Analytical Study on the Effect of Curtailed Shear Walls on the Seismic Performance of High-Rise Buildings

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Abstract

This study explores the effects of shear wall curtailment on the seismic performance of high-rise buildings by comparing symmetrical and unsymmetrical structural configurations. Using STAAD.Pro V8i, dynamic analyses were performed on 21-story building models to assess parameters such as base shear, axial forces, maximum node displacement, shear forces, bending moments, and story drift under varying shear wall arrangements. Five models were analyzed for each configuration: full-height shear walls, and shear walls curtailed from the top 3, 6, and 9 stories, as well as a model without shear walls. The results reveal that full-height shear walls offer the highest seismic resistance. However, curtailing the walls up to 70% of the building height in symmetrical structures, and up to 80% in unsymmetrical structures, does not significantly affect stability or load-bearing capacity. This strategy enables material cost savings without the need for additional structural reinforcements. The study underscores the importance of strategic shear wall placement and curtailment to improve seismic performance while ensuring efficient structural design.

Keywords: Shear Wall Curtailment, Seismic Performance, High-Rise Buildings, Dynamic Analysis, STAAD.Pro V8i, Structural Stability

1. Introduction

Shear walls are critical structural elements in high-rise buildings, designed to resist lateral forces induced by seismic activity and wind loads. These vertically oriented, wide beams transfer earthquake-induced loads to the foundation, enhancing structural stability. This research examines the effect of shear wall curtailment on the seismic performance of high-rise buildings, focusing on both symmetrical and unsymmetrical configurations. The study aims to determine optimal curtailment levels that maintain structural integrity while reducing material costs.

1.1 Background

Shear walls are classified based on their structural materials—such as steel, timber, reinforced masonry, and reinforced concrete—as well as their geometric forms, including rectangular, barbell-shaped, flanged, and coupled types. Their behavior is significantly influenced by the aspect ratio (height-to-width), with short shear walls defined as those having an aspect ratio less than one. In high-rise buildings, shear walls are strategically positioned to ensure adequate stiffness and strength, effectively minimizing torsional effects and controlling lateral displacements within permissible limits.

1.2 Objectives

The primary objectives of this study are as follows:

a) To analyze the maximum story displacement under various shear wall conditions in both symmetrical and unsymmetrical high-rise structures.
b) To evaluate story drift resulting from different shear wall configurations.
c) To assess the maximum base shear experienced under seismic loading.
d) To investigate bending moments and shear forces in structural elements.
e) To study axial forces under different shear wall arrangements.

1.3 Scope

This research focuses on the dynamic analysis of 21-story symmetrical and unsymmetrical high-rise structures using the response spectrum method. It examines structural regularities and irregularities, the role of shear walls, and the contributions of beams and columns to the overall stability of the building.

2. Literature Review

Previous studies have emphasized the critical role of shear walls in enhancing the seismic performance of high-rise buildings. According to [1], shear walls significantly reduce lateral displacements and increase structural rigidity. [2 -4] highlighted the effectiveness of response spectrum analysis in capturing frequency-dependent seismic responses. Recent research has also investigated shear wall curtailment as a means to optimize material usage while preserving structural integrity. However, there is limited comparative analysis of symmetrical and unsymmetrical configurations under dynamic loading. This study extends the existing body of knowledge by analyzing the impact of shear wall curtailment on various structural parameters in both symmetrical and unsymmetrical high-rise structures.

3. Methodology

The study utilizes STAAD.Pro V8i for 3D modeling and dynamic analysis, employing the response spectrum method in accordance with IS 1893-2002 (Part I). The methodology includes the modeling, load application, and analysis of 21-story symmetrical and unsymmetrical high-rise structures to evaluate their seismic performance.

3.1 Structural Models

Five models were developed for both symmetrical (SM21) and unsymmetrical (USM21) structural configurations [5]:

- **Model 01:** G+21 structure with full-height shear walls.
- **Model 02:** G+21 structure with shear walls curtailed from the top 3 stories.
- **Model 03:** G+21 structure with shear walls curtailed from the top 6 stories.
- **Model 04:** G+21 structure with shear walls curtailed from the top 9 stories.
- **Model 05:** G+21 structure without shear walls.

3.2 Structural Parameters

The models were designed with the following specifications:

- **Plan dimensions:** 10 m × 30.9 m
- **Number of stories:** 21
- **Floor height:** 4 m
- **Column size:** 0.230 m × 0.600 m
- **Beam size:** 0.230 m × 0.600 m
- **Slab thickness:** 0.125 m
- **Shear wall thickness:** 0.230 m
- **Concrete density:** 25 kN/m^3
- **AAC block density:** 6.5 kN/m^3
- **Live load:** 4 kN/m^2
- **Dead load:** 4 kN/m^2 (including 1 kN/m^2 for finishing)
- **Foundation depth:** 4 m

3.3 Analysis Method

The seismic analysis was conducted using the response spectrum method, incorporating parameters such as Zone V seismic factor (0.36), response reduction factor (5), soil type I, and the Square Root of the Sum of Squares (SRSS) combination method. Loads were applied in accordance with IS 1893-2002 and IS 875 standards, including self-weight, dead loads, live loads, and relevant load combinations.[6]

4. Modeling and Analysis

The models were developed in STAAD.Pro V8i, with structural elements defined in accordance with ARE 456:2000 and IS 13920 standards. Fixed support conditions were assumed at a foundation depth of 4 meters. The analysis procedure included the following steps [7]:

- Defining the structural geometry with 7 bays in the X-direction and 22 bays in the Y-direction.
- Assigning material properties such as modulus of elasticity and Poisson's ratio.
- Applying seismic definitions, along with self-weight, dead loads, and live loads.
- Performing response spectrum analysis to evaluate structural responses under dynamic loading [8].

5. Results and Discussion

The analysis produced results for base shear, axial forces, maximum node displacement, shear forces, bending moments, and story drift, which were compared across all models.

5.1 Symmetrical Models

The following tables show the results obtained with symmetrical models.

Table 1: Results of Symmetrical Models

Model	Base Shear (kN)	Axial Force (kN)	Max. Displacement X (mm)	Max. Displace
Model01	1830.581	2509.998	100.551	209.
Model02	1803.737	2407.038	101.155	257.
Model03	1737.543	2394.095	105.256	296.
Model04	1671.454	2908.990	118.260	337.
Model05	1475.986	5232.182	368.826	2767.

Table 2: Maximum Shear Force and Bending Moment in Symmetrical Models

Model	Shear Force Fy (kN)	ShearForce Fz (kN)	Bending Moment My

			(kNm)
Model01	283.920	48.629	79.070
Model02	319.461	88.991	135.928
Model03	323.171	112.212	157.510
Model04	395.440	116.070	178.943
Model05	373.226	343.984	357.020

5.2 Unsymmetrical Models

The analysis produced results for base shear, axial forces, maximum node displacement, shear forces, bending moments, and story drift, which were compared across all models.

Table 3: Results of Unsymmetrical Models

Model	Base Shear (kN)	Axial Force (kN)	Max. Displacement X (mm)	Max. Displace
Model01	1824.731	2180.196	106.546	306.
Model02	1763.851	2141.146	111.295	369.
Model03	1703.031	2121.135	119.585	470.
Model04	1642.207	2992.930	141.232	452.
Model05	1442.936	5828.676	435.390	2983.

Table 4: Maximum Shear Force and Bending Moment (Unsymmetrical Models)

Model	Shear Force Fy (kN)	ShearForce Fz (kN)	Bending Moment My (kNm)
Model01	262.025	46.629	69.802
Model02	290.717	104.589	149.375
Model03	336.198	146.825	194.980
Model04	410.876	148.471	209.669
Model05	451.865	384.172	403.857

5.3 Comparative Analysis

Base Shear:

In symmetrical models, base shear decreases by 1.47%, 5.08%, 8.69%, and 19.37% in Models 02 to 05, respectively, when compared to Model 01. In unsymmetrical models, the reductions are slightly higher—3.33%, 6.67%, 10%, and 20.92%—indicating greater sensitivity to shear wall curtailment.

Axial Forces:

Axial forces show a slight decrease in Models 02 and 03 but increase significantly in Models 04 and 05. Unsymmetrical models exhibit up to 12% more variation in axial forces compared to their symmetrical counterparts.

Node Displacement:

Displacements in both X and Z directions increase as shear wall curtailment progresses. Unsymmetrical models exhibit 4–10% higher displacements in the X-direction and 2–5% lower displacements in the Z-direction compared to symmetrical models.

Bending Moments:

Bending moments (My and Mz) increase with shear wall curtailment. Unsymmetrical models show 5–12% higher My values and 1–10% lower Mz values compared to symmetrical configurations.

Shear Forces:

Shear forces (Fy and Fz) also increase with curtailment. Unsymmetrical models demonstrate greater variation in Fz values than symmetrical ones.

6. Conclusion

The study concludes the following:

a) Full-height shear walls (Model 01) offer the best seismic performance in both symmetrical and unsymmetrical high-rise structures.

b) Shear wall curtailment up to 70% of the building height in symmetrical structures and up to 80% in unsymmetrical structures maintains acceptable stability and load-carrying capacity.

c) Curtailment reduces material usage, resulting in cost savings without requiring larger beams or columns.

d) Unsymmetrical models show greater variation in seismic responses, highlighting the need for careful shear wall placement to minimize torsional effects.

7. Future Scope

Future research could explore the following areas:

a) Experimental validation of shear wall behavior with openings under dynamic loading.

b) Influence of opening shapes and sizes on the structural response.

c) Seismic performance of taller and more slender shear walls.

d) Post-fire seismic behavior of reinforced concrete shears walls.

e) Application of alternative dynamic analysis methods beyond the response spectrum method.

f) Performance of core/lift walls with openings in high-rise buildings.

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