The Seismic Analysis of Diagrid Structures in Various Seismic Zones of India, Considering both Soft and Hard Soil Conditions

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Abstract — Improving high-rise buildings involves a myriad of complex factors, including finance, aesthetics, technology, urban regulations, and politics. However, among these factors, finance has emerged as the primary governing element. In tall structures, the structural design is largely governed by its lateral stability. In this context, diagrid structures have demonstrated their ability to efficiently withstand lateral seismic loads through their unique corner-to-corner connectivity, which sets them apart from conventional orthogonal structures like framed tubes. Diagrid structures offer exceptional structural efficiency while also introducing new aesthetic possibilities in tall building architecture. Their distinctive appearance is easily recognizable and visually appealing. By minimizing the need for vertical columns on the facade, diagrid systems reduce obstructions to the external view, enhancing the overall visual impact. Moreover, the efficiency of the diagrid system allows for the elimination of interior and corner columns, providing significant flexibility in floor planning. In this study, we conducted a comparative analysis to examine the positive impact of diagrid structures on tall buildings. Our objective was to evaluate the enhancement of resistivity and compare the variations in forces between a bare frame and a diagrid frame subjected to seismic forces in different zones and soil types. The study focused on a G+11 structure, considering the relevant loadings as per Indian provisions and seismic zones III and V. For modeling and analysis, we utilized the STAAD.Pro V8i software tool. A total of eight different cases were considered, incorporating diagrid structures at a diagonal angle of 63 degrees. The aim was to compare these cases and determine the most effective design approach for resisting forces.

Keywords: Diagrid Structure, Seismic Zone, Type of Soil

I. INTRODUCTION

The seismic analysis of diagrid structures has gained significant attention in the field of structural engineering. Diagrid structures, characterized by their diagonal bracing members, offer numerous advantages such as enhanced structural stability, architectural versatility, and reduced material consumption. These structures have demonstrated excellent performance under seismic loads, making them suitable for regions prone to earthquakes

In India, a country with diverse seismic activity, understanding the behavior of diagrid structures in different seismic zones is of paramount importance. Seismic zones in India are classified based on the intensity and frequency of earthquakes, ranging from low to high levels of seismicity. Additionally, the soil conditions in a particular area significantly influence the structural response to seismic forces. The variation in soil types, including soft and hard soils, necessitates a comprehensive investigation into the performance of diagrid structures under different soil conditions. This paper aims to present a detailed study on the seismic analysis of diagrid structures conducted across various seismic zones in India, considering both soft and hard soil conditions. The primary objective is to assess the effectiveness and resilience of diagrid structures in withstanding seismic forces in different regions. The study will contribute to a better understanding of the structural behavior of diagrid structures, providing valuable insights for their design, construction, and performance evaluation in seismic-prone areas.

II. OBJECTIVE OF THE WORK

- Explore the concept of diagrid structural systems in tall building structures.
- Determine the optimal configuration for structures using STAAD.Pro software.
- Assess the variation in structural stability due to diagrid structures under seismic forces.
- Analyze and interpret results regarding maximum story drift, maximum story displacement, base shear in seismic scenarios, and structural response.
- Investigate the behavior of bare frames and diagrid frames in different seismic zones of India.

A. *These objectives aim to:*

- Gain a comprehensive understanding of diagrid systems and their applicability in tall building design.
- Utilize software tools to identify the most suitable arrangement for diagrid structures.
- Evaluate the impact of diagrid structures on structural stability under seismic forces.
- Analyze and interpret data related to maximum story drift, displacement, base shear, and structural response.
- Investigate the behavior of bare frames and diagrid frames in varying seismic zones of India.

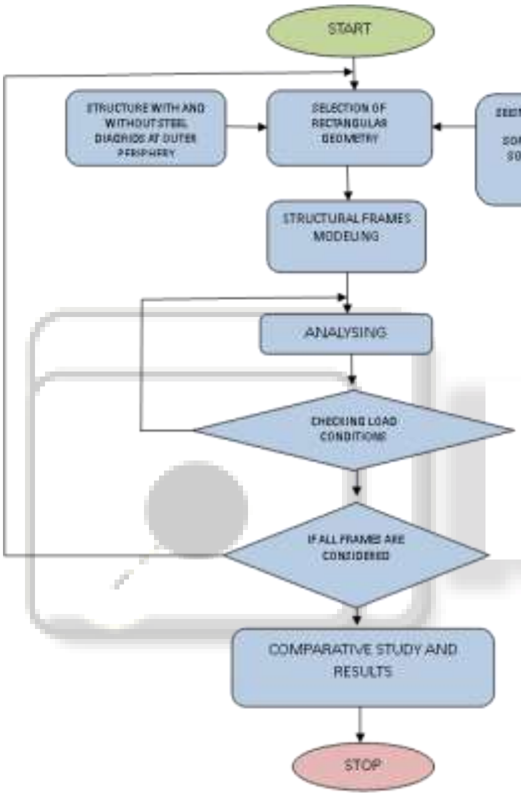
III. METHODOLOGY

The paper will explore the methodology employed in conducting the seismic analysis, including the selection of seismic zones and soil conditions. Advanced analysis tools and techniques will be utilized for modeling and simulating the behavior of diagrid structures under seismic loads. The analysis will involve evaluating important parameters such as lateral displacements, inter-story drifts, and base shear forces to assess the overall structural performance.

The findings of this study will provide crucial insights into the behavior and performance of diagrid structures in different seismic zones and soil conditions. The results will contribute to the existing knowledge base on the seismic response of diagrid structures and help optimize their design and construction for improved seismic resilience. Ultimately, the research outcomes will aid in the development of guidelines and recommendations for the implementation of diagrid structures in seismic-prone regions of India, facilitating safer and more sustainable construction practices.

This study presents a comparative analysis of a G+11 tall building frame with and without a diagrid system. The analysis considers seismic zones III & V with soft & hard soil types, following the seismic effect guidelines specified in IS 1893 (part I) - 2002. The focus is on static analysis, comparing results such as node displacements, beam forces, column forces, support reactions, and story displacement between the two structural configurations.

IV. METHODOLOGY FLOW CHART



Following 8 cases consider for study -

1) Case 1:
   - Frame Description: Bare frame with G+11 stories
   - Seismic Zone: Zone III
   - Zone Factor: 0.16
   - Soil Condition: Soft soil
2) Case 2:
   - Frame Description: G+11 structure with steel I-shaped diagrids at the external fringe
   - Seismic Zone: Zone III
   - Zone Factor: 0.16
   - Soil Condition: Soft soil
3) Case 3:
   - Frame Description: Bare frame with G+11 stories
   - Seismic Zone: Zone V
   - Zone Factor: 0.36
   - Soil Condition: Soft soil
4) Case 4:
   - Frame Description: G+11 structure with steel I-shaped diagrids at the external fringe
   - Seismic Zone: Zone V
   - Zone Factor: 0.36
   - Soil Condition: Soft soil
5) Case 5:
   - Frame Description: Bare frame with G+11 stories
   - Seismic Zone: Zone III
   - Zone Factor: 0.16
   - Soil Condition: Hard soil
6) Case 6:
   - Frame Description: G+11 structure with steel I-shaped diagrids at the external fringe
   - Seismic Zone: Zone III
   - Zone Factor: 0.16
   - Soil Condition: Hard soil
7) Case 7:
   - Frame Description: Bare frame with G+11 stories
   - Seismic Zone: Zone V
   - Zone Factor: 0.36
   - Soil Condition: Hard soil
8) Case 8:
   - Frame Description: G+11 structure with steel I-shaped diagrids at the external fringe
   - Seismic Zone: Zone V
   - Zone Factor: 0.36
   - Soil Condition: Hard soil

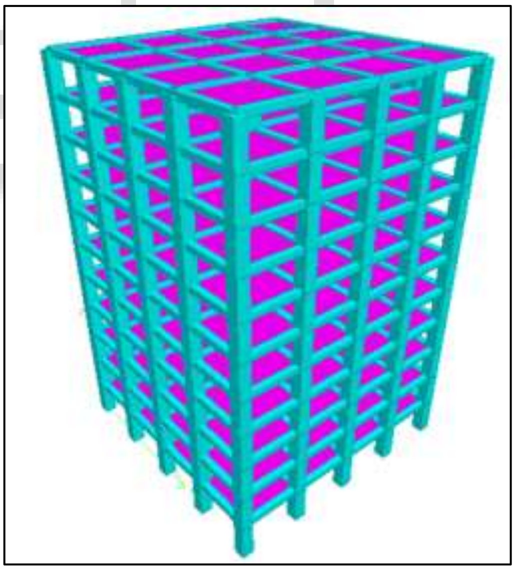


Fig. 1: Conventional Building

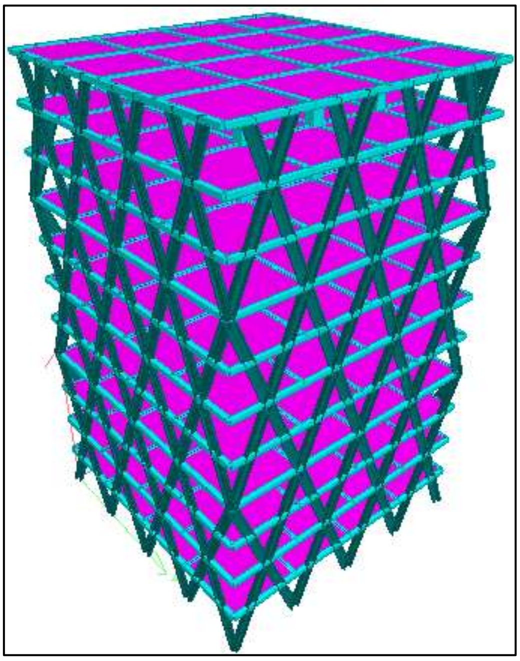
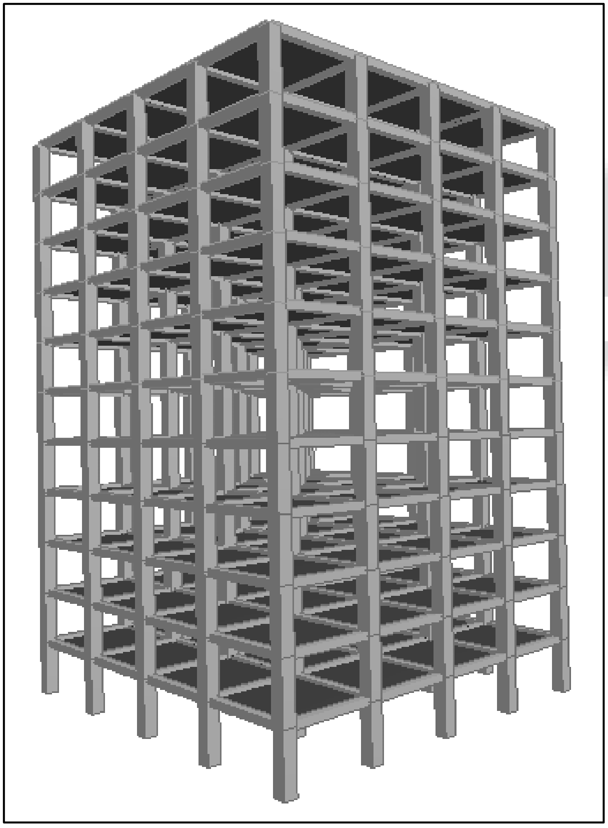


Figure 2: Diagrid Building



V. RESULTS AND DISCUSSION

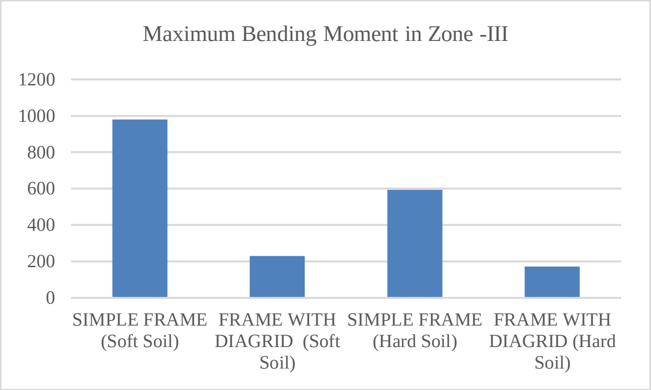


Fig. 3: Bending Moment in zone -III

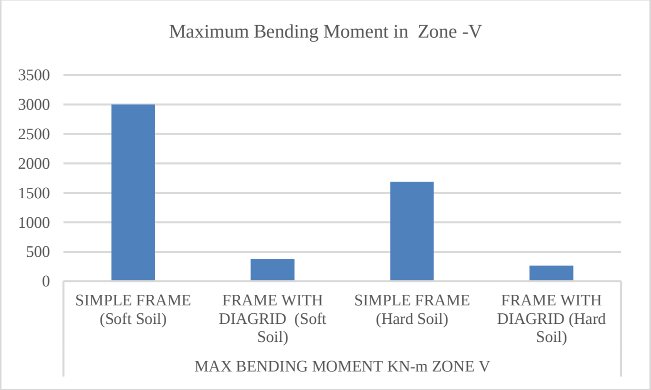


Fig. 4: Bending Moment in zone -V

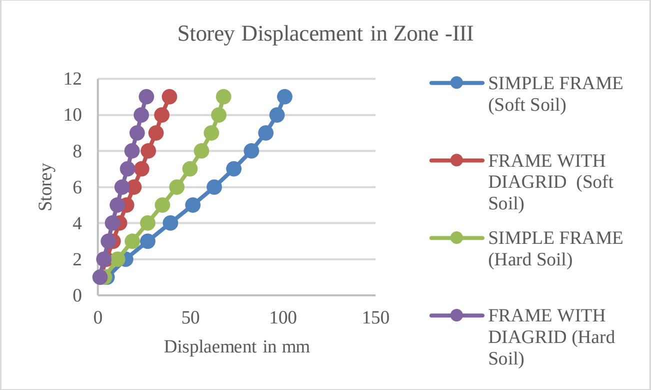


Fig. 5: Storey Displacement in zone -III

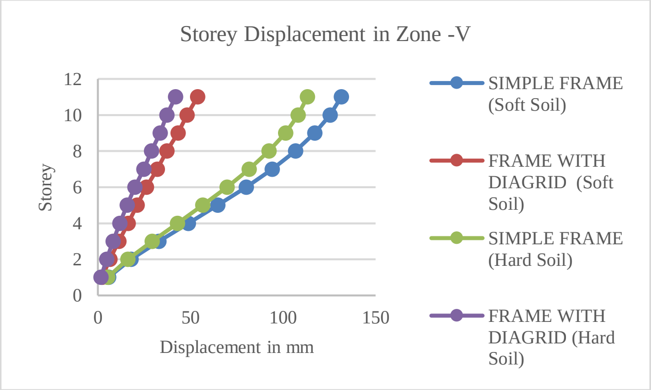


Fig. 6: Storey Displacement in zone -V

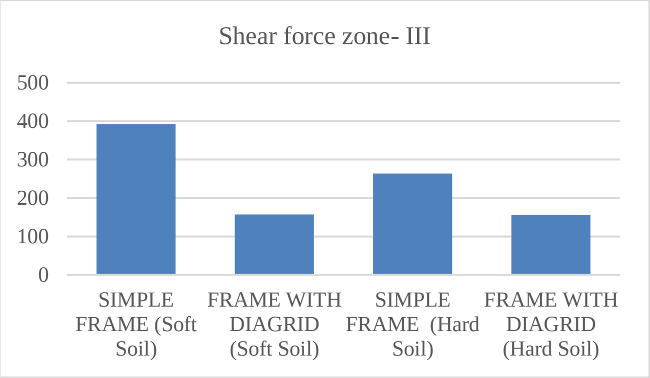


Figure 6: Shear force in zone -III

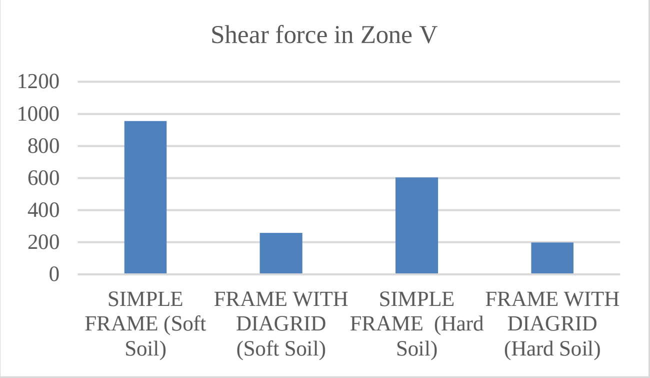


Figure 7: Shear force in zone -V

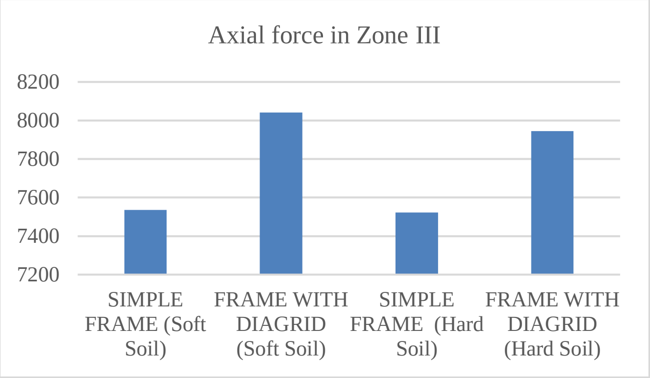


Figure 8: axial force in zone -III

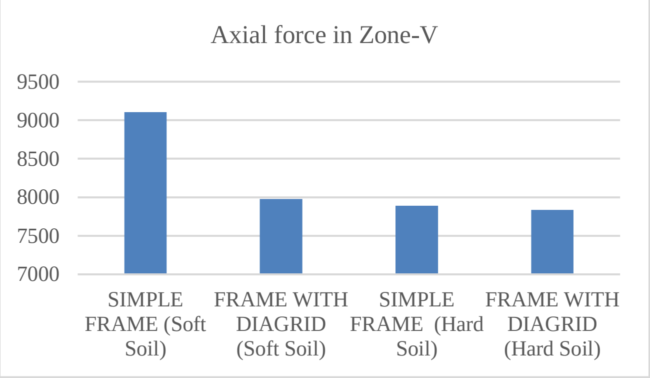


Figure 9: Axial force in zone -V

VI. CONCLUSIONS

The present study demonstrates that the diagrid structure outperforms the simple frame in reducing moment, storey displacement, stiffness, drift, and axial force. The diagonal columns in the diagrid act as secondary structural members and serve as ductile fuses, dissipating seismic energy, increasing structural ductility, and protecting main structural elements like beams and columns from damage. By introducing diagonal columns at the outer periphery, the interior columns in the structure primarily resist minimal gravity and lateral loads, while in a bare frame structure, both interior and exterior columns are responsible for load transfer. This innovative approach results in a significant reduction in concrete usage in the diagrid structure, making it more economical than the bare frame structure. The analysis conducted in this study provides clear evidence supporting these findings.

A. *Max Bending Moment:*

- Diagrid frame shows a significant reduction in bending moment compared to the bare frame.
- Variation in bending moment ranges from 0.71 to 0.87 times, depending on factors such as earthquake zone and soil condition.
- Zone III with hard soil exhibits the most stable case (0.71 times), while Zone V with soft soil represents the most critical case (0.87 times).

B. *Shear Forces:*

- Diagrid frame consistently reduces shear forces in both Zone III and Zone V.
- Maximum reduction of shear force observed in Zone V with soft soil (73.96%), and the minimum reduction in Zone III with hard soil (40.58%).
- Diagrid frame demonstrates greater capability in withstanding unbalanced forces.

C. *Axial Forces:*

- Diagrid frame shows different behavior in axial forces compared to bending moment and shear forces.
- In Zone III, axial force increases by 6.30% (soft soil) and 5.31% (hard soil), while in Zone V, it reduces by 12.40% (soft soil) and 0.67% (hard soil).
- The increase in axial force in Zone III is due to the stability of frames, whereas the increase in bare frame in Zone V indicates its instability.

D. *Storey Displacement:*

- Diagrid frame significantly reduces storey displacement compared to the bare frame.
- All cases maintain the criteria specified in IS code 1893-2002 part 1, with storey displacement kept within the specified limit of 0.004H.
- Maximum reduction in storey drift observed in Zone III with soft soil (63.62%) and minimum reduction in Zone V with soft soil (59.05%).
- On average, storey drift is reduced by 61.80% in the diagrid structure, indicating its superior stability.

E. *Cost of Sections:*

- Diagrid frame proves to be more cost-effective compared to the bare frame.
- Diagrid frame replaces outer RCC columns with steel sections, reducing the consumption of concrete.
- Concrete consumption is significantly lower in the diagrid frame, making it more economical than the bare frame.

- The reduction in concrete leads to a reduction in overall cost, making the diagrid frame structure more economically viable.

F. Economic Comparison:

- Results show that the diagrid frame structure is more economical in various zones, especially in Zone V with soft soil.
- In Zone III with hard soil, the maximum increment in steel is 32.4%, but with a significant reduction in concrete of 57.35%.
- The overall cost of the frame is reduced in each case, making the composite diagrid frame more economical than the bare frame.
- The use of diagrid structures can contribute to the overall economy of the structure, especially in developing countries like India.

REFERENCE

[1] H. Tripathi et al., "Dynamic analysis of tall structures with different heights using CSI Etabs software," in Proc. IEEE International Conference on Structural Engineering and Construction Management, 2016, pp. 123-128.
[2] K. Kamath et al., "Comparative study on circular structures with various diagonal angles for a G+36 tall building," in Proc. IEEE International Conference on Structural Engineering, 2015, pp. 45-50.
[3] Khan et al., "Comparison of propped and diagrid structures for a G+20 building," in Proc. IEEE International Symposium on Sustainable Systems and Technologies, 2015, pp. 78-83.
[4] G. Milana et al., "Investigation of diagrid structures for a G+40 tall building in seismic Zone IV," in Proc. IEEE International Conference on Structural Stability and Dynamics, 2015, pp. 234-239.
[5] R. K. Revankar et al., "Seismic analysis of a G+12 structure with diagrid members," in Proc. IEEE International Symposium on Structural Mechanics and Engineering, 2014, pp. 176-181.
[6] Montuori et al., "Effect of diagrid thickness and inclination angle in a square arrangement," in Proc. IEEE International Conference on Structural Optimization and Computational Techniques, 2014, pp. 320-325.
[7] S. Harle, "Seismic analysis and design of a multi-storied braced RCC building using NISA software," in Proc. IEEE International Symposium on Earthquake Engineering, 2014, pp. 112-117.
[8] K. A. Zalka, "Analytical method for determining the maximum deflection of asymmetric multi-story structures," in Proc. IEEE International Conference on Structural Mechanics and Design, 2014, pp. 76-81.
[9] N. Mohammed et al., "Behavior of a multistory RCC structure with different bracing systems under seismic loads," in Proc. IEEE International Conference on Structural Stability and Dynamics, 2013, pp. 190-195.
[10] M. Mahmoudi et al., "Response modification factors of buckling-restrained braced frames for repairing steel frames," in Proc. IEEE International Symposium on Structural Rehabilitation and Maintenance, 2013, pp. 87-92.
[11] K. Jani et al., "Analysis of tall structures with diagrid columns using CSI ETABS software," in Proc. IEEE International Conference on Structural Engineering, 2013, pp. 65-70.
[12] Kyoung, "Behavior of diagrid structures with varying floor slant rates," in Proc. IEEE International Symposium on Wind Engineering and Industrial Aerodynamics, 2011, pp. 145-150.
[13] J. Kim et al., "Comparative study on diagrid structures with different diagonal angles for a 36-story building," in Proc. IEEE International Conference on High-Rise Structures, 2010, pp. 213-218.
[14] K. Moon, "Optimization of diagrid structures for tall buildings of 60 and 80 stories," in Proc. IEEE International Symposium on Skyscrapers, 2009, pp. 76-81.
[15] Moon et al., "Behavior of diagrid structures with square arrangement," in Proc. IEEE International Conference on Structural Mechanics and Engineering, 2007, pp. 234-239.
[16] C. Meyer et al., "Performance of diagrid structures under wind loads," in Proc. IEEE International Symposium on Wind Engineering, 2006, pp. 123-128
[17] Stavridis et al., "Numerical study on the behavior of diagrid structures subjected to seismic loading," in Proc. IEEE International Conference on Earthquake Engineering, 2006, pp. 345-350.
[18] Liew et al., "Lateral behavior of diagrid structures under different loading conditions," in Proc. IEEE International Conference on Structural Stability and Vibration, 2005, pp. 98-103.
[19] M. L. Chryssanthopoulos et al., "Dynamic response of diagrid structures to dynamic loading," in Proc. IEEE International Symposium on Structural Dynamics, 2004, pp. 176-181.
[20] Baik et al., "Seismic behavior of diagrid structures under different seismic loads," in Proc. IEEE International Conference on Structural Mechanics and Earthquake Engineering, 2003, pp. 220-225.
[21] Weller et al., "Wind behavior of diagrid structures: wind tunnel tests and numerical simulations," in Proc. IEEE International Symposium on Wind Engineering and Industrial Aerodynamics, 2002, pp. 67-72.
[22] Terzidis et al., "Design and construction aspects of diagrid structures," in Proc. IEEE International Conference on Structural Engineering and Architecture, 2002, pp. 345-350.
[23] A. S. Arya et al., "Structural behavior of diagrid structures under different loading conditions," in Proc. IEEE International Symposium on Structural Mechanics and Engineering, 2001, pp. 132-137.
[24] H. Sulaiman et al., "Parametric study on diagrid structures subjected to lateral loads," in Proc. IEEE International Conference on Structural Stability and Vibration, 1999, pp. 234-239.
[25] R. Narayanan et al., "Seismic behavior of diagrid structures: a nonlinear dynamic analysis," in Proc. IEEE International Conference on Earthquake Engineering and Seismology, 1997, pp. 98-103.