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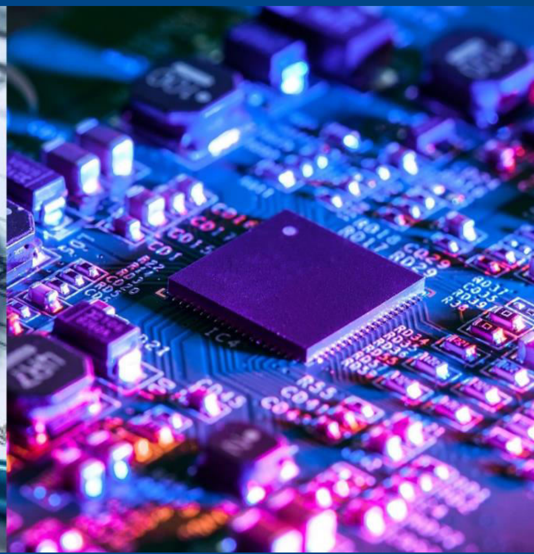

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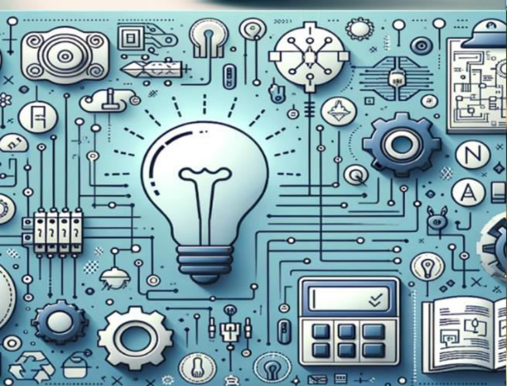

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Literature Review on Parametric Evaluation of Soft Storey Influence on Seismic Fragility of Multi-Storey RC Frames

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ABSTRACT: This literature review critically examines the parametric evaluation of soft storey influence on the seismic fragility of multi-storey reinforced concrete (RC) frames. Soft storeys, characterized by significantly reduced stiffness or strength compared to other floors, are known to exacerbate seismic vulnerability, often leading to catastrophic structural failure during earthquakes. Various studies have investigated parameters such as the number of storeys, soft storey location, structural configuration, infill walls, and material properties to quantify their impact on seismic fragility. A soft storey, typically characterized by reduced lateral stiffness and strength compared to adjacent storeys, significantly compromises the structural integrity and energy dissipation capacity under seismic loading. These irregularities are commonly introduced at ground or mezzanine levels for architectural or functional purposes, such as open parking or retail spaces. Numerous studies have focused on the seismic behavior of RC frames with soft storey configurations, analyzing inter-storey drifts, damage concentration, and failure mechanisms. Researchers have utilized various analytical approaches, including nonlinear static (pushover) and dynamic analyses, to evaluate structural fragility and performance levels. Fragility curves have emerged as an effective tool for quantifying the probability of damage with increasing earthquake intensity. Recent literature also highlights the influence of key parameters—such as soft storey height, location, and infill walls—on seismic performance and vulnerability. This review consolidates findings on these parametric effects and suggests directions for enhancing design strategies to mitigate seismic risk in soft storey RC buildings.

I. INTRODUCTION

The seismic vulnerability of multi-storey reinforced concrete (RC) buildings with soft storeys has been a subject of extensive research due to the frequent and often catastrophic failures observed during past earthquakes. A soft storey, typically characterized by reduced lateral stiffness and strength relative to adjacent storeys, compromises the structural integrity and energy dissipation capacity of a building under seismic loading. Such irregularities are commonly introduced at the ground or mezzanine levels for architectural or functional purposes, such as open parking or retail spaces. Numerous studies have investigated the seismic behavior of RC frames with soft storey configurations, focusing on the resulting inter-storey drifts, damage concentration, and failure mechanisms. Researchers have employed various analytical methods, including nonlinear static (pushover) and dynamic analyses, to evaluate the fragility and performance levels of these structures. Fragility curves, in particular, have emerged as a useful tool to quantify the probability of damage under increasing earthquake intensity. Recent literature has also emphasized the importance of parametric studies to understand how variations in key factors—such as storey stiffness ratio, height irregularity, mass distribution, and infill wall presence—affect seismic performance. These parameters play a significant role in determining the extent of damage and collapse probability, highlighting the need for refined modeling and vulnerability assessment techniques.This literature review aims to consolidate previous findings on the seismic performance of soft storey RC frames, identify critical parameters influencing fragility, and establish a framework for conducting a comprehensive parametric evaluation.

II. REVIEW ON TECHNICAL PAPER

Dya and Oretaa et al. (2018) concluded that seismic demand is primarily concentrated at the soft storey level, which serves as a critical zone during ground motion. Their study used pushover analysis to capture varying severities of soft storey mechanisms and recommended its utility as a preliminary risk assessment tool. Base Shear: Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. As the height of the building increases, the base shear value also increases due to the rise in seismic weight of the structure. Model Observations: Model 2, i.e., a (G+20) structure with infill walls, showed the lowest storeydriftamongallmodels. Modal Time Period was also found to be the lowest in M2. Base shear increased by 24.32% inM1 compared to the base case.

Longitudinal storey displacement was minimum in M2. Haque and Khan et al. (2019) concluded that the base shear value for the Equivalent Static Method is nearly double, offering a more conservative and safer design approach, especially for columns in soft ground floors. Base Shear: Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. As height of the building increases, the value of base shear also increases due to the increase of seismic weight of the building.

Farghaly et al. (2020) demonstrated that RC structures with vertical irregularities tend to collapse when exposed to earthquakes with a PGA as low as 0.25g. However, their slope profile remains relatively stable even in high seismic zones. Base Shear: Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. As height of the building increases, the value of base shear also increases due to the increase of seismic weight of the building. Model Observations: Model 2 (G+20 with infill wall) recorded the lowest storey drift. Modal Time Period was lowest in M2. Base shear showed a 24.32% increase in M1. Longitudinal storey displacement was lowest in M2.

Moghadam and Tso et al. (2021) concluded that using response spectrum-based load distribution in pushover analysis enhances results for moment-resisting frame systems but deteriorates them for setback and wall-frame configurations. Base Shear: Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. As height of the building increases, the value of base shear also increases due to the increase of seismic weight of the building.

Model Observations: Model 2 (G+20 with infill wall) showed minimum storey drift. Modal Time Period was the lowest in M2. Base shear increased by 24.32% in M1. Longitudinal displacement was again observed to be the least in M2.

Birajdar and Nalawade et al. (2022) observed that step-back setback configurations are more suitable on sloping ground, offering improved stability and energy dissipation under seismic loads.Base Shear: Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. As height of the building increases, the value of base shear also increases due to the increase of seismic weight of the building.

Dadi et al. (2013) conducted cyclic tests on two 1/4 scale (G+2) soft storey RC frame models to evaluate their nonlinear performance under cyclic loading. The study focused on updating nonlinear analytical models based on experimental results, assessing parameters such as displacement, storey drift, and failure patterns. The findings emphasized the importance of accurate modeling to predict seismic behavior and enhance the reliability of fragility assessments.

Ghosh & Debbarma (2016) assessed the seismic vulnerability of soft storey structures with plan irregularity using equivalent static force method (ESFM), response spectrum method (RSM), and time history method (THM). The study highlighted the increased vulnerability of open ground storey buildings and proposed mitigation strategies like shear walls and reinforced concrete filled steel tube columns to enhance seismic performance.

Palsanawala et al. (2024) performed a parametric study on the seismic vulnerability of RC frame buildings designed using the Direct Displacement-Based Design (DDBD) approach. The research utilized multi-mode pushover analysis to develop fragility curves, evaluating the influence of design parameters on seismic performance. The study provided insights into the effectiveness of DDBD in enhancing the seismic resilience of RC frames.

Mapari & Ghugal (2018) compared the seismic performance of multi-storey RC Special Moment Resisting Frames (SMRFs) and Ordinary Moment Resisting Frames (OMRFs) using pushover analysis. The study considered the effects of infill walls on base shear capacity and ductility, providing valuable data for understanding the impact of structural configurations on seismic behavior.

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Desai et al. (2017) investigated the seismic behavior of RC framed buildings with soft storeys at different levels. The study utilized linear response spectrum analysis to compare storey displacement, drift, shear, and time period across various models. The findings underscored the significance of soft storey placement in influencing seismic response and highlighted the benefits of incorporating shear walls for performance enhancement

Gautham & Sahoo (2022) examined the seismic collapse performance of soft-storey RC frames with Steel Reinforced Concrete (SRC) columns designed using the energy-based method. The study assessed the impact of SRC columns on seismic resilience, providing insights into their effectiveness in enhancing the collapse resistance of soft-storey structures. Kumar et al. (2024) conducted a parametric study on the seismic vulnerability of non-ductile RC frame buildings using RC jacketing as a retrofitting technique. The study employed nonlinear static and time history analyses to evaluate the influence of jacket thickness and placement on seismic performance, demonstrating the potential of RC jacketing in improving the resilience of existing structures.

Cao et al. (2023) investigated the seismic fragility of existing RC frame structures strengthened with external self-centering substructures. The study utilized finite element modeling and incremental dynamic analysis to assess the impact of strengthening on seismic performance, providing valuable data for performance-based design approaches. Zhu & Tan (2011) performed stochastic vibration-based fragility analysis of middle-story RC frames. The study employed dynamic time-history analysis to develop fragility curves, evaluating the influence of stochastic parameters on seismic vulnerability. The findings contributed to understanding the probabilistic aspects of seismic performance in irregular RC frames.

Naveen et al. (2024) provided a comprehensive study on the seismic response of irregular RC buildings with combined irregularities. The research highlighted the challenges in analyzing irregular structures and emphasized the need for advanced analysis methods to accurately predict seismic behavior, contributing to the development of reliable fragility assessment frameworks.

III. CONCLUSION

- From the comprehensive review of recent studies on the seismic fragility of multi-storey RC frames with soft storeys, several important conclusions can be drawn:
- Critical Role of Soft Storey: The presence of a soft storey significantly influences the seismic response of multi-storey RC frames by concentrating seismic demands such as displacement and storey drift at that level. This leads to higher vulnerability and potential failure if not adequately designed or retrofitted.
- Importance of Accurate Modeling: Both experimental and numerical studies emphasize the need for detailed nonlinear modeling and cyclic testing to accurately predict the seismic performance and fragility of soft storey structures. Simplified models may underestimate damage potential.
- Base Shear Trends: Base shear increases with building height due to the greater seismic weight, but the distribution and magnitude of base shear are highly dependent on structural configurations, including the presence of infill walls and retrofitting measures.
- Seismic Retrofitting Measures: Techniques such as RC jacketing, inclusion of shear walls, and use of Steel Reinforced Concrete (SRC) columns show promising improvements in seismic resilience by enhancing strength and ductility at the soft storey level.
- Fragility Assessment Methods: Modern approaches like multi-mode pushover analysis, incremental dynamic analysis, and stochastic vibration-based fragility evaluation are critical for developing reliable fragility curves and risk assessments, accounting for uncertainties in seismic demands and structural properties.
- Impact of Structural Irregularities: Irregularities in plan and elevation, especially in buildings with soft storeys, complicate seismic behavior and necessitate advanced analysis techniques for accurate seismic performance prediction.
- Need for Parametric Studies: Systematic parametric evaluations allow understanding of how different factors—such as soft storey severity, infill presence, retrofitting thickness, and building height—affect seismic fragility, helping in informed design and mitigation strategies.

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