Grenze International Journal of Engineering and Technology, June Issue

Comparative Study on Structural Behaviour of Single-Column, Four-Column and Conventional Multi-Storey RCC Frame Structure Subjected to Seismic Loading

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***Abstract*— As the demand for open functional spaces has been increased with rapid urbanization, this led to lesser number of columns. Although while designing single column structure, this offers great architecture feasibility but it concerns for safety of structure under seismic loads. The current study consists of comparison analysis of Single column, Four column and Conventional column RCC structures under seismic loads. All three structures are analyzed in STAAD. Pro according to IS 456:2000, IS 875, IS 1893 (Part 1) :2016 with Zone II conditions. Here we compared the results for axial force, bending moment, shear force, deflection, base shear, storey drift and displacement and found that even conventional structure have superior stiffness and stability, while single column structure experience higher forces but the four column structure shows balance performance with allowable seismic responses, causing it good alternative over single column structure or where the reduction of columns are required.**

***Index Terms*— Seismic loading, STAAD. Pro, single column structure, four column structure, conventional multiple column structure, analysis.**

I. INTRODUCTION

With rapid city expansion and urban growth, the land cost also rises which led to effective use of all spaces in multistorey building [1]. Conventional close distance column structure has high strength and stiffness but unreliable in terms of parking layouts, architecture view and many functional planning [2]. To overcome above limitations, structure with fewer number of columns such as single column structure and less column structure got high demand from back few years [3,4]. Single column structure has high working freedom with open floor space [5]. But problem it faces is of high axial force, bending moment and more lateral deformation under seismic loads. [6,7]. This is what makes it complicated for designing as of structural sensitivity [8]. However conventional multiple column structure has high strength and stiffness with uniform load distribution but does not provide open spaces for architectural planning [9,10]. So in between finding for both above structures is a four column structure which fits in structural stability and also gives architectural planning freedom for spaces utilisation.

Grenze ID: 01.GIJET.12.2.308_22

In this load is uniformly distributed in all four columns giving balance configuration in between single column structure and conventional multiple columns structure [11,12]. As there is limited research study available about reduced column structure, moreover in comparison with single column structure and conventional multiple column's structure [13,14]. So, our study fills the gap by comparing structural analysis of single column structure, four column structure and conventional multiple columns structure under seismic loads. The analysis is done in STAAD.Pro according to IS 456:2000, IS 875 and IS 1893 (Part 1): 2016 for Zone II Seismic condition.

II. Literature Review

Certain researchers have have done the study in comparing structural behaviour of conventional multiple columns structure and lesser column structure under seismic loads. The main focus of researchers was to find structural stability, stiffness and serviceability of structure when column numbers are reduced [15]. Ramteke et al. did a comparison analysis of Single column structure and conventional multiple columns structure in STAAD.Pro and their study shows that the single column structure faces high axial force, bending moment and lateral displacement under seismic loads. So they concluded the single column structure requires bigger size column and more reinforcement [16]. Venu Babu and Dumpa Venkateswarlu did a analysis of mono column office building and find its structural behaviour. They found out that single column structure works but requires proper designing and careful detailing as it is structural sensitive under seismic loads [17,18]. Pandey et al.'s research shows when a composite material is used for single column structure its analysis shows improved stiffness and stability. Still storey drift and displacement were high as compared to conventional multiple columns structure, with values remained under permissible limits of IS 1893. Their study also shows that the structure gives freedom to architects to use every space in structure [19]. Other studies focusing on conventional multi-storey RCC buildings that show regular multi-column structure perform better under seismic loading due to uniform load distribution and higher lateral stiffness [20]. Reduced displacement, lower storey drift, and controlled base shear were consistently observed in such systems [21]. From the more recent studies by 2020, Ashok Kumar et al.'s research shows that reducing number of columns from structure directly increases the moment in building [8]. From the research papers available, it is observed that most researchers have focused on either single-column systems or conventional multi-column buildings and no study has been performed on buildings supported on four columns. So, in our study we found out the intermediate solution between single column system and conventional multiple column system. Our four column structure behaves better than single column structure with respect to their seismic performance and structural efficiency.

III. Methodology and Model Description

The present study adopts a numerical analysis approach to compare structural behaviour of buildings with different column configurations under gravity and seismic loading. Structural modelling and analysis are done with STAAD.Pro V8i. Three building models having identical plan dimensions, storey height, material properties, and loading conditions are considered to ensure a fair comparison. The only variation among the models is the column configuration, which governs the load transfer mechanism of the structure. The models considered in the study are:
Model 1: Single-column reinforced concrete building with all floors supported by a central column as shown in Figure 1. Column is located at centre of plan by 6 meter x 6 meter as shown in Figure 2.

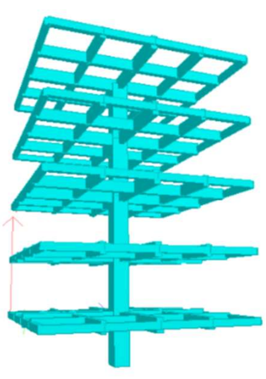


Figure 1. Isometric view of Model-1

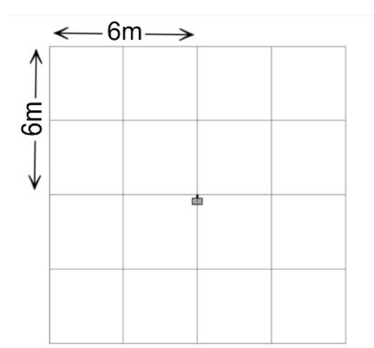
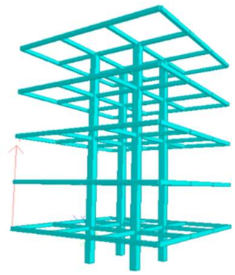


Figure 2. Line plan of Model-1

Model 2: Four-column reinforced concrete building, where gravity and lateral loads are shared by four primary columns as shown in Figure 3. Four columns are located at centre by 4 meter x 4 meter distance as shown in Figure 4.



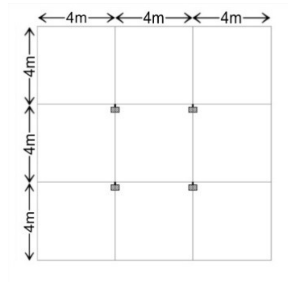
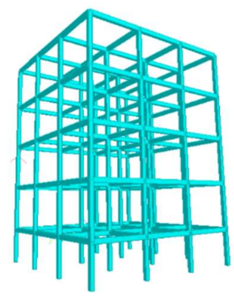


Figure 3. Isometric view of Model-2　　　　Figure 4. Line plan of Model-2

Model 3: Conventional multi-column reinforced concrete framed building with a regular column grid as shown in Figure 5. All columns are at 4 meter distance as shown in Figure 6.



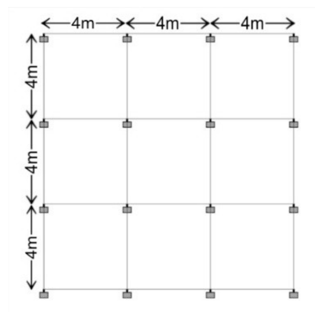
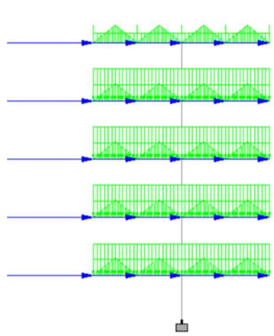
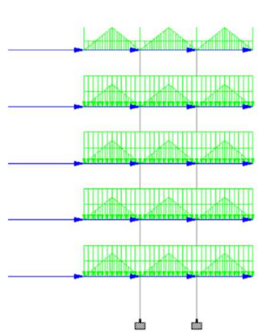


Figure 5.Isometric view of Model-3　　　　Figure 6. Line plan of Model-3

All three building models represent a G+3 (Ground + 3Storey) RCC frame structure with identical geometry. Building configuration, type of structure: RCC framed building, number of storeys: ground+3 floors, plan dimensions:12m x 12m (same for all three models), building height:4 storeys × 4 m = 16 m, column size=0.250m x 0.250m, beam size=0.350 m x 0.800 m (model 1), 0.230 m x 0.350 m (model 2), 0.230 m x 0.350m (model3), storey height: 4.0 m (uniform), slab thickness: 150 mm. All buildings are modelled as G+3storey RCC structures with beams, slabs, and columns designed as per IS 456:2000. Dead loads of internal brick wall 115 mm thick, external brick wall 230 mm thick and parapet wall are taken as 9.2 kN/m, 18.4 kN/m and 5.52 kN/m respectively with 150 mm slab self-weight of 3.75 kN/m² and live load on slab as 3kN/m2 are applied according to IS 875 (Part 1 and Part 2). Seismic analysis is performed as per IS 1893 (Part 1):2016 considering Zone II seismic conditions as shown in Figure 7, Figure 8 and Figure 9. The seismic parameters such as importance factor, response reduction factor, soil type, and damping ratio are defined based on code provisions.





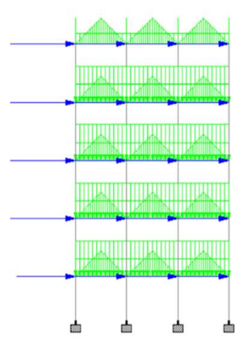


Figure 7. Seismic load on Model-1　　Figure 8. Seismic load on Model-2　　Figure 9. Seismic load on Model-3

Identical load combinations (1.5 DL + 1.5 EQX), (1.5 DL + 1.5 EQY), (1.5 DL - 1.5 EQX), (1.5 DL - 1.5 EQY), (0.9 DL + 1.5 EQX), (0.9 DL + 1.5 EQY), (0.9 DL - 1.5 EQX), (0.9 DL - 1.5 EQY), (1.2 DL + 1.2 LL + 1.2 EQX), (1.2 DL + 1.2 LL + 1.2 EQY), (1.2 DL + 1.2 LL - 1.2 EQX), (1.2 DL + 1.2 LL - 1.2 EQY) are applied to all three models to evaluate their response under gravity and lateral forces. The structural performance is assessed by extracting key response parameters including axial force, bending moment, shear force, deflection, base shear, storey drift, and lateral displacement. These parameters are used to compare the stability, stiffness, and seismic behaviour of the three structural systems.

IV. Results and Discussion

The structural performance of the three building configurations single-column, four-column, and conventional multi-column RCC buildings was evaluated under identical gravity and seismic loading conditions. Critical response metrics of (1.5 DL + 1.5 EQX) from STAAD.Pro provide the basis for the comparison. Axial force, bending moment, shear force, deflection, base shear, storey drift, and lateral displacement are all included in the analysis.

Axial force is maximum in single column structure as whole load is concentrated on single column. While four column structure gives reduced axial force as load is distributed in all four columns. Minimum axial force is obtained in conventional multiple columns structure as of uniform load distribution and stability from Figure 10.

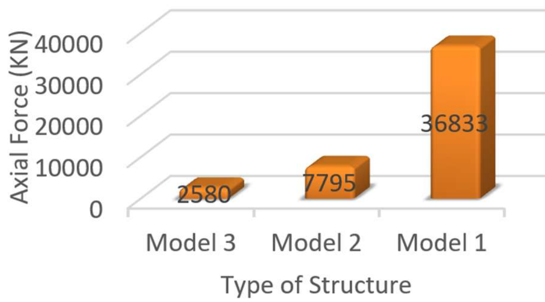


Figure 10. Effect of Maximum Axial force

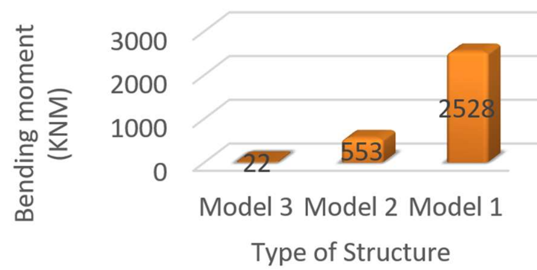


Figure 11. Effect of Maximum Bending moment

Bending moment and shear force are maximum in single column structure due to less structural stiffness and seismic loads. While four column structure gives reduced bending moment and shear force due to less overturning effect. Minimum bending moment and shear force is obtained in conventional multiple columns structure as of regular framing from Figure 11 and Figure 12.

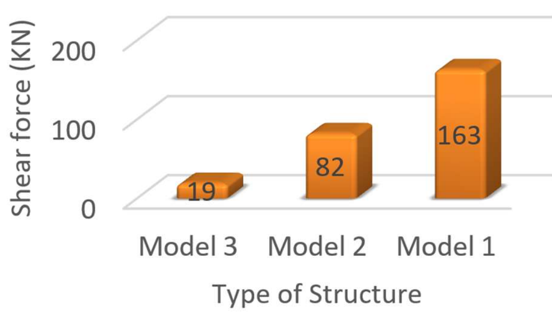


Figure 12. Effect of Maximum Shear force

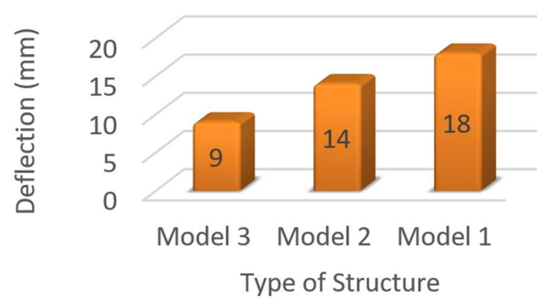


Figure 13. Effect of Maximum Deflection

Deflection is maximum in single column structure due to low stiffness and high flexibility. While four column structure gives reduced deflection as due to improved stiffness. Minimum deflection is obtained in conventional multiple columns structure due to high stiffness and stability from Figure 13. Base shear is maximum in single column structure due to higher effect of seismic loads. While four column structure gives reduced base shear as load is distributed in all four columns. Minimum base shear is obtained in conventional multiple columns structure showing least effect of seismic loads from Figure 14.

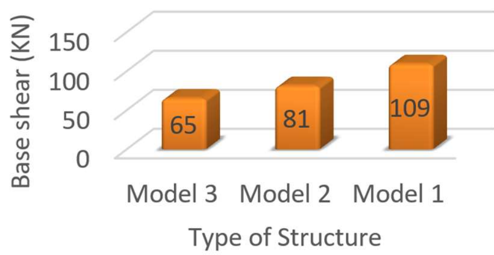


Figure 14. Effect of Maximum Base shear

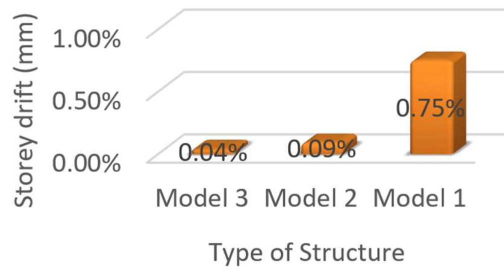


Figure 15. Effect of Maximum Displacement

Storey drift and displacement are maximum in single column structure. While four column structure gives reduced storey drift and displacement, with in code limits of 0.4% storey drift from IS 1893:2016. Minimum storey drift and displacement are obtained in conventional multiple columns structure from Figure 15 and Figure 16.

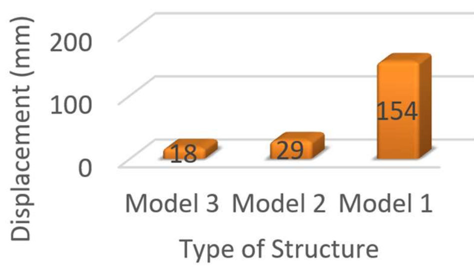


Figure 16. Effect of Maximum Displacement

TABLE I. RESULTS OF DIFFERENT PARAMETERS FOR SINGLE, FOUR AND CONVENTIONAL COLUMN STRUCTURE

Sr.no.	Parameters	Unit	Single column	Four column	Conventional
1.	Axial force	(kN)	36833	7795	2580
2.	Bending moment	(kNm)	2528	553	22
3.	Shear force	(kN)	163	82	19
4.	Deflection	(mm)	18	14	9
5.	Base shear	(kN)	109	81	65
6.	Storey drift	(%)	0.75%	0.092%	0.038%
7.	Displacement	(mm)	154	29	18

So, from Table I we can clearly understand, with reducing the number of columns its seismic responses directly affect the structural stability, strength, stiffness of structure. Jayant Ramteke research shows reducing column increases the bending moment and deflection in structure [16]. However, our four column structure gives balanced results, improved stiffness and proper load distribution while giving architectural freedom within code limits.

V. SUMMARY

This study shows the comparative result for 3 different structure configuration that are single column structure, four column structure and conventional multiple columns structure. All three models are analysed in STAAD.Pro with reference to IS 456:2000 and IS 1893 (Part 1):2016 and following parameters like axial force, bending moment, shear force, deflection, base shear, storey drift, and lateral displacement are found out to study the influence of reducing columns on structure. The results show that reducing number of columns effect structure by increasing force and high response to seismic loads. So intermediate solution found out to be four column structure which shows balanced results within code limits.

VI. CONCLUSION

From above study and results obtained we conclude that the conventional multiple column's structure performs better in terms of axial force, bending moment, deflection, shear force remaining the most reliable and convenient option for multi-storey structure. The single column structure shows higher axial force, bending moment, shear force proving its less structural stiffness and high flexibility due to high effects of seismic loads. The storey drift in single column structure is 0.75 % which exceeds IS 1893:2016 code limit that is 0.4 %. The four column structure has a storey drift of 0.092 %, much lesser than single column structure and code limit, which shows balanced structural behaviour in between all three models, reflecting its high efficiency within code limits. Also shows improvement in seismic performance from single column structure. From structural point of view, we can conclude conventional multiple column structure perform best but the four column structure gives satisfactory results when column reduction is required as providing safety, serviceability and open space utilization. Hence a four column structure can be considered as a good alternative to conventional multiple columns structure when there are architectural requirements.

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