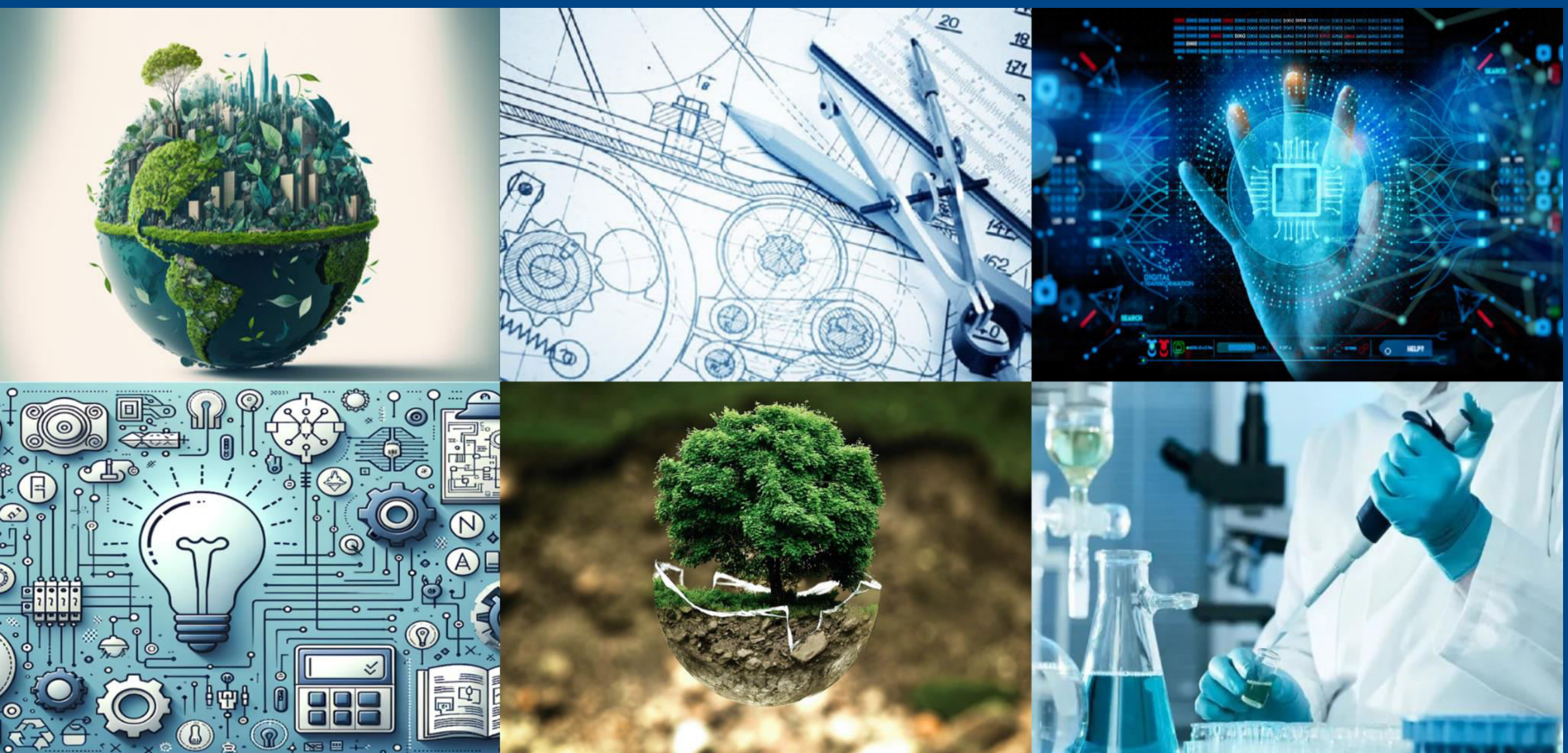
ISSN: 2582-7219

International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 8, Issue 6, June 2025

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ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Parametric Evaluation of Soft Storey Influence on Seismic Fragility of Multi-Storey RC Frames

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ABSTRACT: The seismic fragility of multi-storey reinforced concrete (RC) buildings is significantly affected by the presence of soft storeys, which are known to alter the dynamic response and amplify structural vulnerability during earthquakes. This study presents a detailed parametric evaluation of the influence of soft storeys on the seismic performance of high-rise RC frames using both linear and nonlinear analysis techniques. The investigation considers four standard seismic analysis procedures—two linear (Equivalent Static Method and Response Spectrum Analysis) and two nonlinear (Pushover Analysis and Time History Analysis)—to capture the full spectrum of structural response characteristics. The work specifically focuses on RC buildings with soft storeys introduced at different levels, examining variations in seismic demand and fragility under strong ground motion. Special attention is given to the role of masonry infill walls, which, although often classified as non-structural elements, substantially impact the global stiffness, strength, and failure mechanisms of the frames. Performance-based pushover analysis is utilized to assess displacement capacity, base shear demand, and plastic hinge formation across various configurations. The results highlight that soft storey irregularities, especially when positioned in lower levels, drastically increase inter-storey drifts and concentration of seismic demand, making the building more susceptible to collapse. The presence of infill walls in upper storeys further compounds the irregularity and modifies the fragility profile. This parametric evaluation serves as a critical step toward understanding and mitigating soft storey-related failures in seismic design and retrofit strategies.

I. INTRODUCTION

The performance of reinforced concrete (RC) buildings during past earthquakes has revealed a critical vulnerability associated with vertical irregularities—especially the presence of soft storeys. A soft storey refers to a storey in a building, typically at ground or mezzanine levels, that exhibits significantly lower stiffness or strength compared to the storeys above. These storeys are often introduced for architectural needs such as open parking, commercial use, or large glazing areas, but their presence introduces abrupt changes in mass and stiffness distribution along the height of the structure, which critically affects seismic behavior.

In high-rise buildings, this irregularity leads to disproportionate lateral deformations, increased inter-storey drifts, and concentrated damage during seismic events, often resulting in catastrophic failure. The 2001 Bhuj Earthquake in India and the 1999 Kocaeli Earthquake in Turkey highlighted numerous instances where soft storey failures caused partial or total collapse of buildings, even when other storeys remained intact. Despite these failures, soft storeys continue to be incorporated in modern construction due to functional needs and urban planning constraints. Seismic codes such as IS 1893 (Part 1): 2016 and FEMA-356 now emphasize the identification and evaluation of such irregularities during structural design. However, many existing buildings were designed under older codes or without considering non-linear behavior, making them susceptible to damage. This study undertakes a parametric evaluation of soft storey influence on the seismic fragility of multi-storey RC frames. A systematic approach using both linear (Equivalent Static and Response Spectrum Methods) and nonlinear (Pushover and Time History Analysis) techniques is adopted to investigate the impact of soft storey location, building height, and infill wall configurations on key seismic response parameters. The nonlinear pushover method is particularly emphasized for capturing real behavior under increasing lateral loads and identifying the formation of plastic hinges.

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The presence of masonry infill walls, often treated as non-structural elements, also significantly alters stiffness and damping characteristics, influencing fragility curves and failure patterns. Therefore, their contribution is also considered in this analysis to evaluate more realistic seismic behavior. The ultimate aim of this research is to assess how different soft storey configurations affect seismic fragility and to provide recommendations for improved seismic design and retrofit strategies for high-rise RC buildings in earthquake-prone regions.

II. MODEL DESCRIPTIONS

Model ID	Building Type	No. of Storeys	Soft Storey Location	Infill Wall Condition
M1	Regular RC Frame	G+10	None (Uniform)	Fully infilled
M2	Soft Storey at Ground	G+10	Ground Floor	Bare soft storey, infilled above
M3	Soft Storey at Mid	G+10	5th Floor	Bare mid-storey, infilled elsewhere
M4	Soft Storey Top	G+10	10th Floor	Bare top floor, infilled below
M5	Dual Core + Soft Storey	G+10	Ground Floor	Shear wall core, bare soft storey

III. PUSHOVER ANALYSIS RESULTS

Model ID	Base Shear (kN)	Roof Displacement (mm)	Performance Level (FEMA-356)	Max Storey Drift (%)	Plastic Hinge Concentration
M1	950	128	Immediate Occupancy	0.5	Uniform
M2	720	182	Life Safety	1.2	Ground floor
M3	760	165	Life Safety	1.1	5th floor
M4	890	140	Immediate Occupancy	0.7	Top storey
M5	830	155	Life Safety	0.9	Ground floor

Response Spectrum Analysis Results (Zone V, Soil Type II, Importance Factor 1.0)

Model ID	Time Period (sec)	Base Shear (kN)	Max Storey Displacement (mm)	Mode Participation (1st Mode, %)
M1	0.89	1020	110	72.5
M2	1.15	810	162	66.2
M3	1.08	840	155	68.7
M4	0.95	980	120	70.1
M5	1.02	870	140	69.3

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IV. CONCLUSION

From the parametric study conducted on various multi-storey RC frame models with and without soft storey configurations, the following key conclusions can be drawn:

➢ Soft Storey Significantly Reduces Seismic Performance: Buildings with soft storeys, especially at the ground and mid-levels (Models M2 and M3), exhibit reduced base shear capacity and increased lateral displacements compared to regular infilled frames (Model M1). This highlights their vulnerability under seismic loading.

➢ Location of Soft Storey Matters: The location of the soft storey plays a crucial role in the seismic behavior. A soft storey at the ground floor induces the highest concentration of plastic hinges and story drifts, often leading to potential collapse scenarios. Soft storey at upper levels (Model M4) is comparatively less critical but still affects overall performance.

➢ Increased Time Periods: The presence of a soft storey increases the fundamental time period of the structure, thereby reducing base shear in response spectrum analysis but increasing displacement demands due to flexibility.

➢ Shear Walls Improve Performance but Are Not a Complete Solution: The use of a dual-core shear wall system (Model M5) provides better stiffness and base shear resistance than bare-frame soft storey models, but still shows localized weaknesses at the soft storey level.

➢ Performance-Based Analysis Is Essential: Pushover analysis revealed that soft storey models transition from Immediate Occupancy to Life Safety or even Collapse Prevention levels more quickly, indicating a need for performance-based design for such irregular configurations.

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