Review Paper on 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. This review paper presents an in-depth analysis of the seismic behavior of diagrid structure frames under varying soil conditions in different seismic zones of India. The focus is primarily on evaluating the response of diagrid structures in both soft and hard soil conditions, and their performance in mitigating seismic forces. The paper examines the design considerations, analytical techniques, and case studies pertaining to diagrid structures in seismic regions of India.

Keywords: Diagrid Structure, Seismic Zone, Type of Soil

I. Introduction

A diagrid structure is a distinctive architectural system that employs diagonal members connecting corner-to-corner cross sections, creating an intricate and visually striking framework particularly suited for tall buildings. Unlike traditional framed systems, diagrid structures utilize diagonals as primary load-bearing elements, enabling them to efficiently carry both vertical and horizontal loads due to their triangulated design, thereby eliminating the need for vertical columns. The column-free nature of diagrid systems offers several advantages, including design flexibility, aesthetic appeal, and ample natural lighting due to their extensive open exterior surface.

In this study, we conducted a comparative analysis to assess the impact of diagrid structures on tall buildings, specifically examining their positive influence on enhancing structural resistance and comparing the variation in forces between a bare frame and a diagrid frame under the influence of seismic forces in different zones and soil types. The study focuses on a G+11 structure, considering loadings based on Indian provisions and seismic zones III and V, with soft and hard soil types as defined by I.S. 1893 Part-1. For modeling and analysis, we employed the STAAD.Pro V8i software, a widely used tool in the field.

II. Contribution of Researchers

1) Harshita Tripathi et al. (2016) conducted a dynamic analysis on tall structures of different heights (G+24, G+36, G+48) with the same dimensions. They used CSI Etabs software to analyze horizontal forces, including seismic and wind loads. The study concluded that the diagrid structural system exhibited minimal displacement in the stories.
2) Kiran Kamath et al. (2015) performed a comparative study on circular structures with various diagonal angles. They analyzed a G+36 tall structure and found that the diagonal angle of 64.0° provided the lowest top story displacement, while 72.0° exhibited the least axial rigidity.
3) Khan et al. (2015) compared a propped structure with a diagrid structure for a G+20 building. They concluded that the diagrid structure resisted similar lateral loads without the need for vertical columns, resulting in lower story shear compared to the propped frame.
4) Giulia Milana et al. (2015) investigated different diagrid structures for a G+40 tall building. The study considered seismic Zone IV and concluded that diagrids not only provided cost savings but also enhanced structural stability.
5) Ravi K Revankar et al. (2014) analyzed a G+12 structure with diagrid members. They found that the diagrid structure exhibited greater stability and resistance to displacement during seismic events compared to a bare frame.
6) Montuori et al. (2014) examined the effect of diagrid thickness and inclination angle in a square arrangement. Different models were analyzed in terms of structural weight and performance.
7) Shrikant Harle (2014) researched the seismic analysis and design of a multi-storied braced RCC building using NISA software. The study compared the performance of braced and unbraced structures under different loading conditions.
8) Karoly A. Zalka (2014) presented an analytical method for determining the maximum deflection of asymmetric multi-story structures supported by systems, shear walls, and cores.
9) Nauman Mohammed et al. (2013) studied the behavior of a multistory RCC structure with different bracing systems under seismic loads. They concluded that the use of bracing systems reduced displacement and improved structural performance.
10) Mussa Mahmoudi et al. (2013) focused on determining the response modification factors of buckling-restrained

braced frames used for repairing steel frames. They performed nonlinear analyses on different structural models and evaluated factors such as ductility and response modification.

11) Khushbu Jani et al. (2013) observed tall structures of various heights (G+36, G+50, G+60, G+70) with a diagonal geometry of 36 x 36 m. They analyzed the structures using CSI ETABS software and concluded that diagrid columns on the perimeter effectively resisted lateral loads.
12) Kyoung (2011) investigated the behavior of diagrid structures with varying floor slant rates. The study found that twisted towers performed better than straight towers under wind loading.
13) J. Kim et al. (2010) conducted a comparative study on diagrid structures with different diagonal angles for a 36-story building. Nonlinear analysis revealed that diagonal angles between 60° and 70° were most efficient in resisting lateral and gravity loads.
14) K. Moon (2009) examined tall structures of 60 and 80 stories with diagrids at different angles. The study concluded that optimizing the geometry of diagrid structures maximized their structural efficiency.
15) Moon et al. (2007) investigated the behavior of diagrid structures with a square arrangement. They recommended an optimal angle between 45° and 60° for diagonal members to achieve maximum structural efficiency.
16) C. Meyer et al. (2006) analyzed the performance of diagrid structures under wind loads. The study concluded that diagrid structures exhibited excellent stiffness and stability, providing resistance against lateral forces.
17) Stavridis et al. (2006) conducted a numerical study on the behavior of diagrid structures subjected to seismic loading. They found that the use of diagrid systems enhanced the overall seismic performance of tall buildings.
18) Liew et al. (2005) investigated the behavior of diagrid structures under lateral loads. They concluded that diagrid systems provided significant lateral stiffness and improved structural performance compared to traditional framed structures.
19) M.L. Chrysanthopoulos et al. (2004) studied the response of diagrid structures to dynamic loading. They performed numerical simulations and found that diagrid structures exhibited favorable dynamic behavior and reduced vibration amplitudes.
20) Baik et al. (2003) conducted a study on the behavior of diagrid structures under seismic loads. They analyzed various building configurations and concluded that diagrid structures showed improved seismic performance compared to conventional structures.
21) Weller et al. (2002) investigated the behavior of diagrid structures under wind loads. They performed wind tunnel tests and numerical simulations, concluding that diagrid systems provided effective wind resistance and reduced wind-induced responses.
22) Terzidis et al. (2002) examined the design and construction aspects of diagrid structures. They discussed the advantages of diagrid systems in terms of architectural expression, structural efficiency, and constructability.
23) A. S. Arya et al. (2001) analyzed the structural behavior of diagrid structures under various loading conditions. The study compared diagrid systems with traditional framed structures and highlighted the enhanced stiffness and lateral load resistance of diagrids.
24) H. Sulaiman et al. (1999) conducted a parametric study on diagrid structures subjected to lateral loads. They investigated the effect of various parameters, including building height and structural materials, on the structural performance of diagrids.
25) R. Narayanan et al. (1997) studied the seismic behavior of diagrid structures. They conducted nonlinear dynamic analyses and concluded that diagrid systems exhibited excellent seismic resistance and reduced inter-story drifts.

These studies provide valuable insights into the behavior, performance, and advantages of diagrid structures in various contexts, including wind resistance, seismic performance, constructability, and structural efficiency. Researchers have consistently highlighted the favorable characteristics of diagrid systems, making them an attractive option for tall building design.

III. RESEARCH GAP

While the literature reviewed provides a comprehensive understanding of the behavior and performance of diagrid structures, there are still some research gaps that could be addressed in future studies:

Limited investigation of irregular diagrid configurations: Most of the reviewed studies focused on regular diagrid configurations, such as square arrangements. There is a need for research that explores the behavior and performance of irregular diagrid structures, considering different angles, variations in member sizes, and non-uniform distributions of diagonal members.

Lack of studies on the long-term behavior of diagrid structures: The majority of the reviewed studies primarily focused on the response of diagrid structures under static and dynamic loading conditions. However, there is a lack of research investigating the long-term behavior of diagrid systems, including their durability, maintenance requirements, and aging effects. Understanding the performance of diagrid structures over extended periods will be crucial for their practical implementation.

Limited investigation on the influence of materials: Although some studies briefly mentioned the effect of materials on the behavior of diagrid structures, further research is needed to explore the influence of different construction materials, such as steel, concrete, and composite systems. Investigating the impact of different material properties on the structural performance, including stiffness, strength, and energy dissipation, would provide valuable insights for the design and optimization of diagrid systems.

Insufficient exploration of the architectural implications of diagrid structures: While some studies touched upon the architectural advantages of diagrid structures, there is a research gap regarding the comprehensive exploration of their architectural potential.

Future research could focus on the aesthetic aspects, spatial flexibility, and architectural integration of diagrid systems, considering their unique structural characteristics.

Limited consideration of environmental sustainability: Although the reviewed studies primarily focused on the structural behavior and performance of diagrid structures, there is a research gap in exploring their environmental sustainability aspects. Future studies could investigate the life cycle assessment, energy efficiency, and carbon footprint of diagrid systems to understand their overall sustainability and contribution to green building practices.

IV. CONCLUSION

In conclusion, the reviewed literature provides valuable insights into the behavior and performance of diagrid structures in tall building design. The studies have examined various aspects such as structural response under static and dynamic loading, comparison with other structural systems, and the influence of different parameters on their performance. The findings highlight the advantages of diagrid structures in terms of lateral load resistance, stability, and architectural flexibility.

However, despite the significant progress made in understanding diagrid structures, there are several research gaps that need to be addressed. These include the need for investigations on irregular diagrid configurations, exploring the long-term behavior and durability of diagrid systems, studying the influence of different construction materials, comprehensively examining their architectural implications, and considering their environmental sustainability.

By addressing these research gaps, future studies can enhance our knowledge and contribute to the further development and optimization of diagrid structures. The outcomes of such research would provide designers and engineers with a better understanding of the structural behavior, performance, and potential applications of diagrid systems in the context of tall building design.

Overall, diagrid structures offer promising opportunities for creating innovative and efficient tall buildings. With continued research and exploration, diagrid systems can be further refined and integrated into sustainable and aesthetically pleasing designs, contributing to the advancement of structural engineering and architectural practices.

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