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Strategic Shear Wall Placement for Enhanced Seismic Resilience

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Abstract – Reinforced concrete shear walls play a crucial role in shielding buildings from seismic forces by providing both strength and stiffness. This study focuses on optimizing the placement of shear walls in high seismic zones. Through static and dynamic nonlinear analyses on an eight-story building, various scenarios of shear wall positions are explored to evaluate their impact on seismic performance. Utilizing a performance-based seismic design (PBSD) approach, the study aims to meet acceptance criteria concerning inter-story drift ratio and damage levels. Results highlight the importance of concentrating shear walls in the central area of the building during design, which proves more effective in reducing inter-story drift and minimizing potential damage during seismic events compared to peripheral distributions. Additionally, the research investigates the use of complete shear walls that infill the frame, creating compound shapes such as Box configurations. Incorporating such complete shear walls significantly enhances the structure's reliability concerning inter-story drift. Conversely, the absence of complete shear walls within the frame reduces stiffness and may lead to the deterioration of short beams.

***Keywords*:** Performance level, Pushover analysis, Shear wall, Plastic hinge, PBSD, Reinforced concrete.

1. Introduction

The threat posed by seismic events to buildings worldwide is a pressing concern, given the potential for catastrophic collapse and damage, resulting in significant loss of life [1-4]. In response, engineers and researchers are consistently working on innovative strategies to boost a structure's resilience and minimize earthquake-induced damage. One notably effective approach, as highlighted by Djafar-Henni and Chebili in 2023 [5], involves incorporating shear walls into building designs. Shear walls play a crucial role in withstanding the lateral forces generated during earthquakes. Their purpose extends to redistributing these forces, providing protection to the main structural elements of the building. Through the effective dissipation of seismic energy, shear walls contribute substantially to reducing overall structural damage and, consequently, enhancing the safety of occupants.

Studying the behaviour of shear walls and their influence on seismic performance stands as a crucial area of exploration. This knowledge is essential for ensuring the reliable design and construction of shear wall systems. Numerous studies in the literature have delved into assessing the performance of reinforced concrete buildings equipped with shear walls under earthquake excitations. Notable contributions include the works of Çavdar et al. (2018), and Sumit and Gupta (2019) [6,7]. These studies aim to comprehensively evaluate the structural behaviour, seismic response, and effectiveness of shear walls in enhancing the seismic performance of buildings. This evaluation is carried out through a variety of numerical and experimental approaches, providing valuable insights for the continued improvement of shear wall systems in seismic-prone regions.

Determining the optimal location for shear walls in building designs is crucial for enhancing a structure's resilience to earthquakes. Proper placement can significantly reduce lateral forces during seismic events, preventing excessive displacement and ensuring safety. Mahmoud study in 2021 [8] emphasized the importance of shear wall positioning, revealing that layouts with shear walls on the outer periphery outperformed those with inner placements, resulting in a remarkable 50% reduction in seismic response. This reduction not only enhances safety but also holds the potential for cost-effective earthquake design. Further investigation into shear wall positioning in reinforced concrete multi-story structures across different seismic zones corroborated the idea that shear walls are most effective when situated at the periphery of the building. The study also highlighted the benefits of placing shear walls at the center or corners of the building plan, forming a box-like structure. This configuration notably enhances stability in terms of critical parameters like displacement and inter-story drift, as demonstrated by Magendra et al. in 2016 [9].

Despite existing literature offering valuable insights into the effects of shear walls, a notable gap persists in understanding the optimal positioning of shear walls in building design. This study seeks to address this gap by delving into the economic and performance aspects of shear walls in the context of an eight-story building situated in a high-seismicity zone. The methodology employed involves a nonlinear analysis that considers capacity curves, inter-story drift, and performance levels. The study explores various scenarios, scrutinizing different plan layout distributions. Importantly, it incorporates principles of performance-based seismic design (PBSD) to ensure a comprehensive investigation. Through this approach, the research aims to shed light on the most effective and economically viable positioning of shear walls in the specified seismic setting.

2. Methodology

The study employs Performance-Based Seismic Design (PBSD) methodology, emphasizing specific performance objectives for structures facing seismic forces, such as safety, functionality, and reparability. The primary goal is to ensure buildings meet desired performance levels during seismic events, considering various objectives for different structure types.

The study defines performance objectives in terms of immediate occupancy (IO), life safety (LS), and collapse prevention (CP). The prioritized objective in this study is life safety (LS), focusing on minimizing risks to human life and maintaining the building's economic viability.

Acceptance criteria, including inter-story drift ratio (IDR) and plastic hinge measures, are employed to assess structural response and potential damage levels. The drift limit is set at 1.0% according to the Seismic Algerian Code [10], and plastic hinges are used to evaluate deformation at critical locations within the structure.

Pushover analysis, a commonly used technique in PBSD, is conducted to assess the building's response to incremental lateral loads. The analysis aims to determine the capacity curve of the building, select an appropriate performance point, and identify inter-story drift and plastic hinge occurrences.

3. Structures models

As depicted in Fig. 1, the primary objective of this study was to pinpoint the most effective locations for shear walls, with the aim of averting torsional response by eliminating eccentricity between the rotation center and mass center under lateral loads. Ensuring symmetry in both the X and Y directions within the building models emerged as a crucial strategy to alleviate torsional effects, underscoring the pivotal role of the center of rotation in shaping force and moment distribution during seismic events.

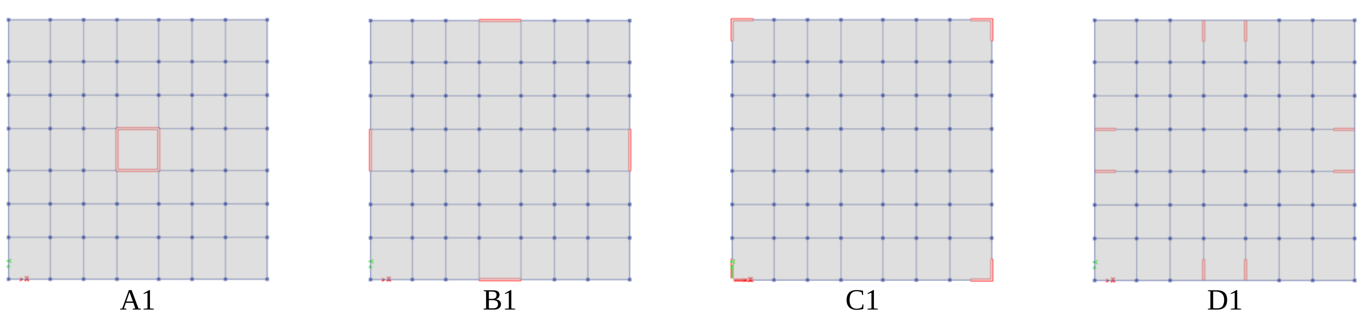

Fig. 1: The studied models.

The considered reinforced concrete (RC) structures exhibit in-plan views with uneven spacing. Essential details on the dimensions and reinforcement of RC elements, such as beams, columns, and shear walls. All models represent residential buildings situated in a high-seismicity Zone III. The slabs, comprising floors and roofs, are designed to support a total dead load of 4.0 kN/m^2 and a live load of 1.5 kN/m^2. Seismic loads are generated in accordance with the Algerian seismic code of 2003 [10].

4. Results and discussion

The analysis of Fig. 2 consistently reveals that model A1 displayed the highest stiffness values compared to the other analyzed models. In descending order, models B1, C1, and D1 exhibited stiffness values that were 44.24%, 47.18%, and 57.62% lower than model A1, respectively. Additionally, the maximum base shear, reflecting the total lateral force experienced at the base of the structure, consistently demonstrated higher values for model A1 compared to the other models. In descending order, models B1, C1, and D1 exhibited base shear values that were 22.80%, 20.90%, and 27.50% lower than model A1, respectively.

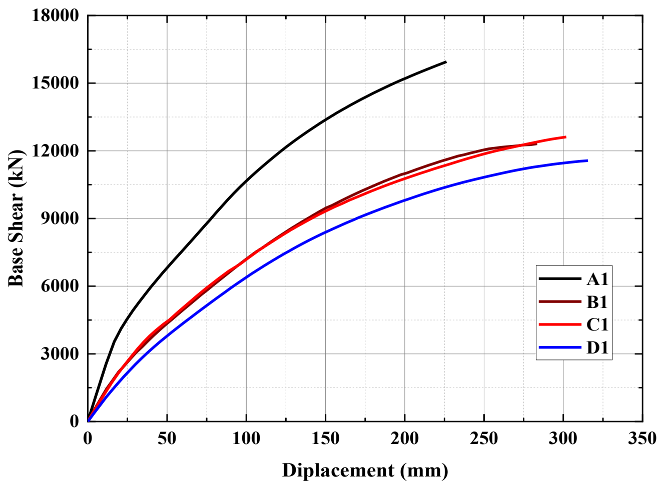

Fig. 2: Capacity curve.

Concerning maximum displacement, representing the lateral movement experienced during seismic events, model A1 exhibited the smallest value among the models. In ascending order, models B1, C1, and D1 displayed displacement values that were 25.24%, 33.37%, and 39.42% higher than model A1, respectively.

These findings underscore the importance of selecting appropriate shear wall positions to achieve optimal stiffness, minimize base shear, and simultaneously reduce displacement.

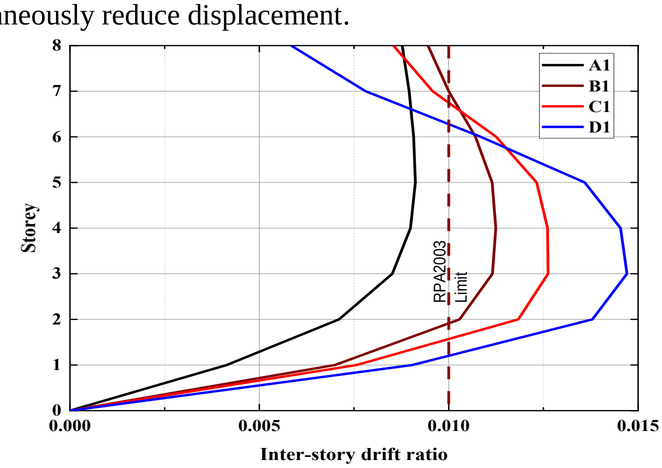

Fig. 3: The inter-story drift ratio.

As illustrated in Fig. 3, model A1 stands out with the lowest inter-story drift ratio (IDR) value among the compared models. Models B1, C1, and D1, in ascending order, exhibit IDR values that are 23.26%, 38.39%, and 61.24% higher that of model A1, respectively. These findings strongly affirm the critical role of selecting optimal shear wall positions achieving the lowest possible drift values.

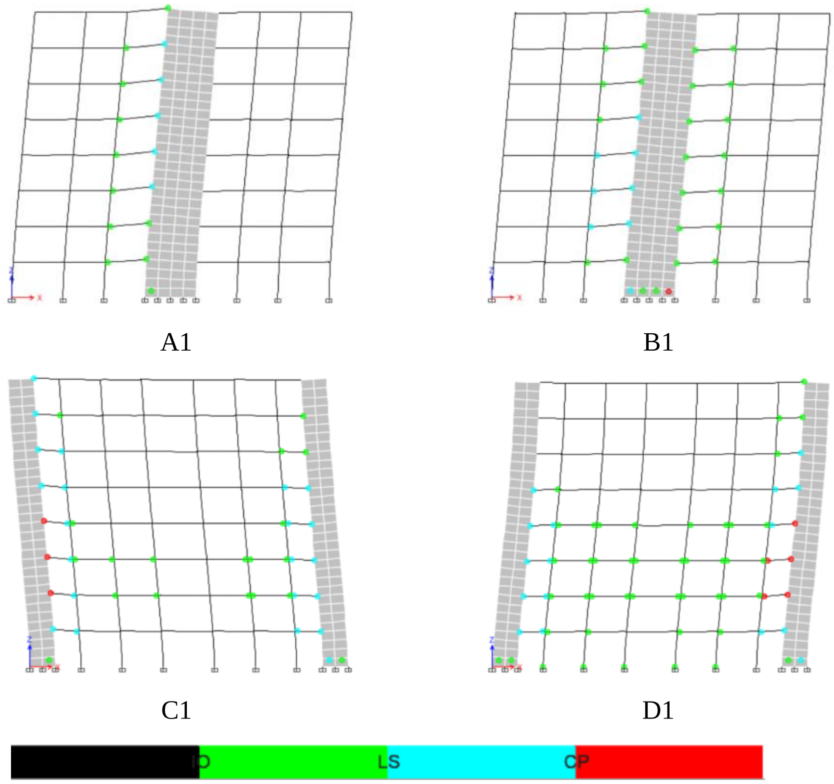

Fig. 4: Plastification of Building Models due to Static Pushover.

Examining Fig. 4, the assessment of damage across the models indicates that model A1 attains the desired level of performance concerning damage limitation and life safety. However, models B1, C1, and D1 exhibit additional visible damage, with certain reinforced concrete elements approaching the level of collapse prevention. This introduces potential vulnerabilities in the design and construction of these models, notably attributed to factors such as the presence of short beams attached to shear walls in Models C1 and D1, as well as the ground floor shear wall in Model B1.

4. Conclusion

The superior performance of model A1 over the others underscores its capability to withstand seismic loads and ensure the safety of occupants. This superiority can be attributed to the centralized placement of shear walls at the center of the structure.

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