Progressive Collapse of RC Frame Structures with Effect of Soil Structure Interaction Using Software -A Review

Chandak Narayan[1], Mohammad Israr[2]

[1] Post-Doctoral Fellow, Lincoln University College, Petaling Jaya, SDE, Malaysia. Professor, Department of Civil Engineering, SVKMs Institute of Technology, Dhule, India.
Email: narayanch1979@gmail.com

[2] Supervisor, Maryam Abacha American University of Nigeria, Hotoro GRA, Kano State, Federal Republic of Nigeria.
Email: president@maaun.edu.ng

Abstract

The phenomenon of progressive collapse in structural engineering refers to a failure mechanism where a localized failure precipitates a chain reaction, ultimately leading to the total collapse of a building. Literature emphasizes the criticality of understanding load redistribution mechanisms and structural robustness, particularly in multi-storey reinforced concrete (RC) buildings. A review is presented here to understand the need of considering various factors responsible for failure of building due to accidental loads. Study signifies that the removal of exterior corner columns poses significant risks due to increased axial forces, bending moment and base shear underscoring the need for robust design strategies. The study also suggests of considering soil structure interaction, to understand its role in progressive failure.

Keywords: Progressive collapse; RC frame; Soil structure interaction; SAP2000.

Introduction

Progressive collapse of a reinforced concrete (RC) building is a catastrophic process in which a localized failure-caused by events such as explosions, impacts, or earthquakes-triggers a chain reaction that can lead to partial or total structural collapse. This occurs when remaining members cannot adequately redistribute the loads previously carried by the damaged components. Traditional design approaches mainly focused on the superstructure's ability to bridge over lost elements. However, modern research recognizes that structural stability is strongly influenced by the supporting ground.

Soil-structure interaction (SSI) plays a crucial but often neglected role in progressive collapse resistance. Conventional analysis typically assumes fixed supports, overlooking the fact that soil behaves as a flexible medium. Following the loss of a key column, load redistribution generates significant stress in the foundation. In soft or poorly consolidated soils, this may cause differential settlement or deformation. While soil flexibility can sometimes dissipate energy through damping, it can also intensify collapse by increasing joint rotations and column displacements. Therefore, incorporating soil stiffness and damping characteristics is essential for realistic assessment and resilient design. This study emphasizes the influence of SSI on RC building performance, an area that remains relatively underexplored.

Literature Review

Mirzahosseini et al., 2022 found that beam-column joints are critical components of reinforced concrete (RC) constructions, affecting their performance under varying loads. Adding HPFRCCs in beam-column joints greatly increased the robustness of concrete moment-resisting frames, as evidenced by estimated robustness indices and plastic rotation-based damage distribution analysis.

Lan et al., 2023 investigated that the fire is an unintentional load that can cause structures to collapse gradually, but the behaviour of fire-exposed reinforced concrete (RC) frames in preventing such collapse is not well understood. A computational analysis was carried out utilizing a thermal-mechanical coupling approach to assess the impacts of fire on the failure mode, load capacity, and resistance mechanisms of RC frames. **Tsai and Lin 2008** investigated the progressive collapse resistance and inelastic response of RC building subjected to column failure under earthquake. **Tavakoli and Alashti 2012** evaluated the progressive collapse of multi-storey moment resting steel frame under lateral load using codes. 3-D and 2-D pushover analysis is conducted for 15 story building with 4 and 6 bays by applying alternate path load. **Ferraioli et al. 2024** described the progressive collapse analysis and retrofit of a steel reinforced concrete hospital building. Two-step pushdown procedure is used to evaluate dynamic amplification factor (DIF). They inferred that DIF=2 and inversely proportional relationship between DIF and vertical deflection proved to be ineffective due to the catenary effect. **Buitrago et al. 2024** presented an in-depth analysis of damage occurred during test conducted on precast building. They conducted experiment and computational simulation and observed that damages have happened in the upright part of the structure. **Vinay et al. 2022** presented study of 10 story regular RC framed structure with different column removal scenarios both in plan and elevation. They adopted alternate load path method using nonlinear staged construction available in software. They observed that results of dynamic analysis are more accurate than static analysis as it includes effect of progressive collapse. **Gu et al. 2021** tested 1/4th scaled RC sub-structural model with middle column-removal case to understand progressive collapse mechanism. They tested 2 RC beam column sub-assemblies with different types of joints and 3-T beam column assemblies with different beam flange widths. They also studied the effect of splice length of the bottom bars in beams at the middle joint as per Chinese code. **Wang et al. 2020** studied the effect of infill walls on the performance of precast concrete framed sub-structure subjected to progressive collapse situation. They studied 3 PC specimens with different conditions like bare frame under a centre column loss scenario. They found that infilled specimen leads to increase in load carrying capacity at flexural and catenary stage when compared with the bare frame. They also pointed that the size, position of the openings in the building has a significant impact on structural resistance of an infilled PC frame at flexural stage.

Qian and Li 2017 presented dynamic response of building model with different degrees of damage and re-assessed it by push-down loading regime to understand their behaviour. The results shown damage caused by the dynamic response has significantly affected the initial stiffness and reduced efficiency of compressive arch action and membrane action. Author found that when specimen undergoes plastically dynamic response, there were no compressive arch action and membrane action are developed. SDOF has predicted the peak dynamic displacement correctly while over-estimates the vibration and under-estimates residual deformation. **Alshaikh et al. 2020** summarizes previous research work on progressive collapse of RC structures and focused on experimental studies on various types of structures like beam-column, and beam slab sub-assemblies, etc. **Chen et al. 2026** used macroscopic-scale analysis to understand the structural performance of composite bolted joints. They proposed top-down multi-scale numerical approach and macro-scale damage together. This helped to capture the initiation and propagation of micro cracks. They also used tensile test and scanning electron microscopy (SEM) to analyse the failure characteristics of the joint with different interference percentage. **Long et al. 2026** claimed that the tensile membrane action of RC beam-slab-sub assembles were the key mechanism for resisting progressive collapse due to column removal. They pointed out drawbacks of simplifies material models and FE approaches due limitations of heterogeneity of concrete and other parameters. They found that the proposed framework directly links with TNA-dominated deformation to underlying 3D mesoscopic failure mechanism under sudden column failure due to blast or other accidental loadings.

Fan et al. 2026 carried experimental investigations into progressive collapse behaviour of model of 2-storey 3D steel frame structure subjected to local fire in a corner room. They captured the distribution of damage due to fire. **Shahriar and Amanat (2025)** investigated collapse mechanism of soft ground storey using pushover analysis. They adopted linear static analysis and other methods to investigate the behaviour of masonry-infilled soft ground story

Numerical Study

Sample buildings described herein were selected as typical G+7 story reinforced concrete building. Building is modelled using FEM software SAP 2000. Following data were used in modelling as shown in Table 1.

Table.1 Data of G+7 Building

Building type G+7 Residential Building	Wall load: 11.26 kN/m
Plan area: 16.70*23.75 m	Concrete grade: M25
Beam size: 275*600, 200*600, 150*600 mm	Steel grade: Fe500
Column size 275*800, 200*800 mm	Earthquake zone: III
Slab thickness: 150 mm	Seismic zone factor: Z = 0.16
Typical story height: 3 m	Global direction: X-Direction
Bottom story height: 2.6 m	Soil type: Medium hard
Live load: 2 kN/m²	IS code: IS 456, IS 1893-2002

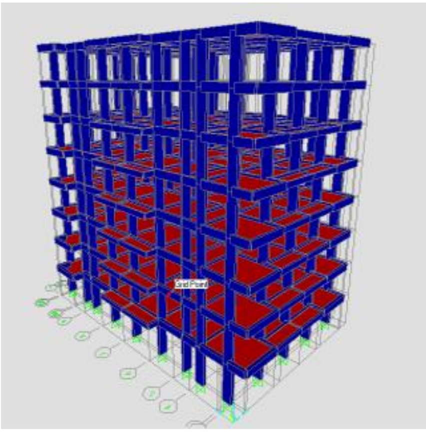

Figure 1. FEM model of RC

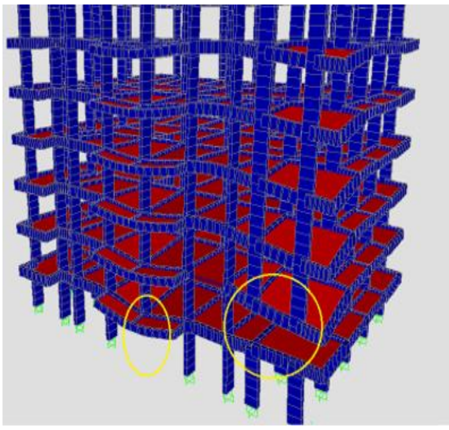

Figure 2. FEM model of RC building with column removal

Results and Discussions

To examine how the abrupt loss of structural elements affects a building's seismic behaviour, a response spectrum analysis was carried out using SAP2000. Column no. 26 was selected for monitoring, and its axial load and other parameters are evaluated under two different conditions: one with its neighbouring columns intact, and other with those columns removed to simulate a potential progressive collapse scenario.

Axial Force:

The results revealed a clear shift in axial force demand. With adjacent columns in place, column no. 26 carried a load of 51.14 kN after their removal, the load rose sharply to 77.08 kN i.e. increase of approximately 50.78%. This rise highlights how the structural system compensates by redistributing vertical forces to remaining members, increases stress concentrations in those elements.

Moment:

With the column included, the moment value is seen to be 33.93 kNm, whereas after column removal, the value increases to 36.55 kNm, indicating a 7.7% increase in the moment. The presence of the column appears to slightly reduce the overall moment, due to improved load distribution and increased structural stiffness, which helps in dissipating forces more effectively.

Base Shear:

With the column included, the base shear value is 565.041 kN, whereas after column removal, the value decreases slightly to 559.921 kN, indicating a 5.12 kN decrease, when the column is present. It is likely due to improved load distribution and increased structural stiffness, helping the structure to dissipate forces more effectively under seismic conditions.

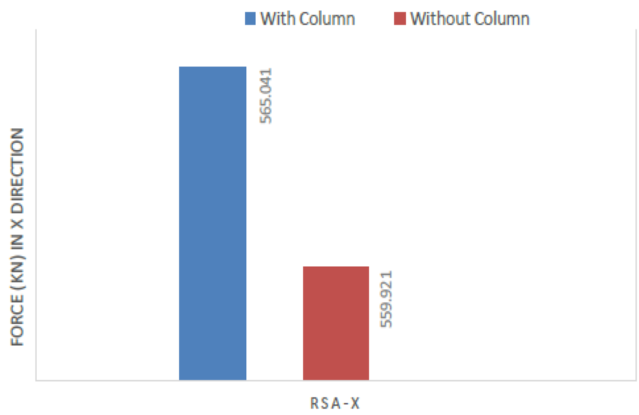

Figure 3. Base Shear

Concluding Remarks

The paper highlights the critical need to address progressive collapse in reinforced concrete (RC) frame buildings, particularly in seismic zones. Following conclusions are drawn:

- A local failure in the structure triggers a chain reaction, ultimately leading to the complete collapse of the building.
- There is a need of considering soil structure interaction, to understand its role in progressive failure.
- Key solutions include using stronger columns and weak beam, integrating braced systems, and incorporating infill walls to enhance structural resilience.

References

[1] Mirzahosseini, H., Mirhosseini, S. M., and Zeighami, E., “Progressive collapse assessment of reinforced concrete (RC) buildings with high-performance fiber-reinforced cementitious composites (HPFRCC),” *Structures*, vol. 49, pp. 139–151, Mar. 2023, doi: 10.1016/j.istruc.2023.01.114.

[2] Lan, D.Q., Jin, L., Qian, K., Zhang, R.B., and Li, J., “Progressive collapse resistance of RC frames subjected to localized fire,” *Journal of Building Engineering*, vol. 79, pp. 107746, Nov. 2023, doi: 10.1016/j.jobe.2023.107746.

[3] Tsai, M.H., and Lin B. H., “Investigation of progressive collapse resistance and inelastic response for an earthquake-resistant RC building subjected to column failure”, *Engineering Structures*, vol.30, 2008, pp. 3619-3628. doi:10.1016/j.engstruct.2008.05.031

[4] Tavakoli, H.R., and Alashti, A. R., “Evaluation of progressive collapse potential of multi-story moment resisting steel frame buildings under lateral loading”, *Scientia Iranica A*, vol. 20, no. 1, 2013, pp. 77–86. doi:10.1016/j.scient.2012.12.008

[5] Ferraioli, M., Laurenza, B., Lavino A., and Matteis, G. De., “Progressive collapse analysis and retrofit of a steel-RC building considering catenary effect”, *Jr. of Constructional Steel Research*, vol. 213, 2024, 108364. https://doi.org/10.1016/j.jcsr.2023.108364

[6] Buitrago, M., Setiawan, A., Makoond, N., Gerbaudo, M. L., Marin L., Cetina D., Caredda, G., Sempertegui, G., Oliver, M., Adam, J. M., “Failure analysis after the progressive collapse of a

precast building", *Engineering Structures*, vol. 321, 2024, 118893. https://doi.org/10.1016/j.engstruct.2024.118893

[7] Vinay, M., P. Rao, K. R., Dey, S., Swaroop, A.H.L., Sreenivasulu, A., Rao, K. V., "Evaluation of progressive collapse behaviour in reinforced concrete buildings", *Structures*, vol. 45, 2022, pp. 1902–1919. https://doi.org/10.1016/j.istruc.2022.10.001

[8] Gu, X. L., Z. Bin, Wang Y., Wang, X.L., "Experimental investigation and numerical simulation on progressive collapse resistance of RC frame structures considering beam flange effects", *Jr. of Building Engineering*, vol. 42, 2021, 102797. https://doi.org/10.1016/j.jobe.2021.102797

[9] Wang, F., Yang, J., Nyunn, S., Azim, I., "Effect of concrete infill walls on the progressive collapse performance of precast concrete framed substructures", *Jr. of Building Engineering*, vol. 32, 2020, 101461. https://doi.org/10.1016/j.jobe.2020.101461

[10] Qian, K., Bing Li., "Dynamic and residual behaviour of reinforced concrete floors following instantaneous removal of a column", *Engineering Structures*, vol. 148, 2017, pp. 175–184. http://dx.doi.org/10.1016/j.engstruct.2017.06.059

[11] Alshaikh, I.M.H., Bakar, B.H.A., Alwesabi, E.A.H., Akil, H. Md., Experimental investigation of the progressive collapse of reinforced concrete structures: An overview, *Structures*, vol. 25, 2020, pp. 881-900. https://doi.org/10.1016/j.istruc.2020.03.018

[12] Chen, L., Lin, J., Li, M., Xu, Q., Zhu, W., Ke, Y., "Multiscale modelling for bearing performance and progressive failure analysis of interference-fit CFRP joints", *Composite Structures*, vol. 379, 1 March 2026, 119949. https://doi.org/10.1016/j.compstruct.2025.119949

[13] Xu Long, Bun Theavuth Ketekun, Percy M. Iyela, Multiscale analysis of progressive collapse resistance in RC beam-slab sub-assemblages under tensile membrane action. *Jr. of Building Engineering*, vol. 118, 15 January 2026, 115101. https://doi.org/10.1016/j.jobe.2025.115101

[14] Fan, S., Ding, R., Xu, T. , Liu, M., "Experimental study on progressive collapse resistance of steel frame structures under local real fire", *Jr. of Building Engineering*, vol.117, 1 January 2026, 114785. https://doi.org/10.1016/j.jobe.2025.114785

[15] Shahriar, Md. S., Amanat, K. M., "Investigation on collapse mechanism of soft ground storied buildings at different locations of Bangladesh based on pushover analysis", *Structures*, vol. 79, 2025, 109620. https://doi.org/10.1016/j.istruc.2025.109620