EVALUATING THE STRUCTURAL PERFORMANCE OF DIAGRID STEEL SYSTEMS IN ENHANCING THE BEHAVIOUR OF RCC CORE FRAME BUILDINGS

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Abstract: This study investigates the seismic performance of a G+20 commercial building (15m × 15m, height 62m) using diagrid structural systems with varying angles (45°, 64°, 72°) and cross-sections (I-section, circular hollow, rectangular hollow). The Response Spectrum Analysis method in ETABS, following IS 1893 (Part 1): 2016, was employed to evaluate storey displacement, drift, and base shear under seismic loads for Zone III, importance factor 1, damping 5%, response reduction factor 5, and soil type II. Results indicate that diagrid structures substantially enhance stiffness and reduce lateral displacement compared to conventional frames. Among angles, the 64-degree diagrid showed minimum storey displacement, while the 72-degree diagrid exhibited the lowest inter-storey drift. I-section members consistently outperformed other cross-sections in reducing displacement, drift, and base shear. The study demonstrates that the combination of 64-degree angle and I-section diagrid provides optimal seismic performance, maintaining displacements well within IS 1893:2016 limits. These findings confirm that diagrid systems offer efficient, safe, and economical solutions for high-rise buildings in earthquake-prone regions.

Keywords: *Diagrid structure, Seismic analysis, Storey displacement, Storey drift, Base shear, Response Spectrum Method, High-rise buildings, ETABS, IS 1893.*

1.INTRODUCTION

In contemporary high-rise building design, structural efficiency and architectural elegance are equally vital. Diagrid structural systems have emerged as an innovative solution, offering both aesthetic appeal and superior structural performance [1]. The diagrid system, characterized by a network of diagonal members forming triangular grids on the building façade, efficiently resists lateral and vertical loads while minimizing the need for conventional vertical columns [2][3]. This dual functionality provides architects and engineers the freedom to achieve open floor plans and unconventional building geometries without compromising structural safety [4] [5]. The horizontal strength of diagrid structures plays a critical role in their performance under diverse load conditions [6]. These structures are subjected to both static and dynamic loads, including wind forces acting along various directions. Research and observations have shown that lateral responses induced by across-wind loading, often due to vortex shedding, are significantly higher compared to the windward direction [7]. This highlights the importance of designing diagrid systems to resist complex aerodynamic effects, ensuring occupant comfort and structural stability under fluctuating environmental conditions [8].

The braced tube concept, which underpins the diagrid system, demonstrates that external mega-diagonals are capable of carrying both vertical and horizontal loads simultaneously. Traditionally, vertical columns were responsible for gravity loads, while lateral loads were resisted by external bracing systems [9]. In a diagrid configuration, however, the diagonal elements combine these functions, effectively redistributing loads and reducing structural redundancy [10]. This integration allows for the elimination of conventional vertical columns in many cases, resulting in material efficiency, reduced construction costs, and enhanced architectural flexibility [11]. The primary objective of employing diagrid structural systems is to achieve a balance between structural performance and architectural expression [12]. By integrating diagonal and grid elements, diagrid systems enhance lateral stiffness, reduce deflections under wind and seismic forces, and provide energy-efficient load transfer mechanisms [13]. This makes them particularly suitable for supertall buildings where conventional framing may become inefficient or impractical [14]. Moreover, the diagrid system offers improved resilience against dynamic loading, such as wind-induced vibrations, while maintaining a visually striking façade. Overall, diagrid structures represent a paradigm shift in modern structural engineering, where form and function converge [15]. The system's ability to simultaneously address vertical and lateral load demands, coupled with its material efficiency and architectural versatility, underscores its growing adoption in high-rise construction worldwide [16]. Understanding the behavior of diagrid systems under combined loading is essential for optimizing their design and ensuring long-term performance in diverse environmental conditions.

1.1 Diagrid System

Blending the terms "diagonal" and "grid" to depict the uniform and dispersed triangulated shape, "Diagrid" is becoming a more and more common structural element in modern architectural designs (Boake, 2013). A traditional bracing system, in which the braces only offer lateral stiffness, is far less efficient than a diagrid system, whose perimeter diagonal components provide stiffness for both lateral and gravity loadings. This makes diagrid systems unique structural systems [14] [15] [17]. Figure 1 displays a Diagrid structure's basic load diagram (Singh et al, 2014). The diagonal members' strength and axial stiffness determine the Diagrid's stiffness. More precisely, the diagonal angle determines the primary variable for Diagrid stiffness if the cross-section, length, and material property are specified as constants. As the angle varies, Diagrids' lateral and vertical stiffness would change accordingly. As the diagonal members are designed to be more vertical (i.e. the sine of the diagonal angle increases), the gravity stiffness would increase while the lateral stiffness would decrease and vice versa (Liptack, 2013).

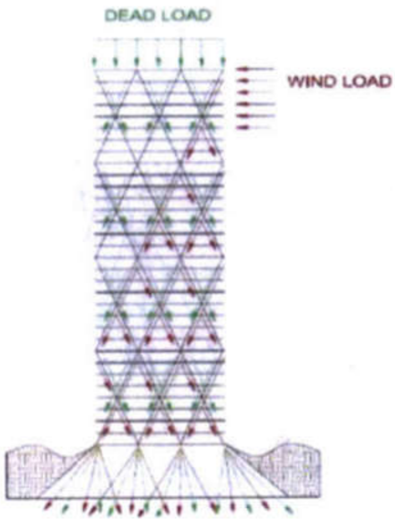

Figure 1. Simplified Load Diagram for Typ 1

Diagrid geometry in low-rise structures eliminates traditional columns and cores, creating flexible architectural space. For high-rise buildings over 50 stories, a perimeter diagrid system, combined with a structural core, provides lateral stiffness, with the diagrid handling roughly 80% of lateral stresses. The system is structurally efficient because it transfers loads primarily through axial forces in diagonal members, reducing material usage and shear deformations more effectively than traditional moment frames. This axial action makes diagrids highly efficient for structural core design in very tall buildings. Compared to outrigger systems, which improve moment and lateral drift but require a rigid shear core, diagrids inherently provide both bending and shear rigidity due to their triangulated configuration, offering a more integrated solution for lateral load resistance.

2. Related work

Diagrid structures have been widely studied for their efficiency and applicability in tall and complex-shaped buildings. Kyoung Sun Moon et al. (2011) explored the structural performance and constructability of diagrid systems for twisted, tilted, and freeform towers. Their study emphasized the efficiency of diagrid systems in handling various geometric configurations, using parametric structural models to investigate the impact of twisting rates and tilting angles, while highlighting the structural and aesthetic potential of diagrids in urban contexts. Building on this, Elena Mele et.al (2012) focused on the triangle diagrid module as the basic unit of diagrid systems. They analyzed internal force distribution in relation to module geometry, load paths, and building curvature, presenting case studies of iconic diagrid buildings such as Swiss Re, Hearst Tower, and Guangzhou

West Tower. Their findings showed that diagrid structures provide superior stiffness, strength, dynamic performance, and reduced steel weight compared to conventional framed tube systems like the World Trade Center, while suggesting optimal module angles to improve global structural behavior. Khushbu Jania and Paresh V. Patel (2013) investigated the analysis and design of high-rise steel buildings using diagrid systems. Using ETABS, they modeled a 36-story diagrid building under wind and earthquake loads and compared results for 36-, 50-, 60-, 70-, and 80-story structures. Their study concluded that diagrid systems effectively reduce lateral displacement and inter-story drift, with design considerations for diagonal members and floor beams according to IS 800:2007 standards. Similarly, Rohit Kumar Singh, Vivek Garg, and Abhay Sharma (2014) performed a comparative study of a 5-story concrete diagrid building and a conventional frame building. Using STAAD.Pro software, they found that the diagrid configuration exhibited lower lateral displacement, drift, and steel reinforcement requirements, demonstrating its viability in seismic-prone zones.

Shah et.al (2016) reviewed diagrid structures, focusing on their flexibility, aesthetic appeal, and material efficiency. Their study highlighted research questions on optimal forms, geometries, performance evaluation, and software tools for analysis, emphasizing the integration of structural efficiency with architectural expression. Potdar et al. (2017) conducted a comparative study between 20-story conventional frame buildings and diagrid systems with varying angles, demonstrating that diagrid systems reduce axial loads on internal columns and shear forces on interior beams. They identified an optimal diagrid angle range of 60°–70° for enhanced performance. Mirniazmandan et al. (2018) investigated structural optimization of tall buildings using geometric modifications and diagrid configurations. Their results indicated that a 63° diagrid angle minimizes lateral top-story displacement, allowing for material savings while maintaining stiffness. Kakade et al. (2018) compared storey drift and base shear in 32-story diagrid frameworks with and without vertical periphery columns using ETABS and SAP, emphasizing the importance of lateral load resistance in high-rise design. Joonho Lee, Jieun Kong, and Jinkoo Kim (2018) evaluated the seismic performance of 33-story axis-symmetric steel diagrid buildings with various vertical geometries, finding that cylindrical structures provided maximum stiffness while gourd-shaped structures were more vulnerable.

3.Methodology and Modelling

The present study investigates the seismic performance of high-rise buildings using diagrid and conventional structural systems. A G+30 commercial building with 15m × 15m plan dimensions is modeled in ETABS software to analyze both static and dynamic responses under gravity, wind, and seismic loads. Response Spectrum Analysis (RSA) is employed as the primary seismic analysis method in accordance with IS 1893 (Part 1): 2016, considering Zone III, 5% damping, importance factor 1, and response reduction factor 5. Various diagrid configurations (45°, 64°, 72°) and conventional framed structures are examined. Auto Select features in ETABS are utilized to optimize section properties for I-sections, rectangular hollow, and circular hollow diagrid members. Comparative assessments include inter-story drift, lateral displacement, axial forces, and shear forces to evaluate structural efficiency and performance under seismic excitations.

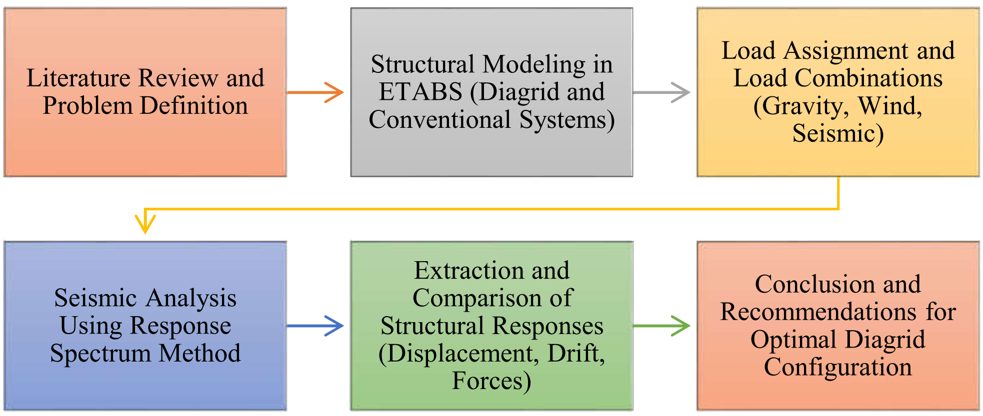

Figure 2. Flowchart of Methodology

3.1 Loads and Load Combinations

When a structure is subjected to multiple types of loads, a load combination is created. Design regulations often provide a range of load combinations together with load factors for each type of load in order to ensure the safety of the structure under various loadings. The load combinations listed below were employed for the analysis in accordance with IS 1893 (Part 1): 2016.

1) 1.5 (DL+LL)

2) 1.2 (DL+FL+LL±RSX)

3) 1.2 (DL+FL+LL±EQX)

4) 1.2 (DL+FL+LL±RSY)

5) 1.2(DL+FL+LL±EQY)

6) 1.5 (DL+FL±RSX)

7) 1.5 (DL+FL±EQX)

8) 1.5 (DL+FL±RSY)

9) 1.5 (DL+FL±EQY)

10) 0.9(DL+FL) ±1.5RSX

11) 0.9(DL+FL) ±1.5EQX

12) 0.9(DL+FL) ±1.5RSY

13) 0.9(DL+FL) ±1.5EQY

Table 1: Methods of Seismic Analysis and Key Parameters for Diagrid Buildings

Analysis Type	Methods / Techniques	Remarks / Parameters
Linear Static Analysis	Seismic Coefficient Method	Suitable for preliminary seismic design.
Nonlinear Static Analysis	P-Delta Analysis, Pushover Analysis	Considers geometric nonlinearity and structural redistribution.
Linear Dynamic Analysis	Linear Time History Analysis, Response Spectrum Analysis	Accounts for building vibration characteristics.
Nonlinear Dynamic Analysis	Nonlinear Time History Analysis	Considers material and geometric nonlinearity under dynamic loads.
Seismic Parameters (Study)	Response Spectrum Analysis	As per IS 1893 (Part 1): 2016; Zone III; Importance Factor = 1; Damping = 5%; Response Reduction Factor = 5; Soil Type II

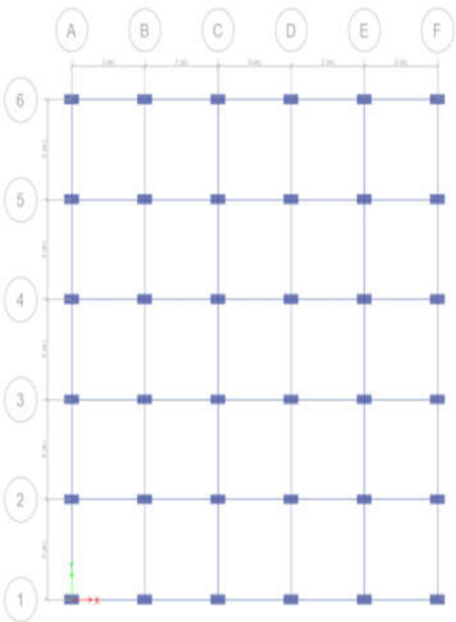

Figure 3. Plan of Conventional & Diagrid Buildings

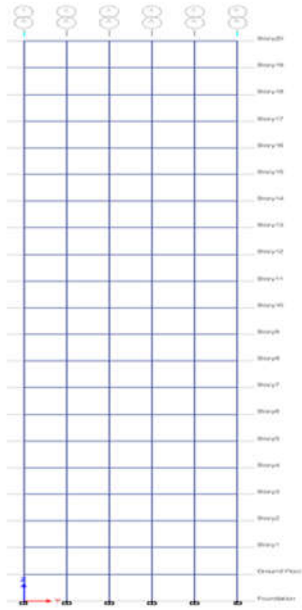

Figure 4. Conventional Building Elevation

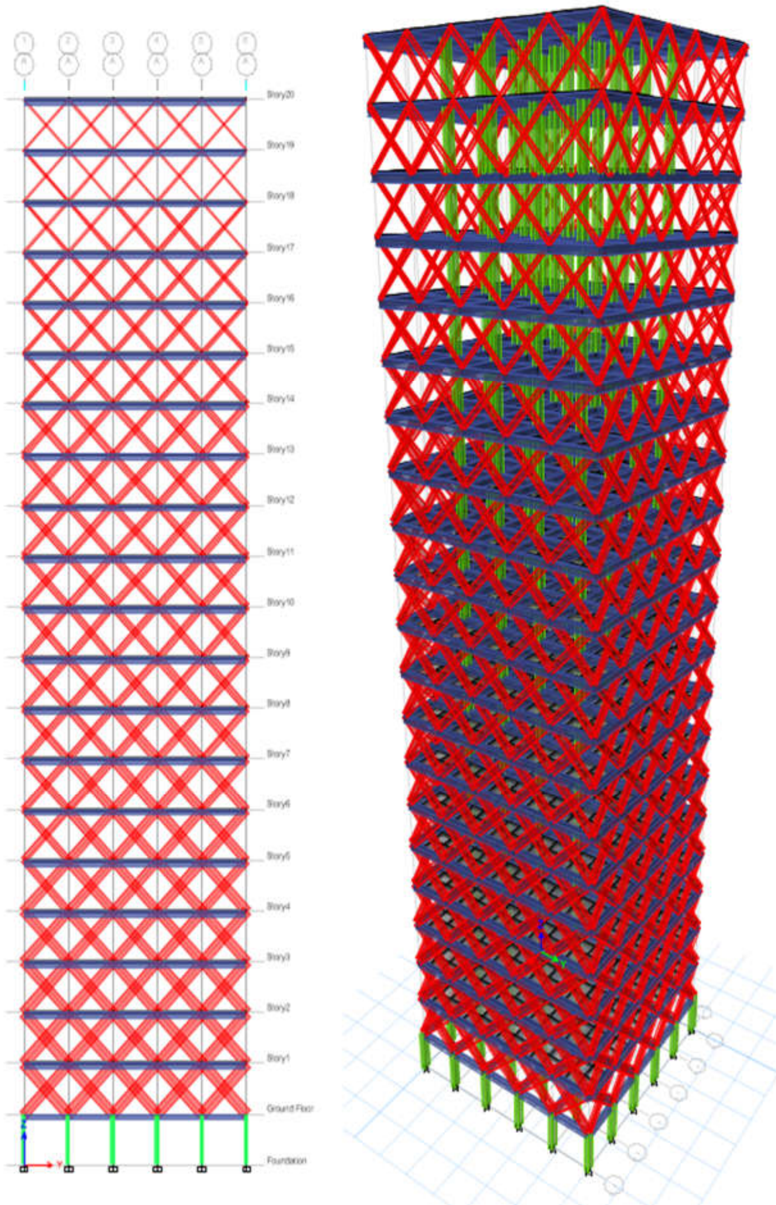

Figure 5. 45-degree diagrid structure elevation and 3D extruded view

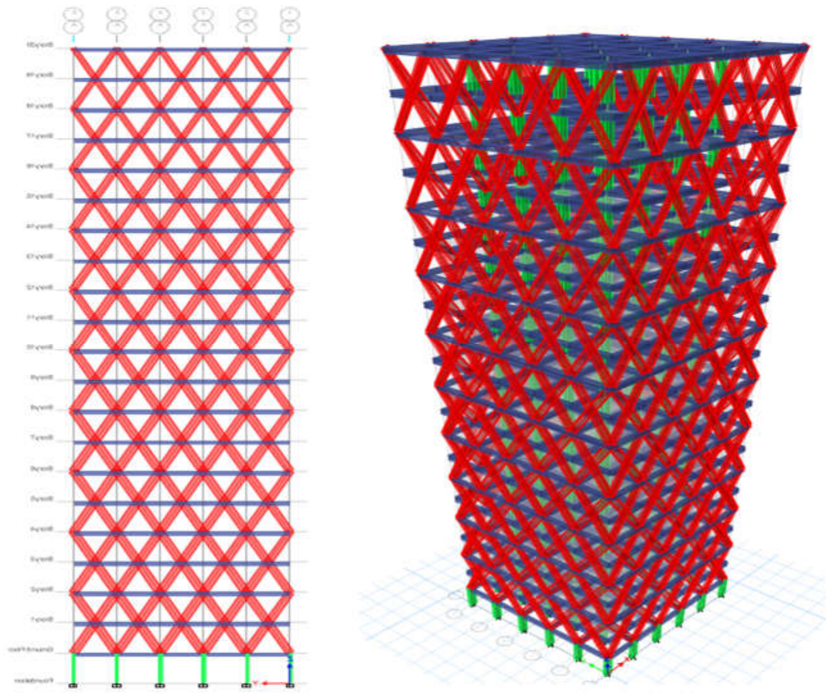

Figure 6. 64 -degree diagrid structure elevation and 3D extruded view

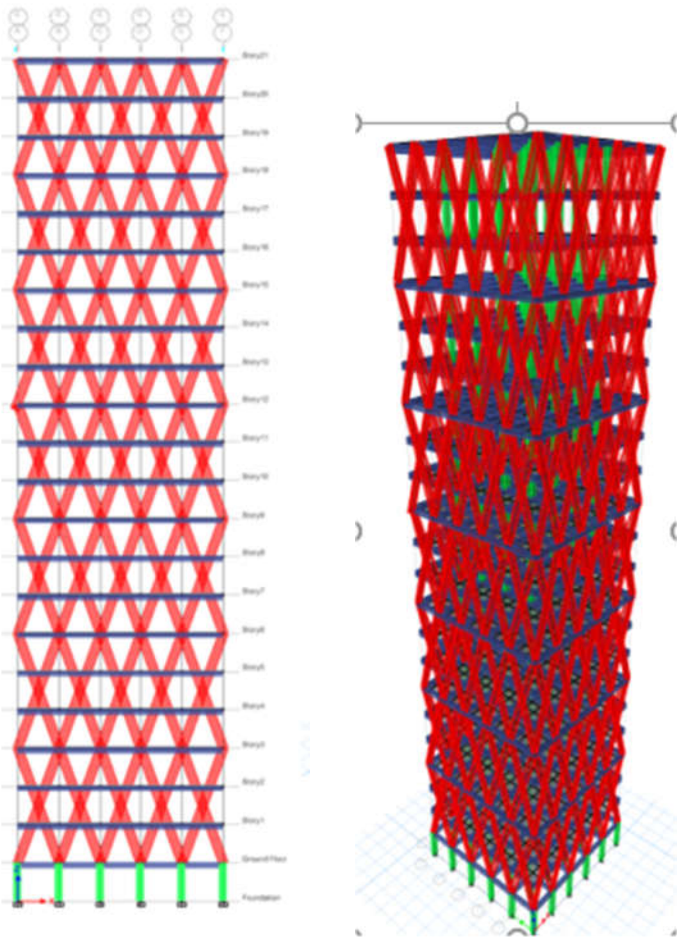

Figure 7. 72 -degree diagrid structure elevation and 3D extruded view

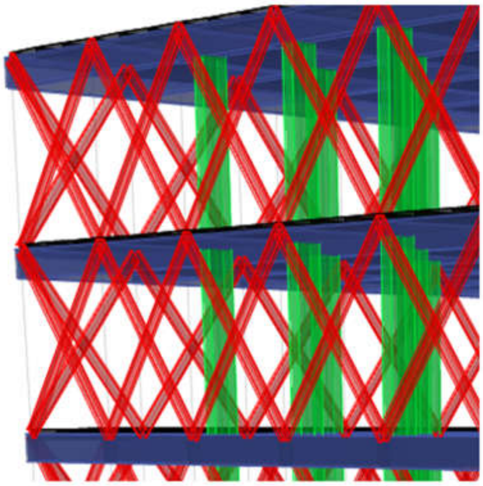

Figure 8. I Section Diagrids

Table 2: Structure Details and Specifications

Sr. No.	Description	Specification
1	Structure Type	Symmetrical and Unsymmetrical Diagrid Building
2	Number of Storeys	G + 30
3	Material Used	Concrete (M30) and Structural Steel (Fe 345)
4	Method of Analysis	Response Spectrum Method (as per IS 1893:2016)
5	Loads Considered	Dead Load, Live Load, Earthquake Load, Wind Load
6	Software Used	ETABS 2022

4. Results and discussion

This chapter presents the analysis results of diagrid structures under seismic loading, comparing different diagrid angles and cross-sections. Key responses such as storey displacement, drift, and shear are evaluated using the Response Spectrum Method (IS 1893:2016) to determine the most efficient configuration for enhanced lateral stability and structural performance.

4.1 Maximum story displacement in X direction for different angle of diagrids

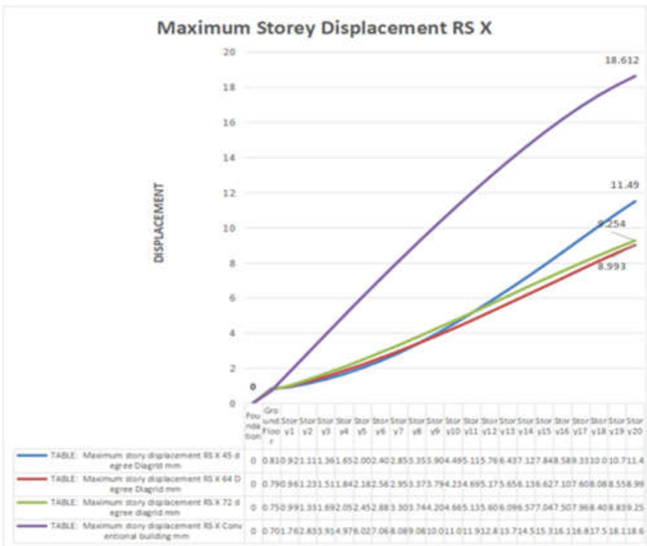

Figure 9. Combined Maximum Storey Displacement Plot for Conventional building and for specified angle of diagrids in X-Direction

Figure 9 illustrates the Maximum Storey Displacement in the X-direction. The Conventional building (purple) has the highest displacement, reaching 18.612 mm at the 20th storey. The addition of a diagrid significantly reduces this drift. The 72∘ diagrid (green) is the most effective, achieving the minimum displacement of 8.839 mm. All diagrid designs (45∘, 64∘, 72∘) provide superior lateral stiffness compared to the conventional frame, with the 72∘ configuration showing the best performance in drift control.

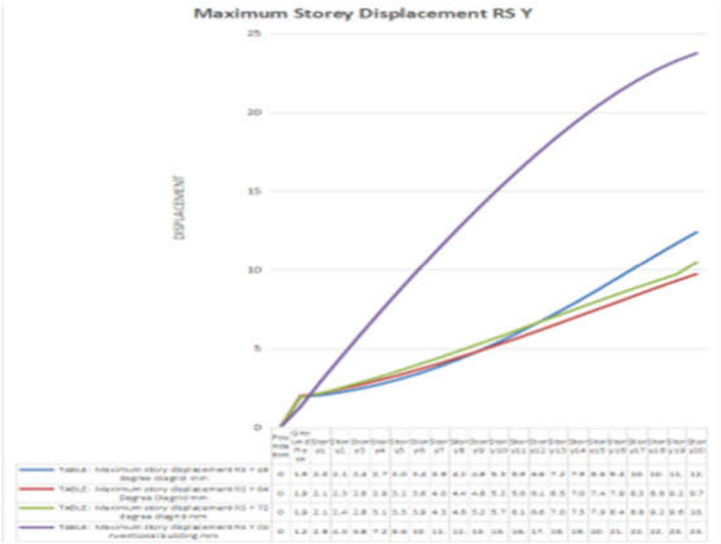

Figure 10. Combined Maximum Storey Displacement Plot for Conventional building and for specified angle of diagrids in Y-Direction

Figure 10 displays the Maximum Storey Displacement in the Y-direction. The Conventional building (purple) has the highest displacement, around 24.5 mm. All diagrids significantly reduce this. The 64∘ (red) and 72∘ (green) diagrids are most effective, limiting displacement to roughly 10.2 mm. These results confirm that diagrid systems, particularly the 64∘ and 72∘ angles, offer superior control over lateral drift in the Y-direction.

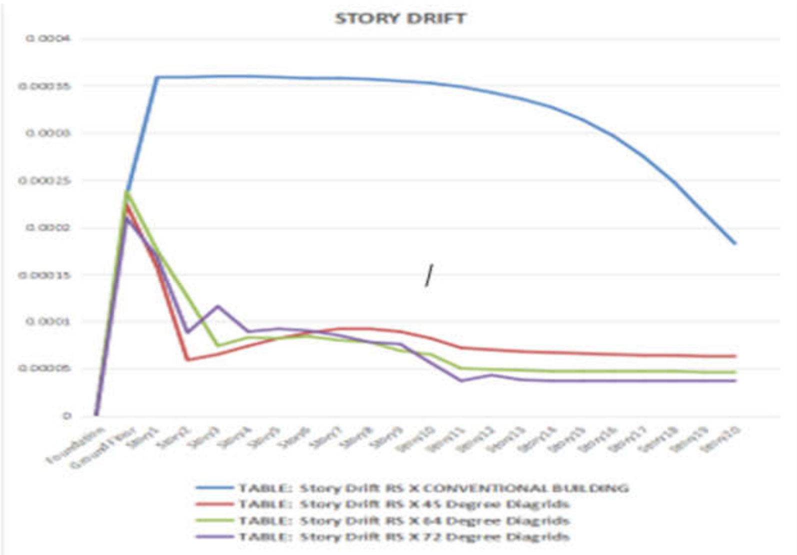

Figure 11. Combined Maximum Storey drift Plot for Conventional building and for specified angle of diagrids.

Figure 11 compares Maximum Storey Drift in the X-direction. The Conventional building (blue) has the highest drift, peaking at about 0.00036. All diagrid systems drastically reduce drift. The 64∘ and 72∘ diagrids provide the lowest and most stable response, remaining around 0.00004 in the upper stories. This highlights the superior inter-storey drift control offered by the diagrid system, especially the 64∘ and 72∘ angles.

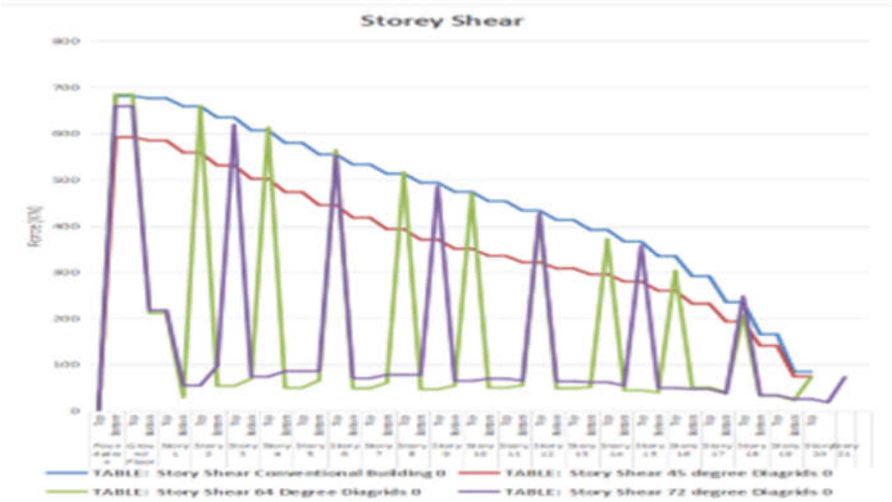

Figure 12. Combined Maximum Storey Shear Plot for Conventional building and for specified angle of diagrids.

Figure 12 compares Maximum Storey Shear. The Conventional building (blue) has the highest demand, starting around 680 kN at the base. The diagrids redistribute shear, leading to a sawtooth pattern for the 64∘ and 72∘ angles. While peak shear is similar to the 45∘ diagrid (around 600 kN), the shear in intermediate floors is much lower, demonstrating a more efficient load transfer system.

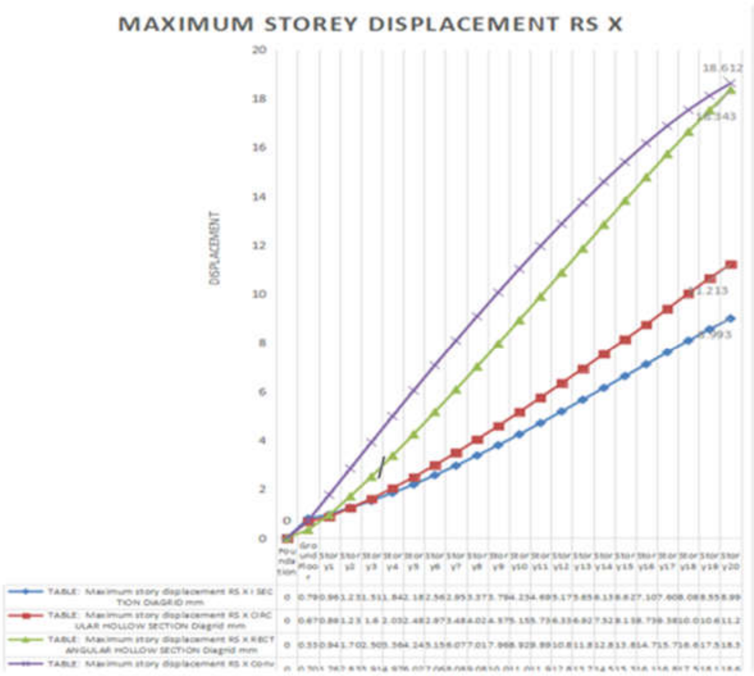

Figure 13. Combined Maximum Story displacement Plot for Conventional building and for specified cross-section of diagrids.

Figure 13 compares Maximum Storey Displacement in the X-direction for a conventional building and three diagrid cross-sections. The Conventional building (purple) has the highest drift at 18.612 mm. The Rectangular Hollow Section (RHS) Diagrid (blue) is the most effective, limiting displacement to 8.558 mm. The CHS (10.213 mm) and RAHS (13.343 mm) diagrids follow. The RHS section offers the optimal increase in lateral stiffness.

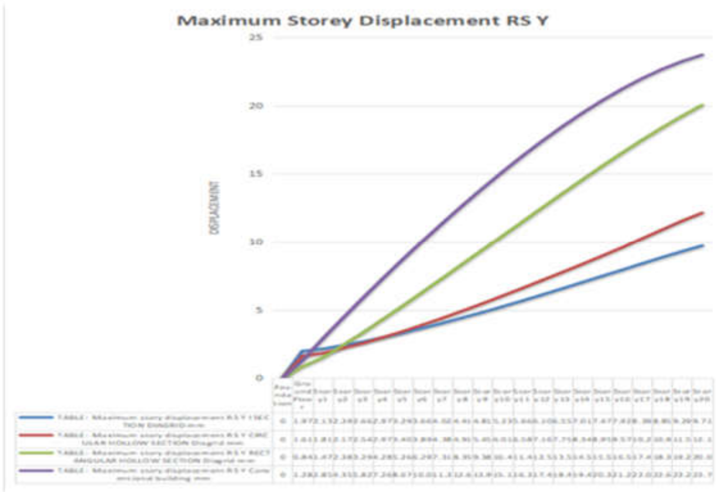

Figure 14. Combined Maximum Story displacement Plot for Conventional building and for specified cross-section of diagrids.

Figure 14 compares Maximum Storey Displacement in the Y-direction for a conventional building and three diagrid cross-sections. The Conventional building (purple) has the highest drift, approximately 23.7 mm. The Rectangular Hollow Section (RHS) Diagrid (blue) is the most effective, limiting displacement to 9.99 mm. The CHS (12.0 mm) and RAHS (19.5 mm) diagrids follow. The RHS section provides the optimal increase in lateral stiffness in the Y-direction.

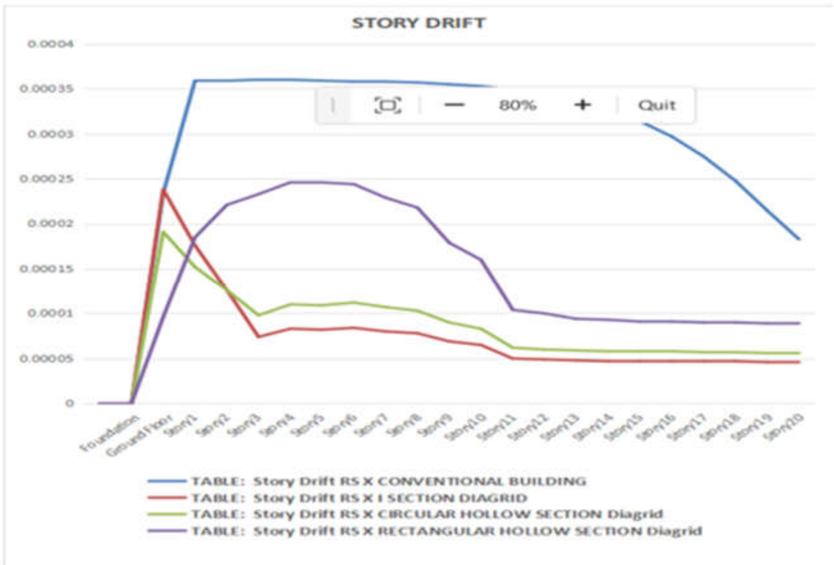

Figure 15. Combined Maximum Story drift Plot for Conventional building and for specified cross-section of diagrids.

Figure 15 compares Maximum Storey Drift in the X-direction. The Conventional building (blue) shows the highest drift, peaking near 0.00036. All diagrids significantly reduce this. The I-Section Diagrid (red) is the most effective, maintaining the lowest drift (around 0.00005) in upper stories. The RHS Diagrid (purple) shows the highest drift among the diagrids. The I-Section offers superior inter-storey drift control.

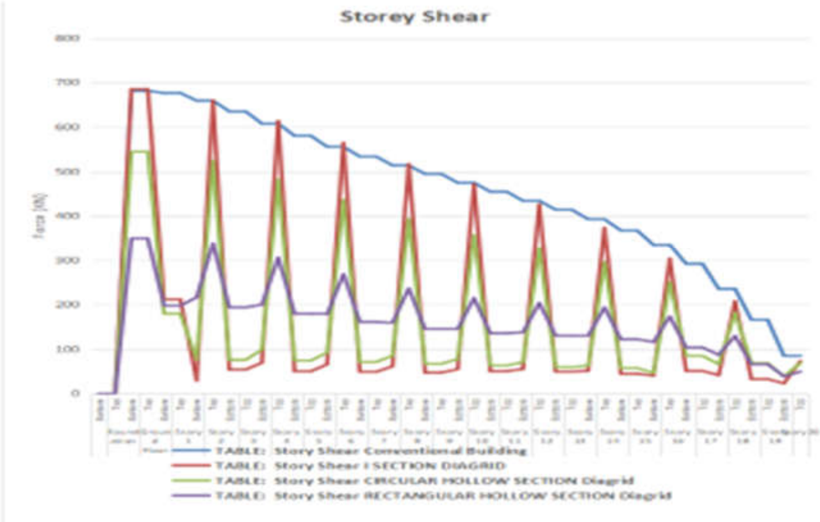

Figure 16. Combined Maximum Story shear Plot for Conventional building and for specified cross-section of diagrids.

Figure 16 compares Maximum Storey Shear. The Conventional building (blue) has the highest demand (up to 700 kN). All diagrid systems redistribute shear drastically. The I-Section (red) and RHS (purple) diagrids show a pronounced sawtooth pattern, concentrating peak shear (around 680 kN) at the nodes while minimizing shear in the intermediate floors (as low as 50 kN).

Table 3: Combined Storey Response Table for specified angles of diagrid

Criteria	Maximum Story Displacement (mm)	Maximum Story Drift	Maximum Base Shear (KN)
Conventional Building	18.6	0.00018	84.7246
45∘ diagrid	11.49	0.000063	74.5193
64∘ diagrid	8.993 (minimum)	0.000046	73.027 (minimum)
72∘ diagrid	9.254	0.000037 (minimum)	73.1872
Percentage difference between conventional system & the minimum value of the diagrid system	51.60%	79.40%	13.80%

Table 4: Combined Storey Response Table for specified Cross sections of diagrid

Criteria	Maximum Story Displacement (mm)	Maximum Story Drift	Maximum Base Shear (KN)
Conventional Building	18.6	0.00018	84.7246
I section diagrid	8.993 (minimum)	0.000046 (minimum)	73.027
Circular hollow section diagrid	11.213	0.000056	68.517
Rectangular hollow section diagrid	18.3	0.000089	49.42 (minimum)
Percentage difference between conventional system & the minimum value of the diagrid system	51.60%	74.40%	41.60%

4.Conclusion

The present study evaluates the seismic performance of a G+20 commercial building with a 15m × 15m plan and 62m height, focusing on diagrid systems of varying angles (45°, 64°, 72°) and cross-sections (I-section, circular hollow, rectangular hollow). Analysis was performed in ETABS using the Response Spectrum Method as per IS 1893 (Part 1): 2016, considering Zone III seismicity, importance factor 1, damping ratio 5%, response reduction factor 5, and soil type II. Results indicate that diagrid systems significantly enhance structural performance compared to conventional frames. Among angles, the 64-degree diagrid showed the lowest storey displacement, reducing X and Y directional displacement by 51.6% and 52.86% relative to conventional structures. I-section members exhibited the least displacement among cross-sections, with reductions up to 53.72% compared to rectangular hollow sections. Storey drift analysis revealed that the 72-degree diagrid achieved the minimum drift, reducing relative displacement by up to 80% compared to conventional frames, while I-section members again provided optimal drift control among cross-sections. Base shear analysis showed that the 64-degree diagrid produced the lowest lateral force, decreasing X and Y directional shear by over 13% compared to conventional structures, while rectangular hollow sections further minimized base shear among cross-sections. Overall, the study demonstrates that diagrid systems provide superior stiffness, reduced lateral displacement, minimized inter-storey drift, and lower base shear, enhancing the earthquake resilience of high-rise buildings. The combination of a 64-degree angle with I-section diagrid members emerged as the most effective configuration, meeting IS 1893:2016 displacement limits. This research confirms that carefully designed diagrid structures are highly efficient, safe, and economical solutions for seismic-resistant high-rise construction, offering both structural performance and material optimization.

REFRENCES

[1] Abhishek Admane, & Shaikh, S. H. (2021). Review on a comparative study of diagrid structure with conventional buildings having different heights. International Journal of Advance Scientific Research and Engineering Trends, 6(6), June 2021. ISSN (Online) 2456-0774.

[2] Agrawal, S., Mani, S., Jain, A., & Ganesan, K. (2020). State of Electricity Access in India: Insights from the India Residential Energy Survey (IRES) 2020.

[3] Alejandro Palacio-Betancur, & Gutierrez Soto, M. (2021). Properties of Tall Diagrid Buildings Using a Neural Dynamic Model for Design Optimization. ASCE Journal of Structural Engineering. https://doi.org/10.1061/(ASCE)ST.1943-541X.0003271

[4] Amruta K. Potdar, & Patil, G. R. (2017). Optimum design of concrete diagrid building and its comparison with conventional frame building. International Research Journal of Engineering and Technology (IRJET), 4(8), August 2017.

[5] Dengjia Fang. (2021). Mechanical characteristics and deformation calculation of steel diagrid structures in high-rise buildings. Journal of Building Engineering, 42, 103062. https://doi.org/10.1016/j.jobe.2021.103062

[6] Dr. Eleyan Issa Jamal, & Dr. Shagin Musa Saleh. (2020). Structural Efficiency of the Building Form for Optimization of the Diagrid Structure. International Journal of Advanced Science and Technology, January 2020. https://www.researchgate.net/publication/343818488

[7] Joonho Lee, Kong, J., & Kim, J. (2018). Seismic Performance Evaluation of Steel Diagrid Buildings. International Journal of Steel Structures, 18(3), 1035–1047. https://doi.org/10.1007/s13296-018-0044-8

[8] Khushbu Jania, & Paresh V. Patel. (2013). Analysis and Design of Diagrid Structural System for High Rise Steel Buildings. Elsevier Ltd., under responsibility of Institute of Technology Nirma University.

[9] Krishna Chandran Sethumadhavan, & Dixon David. (2021). Seismic Response of Diagrid Systems: Ductility Concerns in Low- to Midrise Structures. ASCE Journal of Structural Engineering. https://doi.org/10.1061/(ASCE)SC.1943-5576.0000601

[10] KYOUNG SUN MOON. (2011). Diagrid Structures for Complex Shaped – Tall Buildings. International Journal of High-Rise Buildings, 5(4), 243–250. http://dx.doi.org/10.21022/JHRB.2016.5.4.243

[11] Manthan I. Shah, Snehal V. Mevada, & Vishal B. Patel. (2016). Comparative Study of Diagrid Structures with Conventional Frame Structures. International Journal of Engineering Research and Applications, May 2016. https://www.researchgate.net/publication/302928668

[12] Mele, E., Toreno, M., Brandonisio, G., & De Luca, A. (2012). Diagrid structures for tall buildings: Case studies and design considerations. The Structural Design of Tall and Special Buildings, 23, 124–145. https://wileyonlinelibrary.com

[13] Mirniazmandan, S. (2018). Mutual effect of geometric modifications and diagrid structure on structural optimization of tall buildings. Architectural Science Review, May 2018.

https://www.researchgate.net/publication/325343879
[14] Morteza Sohrabi-Haghighat, & Payam Ashtari. (2019). Evaluation of Seismic Performance Factors for High-rise Steel Structures with Diagrid System. KSCE Journal of Civil Engineering, 23(11), 4718–4726.
[15] Rohit Kumar Singh, Dr. Vivek Garg, & Dr. Abhay Sharma. (2014). Analysis and design of concrete diagrid building and its comparison with conventional frame building. International Journal of Science, Engineering and Technology, 2(6), August 2014.
[16] Seyedehaida Mirniazmandan. (2018). Mutual effect of geometric modifications and diagrid structure on structural optimization of tall buildings. Architectural Science Review, May 2018. https://www.researchgate.net/publication/325343879
[17] D. N. Kakade. (2018). Comparative Analysis of Storey Drift and Base Shear Using ETABS and SAP Software. Journal of Structural Technology, 2(3). https://www.researchgate.net/publication/326246700