IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 12, Issue 1, January 2025

DOI: 10.17148/IARJSET.2025.12123

Comparative Study of Bundled Tube System with Bracing System for High Rise Building

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Abstract: The development of tall buildings have been rapidly increasing worldwide because of rapid growth of the urban population, high cost of land and the need to preserve important agricultural production. It is inevitable to create high-rise structure and on high-rise structure lateral forces due to wind or seismic loading is governing criteria. It is found that the design of tall buildings is governed by lateral loads. In the tubular system, closely spaced periphery columns create very high moment of inertia compared to the simple frame system. The tube is formed by closely spaced peripheral columns. This effect provides stiff moment of resistance against lateral loads. For profound effect, the created group of tubes is known as a bundled tube system. For the study purpose in this article 64, 80, 96 stories building structure have been studied for peak displacement, story drift, base moment, story shear and structural system weight. The comparative study shows that the overall weight of bundled tube system is very low, hence it is economical. The peak displacement response of building is within the permissible limit of IS: 800-2007. Moreover, shear-leg effect seems to be disappeared.

Keywords: Bundled Tube System, Bracing System, Dynamic analysis, Story Displacement, Story Drift, ETABS, Tube-in tube Structure.

I. INTRODUCTION

The rapid development of tall buildings worldwide has significantly impacted the innovative development of structural systems. As urban populations continue to grow, the demand for space increases, leading to the construction of taller buildings to maximize the use of limited land. This trend is driven by the need to accommodate the increasing population density and the diminishing availability of land, which also drives up land prices. High-rise buildings are subjected to significant lateral loads due to wind and seismic forces. These lateral loads can cause large deformations and stresses in the structure, affecting its stability and performance. Therefore, it is crucial to design high-rise buildings with efficient structural systems that can resist these loads and provide adequate safety and serviceability [14-27].

There is no exact definition of a "tall building," but according to the Council on Tall Buildings and Urban Habitat (CTBUH), a building can be considered tall if it fulfils any of the following criteria: Height compared to surroundings: The building is much taller than other buildings in its area, making it a prominent feature of the skyline. Proportion: The building appears slim enough to be perceived as tall, often characterized by a high aspect ratio.
New techniques for tall buildings: The building includes special systems like elevators designed for tall buildings or structural bracing systems to resist wind and seismic forces. These innovations are essential for ensuring the functionality and safety of tall structures [14-27].

For structural engineers, a building is considered tall when forces like wind or earthquakes significantly affect its design. This research work focuses on comparing different types of lateral load-resisting systems to determine the most efficient and cost-effective system for resisting lateral loads, such as wind and seismic loads. The study involves a comprehensive review of literature and a comparative analysis of various lateral load-resisting systems, including belt trusses, tubular systems like bundled tubes and framed bundled tubes, braced systems, and tube-in-tube systems. Each of these systems has unique characteristics and advantages that make them suitable for different applications [14-27].

The analysis has been conducted using ETABS-2015 software, considering different methods of analysis for static earthquake forces, dynamic earthquake forces (Response Spectrum analysis as per guidelines of IS: 1893-(Part 1) 2016), and static wind forces as per IS 875 (Part-3)-2015. The design is based on IS: 800-2007 code provisions. The aim of the research is to identify the most effective and economical lateral load-resisting system for high-rise buildings in the given context, taking into account the requirements of seismic and wind load resistance. By evaluating these systems, the research aims to provide valuable insights for the design and construction of safer and more efficient tall buildings [14-27].

1. Analysis and Optimization: The author has conducted extensive analysis and optimization using various techniques, including finite element analysis (FEA). FEA is a powerful computational tool that allows for the detailed simulation of structural behaviour under different loads and conditions. By using software like MATLAB, the author has been able to model and analyse the stability of tall and slender structures, ensuring they can withstand various forces and stresses. This approach helps in identifying potential weaknesses and optimizing the design for better performance and safety [13-27].

2. Optimization of RCC Structures: Optimizing reinforced concrete (RCC) structures is a complex and iterative process. It involves numerous trials and adjustments to find the most efficient and effective design. This process requires a deep understanding of material properties, load distribution, and structural behaviour. The author has explored various optimization techniques, engaging in extensive debate and discussion to arrive at the best solutions. This research aims to minimize material usage and cost while maximizing structural integrity and performance [28-32].

3. Optimization of Steel Structures: The optimization of steel structures is generally more straightforward compared to RCC structures due to the unique properties of steel. Steel is a strong and ductile material, making it ideal for creating structural frames that can withstand significant loads. The author has investigated different structural system extensions and the inherent strength of steel, focusing on how to best utilize this material in high-rise buildings. This research includes exploring various design configurations and load-resisting mechanisms to enhance the overall efficiency and safety of steel structures [33-39].

4. Seismic and Random Vibration Studies: The author has studied the effects of seismic and random vibrations on various structures, with a particular focus on lead rubber bearing (LRB) isolators. LRB isolators are used to reduce the impact of seismic forces on buildings by absorbing and dissipating energy. This research involves analysing how different structures respond to seismic events and identifying the most effective isolation techniques to protect buildings from earthquake damage. The findings contribute to the development of safer and more resilient structures in seismically active regions [40-44].

5. Lateral Load Controlling Systems: The research includes an examination of various lateral load controlling systems, both passive and active. Passive systems, such as tuned mass dampers (TMD), are designed to absorb and dissipate energy from lateral loads like wind and earthquakes. Active systems, on the other hand, use sensors and actuators to actively counteract these forces in real-time. The author has explored the effectiveness of these systems in different scenarios, aiming to identify the best solutions for enhancing the stability and performance of high-rise buildings [45-53].

6. Time History Analysis: The author has conducted time history analysis to understand the dynamic effects of loads on medium to low-rise structures. Time history analysis involves simulating the response of a structure to time-varying loads, such as those caused by earthquakes or wind gusts. This method provides detailed insights into how structures behave under dynamic conditions, helping engineers design buildings that can better withstand these forces. The research findings contribute to the development of more robust and resilient structures [55-59].

7. Soil-Structure Interaction: In some articles, the author has discussed soil-structure interaction, emphasizing the importance of considering the interaction between the soil and the structure in the design process. Soil-structure interaction refers to the mutual influence between a building and the ground it is built on. This interaction can significantly affect the performance and stability of a structure, especially during seismic events. The author has explored various aspects of soil-structure interaction, including how different soil types and conditions impact structural behaviour. This research helps in designing foundations and structures that are better suited to their specific site conditions [54].

II. LITERATURE REVIEW

Patel & Jangid [37] investigated It is well established that properly designed tuned mass dampers (TMD) systems can effectively mitigate vibrations caused by wind or seismic activity. TMDs are among the most commonly used passive control systems in modern high-rise structures, especially with recent advancements in engineering. To determine the optimal parameters for these damped systems, numerical optimization techniques or trial-and-error methods are typically used. These methods, while effective, add complexity when selecting parameters under optimal conditions. However, the study of optimal parameters based on modal multiplicity criteria presents a complete closed-form solution that is independent of other parameters. The parameters derived in this research depend solely on structural damping and mass ratio. The study compares these newly derived optimal parameters with those already established in the field. Additionally, it explores the impact of parametric uncertainties in structural configurations subjected to harmonic excitation. To assess the robustness of the system under random vibrations, various earthquake time-history loads are applied to examine the effects on structural displacement and acceleration responses. Finally, the concept of energy is applied to demonstrate how the optimal TMD parameters effectively reduce kinetic, damping, strain, and input energies.

Patel & Jangid [28] study introduces and systematically explains a new technique called "equal modal frequency and damping" (EMFD) to derive complete closed-form solutions for tuned mass dampers (TMDs), aiming to reduce the dynamic response of structural systems. Traditionally, determining the optimal parameters for damped systems has relied on numerical search methods or trial-and-error techniques, which can complicate the selection process. The EMFD method, however, offers a straightforward closed-form solution that is independent of other parameters, simplifying the optimization process. The parameters derived from this method are based solely on structural damping and mass ratio, and the study identifies multiple optimal solutions. It also explores the performance of these solutions under harmonic excitation and compares them with existing research. To further validate the robustness of the solutions under real-world conditions, various earthquake time-history loads are applied, and the behavior of different solutions is examined. The study also provides a demonstration of a shear building subjected to both harmonic and random excitation, offering practical insights for future research. Ultimately, the article presents an efficient way to find optimal parameters without the need for numerical calculations, highlighting the importance of multiple optimal solutions, particularly when structural systems are exposed to random excitation.

Patel & Patel [2] analysis and design of a tubular system involved assigning dead, live, lateral, earthquake, and wind loads. Earthquake loads were analysed using static and response spectrum methods. Buildings are considered to be the study, conducted in zone-V, found that diagrids have lower displacements on each story and story drifts than conventional frames, allowing for greater spacing between exterior columns in bundled tube systems compared to framed tube systems. The bundled tube structural system outperforms other lateral load resisting systems in terms of displacement, story drift, base shear, and stiffness. It can also withstand wind forces at higher heights.

Rana & Patel [42] study examines the seismic risk of asymmetric frame buildings, with a focus on understanding their ultimate behavior when exposed to dynamic forces from earthquakes. It underscores the importance of using fragility curves as a means to assess this risk. Specifically, the research investigates how various eccentricities impact seismic risk, developing fragility curves for different eccentricity cases and structural configurations of five-story reinforced concrete (RCC) bare frame buildings. The methodology involves conducting Incremental Dynamic Analyses to assess the buildings' responses to earthquake excitations, and the Monte Carlo method is applied to create fragility curves based on different performance levels according to ATC-40 guidelines. The findings reveal that as structural eccentricity increases, the probability of failure under the immediate occupancy failure criteria rises. However, there is minimal variation in failure probabilities during the life safety and collapse prevention stages.

Shah & Patel [15] parametric analysis of tall structures incorporating a diagrid structural system was conducted. The diagrid is an external structural system designed to resist lateral forces through the axial actions of its diagonal members arranged along the periphery of the building. The primary objective was to determine the most effective module size for the diagrid. The analysis involved five steel buildings, each with a typical plan area and varying heights of 12, 24, 36, 48, and 60 storeys. The study considered different module sizes of 4, 6, and 8 storeys for the diagrid system, and the analysis was performed using ETABS 2017 software. Key parameters evaluated included the fundamental time period, maximum storey displacement, maximum storey drift, and maximum base shear.

III. OBJECTIVE

The objective of this study is to analyse a bundled tube structure for the design of a tall and resilient building that can endure significant wind and earthquake forces [28-37]. The focus will be on comparing the performance of a braced system versus a bundled tube system across buildings with 96 story. The evaluation will include a comparative assessment of key structural parameters such as maximum displacement, story drift, base shear, time period, and the overall weight of the structural system [29-35].

IV. NUMERICAL STUDY

In this paper, compares a 96-story building using V and inverted V bracing systems with a building that has no bracing system. Here are some general data needed for the comparison. In this study, 6 different models are prepared and analysis.

4.1 General Data:

Table-I Properties and Data

Parameters	**Value**
Numbers of Stories	96
Height of each story	3.2m to all story
Plan Area	60m x 60m
Height of structure	307.2m
Grade of steel	Fe250
Grade of concrete	M30
Model damping	2%
Earthquake Load	As per IS:1893(Part 1)(Both Direction)
Slab Thickness	180 mm
Floor Finish	1.5 KN/M^2
Live Load	2.5 KN/M^2
Seismic Zone	V (Bhuj)
Importance Factor	1.5
Response Reduction Factor	5
Soil Type	2
Wind Speed	50 m/s
K1	1.08
K3	1
Wind Load	IS:875(Part-3)-2015

4.2 Modelling of Building:

This study utilizes ETABS software to analyse critical seismic parameters, including Maximum Story Displacement, Maximum Story Drift, Base Shear, Time Period, and Steel Weight, in order to assess the structural performance of a building model. By conducting a thorough analysis with ETABS, the study enables informed design and retrofitting decisions aimed at enhancing the building's resilience to earthquakes. This process involves identifying potential vulnerabilities and optimizing the structural design to improve overall safety and performance. The analysis encompasses both static and dynamic methods, with wind analysis categorized as a dynamic assessment.

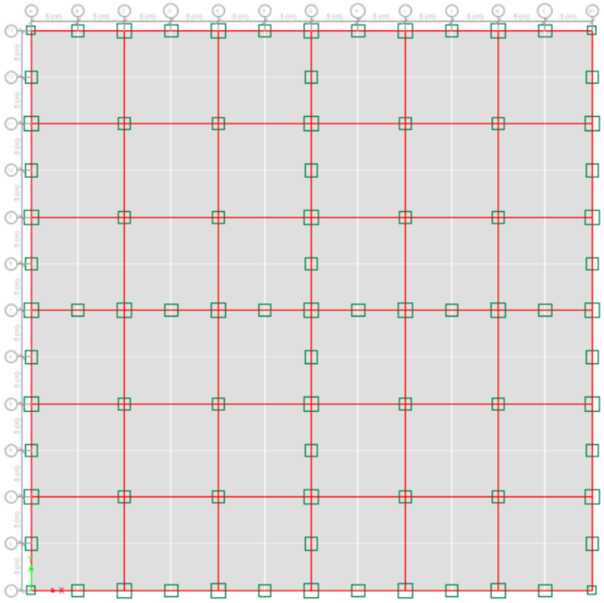

Fig. 1. Plan of 96 Story V bracing and Inverted V Bundled Tube System

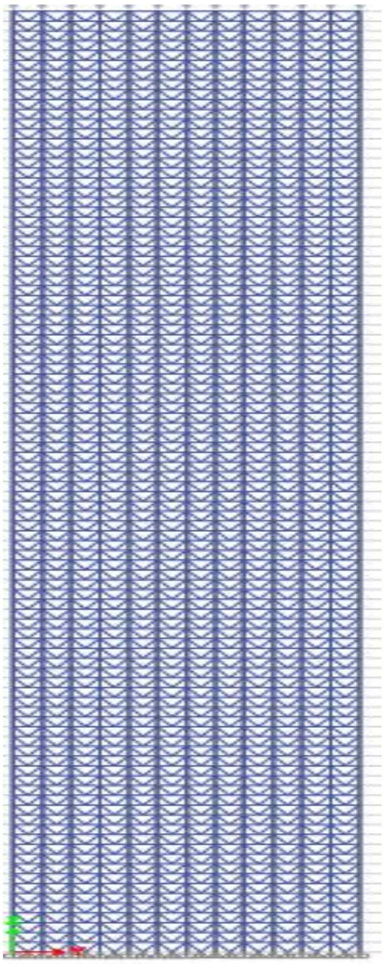

Fig.2. Elevation of V Bracing System

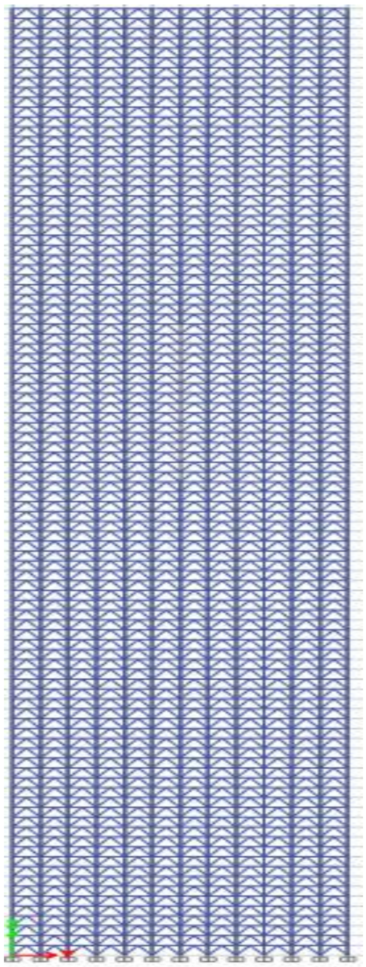

Fig.3. Elevation of Inverted V Bracing System

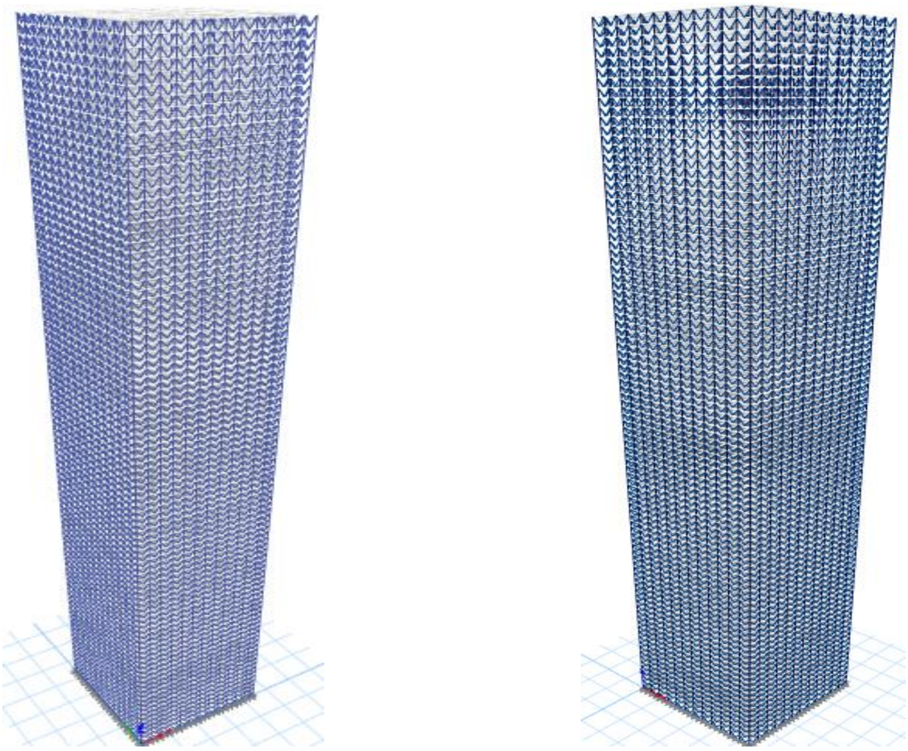

Fig. 4. 3D View of V and Inverted V Bracing Bundled Tube System

V. RESULTS AND DISCUSSION

Results comparison between V Bracing, Inverted V Bracing and No bracing Bundled tube system are shown below.

A. Maximum Story Displacement

Fig.5 Maximum Story Displacement Comparison graph

Fig.5 shows that the maximum story displacement is 39.23% higher in No bracing as compare to V Bracing. And 45% higher in No bracing as compare to Inverted V Bracing.

B. Maximum Story Drift

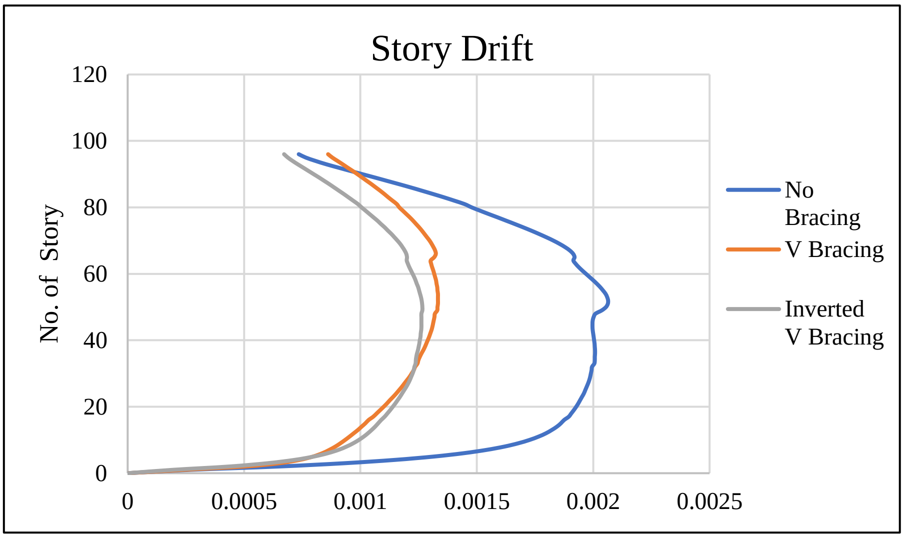

Fig.6 Maximum Story Drift Comparison graph

Fig.6 shows that the maximum story drift is 41.05% higher in No bracing as compare to V Bracing. And 45.33% higher in No bracing as compare to Inverted V Bracing.

C. Base Shear

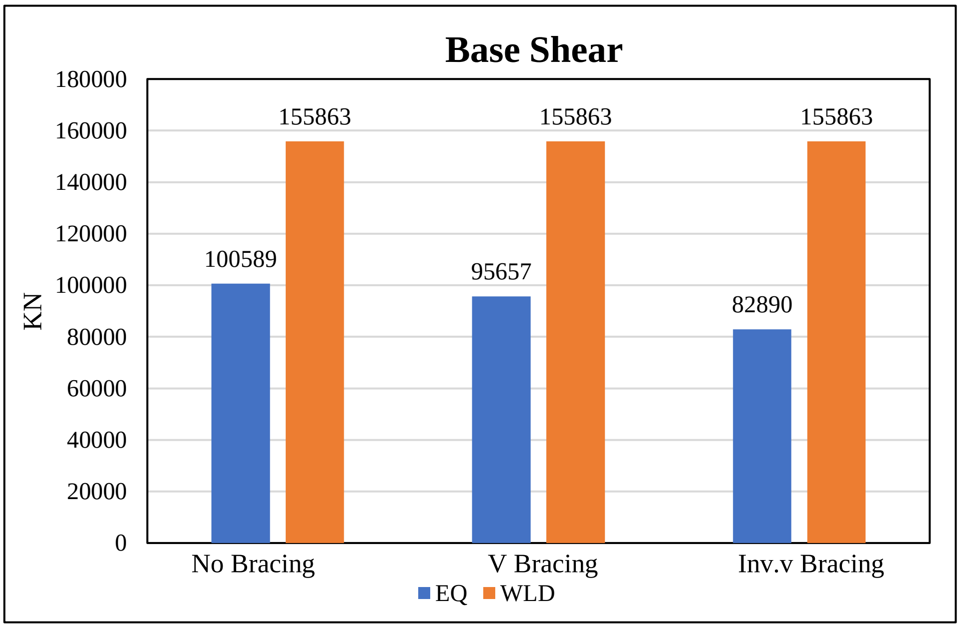

Fig.7 Base Shear Comparison graph

Fig.7 shows that the base shear is 5.02% higher in No bracing as compare to V Bracing. And 19.23% higher in No bracing as compare to Inverted V Bracing.

D. Time Period

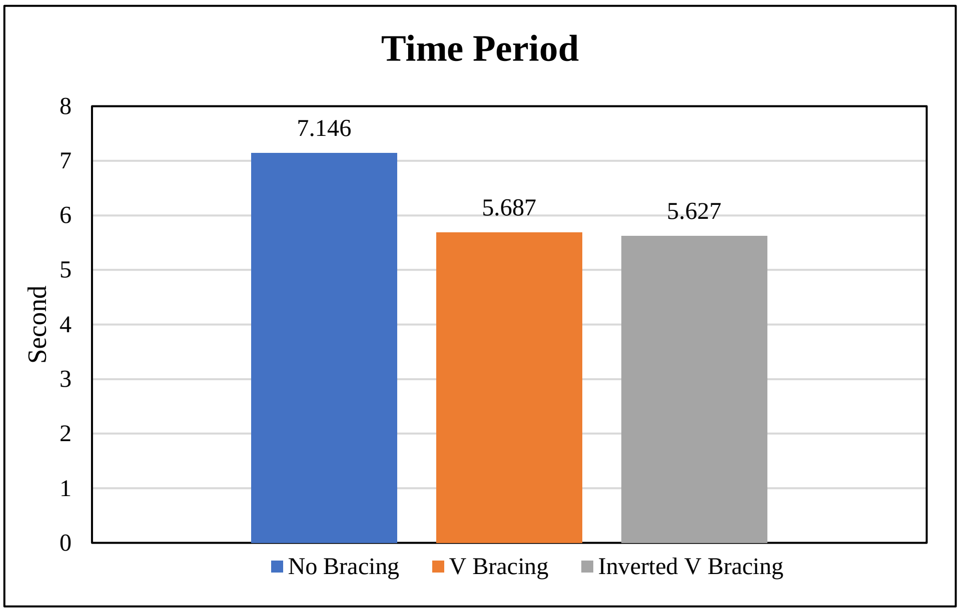

Fig.8 Time Period Comparison graph

Fig.8 shows that the base shear is 23% higher in No bracing as compare to V Bracing. And 24% higher in No bracing as compare to Inverted V Bracing.

E. Steel Weight

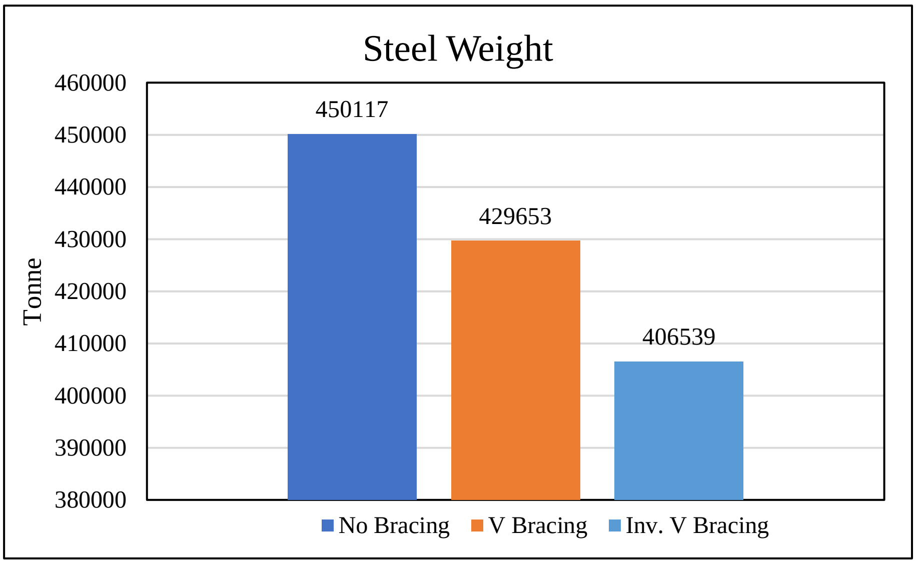

Fig.9 Time Period Comparison graph

Fig.9 shows that the base shear is 4.65% higher in No bracing as compare to V Bracing. And 10.17% higher in No bracing as compare to Inverted V Bracing.

Table-II Analysis Result of Bracing system compare to without bracing bundled tube system

	No Bracing	**V Bracing**	**Inverted V Bracing**
Maximum Story Displacement(mm)	524.217	351.93	331.627
Maximum Story Drift	0.002008	0.001324	0.001266
Base Shear(KN)	100589	95657	82892
Time Period(Second)	7.146	5.687	5.627
Steel Weight(Tonnes)	450117	429653	406539

VI. CONCLUSION

From the above analysis and results, the following conclusions are drawn below.

1. It is observed that without bracing, displacement of building is more. So bracing system are provided more stiffness of building to reduce displacement.
2. It is observed that Inverted V bracing bundled tube system is more stiffness provided compare to V Bracing bundled tube system.
3. Story drift, Time period, Base shear and Steel weight of bundled tube structure with bracing system is more effective and convenient than without bracing system.
4. Inverted V Bracing bundled tube system is more economical than V bracing bundled tube system.

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