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Evaluating the Structural Performance of Building Frame and Dual Frame System Incorporating Shear Walls

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ABSTRACT

As cities grow and more high-rise buildings are constructed in earthquake-prone areas, ensuring these structures can withstand seismic forces has become a top priority. In this study, we used ETABS software and the Finite Element Method to analyze and design a G+7 building, focusing on its performance under static and earthquake loads based on UBC-97 standards. We compared two structural systems—a building frame and a dual frame system—to understand how changes in dimensions, material strength, and the placement of shear walls affect the building's safety and stability. The findings showed that positioning the shear wall at the core of the building provides the best results, reducing story drift and displacement while maintaining overall safety. This research emphasizes the importance of smart design choices and modern tools in creating safer, earthquake-resistant buildings that meet the challenges of urban growth.

1. Introduction

The structural design of buildings for seismic loading is primarily concerned with structural safety during major earthquakes. However, serviceability and the potential for economic loss are also concerns [1]. It is crucial to ensure adequate lateral stiffness to resist seismic loads. Other lateral loads such as wind load depend on the building height, wind flow, surrounding exposure, and building shape. It is also significant for multi-story buildings [1]. When the buildings are tall, the dimensions of other structural members also increase and the beam and column sizes become quite heavy, and the steel required is large which makes a lot of congestion at their joints, and it is very difficult to place and vibrate concrete at these places. And because the column of the structure only takes the gravity loads and do not resist the lateral loads so there will be a need for the structural walls, commonly known as shear walls in buildings to resist these seismic forces.

The shapes of the building also affect the result of the shear wall. A shear wall is a structural panel that can resist lateral forces acting on it. Shear walls in symmetrical shapes give better results than asymmetrical shapes as in base shear and story drift [3]. Structural safety is more important; that is why a dual system is adapted to meet the requirement.

The primary objective of this study is to analyze the behavior of a G+7 building frame system and dual frame system incorporating shear walls, and to compare the effects of reducing member dimensions and steel area in both systems with different shear wall placements. Four models were developed by ETABS following the provisions of UBC-97.

The effectiveness of shear walls, structural shapes, and bracing systems in enhancing the seismic performance of high-rise buildings has been extensively explored in recent research. (Barua & Sultana, 2020) analyzed two models, one with a core shear wall and one without and found that the presence of a core shear wall significantly reduced critical parameters like story drift, base shear, overturning moments, column reactions, and maximum bending moments, highlighting the importance of shear walls in improving seismic resistance [1]. Similarly, Chandurkar and Pajgade (2013) explored the impact of shear wall sizes and concluded that larger shear walls are particularly effective for buildings with more than ten stories, making them both efficient and economical for high-rise construction [2]. In terms of structural shapes, Sultan and Peera (2015) compared rectangular, L-shaped, I-shaped, and C-shaped buildings and discovered that rectangular shapes had the least story drift, while irregular shapes experienced more deformation under seismic forces, emphasizing the advantage of regular, symmetrical designs in minimizing seismic risks [3]. Guleria (2014) further supported these findings, concluding that symmetrical shapes such as rectangular and I-shapes offer superior performance over asymmetrical shapes, as these designs are inherently more stable during earthquakes [9]. In addition, Arlekar et al. (1997) analyzed the importance of ground-story stiffness, suggesting that ground-story columns should be 50% stiffer than upper-story columns to effectively resist seismic forces. Their research also highlighted the critical role of a concrete service core in reducing lateral drift and lowering the strength demand on ground-story columns [4]. Furthermore, the use of bracing systems in steel frames has been shown to significantly increase lateral load resistance. Inamdar and Kumar (2014) demonstrated that ISMB bracing boosts the stiffness of a steel frame by 70%, substantially enhancing its capacity to bear seismic loads [5]. Collectively, these studies underline the importance of shear walls, structural shape, and bracing systems in improving the earthquake resistance of buildings, providing a foundation for further research aimed at optimizing structural safety in high-rise construction.

2. Methodology

This research focuses on examining four different models of a G+7 building to understand how shear walls affect the building's ability to withstand seismic forces. One of the models is designed without shear walls, behaving as a traditional building frame system, while the other three models include shear walls, forming dual systems. The main goal is to analyze the performance of the building frame system, reduce the dimensions of the frame sections to identify potential failure points, and then apply these modified dimensions to the models with shear walls for further analysis.

The four models analyzed in this study are:

1. Building Frame System (no shear walls)
2. Dual System with Four Shear Walls
3. Dual System with Two Shear Walls
4. Dual System with Core Shear Wall

2.1 PLAN and 3D VIEW:

2.1.1 Building Frame System (no shear walls)

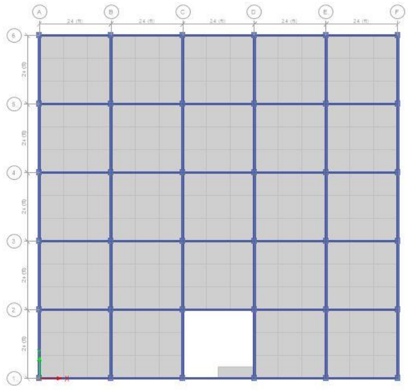

Figure 2.1; *Model 1 Plan view*

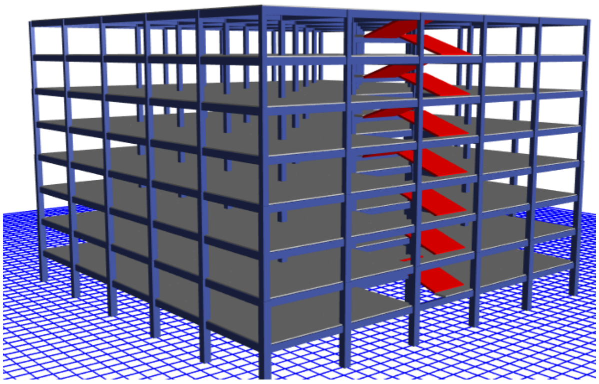

Figure 2.2; *MODEL 1 3D VIEW*

2.1.2 Dual System with Four Shear Walls

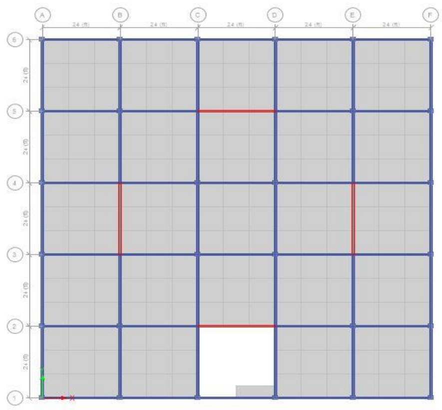

Figure 2.3; *Model 2 Plan view*

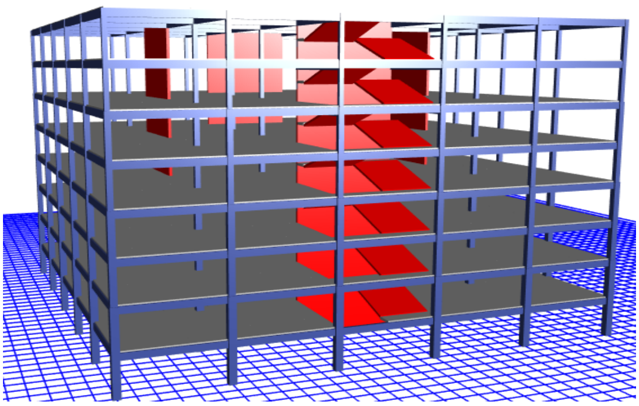

Figure 2.4; *MODEL 2 3D VIEW*

2.1.3 Dual System with Two-Shear Walls

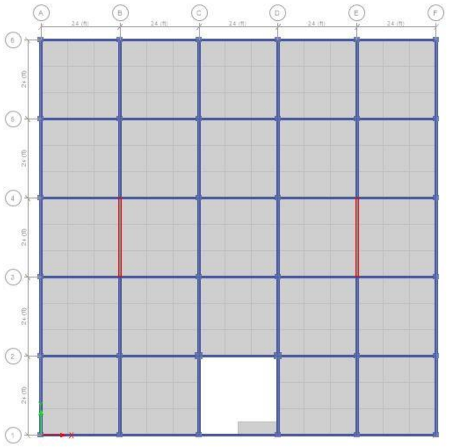

Figure 2.5; *Model 3 Plan view*

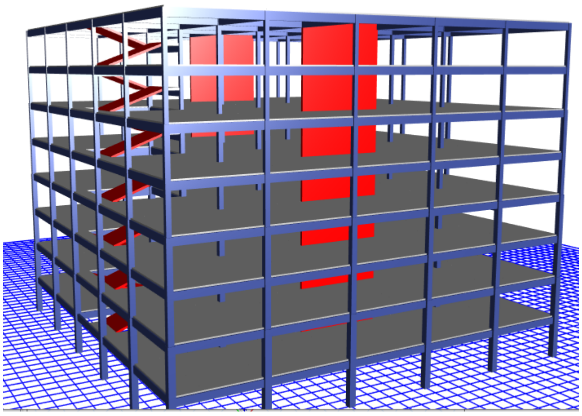

Figure 2.6; *MODEL 3 3D VIEW*

2.1.4 Dual System with Core Shear Wall

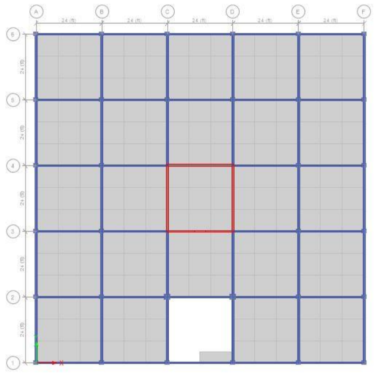

Figure 2.7; *Model 4 Plan view*

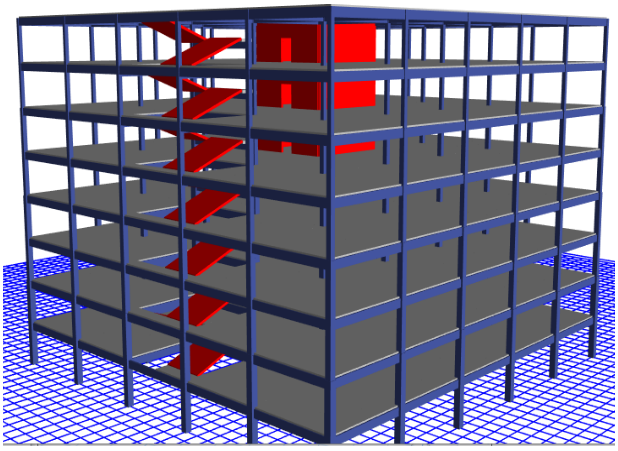

Figure 2.8; *MODEL 4 3D VIEW*

2.2 Material Properties

Material properties for concrete, reinforcement, and steel are summarized in Table 2.1. Frame sections (beams and columns) are listed in Table 2.2, while slabs and wall thicknesses are shown in Table 2.3. Shear walls were modelled as thin shell elements with thicknesses of 9–12 in, depending on their placement.

TABLE: 2.1: Material Properties - Summary					
Name	Type	E	ν	Unit Weight	Design Strengths
		lb/in²		lb/ft³	
A615Gr60	Rebar	29000000	0.3	490	Fy=60000 lb/in², Fu=90000 lb/in²
C4500	Concrete	3823676	0.2	149.99	Fc=4500 lb/in²
CONC	Concrete	3600000	0.2	149.99	Fc=3000 lb/in²
OTHER	Other	29000000	0.3	489.02	
STEEL	Steel	29000000	0.3	489.02	Fy=50000 lb/in², Fu=65000 lb/in²

TABLE 2.2: Frame Sections - Summary		
Name	**Material**	**Shape**
B8X24	CONC	Concrete Rectangular
B8X27	CONC	Concrete Rectangular
B8X30	CONC	Concrete Rectangular
B8X33	CONC	Concrete Rectangular
C12X12	CONC	Concrete Rectangular
C15X15	CONC	Concrete Rectangular
C15X18	CONC	Concrete Rectangular
C18X18	CONC	Concrete Rectangular
C18X21	CONC	Concrete Rectangular
C21X21	CONC	Concrete Rectangular
C24X27	CONC	Concrete Rectangular

TABLE 2.3: Shell Sections – Summary				
Name	**Design Type**	**Element Type**	**Material**	**Total Thickness**
				in
RW12	Wall	Shell-Thin	4000	12
S5	Slab	Shell-Thin	C3000	5
S6	Slab	Shell-Thin	C3000	6
S7	Slab	Shell-Thin	C3000	7
S8	Slab	Shell-Thin	C3000	8
STAIR8	Slab	Shell-Thin	C3500	8
SW12	Wall	Shell-Thin	C3500	12
SW10	Wall	Shell-Thin	C3500	10
SW9	Wall	Shell-Thin	C3500	9

2.3 Modeling Assumptions

Key assumptions in the modeling included:

a) Rigid diaphragm action was assumed at each floor level.

b) Cracked section stiffness was considered for reinforced concrete members.

c) A damping ratio of 5% was adopted for dynamic response.

4) Shear walls were assumed to be continuous from foundation to roof.

These assumptions reflect standard practice in ETABS modeling for medium-rise reinforced concrete buildings.

2.4 Analysis Procedure

To achieve the research objectives, the methodology followed several key steps. Initially, the models were designed according to the UBC-97 code of practice. Once the design was complete, the models were tested under earthquake loads to assess their seismic performance. The study primarily focused on static analysis, a method that helped determine how the building behaved when subjected to earthquake forces. Key factors like story drift, base shear, and displacement were evaluated to better understand the building's resilience.

By carrying out these analyses, the study aimed to provide valuable insights into how shear wall configurations influenced the structural performance of high-rise buildings during earthquakes, ultimately leading to safer and more efficient designs.

3. Result and Discussion

After the analysis of different positions of shear wall in the building configuration the total members reduced in the models are given below

Model 2 (64 members)

Model 3 (64 members)

Model 4 (64 members)

Also, the comparison in percentage reduction of Story displacement, story drift along with total reduction the area of steel used in the building frame system was carried out. Following tables show the results.

3.1 Story Displacement

After making all members of the models pass, the story displacement is analyzed, and results are calculated as a %reduction in story displacement of Dual models compared to the building frame system. The results are tabulated below:

Table 3.1; *Story Displacement*		
MODEL	**EQX**	**EQY**
MODEL 2	75.88	71.7
MODEL 3	3.37	70.36
MODEL 4	89.01	85.79

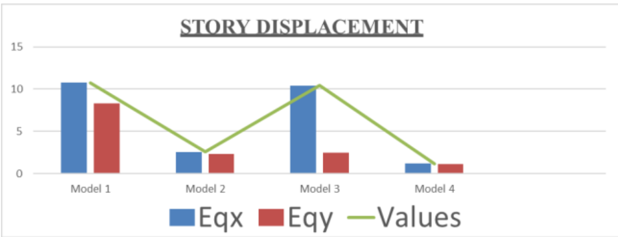

Figure 3.1; Story Displacement Graph

3.2 Story Drift

After making all members of models pass, the story drift is analyzed, and results are calculated as %reduction in story drift of dual models compared to building frame system. The results are tabulated below:

Table 3.2; Story Drift		
MODEL	**EQX**	**EQY**
MODEL 2	75	72
MODEL 3	11.76	69.89
MODEL 4	89.07	86.02

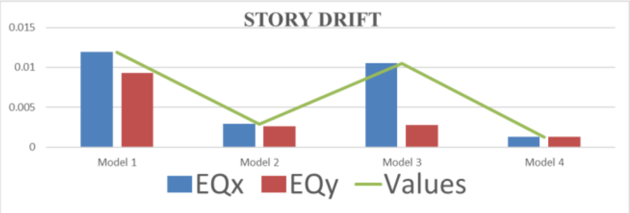

Figure 3.2; Story Drift Graph

3.3 Area of Steel

The area of steel used in column, beam, and shear wall is calculated for all models of building frame and dual frame systems, and the percentage reduction of steel for all dual frame systems is calculated concerning area of steel used in building frame system and is shown in tabulated form.

Table 3.3; Area of Steel Reduction	
MODELS	**% REDUCTION**
MODEL2	34.22
MODEL 3	9.85
MODEL 4	29.76

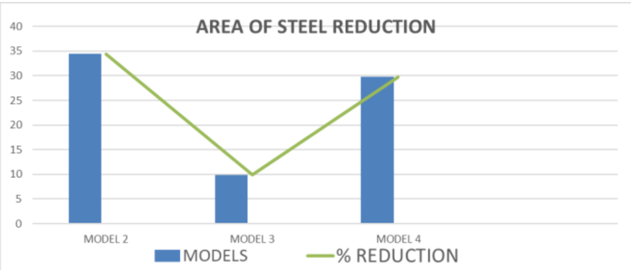

Figure 3.3; Area of steel Reduction

4. Conclusion

Among the models studied, Model 4, which includes a core shear wall, showed clear advantages. Its beam sizes were reduced from 8x24 to 8x12, and 32 columns and beams were removed, making the structure significantly more economical and efficient. The performance of Model 4 stood out in other ways too. It reduced story displacement by 89.01% in the X-direction and 85.07% in the Y-direction, while story drift was reduced by 89.07% in the X-direction and 86.02% in the Y-direction. When it came to material usage, we found that Model 2 achieved the highest reduction in steel area, saving up to 34.22%.

Based on these findings, Model 4 is clearly the best option. It balances safety and cost-effectiveness, reducing story drift and displacement while cutting down on dimensions and materials without compromising strength. This research underscores the importance of incorporating well-designed shear walls in high-rise buildings to improve stability, safety, and efficiency.

Acknowledgment

Not Available

Reference

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