International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 02 Issue: 10 October 2024
Page No: 2470 - 2476
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2024.0338

Progressive Collapse Analysis of G+10 RCC Building

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Abstract
This study important of the progressive collapse that final damage of the structure is not similar as the initial collapse of structure. The key parameters used story displacement in eleven-storey building of regular shape that has modelled and analyzed by the ETABS 2018 software by using the Indian standard codes. Then for the calculation of progressive collapse we use U.S General Service Administration (GSA 2016) guidelines. The demand capacity ratio (DCR) values of the neighboring member are taken into account after the damage the DCR values for regular structure must be with in (2). In this study the progressive collapse is considered in three different cases that is at corner, interior and at exterior columns.
Keywords: *Progressive Collapse Analysis: Demand-Capacity Ratio: Story Displacement.*

1. Introduction
The multistory building undergoes progressive collapse when the columns or primary structural element are collapsed due to which the entire structure begins to collapse progressively, Progressive collapse may occur due to natural or man-made destruction like material failure, vehicular impact or due to fire hazard or may be due to seismic The reviewed literature highlights the critical issue of progressive collapse in reinforced concrete (RC) structures, with a focus on column removal scenarios. Various studies using ETABS and GSA guidelines demonstrate that interior and ground-floor column failures are most critical. (Sonu Kumar, 2023) (Anjali G. Dole, 2021) This study investigates the progressive collapse potential of a G+10 reinforced concrete building using ETABS, focusing on column removal scenarios to assess structural vulnerability. Based on GSA guidelines, the research aims to evaluate how the sudden loss of critical columns affects the building's stability. Previous studies have shown that interior and lower-story columns are most critical in collapse scenarios. By identifying weak points, this study seeks to propose design improvements that enhance resistance against progressive collapse in multi-story buildings. The objectives of this study to analyse the G+10 building for the progressive collapse performance under the seismic loading. To study DCR values for the 2nd, 5th, 7th floor columns, considering the removal of columns at different locations i.e. exterior, interior, and corner column [1]. To assess the performance of a building in terms of story drift, displacement and story shear after the removal of column in 2nd, 5th, and 7th floor.

1.1. Acceptance Criteria
For both primary & secondary structural elements the acceptance criteria can be established as DCR - Demand Capacity Ratio as shown in the equation:

$DCR = QUD/QCE$

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

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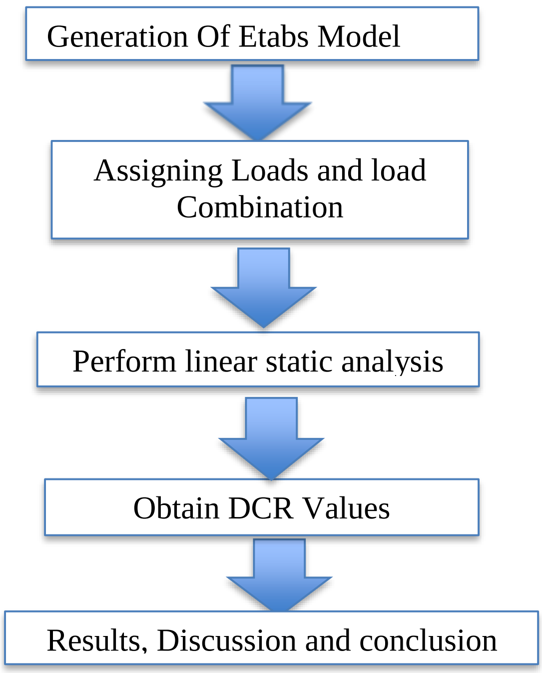
component r a connection, GSA guidelines suggests enhancing the strength of the design material by a factor called strength- increase in order to obtain the material strength as per the expectation [2].

2. Methodology

In this work, the analysis based on linear static method is used to investigate Progressive Collapse Analysis of G+10 Rcc building under Removal of Columns and its Modeling Using ETABS Software as per IS-standards (Figure 1). In order to study on Progressive Collapse in zone II of India is considered.

Figure 1 Flow Char of Methodology



2.1. Modelling and Building Information

The G+10 RCC structure, with 26m x 26m plan dimensions, features 3.5m story height (Table 1). Constructed with M30-grade concrete and Fe-500 reinforcing steel, columns are sized 600mm x 600mm, beams 300mm x 600mm, and slabs 150mm thick. The building design follows IS 875 for dead/live loads and IS 1893(part 1) for seismic loading in Zone II on medium soil. The building is a G+10 RCC structure with plan dimensions of 26m x 26m and a floor height of 3.5m per story. It uses M30 grade concrete for columns and slabs, with Fe-500 reinforcing steel.

Table 1 Building Information

PARTICULARS	RCC STRUCTURE
Plan dimensions	26m*26m
Hight of each story	3.5m
No. of story	G+10
Type of building	Rcc building
Grade of concrete	M30(column) M30(slab)
Grade of reinforcing steel	Fe-500
Size of column	C-600*600
Size of beam	B-300*600
Size of slab	150 mm
Wall thickness	300 mm
Dead load	As per IS 875 (Part I)
Live load	As per IS 875 (Part II)
Floor Finish	1KN/m2
Live Load	3 KN/m2
Seismic loading	As per IS: 1893(Part I)
Zone	II
Soil Type	Type II, medium soil

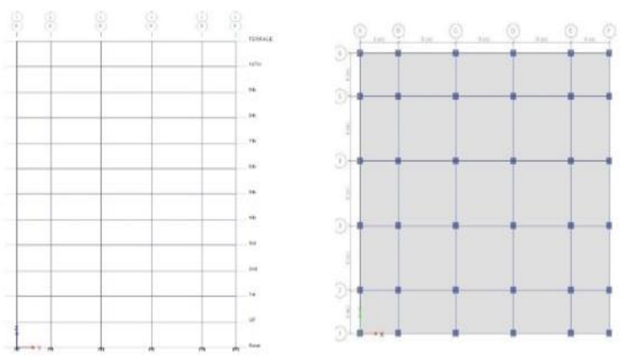


Figure 2 Plan and Elevation

Columns are sized 600x600 mm, beams 300x600 mm, and slabs are 150 mm thick [3]. The structure follows IS 875 for dead and live loads, IS 1893:2018 for seismic loading, and is located in seismic Zone II with medium soil conditions.

3. Results and Discussions

3.1. Story Displacement

The lateral displacement of each story concerning the base (Figure 2). The lateral force resisting system effectively controls and restricts excessive lateral movement within the building. For wind load scenarios, the acceptable lateral displacement limit can be considered as H/500 or H/300, where H

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represents the building height [4].

- Using H/300: Δ=42/300=140mm
- Using H/500: Δ=42/500=84mm

According to IS 1893(part 1), the maximum lateral displacement for a 42 m high building would typically range between 84 mm and 140 mm.

1. **Storey Response (maximum storey displacement) Graph for Corner column (C1) removed in second, fifth, and seventh floor Removal.**

In Figure 3, the graph shows that 2nd Floor C1: 95.382 (Terrace),5th Floor C1: 94.466 (Terrace),7th Floor C1: 93.994(Terrace)By identifying the maximum displacement values analyze how the structure behaves under lateral forces such as wind or seismic activity [5]. to progressive collapse, focusing on the areas of maximum displacement for safety evaluations.

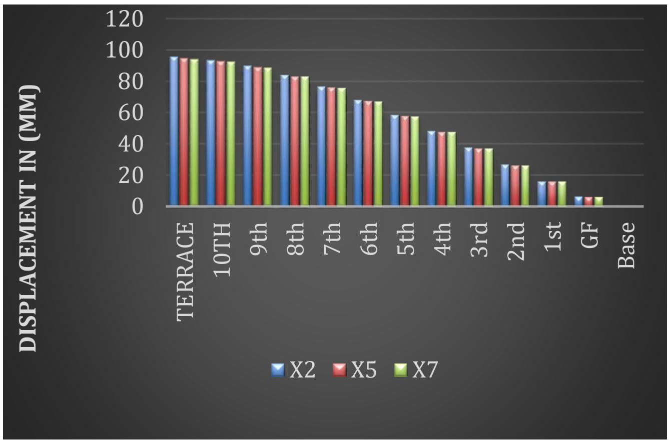

Figure 3 **Maximum Story Displacement Curves for EQX Direction**

2. **Storey Response (maximum storey displacement) Graph for Interior column (C21) in removed in second, fifth, and seventh floor Removal.**

In Figure 4, the graph shows that 2nd Floor C21: 93.827 (Terrace),5th Floor C21: 93.843 (Terrace),7th Floor C21: 93.827 (Terrace). By identifying the maximum displacement values analyze how the structure behaves under lateral forces such as wind or seismic activity [6]. to progressive collapse under permissible limit focusing on the areas of maximum displacement for safety evaluations.

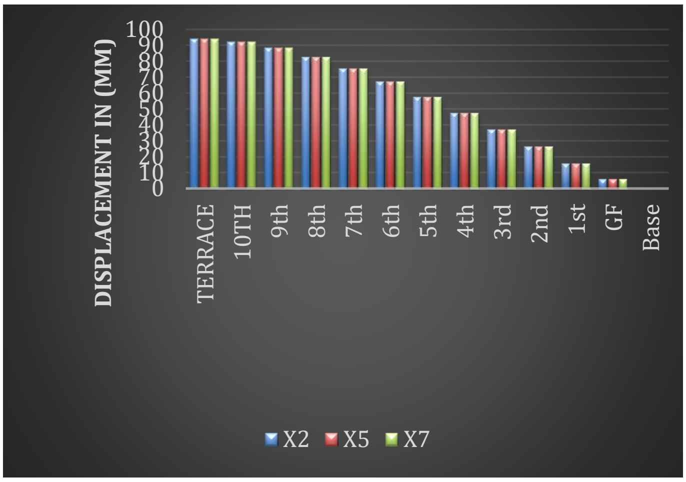

Figure 4 **Maximum Story Displacement Curves for EQX Direction**

3. **Storey Response (maximum storey displacement) Graph for exterior column (C13) in removed in second, fifth, and seventh floor Removal.**

In Figure 5, the graph shows that 2nd Floor C13: 95.73 (Terrace),5th Floor C13: 94.591 (Terrace),7th Floor C13: 94.029 (Terrace). The maximum displacement values analyze how the structure behaves under lateral forces such as wind or seismic activity. to progressive collapse under permissible limit focusing on the areas of maximum displacement for safety evaluations [7].

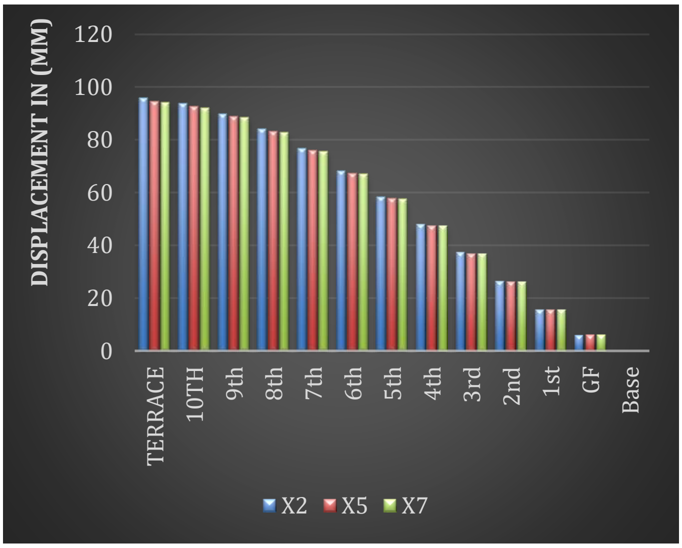

Figure 5 **Maximum Story Displacement Curves for EQX Direction**

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https://doi.org/10.47392/IRJAEH.2024.0338

3.2. Response of the Building on a Corner Column(C1) Collapse in Second Floor

Table 2 The Corner C1 Column is Removed and DCR Values of the Surrounding Column are Tabulated

Story	Column Removed	C1	C2	C7
G		0.613	0.589	0.817
1^{ST}		0.606	0.735	0.657
2^{ND}	C1	-	0.43	0.862
3^{RD}		0.665	0.456	**0.997**
4^{TH}		0.275	0.495	0.986
5^{TH}		0.698	0.337	0.41
6^{TH}		0.206	0.397	0.356
7^{TH}		0.179	0.409	0.213
8^{TH}		0.18	0.403	0.491
9^{TH}		0.296	0.295	0.141
10^{TH}		0.226	0.144	0.231
TER		0.093	0.264	0.16

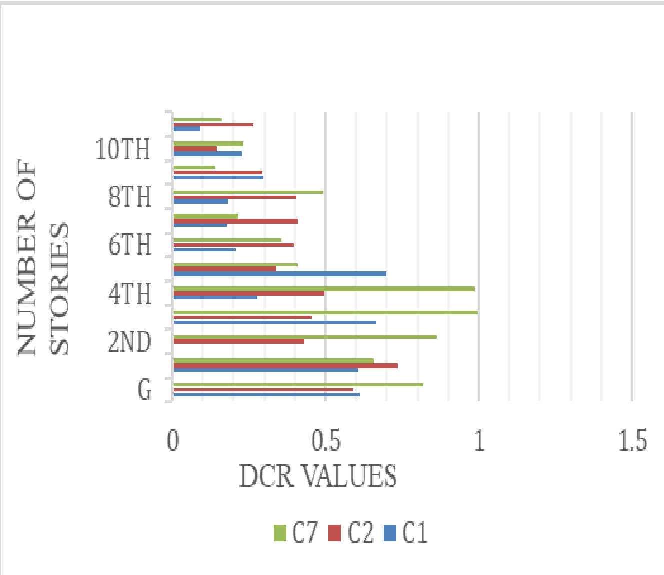

Figure 6 DCR Value V/S Number of Stories After Corner Column Removal

The collapse of corner column C1 has cascading effects on the surrounding columns, notably C2 and C7, with varying impacts throughout the building. Continuous monitoring and potential reinforcement may be required, especially for columns with lower DCR values.

3.3. Response of The Building on a Corner Column (C6) Collapse in Second Floor

Table 3 The Corner C6 Column Is Removed and DCR Values of the Surrounding Column Are Tabulated

Story	Column Removed	C6	C12	C5
G		0.368	0.991	0.928
1ST		0.605	0.673	0.994
2ND	C6	-	**0.99**	0.708
3RD		0.605	0.818	0.708
4TH		0.383	0.436	0.862
5TH		0.918	0.605	0.664
6TH		0.343	0.496	0.578
7TH		0.942	0.35	0.526
8TH		0.18	0.296	0.311
9TH		0.116	0.258	0.236
10^{TH}		0.344	0.139	0.23
TER		0.23	0.194	0.179

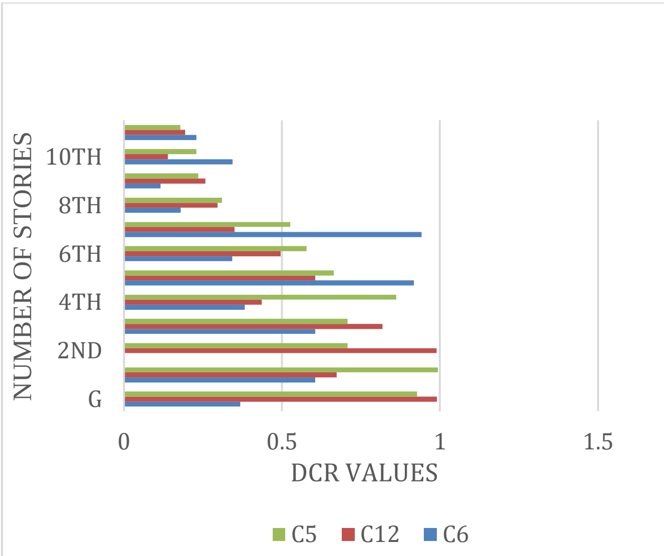

Figure 7 DCR Value V/S Number of Stories After Corner Column Removal

The collapse of corner column C6 on the second floor has notable implications for the Demand-Capacity Ratio (DCR) of the surrounding columns (C12 and C5) [8]. The DCR values indicate how much load each column can bear compared to the load it is experiencing.

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3.4. Response of the Building on an Interior Column (21) Collapse in Second Floor

Table 4 The Interior C21 Column is Removed and DCR Values of the Surrounding Column are Tabulated

Story	Col rem	C21	C22	C15	C20	C27
G		0.887	0.613	0.793	0.766	0.751
1^{ST}		0.541	0.526	0.629	0.748	0.609
2^{ND}	**C21**	-	0.506	0.732	0.715	0.546
3^{RD}		0.596	0.704	0.624	0.456	0.721
4^{TH}		0.591	0.511	0.734	0.461	0.742
5^{TH}		0.608	0.991	0.733	0.416	0.751
6^{TH}		0.614	0.503	0.678	0.373	0.765
7^{TH}		0.648	**0.993**	0.761	0.31	0.743
8^{TH}		0.644	0.882	0.36	0.229	0.777
9^{TH}		0.643	0.412	0.256	0.165	0.727
10^{TH}		0.606	0.21	0.35	0.282	0.611
TER		0.854	0.108	0.499	0.347	0.721

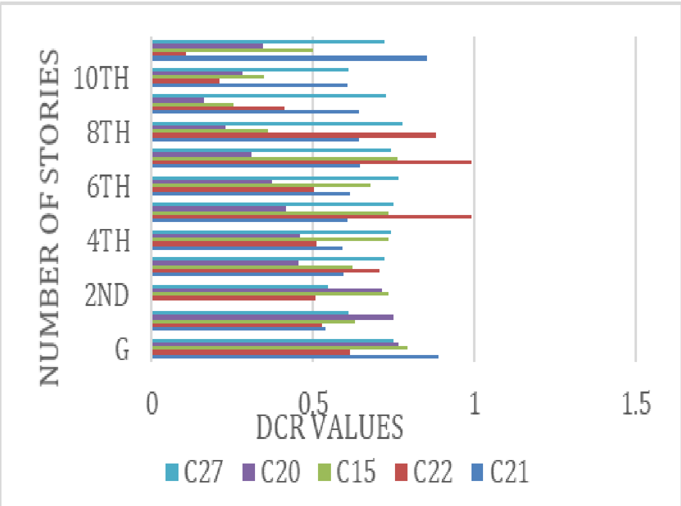

Figure 8 DCR Value V/S Number of Stories After Corner Column Removal

The removal of interior column C21 significantly impacts the surrounding columns, particularly C22, C15, C20, and C27. The DCR values reflect an increased load on these columns, especially on the second floor, where C22 is particularly stressed.

3.5. Response of the Building on an Interior Column (29) Collapse in Second Floor

Table 5 The Interior C29 Column is Removed and DCR Values of the Surrounding Column are Tabulated

Story	Col rem	C29	C30	C23	C28	C35
G		0.493	0.717	0.68	0.991	0.706
1^{ST}		0.443	**0.997**	0.706	0.898	0.396
2^{ND}	**C29**	-	0.616	0.567	0.733	0.368
3^{RD}		0.293	0.744	0.622	0.539	0.751
4^{TH}		0.276	0.67	0.596	0.643	0.984
5^{TH}		0.925	0.653	0.589	0.653	0.859
6^{TH}		0.278	0.743	0.576	0.671	0.977
7^{TH}		0.923	0.324	0.585	0.773	0.84
8^{TH}		0.853	0.436	0.422	0.522	0.361
9^{TH}		0.739	0.477	0.301	0.62	0.437
10^{TH}		0.864	0.299	0.224	0.346	0.296
TER		0.899	0.679	0.202	0.29	0.493

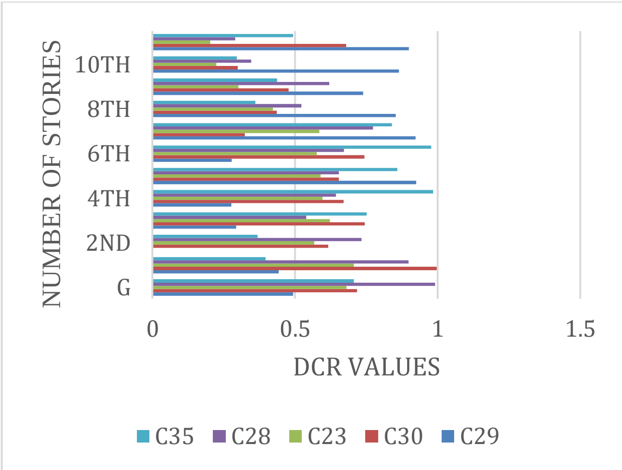

Figure 9 DCR Value V/S Number of Stories After Corner Column Removal

The collapse of the interior column C29 on the second floor leads to increased load demands on the surrounding columns, especially C30, C28, and C35. These columns show elevated DCR values across multiple floors, with C28 consistently absorbing a significant portion of the redistributed load. The overall building response highlights the importance of designing the surrounding columns to handle such load redistribution in the event of column failure.

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3.6. Response of The Building on an Exterior Column(C13) Collapse in Second Floor

Table 6 The Corner C13 Column is Removed and DCR Values of the Surrounding Column are Tabulated

Story	Col rem	C13	C7	C14	C19
G		0.524	0.514	0.57	0.596
1ST		0.623	0.455	0.628	0.554
2ND	C13	0.813	0.63	0.551	0.489
3RD		0.725	0.511	0.562	0.542
4TH		0.123	0.622	0.569	0.566
5TH		0.663	0.881	0.591	0.469
6TH		0.488	0.773	**0.99**	0.635
7TH		0.308	0.777	0.557	0.676
8TH		0.356	0.451	0.537	0.395
9TH		0.438	0.41	0.319	0.371
10TH		0.377	0.434	0.228	0.179
TER		0.338	0.738	0.179	0.388

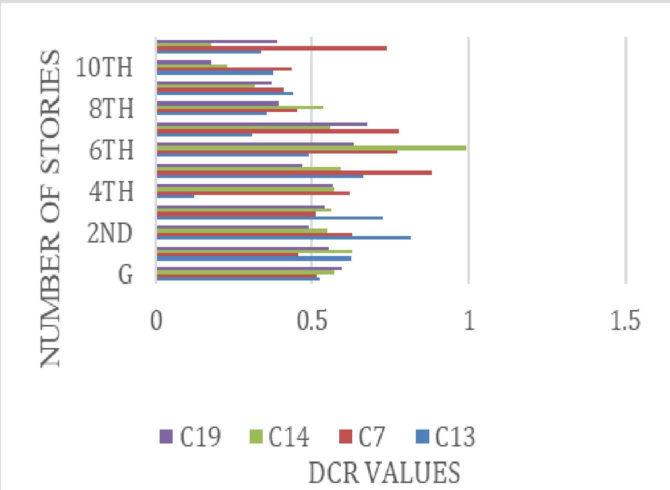

Figure 10 DCR Value V/S Number of Stories After Corner Column Removal

The removal of interior column C21 significantly impacts the surrounding columns, particularly C22, C15, C20, and C27. The DCR values reflect an increased load on these columns, especially on the second floor, where C22 is particularly stressed.

3.7. Response of The Building on an Exterior Column(C7) Collapse in Second Floor

Table 7 The Corner C7 Column Is Removed and DCR Values of the Surrounding Column Are Tabulated

Story	Col rem	C7	C1	C8	C13
G		0.549	0.432	0.775	0.601
1ST		0.625	0.65	0.518	0.546
2ND	C7	-	0.403	0.554	0.391
3RD		0.681	0.609	0.579	0.485
4TH		0.387	0.684	0.619	0.376
5TH		0.832	0.59	0.673	0.48
6TH		0.43	0.604	0.467	0.534
7TH		**0.912**	0.633	0.614	0.727
8TH		0.414	0.462	0.519	0.417
9TH		0.537	0.196	0.382	0.267
10TH		0.23	0.297	0.257	0.329
TER		0.334	0.399	0.197	0.144

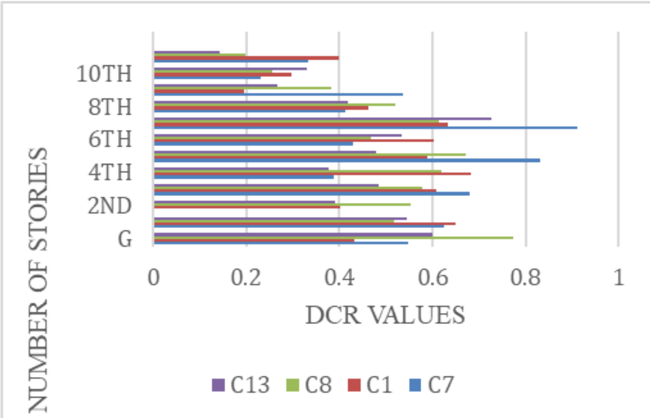

Figure 11 DCR Value V/S Number of Stories After Interior Column Removal

The removal of the exterior column C7 notably affects the surrounding columns, especially C1, C8, and C13. The DCR values indicate that these columns are under considerable stress and may not adequately support the applied loads, particularly on the second floor.

Conclusion

By using ETABS 2016 software the eleven-story regular building model is analysed for both gravity load and seismic load. Earthquake load analysis is done. The Results are shown in Figures 6 to 11 and

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Tables 2 to 7. The multistorey building is analysed. The DCR values of all structural elements are within the limit (2) as per GSA guidelines. The maximum displacement values in Figures 2, 3, and 4 indicate that columns C1, C21, and C13 experience their highest displacements on the 2nd floor, decreasing towards the upper levels. This suggests that under lateral forces such as wind or seismic activity, the lower floors are more vulnerable to progressive collapse. Structural reinforcements should prioritize these critical areas to ensure safety. The collapse of corner column C1 causes localized failure risks, especially between the 2nd and 4th floors near column C7. The collapse of C6 on the 2nd floor significantly stresses columns C12 and C5, with critical DCR values on the 2nd and 3rd floors. The failure of interior column C21 redistributes loads to columns C15 and C22, with C22 at critical stress levels, particularly on the 5th and 7th floors. The collapse C29 collapse stresses columns C28, C30, and C35 on lower floors. Exterior column C13 collapse increases stress on C7, and column C7removal severely impacts C1.

Acknowledgements

I sincerely thank Dr. Ambedkar Institute Technology for providing the resources and support for this research. Special thanks to my guide, Dr. S. Kavitha, for their guidance and encouragement. I also like to thank the structural engineering department's assistance with ETABS software. Finally, I acknowledge for their support in making this study possible.

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