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Evaluating Diagrid Systems: A Modern Approach to Lateral Load Resistance Across Varied Building Heights

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Abstract

Modern architectural design and engineering often incorporate advanced structural systems, with diagrid structures becoming popular for high-rise buildings due to their unique geometric patterns and aesthetic appeal. Despite considerable global research on diagrids, a detailed comparative analysis of their structural efficiency remains limited. This thesis assesses the structural efficiency and seismic performance of diagrid lateral load-resisting systems. The effectiveness of diagrids was compared to conventional building designs in multi-storey buildings i.e. G+3, G+7, and G+11 under seismic loads. Response spectrum analysis using ETABS v17.0 was performed to evaluate storey displacement, storey drift and base shear for 6 models.The results show that diagrid systems perform better than traditional structures by minimizing storey displacement and drift, increasing base shear capacity, and reducing the time period for various building heights. These results highlight the diagrid system's superiority in seismic conditions, advocating for its broader use in earthquake-prone areas to enhance building safety and performance.

Keywords: Diagrid structures, seismic performance, structural efficiency, storey displacement, storey drift, base shear, ETABS, multi-storey buildings, etc.

INTRODUCTION

Modern architectural design and engineering increasingly incorporate innovative structural systems, with diagrid structures standing out as a compelling and visually appealing option for tall buildings, known for their intricate geometric patterns. As the demand for sustainable, efficient, and visually striking high-rise structures grows, it becomes crucial to evaluate diagrid systems across different building types and geometric configurations. The integration of such advanced design approaches can result in tall buildings that are not only structurally resilient but also architecturally distinctive, optimizing material and resource use.

Despite extensive global research on diagrids, a thorough study systematically comparing their structural efficiency remains lacking. Moreover, while diagrid structures have gained traction in various developed and developing countries, they have yet to receive significant attention in our own country. This research seeks to evaluate and compare the lateral load-resisting efficiency of diagrids across varying building heights.

The study focuses on the impact of height variation on the structural performance of diagrid buildings, examining three types: G+3, G+7, and G+11. Each height category presents unique design

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challenges and construction techniques necessary to ensure safety, durability, and performance under different environmental conditions. By analyzing these variations, the study aims to offer valuable insights into optimal design strategies for diagrid structures across various building scales.

AIM AND OBJECTIVES

The research is designed to meet the following key objectives:

- Assess the seismic performance of diagrid lateral load-resisting systems by examining various parameters using ETABS v17.0 software.
- Evaluate the structural behavior of diagrid systems in multi-storey reinforced concrete (RC) buildings.
- Compare the overall efficiency of diagrids as lateral load-resisting systems with other effective systems used in our country.

This project holds significance as it has the potential to revolutionize the design and construction practices of reinforced concrete buildings. By offering an in-depth understanding of diagrid structures across various scenarios, the study contributes to the development of innovative, sustainable, and resilient building solutions that address the structural, environmental, and economic challenges faced by modern cities and societies.

LITERATURE REVIEW

The research by various authors underscores the structural efficiency of diagrid systems when subjected to seismic and wind loads. Nayak et al. [1] observed that Braced Tube Structures with circular plans outperformed those with square and rectangular configurations, with square plan diagrids showing the best performance. Lacidogna et al. [2, 3] identified that diagonal inclinations between 64–72 degrees are ideal for minimizing lateral displacements, while 35–38 degrees are optimal for torsional stiffness. Heshmati et al. [4] demonstrated improved hardening behavior of diagrid cores under seismic conditions. Mohsenian et al. [5] verified the seismic reliability of diagrid systems, suggesting a new multi-level R-Factor. Tirkey et al. [6] used ETABS to illustrate that diagrid systems excel in resisting lateral loads. Kamath et al. [7] found that a 71-degree brace angle enhances base shear performance. Jani et al. [8] determined optimal diagrid angles (65–75 degrees) and stiffness ratios (2-5) for tall buildings. Moon et al. [9] explored diagrid efficiency in complex-shaped buildings, offering design guidelines for twisted, tilted, and freeform structures. Collectively, these studies highlight the structural effectiveness and aesthetic appeal of diagrid systems, particularly in seismic and wind conditions, while providing insights into optimal geometric configurations for various building shapes and heights.

SYSTEM DEVELOPMENT

The study of diagrid structures across multi-storey RC buildings aims to provide a comprehensive understanding of their structural behavior and performance in various architectural forms. This research utilizes the Response Spectrum Method, a widely recognized technique in structural engineering for analyzing seismic response. This method offers an efficient and reliable approach to assess how buildings and structures react to earthquake-induced ground motions, making it essential for seismic design and evaluation. The loading conditions were determined according to Indian standards, with a Floor finish of 1 kN/m² and a live load of 3 kN/m².

Building Specification

For the analysis of design diversity in diagrid structures using ETABS V.17, the primary building specifications considered are as follows: The proposed plan area is 18 meters by 18 meters, with panel sizes of 3 meters by 3 meters for both conventional and square diagrid buildings. This plan is applied across various levels including G+3, G+7, and G+11. Figure 1 shows the plan views for both conventional and diagrid buildings. Figures 2(a), 2(b), and 2(c) illustrate the 3D views of conventional buildings in G+3, G+7, and G+11 configurations, respectively. Similarly, Figures 3(a), 3(b), and 3(c) provide 3D views of diagrid buildings for the corresponding G+3, G+7, and G+11 setups.

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Design parameters used for Study-

- Structure - G+3, G+7, G+11
- Seismic Zone - III
- Floor to floor height - 3.6 m
- Bay Distance – 3 m
- Size of plan - 18m × 18m
- Column cross section – 300 mm × 500 mm
- Beam cross section – 300 mm × 450 mm
- Slab thickness - 125 mm
- Diagrid cross section – 300 mm × 500 mm
- Grade of Concrete - M30
- Grade of steel - Fe 500

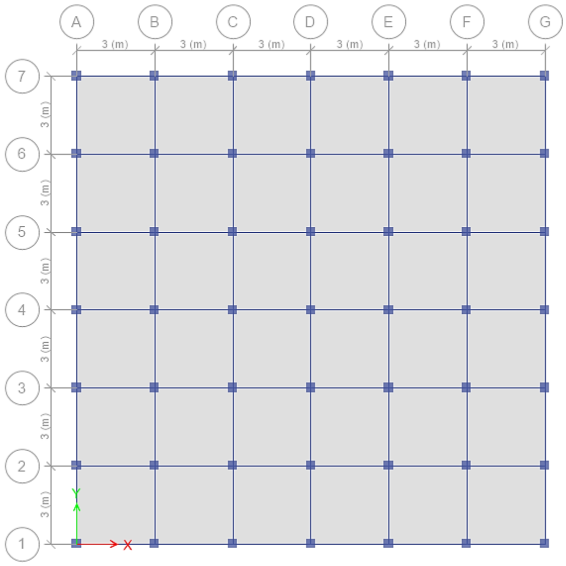
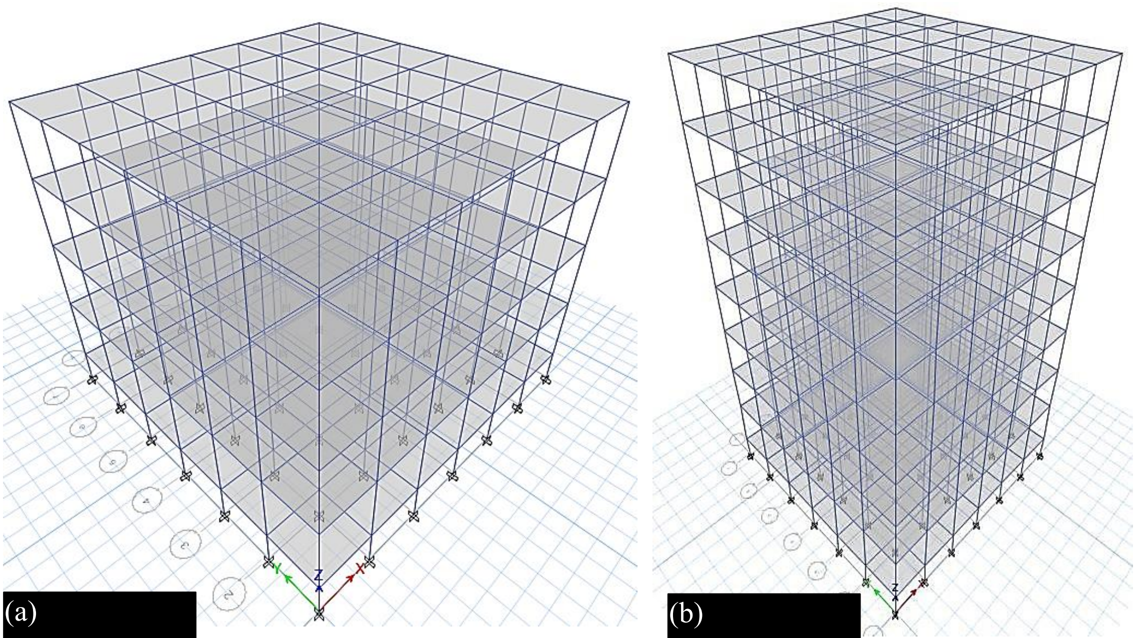
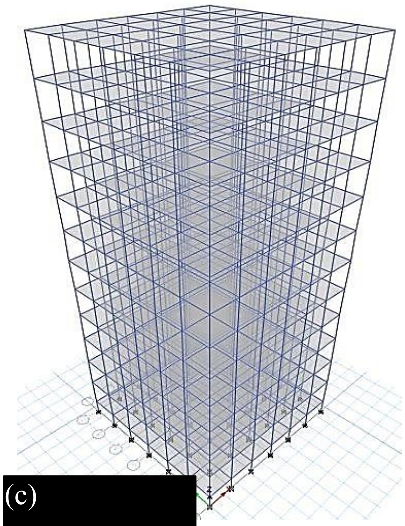


Figure 1. Building Plan View.



(a)

(b)



[redacted]entional Building 3D View: (a) G+3, (b) G+7 and (c) G+11.

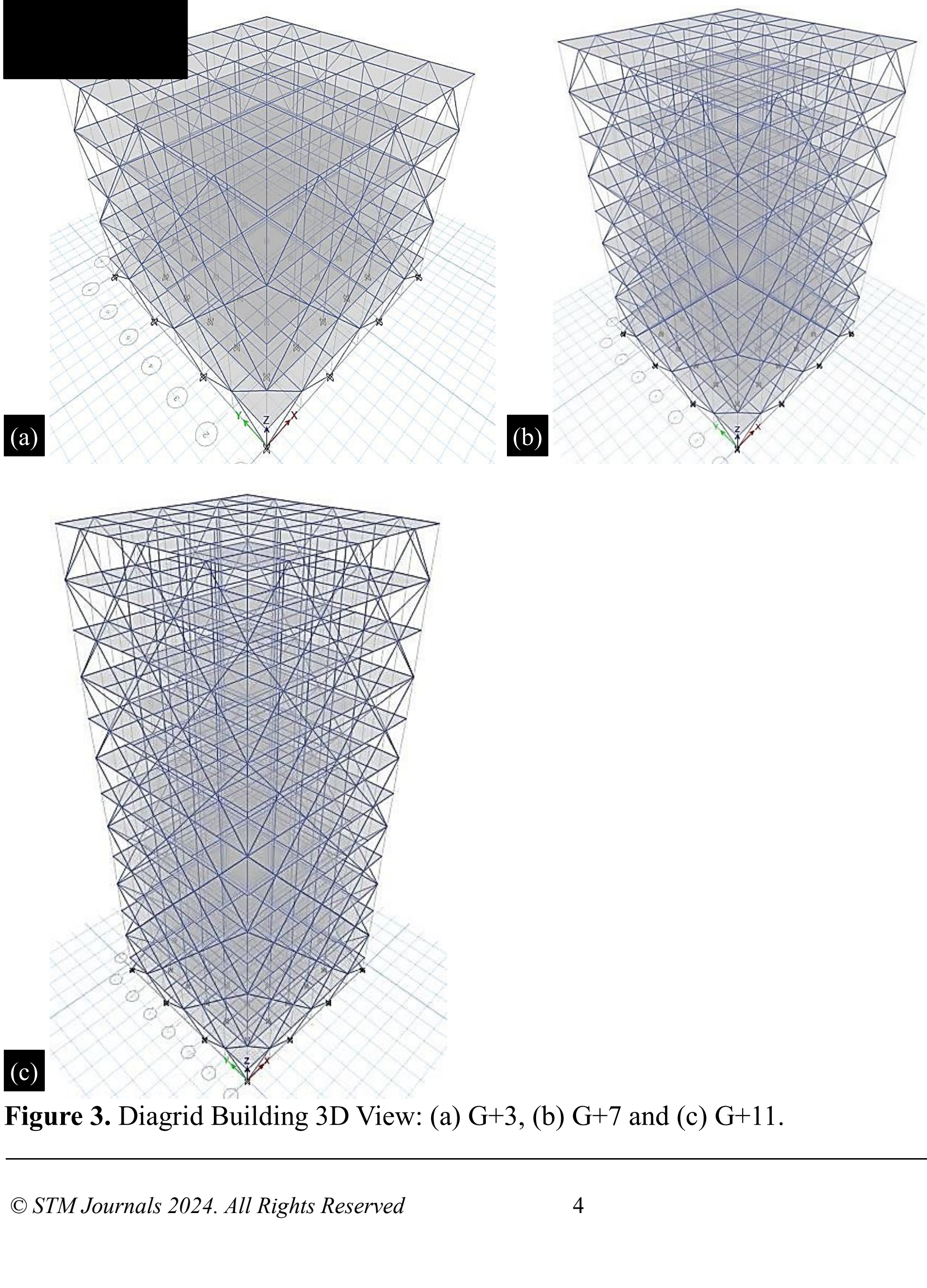


Figure 3. Diagrid Building 3D View: (a) G+3, (b) G+7 and (c) G+11.

RESULTS AND DISCUSSION

The Results and Discussion section provides an in-depth analysis of the seismic performance of G+3, G+7, and G+11 buildings by comparing conventional building designs with diagrid structures. The analysis encompasses various metrics, including storey displacement and drift in both X and Y directions, base shear in these directions, and the time period for different mode shapes. The graphs included highlight the variations in structural responses between conventional and diagrid buildings at various storey levels.

G+3 BUILDINGS

Storey Displacement Comparison Between Conventional and Diagrid Building

Table 1 presents the storey displacement in the X direction for both conventional and diagrid buildings, with Figure 4 providing a graphical representation of these values. In the graph, the X-axis denotes the storey number, and the Y-axis represents storey displacement in millimeters. The conventional building demonstrates a maximum displacement of 2.251 mm, while the diagrid building records a minimum displacement of 0.595 mm on the first storey. Diagrid structures offer multiple load transfer pathways, allowing for redistribution of loads if one path fails. This capability enhances the building's structural integrity and reduces displacement.

Table 1. Storey Displacement in mm in G+3.

S.N.	Storey Displacement in mm		
	Storey No.	***Conventional Building***	***Diagrid Building***
1	Base	0	0
2	Storey1	2.251	0.595
3	Storey2	15.472	3.231
4	Storey3	28.061	5.6
5	Storey4	36.793	7.616
6	Storey5	40.783	8.983

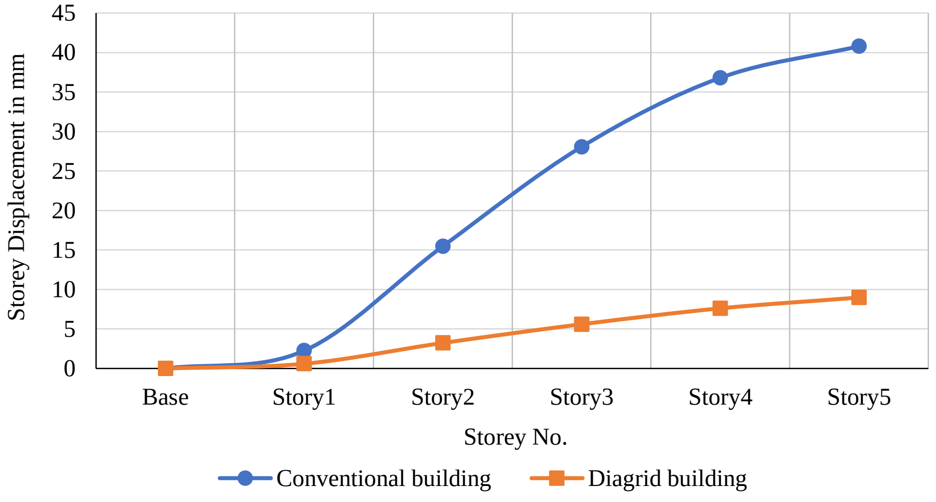


Figure 4. Storey Displacement in mm in G+3.

Storey Drift Comparison Between Conventional and Diagrid Building

Figure 5 illustrates the storey drift in the X direction for both conventional and diagrid buildings, with corresponding values detailed in Table 2. In the figure, the X-axis denotes the storey number, and the Y-axis indicates storey drift. The results show that the conventional building exhibits the highest storey drift at 1.286, while the diagrid building demonstrates the lowest drift at 0.34 on the first storey. The diagonal grid pattern in diagrid structures significantly enhances the building's stiffness, reducing its flexibility and consequently lowering lateral displacements and inter-storey drifts under lateral loads.

Base Shear Comparison Between Conventional and Diagrid Building

The base shear in the X direction for conventional and diagrid buildings is shown in the graph, with storey numbers on the X-axis and base shear values in kN on the Y-axis. According to Table 3, the conventional building has a base shear of 6707.4786 kN, which is lower than the 7067.6388 kN recorded for the diagrid building. The diagrid structure's diagonal members effectively channel lateral loads more directly to the foundation, reducing energy dissipation within the structure and concentrating greater force at the base (Figures 6 and 7).

G+7 BUILDINGS

Storey Displacement Comparison Between Conventional and Diagrid Building

The displacements in X direction for both conventional and diagrid buildings are depicted, with storey numbers on the X-axis and displacements in millimeters on the Y-axis, as detailed in Table 4. On the first storey, the conventional building exhibits a higher deformation of 2.242 mm compared to the diagrid building, which shows a lower deformation of 1.069 mm. The diagrid structure's network of diagonal members creates a triangulated framework that enhances the building's stiffness, allowing for more efficient load distribution and reducing overall lateral displacement (Figure 7 and Table 4).

Table 2. Storey Drift for G+3.

S.N.	Storey Drift in X Direction		
	Storey No.	***Conventional Building***	***Diagrid Building***
1	Storey1	1.286	0.34
2	Storey2	3.673	0.753
3	Storey3	3.512	0.668
4	Storey4	2.466	0.593
5	Storey5	1.151	0.446

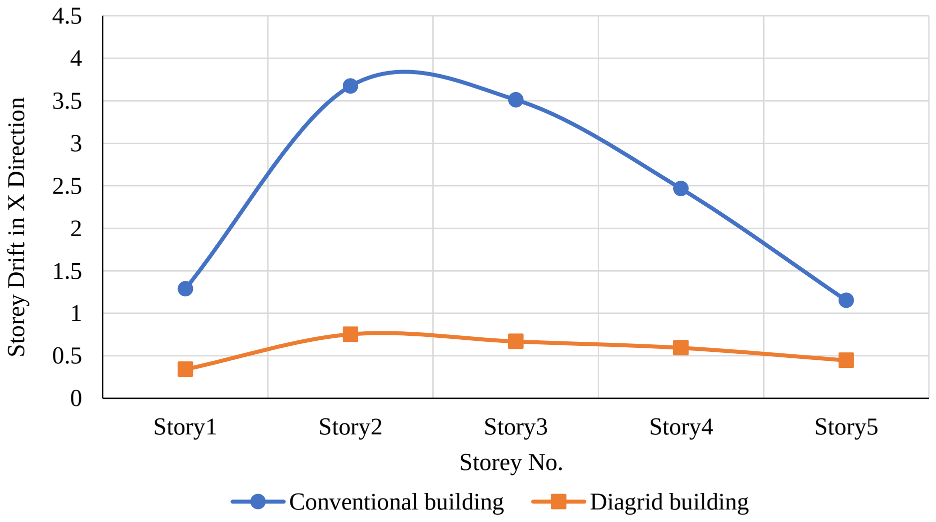


Figure 5. Storey Drift in mm in G+3.

Table 3. Base Shear in KN in G+3.

S.N.	Base Shear in KN		
	Storey No.	***Conventional Building***	***Diagrid Building***
1	Storey1	6707.4786	7067.6388
2	Storey2	6544.4789	6828.4736
3	Storey3	5513.2414	5749.215
4	Storey4	3766.1151	4004.3947
5	Storey5	1415.315	1543.2091

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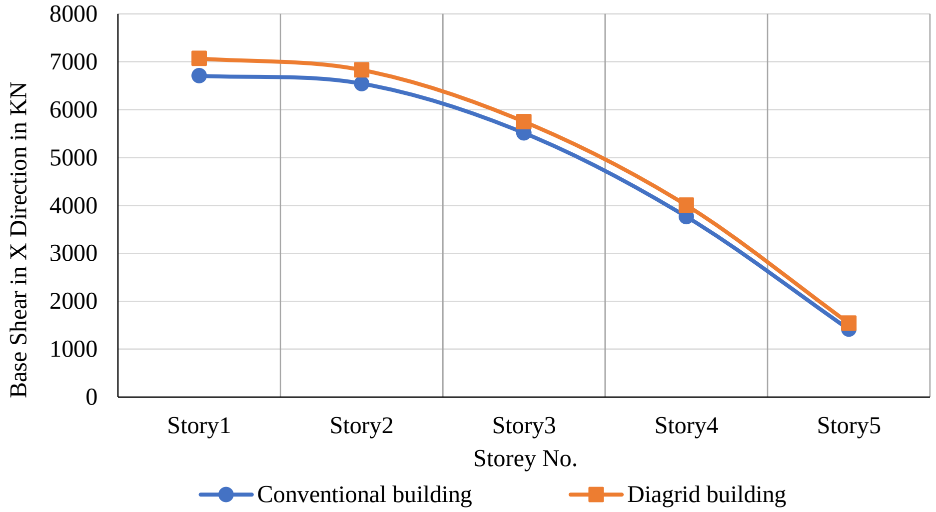

Figure 6. Base Shear in KN in G+3.

Table 4. Storey Displacement in mm in G+7.

S.N.	Storey Displacement in X Direction In mm		
	Storey No.	***Conventional Building***	***Diagrid Building***
1	Storey1	2.242	1.069
2	Storey2	15.781	7.006
3	Storey3	30.362	12.555
4	Storey4	43.904	19.205
5	Storey5	55.909	25.573
6	Storey6	66.065	32.088
7	Storey7	74.057	38.22
8	Storey8	79.545	43.813
9	Storey9	82.465	48.731

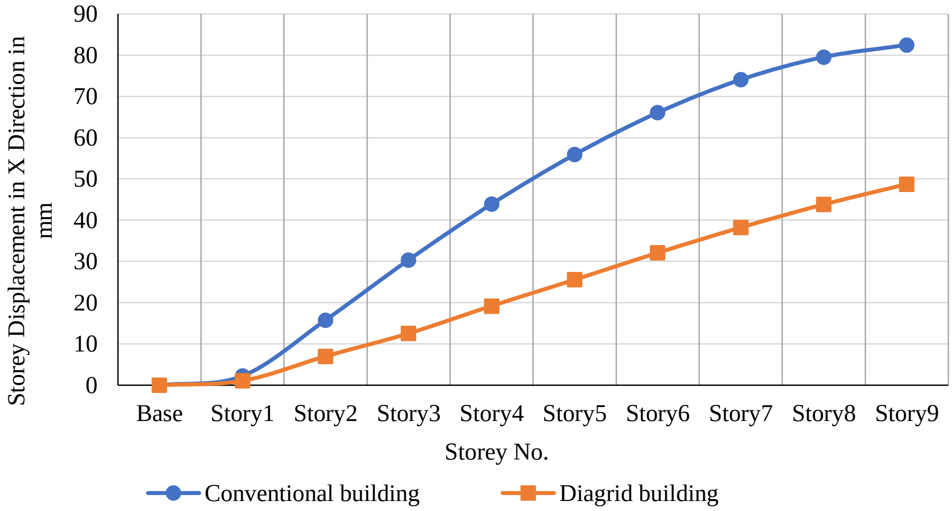

Figure 7. Storey Displacement in mm in G+7.

Storey Drift Comparison Between Conventional and Diagrid Building

Table 5 highlights the differences in X-direction storey drifts between conventional and diagrid buildings, as illustrated in Figure 8. The graph shows drift values on the Y-axis. On the first storey, the conventional building experiences the highest drift at 1.281, while the diagrid building records a significantly lower drift of 0.611. This difference emphasizes the enhanced stability and reduced displacement capabilities of diagrid structures in comparison to conventional buildings.

Base Shear Comparison Between Conventional and Diagrid Building

The base shear values in the X direction for conventional and diagrid buildings are detailed in Table 6. On the first storey, the conventional building records the lowest base shear at 6556.0776 kN, while the diagrid building shows the highest base shear at 12428.764 kN. Figure 9 provides a graphical representation of these values, with storey numbers on the X-axis and base shear values in kN on the Y-axis. The diagonal grid in diagrid structures effectively transfers forces directly to the base, reducing energy absorption by intermediate elements and resulting in higher forces being directed to the base.

Table 5. Storey Drift in G+7.

S.N.	Storey Drift in X Direction		
	Storey No.	***Conventional Building***	***Diagrid Building***
1	Storey1	1.281	0.611
2	Storey2	3.761	1.656
3	Storey3	4.06	1.627
4	Storey4	3.813	1.877
5	Storey5	3.451	1.81
6	Storey6	3	1.855
7	Storey7	2.441	1.759
8	Storey8	1.724	1.6
9	Storey9	0.908	1.448

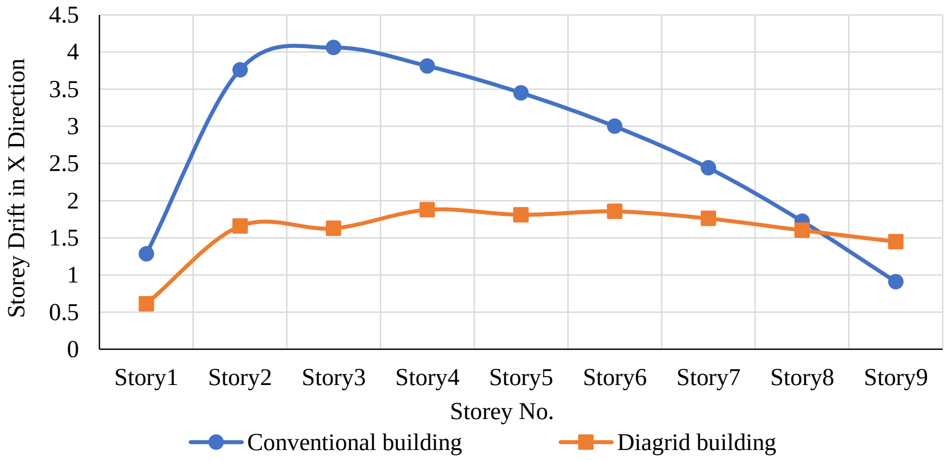

Figure 8. Storey Drift in G+7.

Table 6. Base Shear in KN in G+7.

S.N.	Base Shear in KN		
	Storey No.	***Conventional Building***	***Diagrid Building***
1	Storey1	6556.0776	12428.764
2	Storey2	6497.8478	12327.273
3	Storey3	6128.155	11782.634
4	Storey4	5589.0913	10924.861
5	Storey5	4970.735	9772.6109
6	Storey6	4248.4491	8336.9006
7	Storey7	3389.676	6553.9792
8	Storey8	2287.2685	4343.3498
9	Storey9	834.2384	1606.5879

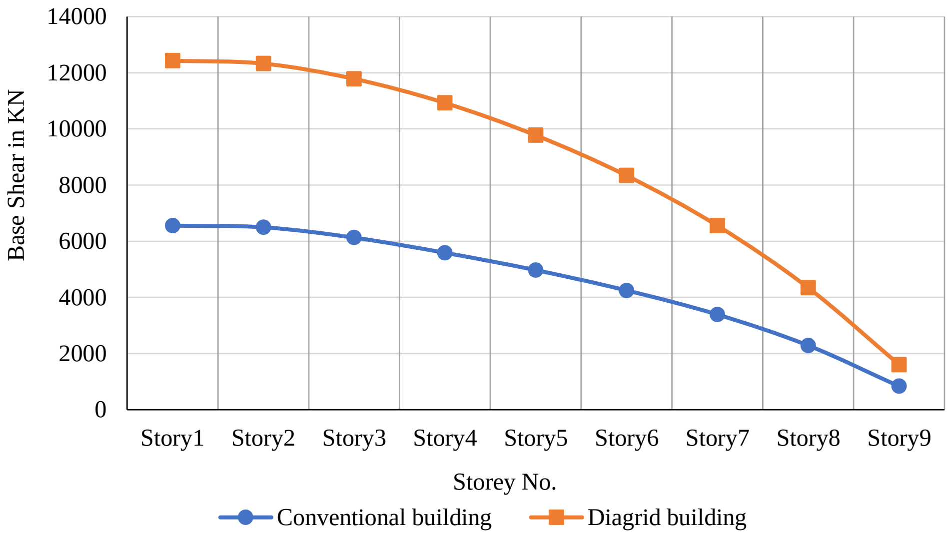

Figure 9. Base Shear in KN in G+7.

Table 7. Storey Displacement in mm in G+11.

S.N.	Storey Displacement in X Direction In mm		
	Storey No.	***Conventional Building***	***Diagrid Building***
1	Base	0	0
2	Storey1	2.279	0.918
3	Storey2	16.129	6.322
4	Storey3	31.399	11.829
5	Storey4	46.126	18.675
6	Storey5	59.94	25.507
7	Storey6	72.756	33.09
8	Storey7	84.554	40.597
9	Storey8	95.299	48.386
10	Storey9	104.908	56.033
11	Storey10	113.238	63.579
12	Storey11	120.07	70.894
13	Storey12	125.141	77.834
14	Storey13	128.406	84.438

G+11 BUILDING

Storey Displacement Comparison Between Conventional and Diagrid Building

Data from Figure 10 sheds light on the storey displacements in the X direction for both conventional and diagrid buildings. The graph plots storey numbers along the X-axis and corresponding displacements on the Y-axis. According to Table 7, the conventional building experiences the highest deformation of 2.279 mm on the first storey, while the diagrid building shows a lower deformation of 0.918 mm. Diagrid structures efficiently manage shear forces by spreading them across a larger area, which helps to reduce excessive horizontal displacement. This effective force redistribution enhances structural integrity and minimizes deformations during seismic events.

Storey Drift Comparison Between Conventional and Diagrid Building

On the first storey, the conventional building demonstrates the highest drift at 1.302, whereas the diagrid building records the lowest drift at 0.525, as shown in Table 8. Figure 11 illustrates the X-direction storey drifts for both conventional and diagrid buildings, with storey numbers on the X-axis and drift values in millimeters on the Y-axis. This comparison highlights the varying degrees of structural displacement experienced by each type of building under similar conditions. Diagrid structures manage shear and torsional forces more uniformly across the building, which helps to reduce the concentration of forces that could lead to larger deformations. By effectively distributing these forces, diagrid buildings maintain greater stability and minimize excessive horizontal drift between various storeys.

Base Shear Comparison Between Conventional and Diagrid Building

Table 9 presents a comparison of base shear values in the X direction for both conventional and diagrid buildings on the first storey, with the data illustrated in Figure 12. The X-axis of the graph denotes the storey number, and the Y-axis shows the base shear values in kN. On the first storey, the conventional building records a base shear of 6620.5076 kN, whereas the diagrid building shows a higher base shear of 10825.2737 kN. The triangular configuration of diagrid structures effectively transfers and redistributes lateral forces, resulting in higher and more evenly distributed base shear values compared to conventional buildings.

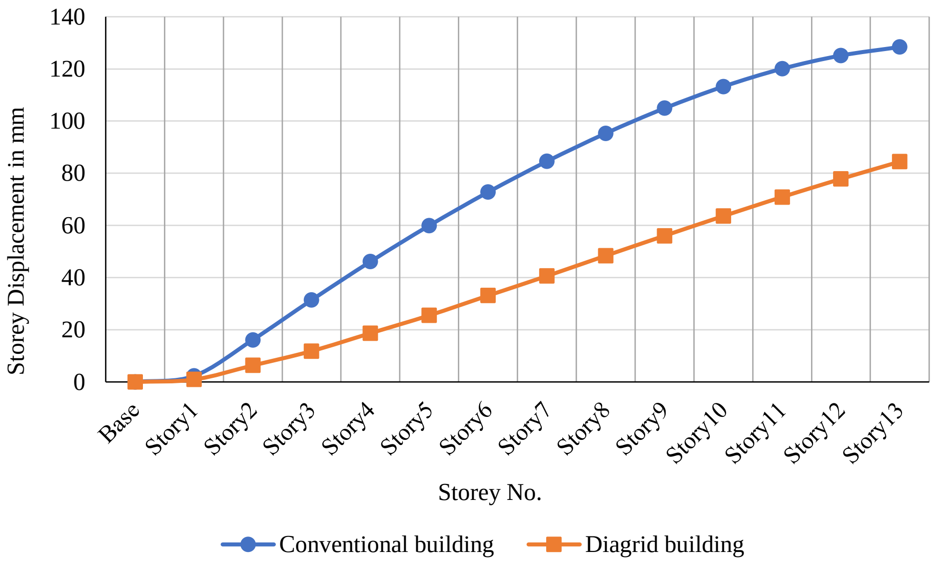

Figure 10. Storey Displacement in mm in G+11.

Table 8. Storey Drift in G+11.

S.N.	Storey drift in X direction		
	Storey no.	***Conventional building***	***Diagrid building***
1	Story1	1.302	0.525
2	Story2	3.847	1.504
3	Story3	4.248	1.531
4	Story4	4.126	1.913
5	Story5	3.94	1.91
6	Story6	3.759	2.135
7	Story7	3.579	2.114
8	Story8	3.377	2.21
9	Story9	3.13	2.166
10	Story10	2.801	2.145
11	Story11	2.338	2.071
12	Story12	1.715	1.958
13	Story13	1.035	1.851

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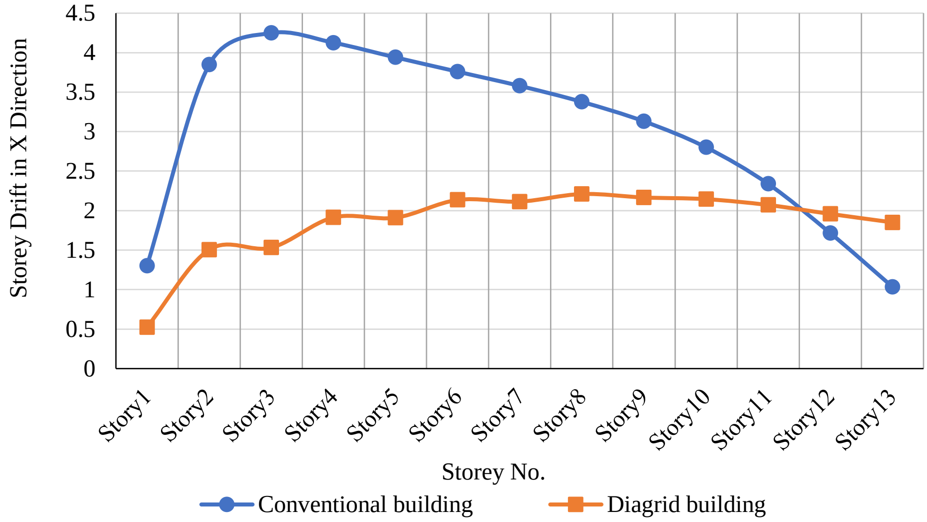

Figure 11. Storey Drift in G+11.

Table 9. Base Shear in KN in G+11.

S.N.	Base Shear in X Direction In KN		
	Storey No.	***Conventional Building***	***Diagrid Building***
1	Storey1	6620.5076	10825.2737
2	Storey2	6582.2134	10748.2465
3	Storey3	6326.1829	10389.7674
4	Storey4	5929.0413	9861.8851
5	Storey5	5515.2209	9249.7959
6	Storey6	5144.6946	8598.3534
7	Storey7	4799.5439	7935.9081
8	Storey8	4443.8302	7265.2209
9	Storey9	4049.1698	6524.5919
10	Storey10	3557.1851	5649.6908
11	Storey11	2867.7441	4537.0365
12	Storey12	1902.4476	3075.3374
13	Storey13	677.055	1161.5039

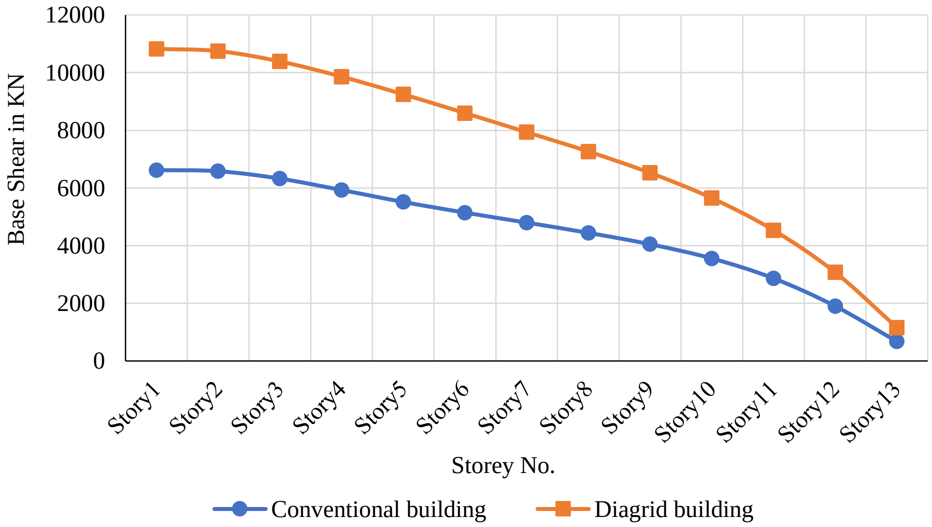

Figure 12. Base Shear in KN in G+11.

CONCLUSIONS

The study thoroughly investigated the structural efficiency and seismic performance of diagrid lateral load-resisting systems in comparison to conventional building designs across various heights. Using advanced computational tools like ETABS v17.0 and response spectrum analysis, the research assessed key parameters including storey displacement, drift, base shear, and time period. The following conclusions were drawn from the results:

- During seismic events, diagrid structures exhibit distinct dynamic behavior compared to conventional frames. Their greater stiffness results in reduced movement while transferring more force to the foundation.
- In G+3 buildings, diagrid systems show storey displacement that is half of that observed in conventional buildings and have a base shear capacity that is 65.32% greater.
- For G+7 buildings, diagrid systems demonstrate a displacement that is three times lower and a base shear capacity that is twice as high as that of conventional buildings.
- In G+11 structures, diagrid buildings achieve a 60.89% reduction in displacement compared to conventional buildings and exhibit nearly double the base shear capacity.

Overall, diagrid structures show enhanced stability and load-bearing capacity in G+3 buildings, improved structural integrity in G+7 constructions, and effective performance under seismic loads in G+11 settings compared to conventional buildings. These findings underscore the diagrid system's superior seismic performance, suggesting its increased to improve building safety and effectiveness.

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