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

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.311 ⁒ Peer-reviewed & Refereed journal ⁒ Vol. 12, Issue 7, July 2025

DOI: 10.17148/IARJSET.2025.12732

Comparative Study on Seismic Analysis Of Diagrid And Hexagrid Structure: A Review

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Abstract: The seismic performance of tall buildings relies heavily on the choice of lateral load-resisting systems. Diagrid and hexagrid structural systems have gained prominence due to their efficient load transfer mechanisms, geometric rigidity, and architectural versatility. This review paper synthesizes insights from ten core research studies to examine the comparative seismic behavior of diagrid and hexagrid structures under earthquake loads. Key findings highlight reductions in lateral drift, enhanced energy dissipation, and optimized material usage in diagrid and hexagrid configurations, contributing to improved seismic resilience in high-rise steel structures. The paper also identifies modeling practices using ETABS and response spectrum methods commonly applied in previous studies. Finally, it outlines research gaps and recommends areas for future exploration, particularly focusing on hybrid grid systems and optimization under varying seismic conditions for sustainable tall building design.

Keywords: Diagrid structures, Hexagrid structures, Seismic analysis, Tall steel buildings, Lateral drift reduction, Response spectrum method, ETABS modeling, Structural efficiency.

I. INTRODUCTION

Tall structures require robust lateral load-resisting systems to ensure safety and serviceability during seismic events. Diagrid and hexagrid structures have emerged as advanced structural systems offering high stiffness and improved seismic performance, which are critical for modern high-rise construction in seismic zones. These systems provide geometric efficiency, effective energy dissipation, and aesthetic flexibility, making them suitable for sustainable tall building design. This review synthesizes insights from ten relevant research studies to highlight the comparative seismic performance of diagrid and hexagrid systems under earthquake loads and identifies key parameters influencing their behavior.

1.1 Background

Tall steel structures are highly susceptible to seismic activities, making the choice of lateral load-resisting systems a significant factor in structural design. Conventional systems often face limitations in controlling lateral drifts and require larger member sections. Diagrid and hexagrid structural systems utilize diagonal and hexagonal configurations, respectively, to transfer lateral loads efficiently while maintaining material economy and structural stability. Their unique configurations contribute to reducing seismic-induced drift and enhancing the building's ability to dissipate energy, ensuring structural safety during seismic excitations.

1.2 Structural System in Focus

Diagrid structures consist of diagonally placed steel members forming triangular patterns along the façade, effectively resisting lateral loads and providing flexibility for interior planning. Hexagrid structures, with their hexagon-based configurations, distribute forces uniformly and reduce stress concentrations under seismic loads. Both systems have been analyzed in previous research using ETABS and response spectrum methods, focusing on parameters such as storey drift, storey displacement, base shear, and modal behavior under seismic loading conditions.

1.3 Objectives

- To review and synthesize seismic performance studies of diagrid and hexagrid structures.
- To identify key parameters affecting seismic behavior, including drift, displacement, and base shear.
- To analyze the advantages and limitations of diagrid and hexagrid systems under seismic loading.
- To explore the effectiveness of response spectrum analysis and modeling approaches applied in previous studies.
- To identify gaps in existing research and suggest future research directions for optimizing grid systems in seismic design.

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II. LITERATURE REVIEW

Over the past decade, the exploration of innovative structural frameworks such as diagrid and hexagrid systems has garnered significant attention within the structural engineering community. These systems are increasingly favored for their potential to improve seismic resilience, material efficiency, and architectural versatility. This review synthesizes key research efforts that investigate the behavior, analysis methods, and comparative performance of these grid systems under seismic excitation.

2.1 Structural Behavior of Diagrid And Hexagrid Systems

S.Yildirim et al. (2024) pioneered an extensive analysis of diagrid structures, focusing on their geometric configuration and dynamic response characteristics. The study revealed that diagrid frameworks inherently possess high lateral stiffness due to their triangulated geometry, which effectively distributes seismic forces throughout the structure. The research also emphasized that diagrid systems allow for architectural flexibility, enabling innovative design solutions while simultaneously enhancing seismic performance. The material efficiency observed in their models indicated potential for cost savings and sustainability benefits.

Building upon this foundation, B. Saraswathy (2017) conducted a comparative study of various structural systems, including moment-resisting frames, braced frames, diagrid, and hexagrid frameworks. The study employed finite element modeling to evaluate ductility, energy dissipation, and lateral stiffness. Results indicated that diagrid structures exhibit superior ductility and energy absorption capabilities, which are crucial for seismic resilience. The triangulated geometry was identified as a key factor contributing to their ability to withstand dynamic seismic loads effectively.

In more recent work, Yash Bhardwaj (2019) focused on the dynamic response of both diagrid and hexagrid systems through eigenvalue analysis and time-history simulations. The study concluded that the geometric configurations significantly influence dynamic behavior, with hexagrid structures offering more uniform force distribution across their network, leading to lower inter-story drifts during seismic events. The findings suggested that hexagrid systems might be more suitable for high seismic zones where force distribution and stability are critical.

2.2 Comparative Seismic Performance of Diagrid and Hexagrid Structures

Robin Singh (2022) provided a detailed comparative assessment of various structural frameworks including tubular, diagrid, pentagrid, and hexagrid systems using nonlinear static and dynamic analysis methods under seismic loads. The research highlighted that while diagrid systems tend to demonstrate higher stiffness and ductility, hexagrid frameworks excel in dissipating seismic energy owing to their geometric configuration. The study found that hexagrid structures could better absorb and distribute seismic forces, resulting in reduced peak displacements and inter-story drifts.

Sayed Adil (2021) investigated high-rise buildings incorporating hexagrid frameworks subjected to seismic excitation using response spectrum analysis. Their results revealed that the hexagrid configuration led to notable reductions in base shear and inter-story drifts compared to traditional moment-resisting frames and other grid systems. These effects were especially pronounced in models subjected to high seismic intensities, demonstrating the system's robustness and suitability for earthquake-prone regions.

2.3 Response Spectrum Analysis and Dynamic Response Evaluation

Response spectrum analysis has been widely adopted as a practical method to evaluate the seismic response of diagrid and hexagrid systems. H Saeidi Nezhad and F. Omidinasab (2021) applied this technique to assess the seismic performance of hexagrid structures, emphasizing that their geometric properties influence dynamic response parameters significantly. Their findings indicated that the inherent stiffness and symmetry in hexagrid frameworks result in lower lateral displacements and reduced seismic forces during ground motion.

Similarly, Xiangrui Chen (2018) conducted a detailed response spectrum analysis on diagrid structures, demonstrating that the triangulated configuration effectively reduces peak accelerations and displacements, thereby enhancing seismic safety. The study highlighted the importance of optimizing the geometric parameters such as the angle and size of the grid elements to maximize seismic performance.

2.4 Summary

From the reviewed literature, several consistent themes emerge:

- Both diagrid and hexagrid systems demonstrate superior seismic performance compared to conventional framed structures, primarily due to their high lateral stiffness, ductility, and energy dissipation capacity.

DOI: 10.17148/IARJSET.2025.12732

- The geometric configuration of hexagrid structures facilitates more uniform force distribution, resulting in smaller inter-story drifts, lower base shear, and improved overall stability during seismic events.
- Diagrid systems, with their architectural flexibility and high ductility, are particularly advantageous in seismic zones requiring resilient and adaptable structural solutions.
- Response spectrum analysis remains an essential tool in evaluating the dynamic response of these systems, guiding engineers in optimizing design parameters for enhanced seismic safety.

III. METHODOLOGY

This review adopts a systematic approach to analyze and compare the seismic performance of diagrid and hexagrid structural systems utilizing the response spectrum method. The process involves multiple stages, detailed as follows:

3.1 Literature Collection and Review Objective: To establish a comprehensive understanding of existing research, case studies, and standards related to the seismic behavior of diagrid and hexagrid structures.
Procedure:
- Collect relevant peer-reviewed journal articles, conference papers, design code guidelines (such as IS 1893, Eurocode 8), and technical reports.
- Focus on studies that employ response spectrum analysis, dynamic modeling, or experimental validation.
- Organize the literature based on structural configurations, analysis techniques, and key findings.

3.2 Selection of Structural Models
Objective: To develop representative models that reflect typical design parameters for diagrid and hexagrid systems.
Procedure:
- Define geometric configurations based on standard tall building dimensions (e.g., height, floor plan).
- Establish material properties such as concrete strength (e.g., M25, M30) and steel reinforcement characteristics.
- Assign member sizes and grid angles consistent with conventional design practices.
- Use CAD or structural modeling software (e.g., ETABS, SAP2000) to create three-dimensional finite element models of the selected structures.

3.3 Seismic Load Definition
Objective: To accurately represent the seismic excitation for analysis.
Procedure:
- Select appropriate response spectra based on seismic zones, soil conditions, and building importance factor.
- Utilize standardized spectra from IS 1893 or Eurocode 8, scaled to the site-specific seismic hazard levels.
- Incorporate the spectral shapes into the dynamic analysis framework.

3.4 Dynamic Analysis using Response Spectrum Method
Objective: To evaluate the maximum expected responses of the structures during seismic events.
Procedure:
- Conduct modal analysis to determine the structure's natural frequencies and mode shapes.
- Calculate the peak response for each mode by applying the spectral acceleration values.
- Combine modal responses using the Complete Quadratic Combination (CQC) method to account for mode coupling effects.
- Determine key response parameters:

Inter-story drift ratios: to assess deformation limits.
Base shear: to evaluate overall lateral load resistance.
Lateral displacements: to examine drift and deformation under seismic forces.
- Repeat the analysis for both diagrid and hexagrid models for comparative purposes.

3.5 Comparative Evaluation
Objective: To analyze and interpret the seismic performance differences between the two systems.
Procedure:
- Compare maximum inter-story drifts to permissible limits.
- Evaluate base shear and lateral displacements to determine structural robustness.
- Assess energy dissipation capacity indirectly through response amplitudes.
- Summarize the relative stiffness, ductility, and stability characteristics based on the results.

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3.6 Validation and Sensitivity Analysis

- Cross-verify results with existing case studies or experimental data.
- Conduct parametric studies to understand the influence of geometric parameters, material properties, and seismic intensity levels on structural response.

IV. ANALYSIS AND DISCUSSION

The comparative seismic analysis of diagrid and hexagrid structures reveals nuanced insights into their dynamic behavior, resilience, and suitability for earthquake-prone regions. Drawing from the extensive literature and existing case studies, the following critical points elucidate the strengths, limitations, and practical implications of each structural system under seismic loading.

4.1 Seismic Response Characteristics

Lateral Force Resistance:

Both diagrid and hexagrid frameworks inherently possess high lateral stiffness due to their triangulated geometries, which effectively resist seismic-induced lateral forces. Yildirim et al. (2024) demonstrated that diagrid structures distribute seismic loads efficiently through their diagonally arranged members, resulting in reduced lateral displacements. Similarly, Sayed Adil (2021) observed that hexagrid systems further enhance load distribution due to their more uniform grid pattern, leading to reduced base shear and inter-story drifts under seismic excitation.

Energy Dissipation and Damping:

Seismic resilience is heavily influenced by a structure's capacity to dissipate energy. Bhardwaj (2019) highlighted that both systems exhibit good ductility, with hexagrid structures showing marginally superior energy absorption owing to their geometric efficiency. The interconnected grid networks facilitate internal damping mechanisms, which mitigate the amplitude of seismic oscillations, as supported by the response spectrum analyses performed in multiple studies.

Displacements and Inter-Story Drift:

Inter-story drift remains a critical parameter for assessing structural safety. Research indicates that hexagrid structures tend to produce lower inter-story drifts compared to diagrid counterparts, primarily due to their more uniform force distribution. Nezhad and Omidinasab (2021) confirmed through spectral response analysis that hexagrid frameworks exhibit reduced lateral displacements and accelerations, thereby enhancing overall stability during seismic events.

4.2 Advantages and Disadvantages

Diagrid Structures:

Advantages: High architectural flexibility, increased stiffness, and ductility, enabling designs that are both resilient and aesthetically appealing. They often require less material for lateral bracing, offering economic benefits.

Disadvantages: Slightly higher susceptibility to localized stresses and potential complexities in construction due to intricate member arrangements. Their performance can be sensitive to geometric configurations, necessitating precise analysis and design.

Hexagrid Structures:

Advantages: Superior load distribution and energy dissipation capabilities, making them highly suitable for seismic zones. Their regular grid pattern allows for more predictable dynamic behavior, which simplifies seismic design considerations.

Disadvantages: Potentially higher material usage and more complex connection details due to the extensive grid network. Architectural constraints may also arise depending on the design context.

4.3 Implications of Response Spectrum Analysis

The application of response spectrum methods across the reviewed studies underscores its effectiveness in evaluating the dynamic performance of these grid systems. Both frameworks demonstrated favorable seismic response characteristics when subjected to spectra representative of design-level earthquakes. The spectral analysis results consistently indicated that hexagrid systems tend to outperform diagrid structures in terms of lower maximum displacements, base shear, and inter-story drifts.

However, it is crucial to recognize that the effectiveness of these systems depends on the accurate modeling of material properties, boundary conditions, and geometric parameters. Sensitivity analyses performed in multiple studies suggest that slight alterations in grid angles or member stiffness can significantly influence seismic response. Therefore, a meticulous approach to design optimization is vital.

DOI: 10.17148/IARJSET.2025.12732

4.4 Practical Considerations and Future Directions

While both diagrid and hexagrid systems exhibit promising seismic performance, their practical implementation must consider factors such as constructability, cost, architectural aesthetics, and local seismic codes. The current literature advocates for further experimental validation—such as shake table testing and real-world monitoring to complement numerical simulations.

Future research should focus on integrating these grid systems with energy dissipation devices (e.g., dampers, base isolators) and exploring hybrid configurations that combine the advantages of both systems. Additionally, development of standardized design guidelines tailored for seismic zones will facilitate broader adoption in engineering practice.

V. CONCLUSION

This reviews has systematically examined the seismic performance of diagrid and hexagrid structural systems using the response spectrum method, incorporating insights from various research studies and case analyses. The key findings are as follows:

Seismic Resilience:
Both diagrid and hexagrid systems demonstrate high potential for earthquake resistance due to their inherent triangulated geometries, which provide excellent lateral stiffness and energy dissipation capacity.

Comparative Performance:
Hexagrid structures generally exhibit superior seismic response characteristics, including lower inter-story drifts, reduced lateral displacements, and higher energy absorption, making them particularly suitable for high seismic zones.

Diagrid systems offer notable architectural flexibility and ductility, with performance that can be optimized through careful design and member detailing.

Design Implications:
The choice between diagrid and hexagrid systems should consider not only seismic performance but also architectural aesthetics, constructability, and economic factors. When seismic resilience is a primary concern, hexagrid configurations tend to provide enhanced safety margins.

Future Directions:
Advancements in hybrid grid systems, incorporation of energy dissipation devices, and comprehensive experimental validation are recommended to further improve seismic performance. Additionally, developing standardized design guidelines tailored for seismic regions can facilitate broader implementation.

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