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# Influence of Geometric Configuration on the Seismic Response of T-Shaped Reinforced Concrete Shear Walls in Steel High-Rise Buildings

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ABSTRACT

T-shaped shear walls, due to their three-dimensional behavior, effectively enhance seismic resistance in both principal directions of high-rise buildings. Their performance is strongly influenced by geometric parameters, particularly the flange length-to-thickness ratio and web position. In this study, the seismic behavior of steel high-rise buildings equipped with reinforced concrete T-shaped shear walls was investigated for various flange length-to-thickness ratios, and a comparative assessment with ┼-shaped shear walls was conducted. Linear dynamic response spectrum analysis was performed on 10-, 20-, and 30-story buildings. Maximum story displacements and inter-story drifts were evaluated. The results indicate that with an increase in the flange length-to-thickness ratio, maximum story displacement decreases by 7–22%, and with a further increase in the ratio, the reduction reaches 20–44% compared to the baseline model across different building heights. Furthermore, T-shaped shear walls consistently outperform ┼-shaped configurations, reducing maximum story displacement by 30, 33, and 43% for 10-, 20-, and 30-story buildings, respectively. These findings highlight the significant influence of geometric parameters on seismic performance and provide practical guidance for preliminary design and optimization of shear walls in high-rise steel structures.

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## 1. Introduction

The rapid growth of urban populations and the increasing demand for urban services have made high-rise buildings indispensable elements of modern cities [1-4]. Ensuring both the safety and economic efficiency of these structures requires careful evaluation of various structural systems [4-7]. Steel frames are commonly adopted in high-rise buildings due to their lightweight nature, ease of construction, and high strength-to-weight ratio. However, providing adequate lateral stiffness and resistance against wind and seismic forces remains a critical challenge. Reinforced concrete shear walls are among the most effective systems for resisting lateral loads, significantly reducing story drifts and mitigating non-structural damage [8-10]. Their high shear stiffness compared to other lateral load-resisting systems makes them particularly attractive for both new construction and retrofitting of existing steel buildings [6, 11, 12].

T-shaped reinforced concrete shear walls have gained considerable attention due to their three-dimensional behavior [13-15]. This configuration enables resistance to lateral loads in both principal directions [16, 17]. The geometric characteristics of these walls, such as flange length-to-thickness ratio, web dimensions, and relative positioning of components, directly influence lateral stiffness, energy dissipation capacity, and seismic performance [13, 18-20]. Adjusting these parameters provides opportunities to optimize the seismic response and material efficiency of high-rise buildings [18, 21-23].

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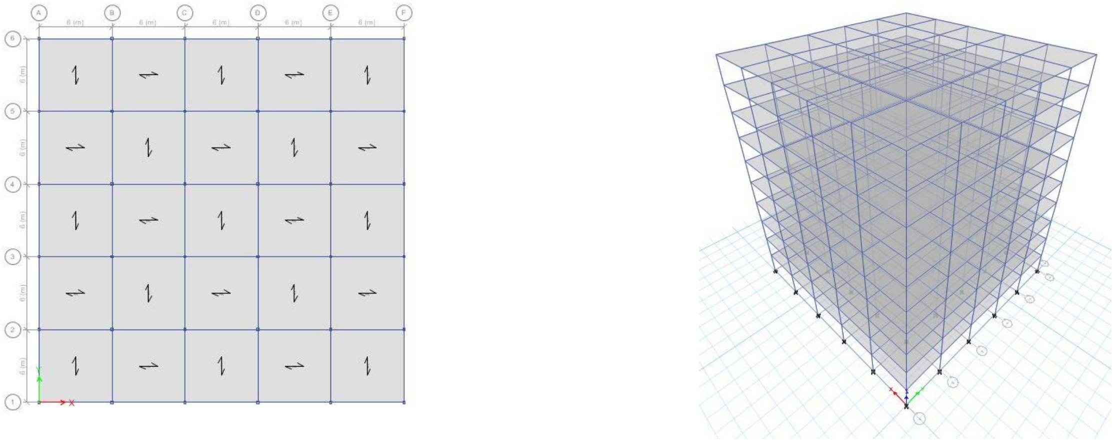
Experimental and numerical studies have extensively examined T-shaped shear walls under various loading conditions. Lefas et al. [24, 25] investigated thirty full-scale walls under combined axial and lateral loads, highlighting the influence of height-to-width ratio, axial force, concrete strength, and horizontal reinforcement on wall performance. Their results indicated that wall strength largely depends on concrete in compression zones, while these zones enhance load-carrying capacity. Thomsen and Wallace [9] observed higher ductility in compression flanges compared to tensioned flanges. Brueggen et al. [21] and Brueggen [26] reported that T-shaped composite walls exhibit lower displacement capacity than rectangular or symmetrically flanged walls, emphasizing careful free-edge design. Rahimi et al. [27, 28] conducted two investigations on T-shaped shear walls in steel high-rise buildings. In the first study [27], they compared rectangular and T-shaped reinforced concrete shear walls within dual systems. Their results showed that T-shaped walls consistently outperform rectangular walls in terms of lateral displacement, inter-story drift, and overall stiffness distribution. The study further demonstrated that optimal performance is achieved when T-shaped walls are placed in intermediate frames, minimizing displacements in both principal directions. In a second study, Rahimi et al. [28] performed an economic assessment, revealing that T-shaped walls require less material while achieving smaller deformations, making them more cost-effective than rectangular walls. Despite the clear advantages highlighted in these studies, the influence of key geometric parameters, particularly the flange length-to-thickness ratio, on seismic performance has not been fully explored. Moreover, comparative assessments with alternative configurations, such as ┼-shaped walls, remain limited.

The present study addresses these research gaps by evaluating the seismic behavior of steel high-rise buildings equipped with T-shaped reinforced concrete shear walls for varying flange length-to-thickness ratios using linear dynamic response spectrum analysis. In addition, a comparative assessment with ┼-shaped walls is performed to examine the impact of geometric modifications on lateral stiffness, story displacement, and inter-story drift. Buildings of 10, 20, and 30 stories are considered to represent typical high-rise structures. The findings provide practical guidance for optimizing shear wall geometry, enhancing seismic performance, and achieving cost-effective design in high-rise building construction.

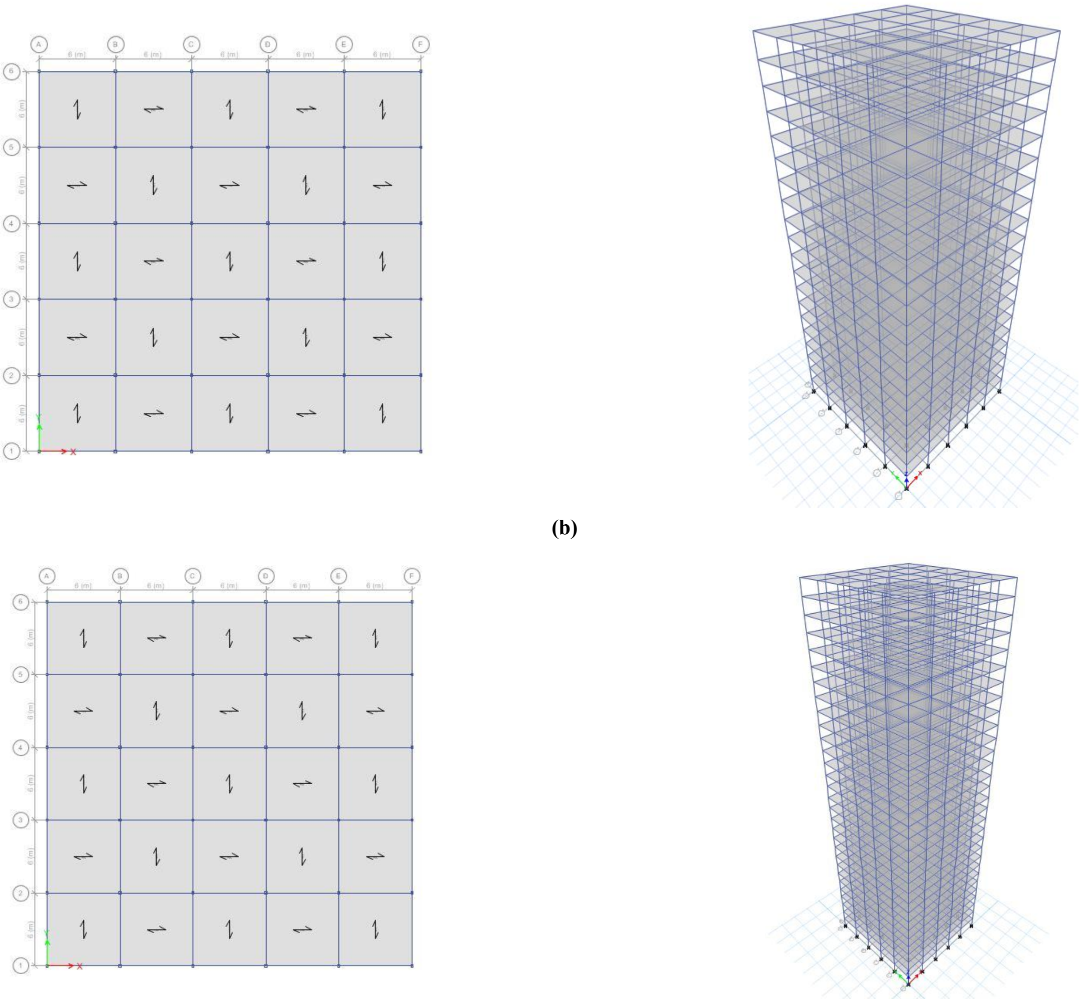
## 2. Methodology

### 2.1. Three-dimensional modeling

The structural modeling of the 10-, 20-, and 30-story buildings was performed using ETABS v15.2.2, which was also employed for the response spectrum dynamic analysis. Three-dimensional models were developed to capture the complete spatial behavior of the structures under both gravity and seismic loads. Fig. 1 illustrates the 3D views and floor plans of the studied buildings, showing a five-bay configuration in both longitudinal and transverse directions, with each bay measuring 6 meters. The typical story height for all buildings was set to 3.5 meters.



**(a)**



(b)

(c)

**Fig. 1. Three-dimensional views and floor plans of the studied high-rise buildings: (a) 10-story, (b) 20-story, and (c) 30-story structures.**

This detailed 3D modeling approach allows for accurate representation of the interaction between steel frames and reinforced concrete shear walls, ensuring realistic prediction of lateral displacements, inter-story drifts, and base shear demands. By using ETABS, both structural response and performance indicators can be precisely evaluated for different geometric configurations of the shear walls.

### *2.2. Structural configuration and loading*

The buildings were designed as dual systems, integrating steel moment-resisting frames with reinforced concrete shear walls. For the 10- and 20-story buildings, intermediate steel moment-resisting frames (IMRFs) were combined with special reinforced concrete shear walls (S-RCWs), while the 30-story building employed special steel moment-resisting frames (SMRFs) along with S-RCWs. For the 10-story building, the thickness of the shear wall on all floors is 30 cm. In the 20-story building, the thickness of the shear wall is 40 cm for the lower 10 floors and 30 cm for the upper 10 floors. In the 30-story building, the thickness of the shear wall is 50 cm for the lower 10 floors, 40 cm for the middle 10 floors, and 30 cm for the upper 10 floors.

Gravity loads were applied as follows: typical floors were assigned a dead load of 500 kg/m², partition load of 100 kg/m², live load of 200 kg/m², and a perimeter wall load of 600 kg/m. For roof floors, dead load was 500 kg/m², live load 150 kg/m², and perimeter wall load 300 kg/m. Seismic analysis was conducted according to the Iranian Seismic Code (Standard 2800, 4th edition) using the response spectrum method. The response spectrum is defined according to the Iranian Seismic Code (Standard 2800, 4th edition), with a damping ratio of 5% for all structural modes. The modal combination was performed using the Square Root of the Sum of the Squares (SRSS) method. For each building, the number of modes considered was sufficient to achieve at least 90% of the total mass participation in both X and Y directions. These additions ensure that the dynamic analysis procedure is fully transparent, reproducible, and consistent with standard engineering practice. Structural steel was modeled as ST37 with a yield strength of 2400 kg/cm² and ultimate strength of 3700 kg/cm², while concrete compressive strength was 25 MPa, reinforced with AIII steel bars. The frames were modeled as I-shaped beams and box-section columns, and P–Delta effects were considered to account for second-order geometric nonlinearities.

This approach provides a robust framework for assessing the influence of geometric parameters, such as flange length-to-thickness ratio, on the seismic performance of T-shaped shear walls and allows for comparative evaluation with ┼-shaped configurations. Key performance indicators, including lateral stiffness, story displacement, inter-story drift, and material consumption, were extracted for detailed analysis.

It should be noted that the present study is based on linear dynamic response spectrum analysis, which evaluates the structural response within the elastic range. Nonlinear material behavior, stiffness degradation, and damage progression under severe earthquakes are not explicitly captured and would require nonlinear time-history analysis.

## 3. Results and discussion

The results of the present study are presented in two main sections. The first section (Section 3.1) focuses on the effects of varying the flange length-to-thickness ratio on the seismic performance of T-shaped reinforced concrete shear walls in steel high-rise buildings. The second section (Section 3.2) provides a comparative assessment between T-shaped and ┼-shaped (cross-shaped) shear walls, in which the web position relative to the flange is altered, while all other parameters remain constant. Sections 3.1 and 3.2 are complementary but examine different aspects of the study: Section 3.1 explores how geometric variations of the T-shaped shear walls influence the building's seismic response, while Section 3.2 investigates how the overall configuration affects lateral displacement, inter-story drift, and structural behavior.

### *3.1. Placement of T-shaped shear walls with different flange length-to-thickness ratios*

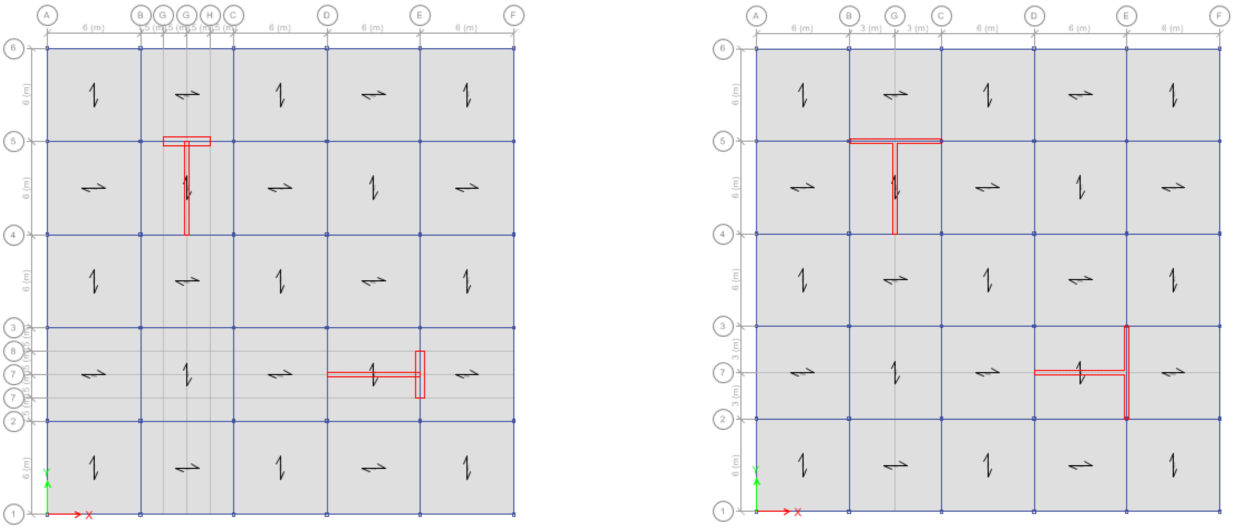
In this section, the seismic behavior of 10-, 20-, and 30-story steel high-rise buildings equipped with T-shaped reinforced concrete shear walls was evaluated for varying flange length-to-thickness ratios using response spectrum analysis. The flange area was kept constant while only the length-to-thickness ratio was varied, and the web dimensions of the shear walls were assumed unchanged. For consistency, the steel frame configuration was maintained identical across all models. As previously mentioned, the plans of the 10-, 20-, and 30-story buildings consist of five bays in both longitudinal and transverse directions, with each bay measuring 6 meters. For the 10-story building, the thickness of the shear wall on all floors is 30 cm. In the 20-story building, the thickness of the shear wall is 40 cm for the lower 10 floors and 30 cm for the upper 10 floors. In the 30-story building, the thickness of the shear wall is 50 cm for the lower 10 floors, 40 cm for the middle 10 floors, and 30 cm for the upper 10 floors.

It is noted that for all models, the cross-sectional area of the shear wall in plan is kept constant to maintain a consistent amount of material. The web dimensions are also fixed across all models. The flange area of the T-shaped shear wall is maintained constant, and the only parameter varied is the flange length-to-thickness ratio. The specific values of these ratios for the different building heights and models are provided in Table 1. This table presents the selected flange length-to-thickness ratios for the T-shaped shear walls in the 10-, 20-, and 30-story buildings. Figs. 2 to 4 illustrate the layout of T-shaped shear walls with different length-to-thickness ratios in the floor plans of the respective buildings.

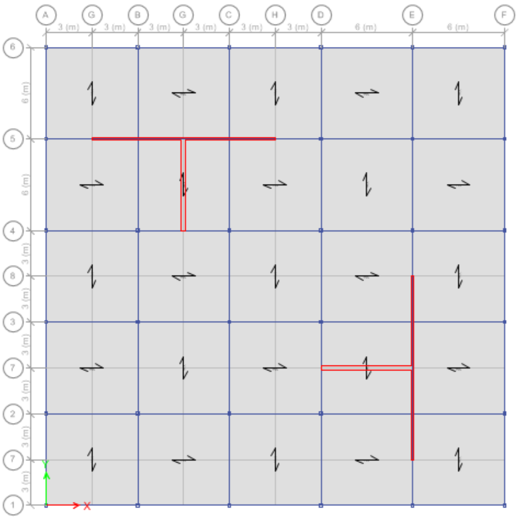
The results are depicted in Figs. 5 to 7, showing the variations in story displacement and inter-story drift. These analyses allow a detailed assessment of how the flange geometry influences the lateral stiffness and overall seismic response of high-rise buildings.

**Table 1. Flange length-to-thickness ratios of T-shaped shear walls in 10-, 20-, and 30-story buildings.**

| | 10 Story | 20 Story | 30 Story |
|---|---|---|---|
| Model 1 | 5 | 6 | 6 |
| Model 2 | 20 | 16 | 11 |
| Model 3 | 80 | 25 | 24 |

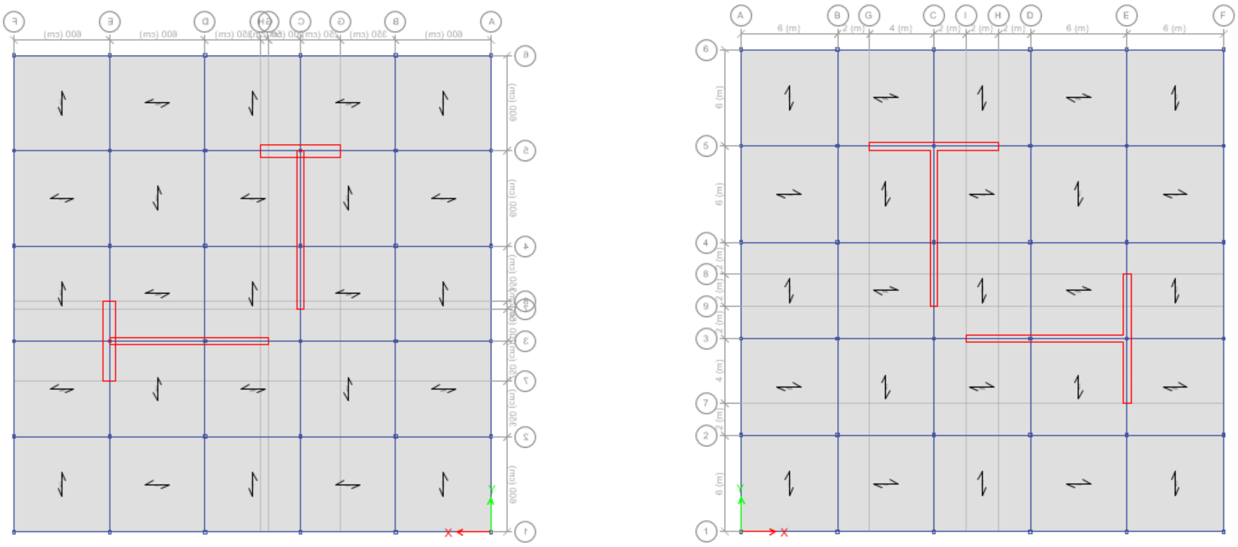


**Model 1** **Model 2**



**Model 3**

**Fig. 2. Layout of T-shaped shear walls with different flange length-to-thickness ratios in the floor plan of the 10-story building.**



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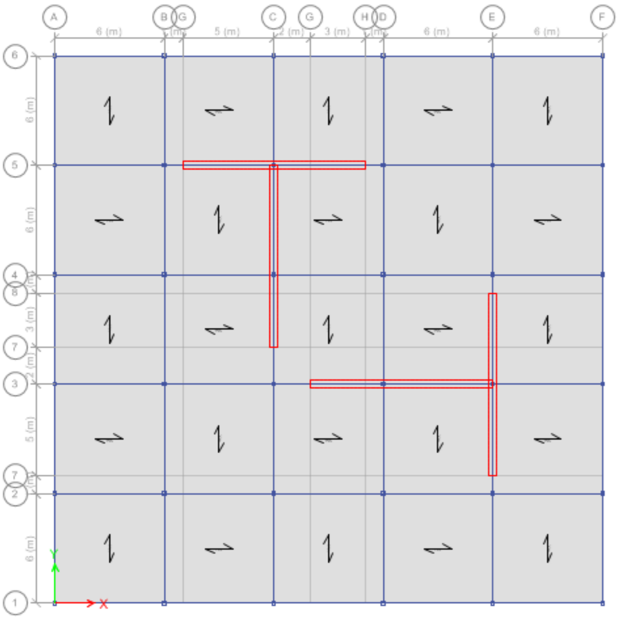
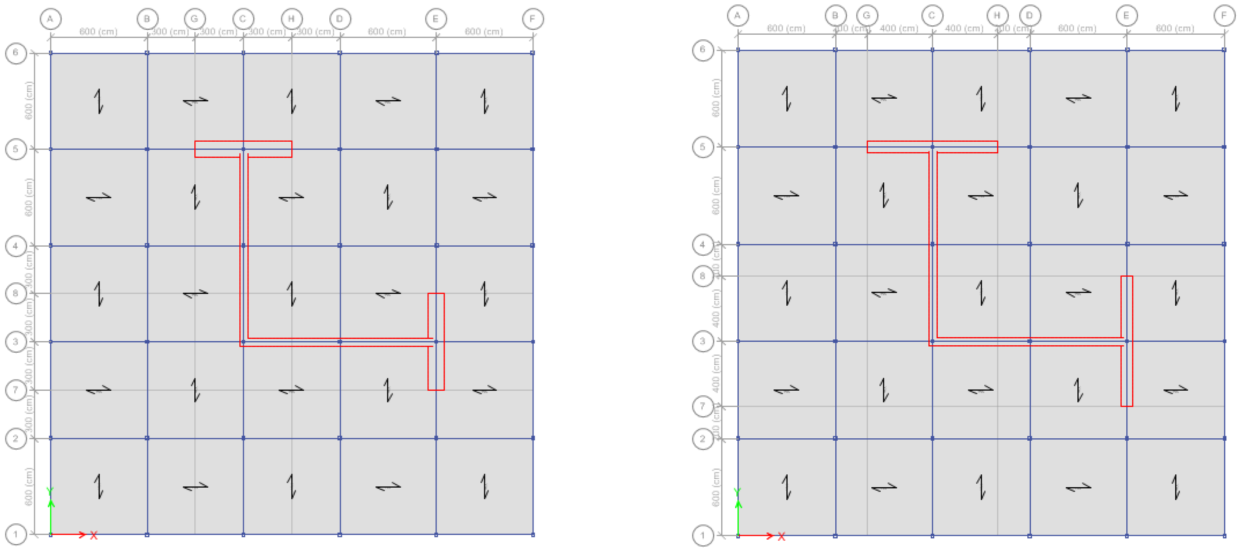
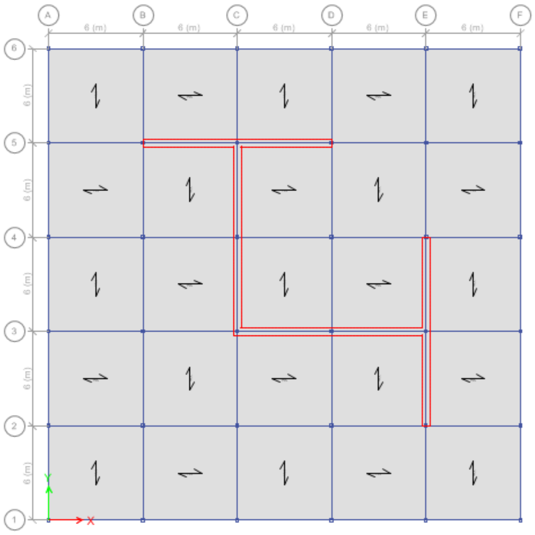


**Model 3**

**Fig. 3. Layout of T-shaped shear walls with different flange length-to-thickness ratios in the floor plan of the 20-story building.**

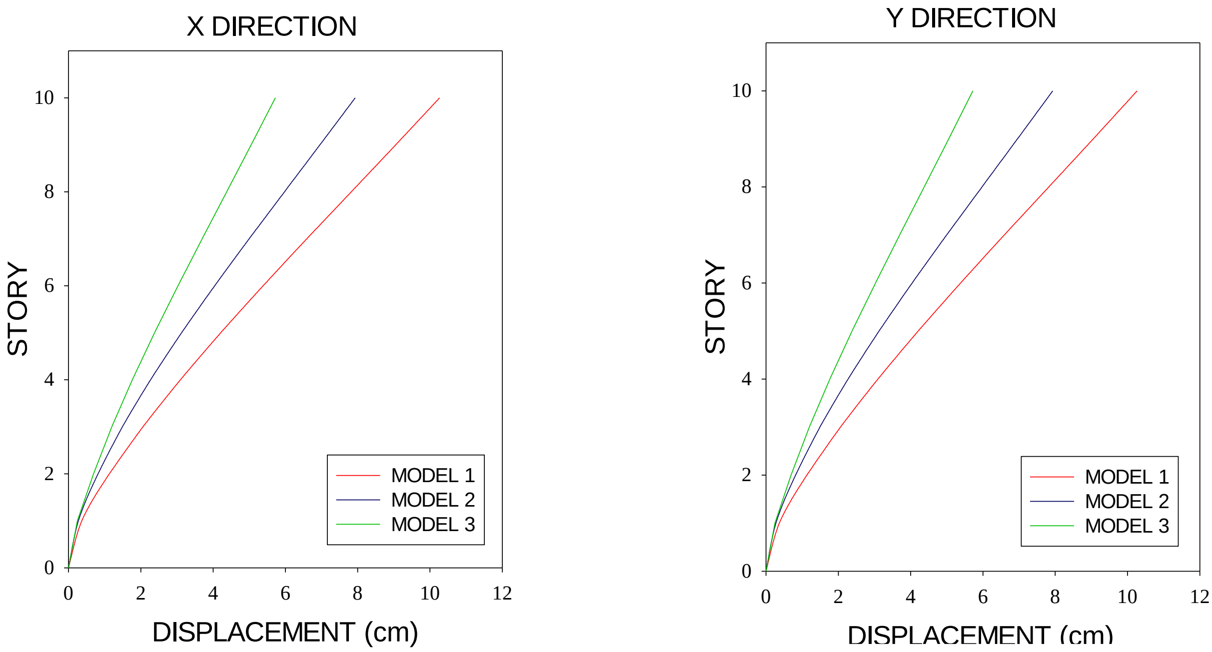


**Model 1** **Model 2**



**Model 3**

**Fig. 4. Layout of T-shaped shear walls with different flange length-to-thickness ratios in the floor plan of the 30-story building.**



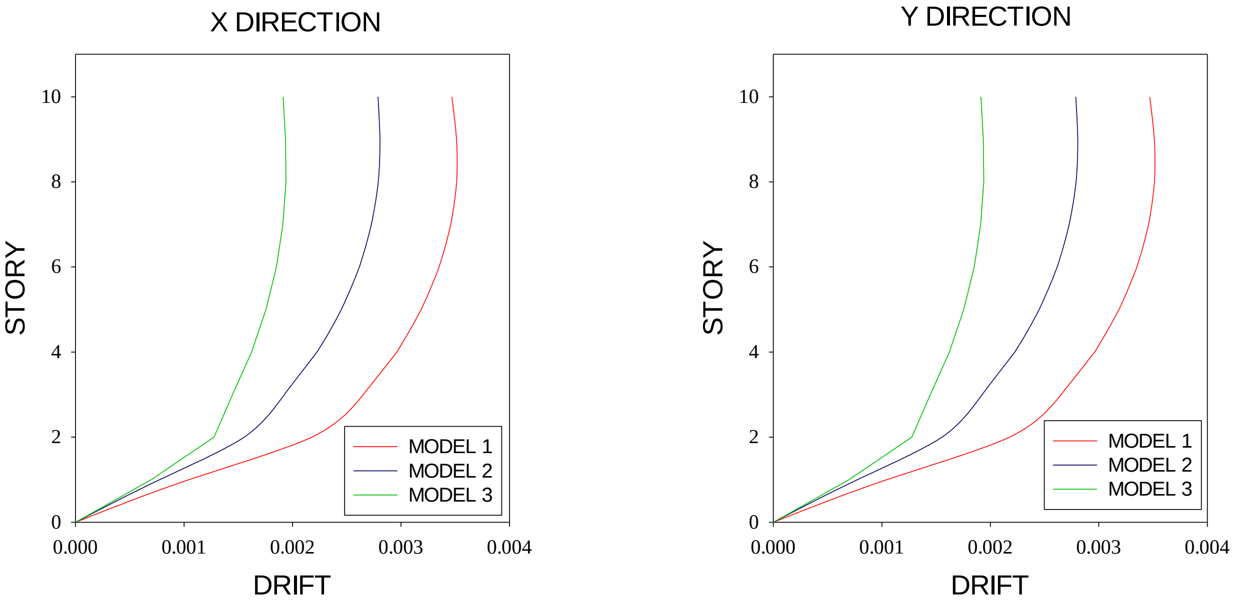


**Fig. 5. Story displacement and inter-story drift of the 10-story building with T-shaped shear walls for different flange length-to-thickness ratios in the X and Y directions.**

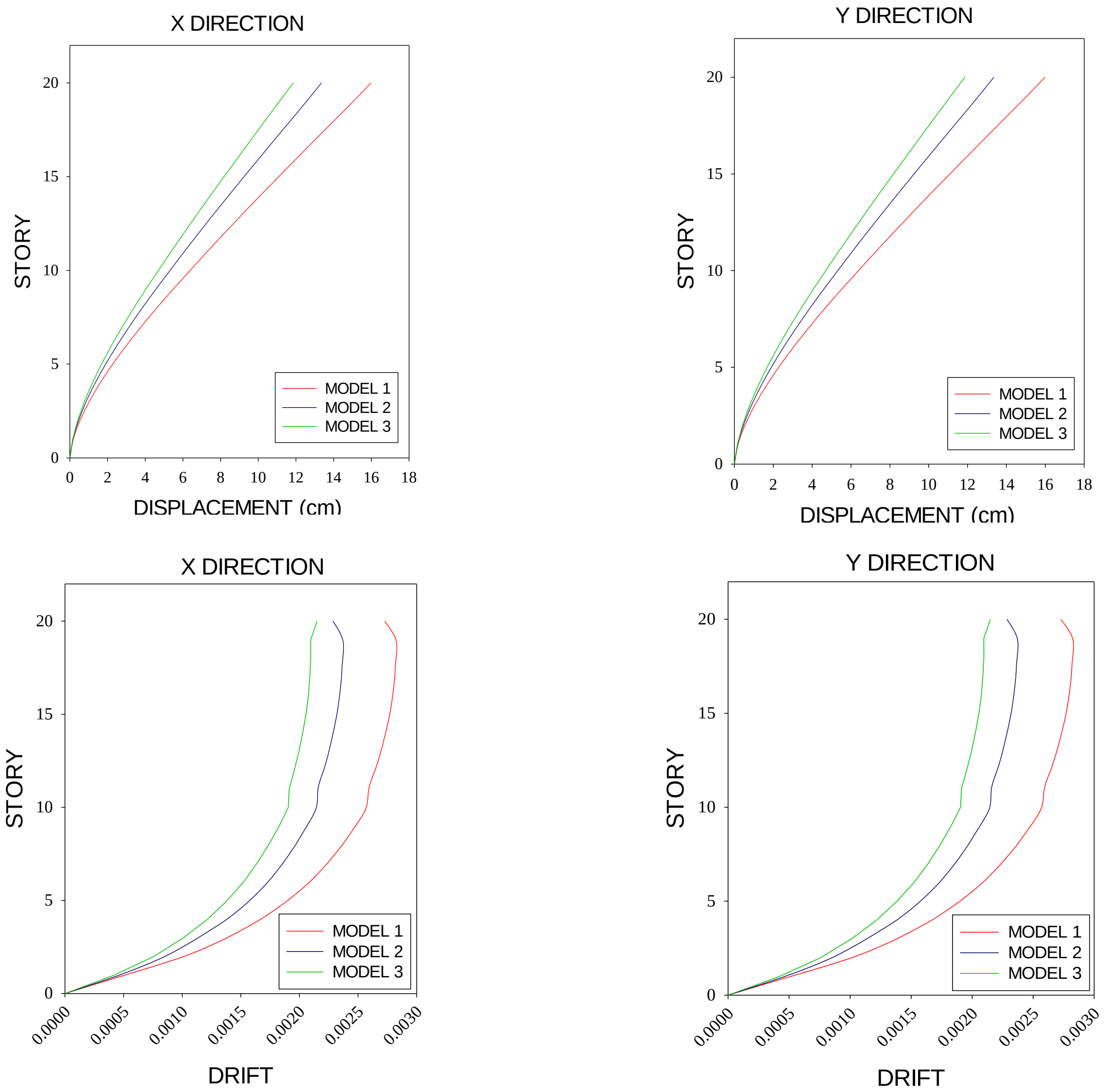


**Fig. 6. Story displacement and inter-story drift of the 20-story building with T-shaped shear walls for different flange length-to-thickness ratios in the X and Y directions.**

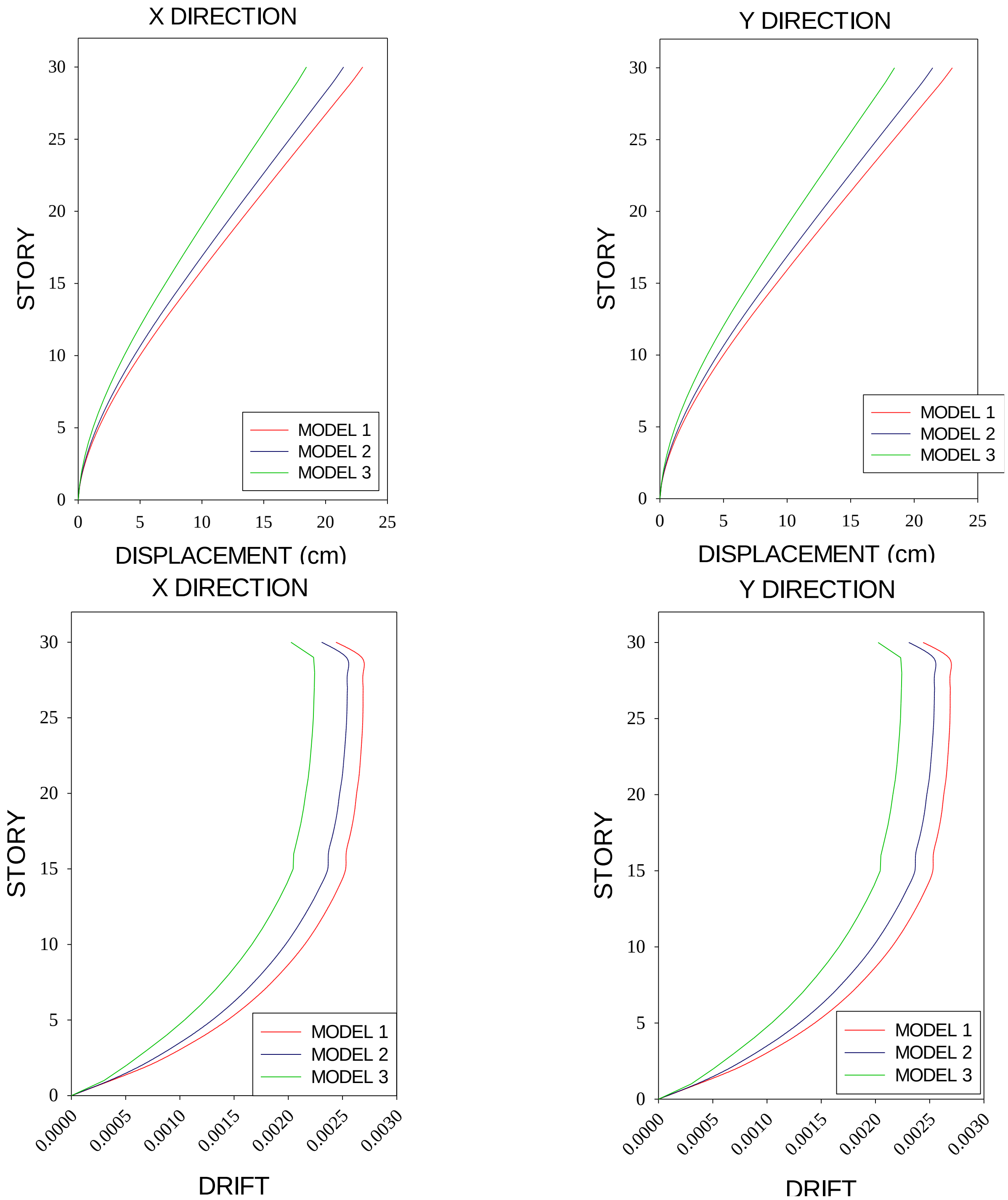


**Fig. 7. Story displacement and inter-story drift of the 30-story building with T-shaped shear walls for different flange length-to-thickness ratios in the X and Y directions.**

As observed, for the 10-, 20-, and 30-story high-rise buildings, when the web dimensions are kept constant and the flange area of the T-shaped shear wall remains unchanged, increasing the flange length-to-thickness ratio leads to a noticeable reduction in both story displacements and inter-story drifts. This behavior can be attributed to the increase in the moment of inertia of the shear wall section as the flange becomes longer and thinner. With a constant web, a higher flange length-to-thickness ratio enhances the in-plane flexural rigidity of the T-shaped wall, resulting in greater lateral stiffness of the structural system. Consequently, the increased stiffness effectively limits lateral deformations, leading to improved seismic performance of the building.

To provide a quantitative comparison of the maximum story displacements under different configurations, the peak story displacement values for Models 1, 2, and 3 in the 10-, 20-, and 30-story buildings are presented in Table 2. Due to the structural symmetry in the X and Y directions, the reported values are representative of both directions. In addition, the percentage reduction in maximum story displacement relative to Model 1 is reported alongside the numerical values for clarity. As observed, increasing the flange length-to-thickness ratio in Model 2 compared to Model 1 results in a reduction of the maximum story displacement in the range of approximately 7% to 22%, depending on the building height. With a further increase in the flange length-to-thickness ratio in Model 3, the reduction becomes more pronounced, reaching approximately 20% to 44% relative to Model 1.

**Table 2. Maximum story displacement values for models 1, 2, and 3 in 10-, 20-, and 30-story buildings.**

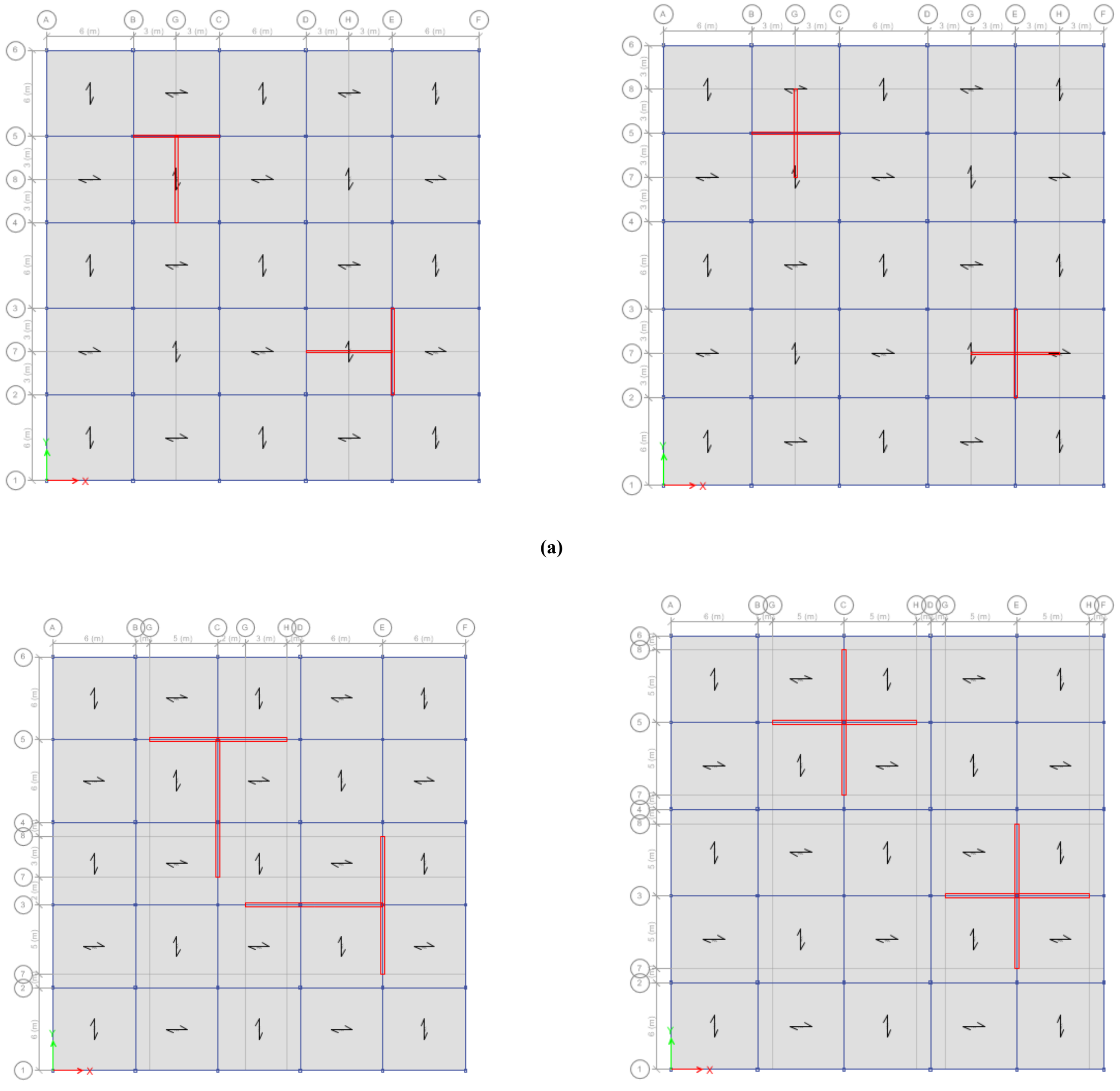
| | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| 10 Story | 10.2 | 7.9 (22%) | 5.7 (44%) |
| 20 Story | 16 | 13.2 (17%) | 11.9 (26%) |
| 30 Story | 23.1 | 21.5 (7%) | 18.4 (20%) |

### *3.2. Comparison of seismic performance of T-shaped and ┼-shaped shear walls*

Fig. 8 illustrates the layout of T-shaped and ┼-shaped shear walls in the floor plans of the 10-, 20-, and 30-story buildings. For the 10-story building, the thickness of the shear wall in all floors is 30 cm. In the 20-story building, the thickness of the shear wall is 40 cm for the lower 10 floors and 30 cm for the upper 10 floors. In the 30-story building, the thickness of the shear wall is 50 cm for the lower 10 floors, 40 cm for the middle 10 floors, and 30 cm for the upper 10 floors.

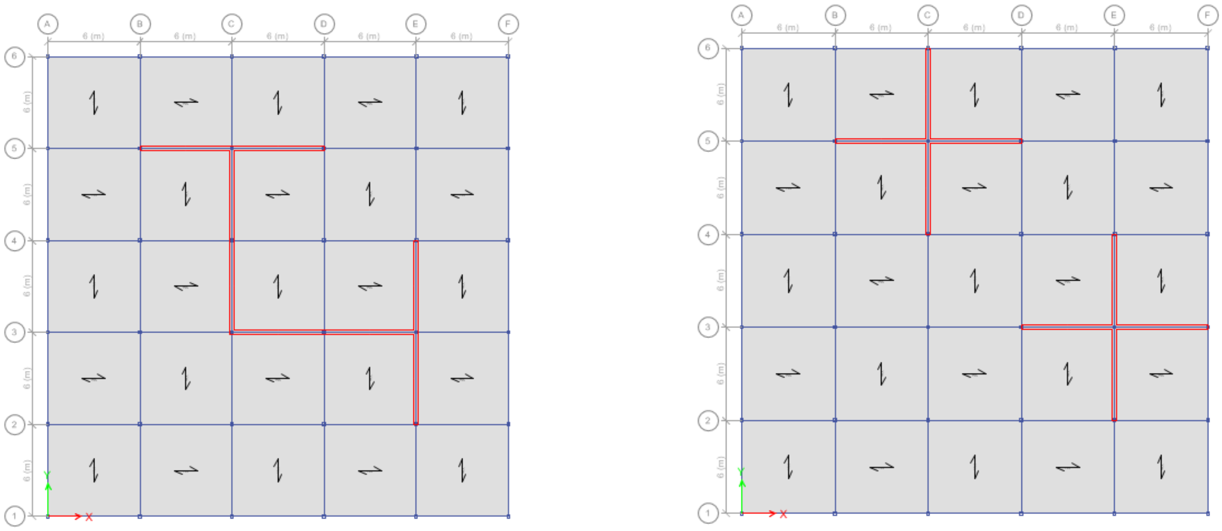
The comparison results of T-shaped and ┼-shaped shear walls in the 10-, 20-, and 30-story buildings are presented in the form of story displacement and inter-story drift diagrams in the X and Y directions, as shown in Figs. 9 to 11.

It is noted that the comparison between the T-shaped and ┼-shaped shear walls was conducted based on equivalent geometric and material assumptions. The cross-sectional area of the shear walls in plan was kept constant to ensure a similar quantity of material in both configurations. In addition, the material properties and overall modeling assumptions were identical for all models. Therefore, the comparison is based solely on the effect of configuration and geometric arrangement on seismic performance.



**(a)**

**(b)**



**(c)**

**Fig. 8. Layout of T-shaped and ┼-shaped shear walls in the floor plans of high-rise buildings: (a) 10-story, (b) 20-story, and (c) 30-story buildings.**

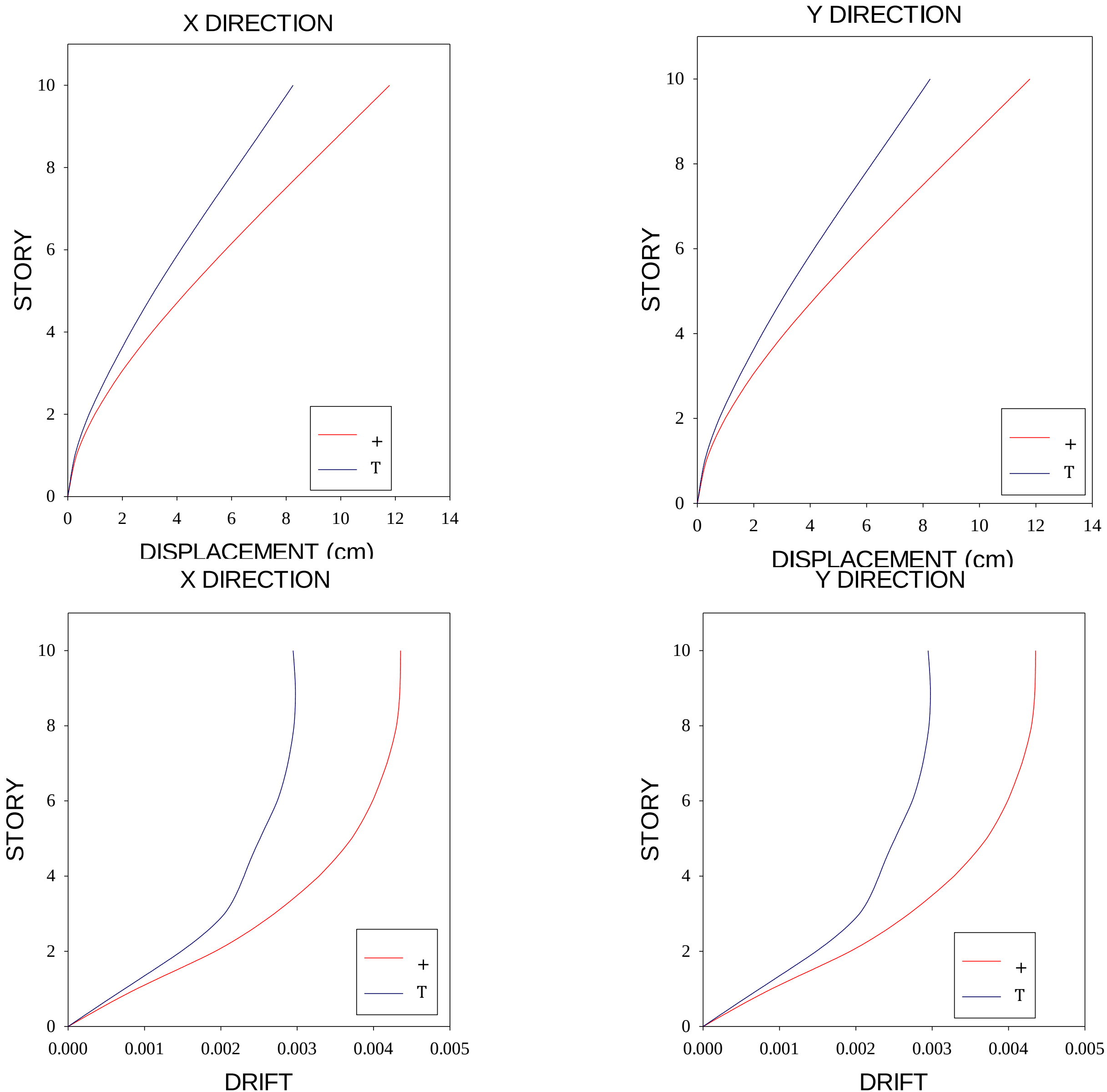


**Fig. 9. Story displacement and inter-story drift of the 10-story building with T-shaped and ┼-shaped shear walls in the X and Y directions.**

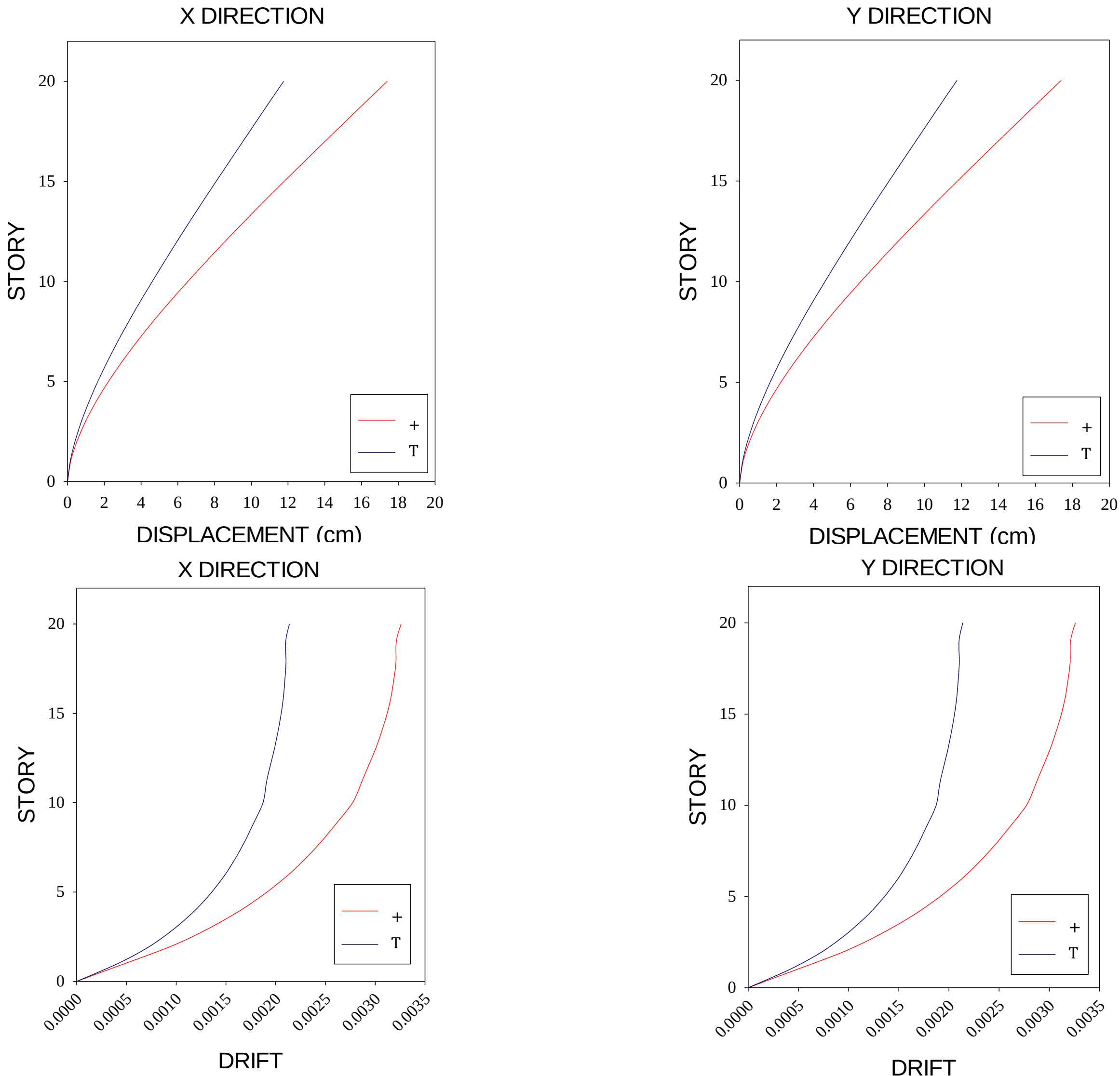
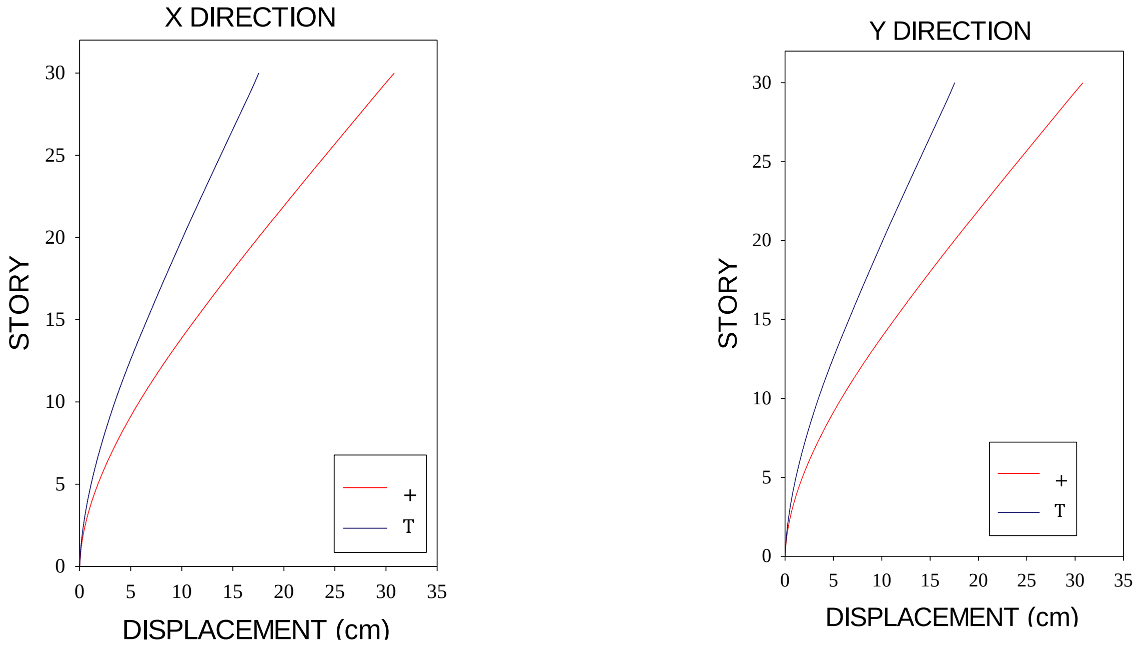


**Fig. 10. Story displacement and inter-story drift of the 20-story building with T-shaped and ┼-shaped shear walls in the X and Y directions.**



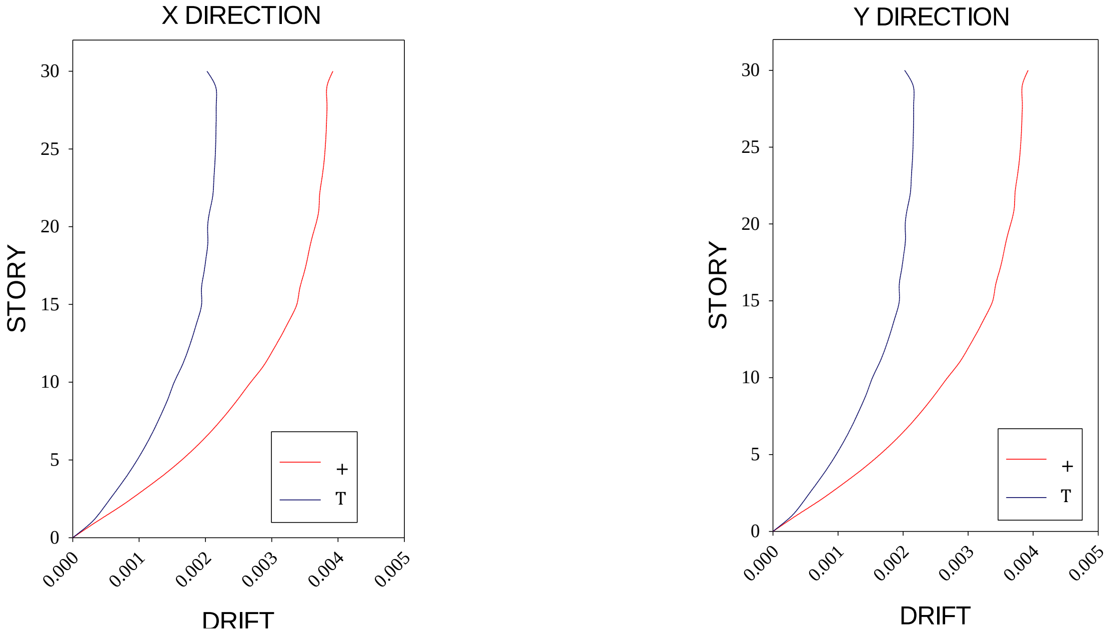


**Fig. 11. Story displacement and inter-story drift of the 30-story building with T-shaped and ┼-shaped shear walls in the X and Y directions.**

As observed, in the 10-, 20-, and 30-story buildings, structures equipped with T-shaped shear walls exhibit superior seismic performance compared to those with ┼-shaped shear walls in terms of both story displacement and inter-story drift. This improvement is primarily attributed to the higher lateral stiffness of the T-shaped configuration. The stiffness of a shear wall is directly related to its in-plane moment of inertia, and the moment of inertia of a T-shaped wall is greater than that of a ┼-shaped wall due to the more effective distribution of material farther from the centroidal axis of the section. Consequently, the increased moment of inertia enhances the lateral stiffness of the structural system, leading to reduced lateral displacements and inter-story drifts.

To provide a quantitative comparison between the T-shaped and ┼-shaped shear wall configurations, the maximum story displacement values for both systems in the 10-, 20-, and 30-story buildings are presented in Table 3. Due to structural symmetry in the X and Y directions, the reported displacement values are representative of both directions. In addition, the percentage reduction in maximum story displacement relative to the ┼-shaped configuration is provided alongside the numerical values for clarity. As observed, the T-shaped shear wall configuration leads to a significant reduction in maximum story displacement compared to the ┼-shaped system. Specifically, the reductions are approximately 30%, 33%, and 43% in the 10-, 20-, and 30-story buildings, respectively. These results indicate that the T-shaped configuration provides improved lateral stiffness efficiency, particularly as building height increases.

**Table 3. Maximum story displacement for T-shaped and ┼-shaped shear walls in 10-, 20-, and 30-story buildings.**

| | **┼-shaped** | **T-shaped** |
|---|---|---|
| 10 Story | 11.8 | 8.2 (30%) |
| 20 Story | 17.5 | 11.7 (33%) |
| 30 Story | 30.8 | 17.6 (43%) |

## 4. Conclusion

This study investigated the seismic behavior of steel high-rise buildings equipped with T-shaped reinforced concrete shear walls, focusing on the influence of flange length-to-thickness ratio and comparing T-shaped walls with ┼-shaped walls. Buildings with 10, 20, and 30 stories were analyzed using three-dimensional modeling and linear response spectrum dynamic analysis. The main conclusions drawn from this research are as follows:

1. Increasing the flange length-to-thickness ratio of T-shaped shear walls, while keeping the flange area and web dimensions constant, significantly enhances the lateral stiffness of the walls. This increase in stiffness leads to reduced story displacements and inter-story drifts in all examined buildings. The improvement is attributed to the higher moment of inertia associated with larger flange ratios, which effectively resists lateral forces.
2. T-shaped shear walls consistently outperform ┼-shaped walls in terms of lateral displacement and inter-story drift. The higher moment of inertia of T-shaped walls, due to the greater distance of the flange from the wall center, results in enhanced plan stiffness and better overall seismic performance.
3. The results indicate that careful adjustment of geometric parameters, particularly the flange length-to-thickness ratio, can be an effective strategy for optimizing seismic performance without increasing material usage. T-shaped walls offer a cost-effective and efficient lateral load-resisting system, suitable for both new constructions and retrofitting of existing high-

rise steel buildings.

4. For high-rise buildings in seismic-prone regions, placing T-shaped shear walls in intermediate frames is recommended to achieve balanced stiffness distribution and minimize displacements in both principal directions. Additionally, adopting T-shaped walls over ┼-shaped configurations can lead to more resilient and economical structural designs.

In conclusion, T-shaped reinforced concrete shear walls provide a superior solution for lateral load resistance in steel high-rise buildings, and optimizing their geometric properties can significantly enhance both structural performance and cost efficiency. Future studies may explore nonlinear dynamic analyses, multi-hazard effects, and hybrid shear wall configurations to further refine design guidelines for high-rise structures.

## 5. Application of research results

The findings of this study have practical implications for the design and optimization of lateral load-resisting systems in steel high-rise buildings. By adjusting the flange length-to-thickness ratio of T-shaped shear walls, engineers can significantly enhance lateral stiffness, reduce story displacements, and minimize inter-story drifts, improving the overall seismic performance of high-rise buildings. Furthermore, the demonstrated superiority of T-shaped walls over ┼-shaped configurations provides guidance for selecting optimal shear wall geometries, enabling more efficient use of materials, cost-effective design, and improved structural resilience. These results can be directly applied in the planning and retrofitting of high-rise structures in seismic-prone regions.

## Statements & Declarations

### *Author contributions*

**Mehran Rahimi:** Conceptualization, Investigation, Formal analysis, Resources, Writing - Original Draft, Writing - Review & Editing.

**Khosrow Bargi:** Conceptualization, Formal analysis, Resources, Supervision, Project administration, Writing - Review & Editing.

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### *Data availability*

The data presented in this study will be available on request from the corresponding author.

### *Declarations*

The authors declare no conflict of interest.

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