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Static and Dynamic Analysis of Conventional, Diagrid and Hexagrid Systems Across Different Storey Heights

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Abstract

In structural engineering, multi-storey buildings' seismic resilience in earthquake-prone areas is crucial. The seismic performance of proposed multi-story buildings with different heights (G+13, G+19, and G+27) is thoroughly examined in this study using traditional structural systems that are octagrid and hexagrid. Under seismic zone III conditions, the study evaluates important parameters such as storey drifts and storey displacements using the Response Spectrum Method. Each structural system's seismic response is assessed using nonlinear dynamic analysis, with an emphasis on classifying bifurcations according to responses that have been observed. The results show that there are notable differences in the seismic performances of the various structural systems, with the diagrid configuration outperforming the others in terms of reducing seismic loads. These findings have implications for designing buildings that are seismically resilient. It is found that the diagrid systems do much better in seismic events by lowering lateral forces and moving buildings less sideways, making it perfect for tall buildings built in places with many earthquakes The results show wide dissimilarity of seismic performance between the various structural systems, diagrid and hexagrid configuration faring better in the reduction of seismic loads than conventional. Findings implications on seismic-resilient building design and construction practices are discussed, with regards to the need to adopt innovative structural systems to promote seismic resilience and safety of building in earthquakes endemic areas. This research provides meaningful insights for structural engineering, notifying the stakeholders and decision-makers about proper strategies for eliminating the seismic hazards and making the environment must safer for inhabitants.

Keywords: Seismic analysis, conventional, diagrid, hexagrid, response spectrum method, multi-storey buildings, comparative analysis, Framed tubular, Braced tubular structure

INTRODUCTION

Extensive research into the behaviour of structures under earthquake loads has become necessary due to the rapid expansion of high-rise buildings in seismically active areas. Tall structures frequently use grid systems to improve load distribution and rigidity. This study explores seismic behaviour of high-rise buildings using conventional, diagrid, and hexagrid structural systems across three height categories: G+13, G+19, and G+27. Models are made up of RCC structures and analysed using ETABS software under seismic Zone III conditions. Lateral response parameters such as storey drift and storey displacement were evaluated using the Response Spectrum Method. Compared to hexagrid and conventional system, diagrid has shown dominance in seismic performance with significantly lower displacements and drifts;

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although hexagrid structures also showed improved efficiency, particularly in G+19 and G+27 structures. All the models are analysed according to IS 456:2000 and IS 1893:2016 standards, which include geometric and material properties. Results shows that diagrid system reduced peak storey displacement by up to 30% in G+27 structures compared to conventional frames.

Figure 1 lists the various kinds of lateral load resisting systems. This issue forced the engineers to create a system of interconnected horizontal, vertical, and diagonal elements that created various shapes, such as triangles, polygons, hexagons, and others, as an alternative to the traditional solution of heavier sections.

LITERATURE REVIEW

Carpinteri *et al.* exhibit FEM analysis approach that gives a faster and reasonable way in comparison with the exact one to study the structural dynamics. This paper discusses the free vibration analysis of high-rise buildings with various forms of vertical stiffness systems including shear wall, braced frame, and core tube structures. This analyses the effectiveness of the developed formula through numerical example as frequency response is in good agreement with FEM analysis [1].

Alexander *et al.* disclose geometry of building performance on diagrid under lateral loads and aim to identify the optimal geometric configurations. The used finite element analysis to simulate the behaviour of diagrid structures with varying geometric parameters. It uses Finite element approach to simulate the behaviour of diagrid structures with varying geometric parameters [2].

Mosavat analysed high rise buildings by comparing hexagrid and diagrid systems for tall buildings. This paper uses the numerical technique that predicts the behaviour of tall structures under seismic loads and provides a scientific ratio for choosing the appropriate structural system from the point of view of design by analysing structural models with comprehensive nonlinear dynamic analyses. Hence, it has been ascertained that when deciding on characteristics of tall buildings it is necessary to take into consideration its height, a seismic hazard level, and architecture constraints [3].

Scaramozzino *et al.* showed a brief description of diagrid and hexagrid structural systems and their prospects in the construction of tall structures. The researchers suggests that hexagrid and diagrid systems can be further developed and optimized to improve structural performance, enhance sustainability, and better showcase architectural expression in tall buildings [4].

Barr published a study on the mathematical and historical development of skyscrapers in Chicago and New York City, examining the influences of urban policy, economics, and technology.

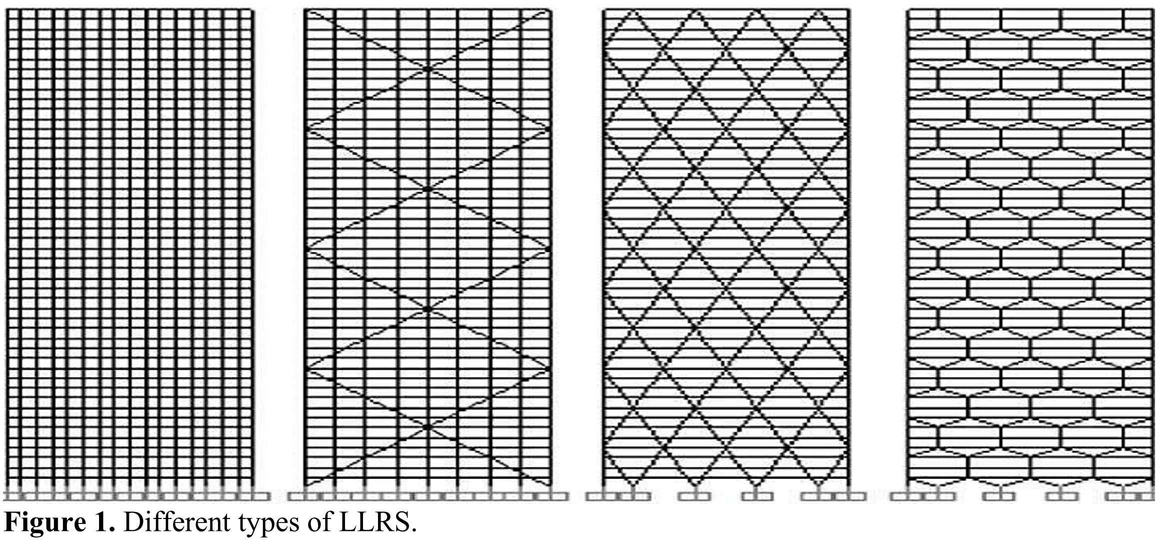

Figure 1. Different types of LLRS.

It makes the narrative more personal by emphasising Chicago's ingenuity that saw it successfully establish new forms of planning and construction as opposed to New York which was first to rule the age of skyscrapers. Besides, the research discloses how intelligence created and built these styles of Chicago and New York city environments, recreating the skyscrapers as the means of human desire [5].

Sun Moon *et al.* aimed at exploring the diagrid structural systems, their nature, design approach, and uses in tall buildings. The study provides a progressive design approach at the initial design state, including member selection, structural evaluation, and joint design. Vital importance is attributed to force of earthquake as well as space energy and architectural flexibility of this architectural innovation known as diagrids. It also presented certain basic questions as architectural and construction projects' complexity, choice of materials and cost, that illustrate the relevance of thinking and designing [6].

Ali *et al.* performed a thorough analysis of current developments in tall building structural systems, highlighting new developments and creative design strategies. In this thesis, the author looks at new features in tall building structural systems, including new designs and technologies. It looks into tube-in-tube, diagrid and hexagrid and reviews its strength, construction methods and architectural effects. This paper also describes the strengths and weaknesses such as the relation, the materials involved as well as aspects of construction difficulty. It thereby emphasizes on the importance of robust and sustainable solutions to serve for current new age city development [7].

Mathews *et al.* exhibited the effect of range of bracing patterns on lateral stiffness, energy absorption, and seismic behaviour in hexagrid structural. This work underlines the significance of the correct dimension of members and connection detailing for the target structure during the occurrence of seismic events. It is useful in the formation of prospective, more efficient and stable hexagrid systems [8].

Mashhadiali *et al.* revealed that, how different bracing configurations affect lateral stiffness, energy dissipation, and overall seismic response in hexagrid structural systems. With the help of mathematical analysis, it determines the sequence of bracing that will improve the performance and solve problems associated with connection, material, and construction techniques. It also reflects on the importance of getting member size and joint details right to accommodate seismic loads within the structure. The following are the conclusions drawn from the investment appraisal:

- The results presented here are useful to design hexagrid systems with best performances and adapted to crowded areas [9].

Taranath *et al.* demonstrate by comparing pentagrid and hexagrid structural systems, especially in tall buildings in terms of behaviour, structural capacity, and performance characteristics under seismic activities. They used the finite element analysis to study how the systems behave under several loadings to compare the difference in such properties as stiffness, strength, and ductility of the two systems. The results suggest that considerable caution has to be exercised while selecting the members, designing the connections, and material specification in order to develop safe and reliable structures [10].

AIM AND OBJECTIVES

1. To explain the effects of diagrid and hexagrid in the scenarios of earthquake in comparison to conventional structures.
2. To focus on the earthquake response difference of multi-storeyed buildings with different heights (G+13, G+19 and G+27) for seismic zone III.
3. To quantify the improvements of inter floor drift and floor displacement offered by different grids systems over conventional structural system.

RESEARCH APPROACH

This research explores the seismic behaviour of different grid structural systems under different design parameters, with an emphasis on the effect of storey height. RCC structure with diagrid and hexagrid lateral load-resisting systems (LLRS) are located along the exterior, and interior columns carrying gravity loads. The structures are located in Seismic Zone III and 3 and 5% damping factor are employed to establish the RSA. Detailed modelling parameters are presented in Table 1. All the models meet IS 456:2000 standards for structural design and IS 1893:2002 standards for seismic loading and have similar plan configurations and member sections in all systems.

According to IS 875 (Part 1):1987, dead loads considered in the analysis include the unit weight of lightweight bricks displayed by Table 2, which may vary with moisture content, specific gravity, and material quality. Accurate estimation is essential, as dead loads significantly influence structural load-carrying capacity.

Additional contributions include a 115 mm thick waterproofing screed and brick bat coba system, evaluated at 20 kN/m³, along with floor finishes based on material type and thickness. A unit weight of 8 kN/m³ is assumed for plastered lightweight brick walls, though actual values may vary with construction techniques. As per IS 875 (Part 2):1987, live loads vary with occupancy, usage, and local regulations.

Table 1. Building description.

S.N.	Building data	Parameters
1	Number of stories	G+13, G+19, G+27
2	Plan dimension	40 m×40 m
3	Number of grid lines along X and Y	4 m and 4 m
4	Height of each storey	4 m
5	Grade of structural steel (Fy)	HYSD 500
6	Grade of concrete (Fck)	M40
7	Slab thickness	150 mm
8	Column dimensions	600×600 mm
9	Parking beam	300×600 mm
10	1st slab beam	300×750 mm
11	Rest all beams	230×750 mm
12	External wall thickness	230 mm
13	Internal wall thickness	150 mm
14	Diagrid and Hexagrid dimensions	350×350 mm

Table 2. Loding Condition and Parameters.

S.N.	Loads	Specification	Value	References
1	Dead Load	Internal wall load	1.84 kN/m²	IS 875 (Part-1) 1987
		External wall load	5.52 kN/m²	
		Floor finish	1 kN/m²	
		Terrace water proofing	3 kN/m²	
2	Live Load	Live load on all floors	5 kN/m²	IS 875 (Part-2)
		Roof live load	1.5 kN/m³	
3	Earthquake Load	Seismic Zone	Zone III	IS 1893 (Part-1) 2016
		Zone Factor (Z)	0.16	
		Soil Type	Medium	
		Damping Ratio	5%	
		Response Reduction Factor (R)	5	
		Importance Factor (I)	1.2	

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Structural elements are illustrated in both plan and 3D views using ETABS V20, as depicted in Figures 2–7.

1. Model 1: G+13 Building using Conventional building in zone III.
2. Model 2: G+19 Building using Conventional building in zone III.
3. Model 3: G+27 Building using Conventional building in zone III.
4. Model 4: G+13 Building using Diagrid system in zone III.
5. Model 5: G+19 Building using Diagrid system in zone III.
6. Model 6: G+27 Building using Diagrid system in zone III.
7. Model 7: G+13 Building using Hexagrid system in zone III.
8. Model 8: G+19 Building using Hexagrid system in zone III.
9. Model 9: G+27 Building using Hexagrid system in zone III.

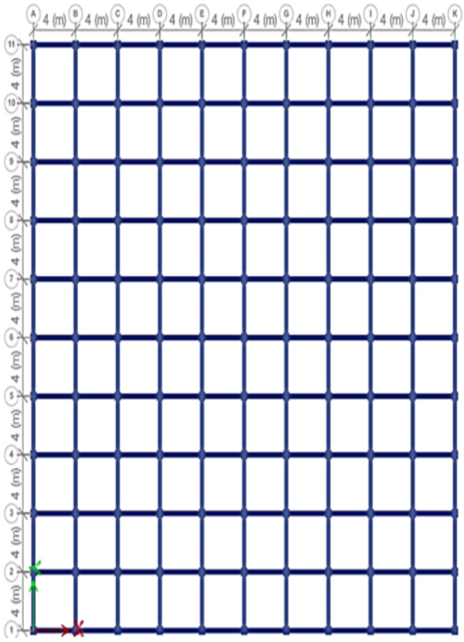

Figure 2. Grid plan view of all the models.

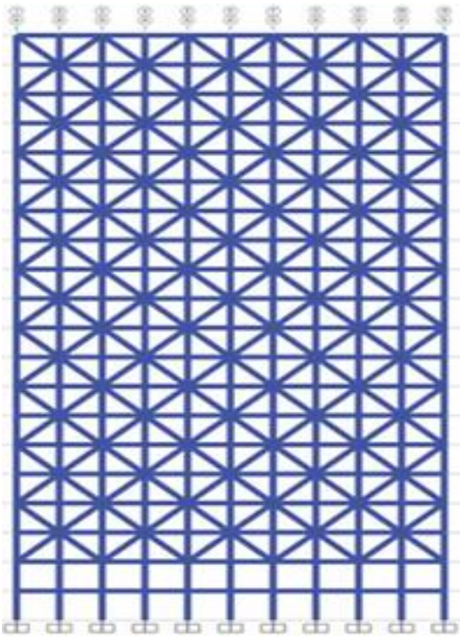

Figure 3. 3D view of conventional building.

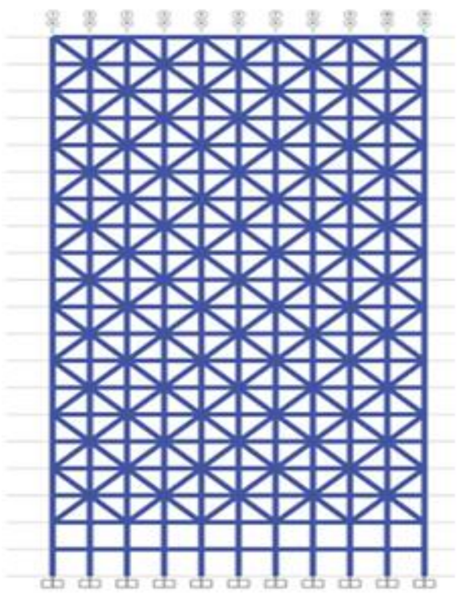

Figure 4. Elevation view of diagrid building.

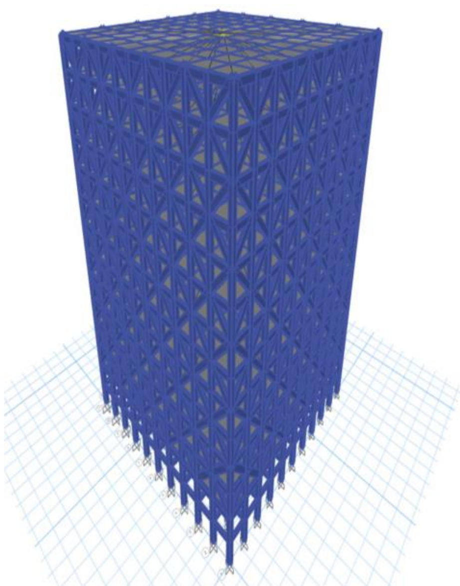

Figure 5. 3D view of diagrid building.

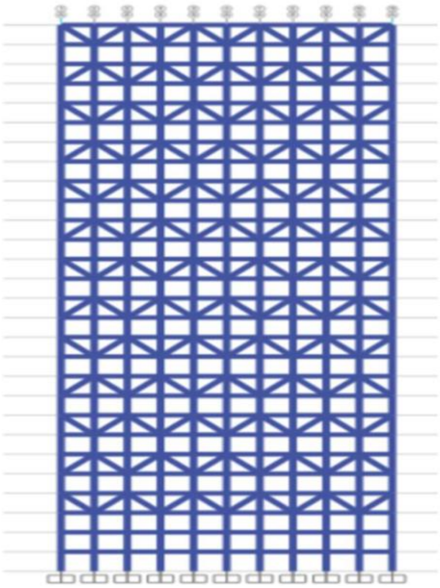

Figure 6. Elevation view of Hexagrid Building.

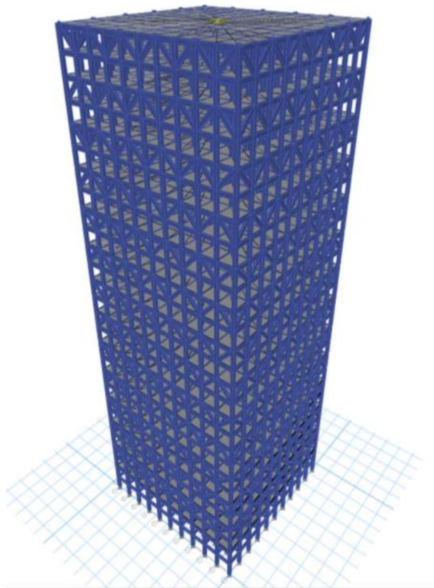

Figure 7. 3D view of Hexagrid Building.

Table 3. Storey displacement comparison for G+13 under zone III.

Storeys	Conventional	Diagrid	Hexagrid
1 Storey	21.514	17.022	15.153
2 Storey	33.076	18.298	21.04
3 Storey	44.922	19.254	22.496
4 Storey	56.688	20.255	27.153
5 Storey	68.204	21.28	28.627
6 Storey	79.326	22.286	33.12
7 Storey	89.893	23.282	34.527
8 Storey	99.725	24.206	38.566
9 Storey	108.643	25.105	39.803
10 Storey	116.371	25.925	43.039
11 Storey	122.617	26.651	44.022
12 Storey	127.176	27.257	46.024

RESULT AND DISCUSSION

Key results on storey displacement and storey drift demonstrate the influence of diagrid and hexagrid system under seismic effect are discussed below.

Storey Displacement

Storey displacement is central in analysing the structure's response to lateral forces including earthquakes and wind loads. Slenderness and height are major determinants for analysing storey displacement. Displacement values for G+13 stories are presented in Table 3 and Figure 8. When a building rises, it tends to be highly vulnerable to lateral forces owing to increased flexibility. Displacement tends to be extreme at the very top of the structure and becomes minimal towards its base. According to IS1893:2016 standards, the maximum permissible deflection is given by H/500, where H is the overall height of the structure.

Both the Diagrid and Hexagrid systems perform better than the Conventional system in minimizing storey displacements for a G+13 building. The Diagrid has greater stiffness and reduced deformations, whereas the Hexagrid is a balanced solution based on performance and feasibility. The selection would be project-driven, but both systems facilitate increased structural efficiency and robustness in mid-rise construction.

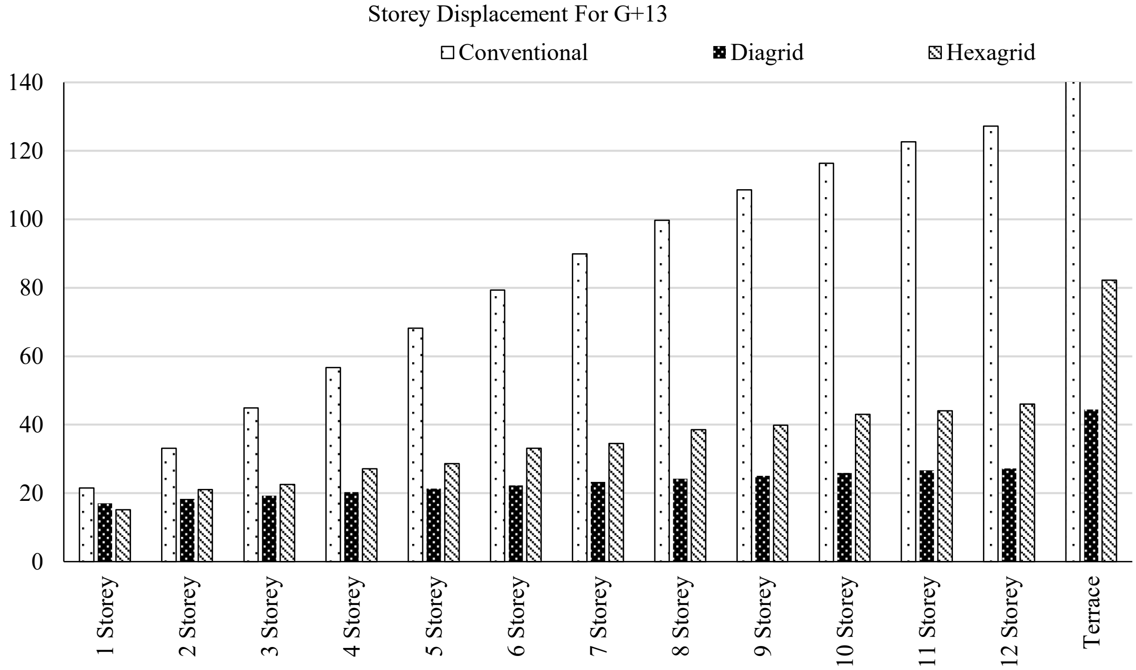

Figure 8. Storey displacement comparison for G+13 under zone III.

Table 4. Storey displacement comparison for G+19 under zone III.

Storeys	Conventional	Diagrid	Hexagrid
1 Storey	31.1	24.917	29.007
2 Storey	43.706	26.304	37.344
3 Storey	56.439	27.354	39.027
4 Storey	69.144	28.466	43.922
5 Storey	81.756	29.642	45.557
6 Storey	94.223	30.818	50.519
7 Storey	106.488	32.04	52.232
8 Storey	118.497	33.252	57.078
9 Storey	130.217	34.483	58.769
10 Storey	141.514	35.692	63.394
11 Storey	152.24	36.894	65.036
12 Storey	162.338	38.057	69.238
13 Storey	171.701	39.187	70.756
14 Storey	180.212	40.26	74.376
15 Storey	187.745	41.273	70.756
16 Storey	194.166	42.21	78.534
17 Storey	199.34	43.061	79.619
18 Storey	203.154	43.817	81.425
Terrace	205.635	44.47	82.203

Diagrid and Hexagrid systems show an improvement in minimizing storey displacements over the Conventional system for the G+19 building. The Diagrid system shows greater stiffness and lower deformation, with consistently lower storey displacements in all floors. Different values of displacement for G+19 storeys are presented in Table 4 and Figure 9. In contrast, the Hexagrid system presents a balanced solution, with significant displacement reductions in mind while also taking into consideration practical considerations such as construction cost and material demand.

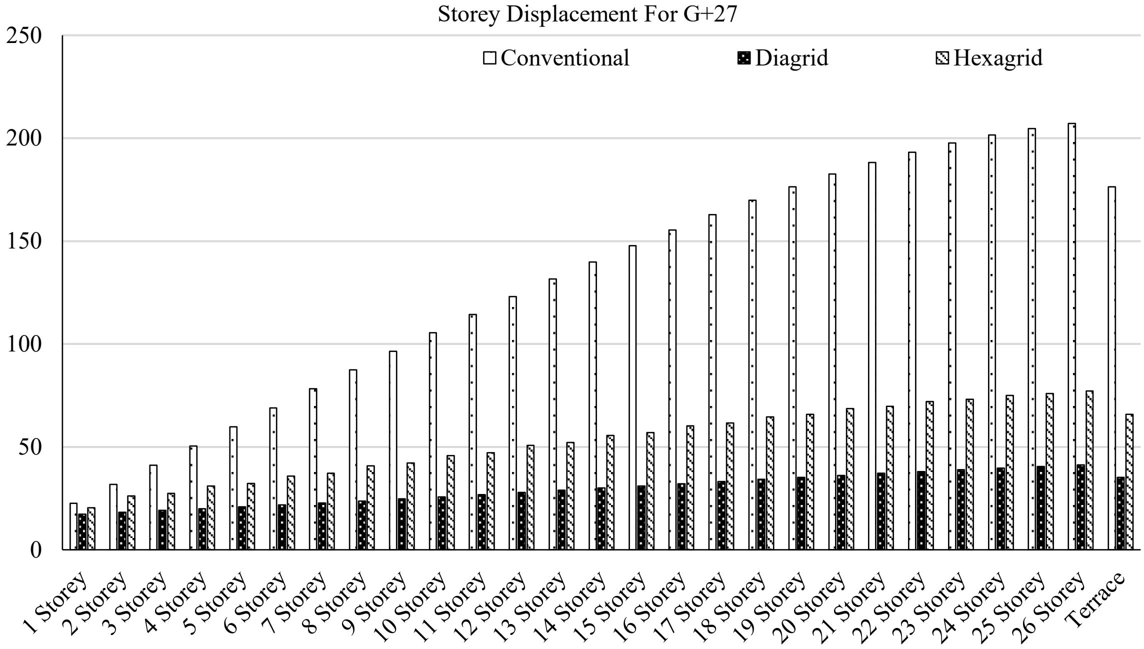

Figure 9. Storey displacement comparison for G+27 under zone III.

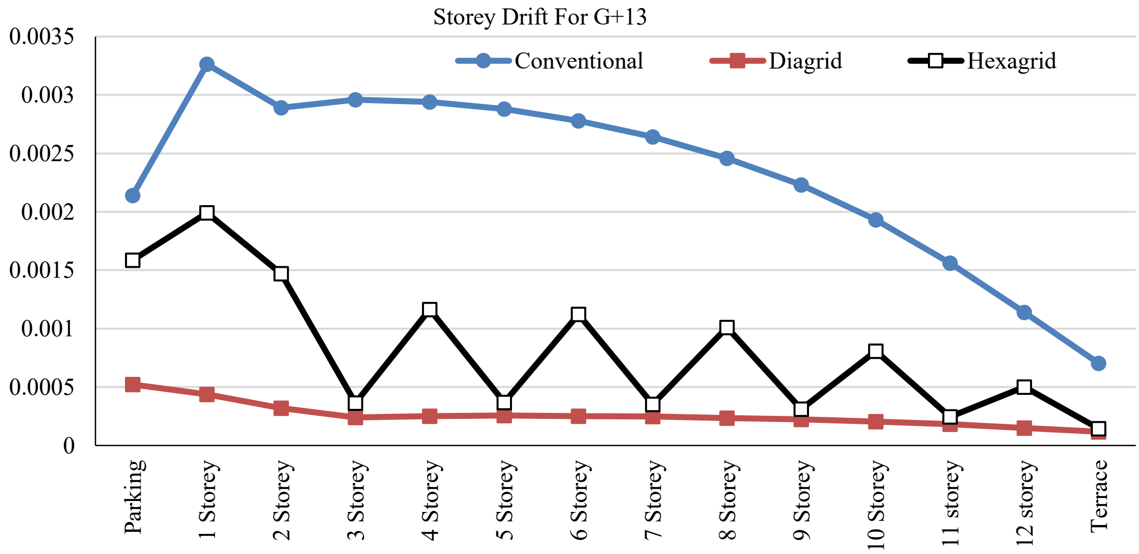

Figure 10. Storey drift comparison for G+13 under zone III.

Hexagrid as well as diagrid systems indicate better performance than the Conventional system in minimizing storey displacements for a G+19 building. Diagrid provides higher stiffness and negligible deformation, whereas Hexagrid offers a reasonable compromise between performance and construction efficiency. Both systems offer efficient alternatives to conventional designs, improving the structural efficiency of high-rise buildings.

The Diagrid system has greater lateral stiffness and less deformation with consistently lower displacements in all storeys. Figure 10 and Table 5 show the ranges of displacements. However, the Hexagrid system provides an equalized structural response with effective reduction of displacements and consideration for practical factors such as construction simplicity, material optimization, and cost-effectiveness. Nevertheless, both systems appear as reasonable options to the traditional structural layouts with greater stiffness and efficiency appropriate for high-rise construction in the modern era.

Table 5. Storey displacement comparison for G+27 under zone III.

Storeys	Conventional	Diagrid	Hexagrid
1 Storey	22.578	17.303	20.335
2 Storey	31.762	18.3	26.211
3 Storey	41.066	19.087	27.449
4 Storey	50.39	19.921	30.953
5 Storey	59.7	20.826	32.184
6 Storey	68.98	21.738	35.799
7 Storey	78.212	22.711	37.139
8 Storey	87.386	23.688	40.78
9 Storey	96.514	24.711	42.143
10 Storey	105.531	25.734	45.751
11 Storey	114.371	26.792	47.17
12 Storey	123.039	27.844	50.715
13 Storey	131.511	28.917	52.128
14 Storey	139.759	29.98	55.555
15 Storey	147.747	31.051	56.961
16 Storey	155.442	32.106	60.209
17 Storey	162.805	33.155	61.566
18 Storey	169.798	34.182	64.574
19 Storey	176.38	35.192	65.866
20 Storey	182.507	36.173	68.561
21 Storey	188.134	37.124	69.761
22 Storey	193.215	38.04	72.069
23 Storey	197.7	38.916	73.146
24 Storey	201.542	39.748	74.984
25 Storey	204.691	40.532	75.921
26 Storey	207.113	41.265	77.207
Terrace	176.38	35.192	65.866

Storey Drift

Floor deflections in structures occur as a result of seismic forces and are also magnified by ductility factors, leading to total deflections that encompass inelastic behaviour. Storey drift is the relative displacement between the top and bottom of a specific storey. Table 6 and Figure 10 depict the drift values for the G+13 structure. It is affected by a combination of factors such as shear deformation within the storey, axial deformation of the floor system, overall structural bending, and foundation rotation. Among different structural response parameters, storey drift is the most sensitive criterion in seismic performance assessment.

Diagrid and Hexagrid structural systems have evident superiority in storey drift control over the conventional building. As per design practices, the maximum allowable drift in any storey should not be more than 0.004 times the height of the storey under the design lateral force. Although the diagrid system provides performance equivalent to the conventional configuration, the hexagrid system shows higher lateral stiffness and stability, leading to lower displacements in all storeys.

Both structural systems have significant benefits in the management of storey drift over the conventional system. Table 7 and Figure 11 display the inter-storey displacement results for the G+19 configuration. The Diagrid system delivers similar or slightly lower drift values compared to the conventional setup, while the Hexagrid system shows increased lateral stiffness and overall stability, resulting in uniformly lower displacements in all storeys. However, both Diagrid and Hexagrid systems are valid and effective alternatives to conventional structural solutions, leading to enhanced resilience and performance in mid-rise building design.

Results for G+27 inter-storey displacements can be found in Table 8 along with Figure 11. The analysis demonstrates that Diagrid alongside Hexagrid structures better regulate lateral movements than conventional structural elements. The Diagrid system produces drift results similar to Conventional systems but the Hexagrid system performs best with its stable properties providing lower lateral deflection throughout all floors. Project requirements and project-specific considerations determine whether a Diagrid or Hexagrid structural configuration should be implemented. The innovative structural designs provide building solutions beyond conventional construction methods which strengthen high-rise building performance and structural reliability.

Table 6. Storey drift comparison for G+13 under zone III.

Storeys	Conventional	Diagrid	Hexagrid
Parking	0.002139	0.000522	0.001586
1 Storey	0.003263	0.0004362	0.001991
2 Storey	0.002891	0.000319	0.001472
3 Storey	0.002961	0.000239	0.000364
4 Storey	0.002941	0.00025	0.001164
5 Storey	0.002879	0.000256	0.000369
6 Storey	0.00278	0.000252	0.001123
7 Storey	0.002642	0.000249	0.000352
8 Storey	0.002458	0.000235	0.00101
9 Storey	0.00223	0.000225	0.000312
10 Storey	0.001932	0.000205	0.000809
11 storey	0.001561	0.000182	0.000246
12 storey	0.00114	0.000151	0.000501
Terrace	0.000704	0.000118	0.000145

Table 7. Storey drift comparison for G+19 under zone III.

Storeys	Conventional	Diagrid	Hexagrid
Parking	0.00431	0.0003809	0.004101
1 Storey	0.004585	0.0003396	0.004224
2 Storey	0.003152	0.000347	0.002084
3 Storey	0.003183	0.000263	0.000421
4 Storey	0.003176	0.000278	0.001224
5 Storey	0.003153	0.000294	0.000409
6 Storey	0.003117	0.000294	0.001241
7 Storey	0.003066	0.000305	0.000428
8 Storey	0.003002	0.000303	0.001212
9 Storey	0.00293	0.000308	0.000424
10 Storey	0.002824	0.000302	0.001166
11 Storey	0.002682	0.0003	0.000411
12 Storey	0.002524	0.000291	0.001051
13 Storey	0.002341	0.000282	0.000379

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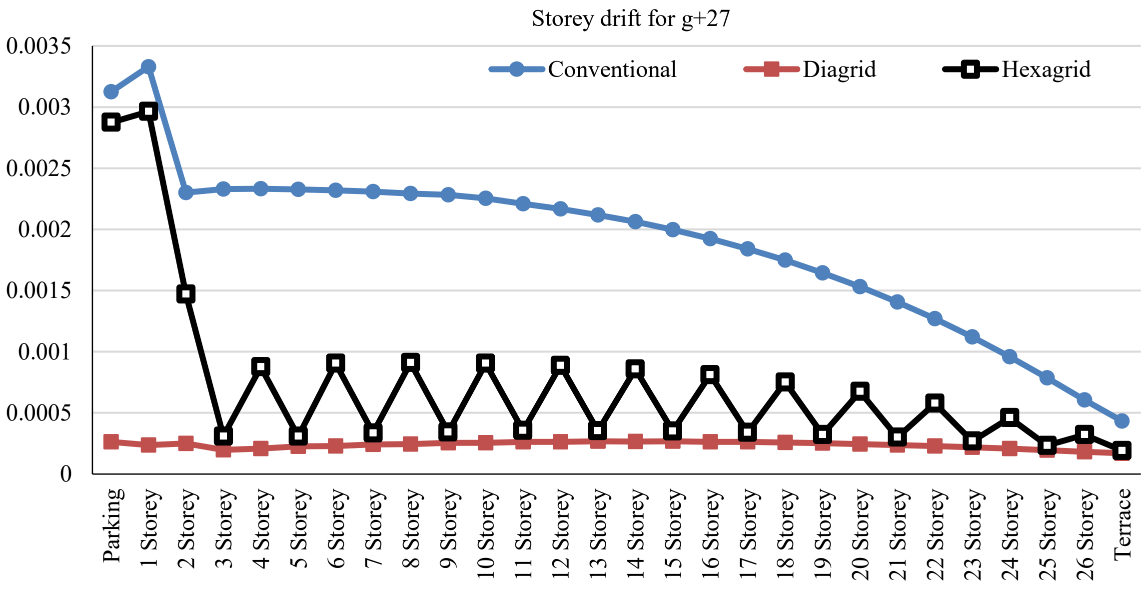

Figure 11. Storey drift comparison for G+27 under zone III.

Table 8. Storey drift comparison for G+27 under zone III.

Storeys	Conventional	Diagrid	Hexagrid
Parking	0.003125	0.0002643	0.002874
1 Storey	0.00333	0.000236	0.002963
2 Storey	0.00230	0.000249	0.001469
3 Storey	0.00233	0.000197	0.00031
4 Storey	0.002331	0.000209	0.000876
5 Storey	0.002328	0.000226	0.000308
6 Storey	0.00232	0.000228	0.000904
7 Storey	0.002308	0.000243	0.000335
8 Storey	0.002293	0.000244	0.00091
9 Storey	0.002282	0.000256	0.000342
10 Storey	0.002254	0.000256	0.000904
11 Storey	0.00221	0.000264	0.000355
12 Storey	0.002167	0.000263	0.000887
13 Storey	0.002118	0.000268	0.000353
14 Storey	0.002062	0.000266	0.000857
15 Storey	0.001997	0.000268	0.000351
16 Storey	0.001924	0.000264	0.000812
17 Storey	0.001841	0.000262	0.000339
18 Storey	0.001748	0.000257	0.000752
19 Storey	0.001645	0.000252	0.000323
20 Storey	0.001532	0.000245	0.000674
21 Storey	0.001407	0.000238	0.0003
22 Storey	0.00127	0.000229	0.000577
23 Storey	0.001121	0.000219	0.000269
24 Storey	0.00096	0.000208	0.00046
25 Storey	0.000787	0.000196	0.000234
26 Storey	0.000606	0.000183	0.000321
Terrace	0.000433	0.00017	0.000192

CONCLUSION

1. The research project monitored functional changes in buildings using conventional and diagrid and hexagrid structural methods at heights spanning from G+13 to G+19 to G+27.
2. The research results showed hexagrid and diagrid systems were more effective than conventional construction at controlling both lateral displacement and storey drift movements.
3. Across the duration of the research the building height gap widened while the hexagrid system delivered better results in tall structures.
4. As research continued, the performance difference between building heights increased and hexagrid construction outperformed at higher elevations.
5. As the investigation continued, the performance difference between building heights increased while the hexagrid system produced better results in taller structures.
6. Base shear reached its maximum value in the conventional system yet the diagrid and hexagrid configurations distributed lateral loads more effectively to reduce base shear effects.
7. Structural efficiency resulting from the correct placement of materials in diagrid and hexagrid construction methods leads to cost-saving potential in the design of tall buildings.
8. The simultaneous integration of the hexagrid and diagrid systems enhanced architectural value and structural performance while enabling new design prospects.
9. A hexagrid system successfully performed under seismic conditions because it both dissipated energy while exhibiting diminished dynamic response.
10. The hexagrid system achieved improved performance metrics that enhanced its suitability to build high-rise structures as buildings became taller.

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