Comparative Structural Analysis of Dia-Grid in Comparison with Other Conventional Structures

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Abstract - The objective of this study is to evaluate the seismic performance of various structural systems and identify the most efficient configuration for tall buildings. Ensuring adequate lateral stability and ductility is critical for reducing damage during strong earthquakes, particularly in high-rise structures located in severe seismic zones. In this work, seven structural models of a G+20 storey building with a plan dimension of 27.5 m × 27.5 m and a storey height of 3.6 m are analyzed. The models include a conventional moment-resisting frame, shear wall system, core wall system, frame with diagonal bracing, diagrid with periphery columns, diagrid without periphery columns, and a combined diagrid–shear wall system. Using ETABS 2015, seismic analysis is performed for Zone V conditions through equivalent static analysis, response spectrum analysis, and time-history analysis. The seismic performance is assessed using key parameters such as bending moments, shear forces, axial forces, storey displacement, drift, stiffness, and overall economy. The comparative results provide insights into the lateral load-resisting efficiency of each structural system and help determine the most suitable configuration for high-rise buildings in high seismic regions.

Keywords: Seismic performance, Tall buildings, Diagrid system, Shear wall, Core wall, Braced frame, ETABS, Response spectrum, Time-history analysis, Storey drift, Lateral stability.

1.INTRODUCTION

Rapid urbanization and the increasing pressure on limited land resources have significantly influenced the development of modern cities, pushing residential and commercial buildings upward rather than outward. High land costs, the need to control continuous urban sprawl, and the importance of preserving surrounding agricultural and natural landscapes have accelerated the demand for tall, efficient, and sustainable structures. Designing such buildings requires innovative structural systems capable of providing high strength, stability, and adaptability. Among the major challenges is ensuring adequate lateral stiffness, as taller buildings are more vulnerable to wind and seismic forces. Conventional lateral load-resisting systems—such as rigid frames, shear walls, braced tubes, wall-frame systems, and outrigger systems—have been widely used, but each comes with limitations in terms of material efficiency and architectural flexibility.

In recent years, the **diagrid structural system** has emerged as a highly efficient and aesthetically appealing alternative for tall buildings. The term "diagrid," derived from "diagonal" and "grid," refers to a framework composed of intersecting diagonal members forming a triangulated pattern. Unlike traditional frames that rely heavily on vertical columns, diagrids eliminate exterior vertical elements and rely on diagonal members to carry both gravity and lateral loads through axial action. This significantly enhances stiffness, reduces shear deformation, and improves structural efficiency.

1.2 RESEARCH SIGNIFICANCE

The rapid growth of urban populations, escalating land costs, and pressure to optimize limited space have made tall buildings an essential component of modern city development. As highlighted in the document, the need for vertical expansion places increasing structural demands on buildings, especially in terms of lateral stiffness, seismic resistance, and wind load performance. Conventional structural systems—such as rigid frames, braced frames, and shear walls—provide reliable load resistance but often require extensive material use and impose architectural limitations, restricting flexibility and floor plan efficiency.

The diagrid structural system emerges as a highly significant innovation in this context. Its triangulated layout allows diagonal members to carry both gravity and lateral loads through axial action, reducing bending stresses and minimizing shear deformation. This axial load–dominant behavior significantly enhances stiffness and structural efficiency, requiring fewer vertical elements and reducing steel consumption by up to 20% compared to framed tube structures. The document also notes that diagrids improve architectural aesthetics, enable column-free perimeters, and allow greater freedom in building form—planar, curved, or crystalline—supporting modern architectural ambitions

In essence, the research is significant because it supports the development of next-generation tall buildings that are more efficient, sustainable, and architecturally flexible. Understanding diagrid behavior compared to conventional systems is essential for improving structural performance, reducing material usage, and enabling innovative vertical construction strategies in rapidly urbanizing environments.

1.3 Objectives of the Present Study

The aim of this study is to analyze the seismic performance of different structural systems and identify the most efficient framework for tall buildings. Ensuring adequate lateral stability and ductility is essential for minimizing structural damage during earthquakes. For this purpose, seven structural models of a G+20 storey building with a plan size of 27.5 m × 27.5 m and storey height of 3.6 m are examined. The models include a regular frame, shear wall system, core wall system, framed structure with diagonal bracing, diagrid with periphery columns, diagrid without periphery columns, and a combined diagrid–shear wall system. Using ETABS 2015, the structures are analyzed for Seismic Zone V through static analysis, response spectrum analysis, and time-history analysis. Comparative results are evaluated based on bending moments, shear forces, axial forces, displacement, drift, storey stiffness, and overall economy to determine the most effective structural configuration.

2. LITERATURE REVIEW

Amol V. Gorle, S. D. Gowardhan[2016] The diagrid structural system is widely adopted for resisting lateral loads due to its superior structural efficiency and architectural flexibility. To determine the optimum performance of a steel diagrid system, a 36-storey building with a plan dimension of 35 m × 35 m was modeled and analyzed using ETABS software. Five analytical models were developed with diagrid member angles of 50°11'24", 67°22'12", 74°28'12", 78°13'48", and 82°5'24". These models were evaluated under seismic loading using response spectrum analysis. The results were compared in terms of top-storey displacement, storey drift, and modal time period. The study concludes that the seismic performance of a diagrid structure is strongly influenced by its stiffness, which in turn depends on parameters such as diagrid angle, member length, cross-sectional area, and material properties. The optimum diagrid angle is found to lie between 60° and 70°, and the effective length of diagrid members should be kept as short as possible to achieve maximum structural efficiency.

Terri Meyer Boake.et.al Recent research highlights significant variations in node configurations within diagrid structures, emphasizing their dependence on modularity, architectural expression, and the decision to expose the structural steel. Advances in digital modeling have greatly improved the link between design and fabrication, enabling seamless communication from conceptual development to the manufacturing of complex nodes. These technological improvements have expanded the use of the term “node” to describe a wide range of applications in tall-building construction, including the increasing use of steel castings for highly customized connection systems.

3.MATERIAL AND METHODOLOGY

3.1 SEISMIC ANALYSIS

For accurate calculation of seismic responses, a complete seismic investigation of the structure is essential. This investigation depends on the type of external forces, structural behavior, and the analytical model selected. Based on these factors, seismic analysis is broadly classified into:

- Linear Static Analysis (Equivalent Static Method)
- Linear Dynamic Analysis (Response Spectrum Method)
- Nonlinear Dynamic Analysis (Time History Method)

The equivalent static method is suitable for regular buildings with limited height. Linear dynamic analysis provides a more realistic understanding of seismic behaviour by considering the dynamic characteristics of the structure. The primary difference between linear static and linear dynamic analysis lies in the magnitude and distribution of forces along the height of the building. Nonlinear dynamic analysis is the most accurate method, as it captures the real behaviour of a structure during earthquakes by numerically integrating the equations of motion while accounting for elasto-plastic deformation of structural components.

3.1.1 Expansive soil

The equivalent static method does not require a full dynamic analysis; however, it represents the overall dynamic behavior of a structure in an approximate manner. It is the simplest seismic analysis procedure, requires minimal computational effort, and follows the guidelines provided in the relevant codes of practice. In this method, the total design base shear for the entire building is first calculated using code-specified seismic parameters. This base shear is then distributed vertically along the height of the structure in proportion to the mass and stiffness at each floor level. The resulting lateral forces at individual storeys are subsequently assigned to the corresponding lateral load–resisting elements, such as frames, shear walls, or braced components. Although approximate, this method provides a practical and efficient means for analyzing regular, low- to medium-height structures where higher-mode effects are not significant.

4. MODELLING AND ANALYSIS

4.1 Introduction

The fundamental requirement of a tall structure is its ability to withstand lateral loads, as the overall building response is governed by its lateral stability parameters. In tall buildings, the structural system is typically designed so that the entire framework behaves like a vertical cantilever fixed firmly at the ground. In this study, seven types of 20-storey structural models are selected, with all member dimensions kept identical across the models to ensure uniform comparison. Each model is analyzed using Equivalent Static Analysis, Response Spectrum Analysis, and Dynamic Time History Analysis, along with detailed Modal Analysis. These analytical approaches provide a comprehensive understanding of the structural performance under different seismic conditions and help evaluate variations in stiffness, displacement, and overall dynamic response among the selected systems.

4.2 Description of Model

In this study, four different structural models are considered for comparative analysis. The plan dimensions, storey height, number of floors, and slab thickness are kept constant for all models to ensure uniformity in evaluation. Each building has a plan size of 27.5 m × 27.5 m, with an internal core measuring 5.5 m × 5.5 m. The total height of the structure is 73.4 m, with each storey having a height of 3.6 m and a slab thickness of 175 mm. The structural elements include columns of size 650 × 650 mm and beams of 200 × 600 mm. The applied loads consist of a live load of 3 kN/m², a floor finish load of 1.5 kN/m², and a wall load of 10.8 kN/m acting on the beams. In the shear wall model, 300 mm thick shear walls are provided on all floors, while in the diagrid bracing model, diagonal members of 300 mm thickness are placed at an angle of 65 degrees. In the conventional bracing model, bracings of 300 mm size are used.

5. **RESULTS AND DISCUSSIONS**

In this study, the seismic performance of framed structures with different bracing and lateral load–resisting systems is analyzed using ETABS through both Equivalent Static Analysis and Response Spectrum Analysis. The investigation focuses on key response parameters, including displacement, storey drift, stiffness, storey shear, modal characteristics, and time-history behavior. These parameters help evaluate how each structural configuration reacts to seismic loading and how effectively lateral forces are resisted.

Displacement

To conduct a comprehensive comparison, seven structural models are developed with distinct lateral load-resisting mechanisms while maintaining identical geometric and loading conditions. The models and their designations are as follows: S1 – Conventional Structure, S2 – Braced Structure, S3 – Diagrid with Columns, S4 – Core Wall Structure, S5 – Diagrid without Columns, S6 – Shear Wall Structure, and S7 – Diagrid with Shear Wall Structure. By comparing these configurations, the study aims to identify the most efficient system in terms of seismic response, overall stiffness, and performance under lateral loads.

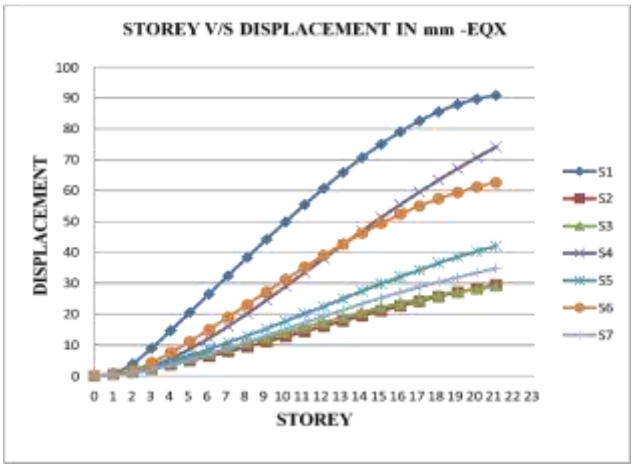

Figure 1. Variation of Storey Displacement for Different Structural Systems in a G+20 Building under Seismic Loading

The displacement profiles clearly show that storey displacement increases with height for all structural systems. The conventional frame (S1) records the highest displacement in every load case, indicating lower lateral stiffness. Compared with S1, models S2, S3, S4, S5, S6, and S7 exhibit significantly reduced displacements in both seismic (EQX, EQY) and wind (WINDX, WINDY) directions. Among them, S2, S3, S5, and S7 consistently show superior performance due to improved stiffness and efficient lateral load distribution. Considering structural efficiency, construction feasibility, cost, and aesthetics, the diagrid without periphery columns (S5) is identified as the most practical and effective system

The storey displacement graph illustrates the seismic performance of seven structural models (S1–S7) under lateral loading. Displacement consistently increases with height for all structures; however, the magnitude varies depending on the lateral load–resisting system. The conventional structure (S1) exhibits the highest displacement, indicating minimal lateral stiffness and poor resistance to seismic forces. The braced frame (S2) shows better performance than S1 but still displays noticeable deformation. The core wall (S4) and shear wall system (S6) demonstrate significantly reduced displacement due to their enhanced lateral rigidity.

The diagrid systems (S3 and S5) perform even better, showing a major reduction in displacement because of their triangulated geometry, which effectively distributes seismic forces. Among all configurations, S7 – the combined diagrid with shear wall model exhibits the lowest storey displacement, proving it to be the stiffest and most efficient structural system. Overall, S7 offers superior seismic performance compared to all other models.

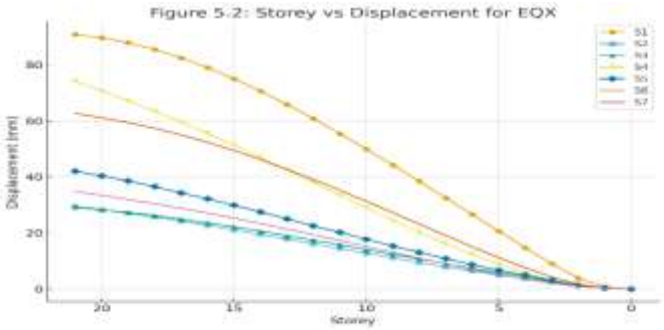

Figure 2. Variation of Storey Displacement for Different Structural Systems in a G+20 Building under Seismic Loading

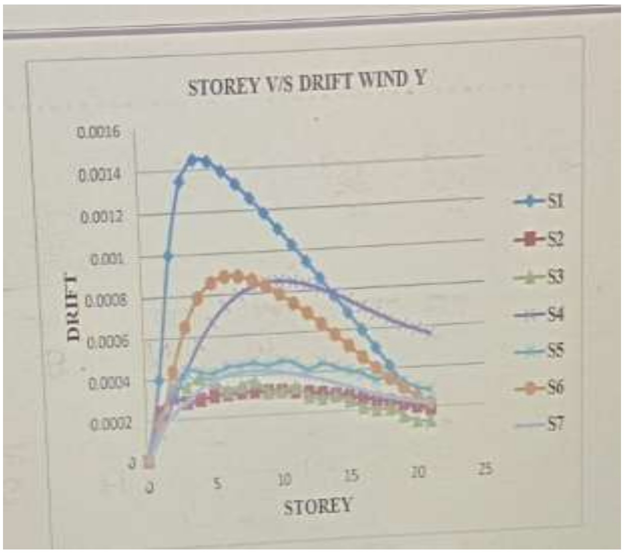

Figure 3: Variation of storey drift for different structural systems (S1–S7) under wind load in Y-direction (WINDY).

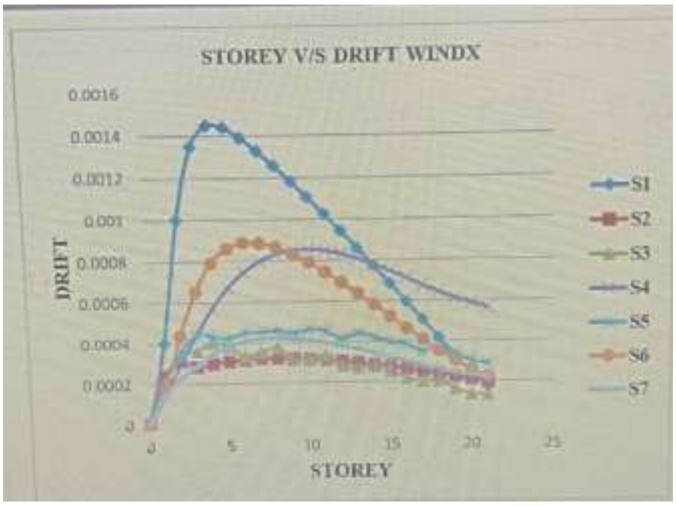

Figure 4: Variation of storey drift for different structural systems (S1–S7) under wind load in Y-direction (WINDY).

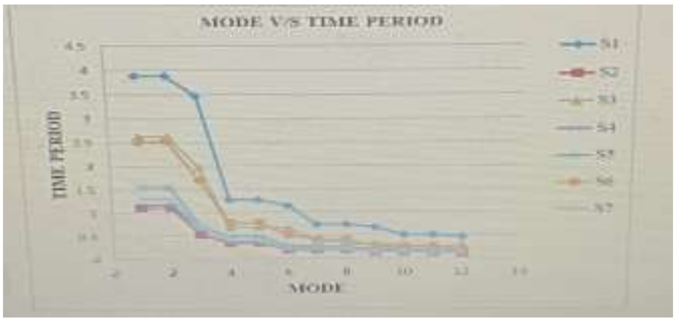

Figure 5: Variation of natural time periods for different vibration modes (Mode 1–12) for structural models S1–S7.

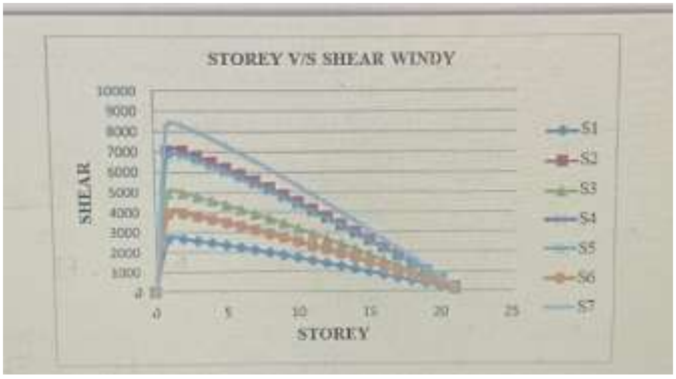

Figure 6: Variation of storey shear for structural models S1–S7 under wind load in Y-direction (WINDY).

Storey drift values for all models remain within IS 1893:2002 limits, with S5 showing a 68.27% reduction. Stiffness and base shear values further confirm the superior lateral performance of diagrid structures. Modal analysis also highlights favorable frequency and time period characteristics. Overall, diagrid systems, especially S5, provide enhanced seismic efficiency and improved architectural appeal.

Storey drift for all structural models increases with height up to certain intermediate storeys and then decreases towards the top in EQX, EQY, WINDX and WINDY cases. The conventional frame S1 shows the highest peak drift (about 0.00164 in earthquake and 0.00145 in wind), indicating comparatively low lateral stiffness. Relative to S1, models S2, S3, S4, S5, S6 and S7 exhibit drift reductions of about 60–75% in most cases, with S2 giving the minimum peak values. Overall, S2, S3, S5 and S7 perform better, while the diagrid without columns (S5) is the most economical and practical system.

Stiffness

The storey stiffness results indicate a progressive reduction in stiffness with increasing height for all structural models under EQX, EQY, WINDX and WINDY load cases. The conventional frame S1 consistently shows the lowest base stiffness (3366472 in EQY and 3421342.7 in WINDX), confirming its lower lateral rigidity. In comparison, models S2, S3, S4, S5, S6 and S7 exhibit significantly higher stiffness—ranging from 70% to over 90%

improvement depending on the load case. Among these, the diagrid system without peripheral columns (S5) and the combined diagrid–shear wall system (S7) demonstrate superior stiffness performance, ensuring better resistance to lateral loads. Considering both stiffness efficiency, construction practicality, and aesthetic suitability, model S5 emerges as the most optimal configuration for tall buildings.

Storey shear

From the shear graphs, it is observed that structure S1 consistently exhibits the lowest base shear in EQX, EQY, WINDX and WINDY cases, indicating comparatively lower lateral resistance. Higher base shear signifies better structural performance under lateral loads, and models S2, S3, S5 and S7 show significantly higher values in all load cases. Among these, S7 records the highest base shear, followed by S2 and S5, demonstrating superior stiffness and energy-dissipation capacity. Considering both structural efficiency and practicality, the diagrid system without peripheral columns (S5) provides an optimal balance between performance, economy, and architectural aesthetics for tall buildings.

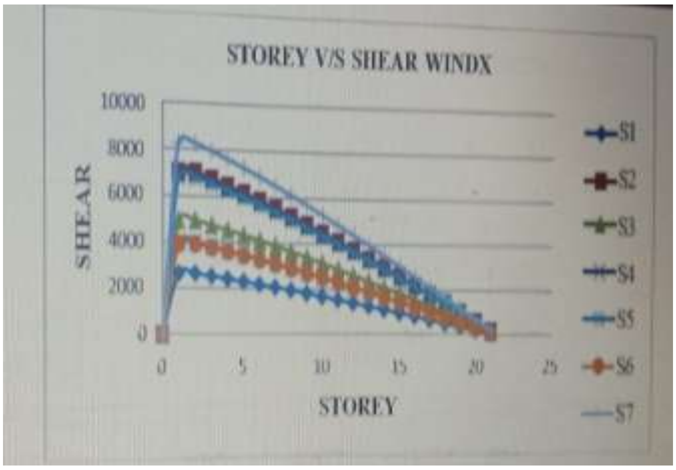

Figure 7: Storey v/s Shear for WINDX

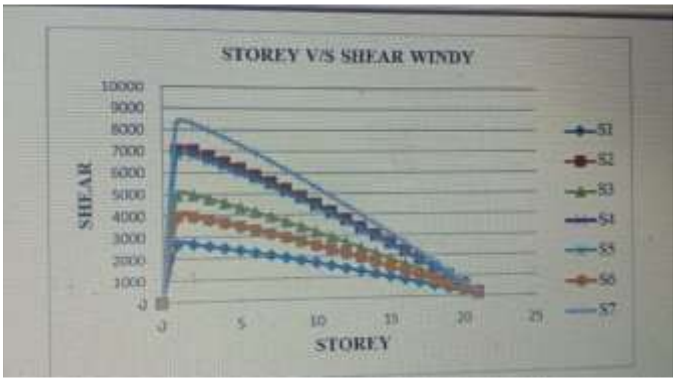

Figure8 : Storey v/s Shear for WINDY

From the WINDY shear graph, it is observed that structure S1 exhibits the lowest base shear value of 2681.54 kN, indicating comparatively lower resistance against wind-induced lateral forces. Higher base shear signifies stronger lateral load-carrying capacity, and models S2, S3, S4, S5, S6, and S7 show significantly higher base shear values of 7073.37, 4991.47, 4024.43, 6841.11, 3965.31, and 8320.11 kN, respectively. Among these, structures S2, S5, and particularly S7 demonstrate superior shear performance. Considering efficiency, economy, and construction practicality, the diagrid system without peripheral columns (S5) provides the most suitable balance for tall building applications.

6. CONCLUSIONS

The study demonstrates that diagrid structural systems provide superior lateral load resistance compared to conventional framed structures due to their efficient diagonal load-carrying mechanism along the building perimeter. This configuration significantly reduces the demand on interior columns, which primarily carry gravity loads. Among all evaluated models, structures S2, S3, S5, and S7 consistently exhibit lower displacement, drift, and higher stiffness and shear capacity. However, considering both structural efficiency, economy, and aesthetic appeal, the diagrid system without internal columns (S5) emerges as the most effective solution.

Storey displacement for S5 is reduced by approximately 53–56% compared to S1 under earthquake and wind loads, while drift values remain within IS 1893 limits. The stiffness and base shear of S5 are significantly higher than the conventional frame, indicating improved rigidity and lateral stability. Modal analysis further confirms satisfactory performance, with S5 showing desirable frequency and time period characteristics.

Overall, diagrid structures—particularly Model S5—offer enhanced seismic and wind performance, greater architectural flexibility, and better aesthetic quality, making them a highly suitable choice for modern high-rise buildings.

6.1 Future Scope

With the increasing adoption of diagrid systems in modern high-rise construction, further research on this structural form is highly valuable. Future studies may focus on evaluating diagrid bracing systems with varying diagonal angles to determine their optimum configuration for enhanced stiffness and seismic resistance. The performance of diagrid structures equipped with supplemental damping devices can also be explored to improve energy dissipation during earthquakes. Additionally, combining diagrid systems with shear walls or other bracing mechanisms offers promising results; hence, research on their structural behavior and material consumption for cost optimization is recommended. The influence of alternative materials—such as tubular sections or advanced steel grades—may also be examined to assess improvements in strength and economy. Studies on mega-bracing systems and the performance of diagrid structures across different seismic zones would provide deeper insights into their applicability under diverse loading and regional conditions.

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