Civil Engineering and Applied Solutions
Research Article
journal homepage: ceas.journals.umz.ac.ir

CEAS Civil Engineering and Applied Solutions

Balancing Cost and Seismic Performance: Rectangular vs. T-shaped Shear Walls in Steel Frame Tall Buildings

Mehran Rahimi [a], Khosrow Bargi [a*], Moein Rezapour [a]

[a] *School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran*

A R T I C L E I N F O

Keywords:
Tall building
T-shaped shear wall
Seismic behavior
Dual system
Structural efficiency

Article history:
Received 19 September 2025
Accepted 01 October 2025
Available online 01 January 2026

A B S T R A C T

The economic importance of tall buildings makes the selection of lateral load-resisting systems a critical challenge, as these systems must also be cost-effective. One widely adopted option for such structures is the steel moment frame combined with reinforced concrete shear walls. In many tall buildings around the world, reinforced concrete shear walls are recognized as an efficient lateral system. Improving the performance of these structures through the optimal placement of shear walls in the building plan can result in significant cost savings. A common practice is to modify conventional rectangular shear walls into T, L, or I-shaped configurations. Due to their three-dimensional efficiency, T-shaped shear walls can provide seismic resistance in both principal directions of a building. In this study, an economic comparison was conducted between rectangular and T-shaped reinforced concrete shear walls in steel-frame tall buildings. The results showed that T-shaped shear walls are economically superior to rectangular ones, as they require less material while achieving smaller deformations. Moreover, T-shaped walls do not impose significant architectural or construction challenges, as their geometry facilitates the integration of functional elements such as elevator shafts.

1. Introduction

Rapid urbanization, population growth, and economic demands have driven the construction of tall buildings worldwide [1-3]. Designing these structures requires balancing safety, performance, and cost-effectiveness [4, 5]. Selecting efficient lateral load-resisting systems is crucial to control wind and seismic forces while minimizing construction and maintenance costs [6, 7]. Dual systems combining steel moment frames and reinforced concrete shear walls are widely used. Steel frames offer high strength-to-weight ratios and ductility, while concrete shear walls provide significant lateral stiffness, controlling displacements and enhancing stability [8, 9]. Hybrid frame–shear wall systems leverage both advantages, enabling resilient and economical designs for buildings typically ranging from 20 to 60 stories [10-12]. Shear wall layout critically affects structural performance. Transforming conventional rectangular walls into T, L, or I-shaped configurations improves lateral and torsional stiffness. T-shaped walls, in particular, exhibit superior three-dimensional performance, reduce lateral displacements, and allow for more economical designs by better force distribution and reduced steel requirements [13, 14].

In recent years, significant attention has been paid to the seismic behavior of T-shaped shear walls. Lefas et al. tested thirty full-scale walls under combined axial and lateral loads, examining the effects of parameters such as height-to-width ratio, axial load, concrete strength, and horizontal reinforcement. Their results indicated that wall strength largely depends on concrete in compression zones, while these zones enhance load-carrying capacity [15, 16]. Thompsen and Wallace observed that when the wall flange is under compression, the ductility is significantly higher, whereas tensioned flanges exhibit a more brittle behavior [17]. Brueggen's tests on two steel–concrete composite walls showed lower displacement capacity in T-shaped walls compared to rectangular or symmetrically flanged walls, emphasizing careful free-edge design [18]. Pin-Le and Qing-ning identified the web

* Corresponding author.
E-mail addresses: kbargi@ut.ac.ir (K. Bargi).

https://doi.org/10.22080/ceas.2025.30091.1043
ISSN: 3092-7749/
How to cite this article: Rahimi, M., Bargi, K., Rezapour, M. Balancing Cost and Seismic Performance: Rectangular vs. T-shaped Shear Walls in Steel Frame Tall Buildings. Civil Engineering and Applied Solutions. 2026; 2(1): 12–21. doi:10.22080/ceas.2025.30091.1043.

region as the main weak point, with failures resulting from concrete crushing and steel yielding under cyclic loading [19]. Lu and Yang reported flexural failures at the free-edge web of narrow steel–concrete walls and emphasized the need for adequate confinement under increasing axial loads [20]. Ji et al. compared Chinese and American design codes, revealing that GB 50011-2010 underestimates boundary element lengths without flanges, potentially causing premature failure [21]. Lan et al. demonstrated that T-shaped composite walls perform well under 45° angled loading; while higher axial loads increase strength, they limit ductility [22]. Building on the findings of the aforementioned studies, more recent research has focused on innovative arrangements and complex loading patterns. Brueggen et al. suggested that uniform distribution of longitudinal reinforcement across the flange, rather than concentrating it in boundary elements, reduces shear lag, crack width, and overall damage in T-shaped reinforced concrete walls under multiaxial loading [23].

Recent advances have emphasized the crucial role of shear wall configuration in the seismic performance of tall buildings. Rahimi and Bargi [24] performed a comparative study on tall buildings with rectangular and T-shaped reinforced concrete shear walls within dual systems. Their results indicated that optimal performance occurs when shear walls are placed in intermediate frames, as this configuration minimizes displacements in both principal directions and achieves a more balanced stiffness distribution. Furthermore, T-shaped walls consistently outperformed rectangular walls in both linear and nonlinear analyses, exhibiting reduced roof displacements and inter-story drifts. This improvement was attributed to the higher moment of inertia of T-shaped walls in the plan layout, which provides greater stiffness and seismic resilience. These findings suggest that T-shaped shear walls can offer a more efficient lateral load-resisting system in high seismic zones, motivating further investigations into their application and potential optimization in tall building design.

In the present study, an economic comparison was conducted between rectangular and T-shaped reinforced concrete shear walls in steel frame tall buildings with 10, 20, and 30 story heights. The analysis was performed for two seismic zones with design base acceleration ratios of A = 0.35 and A = 0.5 to evaluate the effect of varying seismic hazard on the selection and optimization of lateral load-resisting systems. Buildings with 10, 20, and 30 stories represent typical tall structures in the country. The inclusion of A = 0.5 alongside A = 0.35 is motivated by the presence of areas that are located near active faults and thus experience higher seismic risk. Moreover, the critical importance of tall buildings necessitates a more detailed assessment under severe seismic conditions.

2. Methodology

2.1. Geometrical properties of buildings

Figs. 1 to 3 illustrate the three-dimensional view and floor plan of the 10, 20, and 30-story buildings. Each building consists of five bays with a span length of 6 m in both longitudinal and transverse directions. The height of all buildings is 3.5 m. The structural modeling was carried out in three dimensions.

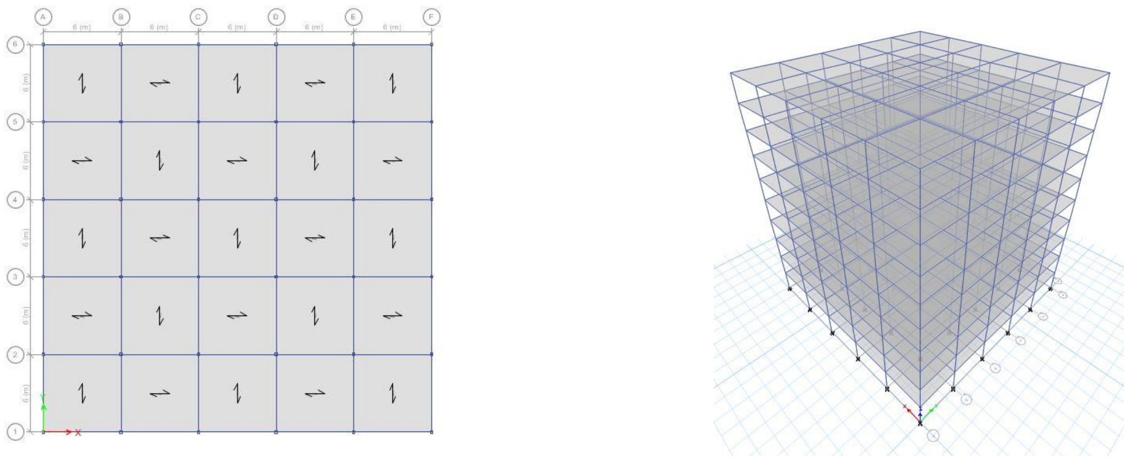

Fig. 1. Three-dimensional view and floor plan of the 10-story building frame.

2.2. Assumptions and modeling details

Three-dimensional modeling and response spectrum dynamic analysis serve as powerful tools for predicting the seismic performance of structures and comparing different design alternatives. In this study, the modeling and design of the buildings were carried out using ETABS v16. The response spectrum dynamic analysis was also conducted using the same software to evaluate the structural behavior under the earthquake response spectrum. By incorporating both the seismic characteristics of each region and the structural properties, this analysis enables the estimation of maximum displacements, forces, and shear demands, thereby providing a basis for the economic and performance comparison of the two shear wall systems. In addition to the use of software, a set of modeling assumptions and code-based standards was considered. These assumptions included the selection of material behavior, connection modeling, bracing conditions, and detailing of walls and frames. Furthermore, economic and performance indicators such as structural weight, steel and concrete consumption, lateral stiffness, inter-story drift, and base shear were employed for comparison and evaluation.

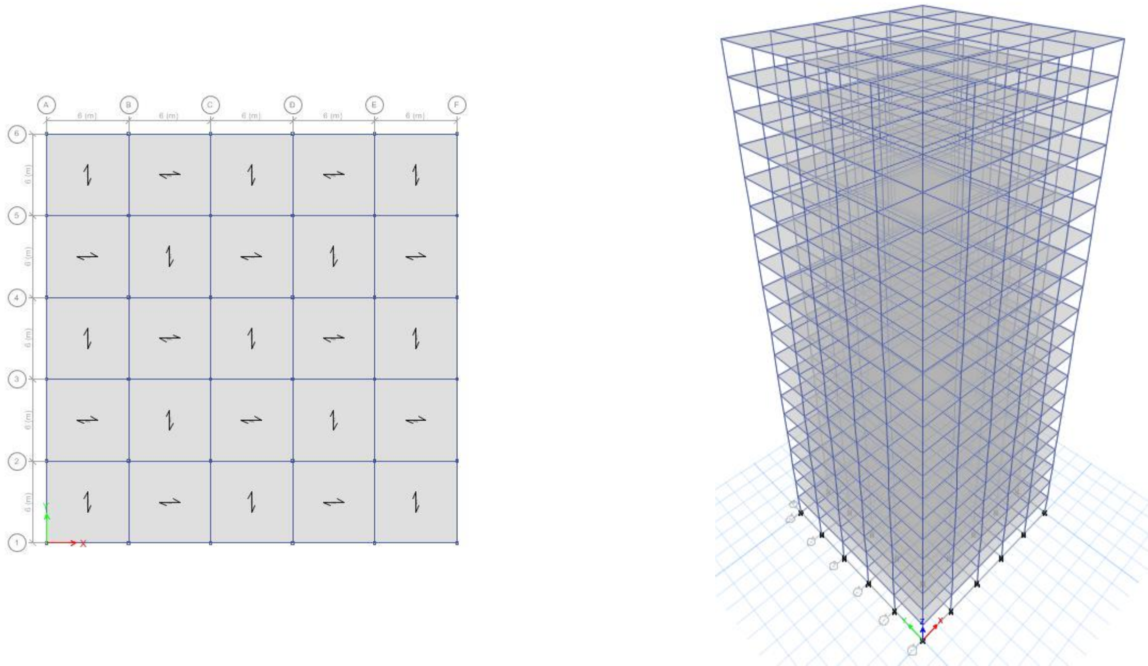

Fig. 2. Three-dimensional view and floor plan of the 20-story building frame.

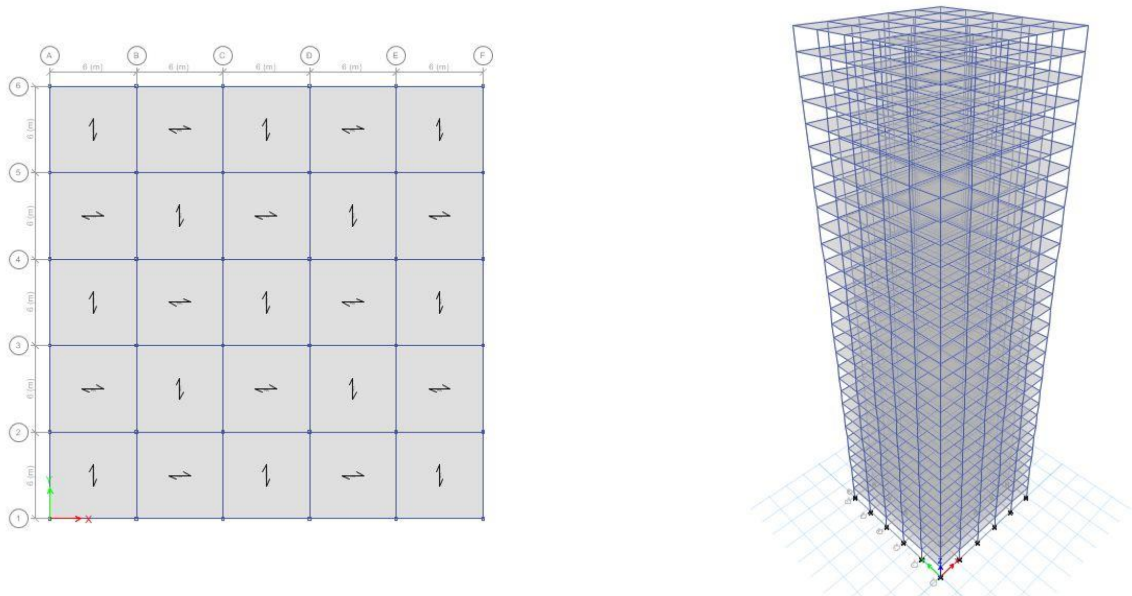

Fig. 3. Three-dimensional view and floor plan of the 30-story building frame.

This comprehensive approach allows for an accurate and scientific assessment of the advantages and limitations of each shear wall type and can serve as a guideline for selecting an optimal lateral load-resisting system in the design of tall buildings.

2.3. Loading conditions

The gravity loads considered for the 10-, 20-, and 30-story buildings are summarized in Table 1.

Table 1. Gravity loads for typical floors and roofs.

Floor type	Dead load (kg/m^2)	Live load (kg/m^2)	Partition load (kg/m^2)	Perimeter wall load (kg/m)
Typical floor	500	200	100	600
Roof	500	150	-	300

The lateral load-resisting system of the 10 and 20-story buildings was designed as a dual system consisting of intermediate steel moment-resisting frames (IMRFs) combined with special reinforced concrete shear walls (S-RCWs). For the 30-story building, the system was designed as a dual system with special steel moment-resisting frames (SMRFs) and special reinforced concrete shear walls (S-RCWs). In all cases, the moment-resisting frames were designed to resist at least 25% of the total seismic base shear, as required by code provisions. Seismic analysis was performed using the response spectrum method based on the Iranian Seismic Code (Standard 2800, 4th edition), ensuring that the dynamic base shear was not less than the corresponding equivalent static base shear. The buildings were assumed to have residential occupancy. The beams of the steel frames were modeled as I-shaped rolled sections, while the columns were modeled as box sections. Structural steel was assumed to be ST37 with a yield strength of 2400 kg/cm² and ultimate strength of 3700 kg/cm². The compressive strength of concrete in the shear walls was taken as 25 MPa, and the reinforcement was modeled using AIII-grade steel. P–Delta effects were also incorporated in the analysis. The following codes and standards were used for loading, linear analysis, checking, and design of the studied structures:

1. Iranian National Building Code, Part 6: Loads (2019 edition)
2. Iranian Seismic Code, Standard No. 2800, 4th edition
3. ACI 318-19: Building Code Requirements for Structural Concrete
4. AISC 360-16: Specification for Structural Steel Buildings
5. Consideration of wall cracking effects in shear wall design

3. Results and discussion

3.1. Placement of rectangular and T-shaped shear walls in the plan

The placement of rectangular and T-shaped shear walls in the 10, 20, and 30-story buildings is illustrated in Figs. 4 to 6. In a recent study by Rahimi and Bargi [24], which was also mentioned in the introduction, various arrangements of both rectangular and T-shaped shear walls were selected based on practical considerations and common structural design practices to cover a wide range of possible placements within the building plan. These arrangements included locations near the perimeter, at the center, and within intermediate frames, allowing for a comprehensive evaluation of the influence of wall placement on the seismic response of the structure. The results revealed that the optimal configuration for both rectangular and T-shaped shear walls in steel frames occurred when the walls were positioned in intermediate frames, rather than being close to the center or placed at the farthest distance from it. The primary criterion for identifying the optimal configurations was minimizing roof displacement, as this parameter directly reflects the overall lateral stiffness and seismic performance of the structure. After performing linear response spectrum analyses for all configurations, the two arrangements with the lowest roof displacements were identified as optimal and subsequently subjected to nonlinear time-history analyses for further evaluation. In both linear dynamic spectrum and nonlinear time-history analyses, the intermediate placement was confirmed as the most effective configuration. In the present study, the economic comparison of rectangular and T-shaped shear walls is conducted based on the optimal configuration identified in the referenced work.

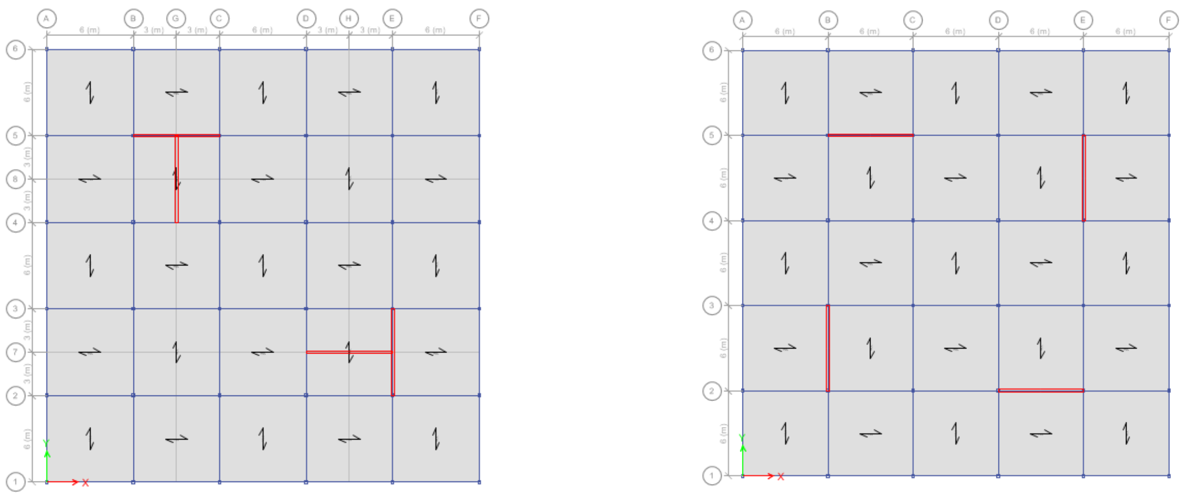

Fig. 4. Placement of rectangular and T-shaped shear walls in the plan of a 10-story building.

3.2. Economic comparison

In this section, an economic comparison between rectangular and T-shaped shear walls in tall buildings is presented. For this purpose, steel buildings with heights of 10, 20, and 30 stories were analyzed and designed in ETABS v16, considering two cases of rectangular and T-shaped shear walls with equal wall areas in plan. Since the wall areas in plan are identical, the amount of consumed concrete is the same in both cases, thereby minimizing the influence of wall geometry on the total concrete volume in the economic comparison. The concrete weight for the designed buildings in both seismic zones, with design base acceleration ratios of A = 0.35 and A = 0.5, is 525 tons for the 10-story building, 2,450 tons for the 20-story building, and 5,040 tons for the 30-story building. The steel frames in both seismic zones were designed in accordance with the AISC 360-16 provisions. For the selection of beam and column sections, 50 different beam profiles and 50 different column profiles were considered, enabling the automatic design of the steel frame in ETABS.

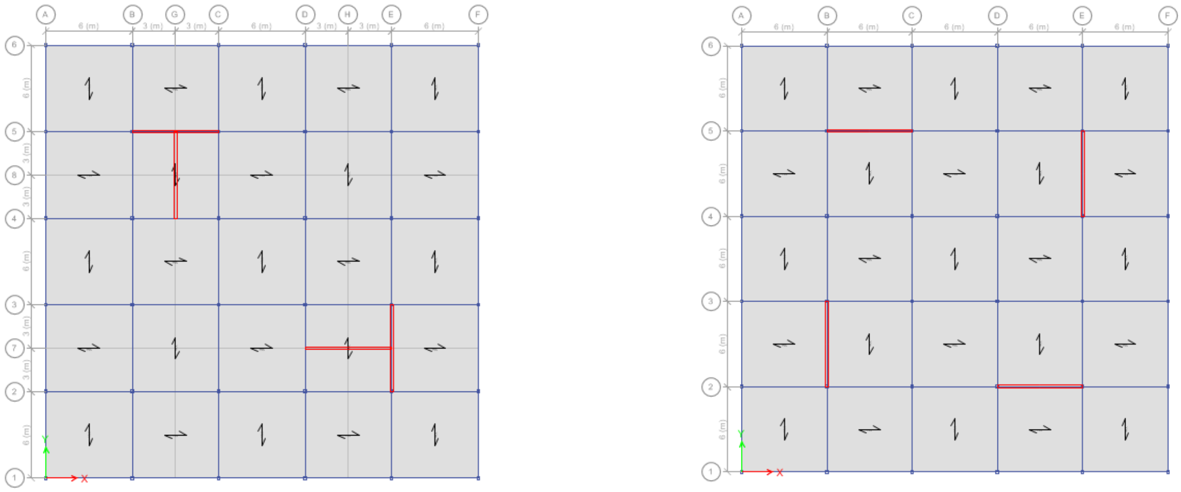

Fig. 5. Placement of rectangular and T-shaped shear walls in the plan of a 20-story building.

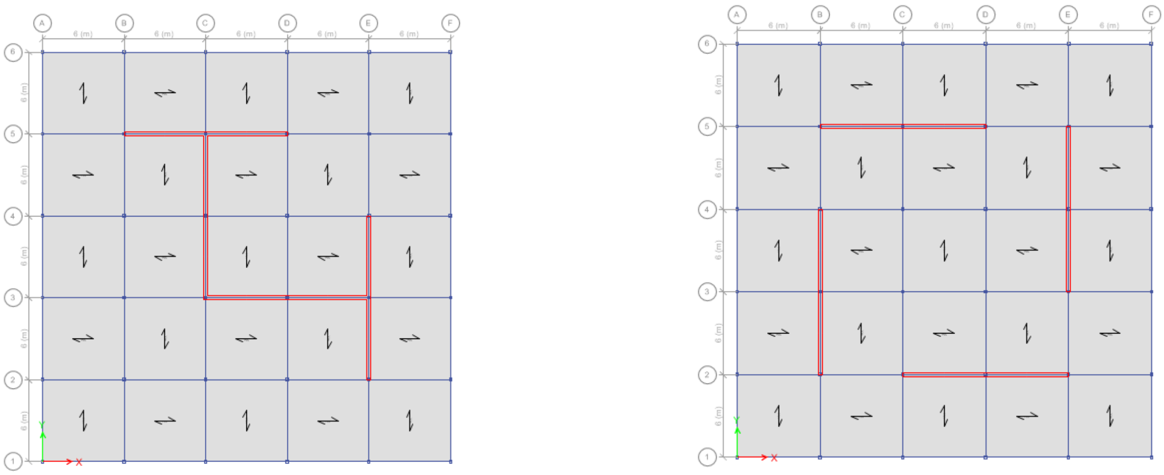

Fig. 6. Placement of rectangular and T-shaped shear walls in the plan of a 30-story building.

This methodology ensures that the most efficient combination of sections is selected for each building height, based on both seismic performance and economic criteria. In addition, the adequacy of the designed members was verified using a MATLAB code, confirming that the ratio of the applied stresses to the member capacities remained within the acceptable range, specifically not less than 0.95. Figs. 7 and 8 present the steel weight used in the design of the frames for the 10, 20, and 30-story buildings. These figures illustrate the economic differences in steel usage between rectangular and T-shaped shear wall systems and provide the basis for the economic analysis of the project.

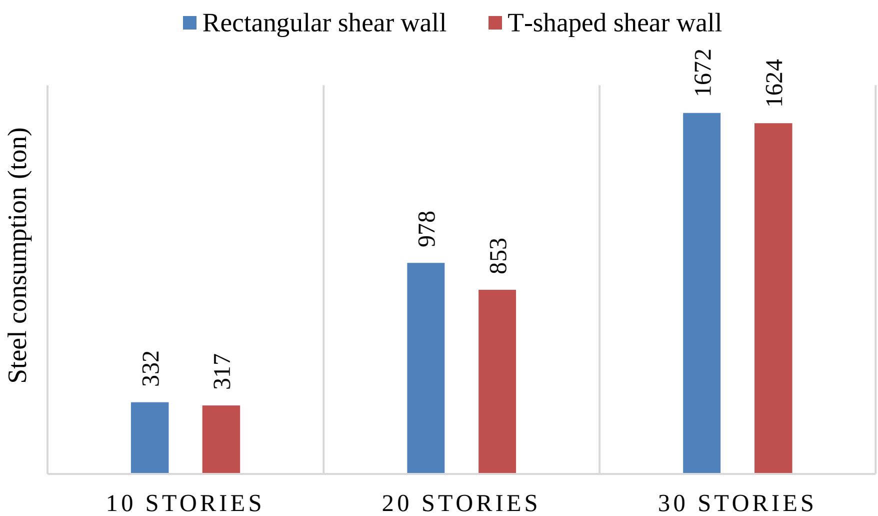

Fig. 7. Steel consumption in frame design for the seismic zone with a design base acceleration ratio of *A* = 0.35.

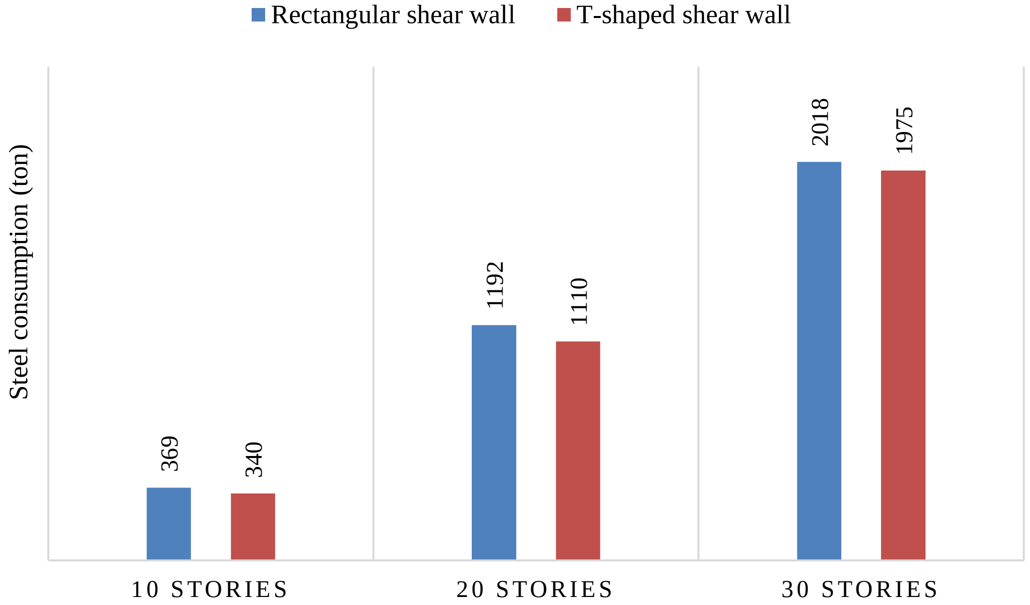

Fig. 8. Steel consumption in frame design for the seismic zone with a design base acceleration ratio of *A* = 0.5.

Furthermore, in Figs. 9 to 14, the roof displacements of the designed buildings in the two seismic zones with design base acceleration ratios of $A = 0.35$ and $A = 0.5$ are compared for both rectangular and T-shaped shear walls. This comparison enables the assessment of seismic behavior and lateral stiffness of the structures and demonstrates that the shear wall geometry has a direct effect on reducing or increasing roof displacements.

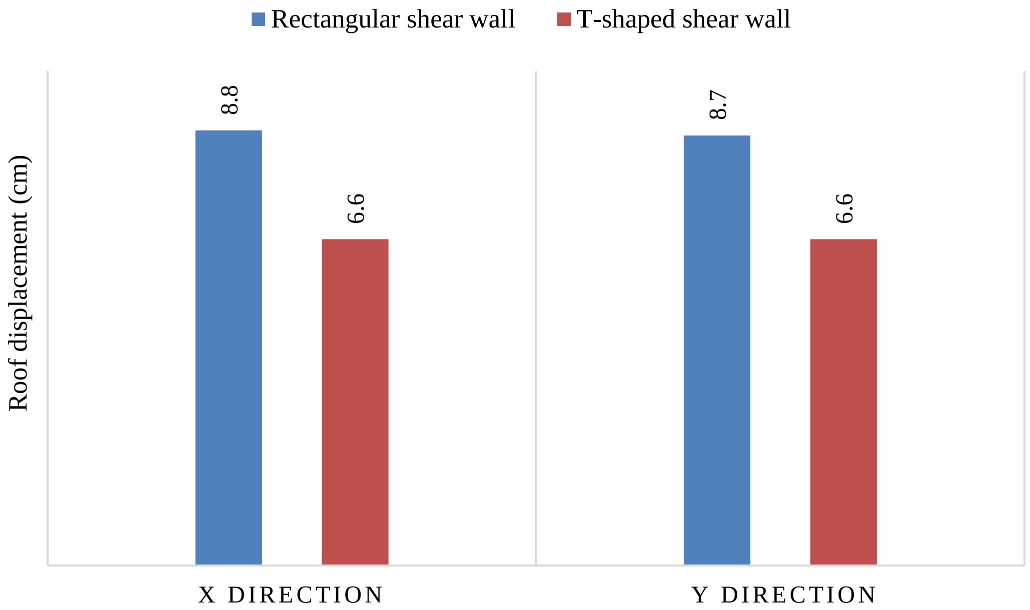

Fig. 9. Roof displacement of 10-story buildings designed with rectangular and T-shaped shear walls in the seismic zone with a design base acceleration ratio of *A* = 0.35.

As observed, frames with T-shaped shear walls not only exhibit smaller displacements in both X and Y directions compared to rectangular walls, but also require less steel for beams and columns. This is because the stiffness of a shear wall is related to its moment of inertia in plan, and the moment of inertia of a composite wall, such as a T-shaped wall, is higher than that of a rectangular wall. By converting rectangular shear walls into a T-shaped configuration, the resulting composite section has an increased moment of inertia, which leads to greater stiffness and reduces the forces transmitted to the frame. Consequently, the member forces in the frame decrease, allowing for smaller cross-sections and ultimately lower material consumption. This trend is consistent across the 10-, 20-, and 30-story buildings in both seismic zones with design base acceleration ratios of $A = 0.35$ and $A = 0.5$.

The results of this section provide valuable guidance for the optimal selection of lateral load-resisting systems in tall building design and highlight their significant role in achieving an efficient balance between structural performance and material economy, particularly regarding the use of concrete and steel sections.

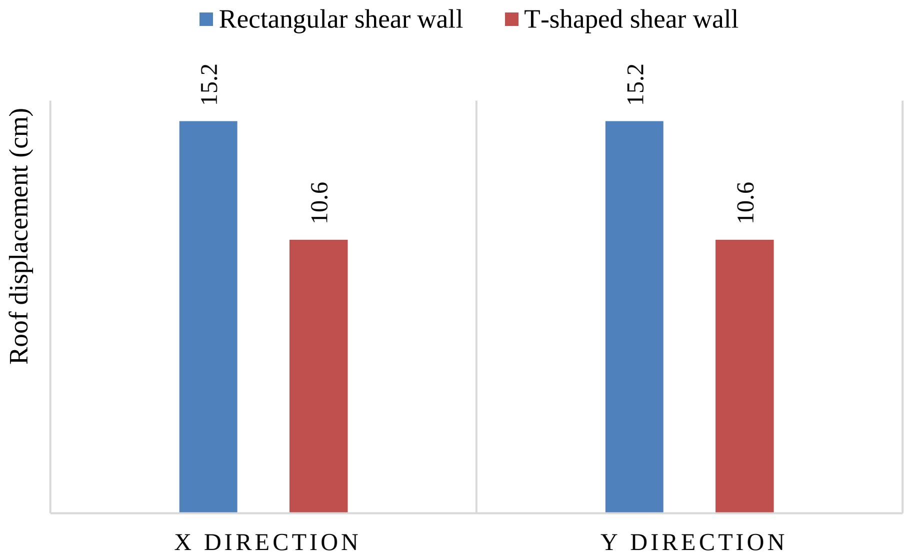

Fig. 10. Roof displacement of 20-story buildings designed with rectangular and T-shaped shear walls in the seismic zone with a design base acceleration ratio of *A* = 0.35.

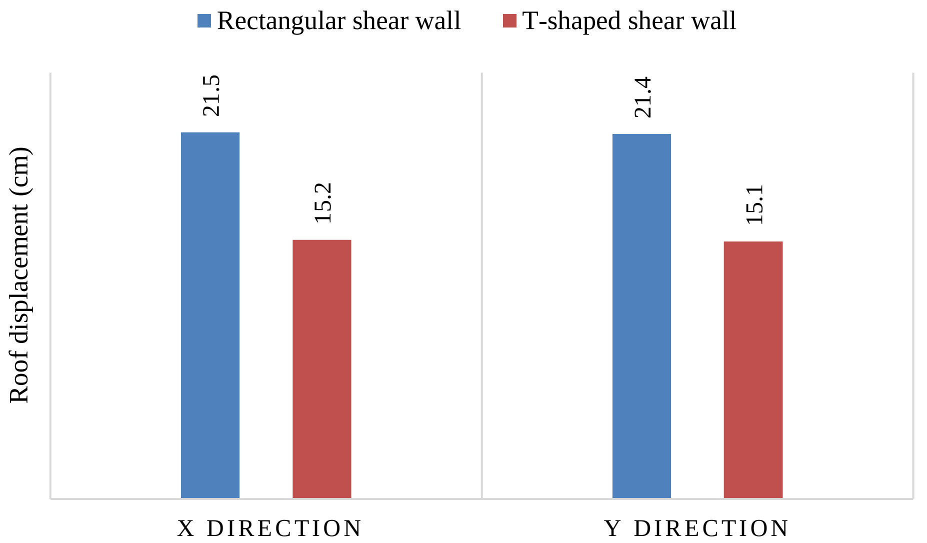

Fig. 11. Roof displacement of 30-story buildings designed with rectangular and T-shaped shear walls in the seismic zone with a design base acceleration ratio of *A* = 0.35.

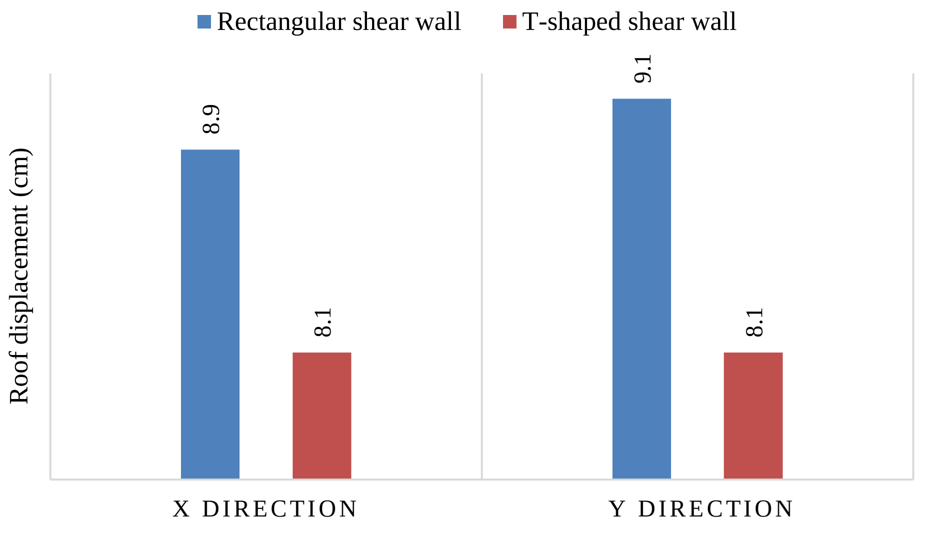

Fig. 12. Roof displacement of 10-story buildings designed with rectangular and T-shaped shear walls in the seismic zone with a design base acceleration ratio of *A* = 0.5.

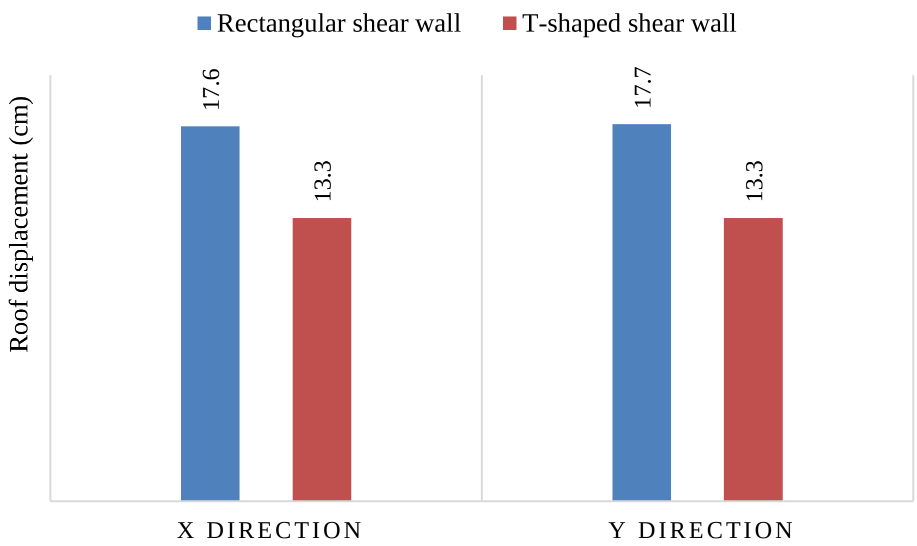

Fig. 13. Roof displacement of 20-story buildings designed with rectangular and T-shaped shear walls in the seismic zone with a design base acceleration ratio of *A* = 0.5.

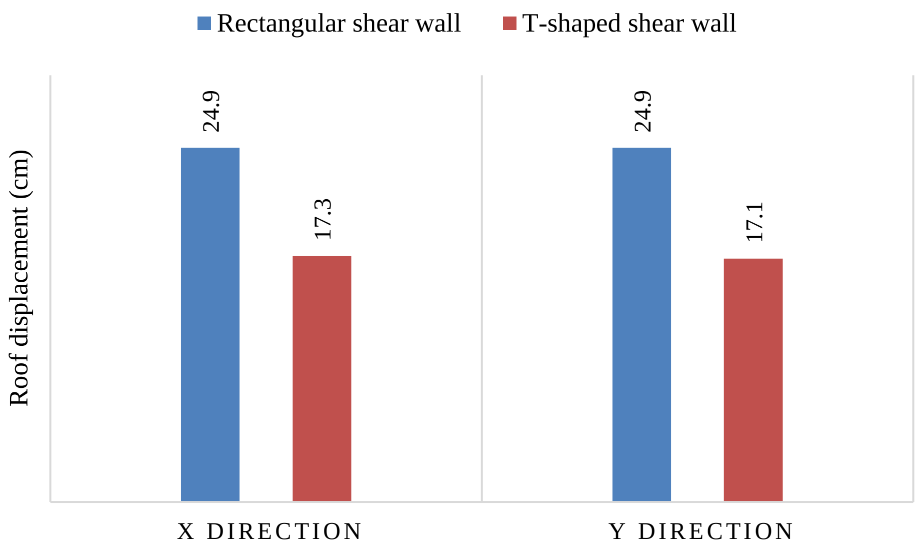

Fig. 14. Roof displacement of 30-story buildings designed with rectangular and T-shaped shear walls in the seismic zone with a design base acceleration ratio of *A* = 0.5.

4. Conclusion

In this study, an economic comparison was conducted between rectangular and T-shaped reinforced concrete shear walls in steel-frame tall buildings. The main findings are as follows:

1. As observed, in all studied buildings, frames with T-shaped shear walls not only exhibited lower roof displacements compared to rectangular walls but also required less steel for beams and columns. This is because the lateral stiffness of a shear wall is related to its moment of inertia in plan, and a T-shaped wall has a higher moment of inertia than a rectangular one. Consequently, greater stiffness results in lower forces transmitted to the frame, leading to smaller member sections and reduced material consumption. These results were consistent across all building heights and seismic zones considered.
2. T-shaped shear walls provide both superior seismic and economic performance without significant architectural or construction challenges, as their geometry allows easy accommodation of architectural elements such as elevator shafts.
3. A hybrid layout combining T-shaped and rectangular shear walls can offer a promising strategy to balance cost and structural performance. While T-shaped walls provide higher stiffness and seismic resistance, rectangular walls are generally simpler and more economical to construct. By strategically combining these wall types based on location and performance requirements, designers can optimize both economic efficiency and seismic performance in tall buildings.

Statements & Declarations

Author contributions

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

Khosrow Bargi: Conceptualization, Methodology, Project administration, Supervision, Writing - Review & Editing.

Moein Rezapour: Investigation,Writing - Review & Editing.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Data availability

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

Declarations

The authors declare no conflict of interest.

References

[1] Rahimi, M., Davoodi, M.-R., Nematzadeh, M., Yousefpour, H. The effect of type of mechanical anchors on bond behavior of ribbed-surface GFRP bars embedded in concrete. Journal of Building Engineering, 2024; 82: 108307. doi:10.1016/j.jobe.2023.108307.

[2] Rahimi, M., Davoodi, M.-R., Nematzadeh, M., Yousefpour, H. Bond performance of GFRP bars with mechanical steel anchors using RILEM beam bond tests: Experimental and theoretical study. Engineering Structures, 2024; 304: 117615. doi:10.1016/j.engstruct.2024.117615.

[3] Das, A., Konar, T. Asymmetric nonlinear compliant deep tank dampers-inerter for mitigating response of tall buildings under near-fault ground motions. Structures, 2025; 76: 108970. doi:10.1016/j.istruc.2025.108970.

[4] Rahimi, M., Davoodi, M.-R., Nematzadeh, M., Yousefpour, H., Azarbera, M., Fattahi, Z. A comparative study between beam and pull-out tests on bond behavior of ribbed GFRP bar in concrete conforming to RILEM standards. Archives of Civil and Mechanical Engineering, 2024; 25: doi:10.1007/s43452-024-01095-1.

[5] Elnimeiri, M. M., Hwang, Y. Towards Sustainable Structure of Tall Buildings by Significantly Reducing the Embodied Carbon. Sustainability, 2025; 17: 2754. doi:10.3390/su17062754.

[6] Razavi, M., Rahimi, M., Tichi, A. H., Nematzadeh, M. Synergistic effects of recycled nylon granules and bacterial nano-cellulose in lightweight concrete: Experiments and predictions. Construction and Building Materials, 2025; 493: 143124. doi:10.1016/j.conbuildmat.2025.143124.

[7] Emad, S., Aboulnaga, M., Wanas, A., Abouaiana, A. The Role of Artificial Intelligence in Developing the Tall Buildings of Tomorrow. Buildings (2075-5309), 2025; 15: doi:10.3390/buildings15050749.

[8] Kamarudin, M. A. A., Ahmad, S. W., Alsakkaf, H. A., Mustopha, S. I. S., Shafiq, O. The Assessment of Tall Building Structure Performance Due to Seismic Effect in Malaysia. Journal of Advanced Research Design, 2025; 129: 112-129. doi:10.37934/ard.129.1.112129.

[9] Rezapour, M., Ghassemieh, M. Macroscopic modelling of coupled concrete shear wall. Engineering Structures, 2018; 169: 37-54. doi:10.1016/j.engstruct.2018.04.088.

[10] Tiwari, N. D., Sarkar, P. P. Prediction of dynamic loads and responses of a tall building in tornado wind: Numerical analysis and experimental validation. Engineering Structures, 2025; 326: 119510. doi:10.1016/j.engstruct.2024.119510.

[11] Khorasani, M., Mostofinejad, D., Muciaccia, G., Kheyroddin, A. Enhancing RC shear wall performance against shear failure modes using fiber-reinforced polymer (FRP) composites: A comprehensive review. In: Structures; 2025; p. 108162. doi:10.1016/j.istruc.2024.108162.

[12] Rezapour, M., Ghassemieh, M. Macroscopic Modelling of the Concrete Shearwall with Asymmetrical Openings. Modares Civil Engineering journal, 2023; 23: 35-49. doi:10.22034/23.5.4.

[13] Wang, J., Cao, S., Tim, K., Li, S., Fung, J. C., Li, Y. A novel life-cycle analysis framework to assess the performances of tall buildings considering the climate change. Engineering Structures, 2025; 323: 119258. doi:10.1016/j.engstruct.2024.119258.

[14] Sun, P., Nie, P., Liang, K., Wang, D. The performance analysis of shear walls with opening based on quantitative identification method of vibration modes. Alexandria Engineering Journal, 2025; 120: 637-647. doi:10.1016/j.aej.2025.02.074.

[15] Lefas, I., Kotsovos, M. NLFE analysis of RC structural walls and design implications. Journal of Structural Engineering, 1990; 116: 146-164. doi:10.1061/(ASCE)0733-9445(1990)116:1(146).

[16] Lefas, I. D., Kotsovos, M. D., Ambraseys, N. N. Behavior of reinforced concrete structural walls: strength, deformation characteristics, and failure mechanism. ACI Structural Journal, 1990; 87: 23-31. doi:10.14359/2911.

[17] Thomsen IV, J. H., Wallace, J. W. Displacement-based design of slender reinforced concrete structural walls—experimental verification. Journal of Structural Engineering, 2004; 130: 618-630. doi:10.1061/(ASCE)0733-9445(2004)130:4(618).

[18] Brueggen, B. L. Performance of T-shaped reinforced concrete structural walls under multi-directional loading, (PhD Thesis). Minneapolis (MN): University of Minnesota; 2009.

[19] Pin-Le, Z., Qing-ning, L. Cyclic loading test of T-shaped mid-rise shear wall. The structural design of tall and special buildings, 2013; 22: 759-769. doi:10.1002/tal.723.

[20] Lu, X., Yang, J. Seismic behavior of T-shaped steel reinforced concrete shear walls in tall buildings under cyclic loading. The structural design of tall and special buildings, 2015; 24: 141-157. doi:10.1002/tal.1158.

[21] Ji, X., Liu, D., Qian, J. Improved design of special boundary elements for T-shaped reinforced concrete walls. Earthquake Engineering and Engineering Vibration, 2017; 16: 83-95. doi:10.1007/s11803-017-0370-4.

[22] Lan, W., Zhang, Z., Li, B. Seismic performance of T-shaped steel-concrete composite structural walls subjected to loadings from different directions. Journal of Constructional Steel Research, 2017; 128: 7-18. doi:10.1016/j.jcsr.2016.08.007.

[23] Brueggen, B. L., French, C. E., Sritharan, S. T-shaped RC structural walls subjected to multidirectional loading: test results and design recommendations. Journal of Structural Engineering, 2017; 143: 04017040. doi:10.1061/(ASCE)ST.1943-541X.0001719.

[24] Rahimi, M., Bargi, K. Comparative Evaluation of Seismic Behavior of T-Shaped versus Rectangular Concrete Shear Walls in High-Rise Buildings. Civil Engineering and Applied Solutions, 2025; 1: 16-26. doi:10.22080/ceas.2025.29715.1029.