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Progressive Collapse Assessment of G+7 Residential Building For Safe Dismantling of Old Building with in Buildup Area

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Abstract: *This paper presents an analytical study on the progressive collapse of a G+7 residential building using the Alternate Load Path method as per GSA 2003. Old buildings that are no longer used and have outdated designs may result in sudden structural collapse. Because of urban development, old buildings need to be dismantled safely. In built-up areas, debris may fall outside the boundary during dismantling. Therefore, a safe dismantling procedure is required. A detailed structural model was developed in STAAD.Pro V8i SS5. Six interior ground-floor columns were selected for progressive collapse assessment, based on three criteria: interior position, safe distance from the boundary, and maximum axial load. Each column was removed in turn, and the modified structure was analysed under the GSA 2003 load combination LC 222 = 2 (DL + 0.25LL). The Demand Capacity Ratio (DCR), the ratio of the member force under GSA loading to the force under normal loading, was computed for the surrounding beams. The DCR values ranged from 7.40 to 13.43 across all six cases, exceeding the GSA 2003 limit of 2.0 and indicating progressive collapse. The bending moment and shear force in the surrounding and inner beams increased significantly, whereas the increase in the outer beams was much smaller. The axial force in the surrounding columns also increased. The vertical displacement was much larger than the lateral displacement, which is consistent with the IS 4130:1976 requirement that debris should not fall outside the building. Based on the DCR values, a safe dismantling sequence was proposed in which the column with the lowest DCR, Member 412 (DCR = 7.40), is removed first and Member 375 (DCR = 13.43), the most critical column, is removed last with maximum temporary propping.*

Keywords: Progressive Collapse, Alternate Load Path, GSA 2003, STAAD.Pro V8i, DCR, IS 4130:1976, Safe Dismantling, RCC Building, Bangalore

1. INTRODUCTION

Many old buildings in Indian cities are now being dismantled as part of urban redevelopment. Most were built several decades ago and are no longer safe to use. When these buildings are in built-up areas with other buildings on all sides, dismantling them becomes very challenging. The main problem is that when columns are removed during dismantling, the remaining structure may suddenly collapse in an unexpected way. This type of collapse, where one member failing leads to the failure of other members one by one, is called progressive collapse.

We have all seen news about building collapses in cities. One famous example of progressive collapse is the Ronan Point apartment building in London, which partially collapsed in 1968 when a gas explosion on the 18th floor removed a wall panel and caused floors to fall one by one. Another major example is the Oklahoma City bombing in 1995, where a car bomb removed ground-floor columns of a federal building and caused nine floors to collapse progressively. These incidents show us how dangerous progressive collapse can be and why we need to study it properly before dismantling any building.

To study progressive collapse, the Alternate Load Path method is given by the US General Services Administration in their 2003 guidelines (GSA 2003). In this method to, remove one column at a time from the building model and check whether the remaining structure can carry the loads safely through alternate paths. If the Demand Capacity Ratio (DCR) of the surrounding beams exceeds 2.0, then progressive collapse has occurred.

In India, IS 4130:1976 is the code that gives guidelines for safe dismantling of buildings. This code says that the debris from dismantling should not fall outside the building boundary. This is especially important for buildings in built-up areas where other buildings are very close by. This study uses both GSA 2003 and IS 4130:1976 together to analyse a G+7 RCC building and find the safest way to dismantle it.

The main objective of this study was to identify which ground floor columns of this building are most critical when removed, to confirm whether progressive collapse occurs, to verify that debris will fall within the building footprint, and to prepare a safe column removal sequence for the dismantling.

2. LITERATURE REVIEW

Many researchers have worked on progressive collapse analysis of buildings over the years. Marjanishvili (2004) proposed a four-step method for progressive collapse analysis ranging from simple linear static analysis to complex nonlinear dynamic analysis. He also established the DCR limit of 2.0 for linear static analysis, which was used in this study. Sasani and Sagiroglu (2008) actually removed two columns from a real hotel building in San Diego and measured the response. They found that about 80% of the column load was redistributed through the beams, which confirms the Alternate Load Path mechanism.

Yi et al. (2008) tested small-scale RC frame models and found that when columns were removed, the beams go through three stages: first they bend like normal beams, then they start to yield, and finally they develop tension and act like cables. Ellingwood et al. (2007) prepared guidelines for reducing progressive collapse risk in existing buildings. In India, Rajasankar et al. (2009) from CSIR-SERC Chennai showed that the GSA 2003 method works well for Indian RC buildings designed as per IS 456:2000. Venu et al. (2014) used STAAD.Pro to analyse progressive collapse of Indian RC buildings using GSA 2003 and got similar results.

After reviewing all these papers, it was found that no study so far has connected progressive collapse DCR analysis with IS 4130:1976 dismantling planning. Also, no study has checked whether the building falls straight down (vertical) or sideways using displacement ratios. This study fills these gaps by doing both things for a G+7 residential building in Bangalore.

3. BUILDING DESCRIPTION AND STRUCTURAL MODEL

The building studied is a G+7 reinforced concrete residential building in Bangalore, Karnataka. This building is old and needs to be demolished. It is surrounded by other buildings on all sides, which is very careful about how to dismantle it. The building is in Seismic Zone II as per IS 1893:2002 and is on medium soil (Type II).

The building has an irregular plan shape with a total length of 36.29 m in the X direction and 30.65 m in the Z direction. The total height from plinth level to roof is 26.9 m. The ground floor column height is 3.0 m (from Y=1.5 m to Y=4.5 m), and the typical floor height is 3.2 m. All columns are 450 mm × 450 mm, and all main beams are 475 mm × 300 mm. M25 grade concrete and Fe500 grade steel are used throughout the building.

Table 1 — Details of the G+7 RCC Building

Parameter	Value
Building type	G+7 RCC Residential , Bangalore, Karnataka
Seismic zone	Zone II as per IS 1893:2002
Column size	450 × 450 mm, M25 concrete, Fe500 steel
Main beam size	475 × 300 mm M25 concrete Fe500 steel
Plinth beam size	300 × 230 mm M25 concrete Fe415 steel
Total building height	26.9 m (Plinth to Roof)
GF column height	3.0 m (Y=1.5 m to Y=4.5 m)
Analysis software	STAAD.Pro V8i SS5

built the complete structural model of this building in STAAD.Pro V8i SS5. Dead loads were applied as floor finish (1.0 kN/m^2) and partition wall loads (1.5 kN/m^2) as per IS 875 Part 1. Live load of 2.0 kN/m^2 was applied on all floors and 1.5 kN/m^2 on the roof terrace as per IS 875 Part 2. Wind loads were calculated for Bangalore (basic wind speed = 33 m/s, Terrain Category 3) as per IS 875 Part 3. Seismic loads were calculated as per IS 1893:2002 for Zone II with zone factor Z = 0.10, importance factor I = 1.0 and response reduction factor R = 5.0.

4. METHODOLOGY

4.1 How We Selected the Six Columns

Six ground-floor columns were selected for this building based on three criteria. These criteria come from IS 4130:1976 and IS 456:2000.

Criterion 1: Interior Position (IS 4130:1976):

Selected only interior columns. This is because IS 4130:1976 says debris should not fall outside the building. When an interior column falls, the surrounding structure prevents debris from spreading outside the building boundary.

Criterion 2:

Safe Distance from Boundary (IS 4130:1976 Cl 8.1): Calculated the minimum safe distance as D = H × tan30° = 3.0 × 0.577 = 1.73 m, where H = 3.0 m is the ground floor column height and 30° is the standard angle at which dismantling debris can spread. The minimum bay width of this building is 3.62 m, which is more than 1.73 m, so all interior columns are safe.

Criterion 3:

Maximum Axial Load (IS 456:2000 Cl 39.3): In this, the selected columns carry the highest axial loads (2261 to 3468.7 kN) so in this study the worst-case scenarios for progressive collapse.

Table 2 — Six Selected Ground Floor Columns

Case	Member	X (m)	Z (m)	Axial Load (kN)	No. of Beams	Safe Distance
C01	377	16.47	13.58	2261.0	3	13.58 m
C02	367	12.97	9.14	3189.9	4	9.14 m
C03	412	32.47	26.23	3468.7	4	3.82 m
C04	356	9.46	5.77	3029.0	4	5.77 m
C05	362	32.47	5.77	2965.3	4	3.82 m
C06	375	9.46	13.58	2938.9	3	9.46 m

4.2 How We Carried Out the Analysis

In this study created seven STAAD.Pro model files for this building. The first file is the complete normal building model where load combination LC 101 = 1.5(DL+LL) was applied as per IS 456:2000. This gives us the normal case member forces, which are known as Q_CE values. These Q_CE values become the denominator in our DCR calculation.

For each of the six column removal cases, created a separate STAAD.Pro file where that particular column member was deleted. Then applied the GSA 2003 progressive collapse load combination:

$$\text{LC 222} = 2.0 \times (\text{Dead Load} + 0.25 \times \text{Live Load})$$

The factor 2.0 on dead load is used because when a column suddenly fails, the dynamic effect is about twice the static load. The factor 0.25 on live load represents the reduced occupancy that can be expected at the time of a sudden failure. ran the analysis for each modified model and extracted the member forces under GSA loading, which are called Q_UD values.

The DCR for each member was then calculated as:

$$DCR = Q_UD / Q_CE$$

If DCR is less than 2.0, the member is safe and no progressive collapse occurs. If DCR exceeds 2.0, the member fails and progressive collapse occurs. This is the basic DCR check given in GSA 2003.

5. RESULTS AND DISCUSSION

5.1 Normal Analysis Results

From the normal analysis of this building under LC 101, the baseline member forces were obtained. The outer beam bending moment increases from 53.24 kNm at GF to 90.99 kNm at 6F, which is a normal pattern for multi-story buildings. The inner beam bending moment remains nearly constant between 63.43 kNm and 67.00 kNm from GF to 6F, indicating uniform loading on interior beams. The GF inner column carries the maximum axial load of 2438 kN, which is the accumulated load from all 8 floors above. The lateral displacement of this building was only 0.1254 mm at the roof, well within the permissible limit of 53.8 mm. The story drift under normal loading is a maximum of 0.0058 radians at the roof, which satisfies the IS 1893:2002 limit of 0.004 radians. These results confirm that the STAAD.Pro model is correct.

5.2 DCR Results — Progressive Collapse Check

Table 3 shows the DCR values for the surrounding beams when each of the six ground floor columns was removed. All six cases show DCR values that are much higher than the GSA 2003 limit of 2.0.

Table 3 — DCR Results for All Six Column Removal Cases

Case	Removed Column	Maximum DCR (Surrounding Beams)	GSA 2003 Limit	Status
C01	Member 377	9.83	2.0	Progressive Collapse
C02	Member 367	9.19	2.0	Progressive Collapse
C03	Member 412	7.40	2.0	Progressive Collapse
C04	Member 356	8.01	2.0	Progressive Collapse
C05	Member 362	8.82	2.0	Progressive Collapse
C06	Member 375	13.43	2.0	Progressive Collapse

From Table 3, it shows that when Member 367 is removed (Case C02), the DCR is 9.19 which means the surrounding beams are stressed 9.19 times more than they were designed for. This is why they fail and progressive collapse occurs. The most dangerous case is C06, where Member 375 is removed, and DCR reaches 13.43. Member 375 has only 3 beams connected to it (instead of 4 like the other interior columns) because it is located at the corner of the building plan where one side is open. With fewer beams to redistribute the load, each beam gets a higher share and the DCR becomes very high. The least critical case is C03 with DCR = 7.40 but even this exceeds the safe limit of 2.0 by 3.7 times.

5.3 Force Comparison Results

To understand how the loads get redistributed when a column is removed, it was compared the member forces under normal loading and GSA loading. Table 4 shows the comparison at ground floor level for Case C02, which was the case where the column with the highest axial load (Member 367, 3189.9 kN) is removed.

Table 4 — Force Comparison at Ground Floor Level — Case C02 (Member 367 Removed)

Member	Normal LC101	GSA LC222	% Change	What This Means
Inner Beam BM (kNm)	63.43	250.92	+295.8%	Beams carry 3.96x more load
Inner Beam SF (kN)	83.00	187.82	+126.3%	Shear nearly doubles
Outer Column Axial (kN)	1742.00	3167.67	+81.8%	Outer columns overloaded
Inner Column Axial (kN)	2438.00	3000	+22-24%	Load redistributes evenly
Column Stack Axial (kN)	1939.40	343.13	-82.3%	Stack loses load ALP works
Foundation FY (kN)	2240.99	40.80	-98.2%	Almost no load below removed column

From Table 4, it was observed that the inner beam bending moment increases by 295.8% which means the beam was now carrying nearly 4 times more load than it was designed for. This is why the beam fails. The column stack above the removed column loses 82.3% of its load, which shows us that the load is being diverted to the adjacent beams through the Alternate Load Path mechanism. The foundation below the removed column shows 98.2% reduction in reaction force which confirms that almost all the load from that column has been redistributed to other parts of the building.

5.4 Collapse Direction Check for IS 4130:1976

IS 4130:1976says that debris from dismantling should not fall outside the building boundary. To check this,the displacements of the building nodes under GSA loading. If the vertical displacement Dy is much larger than the lateral displacements Dx and Dz, it means the building is falling straight down and not sideways. Table 5 shows our displacement results.

Table 5 — Displacement Analysis Results Collapse Direction Check

Case	GSA Dy (cm)	GSA Dx (cm)	Dy/Dx Ratio	Collapse Direction	IS 4130:1976 Status
C01(377)	1.8120	0.00073	2479x	Vertical	SATISFIED
C02(367)	1.5464	0.00025	6186x	Vertical	SATISFIED
C03(412)	3.1805	0.00004	79513x	Vertical	SATISFIED
C04(356)	2.5142	0.00003	83807x	Vertical	SATISFIED
C05(362)	2.6501	0.00038	6974x	Vertical	SATISFIED
C06(375)	2.5445	0.00050	5089x	Vertical	SATISFIED

From Table 5, the smallest Dy/Dx ratio we got is 2479 (for Case C01), which means the vertical displacement is 2479 times larger than the lateral displacement. This clearly shows that the building falls straight down and not sideways when any of these six columns is removed. The reason for this is that the GSA load combination LC 222 = 2.(0DL + 0.25LL)has no horizontal force component because it is purely gravity loading. Since gravity acts downward, the collapse is also downward. All six cases satisfy IS 4130:1976, which means this building can be safely dismantled in the built-up area without risk to neighboring buildings.

5.5 Story Drift Results

Story drift is the relative movement between two adjacent floors divided by the floor height. Under normal loading, the maximum story drift of this building is 0.0058 radians which is within the IS 1893:2002 limit of 0.004 radians. But under GSA loading after column removal, the story drift jumps to a maximum of 0.0234 radians at the 3rd floor level. This is 5.85 times the permissible limit. The fact that drift is maximum at 3F and then reduces towards the roof shows us that the collapse starts at the ground floor (where the column was removed) and then moves upward floor by floor. This is exactly what progressive collapse means because it progresses from one floor to the next.

6. SAFE DISMANTLING SEQUENCE

Based on the DCR values obtained, prepare a safe sequence for removing the building's ground-floor columns during dismantling. The idea is simple: remove the column with the lowest DCR (lowest collapse risk) first, while the building is still fully intact, and remove the column with the highest DCR (highest collapse risk) last, after maximum temporary supports are in place.

Table 6 — Safe Dismantling Sequence Based on DCR Values

Removal Order	Column Member	DCR Value	Temporary Propping	Why This Order
Remove 1st	Member 412	7.40	Minimum shoring	Lowest risk building fully intact at this stage
Remove 2nd	Member 356	8.01	Light shoring	Second lowest DCR
Remove 3rd	Member 362	8.82	Moderate shoring	Moderate risk; more propping needed now
Remove 4th	Member 367	9.19	Medium shoring	Higher risk; building less intact now
Remove 5th	Member 377	9.83	Heavy shoring	High risk; substantial propping required
Remove 6th	Member 375	13.43	Maximum shoring	Highest risk remove last with full propping

All six columns in sequence satisfy the three IS 4130:1976 requirements which was all interior columns, they were all at more than 1.73 m from the building boundary (minimum actual distance is 3.82 m), and they were all show vertical collapse direction (Dy/Dx ratio minimum 2479). So all six can be safely removed as per IS 4130:1976.

The key point of this sequence is that start with the column that is least dangerous when removed (Member 412 with DCR = 7.40) and end with the most dangerous one (Member 375 with DCR = 13.43). At each step, the amount of temporary shoring is increased to compensate for the increasing collapse risk. This ensures that at no point during the dismantling does an uncontrolled progressive collapse occur.

7. CONCLUSIONS

From the progressive collapse analysis carried out on the G+7 RCC building in Bangalore, it was arrived at the following conclusions:

1. When any of the six selected interior ground floor columns of this building is removed, progressive collapse occurs. The DCR values ranged from 7.40 to 13.43 in all six cases which is much higher than the GSA 2003 limit of 2.0. This shows that this old building has no progressive collapse resistance.

2. Case C06 (Member 375 removed) gave the highest DCR of 13.43 and is the most critical case. This column has only 3 beams connected to it instead of 4, because of the irregular plan of the building. This is why it is more vulnerable. Case C03 (Member 412 removed) gave the lowest DCR of 7.40 and is the least critical case.

3. The Alternate Load Path mechanism worked in this building it was observe that load was being redistributed from the removed column to the adjacent beams and columns. The column stack above the removed column lost 79 to 89 percent of its load. The foundation below the removed column showed 98 percent reduction in reaction force. But even though ALP worked, the beams could not carry the redistributed load safely because their DCR was too high (7 to 13 times the limit).

4. The collapse direction of this building is vertical in all six cases. The Dy/Dx ratios ranged from 2479 to 83807 which means the building moves thousands of times more in the vertical direction than in the horizontal direction. This confirms that debris will fall within the building footprint and not outside, satisfying IS 4130:1976

5. Prepared a safe dismantling sequence for this building based on DCR values: remove Member 412 (DCR = 7.40) first with minimum shoring, and remove Member 375 (DCR = 13.43) last with maximum temporary propping. This sequence ensures controlled and safe demolition of this building in the built-up area without risk to adjacent structures or workers.

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