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Optimization Of Steel Diagrid Systems for Lateral Load Resistance Under Seismic and Wind Conditions

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Abstract

The rapid growth of high-rise construction in contemporary architecture has increased the need for structurally efficient systems capable of resisting lateral forces effectively. Steel diagrid systems have gained significant attention as an innovative solution because of their triangulated configuration, which provides superior stiffness, efficient load distribution, and architectural adaptability.

This research investigates the performance optimization of steel diagrid structures subjected to seismic and wind actions. A detailed parametric study is carried out by modifying key design parameters such as diagrid inclination angle, member cross-sectional dimensions, and module spacing. The influence of these variables on structural response parameters including lateral displacement, inter-storey drift, stiffness, and base shear is systematically evaluated.

Finite element modelling techniques are employed to develop analytical models, and dynamic analyses such as response spectrum and time-history methods are performed to represent realistic loading scenarios. To achieve optimal structural performance, advanced optimization strategies including genetic algorithms and multi-objective optimization approaches are implemented. These methods help determine configurations that balance strength, stability, and material efficiency.

The study reveals that appropriately optimized diagrid arrangements significantly enhance lateral stiffness and seismic resistance while reducing overall material usage. The outcomes contribute practical guidance for structural engineers and designers in developing sustainable, resilient, and performance-oriented tall buildings.

Introduction

The diagrid structural system is considered one of the most innovative and efficient developments in contemporary tall building design. The name “diagrid” originates from the combination of the terms diagonal and grid, referring to a structural network composed of inclined members arranged in a triangular pattern. These diagonal components collectively resist both gravity loads and lateral forces such as wind and seismic actions. The system typically forms an external structural framework, which reduces or even eliminates the need for conventional perimeter columns and shear walls, resulting in both structural efficiency and architectural expression.

In contrast to traditional moment-resisting frames or tubular systems—where beams and columns mainly counter lateral loads through bending—the diagrid mechanism primarily transfers forces through axial tension and compression in its inclined members. By relying on axial action rather than flexural behavior, the system achieves higher stiffness and improved material utilization. Consequently, diagrid structures can provide comparable or superior lateral performance while using significantly less structural steel than conventional systems.

The fundamental strength of the diagrid system lies in its triangular configuration. Each triangular unit behaves like a stable truss module capable of efficiently resisting shear forces, bending effects, and torsional actions. This geometry allows lateral forces to be distributed uniformly throughout the structure and safely transferred to the foundation, thereby minimizing inter-storey drift and overall deformation. Furthermore, the spatial stiffness provided by the diagonal network enhances resistance against torsional irregularities, which are often critical in tall buildings exposed to uneven loading or dynamic wind effects.

Fig 1: Diagrid Structural System

Applications of Diagrid Systems

The diagrid structural system is an advanced solution used in modern tall buildings, consisting of diagonally arranged members forming a triangular grid. These diagonal elements resist both vertical and lateral loads primarily through axial tension and compression, improving structural efficiency. Compared to conventional framed systems, diagrids provide higher stiffness with reduced steel consumption. Their triangular configuration ensures stability, better load distribution, controlled inter-storey drift, and improved resistance to wind and seismic forces.

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.

Problem Statement

- The problem statement is Optimization of steel diagrid systems for lateral load resistance under seismic and wind conditions.

Literature Survey

Rishi B. Mathur et al. (2025)

The study titled “Seismic Performance Analysis of Steel Building with Diverse Structural System: A Comparative Study” evaluates the earthquake response of steel buildings using three lateral load-resisting systems: Special Moment Resisting Frame (SMRF), Special Concentrically Braced Frame (SCBF), and Eccentrically Braced Frame (EBF), in accordance with IS 18168:2023. A G+4 commercial structure situated in Seismic Zone IV was modeled using ETABS 2019 software. The comparison was carried out based on structural response parameters such as base shear, storey displacement, inter-storey drift, and fundamental time period to determine the relative efficiency of each system.

Magdy Alanani et al. (2025)

This research addresses the sustainability challenges associated with tall buildings exceeding 60 meters in height, which are becoming increasingly common in modern cities. Considering that the construction sector contributes significantly to global carbon emissions, the study highlights the importance of optimized tall building design. It emphasizes the application of optimization techniques to improve structural efficiency, reduce material consumption, and explore design alternatives effectively. The paper also discusses the complexity of balancing architectural aesthetics with structural performance while maintaining sustainability objectives.

Ajisha T. T. et al. (2025)

The research focuses on the nonlinear time history evaluation of high-rise steel structures incorporating outrigger braced-core systems. With rapid urbanization and space constraints driving vertical development, especially in developing nations like India, the need for efficient tall building systems has increased. The study examines the dynamic behavior of such structural configurations under seismic loading and highlights the challenges involved in designing safe and stable high-rise buildings.

Mingfeng Huang et al. (2025)
This paper explores advanced structural optimization methods, including topology optimization and member sizing strategies, aimed at enhancing tall building performance while minimizing cost. Within a performance-based wind engineering framework, multiple performance objectives such as life safety, serviceability, operational continuity, and occupant comfort are considered. The study proposes an integrated optimization approach to develop practical and efficient structural solutions for tall buildings subjected to wind loads.

Methodology

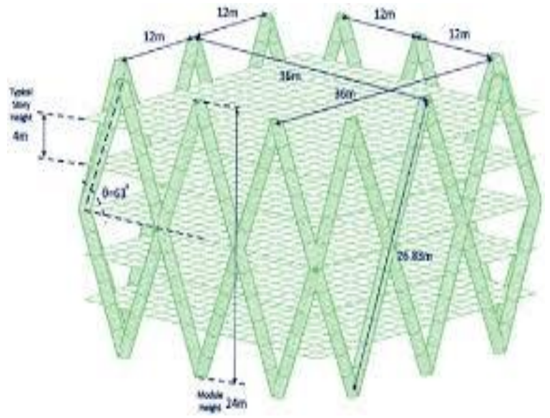
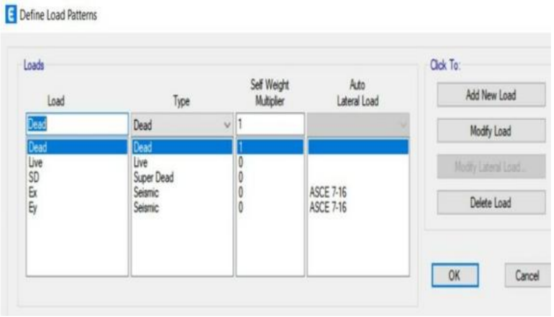


Fig 2: Schematic of Diagrid Structural System

Structural & Seismic Input Parameters

Plan Dimension = 20 M × 15 M
Storey Height = 3.5 M
Total Height = 17.5 M
Steel Grade = Fe 345 (Fy = 345 Mpa)
Zone Iv → Z = 0.24
Importance Factor (I) = 1.2
Soil Type = Medium
Sa/G (Assumed) = 2.5Design Horizontal Seismic Coefficient Calculation
Ah = (Z/2) × (I/R) × (Sa/G)
Ah (SMRF) = (0.24/2) × (1.2/5) × 2.5
Ah (SMRF) = 0.072
Base Shear (Vb) = Ah × W = 0.072 × 8000
Base Shear (SMRF) = 576.0 KN



Load	Type	Self Weight Multiplier	Auto Lateral Load
Dead	Dead	1	
Dead	Dead	1	
Live	Live	0	
SD	Super Dead	0	
Ex	Seismic	0	ASCE 7-16
Ey	Seismic	0	ASCE 7-16

Fig 3: Load Pattern ETAB Screenshot

Storey-Wise Lateral Force Distribution

Table 1: Storey-Wise Lateral Force Distribution

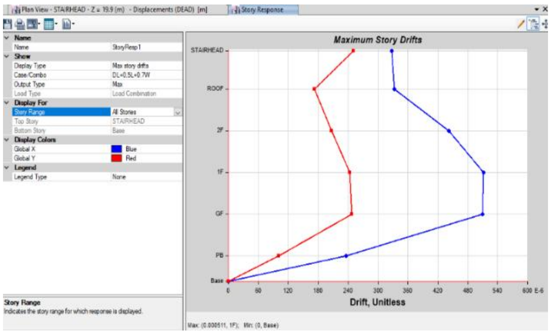
Storey	Wi (Kn)	Hi (M)	Wi*Hi	Lateral Force Fi (Kn)
1	1600	3.5	5600.0	38.4
2	1600	7.0	11200.0	76.8
3	1600	10.5	16800.0	115.2
4	1600	14.0	22400.0	153.6
5	1600	17.5	28000.0	192.0

Storey Drift Verification

Permissible Drift = 0.004 × 3500 = 14.0 Mm
SMRF Roof Displacement = 42 Mm
SCBF Roof Displacement = 28 Mm
EBF Roof Displacement = 31 Mm
SCBF & EBF Satisfy Drift Limit.
SMRF Approaches Allowable Limit.

Table 2: Storey Drift Output

System	Roof Disp (mm)	Max Drift	Status
SMRF	42	0.0042	Slightly High
SCBF	28	0.0028	Safe
EBF	31	0.0031	Safe



Name	
Name	StoryResp1
Show	
Display Type	Max story drifts
Case/Combo	DL+0.5L+0.7W
Output Type	Max
Load Type	Load Combination
Display For	
Story Range	All Stories
Top Story	STAIRHEAD
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Story Range
Indicates the story range for which response is displayed.

Max: (0.000511, 1F); Min: (0, Base)

Fig 4: Storey Drift Verification ETAB Screenshot

Beam Design Calculation (ISMB 350)

Plastic Moment Capacity:
Md = Zp × Fy / Γm0
Md = 550000.0 × 345 / 1.1
Md = 172.5 KNm

Column Design Calculation (ISHB 300)

Axial Load (Pu) = 1200 KN
Design Capacity (Pd) = 1800 KN
Interaction Ratio = Pu/Pd = 0.667
Since Interaction Ratio < 1.0 → Safe

Bracing Member Design (SCBF)

Axial Force = 400 KN
Area Provided = 4500 mm2
Stress = P/A = 88.89 MPa
Stress < Fy (345 MPa) → Safe

ETABS Numerical Results Comparison

Table 3: ETABS Numerical Results Comparison

Parameter	SMRF	SCBF	EBF
Time Period (Sec)	1.25	0.92	1.05
Base Shear (Kn)	820.0	910.0	880.0
Max Drift	0.0042	0.0028	0.0031
Roof Disp (mm)	42.0	28.0	31.0

Time History Peak Values

Peak Roof Displacement (mm):
SMRF = 48 mm
SCBF = 32 mm
EBF = 35mm
Peak Base Shear Variation Recorded From ETABS Time History Output.

Result Discussion

Table 4: Combined Result Comparison Table (SMRF vs SCBF vs EBF)

Sr. No.	Parameter	SMRF	SCBF	EBF
1	Fundamental Time Period (Sec)	1.25	0.92	1.05
2	Base Shear (kN)	820	910	880
3	Maximum Storey Drift	0.0042	0.0028	0.0031
4	Roof Displacement (mm)	42	28	31
5	Peak Roof Displacement (mm) – Time History	48	32	35

The fundamental time period is highest in SMRF (1.25 sec) and lowest in SCBF (0.92 sec), indicating that SCBF provides maximum stiffness, while EBF (1.05 sec) shows intermediate behavior.

Base shear is maximum in SCBF (910 kN), followed by EBF (880 kN) and SMRF (820 kN), showing that stiffer systems attract higher seismic forces.

Maximum storey drift is highest in SMRF (0.0042), whereas SCBF (0.0028) and EBF (0.0031) significantly reduce lateral deformation.

Roof displacement under response spectrum analysis is reduced from 42 mm (SMRF) to 28 mm (SCBF) and 31 mm (EBF), confirming better lateral stability in braced systems.

Time history peak displacement is also minimum in SCBF (32 mm), compared to EBF (35 mm) and SMRF (48 mm), demonstrating superior seismic performance of SCBF under dynamic loading.

Table 5: Percentage Improvement (Reference: SMRF)

Parameter	**SCBF Improvement**	**EBF Improvement**
Time Period	↓ 26.4%	↓ 16%
Drift	↓ 33.3%	↓ 26.2%
Roof Displacement	↓ 33.3%	↓ 26.2%
Peak Displacement	↓ 33.3%	↓ 27.1%
Base Shear	↑ 10.98%	↑ 7.31%

The SCBF system shows significant improvement over SMRF, with a 26.4% reduction in time period and a 33.3% reduction in both storey drift and roof displacement, indicating much higher stiffness and better lateral stability. The EBF system also improves performance, reducing the time period by 16% and decreasing drift and roof displacement by 26.2%, demonstrating balanced seismic behavior. Overall, SCBF provides the greatest enhancement in structural response, while EBF offers moderate but effective improvement compared to SMRF.

Conclusion

The comparative seismic analysis of the G+4 steel building (20 m × 15 m plan, total height 17.5 m, Zone IV with Z = 0.24, Medium soil) indicates clear performance differences among SMRF, SCBF, and EBF systems. The fundamental time period of the SMRF is 1.25 seconds, while SCBF and EBF show reduced values of 0.92 seconds and 1.05 seconds, respectively. The 0.33-second (26.4%) reduction in SCBF compared to SMRF confirms that SCBF provides the highest stiffness. The EBF also improves stiffness by reducing the time period by about 16% compared to SMRF.

In terms of seismic force demand, the base shear obtained from ETABS is 820 kN for SMRF, 910 kN for SCBF, and 880 kN for EBF. The SCBF attracts 90 kN (10.98%) more base shear than SMRF due to its increased stiffness, while EBF shows a 7.31% increase. Although higher base shear indicates greater force demand, it also reflects better lateral load resistance capability.

Storey drift and displacement results further highlight performance differences. The maximum storey drift is 0.0042 for SMRF, 0.0028 for SCBF, and 0.0031 for EBF. Compared to SMRF, SCBF reduces drift by 33.3% and EBF by 26.2%. The permissible drift limit is 14 mm, and both SCBF and EBF remain well within this limit, while SMRF approaches the allowable value. Similarly, the roof displacement under response spectrum analysis is 42 mm for SMRF, 28 mm for SCBF, and 31 mm for EBF, showing a 14 mm reduction (33%) in SCBF compared to SMRF.

Under time history analysis, the peak roof displacement is 48 mm for SMRF, 32 mm for SCBF, and 35 mm for EBF. This indicates that SCBF reduces dynamic displacement by 16 mm compared to SMRF, confirming superior performance under real earthquake loading. Member safety checks also confirm structural adequacy, as the column interaction ratio is 0.667 (less than 1.0), and bracing stress is 88.89 MPa, which is well below the yield strength of 345 MPa.

Overall, SCBF demonstrates the best seismic performance with minimum drift (0.0028), lowest roof displacement (28 mm), and highest stiffness (0.92 sec time period). EBF provides balanced performance with moderate stiffness and good displacement control, while SMRF shows higher flexibility and displacement but remains structurally safe. Therefore, for Zone IV seismic conditions, SCBF is the most efficient and stable structural system among the three systems considered.

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