, Linear Static Analysis, Push-down Analysis, DCR, Step Back-Set Back.**

## 1. INTRODUCTION

Progressive collapse is that the spread of an initial local failure from a structural element resulting, eventually, within the collapse of a whole structure or an outsized a part of it (just like how one domino can knock down a whole series of blocks). This phenomenon is additionally called disproportionate collapse, for the rationale that the collapse is out of proportion to the triggering event. The susceptibility of structures to progressive collapse varies to a particular degree and depends on many factors.

DCR (Demand Capacity Ratio) determines whether the structural member fails or not. The GSA guidelines advised the use of the DCR which is defined as the ratio of the structural member force after the sudden removal of a column to the member strength (capacity), as a benchmark to work out the failure of major structural members by the linear static analysis procedure.DCR (Demand Capacity Ratio) determines whether the structural member fails or not. The GSA guidelines advised the use of the DCR which is defined as the ratio of the structural member force after the sudden removal of a column to the member strength (capacity), as a benchmark to work out the failure of major structural members by the linear static analysis procedure.

## 2. MODELING AND ANALYSIS OF STEP BACK-SET BACK BUILDING

In this study, a 12 story RC building is considered having step back-set back configuration designed in accordance with IS 456. The building is analyzed in ETABS.

### 2.1. Geometry of the Building

The buildings have 4 bays in both longitudinal and transverse direction and a uniform story height of 3.75 m. The thickness of exterior and interior walls is 230 mm and 115 mm respectively. The imposed load and floor finish load of 4 $kN/m^2$ and 1 $kN/m^2$ , respectively, is taken on floors of 150 mm thick. Concrete of grade M25 ($f_{ck}$ = 25 $N/mm^2$) and reinforcement of grade Fe 415 ($f_y$= 415 $N/mm^2$) is used for analysis and design of RC frames. Design details of structural members are shown in Table 1.

**Table – 1:** Column and Beam Details

| Structural Element | Floor | Dimensions (mm) |
|---|---|---|
| Beam | 1F – 12F | 250 x 500 |
| Column | 1F – 4F | 650 x 650 |
| | 5F – 8F | 550 x 550 |
| | 9F – 12F | 450 x 450 |

### 2.2. Load Details

It is mentioned in the GSA guidelines that a load combination of full dead load (DL) and 0.25 times live load (LL) must be applied for analyzing the progressive collapse scenario. A structure responds dynamically after losing a load-bearing element like a column. Although this dynamic effect is spontaneously accounted for during a dynamic analysis, static analysis isn't ready to account for this dynamic effect during the analysis process. Due to this reason, the GSA has specified a dynamic multiplier of two when static analysis is administered. That is, 2(DL + 0.25LL).

### 2.3. Analysis and Result

The analysis of step back set back building with corner column removal scenario is carried out and the corresponding values of time period, displacement and bending moment are noted. The 3-D & elevation views of building, time period, displacement and bending moments of the column removal scenario with maximum DCR value is shown in the following figures:

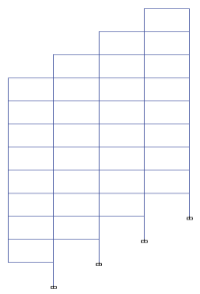

**Fig – 1:** 3-D View

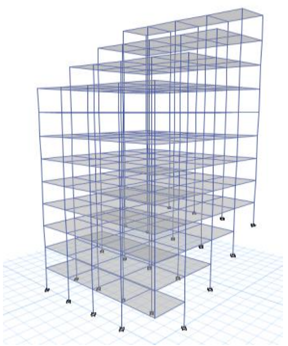

**Fig – 2:** Elevation

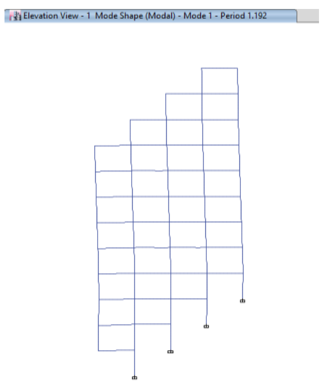


**Fig – 3:** Time Period

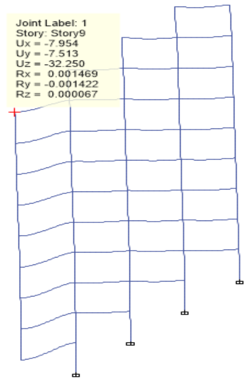


**Fig – 4:** Maximum Displacement

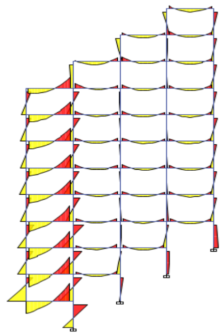

**Fig – 5:** Bending Moment Diagram

The time period value obtained here is 1.192s. Table 2 shows the minimum and maximum values of displacement and DCR values obtained from the analysis. The results depict the displacement and DCR values shown in the corner column removal scenario with 9 stories having DCR > 2.

**Table -2:** Displacement & DCR Values

| Story No. | Displacement | | DCR | |
|---|---|---|---|---|
| | Minimum | Maximum | Minimum | Maximum |
| 1 | 1.94 | 31.77 | 2.23 | 3.16 |
| 2 | 3.7 | 31.8 | 2.19 | 3.11 |
| 3 | 5.24 | 31.85 | 2.02 | 2.95 |
| 4 | 6.54 | 31.91 | 1.79 | 2.72 |
| 5 | 8.06 | 31.99 | 1.53 | 2.54 |
| 6 | 9.29 | 32.08 | 1.45 | 2.46 |
| 7 | 10.23 | 32.15 | 1.38 | 2.39 |
| 8 | 10.87 | 32.2 | 1.29 | 2.29 |
| 9 | 11.42 | 32.25 | 0.89 | 2.02 |

The displacement increases from ground story to top story while the DCR value is highest for beam closer to exterior corner column in ground story. Since all the 9 stories have DCR value greater than 2, it means they all have failed. So, appropriate strengthening methods need to be provided to increase the building's performance against progressive collapse.

## 3. PROVIDING SECONDARY COLUMNS

In order to increase the performance of step back-set back building against progressive collapse and lower the DCR value to less than 2, secondary columns are provided near exterior columns along the horizontal direction of irregularity of the same building as described above. The secondary columns provided are ISWB – 600 steel columns.

### 3.1. Analysis and Results

The analysis of step back-set back building provided with secondary columns is carried out and the corresponding values of time period, displacement and bending moment is noted. The 3-D & elevation views of building, time period, displacement and bending moments of the column removal scenario with maximum DCR value is shown in the following figures:

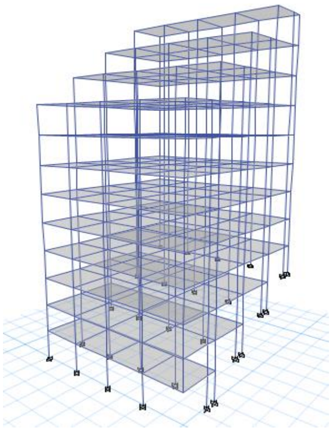

**Fig – 6:** 3-D View

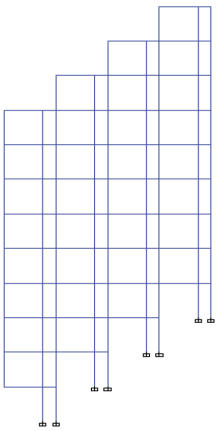

**Fig – 7:** Elevation

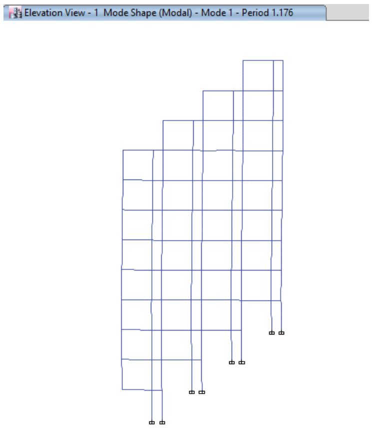


**Fig – 8:** Time Period

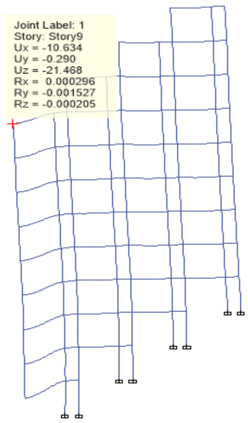


**Fig – 8:** Maximum Displacement

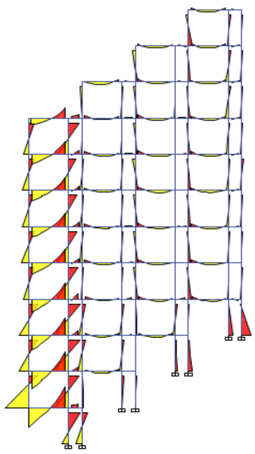

**Fig – 9:** Bending Moment Diagram

The time period value obtained here is 1.176s. Table 3 shows the minimum and maximum values of displacement and DCR values obtained from the analysis. The results depict the displacement and DCR values shown in the corner column removal scenario with 4 stories having DCR > 2.

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**Table – 3:** Displacement & DCR Values

| Story No. | Displacement (mm) | | DCR | |
|---|---|---|---|---|
| | Minimum | Maximum | Minimum | Maximum |
| 1 | 2.16 | 20.94 | 2.54 | 2.8 |
| 2 | 3.89 | 20.98 | 2.24 | 2.6 |
| 3 | 5.3 | 21.04 | 1.97 | 2.34 |
| 4 | 6.49 | 21.11 | 1.68 | 2.07 |
| 5 | 7.52 | 21.21 | 1.44 | 1.88 |
| 6 | 8.34 | 21.29 | 1.36 | 1.78 |
| 7 | 8.97 | 21.37 | 1.29 | 1.72 |
| 8 | 9.41 | 21.42 | 1.22 | 1.67 |
| 9 | 9.65 | 21.47 | 0.81 | 1.37 |

## 4. COMPARISON OF RESULTS

It is clear from both analysis results that the performance of step back-set back against progressive collapse increased significantly when provided with secondary columns. Chart 1 & Chart 2 shows the comparison of maximum values of displacements and DCR values from both analyses. Table 4 shows the comparison of maximum DCR values and the no. of stories failed in both cases.

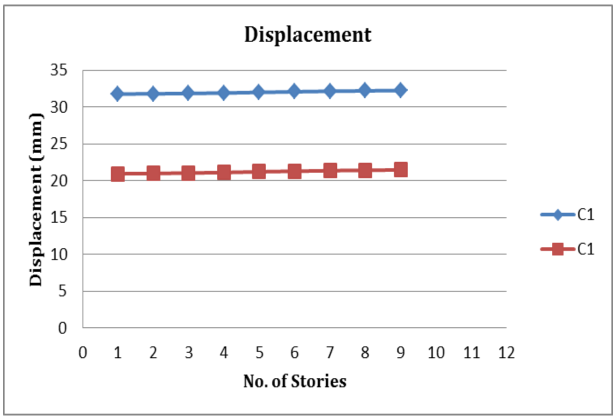


**Chart – 1:** Comparison of Displacement Values

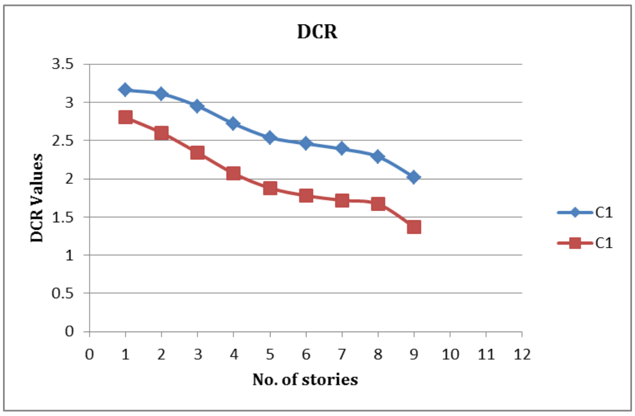


**Chart – 2:** Comparison of DCR Values

**Table – 4:** Comparison of Results

| Secondary Columns | Displacement (mm) (max) | DCR (max) | No. of stories with DCR > 2 |
|---|---|---|---|
| Without | 32.25 | 3.16 | 9 |
| With | 21.47 | 2.8 | 4 |

## 5. CONCLUSIONS

In this paper, progressive collapse phenomenon, its effects on irregular RC buildings as well as appropriate strengthening method to increase the building performance is presented. Progressive collapse was induced on step back-set back buildings by removing exterior corner column from the ground story. In order to study the behavior of irregular buildings towards progressive collapse, time period, displacement and DCR values were calculated. The strengthening method implemented to increase the performance of the buildings against progressive collapse was providing secondary columns. It proved to be quite effective in lowering the DCR values which indicates increased resistance against progressive collapse. Two 12-story buildings were modeled and analysed in ETABS for this purpose. Based on the analysis results, the following conclusions are drawn:

1. Providing secondary columns decreases the displacement of building stories. Here, the displacement was reduced by 33.43%.

2. It also lowered the DCR values by 11.39% Increasing the performance of step back-set back building against progressive collapse. The no. of stories failed reduced from 9 to 4 because of implementation of secondary columns as a strengthening method.

## REFERENCES

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