Experimental Investigation of Seismic Resistant Construction Techniques

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1. INTRODUCTION

Reinforced concrete (RC) framed structures are often designed without considering the structural contributions of masonry infill walls, which are commonly used as interior partitions or external walls in buildings. These walls, typically made of brick masonry, are treated as non-structural elements, yet they significantly enhance the strength, rigidity, and lateral load-bearing capacity of RC frames. In many regions, masonry infill walls are integrated as panels within RC frames, where their interaction with the surrounding structure increases lateral stiffness. However, the Indian Standard Code IS 1893 (Part-I):2002, which provides guidelines for earthquake-resistant design, does not account for the advantages offered by masonry infill walls. When present across all stories, these walls significantly improve energy dissipation capacity, reducing demands on frame elements and minimizing displacements during seismic events.

The presence of a sudden reduction in stiffness at any particular story in a building, known as a soft story, poses a critical vulnerability in seismic conditions. IS 1893 (Part-I):2002 defines a soft story as one with stiffness 50% less than the adjacent floors. To analyze this phenomenon, the seismic behavior of RC frames was studied using ETABS software, focusing on five different structural models: a bare frame, a fully infilled frame (modeled with masonry as a single diagonal strut), a soft ground story (modeled with masonry as a single diagonal strut), a fully infilled frame (modeled with masonry as cross-bracing), and a soft ground story (modeled with masonry as cross-bracing). The study employed the Demir and Sivri (2002) method, which models masonry infill walls as equivalent diagonal strut elements.

The analysis, which included both equivalent static and response spectrum methods, revealed that RC frames with masonry infill walls exhibit significantly enhanced seismic performance, with the lowest risk of collapse. In contrast, bare frames, lacking the added stiffness and energy dissipation capacity of masonry infills, were the most vulnerable to seismic-induced failure. This highlights the crucial role of masonry infill walls in improving the resilience of RC frames, underscoring the need to consider them as integral components in earthquake-resistant design to ensure safer and more robust structures.

2. REVIEW OF LITERATURE

Structural walls, especially seismic shear walls, are critical for resisting lateral loads and ensuring building stability. Their effectiveness is influenced by design parameters like lateral displacement, story drift, and cost. Chopra & Goel (2002) analyzed seismic demand through modal pushover analysis.

Constantinou et al. (1992, 1998, 2001) demonstrated that dampers significantly reduce inter-story drift and shear forces, with guidelines for passive energy dissipation systems. Diptesh & Murty (2004) observed infills increase stiffness but reduce ductility. Studies by Dubey & Deodhar (1996) and Durgesh et al. (2006) highlighted reinforcement's role in strength and seismic detailing inadequacies.

Numerous researchers, including Gopenpaul et al. (2012) and Hameed et al. (2014), emphasized the improved performance of retrofitted structures with damping systems. Haroon & Umesh (2012) recommended infilled frames in seismic zones.

Hasan et al. (2010) and Hejazi et al. (2014) explored shear walls and viscous dampers for seismic resistance. Experimental studies, such as those by Kaltakci et al. (2008) and Mehmet & Tugrul (2011), confirmed enhanced strength and energy dissipation in reinforced and infilled frames. Computational analyses, including those by Panchal & Marathe (2011), revealed the superiority of composite structures in seismic zones.

Shilpa et al. (2014) and Wakchaure & Ped (2012) evaluated high-rise building behavior under seismic loads using software like STAAD.Pro and ETABS, show that infill walls reduce displacements and increase base shear. Viswanath et al. (2010) and Wongprasert & Symans (2004) advocated for steel bracing and optimized damper placement to improve seismic performance.

Overall, these studies underline the importance of advanced seismic detailing, infill panels, damping devices, and retrofitting techniques to enhance structural resilience against earthquakes.

3 MODELLING

Modeling of Masonry Infill Walls

Masonry infill walls in RC frames are typically modeled using the single strut approach, which remains the most widely adopted method due to its simplicity. Although multi-strut models can provide more precise results by capturing localized effects, the single strut model is better suited for large-scale structural analyses. In this method, RC frames with unreinforced masonry walls are represented as equivalent braced frames, where infill walls are replaced by single equivalent diagonal struts. These struts are considered to have no tensile strength, carry only axial forces, and are pinned at both ends. The load from the infill wall is transferred to the beams. To account for earthquake forces in both positive and negative directions, the infill wall is modeled as cross bracing. In the present study, the effective width of the diagonal strut is determined based on the approach proposed by Stafford Smith (1962), ensuring reliable results for RC frame analysis.

Structural Model

The study analyzes a ten-story reinforced concrete building with plan dimensions of 30m x 25m, featuring five bays along both longitudinal and transverse directions, and a story height of 3m for all floors. The structural materials used are M25-grade concrete and Fe500 steel. The concrete has a unit weight of 25 kN/m³ and a Poisson’s ratio of

0.2. The masonry infill walls have a modulus of elasticity of 2500 N/mm² and a Poisson's ratio of 0.2. The mass of the infill walls is concentrated at floor levels for seismic analysis. The slabs, including the roof, are modeled as 150mm thick, and the external brick walls are 230mm thick. The live load is assumed to be 4 kN/m² for floors and 1.5 kN/m² for the roof. The beam and column dimensions are 350mm x 500mm and 600mm x 600mm, respectively. The building is situated in seismic Zone IV and rests on medium soil. Seismic weight calculations include the full dead load and 50% of the live load, as specified in IS 1893 (Part 1):2002.

Analysis of the Building

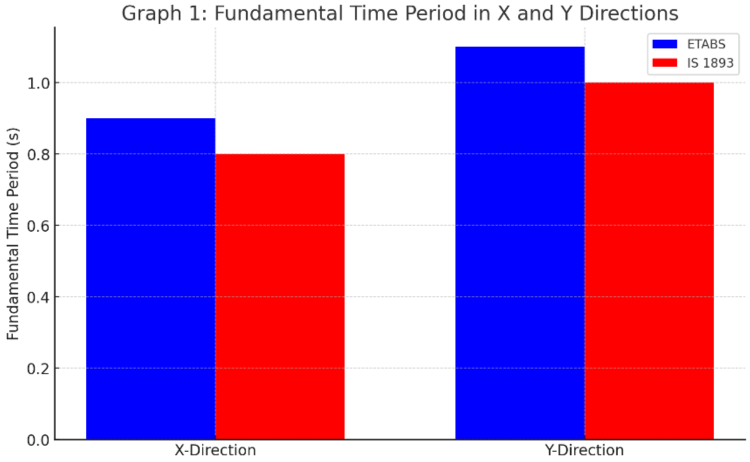
The structural analysis was carried out using equivalent static and dynamic response spectrum methods in compliance with IS 1893 (Part 1):2002. ETABS v20 software was employed for this purpose. The distribution of lateral loads along the height of the building was calculated and applied as per code provisions. The seismic weight was determined by combining the full dead load and 50% of the live load, and the results of both analysis methods were compared to evaluate the seismic performance of the building.

4. RESULTS AND DISCUSSION

This section presents and analyses the results obtained from evaluating a ten-story building under different conditions. The study focuses on parameters such as the fundamental period, displacement versus story, base shear, and inter-story drift ratio.

4.1 Fundamental Period

The fundamental vibration periods of the building were determined using eigenvalue analysis in ETABS v9.7.0, considering the effects of infill stiffness. Including infill walls in the analysis led to a reduction in the fundamental period due to the increased stiffness of the structure. The results, derived from both IS 1893 (Part 1): 2002 and ETABS software, reveal that infill significantly reduces the fundamental period. Notably, the IS 1893 (Part 1): 2002 method consistently yielded lower periods compared to ETABS, resulting in higher base shear values. These relationships are visually represented in **Graph 1**, comparing the periods in x- and y-directions for the building.



4.2 Displacement vs. Story

The displacements across various stories were analyzed using both static and dynamic response spectrum methods.

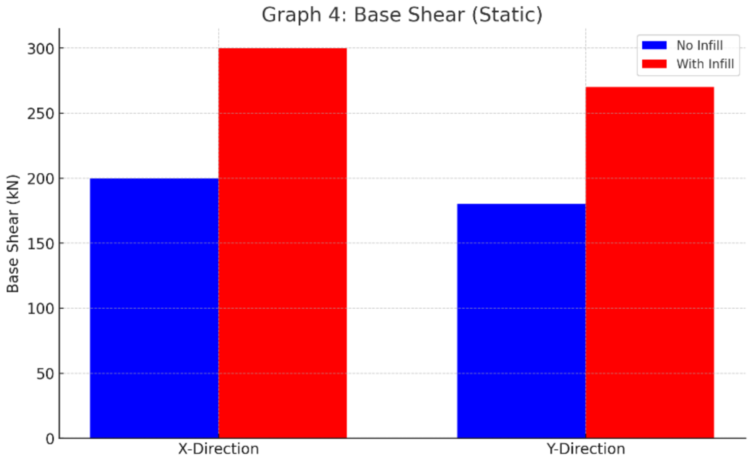
In the **static method**, the highest displacement values at the top story occur when no infill is included. The introduction of infill walls significantly reduces these displacements, with reductions of approximately 35% in some cases and up to 45% in others.

Similarly, for the **dynamic response spectrum method**, displacements reduce by approximately 34% to 43% when infill is incorporated. These findings underscore the significant contribution of infill walls to structural stiffness and the reduction of lateral deformations.

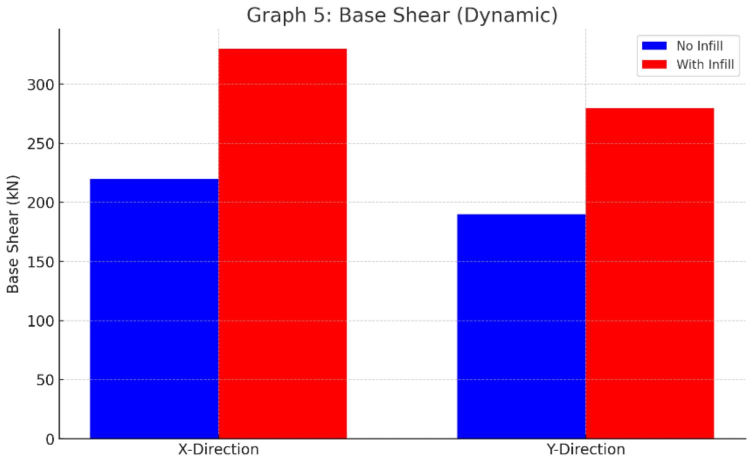
4.3 Base Shear

Base shear, a crucial parameter for assessing seismic performance, was evaluated using both static and dynamic response spectrum methods.

In the **static method**, the inclusion of infill results in significant increases in base shear values. For example, base shear in the x-direction increases by 40% to 54%, and in the y-direction by 33% to 49%, compared to conditions without infill. These trends are depicted in **Graph 4**.



The **dynamic response spectrum method** follows a similar pattern, with base shear increasing by approximately 38% to 53% in the x-direction and 33% to 48% in the y-direction. These results are shown in **Graph 5**, further highlighting the positive impact of infill on seismic performance.


Graph 5: Base Shear (Dynamic)

5. CONCLUSION

The study highlights the significant impact of masonry infill on the dynamic characteristics, stiffness, strength, and seismic performance of reinforced concrete frame buildings. The inclusion of infill walls enhances the building's stiffness and strength, effectively reducing inter-story drift and controlling lateral displacements, especially at the top stories. Key observations from the analysis reveal that the presence of infill results in a reduction in the fundamental period of the structure. Additionally, the displacement, particularly at the top story, is notably lower in buildings with infill compared to bare frames. Furthermore, the base shear increases with the inclusion of infill, with substantial variations observed between different models, especially under the dynamic response spectrum method. Finally, the study shows that story drift is significantly reduced in infilled frames compared to bare frames, leading to improved seismic performance and stability of the building.

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