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# Review paper on Optimization of steel diagrid systems for lateral load resistance under seismic and wind conditions

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**Abstract**

The diagrid structural system represents one of the most advanced and efficient structural innovations in the domain of modern high-rise construction. The term diagrid is derived from the words diagonal and grid, describing a triangulated network of diagonal members that work together to resist gravity as well as lateral loads such as wind and earthquake forces. The diagrid framework forms a rigid external skeleton that eliminates the necessity for traditional vertical columns and external shear walls, making it structurally efficient and architecturally distinctive.
Unlike conventional rigid frame or tube system where beams and columns primarily resist lateral forces through bending the diagrid system relies primarily on axial tension and compression in its diagonally arranged members. This shift from flexural to axial load behavior greatly enhances the material efficiency and overall stiffness of the structure. As a result, diagrid systems can achieve the same or higher lateral resistance with 20–30% less steel consumption compared to equivalent conventional systems.

## INTRODUCTION

The essence of the diagrid lies in its triangular geometry, which forms a self-stabilizing configuration. Each triangular module acts as a rigid truss element, effectively carrying shear, bending moment, and torsional forces through its diagonals. This triangulated action distributes lateral loads evenly to the ground, reducing inter-Storey drift and structural deformation. In addition, the three-dimensional stiffness generated by the diagonal grid mitigates the torsional effects commonly observed in tall buildings subjected to asymmetric loading or wind vortices.

From a mechanical perspective, diagrid systems work on the principle of triangulation. In a conventional rectangular frame, lateral loads cause significant bending in vertical columns and horizontal beams. However, in a diagrid structure, the diagonals form triangles that transform lateral forces into axial forces, thereby reducing bending moments and enabling the structure to resist higher loads with less material. The axial nature of forces also improves the performance of steel members, since steel exhibits excellent behavior under both tension and compression.

### Structural Configuration

In a typical diagrid system, diagonal members are arranged in a regular pattern along the building's façade, intersecting at node points that define triangular modules. These modules may vary in height depending on the design intent and the required stiffness. Common diagrid angles range from 60° to 75° to the horizontal, providing an optimal balance between vertical load transfer and lateral stiffness.

*Fig 1: Diagrid Structural System*

**Advantages of Diagrid Structures**

The diagrid system offers a combination of engineering efficiency, aesthetic freedom, and economic benefits, making it a preferred choice for contemporary high-rise construction. The key advantages are elaborated as follows:

(a) High Structural Efficiency

The triangular geometry of diagrids forms a highly stable and redundant structural system. Because the members carry loads primarily through axial action, the stiffness-to-weight ratio is significantly higher than in conventional framed systems. The diagrid's triangulated configuration reduces lateral displacement, inter-storey drift, and overall deflection under wind or seismic excitation.

In practical applications, the diagrid system achieves a higher load-carrying capacity and enhanced stiffness for the same or lesser material usage. This efficiency makes it ideal for super-tall buildings where lateral deflection and dynamic response are the governing design factors.

(b) Material Optimization

Since diagrid members are primarily loaded axially, the system allows for optimal use of structural steel. Studies (Moon, 2007; Kwon & Kim, 2015) have demonstrated that diagrid structures can reduce steel consumption by up to 25% compared to equivalent rigid frame structures. This optimization not only reduces cost but also lowers the structure's dead weight, which further decreases seismic base shear. Material efficiency also translates to sustainability benefits, as reduced material use directly lowers the embodied carbon footprint of the building.

(c) Architectural Flexibility

The diagrid system's external configuration eliminates the need for interior columns, enabling large open floor spaces that are highly desirable in commercial, residential, and institutional buildings. The façade-integrated diagrid provides structural strength while freeing the interior from structural constraints, allowing architects to design flexible layouts and panoramic views without obstruction.

In addition, the geometry of the diagrid can be manipulated to produce curvilinear, twisting, or tapering forms, giving designers freedom to create distinctive and aerodynamic building shapes that are both functional and expressive.

(d) Sustainability

Diagrid systems align well with modern sustainability goals. The reduction in material consumption directly contributes to lower greenhouse gas emissions. Furthermore, diagrid frameworks facilitate prefabrication and modular construction, leading to less on-site waste and faster erection times. The use of high-strength steel in optimized configurations also enhances the durability and recyclability of the structure.

**Need for Optimization**

Steel diagrid systems are highly efficient structural configurations, but their performance and economy depend heavily on proper design and optimization. Optimization is the process of adjusting key design parameters to achieve maximum structural efficiency while minimizing material usage and cost. Without careful optimization, a diagrid system may be overdesigned, leading to excessive steel consumption, higher construction costs, and potentially inefficient architectural layouts.

**Importance of Optimization**

The need for optimization arises from the interplay between structural performance, architectural form, and economy:

Structural Performance: Optimized diagrids ensure that axial forces, bending moments, and inter-story drifts are distributed efficiently across the structure. Properly designed diagonals can reduce lateral displacements and base shear, improving stability during wind and seismic events.

Architectural Aesthetics: Diagrids are often exposed on the exterior of buildings, making their geometry a key part of the architectural expression. Optimization ensures that the structural system supports creative forms without compromising performance.

Economy: Overdesigned members increase steel tonnage unnecessarily, raising material costs and labor expenses. Optimizing member sizes and geometry reduces costs while maintaining safety and serviceability.

**Aim**

- To evaluate and compare the seismic

performance of different steel lateral load-resisting systems for medium-rise buildings using the latest IS 18168:2023 design code.
- To identify the most efficient steel structural system in terms of stiffness, ductility, and energy dissipation for safe and economical design.

**Objectives**
- To develop and analyze G+4 steel building models with Special Moment Resisting Frame (SMRF), Special Concentrically Braced Frame (SCBF), and Eccentrically Braced Frame (EBF) under seismic loading using modern analytical tools like ETABS.
- To perform comparative evaluation of key seismic response parameters (base shear, storey drift, lateral displacement, fundamental period) and recommend the optimal system for medium-rise steel buildings in compliance with updated codes.

## LITERATURE REVIEW

### Rishi B. Mathuretal (2025)

The paper "Seismic Performance Analysis of Steel Building with Diverse Structural System: A Comparative Study" investigates the seismic behavior of steel buildings using three structural configurations Special Moment Resisting Frame (SMRF), Special Concentrically Braced Frame (SCBF), and Eccentrically Braced Frame (EBF) as per the new Indian Standard IS 18168:2023. A G+4 commercial building located in Seismic Zone IV was modeled in ETABS 2019, and the systems were compared based on base shear, storey drift, displacement, and time period. Results show that the EBF system exhibits the highest base shear and least displacement, indicating superior stiffness and energy dissipation capacity, while SMRF demonstrates the greatest flexibility with higher drift values. SCBF performs effectively in the direction of bracing but less so perpendicular to it. Overall, the study concludes that EBF offers the best seismic performance among the three systems, and the introduction of IS 18168:2023 significantly improves the ductile design and detailing of steel buildings in seismic regions.

### Magdy Alananietal (2025)

Tall buildings, over 60 m in height, are characteristic of modern urban cities and are expected to form a significant portion of future urban habitats. Given that the construction industry accounts for 38% of worldwide carbon emissions, targeting sustainability in this sector is vital. Due to the multi-dimensional nature of the tall building design process, optimization shows growing promise in developing solutions that increase design efficiency while sufficiently exploring design spaces and limiting computational costs. However, integrating architectural concepts with structural design to ensure that aesthetic goals are met without compromising structural integrity is challenging. Additionally, the critical dependency of lateral load magnitudes on a building's outer shape and structural details underscores the need for a holistic design approach to meet both serviceability and capacity requirements for highly tall and flexible structures. Characterized as dynamically sensitive structures, tall buildings require thorough consideration of wind and seismic loads, which exert a dominant influence on the structural system. This paper provides a roadmap for the structural optimization of tall buildings, focusing on wind loads, presenting a perspective on design parameters, algorithms, and modeling techniques, in addition to utilizing machine learning in various design stages. It also assesses the impact of different load types on the optimization process, the role of surrogate models in facilitating design frameworks, and innovative methods offering promising solutions surpassing current capabilities. Cumulatively, this paper addresses avenues for future research into optimization and tall building design.

### Ajisha T Tetal (2025)

This investigation focuses on the nonlinear time history analysis of outrigger braced-core steel frame high-rise structures. Rapid urban population growth and limited space have led to the inevitable development of high-rise buildings in the 21st century. The continuous advancement of such structures is particularly vital for the progress of developing countries like India. However, the design and construction of tall buildings pose significant challenges. As building height increases, structural stiffness and resistance to lateral forces become critical considerations. Wind and seismic forces are the predominant lateral loads affecting high-rise structures. Therefore, controlling lateral displacement and inter-story drift is a key design requirement. To resist lateral loads, various systems such as shear walls, diagrids, braced frames, and outriggers have been adopted over recent decades. In this study, the seismic performance of three 40-story steel braced-frame structures using outrigger systems is examined. A structure with two outriggers located at 1/3 and 2/3 of the total height, A structure with two outriggers and a belt truss at the same levels (1/3 and 2/3), and structure with two outriggers and a belt truss placed at mid-height and the top story. Nonlinear time history analysis is carried out for all models using SAP2000 v20 software.

**Mingfeng Huangetal (2025)**
Structural optimization, which includes element sizing and topology optimization, is an effective method for improving structural performance with the minimum structural costs. Performance-based wind engineering design framework for tall buildings has been proposed by considering multiple performance levels, e.g., life safety, immediate occupancy, operational, and motion perception. The research presented in this paper aims to develop an efficient structural topology and element sizing design optimization method for practical tall buildings in the framework of performance-based wind engineering. A computer system is developed to optimize structural member sizes and topology with the combination of genetic algorithm (GA) and the optimality criteria-particle swarm optimization (PSO) method (OC-PSO). GA is particularly useful for the global exploration of optimal topologies, while the OC-PSO technique acts as a local search operator, ensuring efficient element sizing optimization for specified topologies. A surrogate model based on the virtual work principle is proposed to predict the structural natural frequency and wind-induced drift so that the overall computation time of the optimization process can be reduced. In addition, this study addresses the optimization formulation of a complex structural system, including sizing optimization of concrete-filled steel tubes (CFST) and I-section members, as well as topological optimization of the shear wall layout and outrigger system. The applicability and efficiency of the proposed methodology were tested with two full-scale tall frame-core tube buildings. The results show that the proposed method is effective and efficient to generate an optimal solution satisfying multiple wind-induced performances for practical wind-sensitive tall building design.

**Xian-Lin Yangetal (2025)**
To the quantitative assessment of structural safety throughout the entire lifecycle and the achievement of performance-based seismic design, the multi-level life-cycle seismic reliability evaluation framework has been proposed, leveraging the time-discretization approach. It comprehensively accounts for performance degradation and quantifies life-cycle failure probabilities at different stages of its service life. The framework adopts a performance-based seismic design concept, conducting reliability assessments for structures at various seismic hazard levels and different performance levels. Moreover, given the complexity and high dimensionality of earthquake-resilient structural systems, an Adaptive Sampling Back propagation Neural Network (AS-BPNN) with Euclidean distance constraints has been introduced to enhance the accuracy and computational efficiency of failure probability. The global seismic reliability analyses of steel frame structures with replaceable connections were performed for the load-bearing capacity and deformation capacity. The results demonstrated that the impact of life-cycle effects on deformation capacity limit states is more pronounced than on load-bearing capacity. As the seismic hazard levels increase, the impact of life-cycle degradation on the deformation capacity limit state of earthquake-resilient steel frames becomes more evident. For earthquake-resilient steel frame structures that are more sensitive to deformations, the influence of life-cycle degradation on the seismic capacity of structures should be considered.

**Research Gap**
Although many studies have analyzed the seismic and wind performance of steel and tall buildings, few have compared different steel structural systems under the latest design code IS 18168:2023. Most research focuses on individual systems or single parameters instead of overall structural behavior and ductility. Hence, there is a need for a comparative study to understand the seismic performance and efficiency of various steel systems using updated codes and modern analysis tools.

**METHODOLOGY**
A diagrid structure typically comprises diagonal steel members forming a triangulated grid along the building façade. These diagonals are generally inclined between 60° and 75° to the horizontal, creating triangular modules that act as the primary lateral load-resisting system.
Key features of diagrid configuration:
Triangular modules: Triangular geometry provides inherent structural stability by efficiently distributing axial forces.
Load transfer path: Lateral loads (wind or seismic) are primarily carried through axial action in the diagonals, rather than bending in vertical columns.
Elimination of conventional columns: Reduces floor obstructions, allowing for open, flexible interior spaces.
Variation in geometry: The diagrid angle, spacing, and member diameter

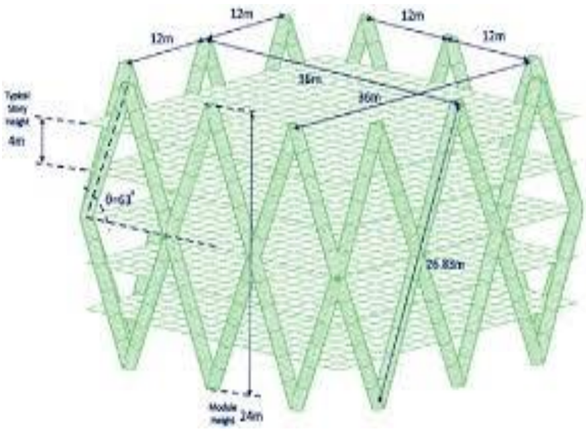


*Fig 2:* Schematic of Diagrid Structural System

*Governing Equations*

**Lateral Displacement**

The lateral displacement δ\deltaδ of a diagrid structure subjected to lateral force FFF can be approximated as:

δ= (f.H^3)/(12EI)

Where:

f = applied lateral force (kN)

H = building height (m)

E = modulus of elasticity of steel (Pa)

Ieq = equivalent moment of inertia of the diagrid system (m4)

**Seismic Base Shear**

For seismic analysis, the base shear Vb is calculated according to IS 1893:2016:

Vb= Ah·W

Where:

Ah = design horizontal seismic acceleration coefficient

W = seismic weight of the structure (kN)

The horizontal seismic coefficient Ah depends on zone factor, importance factor, building period, and soil type as defined in IS 1893.

**Seismic Base Shear**

The global stiffness of a diagrid structure is dominated by the axial rigidity of the diagonal members. Buckling of diagonals is critical and can be estimated using Euler's formula:

Pcr=(n^2 π^2 EI)/L^2

Where:

Pcr = critical buckling load of diagonal member (kN)

n = effective length factor (1 for pinned-pinned, 0.7 for fixed-pinned)

I= moment of inertia of the member (m4)

L = length of diagonal member (m)

**Design considerations:**

Optimizing the diagrid angle reduces axial load demand on individual members, minimizing the risk of buckling.

A well-designed diagrid improves redundancy, distributing lateral forces uniformly across multiple load paths.

**Wind and Seismic Load Modeling**

Wind Load

Wind load is modeled as per IS 875:2015 (Part The design wind pressure at height z is calculated as:

p_z=0.6V_z^2

Where:

Vz = design wind speed at height zzz (m/s)

The factor 0.6 includes air density and conversion factors to kN/m².

Wind analysis involves:

Static wind analysis for preliminary design.

Dynamic analysis for tall buildings to account for vortex shedding, turbulence, and dynamic amplification.

Modal analysis to determine fundamental mode shapes and natural periods.

**Seismic Load**

Seismic loads are modeled as per IS 1893:2016:

Base shear calculated using design horizontal acceleration.

Equivalent static analysis for low to medium-rise buildings.

Response spectrum or time-history analysis for taller buildings or irregular geometries.

Modal combination using SRSS or CQC methods to obtain total displacement and base shear.

**Combined Loading:**

Buildings are subjected to simultaneous wind and seismic loads, and the critical load combination is considered for design.

**CONCLUDING REMARK**

- A literature survey has been carried out to understand the existing research and identify knowledge gaps.
- The aim and objectives of the study have been clearly defined.
- The problem statement has been formulated based on the findings from the literature review.
- The research methodology has been outlined to guide the investigation effectively.
- A detailed research plan has been prepared to structure the overall study process.

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