Progressive Collapse Assessment of a G+30 Reinforced Concrete Tall Building Using the Alternate Path Method

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Abstract—**Progressive collapse is a disproportionate failure mechanism in which the local loss of a load-bearing member produces force redistribution demands that may exceed the reserve capacity of adjoining elements. This paper presents a journal-oriented analytical investigation of a G+30 reinforced concrete tall building subjected to a sudden column-removal scenario using the Alternate Path Method. A three-dimensional ETABS model was developed with M30 concrete, Fe500 reinforcement, 150 mm slab thickness, 250 mm x 450 mm beams and 500 x 500 mm/400 x 400 mm columns. Gravity, wind and seismic actions were considered using relevant Indian code provisions, while structural robustness was evaluated through storey shear, lateral displacement, storey drift and demand-capacity ratio indicators. The removal of the critical column produced a uniform 56% increase in storey shear demand, increased top displacement from 92.0 mm to 143.5 mm and raised the maximum drift from 5.50 mm to 8.58 mm. Despite this increase, the serviceability displacement demand remained below the H/500 limit and the drift demand remained below the IS 1893 limit of 0.004h. The maximum shear DCR increased from 0.62 to 0.97, indicating near-critical reserve capacity at the base. The study demonstrates that alternate load-path evaluation can identify vulnerable zones before disproportionate collapse occurs and can support robustness enhancement through member strengthening, redundancy and improved continuity detailing.**

Index Terms—**Progressive collapse; Alternate Path Method; Demand capacity ratio; Tall building; ETABS; Column removal; Structural robustness**

I. INTRODUCTION

The development of tall buildings has increased the importance of robustness-based structural design because a local failure in a column, transfer member or connection may propagate through the structural system. Conventional strength design is adequate for regular gravity and lateral actions, but it does not explicitly verify whether the building has sufficient alternate load paths after the loss of a critical vertical member. Progressive collapse analysis therefore examines whether the remaining structural system can bridge over the damaged zone and redistribute gravity and lateral demands without triggering instability.

The Alternate Path Method (APM) is one of the most widely used approaches for assessing disproportionate collapse risk. In this method, a critical element is removed from the analytical model and the resulting force redistribution is studied using linear or nonlinear procedures. The approach is particularly relevant for tall reinforced concrete buildings because vertical load transfer is highly dependent on columns, beams, slabs and shear walls acting together. When a column is removed, adjacent beams experience additional flexural and shear actions, floor diaphragms transfer load to neighbouring frames and the base experiences increased shear demand. The demand-capacity ratio (DCR) offers a convenient performance measure for determining whether structural members remain within acceptable resistance limits.

This paper reformulates the Stage II analytical investigation into a Scopus-style research article. The technical focus is the quantitative comparison of a

G+30 reinforced concrete building before and after column removal. Emphasis is placed on code-based loading, ETABS modelling, storey response variation and practical design implications for improving collapse resistance in Indian tall building practice.

II. LITERATURE REVIEW

Existing research on progressive collapse has shown that structural redundancy, continuity, connection ductility and diaphragm action play decisive roles in preventing local failure from becoming global collapse. Experimental and numerical studies on reinforced concrete frames demonstrate that catenary action, compressive arch action and membrane mechanisms can develop after a column is removed, provided the reinforcement is continuous and detailing permits large deformations. Steel and composite systems show similar sensitivity to connection behaviour, because beam-to-column joint failure can interrupt alternate load paths even when member strength is sufficient.

Recent numerical investigations have used finite element and structural analysis platforms to evaluate column removal under static and dynamic procedures. Linear static methods offer a rapid screening tool, while nonlinear dynamic methods better represent inertia, material yielding and geometric nonlinearity. In practice, researchers often combine global modelling for structural response with member-level checks for critical regions. The literature also highlights that infill walls, bracing systems and core-wall arrangements may significantly alter redistribution patterns. However, many studies are case-specific and do not provide easily interpretable DCR-based results for tall Indian RC buildings designed under IS loading provisions.

The present study contributes to this gap by presenting a clear before-and-after column removal comparison for a G+30 building, linking storey shear, displacement, drift and DCR metrics to code-based limits. The use of Indian wind and seismic provisions strengthens its practical relevance for domestic high-rise design and assessment.

III. RESEARCH GAP, NOVELTY AND OBJECTIVES

The research gap lies in the limited availability of integrated APM-based studies for G+30 reinforced concrete buildings that simultaneously report wind loading, storey shear increase, displacement amplification, drift safety and DCR variation in a single performance framework. The novelty of this paper is the conversion of ETABS-based progressive collapse assessment into a concise robustness index format that can be used for preliminary decision-making by practicing engineers.

The objectives are: (i) to develop a G+30 ETABS model under gravity, wind and seismic loading; (ii) to simulate critical column removal using the Alternate Path Method; (iii) to quantify changes in storey shear, displacement and drift; (iv) to evaluate DCR before and after column removal; and (v) to recommend structural measures that enhance robustness against disproportionate collapse.

IV. MATERIALS AND METHODS

Table 1. Modelling and material specification used for progressive collapse assessment

Category	Parameter	Specification/Value
System	Building type	G+30 reinforced concrete tall building
System	Analysis software	ETABS
Materials	Concrete	M30
Materials	Reinforcement steel	Fe500
Geometry	Beam size	250 mm x 450 mm
Geometry	Column size	500 x 500 mm and 400 x 400 mm
Geometry	Slab thickness	150 mm
Loading	Gravity load	Dead load, live load and superimposed dead load as per IS provisions
Lateral loading	Seismic and wind	IS 1893:2016 and IS 875 (Part 3):2015
Progressive collapse scenario	Column removal	Critical vertical member removed to evaluate alternate load paths
Evaluation index	DCR	Demand/capacity ratio for shear, displacement and drift

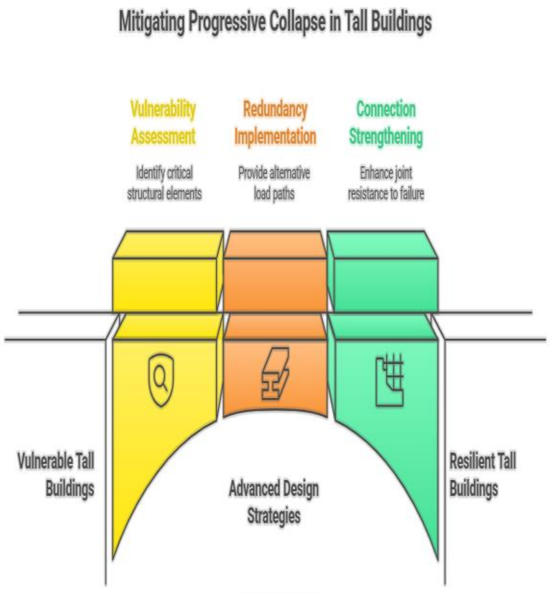

Figure 1. Conceptual framework for mitigating progressive collapse in tall buildings.

The analytical procedure consisted of model development, load assignment, code-based lateral load definition, column-removal modelling and response extraction. The floor system was assumed to act through diaphragm action so that local failure could be redistributed through adjacent beams and columns. The damaged model was compared with the intact model to determine response amplification. DCR was evaluated as a ratio of induced demand to permissible or capacity-based reference value for shear, displacement and drift. This method does not replace a detailed nonlinear collapse simulation, but it provides a robust screening tool for identifying zones where strengthening or redundancy improvement is required.

Table 2. Wind pressure and storey force calculation for the G+30 model as per IS 875 (Part 3):2015

Height z (m)	k2	Vz (m/s)	pz (kN/m2)	pd (kN/m2)	Storey wind force (kN)
10	1.0	39.0	0.913	0.591	69.19
15	1.04	40.56	0.987	0.64	74.84
30	1.08	42.12	1.064	0.69	80.7
45	1.11	43.29	1.124	0.729	85.25
60	1.14	44.46	1.186	0.769	89.92
75	1.16	45.24	1.228	0.796	93.1
93	1.18	46.02	1.271	0.823	96.34

V. NUMERICAL MODELLING AND COLUMN-REMOVAL SCENARIO

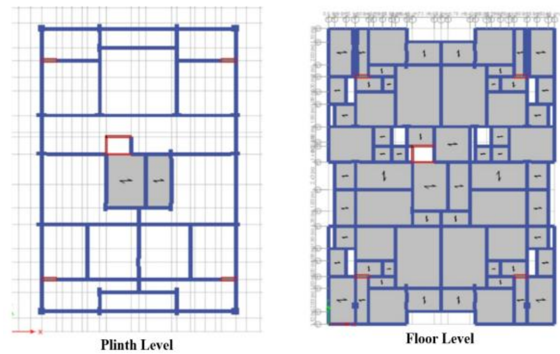

Figure 2. Plan configuration and floor-level column layout considered for alternate load-path assessment.

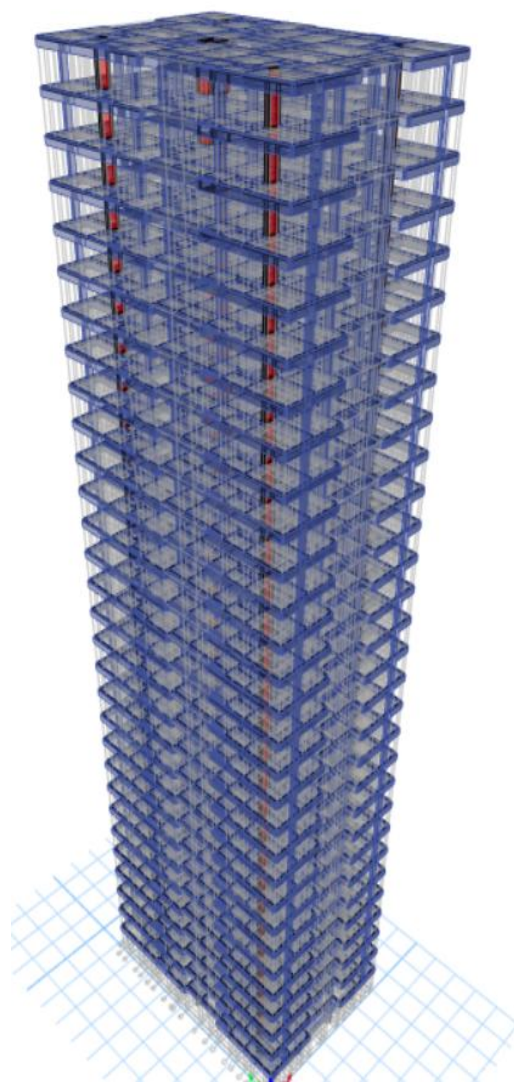

Figure 3. ETABS three-dimensional representation of the G+30 model before critical column removal.

The column removal scenario was selected to represent a localised loss of vertical support. After removing the critical column, the ETABS model was re-analysed under the defined load combinations. The results were extracted at seven representative storey levels to maintain interpretability while preserving the vertical trend of response. The comparison focused on the changes in storey shear, displacement and drift because these parameters collectively indicate redistribution intensity, lateral deformation demand and serviceability acceptability.

VI. RESULTS AND DISCUSSION

Table 3. Response comparison before and after column removal

Storey	Shear Before (kN)	Shear After (kN)	Increase (%)	Disp. Before (mm)	Disp. After (mm)	Drift Before (mm)	Drift After (mm)
0	10000	15600	56	0	0	0	0
5	8900	13884	56	12.0	18.7	3.1	4.84
10	7600	11856	56	28.0	43.7	4.7	7.33
15	6200	9672	56	45.0	70.2	5.5	8.58
20	4700	7332	56	62.0	96.7	5.2	8.11
25	3100	4836	56	78.0	121.7	4.4	6.86
30	1500	2340	56	92.0	143.5	3.2	4.99

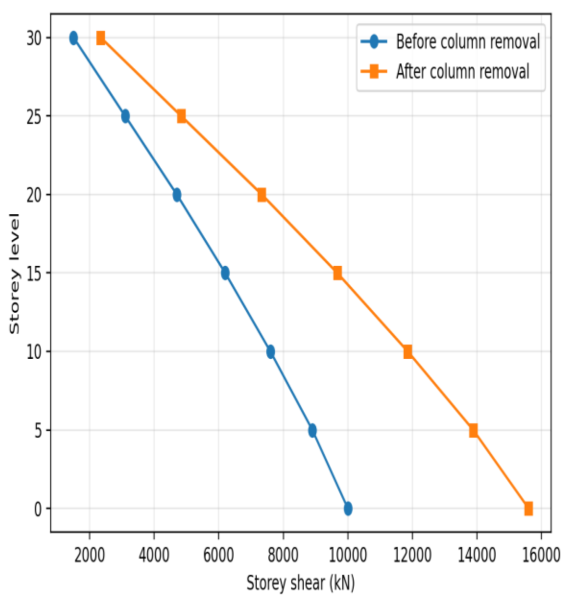

Figure 4. Storey shear comparison before and after column removal.

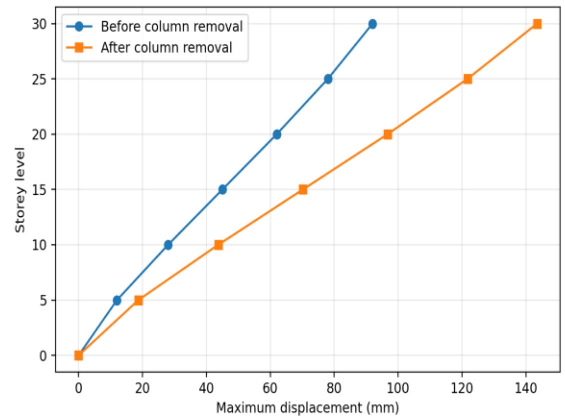

Figure 5. Maximum storey displacement comparison before and after column removal.

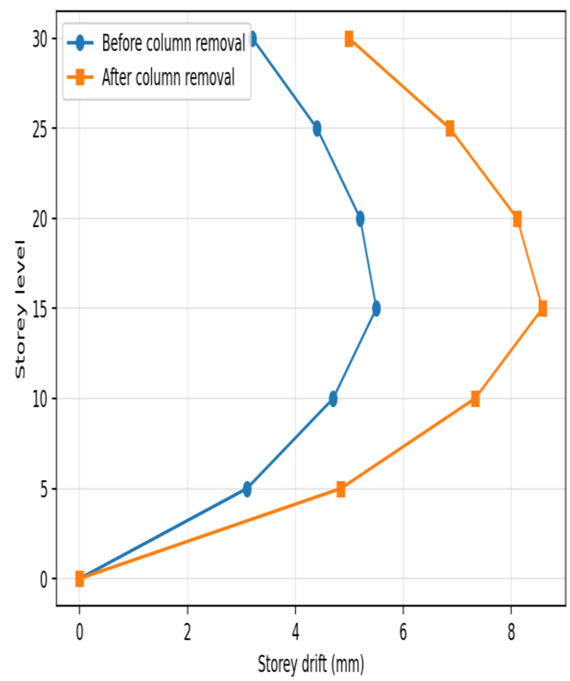

Figure 6. Storey drift comparison before and after column removal.

The results show that column removal substantially increases the internal force demand in the remaining system. Storey shear increased by 56% at all reported levels, indicating that the alternate load path imposed a proportional redistribution demand through the building height. The maximum roof displacement rose from 92.0 mm to 143.5 mm, which corresponds to an increase of approximately 56%. This value remained below the serviceability displacement limit of H/500 = 186 mm, suggesting that global lateral deformation was acceptable for the modelled condition. The maximum drift after column removal occurred around mid-height and reached 8.58 mm, remaining below the 12 mm interstorey drift limit corresponding to 0.004h for a 3 m storey height.

Table 4. DCR comparison for shear, displacement and drift

Storey	Shear DCR Before	Shear DCR After	Disp. DCR Before	Disp. DCR After	Drift DCR Before	Drift DCR After
0	0.62	0.97	0.0	0.0	0.0	0.0
5	0.59	0.92	0.06	0.1	0.26	0.4
10	0.56	0.87	0.15	0.23	0.39	0.61
15	0.52	0.81	0.24	0.38	0.46	0.71
20	0.48	0.75	0.33	0.52	0.43	0.68
25	0.42	0.66	0.42	0.65	0.37	0.57
30	0.34	0.53	0.49	0.77	0.27	0.42

The DCR results provide a more direct interpretation of safety margin. The shear DCR at the base increased from 0.62 to 0.97, indicating that the structure approaches the permissible demand threshold after the column loss. Displacement and drift DCR values were lower than one for all reported storey levels. The most critical displacement DCR was 0.77 at the top storey, whereas the maximum drift DCR was 0.71 at storey 15. These results suggest that the structure retains global serviceability after column removal, but the base and lower-storey shear path requires careful strengthening to avoid near-capacity behaviour.

VII. COMPARATIVE ANALYSIS AND PRACTICAL IMPLICATIONS

Compared with the intact condition, the damaged model demonstrates a consistent amplification pattern. The response is governed not by excessive displacement or drift but by shear reserve reduction. This observation has direct implications for tall building design: progressive collapse resistance cannot be assessed only through lateral drift checks. Member-level shear and connection detailing must be verified because a structure may remain globally stable while local members approach their capacity. Practical mitigation measures include increasing lower-storey column and beam sizes, strengthening beam-column joints, providing continuous reinforcement, introducing local bracing or outriggers, and ensuring diaphragm integrity near potential removal zones.

VIII. LIMITATIONS

The analysis is limited to a representative G+30 model and selected column-removal case. Material nonlinearity, connection fracture, reinforcement bond deterioration and dynamic impact effects were not fully captured in the simplified response comparison. Future work should apply nonlinear dynamic APM with explicit reinforcement modelling and multiple removal scenarios including corner, edge and interior columns.

IX. CONCLUSION AND FUTURE SCOPE

This research demonstrates the usefulness of the Alternate Path Method for evaluating progressive collapse resistance of a tall RC building. The column-removal scenario produced a 56% increase in storey shear, displacement and drift response, but the analysed model remained within displacement and drift limits. The critical observation is that the base shear DCR increased to 0.97, showing that the lower-storey force-transfer mechanism becomes nearly critical after vertical support loss.

Future research should extend the work to nonlinear dynamic simulation, probabilistic removal scenarios, performance-based acceptance criteria and retrofit optimisation. Combining ETABS global analysis with detailed ABAQUS member-level modelling would further clarify stress concentration, catenary action and joint behaviour under extreme load redistribution.

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