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RESEARCH ARTICLE

EFFICIENCY OF LATERAL SYSTEMS IN TALL STEEL STRUCTURES

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ABSTRACT

During the medieval period of the twentieth century, early structures were designed to bear only gravity loads. However, as urbanization has increased, land availability has decreased, and real estate prices have risen, there has been a growing need for vertical development to meet the various demands of human activities. To fulfill these demands, advances have been made in the development of histrength and lightweight materials, changes in structural design, and the creation of slender buildings. However, these innovative methods require careful analysis, particularly with regard to lateral load systems such as wind and earthquake loads, which are critical considerations when constructing tall buildings. A plethora of presently existing structural systems exists to undertake an analysis of the lateral resistance exhibited by tall edifices, whereby the judicious selection of the suitable structural system is indispensable to guarantee the fulfillment of all the pertaining structural and architectural parameters, while concurrently fostering sustainable development for posterity. Therefore, a proper examination of the available options is necessary to determine the most effective type of structural system that can be used to fulfill all our requirements. In this study, the response of various structural systems, such as braced frames, EBFs, etc. in a 20-story building with a typical height of 4m have been analyzed using SAP2000 software. The analysis is performed to compare various structural parameters, including Base Shear, Story Drift, Story Displacement and some frame element responses too.

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INTRODUCTION

Braced Frames: Braced frames consist of diagonal bracing members that are placed in the structure to resist lateral forces. These braces are typically placed at regular intervals along the building's perimeter and within the interior space. The braces can be made from various materials, including steel, concrete, or wood.

Moment-Resisting Frames: Moment-resisting frames rely on the rigidity of the steel members to resist lateral forces. These frames are designed to transfer the forces through the building's structural members and into the foundation. The moment-resisting frames are typically used in buildings with regular shapes, as irregular shapes can cause difficulties in designing these types of frames.

Shear Walls: Shear walls, which are commonly constructed using both reinforced concrete or steel, exhibit the intended functionality of withstanding horizontal forces. These walls are strategically positioned at regular intervals along the periphery of the structure as well as within its internal space. Generally characterized by their considerable thickness, these walls possess the deliberate purpose of effectively transmitting the applied forces across their thickness and subsequently directing them into the foundation.

Buckling-Restrained Braced Frames: These represent a recently developed variety of lateral load resistance systems that employ a distinctive form of bracing element meticulously engineered to thwart buckling when subjected to lateral loads. These frames are predominantly employed in buildings exhibiting irregular geometries, meticulously devised to effectively transmit the imposed forces via the structural constituents of the edifice, ultimately disseminating them into the foundation.

Shear Truss-Outrigger Braced Systems: This system is a combination of shear walls and outrigger trusses. The outrigger trusses are used to connect the shear walls and distribute the lateral forces throughout the building. This system is used for high-rise buildings with a central core.

Framed Shear Wall: A framed shear wall is a system where the shear walls are framed by steel or concrete beams and columns. The beams and columns help distribute the lateral forces and prevent the shear walls from buckling.

Framed Concrete and Steel System: This system uses a combination of reinforced concrete and steel frames to resist lateral loads. The reinforced concrete core provides stiffness, and the steel frames provide flexibility.

Framed Tube System: The framed tube system consists of a core of reinforced concrete or steel surrounded by a perimeter of steel tubes. The tubes act as the primary load-carrying elements, resisting lateral forces.

Tube in Tube System: This system is similar to the framed tube system, but with an additional inner tube. The inner tube provides additional stiffness to the building and reduces the need for external bracing.

Bundled Tubes: The bundled tube system is a variation of the tube system, where several tubes are bundled together to form a larger structural element. This system is used for high-rise buildings and provides excellent lateral resistance.

Truss Tubes without Interior Columns: This system uses a series of trusses connected by diagonals to form a continuous structural system. This system is used for buildings with large open spaces and requires fewer interior columns.

OBJECTIVES OF THE STUDY

Comprehensive assessment and comparative analysis of the effectiveness pertaining to lateral force resisting mechanisms employed in tall steel buildings specifically designed to counteract horizontal forces. These systems under scrutiny include Braced Frames, Eccentric Braced Frames, Outrigger Systems, Outrigger with Belts truss Systems, and Core Wall Systems. Another objective is to analyze the behavior of each lateral system under various lateral loads, including wind loads and seismic loads, using SAP2000 software. Finally, identifying the most efficient lateral system for tall steel structures based on the analysis and comparison of the different systems also been considered as an essential of the study.

RESEARCH SCOPE

Firstly, Steel structure design and analysis part is used as the dominance is of steel structure. Seismic analysis part will be focused because the seismic loads are most vulnerable lateral loads. Lateral load resisting systems in steel structures will be considered for comparison of efficiency. SAP2000 Software has been considered for analysis and design checks. RC Structural walls are used for core of the structural system and hence will be discussed in this project. Slab systems used in this project are composite slab system and the study will be done considering this part of the slab.

LITERATURE SURVEY

Manasa and Manjularani (2017) examined the impact of wind loads on tall buildings using the p - Δ effect. To determine the drift ratio under wind loading, they analyzed the scenario with and without the p - Δ effect for various numbers of stories (10, 20, 30, 40, and 50) using design software. They discovered that the drift ratio was small in lower stories and increased as the number of stories rose, reaching its maximum at the top floor. The p - Δ effect became more significant as the building's height increased, particularly for slender members.
However, this literature review has certain limitations with regard to lateral systems in the structure. It does not examine the impact of a plethora of seismic or wind load systems on the drift ratio under wind loads. Additionally, the study does not consider the effect of dynamic wind loads on the lateral stability of tall buildings, which may vary depending on the building's height, shape, and location. Further research may be required to investigate the impact of these factors on the design and performance of lateral systems in tall buildings subjected to wind loads. Deger, Yang, Wallace, and Jack (2014). Two reinforced concrete (RC) core wall buildings were analyzed to evaluate their seismic performance at different hazard levels. Building 1 was a core wall building without a moment-resisting frame, while Building 2 had a similar core wall but with an additional perimeter moment-resisting frame. Both buildings were designed according to US code guidelines. The findings indicated that Building 2, which had a dual system, performed better in terms of seismic performance compared to Building 1. However, the cost analysis showed that Building 1, which only had a core wall system, was more economical even after retrofitting costs following the earthquake.

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In the study conducted by Nilupa and Nicholas (2010), the behavior of super tall structural systems was analyzed under the simulation of earthquake. The study was done using various methods such as model analysis, DDBD, capacity spectrum method, and N2 method. The findings of the investigation unveiled that due to the presence of heightened mode effects, the applicability of these approaches to super tall structures might not be straightforward. Furthermore, the study effectively depicted the occurrence of an elevated mode period by means of non-linear dynamic analysis performed on a 300m tall edifice. Despite the valuable insights provided by this literature review, there are certain limitations that need to be acknowledged regarding the lateral systems in the structure. Firstly, the study only focused on a few seismic analysis methods and did not cover all possible methods that could be applied to super tall buildings.

PRELIMINARY CONSIDERATIONS

This section provides an overview of the different factors that define the computational geometry of RCC frames that were considered in this research. Geometry includes making preliminary structural plans from the given architectural plans to know the exact location of the structural elements. Followed by geometry is the load combination considerations presented in this section.

MODEL CONSIDERATIONS

A total of 6 structural models were planned, the first one being the ordinary structural system having dominant steel elements. The other remaining systems are Braced frame system, Eccentrically Braced Frames, Outriggers, Outrigger with Belt Truss Systems, Core System. All the discussed structural systems have same general dimensions. The total length of the structure is 60m. The width or shorter dimension of the structure is considered to be 42m. The overall height of the structure is 80m which is divided among 20 storeys, each storey being 4m.

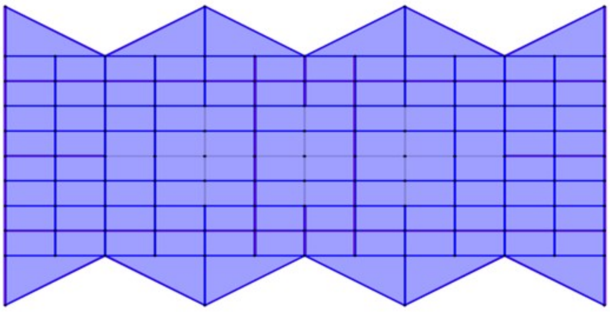

Fig. 1 Structural Plan for Even Storeys

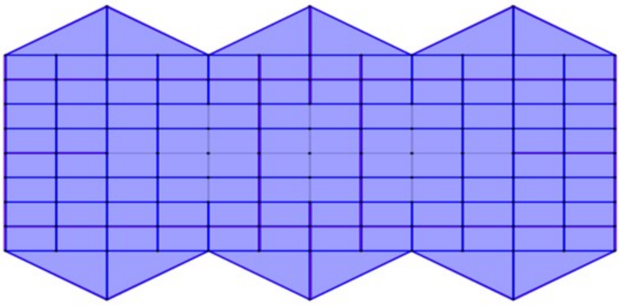

Fig. 2. Structural Plan for Odd Storeys

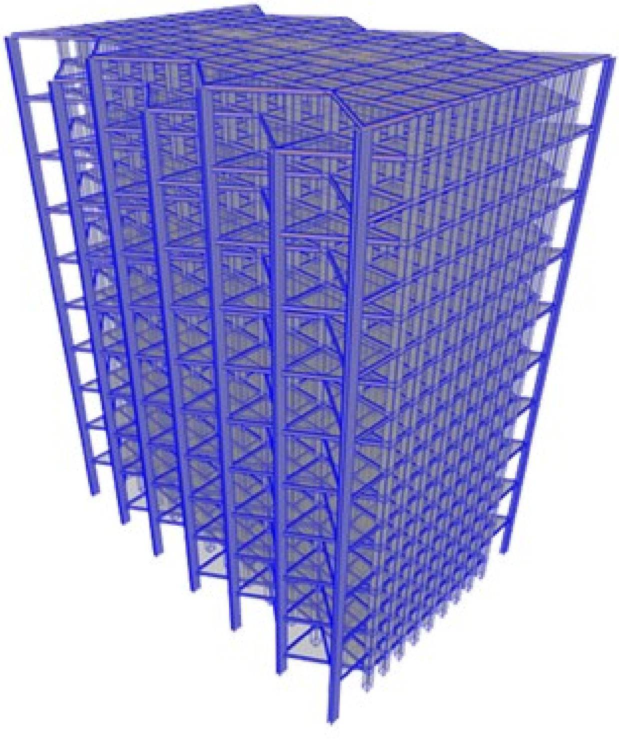

Fig. 3. Isometric Model of Ordinary structure

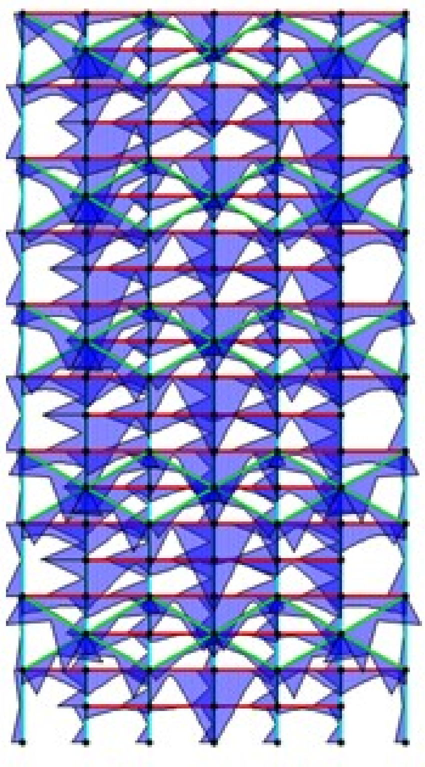

Fig. 4 Bending Moments for Outrigger system with belt truss

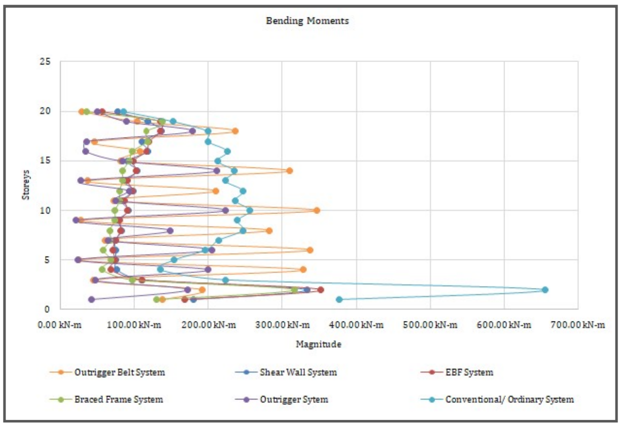

Fig. 5. Bending Moments for Outrigger system with belt truss

RESULTS

BENDING MOMENTS: The values in figure 6 indicate the comparison of the maximum bending moment that the structure experiences due to the RSx load case. The bending moments are higher at the top of the building and decrease towards the bottom. The maximum bending moments are seen on the 2nd floor for all three types of structures, with values of 655.23 kN-m for ordinary, 172.99 kN-m for outrigger, and 316.33 kN-m for braced frame. In general, the outrigger and braced frame structures show lower bending moments compared to the ordinary structures, with the outrigger structures showing the lowest values. However, there are some exceptions, such as on the 14th floor where the braced frame structure has the lowest bending moment.

SHEAR FORCES: For the Ordinary structure type, the shear-force values vary from 6.05 kN at the topmost 20th storey to 89.04 kN at the bottom 1st storey.

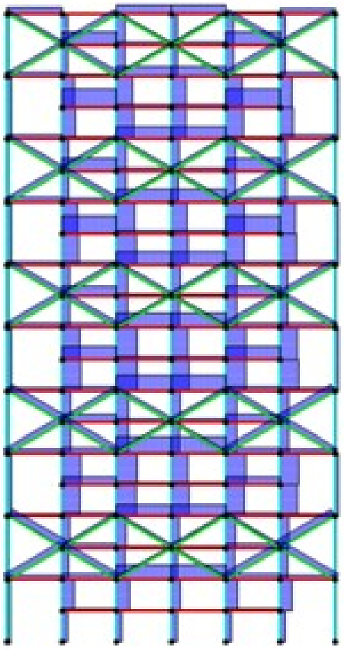

Fig. 6. Shear Forces for Outrigger system with belt truss

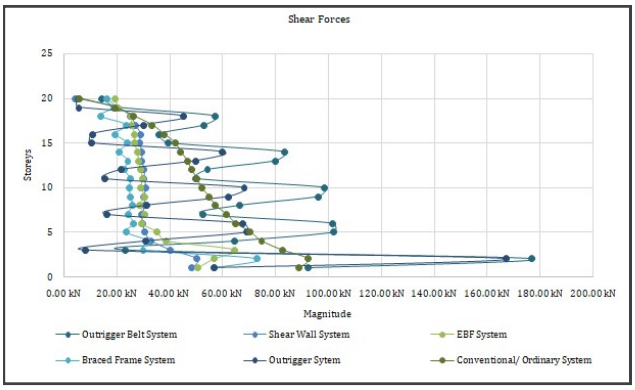

Fig. 7. Shear Forces for Outrigger system with belt truss

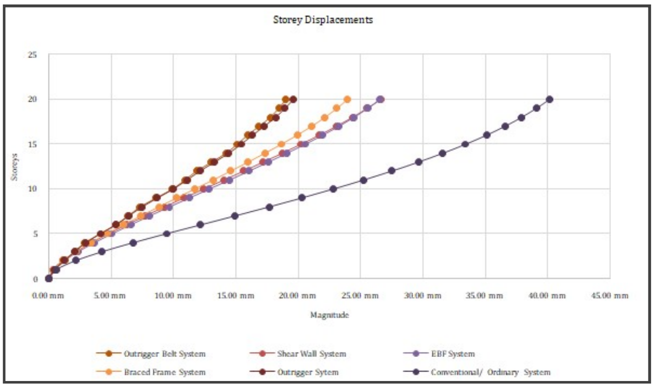

Fig. 8. Shear Forces for Outrigger system with belt truss

For the Outrigger structure type, the shear-force values vary from 5.36 kN at the topmost 20th storey to 167.13 kN at the 2nd storey, and then decrease to 56.76 kN at the bottom 1st storey. And for the Braced Frame structure type, the shear-force values vary from 14.06 kN at the 18th storey to 73.16 kN at the 2nd storey. Overall, it can be observed that the shear-force values are higher for the Outrigger and Braced Frame structure types compared to the Ordinary structure type. This can be attributed to the additional lateral load resistance provided by the outriggers and braces in these types of structures.

DEFLECTIONS: The largest storey displacement for the ordinary structure is 40.13 mm, which occurs at the top storey (20), and the smallest displacement is 0.62 mm at the base. For the outrigger structure, the largest storey displacement is 19.63 mm at the top storey, and the smallest is 0.46 mm at the base. For the braced frame structure, the largest storey displacement is 23.95 mm at the top storey, and the smallest is 0.36 mm at the base. The outrigger structure has the smallest storey displacements of the three structures at each storey, while the ordinary structure has the largest storey displacements. The braced frame structure has storey displacements that fall between those of the ordinary and outrigger structures. For the EBF structure, the maximum displacement is 26.58 mm at storey 20, while for the shear wall and outrigger belt structures, it is 26.65 mm and 18.99 mm, respectively. As we move down the floors, the displacements reduce gradually for all three types of structures. The results show that the EBF structure has the highest displacement compared to the shear wall and outrigger belt structures.

CONCLUSION

On comparing the results, the most effective system in terms of displacement reduction is Belt with outriggers with a total average reduction of 42.75%. Outrigger system and Belt system with outriggers both have similar reductions, but the former has a slightly lower average reduction of 42.49%. The next most effective systems are Braced Frame and Shear Walls, with average reductions of 40.93% and 40.02% respectively. EBF (eccentrically braced frames) has the lowest average reduction rate of 38.66%. In conclusion, the outrigger system with and without belt truss are the most effective systems for displacement reduction, followed by Braced Frame and Shear Walls. EBF is the least effective system in this regard. Use of steel reduces reaction forces, but it affects the economy. So, material amount has to be balanced carefully. Use of outriggers with belt system has helped eradicate this problem.

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