A REVIEW ON PROGRESSIVE COLLAPSE OF RC BUILDING FRAMES: ONE DIRECTION FAILURE

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Abstract - *Progressive collapse is a critical failure phenomenon where the localized failure of one structural component triggers a chain reaction, leading to partial or complete collapse of the structure. This study focuses on progressive collapse propagation in one direction, examining factors such as structural configuration, load redistribution, and failure mechanisms. Structures with weak load paths, insufficient redundancy, or irregular configurations are particularly vulnerable to such collapses, especially under dynamic loads like seismic events. Analytical and numerical modeling methods have been used to simulate these failures and identify critical structural elements. Design strategies, including enhanced robustness and improved load path continuity, are essential to mitigate progressive collapse risks. Understanding the directional propagation of collapse is crucial for developing resilient structures and improving current building codes.*

Key Words: Progressive collapse, one-direction collapse, load redistribution, structural failure, seismic vulnerability, collapse propagation, structural robustness, redundancy, failure mechanism, building codes.

1.INTRODUCTION

The collapse of reinforced concrete (RC) frame buildings due to failure in one direction has raised serious concerns, especially in areas susceptible to seismic activity or strong lateral forces like wind. Several disastrous incidents over the years have exposed the vulnerability of these structures to progressive collapse, particularly when lateral resistance in one direction is lacking. Many of these collapses have occurred due to design deficiencies, improper construction practices, or insufficient understanding of seismic forces and their impact on structures These failures often stem from design flaws, poor construction practices, or a limited understanding of seismic forces and their effects on buildings.

Progressive collapse refers to a scenario where local failure of one or more such a failure occurs in one direction (either along the X or Y axis), the collapse can propagate throughout the structure due to the interconnected nature of the structural system. A collapse of a reinforced concrete (RC) frame building in one direction refers to the structural failure where the building's load-bearing capacity in one specific lateral direction (often due to seismic forces, wind loads, or other horizontal pressures) is insufficient. This leads to progressive collapse, where the failure of key elements such as columns, beams, or joints in a particular direction causes the structure to tilt, lean, or fall in that direction.

Fig.1: Collapsed Building Due to Earthquake

1.1 THEORETICAL BACKGROUND

Structural failures during an earthquake often originate at points of weakness within a building system. These weaknesses are caused by discontinuities in mass, stiffness, and geometry, which can lead to progressive deterioration and ultimately result in structural collapse. Buildings exhibiting these discontinuities are classified as irregular structures, and they constitute a substantial portion of modern urban infrastructure. Among various types of irregularities, vertical irregularities are a major cause of structural failure during earthquakes. For instance, structures with soft stories have been notably prone to collapse. This highlights the critical importance of understanding the effects of vertical irregularities on the seismic performance of buildings.

The dynamic characteristics of buildings with vertically irregular configurations differ significantly from those of regular buildings. According to IS 1893:2002, a building is considered vertically irregular when the horizontal strength of the lateral force-resisting system in any story exceeds 150% of that in the adjacent story. When such buildings are constructed in high seismic zones, the analysis and design process become increasingly complex. Therefore, it is essential for structural engineers to have a thorough understanding of the seismic response of irregular structures to ensure their safe and efficient design.

1.2 Progressive Collapse in One Direction

Progressive collapse in one direction typically starts with a localized failure, which can be triggered by several factors, including:

- Excessive lateral loads (seismic or wind loads).
- Foundation failure or differential settlement.
- Structural deficiencies, such as poor design or construction practices.
- Material failure or degradation over time.

Several failure modes can initiate progressive collapse in an RC frame building, especially in one direction:

- **Beam Failure**: Beams transfer loads between columns and walls. If a beam fails due to excessive lateral forces or due to improper reinforcement, the entire beam-column joint may fail, leading to a progressive collapse.

- **Connection Failure**: The beam-column connections in RC frames are essential for the stability of the building under lateral loads. Inadequate reinforcement, poor detailing, or construction errors can weaken these connections, allowing the structure to fail in one direction when subjected to lateral loads.

- **Column Failure**: Columns are critical in transferring both vertical and lateral loads. If a column in the weaker direction fails, either due to seismic forces or a weak story, the loads it carries are redistributed to adjacent columns. These columns may not be capable of handling the additional loads, causing them to fail and initiating a progressive collapse.

The collapse of RC frame buildings in one direction can be initiated by a variety of factors that reduce the lateral load-bearing capacity in that direction:

- **Seismic Activity**: Earthquakes generate dynamic lateral forces that act in multiple directions. If a building is not properly designed for seismic loads, the structure may collapse in one direction, especially if the seismic forces exceed the design strength of the elements in that direction.

- **Foundation Movement**: The building may move differently as a result of uneven settlement, liquefied soil, or foundation failure. Stress concentrations occur when a building's settlement is greater on one side, particularly in the lateral load-resisting components. Local failure and progressive collapse are two possible outcomes of this.

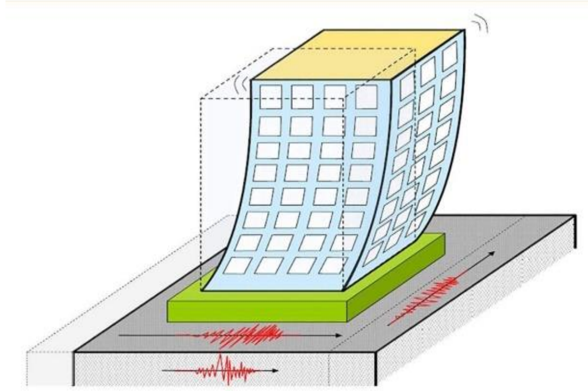

Fig. 2. Progressive Collapse effect

2. LITERATURE REVIEW

Pavel Korenkov et al. (2024) examined the inclusion of elastic-plastic behaviors in structural joint elements. The two types of connections between crossbars and columns that were investigated in their study were a fully rigid connection and a flexible one that included nonlinear compliance in areas like "bending moment-angle of rotation," "transverse force-deformation," and "longitudinal force-deformation." Numerical investigation revealed that the internal forces in reinforced concrete systems are greatly impacted by the nonlinear properties of the materials as well as geometric nonlinearity brought on by joint flexibility, with fluctuations of up to 30%. The system's enhanced adaptability is linked to these distinctions, underscoring the need for more experimental studies on various kinds of structural linkages.

Vitaly I. Kolchunov et al. (2024) developed a model for analyzing shear deformations and crack formation in the intermediate contact zones between precast and monolithic segments of reinforced concrete frame elements. The model accounts for both shear deformations and cracks induced by axial tension or bending. The validation involved comparing the computational results with experimental data obtained from scaled tests on precast frame systems featuring layered beams.. Key factors affecting stiffness and bearing capacity in the intermediate contact zone were studied, along with criteria for shear formation and changes in stiffness and dissipative properties under static-dynamic loading conditions.

Qiao Ling Fu et al. (2023) employed DIANA software to conduct numerical simulations in order to investigate the progressive collapse behavior of reinforced concrete frameworks with many stories.. The analysis focused on load resistance, failure modes, and force redistribution. The research revealed contrasting behaviors between single-story and multistory frames. Single-story frames initially exhibited compressive arch action, transitioning to catenary action under large deformations. For multistory frames, only the first-story beams displayed both mechanisms, while upper-story beams experienced limited axial compression. The proposed method was validated by comparing numerical results, demonstrating its effectiveness in assessing progressive collapse resistance.

Dong Chang et al. (2023) investigated the structures' resistance to progressive collapse in the event of middle-column failure. Infilled walls were modeled using an equivalent three-strut diagonal bracing approach, while prestressed tendons were simulated with node coupling techniques. A pushdown analysis revealed that infilled walls significantly enhance the anti-collapse capacity of IW-PC frames. These walls accelerate peak load attainment and facilitate early transformations of axial forces in beams and tendons, enabling a smoother transition to catenary action, thereby improving overall load-bearing capacity.

Gaurav Verma et al. (2023) analyzed the failure of a reinforced concrete tribune structure to propose appropriate repair solutions. The study employed visual inspections, Hammer Test evaluations, and computational modeling using Staad Pro v8i. Findings indicated that the collapse occurred in beams and floors, necessitating demolition, while columns required minor repairs. The Hammer Test highlighted concrete quality issues at the collapse site, and modeling confirmed inadequate beam reinforcement and weak scaffolding during concrete hardening. Multiple factors, including poor design and construction practices, were identified as causes of the failure.

Said Elkholy et al. (2022) examined how floor system layouts affected the subassemblages of reinforced concrete (RC) frames' ability to withstand progressive collapse and dissipate energy. Using fiber element modeling, the study examined the influence of beam dimensions and reinforcement details across various span lengths. Results showed that slab presence enhances energy dissipation by approximately 28%, and beam size significantly impacts collapse resistance and failure patterns.

Saif Uddin et al. (2022) examined the progressive collapse potential of a G+10 RCC building in Zone III using nonlinear dynamic analysis. Scenarios involving the removal of corner, edge, and interior ground-floor columns were analyzed. To mitigate collapse, V-bracing was integrated into the design. Nonlinear time history analysis conducted via ETABS 2019 showed that interior column removal posed the highest risk to structural stability. Incorporating bracing improved performance by maintaining the demand-to-capacity ratio below critical levels.

Pawan Kumar et al. (2021) examined how catastrophic events like explosions or impacts cause RC constructions to gradually collapse. The study emphasized the need for robust designs, referencing historical collapses like the Ronan Point disaster and the Oklahoma City bombing. Numerical and experimental investigations revealed that infill walls significantly improve collapse resistance compared to bare RC frames.

Anjali G. Dhole et al. (2021) evaluated the progressive collapse risk of a 15-story concrete-framed building under different column removal scenarios using the alternate load path method. Linear static and dynamic analyses in ETABS 2019 revealed demand-to-capacity ratios exceeding allowable limits in all cases, indicating high collapse risk. Mitigation strategies, such as floor-level bracing and increasing beam sizes, were assessed for effectiveness.

Bhavik R. Patel et al. (2017) studied soil-structure interaction (SSI) effects on progressive collapse in RC frames. Using the Winkler approach and SAP2000 software, they analyzed a 15-story building under column failure scenarios. Results highlighted that SSI influences load transfer mechanisms and foundation reactions, making nonlinear static analysis a suitable method for collapse assessment.

Zahrai et al. (2014) compared four analytical approaches for evaluating progressive collapse in intermediate RC frame buildings: linear static, nonlinear static, linear dynamic, and nonlinear dynamic methods. Dynamic procedures were found to provide the most accurate results for determining collapse potential under various column removal scenarios, as outlined by GSA guidelines.

A.R. Rahai et al. (2012) examined progressive collapse in RC structures due to both instantaneous and gradual column removal. Gradual removal, modeled as strength degradation from fire, revealed different redistribution patterns of forces and plastic deformation compared to instantaneous removal scenarios.

3. SUMMARY OF LITERATURE REVIEW

This literature review focuses on the understanding of progressive collapse in one direction, considering factors such as structural design, load distribution, and failure mechanisms Progressive collapse refers to the failure of a structural system that initiates at a localized point of failure and spreads to other parts of the structure, leading to a larger portion or the entire structure collapsing. The phenomenon has been a significant concern in structural engineering, especially in the context of seismic events, accidental loads, or design defects. The findings are as follows:

1. Analyzing the collapse of a high-rise RC building frame structure.

2. Analyzing various load scenarios on the collapse of RC building frame structures.
3. Study of progressive collapse in buildings using software.
4. Numerical study of building frame progressive collapse due to column removal.
5. Failure of the building frame due to element connections.
6. Building collapse due to earthquake or seismic action.
7. Progressive collapse using a non-linear dynamic approach.
8. Considering actual soil conditions, the progressive collapse of reinforced concrete frames is analysed.
9. Building progressive collapse modelling using direct element removal.
10. Analysis of progressive collapse under guidelines.

4. GAPS IN LITERATURE REVIEW

1. Design Recommendations: The direction of Building at the time of collapse can be fix during earthquake

2. Structural Components: The interaction between different structural components (e.g., beams, columns, slabs) during collapse and how these interactions vary under different types of loads (e.g. earthquake, seismic, blast, fire).

3. Loading Scenarios: Consider a variety of loading scenarios, including different types of loads (static, dynamic, seismic) and their combinations. This will provide a more comprehensive understanding of the collapse mechanisms.

4. Column Scenarios: Expand the analysis to include different column removal scenarios, such as corner columns, edge columns, and interior columns. Each scenario can significantly affect the structure's response.

5. Progressive Collapse Mechanisms: Provide a detailed analysis of different progressive collapse mechanisms, such as catenary action, compressive arch action, and Vierendeel action, and how they contribute to the overall structural response.

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