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Lateral Load Bearing Capacity Assessment of RC Buildings with Varying Column Shapes

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Abstract

Reinforced concrete (RC) is the standard construction material in the modern world, used to build millions of new homes and businesses each year to keep up with the world's booming population and economic growth. This study aims to assess the relative lateral load-bearing capacity of rectangular shaped (RS) and specially shaped (SS) column buildings and their behavior against lateral loads (seismic load and wind load) and also to determine some parameters such as- storey drift, displacement, stiffness, and overturning moment with the comparative analysis. The whole procedure involves using ETABS software to do structural analysis on 4 (four) model buildings and in this analysis, BNBC 2015 is followed. The four model buildings are of different combinations of columns having equivalent cross-sectional areas. This analysis is carried out in eight-storied buildings considering lateral loads in two directions. Additionally, the proposed buildings are analyzed in this paper with linear static analysis. After analysis and comparative discussion, it can be inferred that SS column buildings perform better under the same lateral load conditions than conventional RS column buildings.

Keywords: *Lateral load bearing capacity; RC Buildings; Special Shaped Columns; Seismic and Wind load Analysis; Static Analysis.*

1 Introduction

According to research, non-rectangular, special-shaped columns perform well in satisfying spatial needs and increasing aesthetics when subjected to seismic and wind loads. In contrast to conventional rectangular or circular configurations, special-shaped columns in reinforced concrete are non-standard columns having irregular cross-sectional shapes. These columns have a variety of geometric profiles, such as L, T, +, or custom shapes, and are made to satisfy specific architectural or structural requirements. In a variety of applications, including high-rise structures, bridges, and stadiums, their unusual forms add to the aesthetic appeal and structural functionality. The special shaped columns are widely employed in the field of structural engineering because of the advantage of saving indoor space and convenient arrangement for furniture (Zhou et al., 2012). In past decades, the reinforced concrete special shaped columns have been extensively studied. But considering load distribution, bending moments, shear stresses, and torsional effects while designing and reinforcing them is challenging. When consumers desire both functional and aesthetically pleasing excellence, these uniquely formed columns are appropriate for villas and multistorey buildings. The width of the special-shaped column limbs can be the same as the thickness of the building maintenance wall to avoid lobe inside the room, and the layout column grid is flexible, which well achieves the use functions (Wang, 2015). The purpose of this study is to clarify the differences between structures with rectangular columns and those with columns of special shapes. It puts a lot of emphasis on quantifying several factors, like storey drift, storey displacement, storey stiffness, and overturning moment and offers insightful information on how they react to lateral loads.

The primary objectives of this study are to assess the effectiveness of structures with unique column shapes. The specific objectives of this study are listed below.
1. To investigate how lateral loads, such as seismic and wind loads, affect a building's behavior.
2. Determination of storey displacements, storey drifts, storey stiffness, and storey overturning moments of the structures under wind and seismic circumstances.

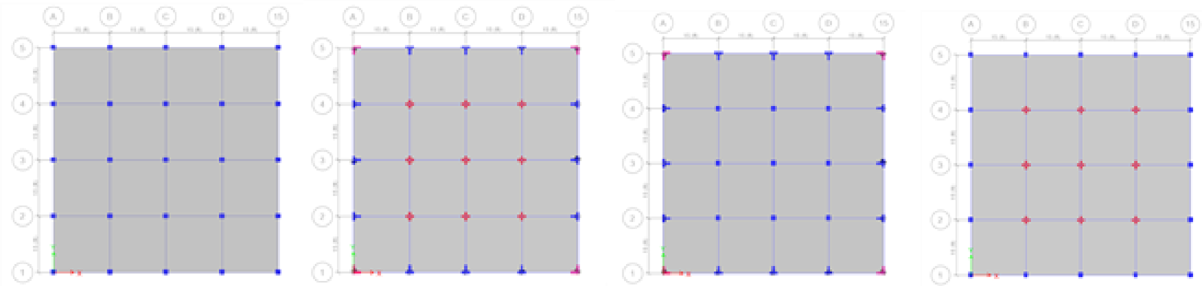
3. To conduct a performance comparison between the structure incorporating special-shaped columns and the one incorporating rectangular columns.

2 Methodology

The building under consideration for this study has a rectangular layout with a total width of 60 feet (Y-direction) and a total length of 60 feet (X-direction). For the comparison of various combinations of specially shaped columns and rectangular columns in a structure. Model 1: all columns are rectangle in shape and spaced 15 feet apart, model 2: corner 4 columns are in L shape, exterior 12 columns are in T shape and the interior 9 columns are in a Cross (+) shape, model 3: corner 4 columns are in L shape, exterior 12 columns are in T shape and the interior 9 columns are rectangle in shape and model 4: the interior 9 columns are Cross (+) in shape and the other corner, exterior 16 columns are rectangle in shape. Building beams, columns, and slab dimensions are considered according to geometrical dimensions and material properties considered in Tables 1 & 2.

2.1 Equivalent Static Load Analysis

The equivalent static force analysis for an earthquake is an exceptional concept that is used in the earthquake-resistant design of structures (Rahaman et al., 2018). This concept is useful since it converts a dynamic analysis into a partly static & dynamic analysis to evaluate the maximum displacements produced in the structure because of earthquakes due to ground motion (Sinha, 1996). Equivalent lateral force for an earthquake is defined as a set of static lateral forces that produce similar peak responses of the structure as that have been produced in the dynamic analysis of the building under similar ground motion (Varyani, 2002). A seismic design response spectrum typically describes the ground motion of an earthquake. It is considered that the building responds in its fundamental mode. ETABS performed an equivalent static load analysis for this study.
The following models are considered for this project:
Model 1: All columns are rectangular;
Model 2: L-shaped and T-shaped columns for the exterior and cross-shaped columns for the interior;
Model 3: L-shaped and T-shaped columns for the exterior and rectangular columns for the interior;
Model 4: Rectangular columns for the exterior and cross-shaped columns for the interior.



Model 1 Model 2 Model 3 Model 4

Figure 1. Models for the analysis

Table 1. Geometrical dimensions of the building and material properties

Member properties		
Slab	Thickness	6″
Column	Rectangular Shaped	14″×16″
	T-Shaped	25″×25″×6″
	L-Shaped	25″×25″×6″
	Cross Shaped	25″×25″×6″
Beam	Grade Beam	16″×14″
	Floor Beam	15″×14″
Concrete	Grade of concrete	4 Ksi
Steel	Grade of steel	60 Ksi

Table 2. Loading data

PARAMETERS	Values
Live load	42 psf
Floor finish load	20 psf
Partition Wall load	0.5 k/ft
Density of concrete	150 lb/ft^3
Density of brick	110 lb/ft^3
Wind velocity	131 mph
Seismic zone	II
Site co-efficient	1.5
Importance factor	1
Response reduction factor	8

3 Results and Discussion

3.1 Storey Displacement

From the equivalent static load analysis, the maximum storey displacement for both rectangular and special-shaped columns is determined.
Figures 2 and 3 show the storey displacement concerning storey height for eight-storey buildings considering earthquake load in both X and Y directions.

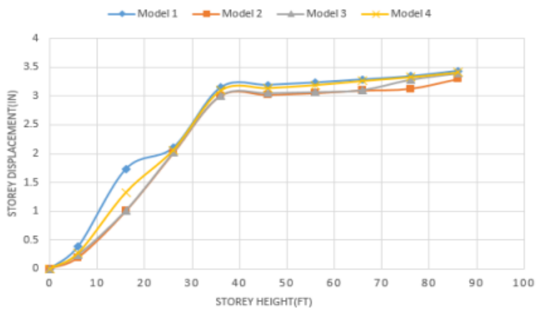


Figure 2. Storey displacement for Eq-x

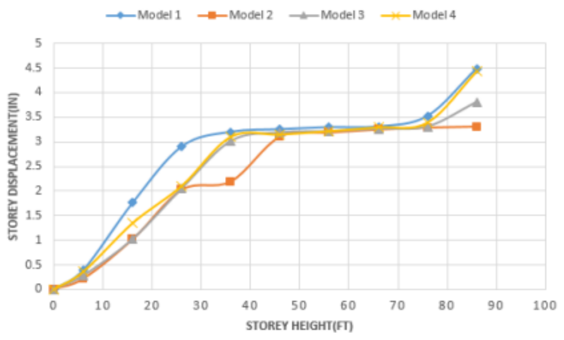


Figure 3. Storey displacement for Eq-y

From the above storey displacement table and graph, the maximum displacement is for model 1(all rectangular column) and the minimum displacement is for model 2(exterior special-shaped column and interior cross-shaped column) in the Y direction for earthquake load (Eq-y). Storey displacement increases by 28.13%, 12.04%, and 19.44% for model 1, model 3, and model 4 respectively compared with model 2.
Model 1(all rectangular column) and the minimum displacement is model 2(exterior special-shaped column and interior cross-shaped column) in X direction for earthquake load (Eq-y). Storey displacement increases 46.13%, 5.8%, and 29.47% for model 1, model 3, and model 4 respectively compared with model 2.
Figure 4 and 5 show the storey displacement concerning storey height for eight-storey buildings considering wind load both in X and Y respectively.

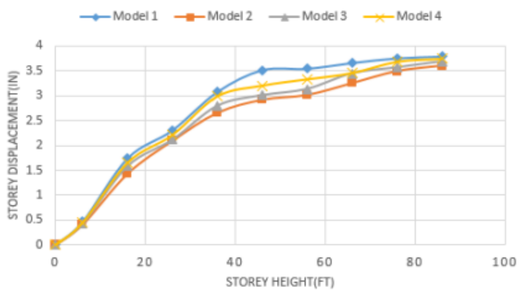


Figure 4. Storey displacement for Wx

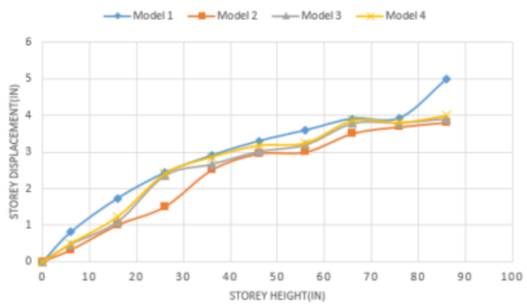


Figure 5. Storey displacement for Wy

From the above storey displacement table and graph, the maximum displacement is for wind load in the Y direction for model 1(all rectangular column) and the minimum displacement is for model 2(exterior rectangular column and interior cross-shaped column). Maximum storey displacement increases 29.34%, 12.23%, and 21.44% respectively for models 1, 3, and 4 respectively compared to model 2.
Maximum displacement is for wind load in the X direction for model 1(all rectangular columns) and minimum displacement is for model 2(exterior rectangular column and interior cross-shaped column). Maximum storey displacement increases by 47.86%, 5.7%, and 32.04% respectively for models 1, 3, and 4 compared to model 2.

3.2 Story Drift

The maximum storey drifts for both rectangular and special-shaped columns are obtained from an equivalent static method. Here earthquake loads and wind loads in both X and Y directions are considered for obtaining maximum storey drift.
Figures 6 and 7 show the storey drift graph for earthquake load both in X and Y directions.

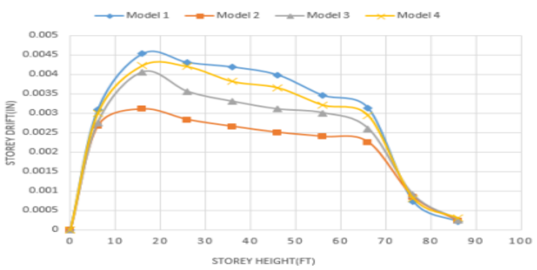


Figure 6. Storey drift graph for Eq-x

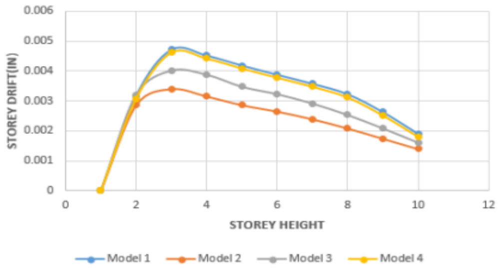


Figure 7. Storey drift graph for Eq-y

From the above storey drift table and graph, the maximum drift is for model 1(all rectangular column) and the minimum displacement is for model 2(exterior special-shaped column and interior cross-shaped column) in the Y direction for earthquake load (Eq-y). Storey displacement increases 25.98%, 11.83%%, and 20.11% for model 1, model 3, and model 4 respectively compared with model 2. Maximum drift is for model 1(all rectangular columns) and the minimum displacement is for model 2(exterior special-shaped column and interior cross-shaped column) in the Y direction for earthquake load (Eq-y). Storey displacement increases by 43.04%, 6.6%, and 29.98% for model 1, model 3, and model 4 respectively compared with model 2. Figures 8 and 9 show the storey drift concerning storey height for eight-storey buildings considering earthquake load and wind load respectively.

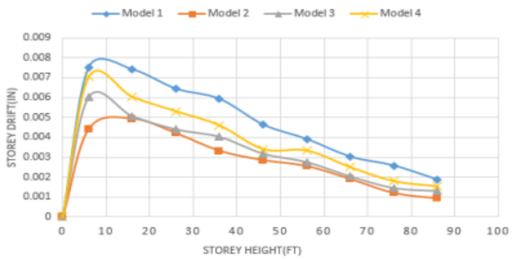


Figure 8. Storey drift graph for Wx

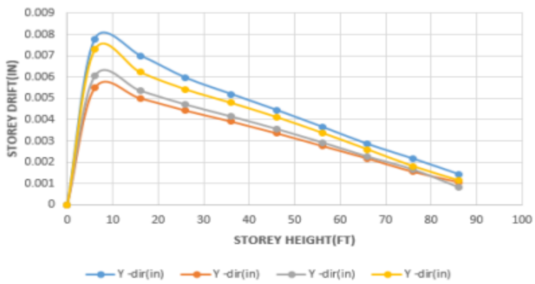


Figure 9. Storey drift graph for Wy

Maximum storey displacement for wind load is in the Y direction for model 1(all rectangular columns) and minimum displacement is for model 2(exterior rectangular column and interior cross-shaped column). Maximum storey displacement increases by 26.55%, 12.04%, and 8.8% respectively for models 1, 3, and 4 compared to model 2. Maximum storey displacement for wind load is in the X direction for model 1(all rectangular columns) and minimum displacement is for model 2(exterior rectangular column and interior cross-shaped column). Maximum storey displacement increases 43.62%, 6.13%%, and 33.25% respectively for models 1, 3, and 4 compared to model 2.

3.3 Story Stiffness

In this study story stiffness is observed from static analysis and load case for both earthquake wind load in both X and Y directions is considered for determining story stiffness.

Figures 10 and 11 show the storey stiffness for various cases of eight-storey buildings considering earthquake load both in X and Y directions.

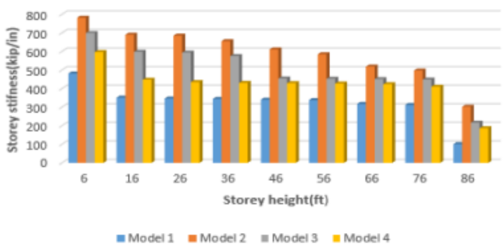


Figure 10. Storey stiffness graph for Eq-x

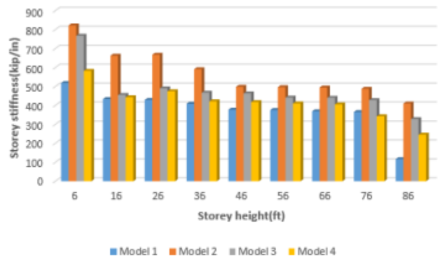


Figure 11. Storey stiffness graph for Eq-y

For models 1, 3, and 4, maximum storey stiffness decreases by 17.54%, 11.35%, and 17.5% respectively compared with building model 2 for earthquake load analysis within the Y direction.
Again for models 1, 3, and 4, maximum storey stiffness decreases by 26.95%, 1.86%, and 23.06 % respectively compared with building model 2 for earthquake load analysis in the X-direction.

Figures 12 and 13 show the storey stiffness for various cases of eight-storey buildings considering wind load both in X and Y directions.

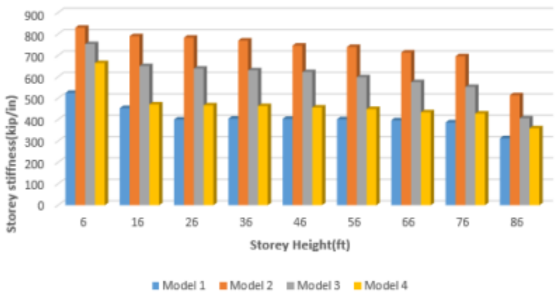


Figure 12. Storey stiffness graph for Wx

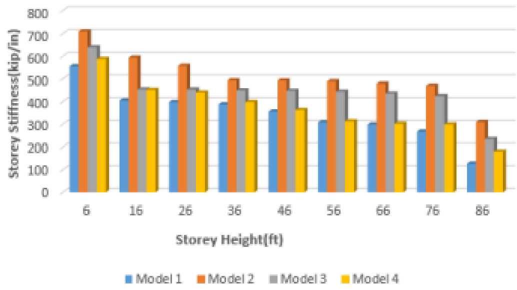


Figure 13. Storey stiffness graph for Wy

For models 1, 3, and 4, maximum storey stiffness decreases by 17%, 11.41%, and 17.68 % respectively compared with building model 2 for wind load analysis in Y.
For the analysis of wind load lateral stiffness for an eight-storey building is the highest for model 2 in Y which is a building with specially shaped columns and lowest for model 1 which is a building with a rectangular-shaped column. For models 1, 3, and 4, maximum storey stiffness decreases by 26.37%, 1.4%, and 23.12% respectively compared with building model 2 for wind load analysis in Y.
Model 2 has the maximum stiffness and model 1 has the minimum stiffness. The relation between load-bearing capacity and storey stiffness is proportional. So, model 2 has a maximum load-bearing capacity.

3.4 Overturning Moment
Figures 14 and 15 show storey overturning moments for eight-storey buildings considering earthquake and wind load respectively.

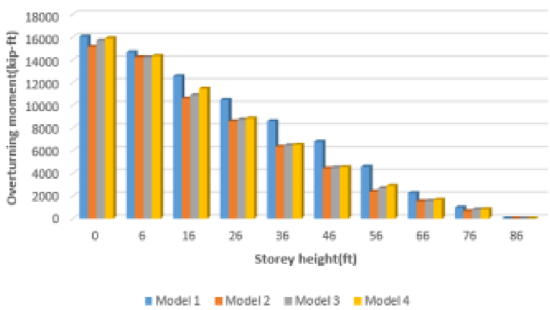


Figure 14. Storey overturning moment for Eq-y

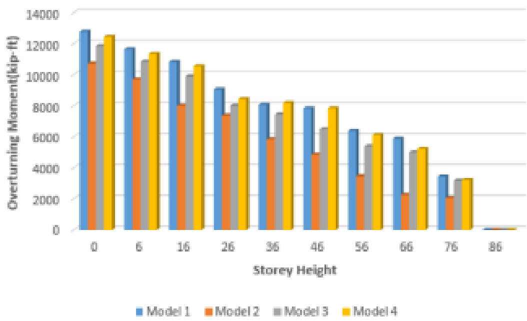


Figure 15. Storey overturning moment for Wy

The above figures show that the overturning moment varies oppositely with the height of the storey. For all cases, storey overturning moment decreases with a rise in the height of the storey. Within the case of rectangular-shaped columns building model 1, produces a higher moment than special-shaped column building models 2, 3, and 4 for an earthquake. Therefore, the overturning moment of model 2 is the lowest. So, the load-bearing capacity of model 2 is the highest. As there's no change in the seismic weight of the building for the change of column shape, the overturning moment for wind load is the same for all model cases.

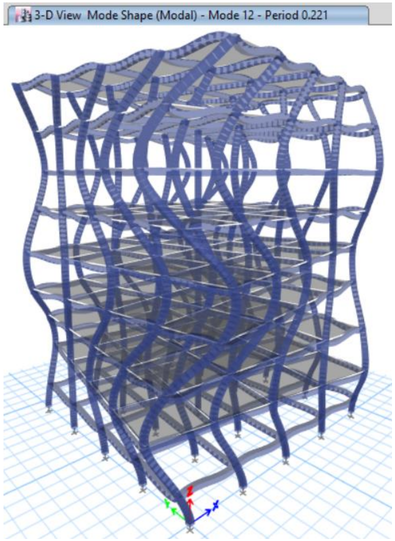


Figure 16. Mode shapes for 12th mode for an eight-storey building using rectangular columns

4 Conclusions

Following the comprehensive comparison analysis, it has been demonstrated that a structure with thin, non-rectangular, specially shaped columns outperforms a structure with rectangular columns under equivalent seismic and wind load circumstances. On the basis of the observations and results from the analysis covered in this paper, the following conclusions were reached:

1. When the deflection of the building is to be minimized, the frame with a combination of L-shaped, T-shaped, and cross-shaped columns is selected because this frame has the highest stiffness among the model types.
2. In comparison to special-shaped column buildings, the storey displacement and storey drift are greatest for rectangular column buildings under seismic and wind load conditions.
3. As the displacement is maximum in model 1(the building of rectangular-shaped columns), the base shear is minimum. And the displacement is minimum in model 2, therefore the base shear is maximum there.
4. Model 1(the building of rectangular-shaped columns) has a higher momentum than that of special-shaped columns. Special-shaped columns produce less moment than rectangular columns, hence less reinforcement is needed to withstand an overturning moment.
5. Specially shaped columns are more capable of withstanding lateral loads than conventional rectangular columns.

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