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Evaluation of Lateral Load Resisting Systems in High-Rise Buildings

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ABSTRACT: The rapid urbanization and the scarcity of residential space in metropolitan areas necessitate the construction of tall structures to meet the growing accommodation demands. This research paper focuses mainly on the structural act of high-rise structures under lateral loads, especially earthquake forces. Three lateral load resisting systems, namely outrigger system, shear wall at core and shear wall at corner are compared and analysed. The study reviews relevant literature, discussing parameters affecting the fundamental time period of structural models and the effectiveness of distributed belt wall systems. The research methodology involves the analysis of a 40-storey regular office building using three different lateral load resisting systems. The results obtained through response spectrum analysis, shows that the outrigger system exhibits efficient structural capability in tall buildings. The maximum lateral displacement is significantly reduced in the outrigger system compared to core shear-wall and corner-shear wall. The study concludes that enhancing lateral load resistance and providing a transition path to perimeter columns subjected to lateral load, as seen in the outrigger-system, proves effective in mitigating the impact of earthquake loads on high-rise buildings.

KEYWORDS: Earthquake load, high-rise buildings, Lateral load resisting systems, Story drift, Structural performance.

1. INTRODUCTION

The expeditious growth of population and the dearth of residential area in metropolitan cities require to construct tall structures to overcome the mentioned issues and fulfill the accommodation demands of the era. The International Building Code (IBC 2000) as well as the Building Construction and Safety Code, NFPA 5000TM-2002, Paragraph 3.3.28.7 of the Life Safety Code®, 2006 edition, define tall structures as structures 75 feet or greater in height to be measured from the G+0 to the floor of the highest occupied story [1]. Along with gravity loads which has to be resisted by structures, there are different types of lateral loads i.e., earthquake forces and wind pressure, both of the loads have to be resisted by the structures in their service life. However, increasing of the height of structures, different lateral loads act differently i.e., the more a structure is high the more it bears earthquake load and wind pressure. To ensure the serviceability, different systems are to be compared to conclude which of them is suitable to resists all the obliteration effects of lateral loads occurring in the members of a structure.

Hence, here three different systems (outrigger system, shear wall at core and shear wall at corner) are compared and analyzed to resist lateral loads.

1. Outrigger system

Outrigger system is a system used commonly to resist lateral loads, it enhances and stabilizes the structure. In this system, the structural strength is increased by providing core shear wall and outrigger increases its lateral stiffness [2].

It might be comprised of deep, stiff girders or trusses joining the core of building to the external columns resulting in the reducing deformation and overturning moment at the core of the structure [3]

2. Shear wall at core

The more the height of a building is increased the more it is subjected to different lateral loads which cause it to increase lateral displacement, to overcome this problem there should be a system which resist the effects of those lateral loads. There is a structure namely shear wall structure, supposed to be one whose resistance to lateral loads is provided completely by shear wall [4].

In high-rise building shear walls are commonly placed at the centeral portion of the structure, frequently in the form of core shear wall system to support vertical translation system and is considered to be a common form for lateral load resisting system and having two major types i.e., concrete core and steel frame core. Recently concrete walls are built in high-rise building and steel framed core is a light core system however abandoned nowadays [5]

3. Shear walls at corner

Shear walls may be provided in different locations in tall buildings to support it against lateral loads. It could be in the form of shear wall at corner, shear walls as belt walls with and without connection with core walls [6]. Here shear walls at corner provided at all the four sides of the building in regular pattern connected with core to resist efficiently against lateral loads (earthquake load) [5].

2. REVIEW OF LITERATURE

[7] It has investigated that the height of the structure is the first parameter that affect the fundamental time period of vibration of the models and it approves the most of currently used methods. The ratio of the shear-walls is another most significant parameter built on the bases of the sensitivity analysis, The number of bays and the percentage of the infill walls had nearly the same effects on the fundamental time period of the structure models. The effects of the number of infill-walls and shear-walls on the fundamental time period of buildings is denied by some of the recently used standards, however it has observed that infill walls had effects on the fundamental time period of the models directly after the first fraction of shear-walls and infill walls showed its effetcs on the fundamental time period that has decreased with the increase of the ratio of infill walls.

[6] It has investigated that If in a high-rise building the distributed belt wall system is provided such that the walls are not connected directly to the core shear walls and acts as real outriggers, are as efficient to reduce lateral drift as the outrigger structures and conventional belt do, However The arrangement and number of belt walls quantify the performance of the distributed belt wall system.

[8] It has investigated that to explore the correlation between outrigger stiffness and the optimal position, a sequence of optimal designs was conducted by modifying the outrigger's cross-sectional area. As the cross-sectional area of the outrigger increases, the optimal location of the outrigger shifts lower in the structure. The variation in the optimal location of the outrigger is diverse within a practical range of the outrigger's cross-sectional area. Specifically, within a two-story range, it is demonstrated that the design variables, encompassing outrigger stiffness and optimal location can be distinctly identified for the optimization of outriggers to meet design limitations, such as permissible lateral displacement. The proposed optimization method utilizing PGI or PLI, is anticipated to be applicable to elastoplastic issues, including seismic pushover analysis, as it yields acceptable results even for analysis models with abrupt changes akin to the Gen model.

[9] It has investigated that the value of story drift and the maximum displacement are higher In high seismic zones that indicates, if a uniform stiffness is provided in a structure, the displacement can be reduced.The building covered by shear wall at all four external corners results good in maximum displacement, story drift and base-shear which means that a building having uniform stiffness has given better result however shear wall at one corner can be subjected to greater lateral load hence the building is required to be provided with uniform stiffness.

[10] It has investigated that the performance of the building is increased with the increase in the number of outriggers and by providing only outriggers, shear band with outriggers and belt trusses is highly effective. In V, inverted V and X type of steel outrigger bracing beams, 4 outriggers combined with Inverted V is more effective but shear walls are the most effective than steel bracing.

[11] The study investigates various structural systems in a G + 16 story RCC building through dynamic analysis. Among the systems studied, the diagrid system emerged as highly effective in handling lateral forces, akin to the shear-walled system. Despite increasing base shear due to added weight, the diagrid system effectively controls displacement, drift and other response parameters. This suggests its potential for enhancing safety and performance in high-rise urban buildings.

[12] This study explores T-shaped steel plate reinforced concrete walls under seismic conditions. Experimental tests and simulations showed these walls perform better than rectangular ones. Various parameters like compression ratio and flange width affect their strength and deformation behavior. The study also highlights ways to mitigate shear lag effects by adjusting parameters like steel plate ratio and shear span ratio in practical engineering applications.

[13] This study tested a scaled double covering composite core wall under biaxial cyclic loads, revealing failure modes and interlinked lateral resistance. It founds energy dissipation impacting hysteresis loops differently in each direction and validated certain structural assumptions. The research supports using these core walls in tall buildings but suggests further exploration of different factors through simulations due to limited experimental models.

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3. RESEARCH METHODOLOGY

Modelling Approach

The study involves a detailed structural analysis of a 40-storey reinforced concrete (RCC) office building located in Jalalabad, Afghanistan. The building plan covers an area of 36m x 36m with a consistent number of bays and bay spans across both directions. Three distinct structural models are considered:

1. Outrigger System Model
2. Core Shear Wall Model
3. Corner Shear Wall Model

Each model incorporates different lateral load-resisting mechanisms but maintains uniformity in height, dimensions, material properties, and loading conditions to facilitate direct comparisons.

Design Parameters

-Building Height: 40 storeys
-Plan Dimensions: 36m x 36m
-Concrete Grade: Grade-30 (f'c = 30 MPa)
-Steel Grade: Fe-415 (fy = 415 MPa)
-Concrete Density: 25 kN/m³
-dead load is 1kn/m^2
-live load is 3kn/m^2
-Dead Load: Assumed as per IS 875 (Part 1)
-Live Load: Assumed as per IS 875 (Part 2)
-Seismic Loads: Based on IS 1893:2016 provisions
-Analysis Tool: ETABS 18

Code Provisions and Design Criteria

The design and analysis adhere to the following Indian Standards:
-IS 1893:2016: Criteria for Earthquake Resistant Design of Structures
-IS 456:2000: Code of Practice for Plain and Reinforced Concrete
-IS 875 (Part 1 & 2): Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures.

Numerical Models

- Outrigger System Model

-Description: The outrigger system includes horizontal structural elements (outriggers) connecting the core to perimeter columns at strategic levels to enhance lateral stiffness and reduce drift.
-Components: Outriggers at predetermined levels, central core.

- Core Shear Wall Model

- Description: Central core shear walls are used as the primary lateral force-resisting system, extending continuously from the foundation to the top of the building.
-Components: Central core shear wall.

- Corner Shear Wall Model

-Description: Shear walls are placed at the corners of the building, providing stability by utilizing the perimeter of the structure.
-Components: Shear walls at the building corners.

Analysis Methodology

-Dynamic Analysis: Response Spectrum Analysis (RSA) as per IS 1893:2016 is utilized to determine the seismic response.
-ETABS 18: The analysis software employed for modelling, simulating, and analyzing the structural performance under seismic loads.

Design Criteria

-Maximum Lateral Displacement: The peak horizontal movement of the structure during seismic events.

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-Storey Drift: The relative horizontal displacement between two consecutive floors, a critical parameter for assessing serviceability.
-Time Frequency: The fundamental natural frequency of the structure, influencing its dynamic response.
-Base Shear: The total horizontal seismic force at the base of the structure.
-Overturning Moment: The moment causing the building to topple during seismic activity.

Results Comparison

The performance of each model (outrigger system, core shear wall, and corner shear wall) is compared based on:
-Maximum Lateral Displacement
-Storey Drift
-Time Frequency
-Base Shear
-Overturning Moment

This comparative analysis aims to determine the most effective lateral load-resisting system for high-rise RCC buildings in seismic zones, ensuring both safety and serviceability.

By elaborating on these aspects, the study provides a comprehensive understanding of the design and analysis of high-rise RCC buildings under seismic loads, facilitating more informed decision-making in structural engineering practice.

Table 1. Details of the properties for various types of structure

Members	Outrigger system	Corner shear wall	Core shear wall
Beam (mm)	350 x 500	350 x 500	350 x 500
Column (mm)	800 x 800	800 x 800	800 x 800
Slab (mm)	150	150	150
Shear wall (mm)	330	350	350
Brace	ISHB450-2	-	-

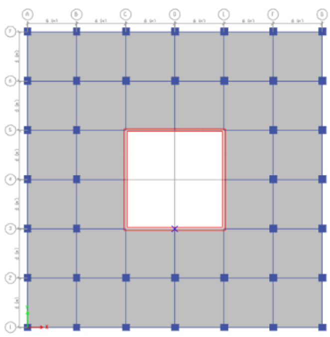

Figure 1: Plan of G+40 story building for outrigger and core shear wall.

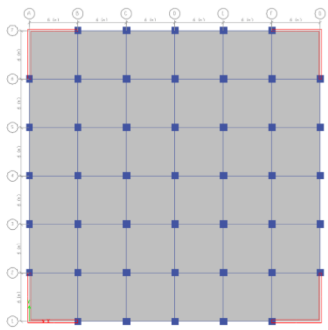

Figure 2: Plan of G+40 story building for Corner shear wall.

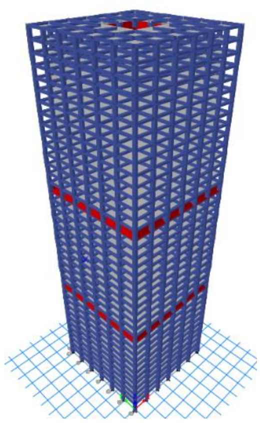

Figure 3: Elevation of G+40 story building for outrigger.

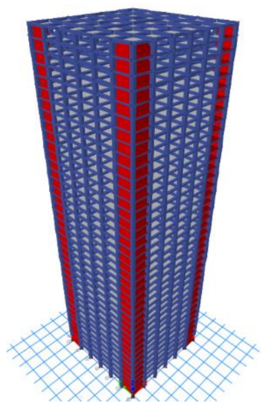

Figure 4: Elevation of G+40 story building for Corner shear wall.

4. ANALYSIS AND RESULTS

The maximum allowed story displacement in a building is H/500, where H is the overall height of the building (Indian Standard & 456 -, 2000) According to the IS code and the maximum allowed story drift in a building is 0.004h, where h is the overall height of the building, according to the IS code [15].

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Table 2: Max- displacement. Drifts, Overturning moment and Frequency

Lateral load resisting system	Max. Displacement (mm)	Max. Story Drifts	Base Shear (KN)	Overturning moment (KN- m)	Frequencies (Hz)
Outrigger system	43	0.000492	6871.826	400201.4	2.725
Core Shear Wall	63	0.000684	6758.299	339626.6	3.582
Corner Shear Wall	118	0.001232	5850.979	334840.7	5.257

There are three forms of structural-models in the collection with various exclusive concrete and steel description with different lateral load resisting systems. All the structural-models have analyzed with the help of using the response spectrum analysis method and contrast graphs for Story drift, lateral displacement, base-shear, time frequencies and overturning moment has illustrated below. The lateral displacement at corner shear wall system is 118 mm and there is deduction in lateral displacement about 64% in Outrigger system, 47% in shear wall at Core, furthermore the Storey drift at corner shear wall is 0.001232 and there is reduction in Storey drift about 60% in Outrigger system, 44% in shear wall at core, moreover the base shear at corner shear wall system is 5851KN and there is an increase in base shear about 17% in outrigger system, 15% in shear wall at Core system, beside the overturning moment at corner shear wall is 334841KN.m and there is an increase in overturning moment about 19% in outrigger system, 1.43% in shear wall at core, In addition the model periods and frequencies at corner shear wall system is 5.257mm and there is a deduction in model periods and frequencies about 48% in Outrigger system and 32% in shear wall at Core system.

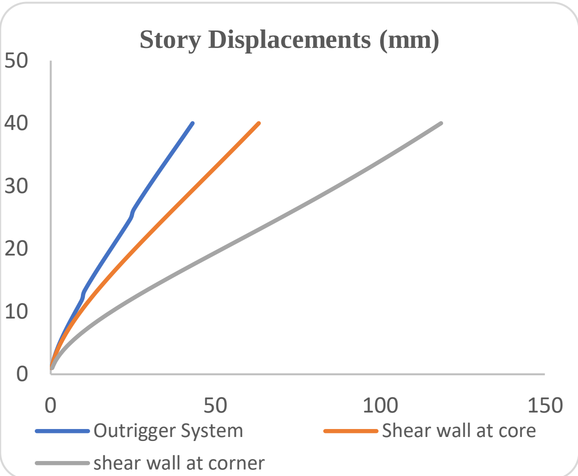

Figure 5: Story Displacements of G+40 story building for all three model.

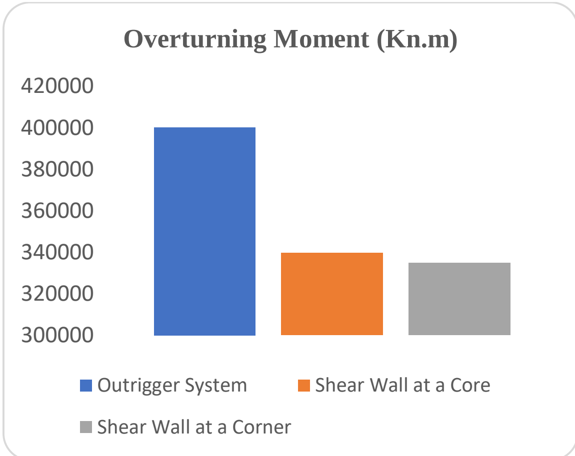

Figure 6: overturning moment of G+40 story building for all three model.

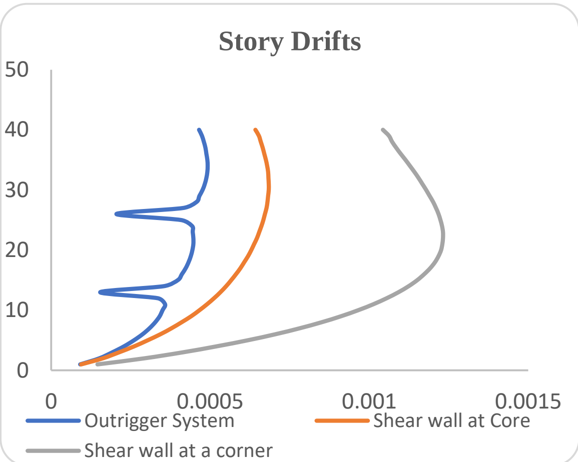

Figure 7: Story Drifts of G+40 story building for all three model.

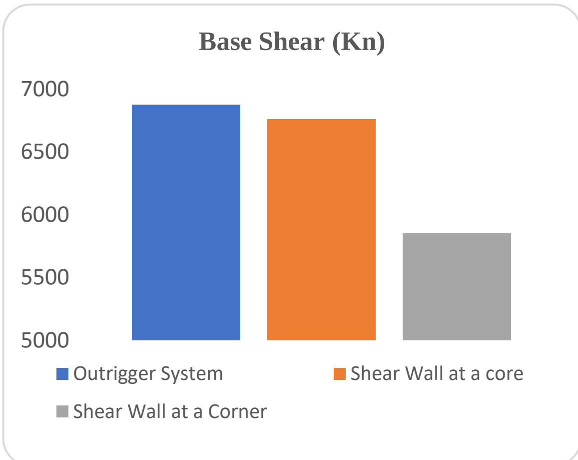

Figure 8: Base Shear of G+40 story building for all three model.

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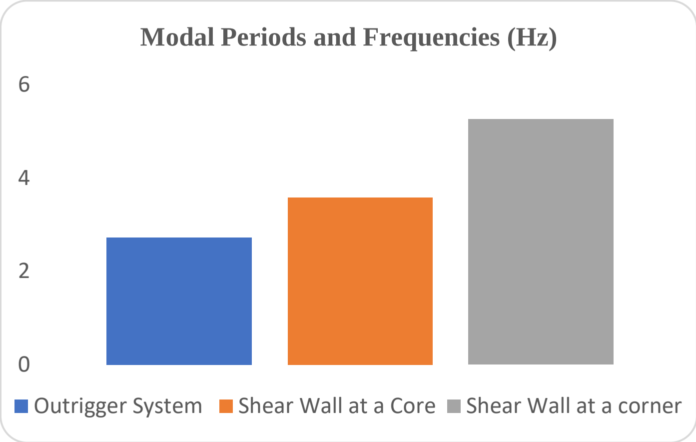

Figure 9: Time frequencies of G+40 story building for all three model.

5. Emphasizing the Innovative Contribution of the Paper:

The innovative contribution of this paper lies in its comprehensive comparative analysis of three different lateral load-resisting systems outrigger systems, core shear walls, and corner shear walls specifically for high-rise reinforced concrete (RCC) buildings in seismic zones. This research advances the state of the art in several significant ways:

1. Holistic Comparison Using Uniform Parameters:

The study rigorously compares the three systems by maintaining consistent building height, dimensions, material properties, and loading conditions across all models. This uniformity ensures that the results are directly comparable, providing clear insights into the relative performance of each system.

2. Detailed Dynamic Analysis:

By employing Response Spectrum Analysis (RSA) using ETABS 18, the paper provides a sophisticated dynamic analysis of the structural models. This method captures the complex interactions between different lateral loads and the building structures, offering a more accurate assessment than static methods.

3. Evaluation of Multiple Performance Metrics:

The research evaluates multiple critical performance metrics, including maximum lateral displacement, storey drift, base shear, overturning moment, and time frequency. This multi-faceted approach allows for a thorough understanding of how each system behaves under seismic conditions, highlighting the strengths and weaknesses of each.

4. Optimization Insights:

The study provides detailed insights into the optimal positioning and design of outrigger systems. By exploring variations in outrigger stiffness and optimal location, it offers practical guidance for optimizing these systems to meet design limitations, such as permissible lateral displacement.

5. Real-world Application:

The analysis is based on a realistic case study of a 40-storey RCC office building located in a seismic zone in Jalalabad, Afghanistan. This practical application underscores the relevance of the findings to real-world engineering challenges.

6. Quantitative Performance Gains:

The results demonstrate significant performance improvements with the outrigger system. For example, the outrigger system shows a 64% reduction in lateral displacement and a 60% reduction in storey drift compared to the corner shear wall system. These quantitative performance gains are critical for designing safer and more resilient high-rise buildings.

7. Code Compliance and Best Practices:

The research adheres to and evaluates performance against established codes, such as IS 1893:2016 and IS 456:2000, ensuring that the findings are not only innovative but also compliant with industry standards. This alignment with best practices enhances the practical utility of the research.

5. CONCLUSION

Of lateral load resisting systems behave under earthquake loads. We have arrived at the following conclusion based on the study.

- The lowest time frequency in outrigger system has calculated to be 2.72 seconds, 3.52 seconds in core Shear wall and the highest time frequency is 5.25 seconds in corner Sher wall.
- The maximum base-shear and overturning moment is generated in outrigger system and the minimum base shear and overturning moment in the corner shear wall system.
- - The outrigger system reduced lateral displacement by 64% and storey drift by 60%, outperforming other systems.
- - The core shear wall system was effective but less robust than the outrigger system.
- - Adherence to industry standards ensures practical and compliant findings.
- - Conclusion: The outrigger system is the most effective for high-rise RCC buildings, enhancing safety and serviceability.

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REFERENCES

1. B. H. Zaveri, J. A. Gadhiya, and H. K. Dhameliya, “A Review on the Comparative Study of Steel , RCC and Composite Building,” pp. 354–365, 2016, doi: 10.15680/IJIRSET.2015.0501045.
2. W. U. Shakir, “COMPARATIVE STYDY ON LATERAL FORCE BEHAVIOR FOR DIFFERENT TYPES OF OUTRIGGER SYSTEMS,” 2020.
3. H. A. Hasrat, “Comparative Study of Various High Rise Building Lateral Load Resisting Systems for Seismic Load & Wind Load : A Review,” no. January, pp. 291–297, 2021.
4. Bryan Stafford Smith and Alex Coull, “Bryan Stafford Smith, Alex Coull - Tall Building Structures_ Analysis and Design-Wiley-Interscience (1991).” pp. 0–537, 1991.
5. FENG FU, DESIGN AND ANALYSIS OF TALL AND COMPLEX STRUCTURES, Ken McComb. Matthew Deans, 2018.
6. T. S. Eom, H. Murmu, and W. Yi, “Behavior and Design of Distributed Belt Walls as Virtual Outriggers for Concrete High - Rise Buildings,” Int. J. Concr. Struct. Mater., pp. 1–13, 2019, doi: 10.1186/s40069-018-0311-2.
7. M. M. Kose, “Parameters affecting the fundamental period of RC buildings with infill walls,” vol. 31, no. 1, pp. 93–102, 2009, doi: 10.1016/j.engstruct.2008.07.017.
8. H. Kim, Y. Lim, and H. Lee, “Optimum location of outrigger in tall buildings using finite element analysis and gradient-based optimization method,” J. Build. Eng., vol. 31, no. April, p. 101379, 2020, doi: 10.1016/j.jobe.2020.101379.
9. S. Akhil Ahamad and K. V. Pratap, “Dynamic analysis of G+20 multi storied building by using shear walls in various locations for different seismic zones by using Etabs,” Mater. Today Proc., vol. 43, no. xxxx, pp. 1043–1048, 2020, doi: 10.1016/j.matpr.2020.08.014.
10. V. Kushwaha and N. Mishra, “A Review on Dynamic Analysis of Outrigger Systems in High Rise Building against Lateral Loading,” no. April, 2022.
11. H. Singh, A. Kumar, S. Thakur, and G. Thakur, “Materials Today : Proceedings Performance evaluation of high-rise reinforced concrete buildings under dynamic loading considering different structural systems,” Mater. Today Proc., no. June 2023, 2024, doi: 10.1016/j.matpr.2023.08.251.
12. X. Ke, Y. Qin, S. Chen, and N. Li, “Seismic performance and shear lag effect of T-shaped steel plate reinforced concrete composite shear wall,” vol. 289, no. April, 2023, doi: 10.1016/j.engstruct.2023.116303.
13. D. Xu, J. Wang, B. Xiang, J. Yan, and T. Wang, “Behavior of double skin composite core wall subject to biaxial cyclic loads,” Eng. Struct., vol. 279, no. December 2022, p. 115591, 2023, doi: 10.1016/j.engstruct.2023.115591.
14. Indian Standard and plain and reinforced concrete-code of practice -, IS 456-2000. 2000.
15. E. R. D. of Structures, “IS: 875(Part3): Wind Loads on Buildings and Structures -Proposed Draft & Commentary.” Department of Civil Engineering Indian Institute of Technology Roorkee Roorkee.

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