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Influence of Shear Wall Opening Configuration on the Seismic Response of Reinforced Concrete Buildings

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Abstract: ***Reinforced concrete (RC) shear walls play a vital role in improving the seismic performance of multi-storey buildings by providing adequate lateral stiffness and strength against earthquake forces. However, architectural and functional requirements often necessitate openings in shear walls for doors, windows, and service ducts, which influence the overall structural behavior. The present study investigates the effect of vertical and staggered shear wall opening configurations on the seismic response of a G+16 reinforced concrete building using ETABS. Two analytical models with identical geometric and material properties were developed, differing only in the arrangement of shear wall openings. The structures were analysed using Response Spectrum Analysis in accordance with IS 1893 (Part 1):2016. The seismic performance of both models was evaluated by comparing key structural response parameters, including base shear, story displacement, story drift, natural time period, modal participation mass ratio, and spandrel beam shear force. The results indicate that the opening configuration has a significant influence on the dynamic behaviour of the building. The model with vertically aligned openings exhibited comparatively lower story displacement, reduced story drift, and a shorter natural time period, indicating improved lateral stiffness and overall seismic performance. Although both configurations satisfied the code requirements, the staggered opening arrangement resulted in relatively higher deformation and increased demand on the spandrel beams due to discontinuity in the load transfer path. The findings of this study highlight the importance of proper shear wall opening arrangement and provide useful guidance for structural engineers in selecting suitable opening configurations for earthquake-resistant reinforced concrete buildings.***

Keywords: Reinforced Concrete Building, Shear Wall Openings, Vertical Openings, Staggered Openings, ETABS, Response Spectrum Analysis, Seismic Performance, Story Drift

1. Introduction

Reinforced concrete (RC) shear walls are one of the most effective lateral load-resisting systems used in medium- and high-rise buildings to withstand earthquake and wind-induced forces. Due to their high stiffness, strength, and ductility, shear walls significantly improve the overall stability of buildings by reducing lateral displacement and inter-storey drift. In seismic-prone regions, the incorporation of shear walls has become an essential design practice to ensure structural safety and serviceability. Modern design standards such as IS 1893 (Part 1):2016, IS 456:2000, and IS 13920:2016 provide comprehensive guidelines for the analysis and design of reinforced concrete shear walls under seismic loading. With advancements in structural analysis software such as ETABS, engineers can accurately evaluate the dynamic behaviour of buildings subjected to earthquake forces using linear and nonlinear analytical methods.

In practical construction, shear walls frequently require openings to accommodate architectural and functional requirements such as doors, windows, lift lobbies, staircases, and utility ducts. Although these openings improve the usability of the building, they interrupt the continuity of the shear wall and modify its stiffness, strength, and load transfer mechanism. The size, location, and arrangement of openings play a significant role in determining the seismic response of the structure. Improperly arranged openings may lead to increased lateral displacement, higher inter-storey drift, stress concentration around the opening corners, and reduced overall structural performance. Therefore, selecting an appropriate opening configuration is an important consideration in achieving both architectural flexibility and structural efficiency.

Several researchers have investigated the influence of shear wall openings using experimental studies, finite element modelling, and numerical simulations. However, limited research has focused on comparing vertical and staggered opening configurations using Response Spectrum Analysis in accordance with the latest Indian seismic design provisions. The present study addresses this gap by performing a comparative seismic evaluation of a G+16 reinforced concrete building modelled in ETABS. Two analytical models, one with vertically aligned openings and another with staggered openings, are analysed under earthquake loading. Their performance is assessed using key response parameters such as base shear, story displacement, story drift, natural time period, modal participation mass ratio, and spandrel beam shear force. The findings of this study provide useful insights into the influence of opening configuration on the seismic performance of RC buildings and offer practical guidance for structural engineers in designing efficient shear wall systems.

2. Literature Review

Several researchers have investigated the influence of openings in reinforced concrete (RC) shear walls on the seismic performance of buildings. Early research primarily focused on understanding the reduction in lateral stiffness and strength caused by the presence of openings. These studies established that the size, shape, and location of openings significantly affect the structural behaviour of shear walls by interrupting the load transfer mechanism and creating stress concentrations around the opening corners. As the opening area increases, the effective wall section decreases, resulting in higher lateral displacement, increased story drift, and reduced energy dissipation capacity under earthquake loading. Khatami et al. (2012) studied the effect of different opening sizes in RC shear walls and reported that larger openings substantially reduce lateral stiffness and increase the fundamental natural time period of buildings. Muthukumar and Kumar (2014) investigated various opening locations using finite element modelling and concluded that centrally located and symmetrically arranged openings provide better structural performance than irregularly positioned openings. Their study also highlighted that appropriate reinforcement detailing around openings can effectively reduce stress concentration and improve the seismic resistance of the wall. Karnale and Shinde (2015) compared different shear wall opening configurations using ETABS and observed that vertically aligned openings generally produce lower story displacement and inter-storey drift than irregular or staggered opening arrangements because they maintain a more continuous vertical load path. Similarly, Swetha and Akhil (2017) emphasized that both the location and arrangement of openings play an important role in controlling the dynamic response of multi-storey buildings. Their findings indicated that improper opening placement may increase torsional effects and adversely affect the lateral load-resisting capacity of the structure.

Recent studies have increasingly utilized advanced finite element software such as ETABS, SAP2000, ABAQUS, and ANSYS to evaluate the seismic performance of buildings with different shear wall configurations. Yadav et al. (2019) demonstrated that the inclusion of shear walls significantly reduces story displacement and drift compared with conventional moment-resisting frame systems. Yadav and Sharma (2020) further reported that the structural efficiency of shear walls depends not only on their location within the building but also on the arrangement of openings and their influence on the overall stiffness distribution. Several researchers have also highlighted the importance of modal participation, coupling beam behaviour, and stress redistribution while assessing buildings with shear wall openings.

A review of the available literature indicates that although numerous investigations have examined the influence of opening size and location, comparatively fewer studies have focused on the performance of vertical and staggered opening configurations under dynamic loading conditions. Most existing studies emphasize displacement and drift behaviour, whereas limited attention has been given to other important response parameters such as modal participation mass ratio, spandrel beam shear force, and the combined assessment of multiple seismic performance indicators using the latest Indian Standard provisions. Consequently, a detailed comparative evaluation of different opening configurations is required to provide practical design recommendations for earthquake-resistant reinforced concrete buildings.

3. Objectives of Analysis

- To Study the seismic behaviour of a G+16 reinforced concrete building with vertical and staggered shear wall openings.
- To Investigate the influence of shear wall opening configuration on the dynamic response of the building under earthquake loading.
- To Analyse the structural response parameters such as base shear, story displacement, story drift, and natural time period.
- To Evaluate the modal participation, spandrel beam shear force, and overall seismic performance of the two opening configurations.
- To Assess the suitability of the vertical and staggered opening configurations for seismic-resistant design in accordance with IS 1893 (Part 1):2016.

4. Methodology

The present study investigates the seismic performance of a reinforced concrete building with different shear wall opening configurations using ETABS. A G+16 reinforced concrete building was selected as the analytical model because it represents a typical medium-rise residential structure commonly adopted in urban areas. Two numerical models having identical geometric dimensions, material properties, member sizes, and loading conditions were developed. The only variation between the two models was the arrangement of the shear wall openings. Model 1 consisted of vertically aligned openings, while Model 2 consisted of staggered openings. This approach ensured that the influence of opening configuration on the structural response could be evaluated independently without interference from other design variables.

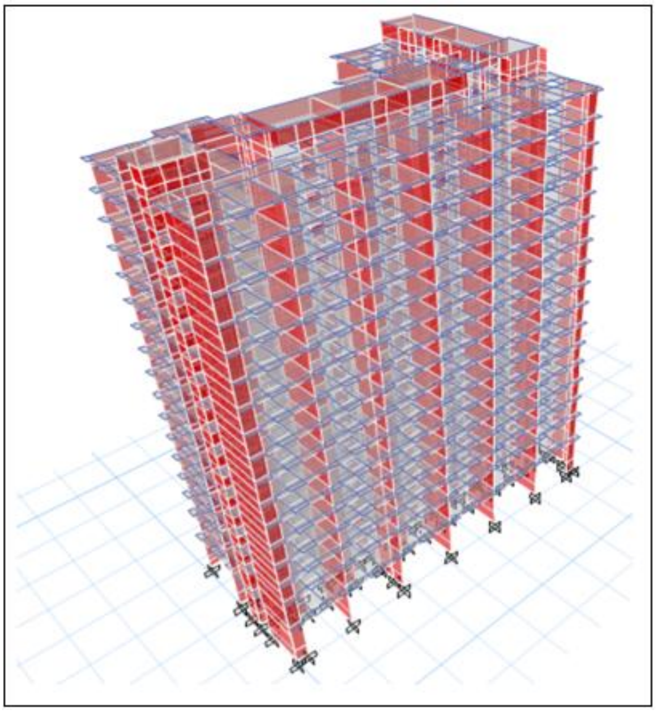


Figure 1: Etabs 3-D View for Building

The structural models were developed in ETABS by considering reinforced concrete beams, columns, slabs, and

shear walls as per the design provisions of IS 456:2000. Seismic loading was defined according to IS 1893 (Part 1):2016, while gravity loads were assigned in accordance with IS 875 (Part 1 and Part 2). The supports at the foundation level were assumed to be fixed, and the floor slabs were modelled as rigid diaphragms to ensure proper distribution of lateral forces. A suitable mass source was defined by considering the self-weight of structural members together with the applicable dead and live loads to accurately represent the seismic mass of the building. The response spectrum function corresponding to the selected seismic zone and soil condition was assigned to perform linear dynamic analysis. The building response was obtained by considering sufficient vibration modes to achieve the required modal mass participation, ensuring reliable dynamic characteristics of the analytical model. Response Spectrum Analysis is widely accepted for evaluating the dynamic response of multi-storey RC buildings because it efficiently captures the contribution of higher vibration modes while remaining computationally practical.
After completion of the analysis, the seismic performance of both models was evaluated and compared using important response parameters including base shear, story displacement, story drift, natural time period, modal participation mass ratio, and spandrel beam shear force. These parameters provide a comprehensive assessment of the lateral stiffness, deformation characteristics, and dynamic behaviour of reinforced concrete buildings under earthquake loading. The comparative evaluation was carried out to identify the opening configuration that provides better structural performance and improved seismic resistance. The adopted methodology enables a systematic comparison of the two opening arrangements and provides practical recommendations for the design of reinforced concrete shear walls with architectural openings.

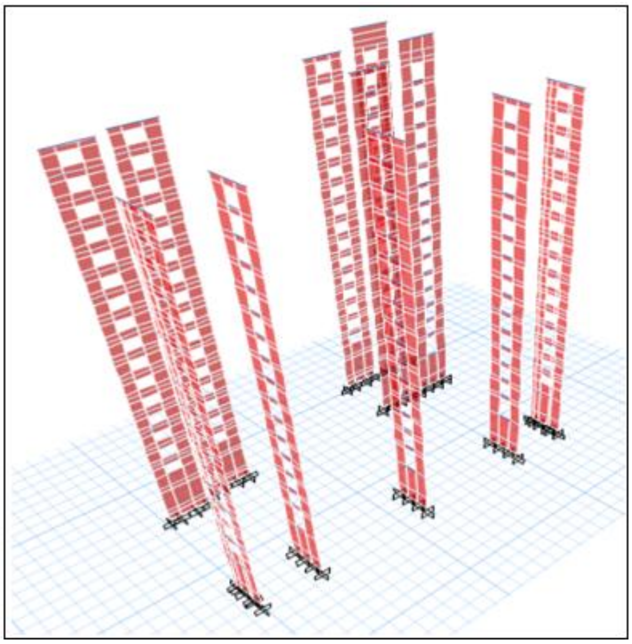


Figure 2: Etabs 3-D View for Vertical Opening (Model-1)

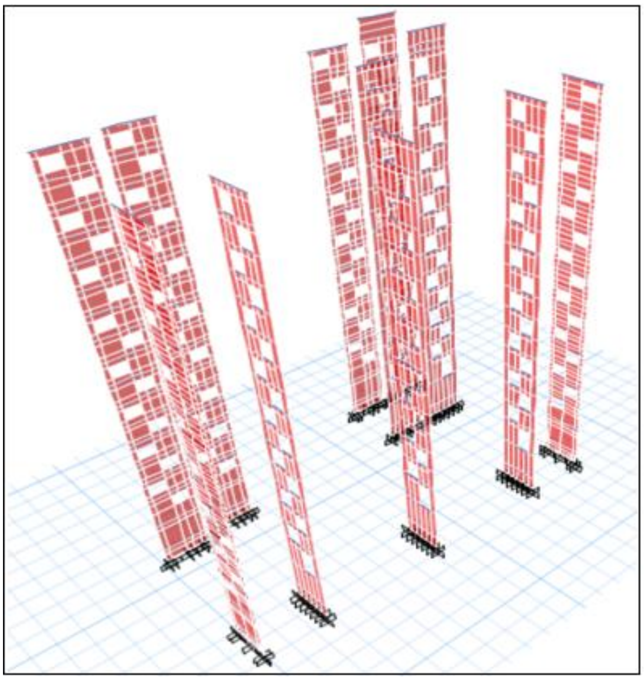
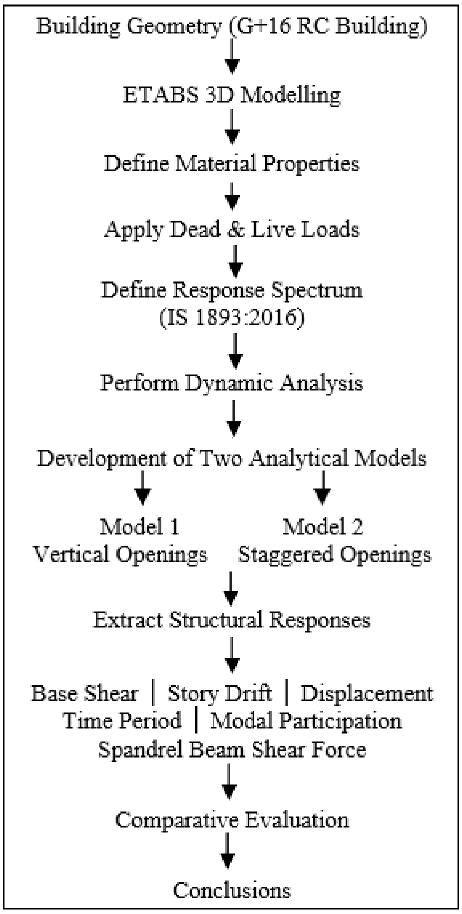


Figure 2: Etabs 3-D View for Staggered Opening (Model-2)



5. Result and Discussion

The seismic performance of the two analytical models was evaluated using Response Spectrum Analysis in ETABS. Model 1 consisted of vertically aligned shear wall openings, whereas Model 2 consisted of staggered shear wall openings. Both models were analysed under identical loading conditions, and their structural responses were compared using parameters such as base shear, story displacement, story drift, natural time period, modal participation mass ratio, and spandrel beam shear force.

5.1 Base Shear

The base shear values obtained from both analytical models indicated only a marginal difference between the two opening configurations. The building with vertically aligned openings exhibited slightly higher base shear due to its relatively greater lateral stiffness. In contrast, the staggered opening configuration resulted in a small reduction in base shear because of the decrease in overall structural stiffness. Although the variation was not significant, the results indicate that opening arrangement influences the lateral force-resisting mechanism of the building.

5.2 Story Displacement

Story displacement gradually increased with building height in both models, with the maximum displacement occurring at the roof level. The staggered opening configuration exhibited comparatively higher lateral displacement than the vertically aligned configuration. This behaviour can be attributed to the discontinuity in the stiffness distribution caused by the staggered arrangement of openings, which increased the overall flexibility of the structure. The vertically aligned openings maintained a more uniform load path, resulting in improved lateral stability.

5.3 Story Drift

The variation of story drift along the building height showed a similar trend for both models. However, the model with staggered openings developed slightly higher inter-storey drift than the model with vertically aligned openings. The increase in drift is mainly associated with the reduction in lateral stiffness caused by the discontinuous opening arrangement. Nevertheless, the maximum story drift values remained within the permissible limits specified by IS 1893 (Part 1):2016, indicating that both configurations satisfy the code requirements for serviceability.

5.4 Natural Time Period

The fundamental natural time period of the building was marginally higher for the staggered opening configuration. The increase in time period indicates a reduction in structural stiffness due to the interrupted load transfer path. Conversely, the vertically aligned opening configuration exhibited a slightly lower natural time period because of its comparatively higher stiffness and better continuity of the shear wall system.

5.5 Modal Participation Mass Ratio

The modal participation results showed that both models achieved the minimum mass participation required for dynamic analysis. The difference between the two opening configurations was relatively small, indicating that both analytical models adequately represented the dynamic characteristics of the structure. However, the vertically aligned openings demonstrated a slightly more efficient distribution of modal mass participation because of their improved stiffness continuity.

5.6 Spandrel Beam Shear Force

The spandrel beams connecting adjacent wall segments experienced higher shear forces in the staggered opening configuration than in the vertically aligned configuration. The irregular arrangement of openings altered the load transfer mechanism and increased the demand on coupling elements. Therefore, appropriate reinforcement detailing of spandrel beams is essential when staggered openings are adopted to ensure adequate seismic performance.

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