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A Review Paper on Progressive Collapse Analysis of Multistorey RCC Building

Mr. Khan Zaiyyan Noorullah[1], Mrs. Ansari Fatima Uz Zehra[2]
[1]M-Tech Student, [2]Assistant Professor, Department of Civil Engineering, Deogiri Institute of Engineering and Management Studies, Aurangabad

Abstract: The spread of an initial local failure from element to element resulting eventually in the collapse of an entire structure or a disproportionately large part of it, is called as progressive collapse. This review paper provides a comprehensive overview of the progressive collapse of multistorey Reinforced Concrete (RC) buildings, focusing on the causes, analysis methods, and mitigation strategies. The paper synthesizes current research and design guidelines from various codes, highlighting key factors influencing collapse resistance and the role of modern analytical techniques which will be helpful in the assessment of progressive collapse. It also discusses the critical aspects of load redistribution, structural redundancy, and ductility in preventing the severe events.
Keywords: Progressive Collapse, Multistorey Reinforced Concrete (RC) buildings, Alternative Load Path, Linear Dynamic Analysis, GSA Guidelines, Demand capacity ratio.

I. INTRODUCTION

Progressive collapse came to the attention of engineers and researchers after the collapse of the entire corner of the 22-story apartment building in East London as a result of a small gas explosion on its 18th floor. This accident showed that special considerations are required for the design of structures to mitigate the possibility of progressive collapse. When a primary load-carrying structural element fails, a building experiences progressive collapse, which leads to the failure of adjoining structural elements, which in turn leads to even further structural failures. Progressive collapse is the term used by ASCE 7-05 to describe the "spread of a initial local failure from element to element, eventually causing the collapse of an entire structure or a disproportionately large portion of it".

There is a certain degree of variability in the susceptibility of structures to progressive collapse that is dependent on many factors. Progressive collapse can be triggered by various events, both natural and man-made, that cause the initial failure of a primary structural component.

Common causes include accidental loads (such as vehicular impact, gas explosion, fire etc.), natural hazards (like earthquake, strong winds), design and construction deficiencies. Design or construction errors and extreme loading conditions are the most notable of the many trigger events that were considered. All structures are expected to withstand many kinds of loads without deforming excessively.

In addition to this, invalid design assumptions, inaccurate data, design and drawings are among the other causes of design errors. Different investigations and studies have been conducted over the years to further examine its nature and various national and international guidelines, such as those from the General Services Administration (GSA) and the American Society of Civil Engineers (ASCE), provide methodologies for progressive collapse analysis and design.

A. Objectives

Following are the basic objectives of review paper.

- To study the progressive collapse potential of Multi-storey building.
- To determine the collapse pattern in the structure due to different failure points.
- To determine the importance of alternate load paths and their role in such failure conditions.
- To study the variation in axial forces, bending moments and shear forces in the neighbouring structural members due to removal of element as per GSA guidelines.
- To understand the international standards for structural safety and evaluate the Demand capacity ratio (DCR).

II. COMMON CAUSES OF PROGRESSIVE COLLAPSE

A. *Design Errors and Construction Defect*

- Inadequate structural redundancy
- Poor detailing or connections
- Improper load assumptions

B. *Material Failures and Deterioration*

- Corrosion or degradation
- Substandard materials
- Fatigue and creep

C. *Extreme Events and Abnormal Load*

- Explosions or impacts
- Earthquakes and wind loads
- Fire

III. METHODOLOGY

A. *Analysis Methods of Progressive Collapse*

1) Linear Static Analysis: The LSA method, often specified in design guidelines like those from the General Services Administration (GSA), is a simplified approach. It involves notionally removing a critical column and applying a magnified gravity load to the remaining structure. This method uses a Dynamic Increase Factor (DIF), typically a value of 2.0, to account for the dynamic effects of the sudden column removal. The demand-capacity ratio (DCR) for the remaining members is then calculated. A DCR value greater than the specified limit (e.g., 2.0 for typical configurations) indicates a potential for progressive collapse.
2) Non-Linear Static Analysis: This method provides a more accurate representation of the structure's behaviour by considering material and geometric nonlinearities. The analysis involves applying gravity loads to the structure while a key element is removed. This method can capture the post-elastic behaviour of the structure, including the development of catenary action in beams and slabs, which is a crucial resistance mechanism.
3) Linear Dynamic Method: The linear dynamic method for progressive collapse analysis is a computational approach used to evaluate the structural response following the sudden removal or failure of a key structural element, such as a column or beam. This method treats the structure as a linear elastic system, meaning it assumes that the materials behave elastically and that the relationship between stresses and strains remains proportional throughout the event. The core of this approach involves modelling the structure using finite element methods and solving the equations of motion dynamically to capture the time-dependent response caused by abrupt changes in load paths. When a critical element is removed the structure undergoes a rapid redistribution of forces. This helps to identify whether the initial local failure triggers a chain reaction that could lead to progressive collapse or if the structure can withstand the damage by redistributing loads to alternate paths. Linear dynamic method is widely used in early-stage design assessments and safety evaluations because of its relative computational efficiency and ability to provide insight into the structural vulnerability under sudden damage conditions.
4) Non-Linear Dynamic Method: It is the most comprehensive and accurate method for assessing progressive collapse. It simulates the time-dependent behaviour of the structure following a sudden column removal. This analysis accounts for inertial forces and the propagation of damage, providing a realistic picture of the collapse sequence. However, Non-linear dynamic analysis is computationally intensive and requires advanced software and expertise.

B. *GSA Guidelines*

The GSA guideline provides a detailed methodology and performance criteria to assess the vulnerability of new and existing buildings to progressive collapse. For the analysis of progressive collapse, the following column removal cases are given in guidelines.

1) External Columns: Remove external columns near the middle of the short side, near the middle of the long side, at the corner of the building, and adjacent to the corner of the building.

2) Internal Columns: For structures with underground parking or areas of uncontrolled public access, remove internal columns near the middle of the short side, near the middle of the long side.

Also remove columns at critical column locations, as determined by engineering judgment in accordance with the standard of practice. At a minimum, the critical locations shall include but not be limited to the following conditions, where:

- The plan geometry of the structure changes significantly, such as abrupt decrease in bay size or re-entrant corners
- The structure has any vertical load discontinuity (i.e. transfer conditions)
- Adjacent columns are lightly loaded
- Adjacent bays have different tributary sizes
- Members frame in at different orientations or elevations. If any other column is within a horizontal distance of 30% of the largest dimension of the associated bay from the column removal location, it must be removed simultaneously as per GSA guidelines.

C. Demand Capacity Ratio

In progressive collapse analysis, the Demand-Capacity Ratio (DCR) is a critical metric used to assess whether structural elements can withstand redistributed loads after the sudden removal of a key component. The performance of structure is evaluated by demand to capacity ratios (DCR), which should not exceed 2 for regular structures and 1.5 for irregular structures or else they are considered as severely damaged or failed. GSA has defined DCR as below.

$$DCR = Demand / Capacity$$

Where, Demand equals the moment demand calculated using bending moment diagram in linear static analysis. Capacity equals the expected ultimate, unfactored capacity of the component.

IV. REVIEW OF KEY FINDING

1) Column Location: Research consistently shows that the location of the failed column significantly impacts progressive collapse vulnerability. The removal of a corner or interior column is often more critical than the removal of a column on the building's perimeter.
2) Structural Configuration: The geometry and configuration of the building play a crucial role. Symmetrical and regular structures tend to be more resilient than irregular or asymmetric buildings (e.g., L-shaped or C-shaped plans) due to better load redistribution capabilities.
3) •Flat Slab Systems: Flat slab-column structures are particularly susceptible to punching shear failure, which can initiate a progressive collapse. The absence of beams reduces the inherent redundancy and necessitates specific design considerations to mitigate this risk.

V. FUTURE RESEARCH & STUDY

Future research should focus on developing more efficient and accurate numerical models, a better understanding of the interaction between various resistance mechanisms, and the development of performance-based design guidelines that are more accessible and practical for everyday design applications.

For the progressive collapse research we have selected multi-storey structure which is Residential building which has Ground floor + 9 structure. Modeling of structure is done in ETABS. The study explores various modeling approaches, including linear static and linear dynamic analysis., under different column removal scenarios as prescribed by the General Services Administration (GSA) guidelines. The analysis will be carried out using a linear dynamic method, i.e. response spectrum method, and various parameters such as axial load, lateral displacement of columns, storey drift, storey stiffness, and demand capacity ratio will be calculated.

Plan size – 18.60 x 14.30 m
Concrete grade – M30
Steel grade – Fe550

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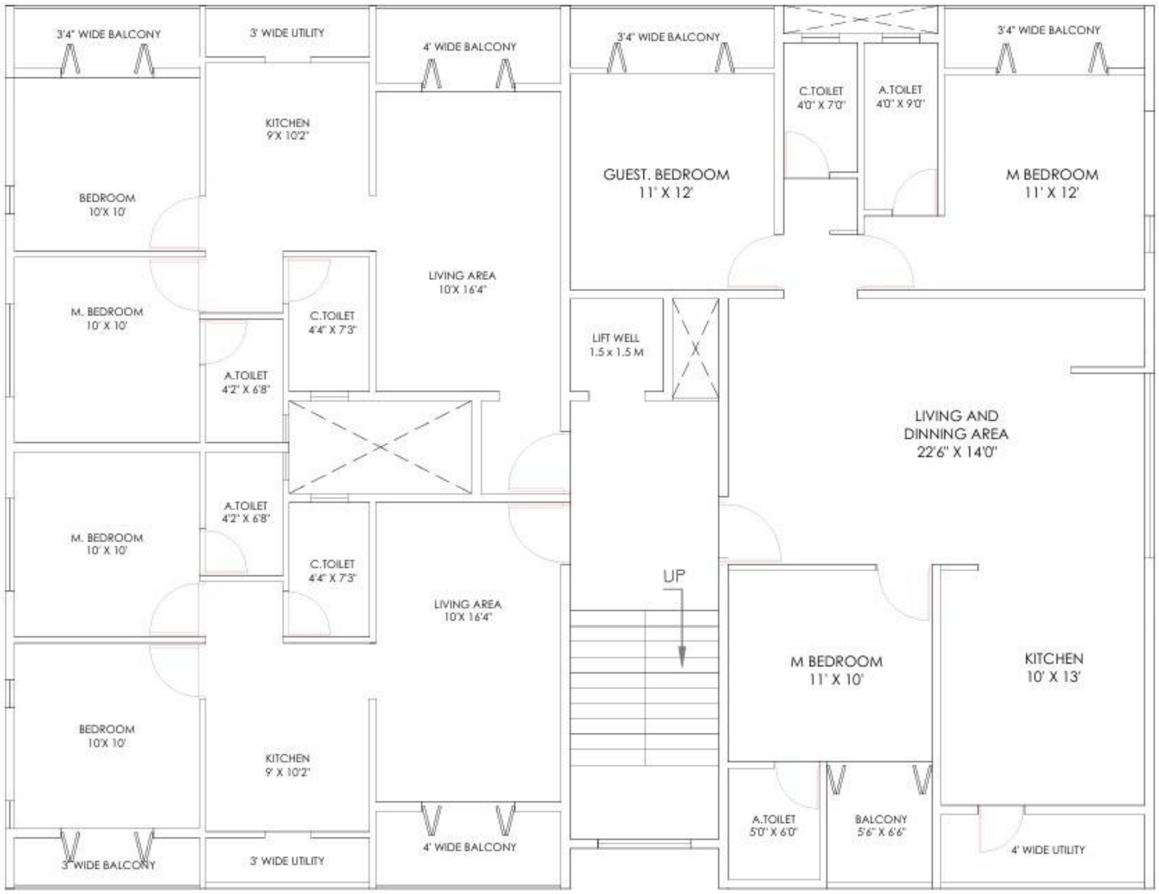

Fig. Architectural plan for future study

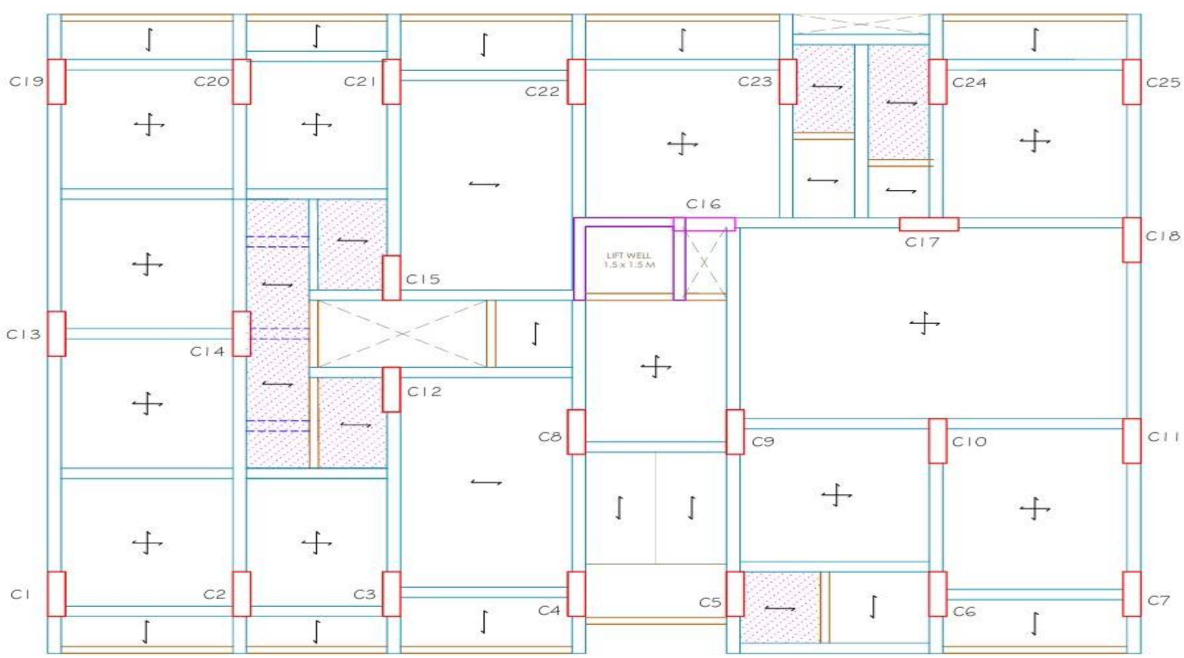

Fig. Structural plan for future study

Following values will be considered in our model.

Basic wind speed	: 39 m/s
Seismic Zone	: Zone III
Seismic Zone factor	: 0.16
Importance factor (I)	: 1.20
Response reduction factor (R)	: 5.00
Soil Type	: Type II (medium soil)

VI. CONCLUSION

The literature emphasizes that factors such as load redistribution mechanisms, redundancy, continuity, and ductility significantly influence a building's response to progressive collapse. Additionally, design strategies such as increasing the robustness of critical members, implementing alternate load paths, and adopting performance-based design criteria have proven effective in enhancing structural resilience. While available software packages offers powerful capabilities for simulating progressive collapse, it is essential to complement numerical results with experimental data and to consider limitations such as simplified assumptions and idealized boundary conditions. The use of linear static analysis provides a quick assessment the industry is moving towards more sophisticated nonlinear dynamic analysis to capture the true behaviour of a structure. Future research should also focus on integrating more realistic failure models and exploring hybrid approaches that combine software with other tools or physical testing to improve predictive accuracy. Continued research is essential to refine design codes and develop innovative solutions to ensure that modern buildings can withstand localized failures without disproportionate collapse.

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