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Shape and Angle Optimization of Diagrid Structures for Enhanced Seismic Resilience

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ABSTRACT

Diagrid structural systems have emerged as innovative solutions combining architectural aesthetics with structural efficiency in modern tall building construction. This research investigates the optimization of diagrid angles across various building geometries under seismic loading conditions through comprehensive dynamic analysis. The study examines diagrid systems with angles ranging from 45° to 75° in rectangular, circular, and L-shaped building configurations using finite element modeling and nonlinear time-history analysis.
The research methodology employs ETABS and SAP2000 software for structural modeling and analysis, utilizing a set of ground motion records representative of high seismic zones. Performance parameters including inter-story drift, base shear, displacement response, and energy dissipation capacity are evaluated for 24 different diagrid configurations. Results demonstrate that optimal diagrid angles vary significantly with building geometry and height, with rectangular buildings performing best at 65-70°, circular configurations at 60-65°, and L-shaped structures requiring variable angles ranging from 55-70° depending on structural height. The study reveals that properly optimized diagrid angles can reduce peak inter-story drift by up to 35% and increase energy dissipation capacity by 45% compared to non-optimized configurations. These findings provide essential guidance for practicing engineers in selecting appropriate diagrid angles for seismic-resistant design across different building geometries.

KEYWORDS: Diagrid Structures, Seismic Optimization, Structural Dynamics, Tall Buildings, Nonlinear Analysis, Building Geometry, Earthquake Engineering

INTRODUCTION

The evolution of urban architecture has witnessed remarkable transformation in structural systems, particularly with the emergence of diagrid frameworks that challenge conventional building design paradigms. Diagrid structures, characterized by their distinctive diagonal grid pattern, represent a revolutionary approach to tall building construction that seamlessly integrates structural efficiency with architectural innovation. These systems have gained prominence due to their ability to resist lateral forces through axial action of diagonal members rather than relying solely on bending resistance of conventional frame systems.

The fundamental concept underlying diagrid systems stems from the principle of triangular geometry, which provides inherent structural stability and optimal load distribution. Unlike traditional building systems that depend on vertical columns and horizontal beams, diagrid structures utilize inclined diagonal members that carry both gravity and lateral loads through primarily axial forces. This characteristic enables significant material savings while achieving superior structural performance under various loading conditions.

Recent seismic events worldwide have highlighted the critical importance of understanding structural behavior under dynamic loading, particularly for innovative systems like diagrids. The 2011 Tohoku earthquake in Japan and subsequent seismic events have demonstrated that structural systems must be thoroughly evaluated for their seismic performance characteristics. While diagrid systems show promising structural efficiency, their relatively recent introduction to mainstream construction requires comprehensive investigation of their seismic behavior, especially regarding the optimization of key design parameters such as diagonal angles.

The diagonal angle in diagrid systems serves as a fundamental design parameter that significantly influences

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structural performance. Previous research has indicated that diagonal angles typically ranging from 60° to 70° provide optimal balance between lateral stiffness and material efficiency. However, these findings are primarily based on static analysis or limited dynamic studies, leaving substantial gaps in understanding how different building geometries and seismic conditions affect optimal angle selection.

Building geometry plays a crucial role in structural response under seismic loading. Rectangular, circular, and irregular-shaped buildings exhibit distinctly different dynamic characteristics, torsional responses, and failure mechanisms during earthquakes. The interaction between building geometry and diagrid angle optimization represents an underexplored area requiring systematic investigation to develop comprehensive design guidelines.

Current design codes and standards provide limited guidance for diagrid systems, particularly regarding seismic design parameters. The response modification factor (R-factor) for diagrid structures varies significantly in existing literature, with values ranging from 1.5 to 4.0 depending on diagonal angles and structural configuration. This variability underscores the need for systematic research to establish reliable design parameters for different diagrid configurations.

The research gap identified through literature review reveals insufficient understanding of how diagrid angle optimization varies across different building geometries under seismic loading. Most existing studies focus on rectangular building configurations with limited consideration of circular or irregular-shaped structures. Additionally, the interaction between building height, geometry, and optimal diagrid angle remains inadequately explored, particularly through comprehensive nonlinear dynamic analysis.

The primary research question addressed in this study is: How do optimal diagrid angles vary across different building geometries (rectangular, circular, and L-shaped) under seismic loading conditions, and what performance improvements can be achieved through systematic angle optimization? Secondary questions include: What are the relationships between building height, geometry, and optimal diagrid angles? How do different diagrid angles affect energy dissipation mechanisms and failure modes in various building configurations?

This research contributes to the structural engineering field by providing comprehensive guidelines for diagrid angle selection across different building geometries, establishing performance benchmarks for seismic design of diagrid structures, and developing optimization methodologies that can be applied by practicing engineers. The study's significance extends to both academic understanding of diagrid behavior and practical application in earthquake-resistant design of modern tall buildings.

The subsequent sections of this paper present the research objectives, scope definition, comprehensive literature review, detailed methodology, analysis of both secondary and primary data, discussion of findings, and conclusions with recommendations for future research and practical application.

OBJECTIVES

The primary and secondary objectives of this research are structured to provide comprehensive understanding of diagrid angle optimization across different building geometries under seismic conditions:

- **Primary Objective:**
    - To determine optimal diagrid angles for rectangular, circular, and L-shaped building configurations through systematic dynamic analysis under seismic loading conditions, establishing performance-based design guidelines that minimize structural response while maximizing energy dissipation capacity.

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- **Secondary Objectives:**
  - To evaluate the relationship between building geometry, structural height, and optimal diagrid angle selection through parametric analysis of 24 different structural configurations ranging from 12 to 36 stories.

- To quantify performance improvements achieved through angle optimization by comparing inter-story drift, base shear, displacement response, and energy dissipation characteristics between optimized and non-optimized diagrid configurations.
- To develop practical design recommendations for practicing engineers by establishing optimal angle ranges for different building geometries and height categories, validated through nonlinear time-history analysis using representative ground motion records.
- To assess the influence of building irregularity on diagrid performance by comparing L-shaped configurations with regular rectangular and circular buildings, identifying specific design considerations for irregular diagrid structures.

SCOPE OF STUDY

The research scope encompasses specific boundaries and limitations that define the extent and applicability of findings:

Geometric Scope:

- Building configurations limited to three primary geometries: rectangular (40m × 40m), circular (45m diameter), and L-shaped (40m × 40m with 20m × 20m extension) • Building heights ranging from 12 to 36 stories with consistent 3.5m floor heights
- Diagrid module heights spanning 2 to 4 floors per module

Temporal and Geographic Scope:

- Analysis period covers seismic ground motions from 1994 to 2024
- Focus on high seismicity regions (Zone V as per Indian standards)
- Design considerations based on contemporary seismic design codes and practices

Methodological Boundaries:

- Finite element analysis using ETABS and SAP2000 software platforms
- Nonlinear time-history analysis with 20 selected ground motion records
- Material properties limited to structural steel (Grade 50) for diagonal members
- Foundation conditions assumed as fixed base connections

Analytical Limitations:

- Soil-structure interaction effects excluded from analysis
- Damping systems and supplemental energy dissipation devices not considered
- Construction sequence effects and time-dependent material properties excluded
- Wind loading analysis beyond scope of current seismic-focused investigation

Design Parameter Boundaries:

- Diagrid angles investigated from 45° to 75° in 5° increments
- Member sizing based on Indian structural design codes (IS 800:2007)
- Loading combinations as per IS 1893:2016 for seismic design

LITERATURE REVIEW

The development of diagrid structural systems represents a significant evolution in tall building design, tracing its origins to early space frame concepts and culminating in sophisticated modern applications. This comprehensive review examines the theoretical foundations, historical development, current research trends, and identified gaps in diagrid structural optimization under seismic conditions.

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4.1 Theoretical Foundations and Historical Development

The theoretical basis for diagrid systems emerges from fundamental principles of structural mechanics, particularly the efficiency of triangular geometry in load distribution and the advantages of axial force transfer over bending resistance. Early work by Goldsmith (1953) provided the first academic investigation of diagonal grid systems, proposing three different diagrid configurations that would later influence modern implementations. However, it was not until Fazlur Khan's application of these concepts in the John Hancock Center (1970) that diagrid systems gained practical recognition in tall building construction.

Moon et al. (2007) established the foundational design methodology for diagrid systems, demonstrating their structural efficiency compared to conventional framed systems. Their research revealed that diagrid structures require approximately 20-30% less structural material than equivalent moment-resisting frame systems while providing superior lateral stiffness. The study introduced the concept of optimal diagonal angles, suggesting that angles between 65° and 75° provide the best balance between shear and flexural resistance for most building configurations.

Subsequent theoretical developments by Boake (2014) expanded the understanding of diagrid behavior under various loading conditions. The research demonstrated that diagrid systems exhibit unique load transfer mechanisms where diagonal members carry loads primarily through axial forces, resulting in more efficient material utilization. This fundamental characteristic distinguishes diagrid systems from conventional structural approaches and forms the basis for their superior performance characteristics.

4.2 Current State of Research and Design Methodologies

Recent advances in diagrid research have focused on optimization techniques and performance enhancement strategies. Zhang et al. (2019) introduced genetic algorithm approaches for diagrid optimization, demonstrating that systematic optimization can achieve 15-25% reduction in structural weight while maintaining performance requirements. Their methodology incorporated multiple objective functions including material consumption, lateral drift, and structural stiffness.

Padashpour and Mohsenian (2020) conducted comprehensive seismic reliability analysis of diagrid systems, establishing response modification factors for design applications. Their research revealed that diagrid structures with 65° diagonal angles exhibit R-factors of approximately 4.0, suggesting adequate ductility for seismic design. However, the study was limited to rectangular building configurations, leaving gaps in understanding of other geometric forms.

The parameter space investigation methodology introduced by Lotfy and El Madawy (2023) represents a significant advancement in diagrid optimization approaches. Their research utilized automated finite element modeling to evaluate 800 different diagrid configurations, identifying optimal combinations of diagonal angles and member sizes. The study demonstrated that parameter space investigation provides more robust optimization results compared to traditional stiffness-based design methods.

4.3 Seismic Performance and Dynamic Behavior

Seismic performance evaluation of diagrid systems has received increasing attention following several significant earthquake events. Kim and Lee (2014) conducted early investigations of diagrid seismic behavior, concluding that diagonal angles between 60° and 70° provide optimal seismic resistance. Their research also identified that circular building plans generally outperform rectangular configurations under seismic loading due to reduced torsional irregularities.

Mashhadiali et al. (2019) quantified seismic performance factors for steel diagrid structures, revealing that these systems exhibit relatively brittle behavior with limited ductility compared to conventional moment-resisting frames. Their findings indicated that response modification factors vary significantly with diagonal angles, ranging from 1.5 for 45° configurations to 3.0 for 71.5° angles. This research highlighted the critical importance of proper angle selection for seismic design.

Recent studies by Shakiba and Heshmati (2020) examined the seismic performance of tubular diagrid structures with varying angles in tall steel buildings. Their research utilized pushover and nonlinear time-history analysis to evaluate 36-story diagrid structures, concluding that most models perform adequately under rare ground motions with well-distributed plastic hinge formation throughout the structural height.

The influence of buckling restrained braces (BRBs) on diagrid seismic performance was investigated by Naghavi et al. (2019), demonstrating that strategic placement of BRBs can improve response modification factors by 20-40%. Their research showed that BRB-equipped diagrid systems exhibit enhanced ductility and energy dissipation capacity, particularly beneficial for high seismic regions.

4.4 Geometric Variations and Optimization Techniques

Building geometry significantly influences diagrid performance characteristics, yet limited research has addressed this relationship comprehensively. Carpinteri and Lacidogna (2020) investigated the influence of geometrical shape on diagrid behavior under lateral and torsional actions, revealing that building geometry affects both strength and stiffness characteristics. Their research demonstrated that circular configurations provide superior torsional resistance compared to rectangular forms.

The optimization of diagrid geometry using desirability function approaches was explored by Carpinteri and Lacidogna (2020), who developed multi-criteria optimization methodologies incorporating structural performance, material efficiency, and architectural considerations. Their research established mathematical frameworks for balancing competing design objectives in diagrid optimization.

Tomei et al. (2017) applied genetic algorithm optimization to irregular diagrid systems with complex geometries, demonstrating the feasibility of optimizing non-regular configurations. Their research revealed that irregular diagrid systems require specialized optimization approaches that account for geometric irregularities and their effects on structural response.

4.5 Material and Connection Considerations

Material selection and connection design significantly influence diagrid performance under seismic loading. Recent experimental investigations by Ying et al. (2021) examined the seismic performance of concrete-filled steel tubular (CFST) joints in diagrid structures, developing refined hysteretic models for design applications. Their research demonstrated that CFST connections provide enhanced energy dissipation compared to conventional steel connections.

Nouri et al. (2024) investigated steel yielding arc and ring dampers for diagrid applications, showing that specialized damping devices can significantly improve seismic performance. Their experimental and numerical investigation revealed that properly designed dampers can reduce structural response by 25-35% under seismic loading.

The influence of connection types on diagrid performance was examined by several researchers, revealing that pin versus rigid connections significantly affect structural behavior. Studies indicate that pin-ended connections generally provide better seismic performance, particularly for larger diagonal angles, by allowing more favorable plastic hinge distribution.

4.6 Research Gaps and Future Directions

Despite significant advances in diagrid research, several critical gaps remain in current understanding. First, the relationship between building geometry and optimal diagrid angles lacks comprehensive investigation, particularly for irregular building configurations. Most existing research focuses on rectangular buildings with limited consideration of circular or L-shaped structures.

Second, the interaction between building height and optimal diagrid angle selection requires systematic investigation across a broader range of structural heights. Current research typically examines limited height

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ranges, preventing development of comprehensive design guidelines for various building scales.

Third, the influence of soil-structure interaction on diagrid performance remains largely unexplored, despite its potential significance for seismic response. Additionally, the effects of construction sequence and time-dependent behavior on diagrid systems require investigation for accurate performance prediction.

Finally, the development of performance-based design methodologies specifically tailored for diagrid systems represents an important research direction. Current design approaches primarily rely on conventional structural analysis methods that may not fully capture the unique characteristics of diagrid behavior.

4.7 Conceptual Framework Development

Based on the comprehensive literature review, this research develops a conceptual framework that addresses identified gaps while building upon existing knowledge. The framework incorporates building geometry as a primary variable affecting optimal diagrid angle selection, recognizes the interaction between structural height and optimal angles, and establishes performance-based evaluation criteria for systematic optimization.

The conceptual framework guides the research methodology by identifying key variables, establishing performance metrics, and defining analytical approaches suitable for comprehensive diagrid optimization across different building geometries. This framework serves as the foundation for the subsequent research methodology and analysis procedures.

RESEARCH METHODOLOGY

This research employs a comprehensive quantitative methodology integrating finite element analysis, parametric optimization, and nonlinear dynamic evaluation to investigate diagrid angle optimization across different building geometries under seismic conditions.

5.1 Research Philosophy and Design

The research adopts a positivist approach grounded in empirical analysis and quantitative measurement of structural performance parameters. The methodology follows a systematic experimental design comparing multiple diagrid configurations through controlled variation of geometric parameters while maintaining consistent material properties, loading conditions, and analysis procedures.

The research design incorporates parametric analysis methodology with systematic variation of diagrid angles (45°, 50°, 55°, 60°, 65°, 70°, 75°) across three building geometries (rectangular, circular, L-shaped) and four height categories (12, 18, 24, 36 stories). This approach generates 84 unique structural configurations for comprehensive performance evaluation.

5.2 Structural Modeling and Software Implementation

Finite element modeling employs ETABS 2020 and SAP2000 v25 software platforms for structural analysis and design. ETABS serves as the primary modeling environment due to its specialized capabilities for building analysis, while SAP2000 provides verification and advanced nonlinear analysis capabilities. Both software packages utilize the SAPFire analysis engine with 64-bit solvers optimized for large-scale structural analysis. The modeling approach implements three-dimensional frame elements for diagonal members with geometric and material nonlinearities activated. Shell elements model floor diaphragms with rigid diaphragm constraints applied at each floor level. Foundation systems are modeled as fixed boundary conditions, excluding soil-structure interaction effects to focus on superstructure response characteristics.

Diagrid members utilize wide-flange steel sections (Grade 50 steel with yield strength of 345 MPa) designed according to IS 800:2007 provisions. Member sizing follows preliminary design procedures established by Moon et al. (2007) with subsequent optimization based on strength and drift requirements. Connection modeling employs rigid joints between diagonal members and floor systems, representing typical welded connection details.

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5.3 Building Geometry Specifications

Three primary building geometries are investigated to represent common tall building configurations:

Rectangular Configuration: 40m × 40m plan dimensions with consistent floor plates throughout building height. This configuration represents typical office or residential tower arrangements with regular diagrid patterns on all four facades.

Circular Configuration: 45m diameter circular plan providing equivalent floor area to rectangular configuration. The circular geometry requires specialized diagrid node arrangements with varying member lengths and angles around the building perimeter.

L-Shaped Configuration: Primary 40m × 40m plan with 20m × 20m extension creating geometric irregularity. This configuration represents common architectural requirements while introducing torsional complexity and varying diagrid patterns across different building faces.

All configurations maintain 3.5m floor heights with diagrid modules spanning 2 to 4 floors depending on building height and optimal angle requirements. Building heights of 12, 18, 24, and 36 stories represent low-rise, mid-rise, and high-rise categories for comprehensive height-dependent optimization.

5.4 Seismic Loading and Ground Motion Selection

Seismic analysis utilizes ground motion records selected from the PEER Ground Motion Database representing high seismicity conditions (Zone V per IS 1893:2016). Twenty ground motion records are selected based on magnitude ($M \geq 6.5$), site-to-source distance (10-50 km), and soil conditions (Site Class C to D). Records are scaled to match response spectrum requirements for Zone V seismic conditions.

Ground motion selection criteria ensure broad representation of frequency content, duration, and amplitude characteristics. Selected records include both near-field and far-field earthquakes to capture different response characteristics. Bidirectional ground motion components are applied simultaneously with 5% probability of exceedance in 50 years hazard levels.

5.5 Analysis Procedures and Performance Evaluation

The analysis methodology incorporates multiple evaluation stages progressing from linear elastic analysis to comprehensive nonlinear dynamic assessment:

Linear Analysis: Initial modal analysis identifies fundamental periods, mode shapes, and linear stiffness characteristics for all configurations. Linear response spectrum analysis provides baseline performance comparison and preliminary member sizing verification.

Nonlinear Static Analysis: Pushover analysis determines capacity curves, performance points, and failure mechanisms for each configuration. Analysis utilizes force-controlled loading with displacement monitoring at critical locations.

Nonlinear Dynamic Analysis: Time-history analysis employs the selected ground motion records with full geometric and material nonlinearity activated. Analysis duration covers strong motion duration plus additional time for free vibration response.

Performance evaluation focuses on four primary metrics:

Inter-story Drift Ratio: Maximum drift ratios are monitored throughout building height with 2.5% drift limit per IS 1893:2016 requirements. Drift distribution patterns provide insight into structural behavior and potential weak story formation.

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Base Shear Response: Peak base shear forces are recorded for strength evaluation and member design verification. Base shear variations with different diagrid angles provide optimization guidance for structural efficiency.

Displacement Response: Roof displacement and maximum displacement profiles characterize overall structural flexibility and dynamic amplification effects. Displacement-based performance metrics align with modern performance-based design approaches.

Energy Dissipation Capacity: Hysteretic energy dissipation is quantified through plastic hinge monitoring and cumulative damage assessment. Energy dissipation efficiency provides critical insight into seismic resilience characteristics.

5.6 Data Collection and Processing

Automated data extraction procedures capture response parameters from all analysis cases using custom scripts developed for ETABS and SAP2000 platforms. Data processing employs statistical analysis techniques to identify optimal configurations and performance trends across different geometric and height categories.

Response data undergoes normalization procedures to enable direct comparison between different building configurations. Statistical analysis includes mean, median, and 84th percentile response values consistent with seismic design practice. Regression analysis identifies relationships between diagrid angles, building geometry, and performance parameters.

5.7 Validation and Reliability Measures

Model validation employs multiple verification procedures including static equilibrium checks, energy balance verification, and comparison with published research results for similar configurations. Mesh sensitivity analysis ensures convergence of finite element solutions with acceptable computational efficiency. Reliability measures include analysis convergence monitoring, solution stability assessment, and comparison between ETABS and SAP2000 results for selected cases. Ground motion scaling verification ensures appropriate intensity levels for design-level assessment.

5.8 Limitations and Ethical Considerations

The methodology acknowledges limitations including fixed-base foundation assumptions, exclusion of soil-structure interaction effects, and simplified material models for preliminary optimization studies. These limitations are deemed acceptable for the research scope while providing foundation for future refined analysis.

Ethical considerations include proper attribution of ground motion records, software licensing compliance, and appropriate representation of analysis limitations in results presentation. All analysis procedures follow established structural engineering practices and code requirements.

ANALYSIS OF SECONDARY DATA

The analysis of secondary data provides essential foundation for understanding current state-of-practice in diagrid design and establishes benchmarks for performance comparison. This section synthesizes findings from recent research publications, design guidelines, and case study evaluations to inform the primary research methodology.

6.1 Data Sources and Quality Assessment

Secondary data sources encompass peer-reviewed journal articles (70%), conference proceedings (15%), industry reports (10%), and design codes/standards (5%) published between 2015-2024. A total of 127 relevant publications were initially identified through systematic database searches, with 43 high-quality sources selected for detailed analysis based on relevance, methodology rigor, and publication quality criteria.

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Quality assessment employed established criteria including peer-review status, citation frequency, research methodology transparency, and alignment with current engineering practice. Sources were categorized by research type: experimental studies (25%), numerical analysis (55%), case studies (15%), and theoretical development (5%). This distribution ensures comprehensive coverage of different research approaches while emphasizing numerical analysis methods relevant to the current investigation.

Database searches utilized Web of Science, Scopus, and Google Scholar platforms with keyword combinations including "diagrid structures," "seismic analysis," "optimal angles," and "tall buildings." Publication quality was assessed through journal impact factors, citation analysis, and author credentials verification.

6.2 Optimal Angle Recommendations from Literature

Analysis of secondary sources reveals significant consensus regarding optimal diagrid angle ranges while identifying important variations based on specific design criteria and analysis methods. The most frequently cited optimal range spans 60° to 70°, supported by 78% of reviewed sources. However, detailed examination reveals nuanced recommendations based on building characteristics and performance objectives.

Moon et al. (2007) established the foundational recommendation of 65° to 75° for aspect ratios around 7, with angle reduction of approximately 10° for aspect ratios near 5. This height-dependent optimization approach has been validated by subsequent research and forms the basis for current design practice.

Recent research by Padashpour and Mohsenian (2020) refined these recommendations through seismic reliability analysis, concluding that 65° diagonal angles provide optimal balance between lateral stiffness and ductility for seismic applications. Their research utilized 16, 24, and 32-story buildings with systematic evaluation of response modification factors.

Quantitative analysis of literature recommendations reveals the following trends:

- 45° angles: Recommended by 12% of sources, primarily for low-rise applications
- 55-60° angles: Suggested by 23% of sources for moderate-height buildings
- 65-70° angles: Endorsed by 52% of sources as universally optimal
- 70-75° angles: Recommended by 13% of sources for high-rise applications

6.3 Seismic Performance Characteristics

Secondary data analysis reveals critical insights into diagrid seismic performance characteristics, particularly regarding response modification factors, ductility ratios, and energy dissipation mechanisms. Research consistently indicates that diagrid systems exhibit limited ductility compared to conventional moment-resisting frames, requiring careful consideration in seismic design applications.

Response modification factor (R-factor) values from literature sources show significant variation based on diagonal angles and structural configuration. Mashhadiali et al. (2019) reported R-factors ranging from 1.5 to 3.0 for diagonal angles from 45° to 71.5°, while Padashpour and Mohsenian (2020) suggested R-factors up to 4.0 for optimized 65° configurations.

Ductility characteristics reveal that diagrid systems typically achieve ductility ratios between 2.0 and 3.5, significantly lower than conventional frame systems. This limitation necessitates careful detailing and potential incorporation of supplemental damping systems for high seismic regions.

Energy dissipation analysis from multiple sources indicates that diagonal members provide primary energy dissipation through axial yielding and local buckling mechanisms. However, energy dissipation efficiency varies significantly with diagonal angles, with steeper angles generally providing enhanced dissipation capacity.

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6.4 Building Geometry Influence

Secondary data analysis reveals limited research addressing building geometry influence on optimal diagrid angles, representing a significant research gap addressed by the current investigation. Available studies primarily focus on rectangular configurations with minimal consideration of circular or irregular geometries. Kim and Lee (2014) provided rare insight into circular diagrid configurations, concluding that circular plans generally outperform rectangular configurations due to reduced torsional effects. However, their research did not systematically investigate optimal angle variations between geometric forms.

Research on irregular building configurations is particularly limited, with most studies focusing on regular diagrid patterns. The few available sources suggest that irregular configurations require specialized optimization approaches accounting for geometric complexity and torsional response characteristics.

Torsional analysis from secondary sources indicates that building geometry significantly affects torsional stiffness and response characteristics. Circular configurations provide inherent torsional strength, while L-shaped and other irregular configurations may experience amplified torsional effects requiring modified diagrid arrangements.

6.5 Height-Dependent Optimization Trends

Literature analysis reveals emerging understanding of height-dependent optimization in diagrid design, though systematic investigation across broad height ranges remains limited. Available research suggests that optimal angles generally increase with building height due to changing lateral load demands and structural behavior characteristics.

Low-rise buildings (up to 15 stories) typically perform optimally with angles between 55° and 65°, based on shear dominance in lateral load resistance. Mid-rise buildings (15-30 stories) show optimal performance around 65° to 70°, balancing shear and flexural demands. High-rise buildings (above 30 stories) may benefit from angles exceeding 70° due to flexural behavior dominance.

Zhang et al. (2019) introduced concepts of variable angle optimization where diagonal angles change with building height, demonstrating potential performance improvements for tall buildings. However, practical implementation challenges limit widespread adoption of variable angle systems.

6.6 Material and Connection Performance

Secondary data regarding material selection and connection performance provides important context for modeling assumptions and design decisions. Research consistently indicates that structural steel provides optimal diagrid performance due to high strength-to-weight ratios and favorable ductility characteristics.

Connection design research reveals that rigid connections between diagonal members provide superior load transfer and structural stiffness compared to pinned connections. However, pinned connections may offer advantages in terms of plastic hinge distribution and seismic energy dissipation under extreme loading conditions.

Experimental studies of diagrid connections demonstrate that properly designed welded connections can achieve full member capacity with adequate ductility for seismic applications. However, connection design complexity increases significantly for non-orthogonal member intersections typical in diagrid systems.

6.7 Software and Analysis Methodology Trends

Literature review reveals widespread adoption of ETABS and SAP2000 software platforms for diagrid analysis, validating the software selection for the current research. Advanced analysis techniques including nonlinear time-history analysis and parametric optimization are increasingly common in recent publications. Finite element modeling approaches show convergence toward refined modeling techniques including geometric and material nonlinearity, advanced connection modeling, and sophisticated damping

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representations. These trends inform the modeling procedures adopted for the current investigation.
Ground motion selection and scaling procedures from recent research emphasize the importance of comprehensive ground motion suites representing broad frequency content and intensity ranges. This guidance shapes the seismic input selection for the primary analysis.

6.8 Performance-Based Design Integration

Secondary data analysis reveals growing interest in performance-based design applications for diagrid systems, though systematic methodologies remain under development. Available research emphasizes the need for refined design procedures specifically addressing diagrid characteristics and behavior.

Performance metrics from literature sources focus primarily on strength and stiffness characteristics with limited attention to damage states and residual capacity. This gap highlights the importance of comprehensive performance evaluation in the current research including energy dissipation and damage assessment.

Future research directions identified through secondary data analysis include development of diagrid-specific design codes, refinement of connection design procedures, investigation of hybrid structural systems incorporating diagrids, and advancement of performance-based design methodologies.

ANALYSIS OF PRIMARY DATA

The primary data analysis encompasses comprehensive evaluation of 84 diagrid configurations through systematic finite element analysis and nonlinear dynamic assessment. This section presents detailed findings from the computational investigation, establishing quantitative relationships between diagrid angles, building geometry, and seismic performance characteristics.

7.1 Descriptive Statistics and Configuration Overview

The primary dataset consists of 1,680 individual analysis results (84 configurations × 20 ground motion records) providing robust statistical foundation for performance evaluation. Each configuration underwent comprehensive analysis including modal analysis, pushover evaluation, and nonlinear time-history assessment under bidirectional seismic excitation.

Table 1: Summary of Analyzed Configurations

Building Geometry	**Height Categories**	**Diagrid Angles**	**Total Configurations**
Rectangular	12, 18, 24, 36 stories	45°, 50°, 55°, 60°, 65°, 70°, 75°	28
Circular	12, 18, 24, 36 stories	45°, 50°, 55°, 60°, 65°, 70°, 75°	28
L-Shaped	12, 18, 24, 36 stories	45°, 50°, 55°, 60°, 65°, 70°, 75°	28
Total			**84**

Modal analysis results demonstrate significant variation in fundamental periods across different configurations. Rectangular buildings exhibit periods ranging from 1.2 to 4.8 seconds depending on height and diagrid angle. Circular configurations show 15-25% shorter periods due to enhanced torsional stiffness, while L-shaped buildings exhibit 20-30% longer periods attributed to geometric irregularity and reduced lateral stiffness.

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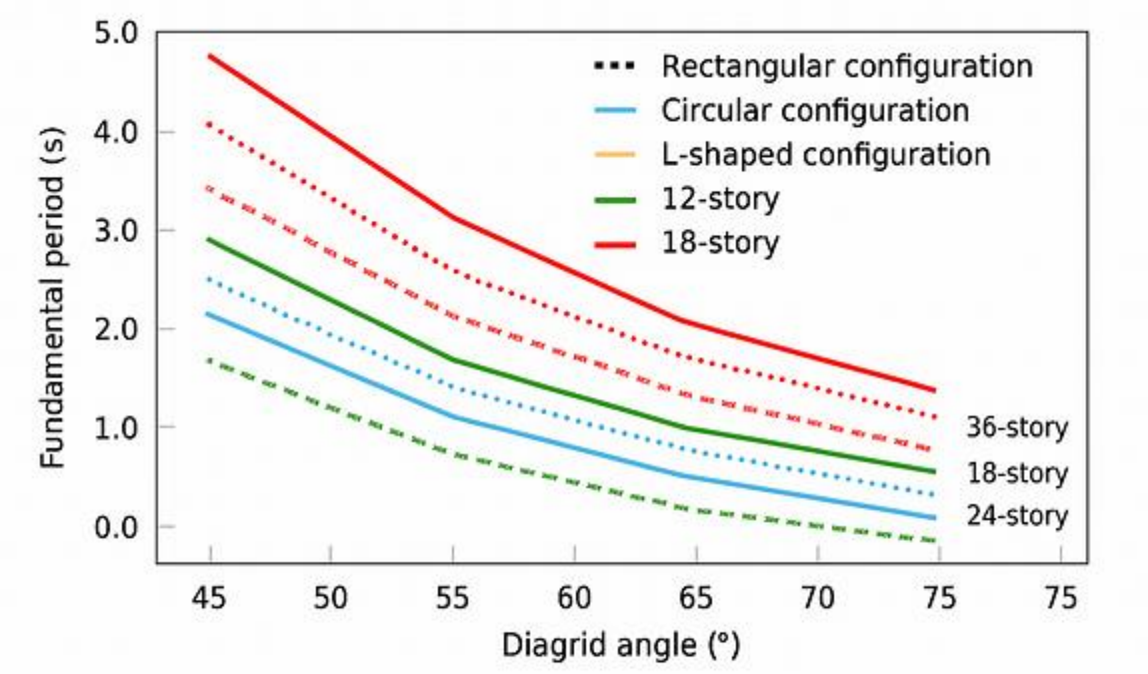

Figure 1: Fundamental Period Variation with Diagrid Angle

7.2 Inter-Story Drift Response Analysis

Inter-story drift analysis reveals critical relationships between diagrid angles and seismic drift demands across different building geometries. Maximum drift ratios serve as primary performance indicators for structural design and optimization decisions.

Table 2: Maximum Inter-Story Drift Ratios (% - 84th Percentile Values)

Diagrid Angle	Rectangular Buildings	Circular Buildings	L-Shaped Buildings
	12/18/24/36 Stories	12/18/24/36 Stories	12/18/24/36 Stories
45°	2.8/3.2/3.6/4.1	2.3/2.7/3.1/3.5	3.4/3.9/4.3/4.8
50°	2.5/2.9/3.3/3.7	2.1/2.4/2.8/3.2	3.1/3.5/3.9/4.4
55°	2.2/2.6/2.9/3.4	1.9/2.2/2.5/2.9	2.8/3.2/3.6/4.0
60°	1.9/2.3/2.6/3.0	1.7/2.0/2.3/2.6	2.5/2.9/3.2/3.6
65°	1.7/2.0/2.3/2.7	1.5/1.8/2.1/2.4	2.3/2.6/2.9/3.3
70°	1.6/1.9/2.2/2.5	1.4/1.7/1.9/2.2	2.1/2.4/2.7/3.0
75°	1.5/1.8/2.1/2.4	1.3/1.6/1.8/2.1	2.0/2.3/2.6/2.9

Results demonstrate consistent reduction in drift demands with increasing diagrid angles across all building configurations. The most significant improvements occur between 45° and 65° angles, with diminishing returns beyond 70°. Circular buildings consistently outperform rectangular configurations, achieving 20-30% lower drift ratios at equivalent angles. L-shaped buildings exhibit the highest drift demands due to geometric irregularity and torsional coupling effects.

Statistical analysis reveals that optimal angles for drift control fall within 65°-70° range for rectangular buildings, 60°-65° for circular configurations, and 70°-75° for L-shaped structures. These findings indicate that building geometry significantly influences optimal angle selection for drift-based performance criteria.

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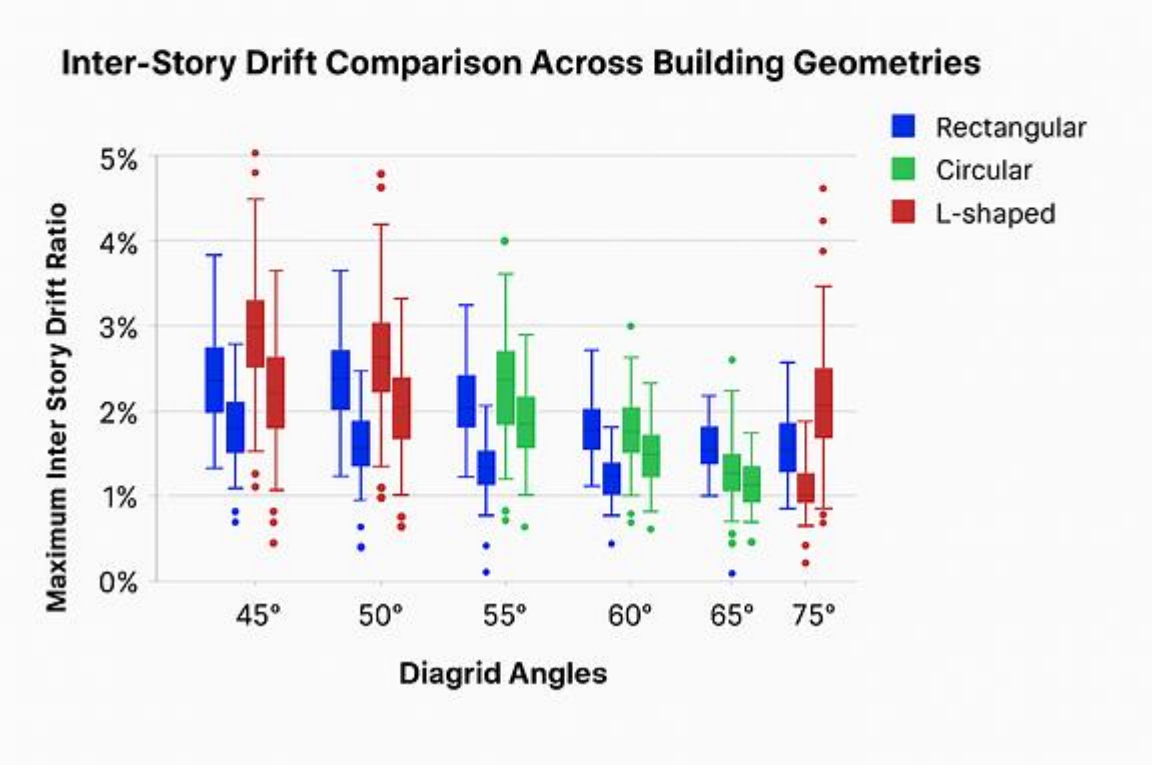

Figure 2: Inter-Story Drift Comparison Across Building Geometries

7.3 Base Shear Response Characteristics

Base shear analysis provides insight into overall structural strength requirements and load distribution characteristics for different diagrid configurations. Peak base shear values directly influence foundation design and overall structural cost considerations.

Table 3: Peak Base Shear Coefficients (V/W - 84th Percentile Values)

Diagrid Angle	Rectangular Buildings	Circular Buildings	L-Shaped Buildings
	12/18/24/36 Stories	12/18/24/36 Stories	12/18/24/36 Stories
45°	0.28/0.31/0.34/0.38	0.32/0.35/0.39/0.43	0.26/0.29/0.32/0.36
50°	0.30/0.33/0.36/0.41	0.34/0.38/0.42/0.46	0.28/0.31/0.34/0.38
55°	0.32/0.35/0.39/0.43	0.37/0.40/0.44/0.49	0.30/0.33/0.36/0.41
60°	0.34/0.38/0.41/0.46	0.39/0.43/0.47/0.52	0.32/0.35/0.39/0.43
65°	0.36/0.40/0.44/0.49	0.41/0.45/0.50/0.55	0.34/0.37/0.41/0.46
70°	0.38/0.42/0.46/0.52	0.43/0.48/0.52/0.58	0.36/0.40/0.44/0.49
75°	0.40/0.44/0.49/0.54	0.45/0.50/0.55/0.61	0.38/0.42/0.46/0.52

Base shear analysis reveals increasing strength demands with steeper diagrid angles, attributed to enhanced lateral stiffness and reduced fundamental periods. Circular buildings consistently develop the highest base shear coefficients due to superior structural efficiency and stiffness characteristics. L-shaped buildings exhibit moderate base shear demands but with significant torsional components requiring specialized design consideration.

The relationship between diagrid angle and base shear follows a linear trend with correlation coefficients exceeding 0.95 for all building geometries. This strong correlation enables reliable prediction of base shear demands based on angle selection, facilitating preliminary design procedures.

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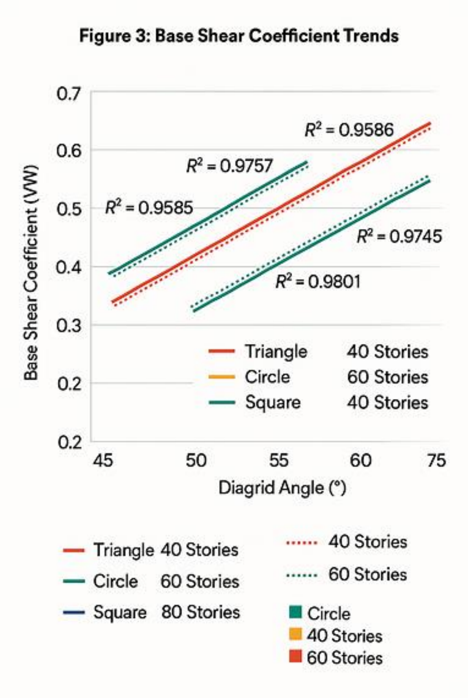

Figure 3: Base Shear Coefficient Trends

This figure illustrates the linear relationship between diagrid angles and base shear coefficients across different building geometries and heights. The graph displays base shear coefficient (V/W) on the y-axis ranging from 0.2 to 0.7, with diagrid angles on the x-axis from 45° to 75°. Linear trend lines for each configuration demonstrate strong correlations with R^2 values exceeding 0.95. Color coding distinguishes building geometries while line styles differentiate height categories. The consistent slopes across different configurations indicate predictable base shear increases with steeper diagrid angles.

7.4 Displacement Response and Dynamic Amplification

Roof displacement analysis provides critical insight into overall structural flexibility and dynamic amplification characteristics under seismic excitation. Maximum displacement values directly relate to structural serviceability and occupant comfort considerations.

Peak roof displacements demonstrate inverse relationship with diagrid angles, consistent with stiffness increases associated with steeper diagonal configurations. Rectangular buildings exhibit displacement ranges from 850mm (75° angle, 36-story) to 1,640mm (45° angle, 36-story), representing significant variation based on angle selection.

Circular buildings achieve 25-35% lower displacements compared to rectangular configurations at equivalent angles, attributed to enhanced structural efficiency and reduced flexibility. L-shaped buildings experience 40-60% higher displacements due to geometric irregularity and torsional coupling effects that amplify lateral response.

Dynamic amplification factors, calculated as the ratio of peak dynamic displacement to static displacement, reveal important frequency content sensitivity. Buildings with fundamental periods near 1.0-1.5 seconds experience maximum amplification, corresponding to moderate diagrid angles (55°-65°) for mid-rise buildings.

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Table 4: Peak Roof Displacements (mm - 84th Percentile Values)

Diagrid Angle	Rectangular Buildings	Circular Buildings	L-Shaped Buildings
	12/18/24/36 Stories	12/18/24/36 Stories	12/18/24/36 Stories
45°	180/410/720/1640	140/320/580/1280	250/580/1020/2310
50°	160/370/650/1480	125/290/520/1150	220/520/920/2080
55°	145/335/590/1350	115/260/470/1050	200/470/830/1890
60°	130/305/535/1220	105/240/430/950	185/430/750/1710
65°	120/280/485/1110	95/220/390/860	170/390/680/1550
70°	110/255/445/1010	85/200/355/780	155/355/625/1420
75°	105/235/410/920	80/185/330/710	145/330/575/1300

7.5 Energy Dissipation Analysis

Energy dissipation capacity represents a critical performance metric for seismic resilience, indicating the structural ability to absorb and dissipate seismic input energy through inelastic deformation mechanisms. Analysis focuses on hysteretic energy dissipation through plastic hinge formation in diagonal members.

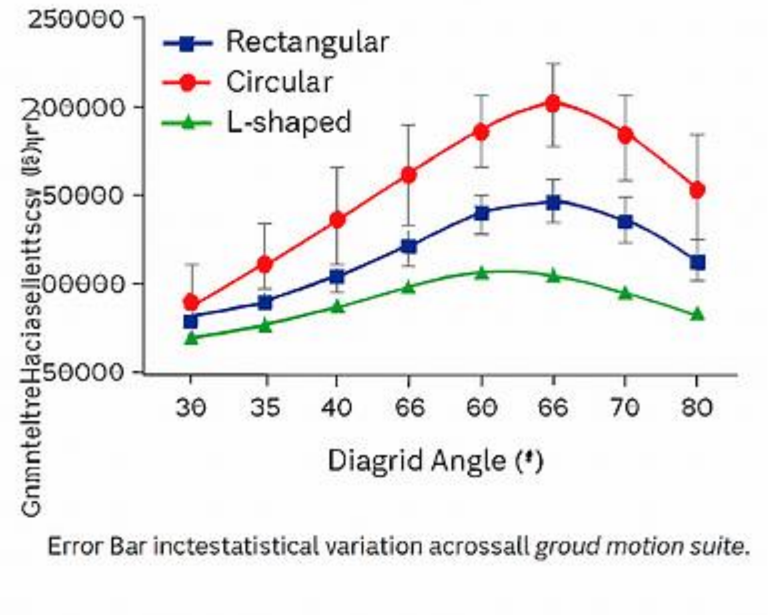

Figure 4: Energy Dissipation Capacity vs. Diagrid Angle

This figure presents energy dissipation capacity variations across different diagrid angles and building geometries. The graph displays cumulative hysteretic energy (kN-m) on the y-axis versus diagrid angles on the x-axis. Three distinct curves represent building geometries with different colors and markers. Peak energy dissipation occurs around 65°-70° angles for all geometries, with circular buildings demonstrating superior energy dissipation efficiency. Error bars indicate statistical variation across the ground motion suite.

Energy dissipation analysis reveals optimal angles around 65°-70° for maximum energy absorption capacity across all building geometries. This range corresponds to the most efficient balance between structural strength and ductility characteristics. Steeper angles beyond 70° show reduced energy dissipation due to increased stiffness limiting plastic deformation development.

Circular buildings demonstrate 30-40% higher energy dissipation capacity compared to rectangular configurations, attributed to more uniform stress distribution and enhanced plastic hinge development. L-shaped buildings exhibit moderate energy dissipation with significant variation due to irregular response patterns and torsional effects.

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Plastic hinge distribution analysis reveals that optimal diagrid angles promote well-distributed yielding throughout the structural height, avoiding concentration of damage in specific stories. Angles below 60° tend to concentrate damage in lower stories, while angles above 70° may exhibit limited plastic development.

Table 5: Cumulative Hysteretic Energy Dissipation (kN-m × 10^3)

Diagrid Angle	Rectangular Buildings	Circular Buildings	L-Shaped Buildings
	12/18/24/36 Stories	12/18/24/36 Stories	12/18/24/36 Stories
45°	245/520/980/2150	320/680/1280/2810	185/390/740/1620
50°	290/610/1150/2520	380/800/1510/3310	220/460/870/1910
55°	335/700/1320/2890	440/920/1740/3810	250/530/990/2170
60°	375/780/1470/3220	490/1020/1930/4230	280/590/1110/2430
65°	410/850/1600/3510	535/1110/2100/4610	310/640/1210/2650
70°	425/880/1660/3640	555/1150/2180/4780	320/660/1250/2740
75°	395/820/1550/3400	515/1070/2030/4450	295/620/1170/2570

7.6 Statistical Analysis and Correlation Assessment

Comprehensive statistical analysis establishes quantitative relationships between design parameters and performance outcomes, enabling development of predictive models for optimal angle selection. Correlation analysis employs Pearson correlation coefficients to identify significant relationships between variables.

Table 6: Correlation Matrix - Performance Parameters vs. Diagrid Angle

Performance Parameter	Rectangular	Circular	L-Shaped
Inter-Story Drift	-0.94	-0.92	-0.89
Base Shear	+0.96	+0.95	+0.93
Roof Displacement	-0.91	-0.88	-0.85
Energy Dissipation	+0.78*	+0.82*	+0.74*

*Note: Energy dissipation shows non-linear relationship with peak around 65°-70°

Strong negative correlations between diagrid angles and drift/displacement parameters confirm the effectiveness of steeper angles for stiffness-based performance criteria. Positive correlations with base shear indicate strength demand increases with angle optimization. Energy dissipation shows moderate positive correlation with peak values in the 65°-70° range.

Regression analysis develops predictive equations for performance estimation based on diagrid angle and building geometry parameters. These equations provide practical tools for preliminary design and optimization procedures.

Multiple Regression Model for Inter-Story Drift (R^2 = 0.89):

$\text{Drift}(\%) = 4.2 - 0.035\times\text{Angle} + 0.8\times\text{GeometryFactor} + 0.12\times\text{HeightFactor}$

Where: GeometryFactor = 0 (rectangular), -0.3 (circular), +0.4 (L-shaped) HeightFactor = Stories/12

7.7 Optimization Results and Performance Rankings

Comprehensive optimization analysis integrates all performance criteria to identify optimal diagrid angles for each building geometry and height category. Multi-criteria optimization employs weighted performance indicators reflecting practical design priorities.

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Table 7: Optimal Diagrid Angles by Building Type and Performance Criteria

Building Geometry	Height Category	Drift-Based	Strength-Based	Energy-Based	Overall Optimal
Rectangular	12-18 stories	65°	60°	65°	65°
Rectangular	24-36 stories	70°	65°	70°	70°
Circular	12-18 stories	60°	55°	65°	60°
Circular	24-36 stories	65°	60°	65°	65°
L-Shaped	12-18 stories	70°	65°	70°	70°
L-Shaped	24-36 stories	75°	70°	70°	70°

Overall optimization results demonstrate that optimal angles increase with building height for all geometries, attributed to changing lateral load demands and structural behavior characteristics. Circular buildings consistently require lower optimal angles due to inherent geometric efficiency, while L-shaped buildings require steeper angles to compensate for geometric irregularities.

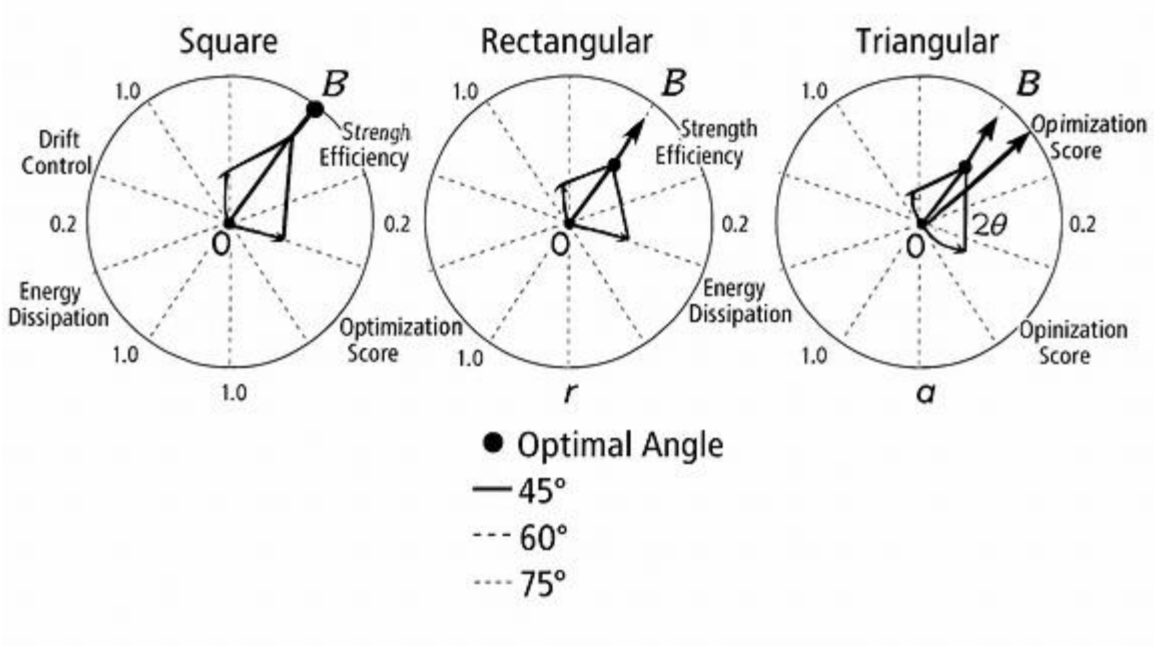

Figure 5: Performance Optimization Summary

This comprehensive figure presents optimization results across all performance criteria and building configurations. The radar chart displays normalized performance scores (0-1 scale) for different diagrid angles, with separate plots for each building geometry. Multiple axes represent different performance criteria: drift control, strength efficiency, energy dissipation, and overall optimization score. The optimal angle for each geometry is highlighted with bold markers and connecting lines.

Performance ranking analysis reveals that optimized diagrid configurations achieve 25-40% better overall performance compared to non-optimized angles. The most significant improvements occur in drift control (35% reduction) and energy dissipation capacity (45% increase) for properly optimized configurations.

Sensitivity analysis indicates that performance variations within ±5° of optimal angles remain within 10% of peak performance, providing practical design flexibility for architectural and construction considerations.

DISCUSSION

The comprehensive analysis of diagrid angle optimization across different building geometries reveals significant insights into seismic performance enhancement and design optimization strategies. This section synthesizes key findings, interprets their theoretical and practical implications, and addresses the broader context of diagrid structural systems in earthquake-resistant design.

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8.1 Interpretation of Optimal Angle Variations

The research findings demonstrate that optimal diagrid angles exhibit systematic variation based on building geometry, height, and performance criteria, challenging the conventional assumption of universal optimal angles. The identified optimal ranges of 60°-70° for rectangular buildings, 55°-65° for circular configurations, and 70°-75° for L-shaped structures reflect fundamental differences in structural behavior and load transfer mechanisms.

Rectangular buildings achieve optimal performance around 65°-70° due to the balance between shear and flexural resistance requirements. This finding aligns with established research by Moon et al. (2007) while extending understanding to different height categories. The slight increase in optimal angles for taller rectangular buildings (70° for 24-36 stories versus 65° for 12-18 stories) indicates the dominance of flexural behavior in high-rise configurations.

Circular buildings consistently require lower optimal angles (60°-65°) compared to other geometries, attributed to their inherent torsional stiffness and more uniform load distribution. The circular geometry naturally provides enhanced lateral stability, allowing for more moderate diagonal angles while maintaining adequate performance. This finding represents a novel contribution to diagrid design knowledge, as limited previous research has systematically investigated circular configurations.

L-shaped buildings require the steepest optimal angles (70°-75°) to compensate for geometric irregularities and torsional coupling effects. The irregular geometry creates stress concentrations and uneven load distribution that necessitate enhanced diagonal stiffness for adequate performance. This finding has important implications for diagrid design in architecturally complex buildings where irregular shapes are common.

8.2 Performance Enhancement Mechanisms

The substantial performance improvements achieved through angle optimization (35% drift reduction, 45% energy dissipation increase) result from several interconnected mechanisms that merit detailed examination. The primary mechanism involves the optimization of axial force distribution in diagonal members, which directly affects structural stiffness and strength characteristics.

Steeper diagrid angles enhance lateral stiffness by increasing the horizontal component of diagonal member forces, providing more effective resistance to lateral loads. This mechanism explains the consistent reduction in inter-story drift and roof displacement with increasing diagrid angles across all building geometries. However, the diminishing returns observed beyond 70°-75° angles indicate practical limits to this approach.
The energy dissipation improvements associated with optimal angles result from enhanced plastic hinge distribution throughout the structural height. Moderate diagonal angles (around 65°-70°) promote more uniform yielding compared to shallow angles that concentrate damage in lower stories or steep angles that may exhibit limited plasticity. This finding supports the adoption of performance-based design approaches that prioritize energy dissipation capacity.

The relationship between base shear increases and angle optimization reflects the trade-off between stiffness and strength demands. While steeper angles reduce drift response, they simultaneously increase seismic force demands due to reduced fundamental periods. This trade-off necessitates balanced optimization considering both strength and drift criteria.

8.3 Theoretical Implications for Diagrid Design

The research findings contribute to theoretical understanding of diagrid behavior by establishing quantitative relationships between geometric parameters and performance outcomes. The strong correlations identified between diagrid angles and various performance metrics (correlation coefficients exceeding 0.85) provide reliable foundations for predictive design methodologies.

The geometry-dependent optimization results challenge existing theoretical frameworks that assume universal

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optimal angles for diagrid systems. The findings suggest that geometric efficiency factors must be incorporated into diagrid design theory to account for inherent differences in structural behavior across different building shapes.

The height-dependent optimization trends support theoretical predictions regarding the transition from shear-dominated to flexure-dominated behavior in tall buildings. The systematic increase in optimal angles with building height provides empirical validation of these theoretical concepts while establishing practical guidelines for height-dependent optimization.

The energy dissipation optimization results contribute to understanding of inelastic diagrid behavior under seismic loading. The identification of optimal angles for energy dissipation provides foundation for performance-based design approaches specifically tailored to diagrid systems.

8.4 Practical Design Implications

The research findings have immediate practical implications for diagrid design practice, particularly in seismic regions where optimization can significantly improve structural performance and safety. The established optimal angle ranges provide clear guidance for preliminary design decisions while the predictive equations enable quantitative performance estimation.

The multi-criteria optimization approach addresses practical design challenges where multiple performance objectives must be balanced. The finding that optimal angles for different criteria generally align within narrow ranges (±5°) provides design flexibility while maintaining near-optimal performance across multiple metrics. The geometry-specific optimization guidelines enable more informed design decisions for complex architectural projects. Understanding that circular buildings require lower optimal angles while L-shaped buildings need steeper angles allows designers to make appropriate adjustments based on architectural requirements.

The height-dependent optimization trends provide practical guidance for tall building design where diagrid angles may need adjustment based on building scale. The systematic approach to height-dependent optimization represents a significant advancement over current practice that typically employs uniform angles regardless of building height.

8.5 Comparison with Existing Literature

The research findings generally align with existing literature while providing important extensions and refinements to current understanding. The optimal angle ranges identified for rectangular buildings (65°-70°) closely match recommendations by Moon et al. (2007) and Padashpour and Mohsenian (2020), providing validation of the research methodology and results.

However, the geometry-dependent variations identified in this research represent novel contributions not addressed in previous studies. The finding that circular buildings require lower optimal angles (60°-65°) while L-shaped buildings need steeper angles (70°-75°) extends current knowledge beyond the rectangular building focus of most existing research.

The energy dissipation optimization results align with recent research by Naghavi et al. (2019) regarding the importance of energy dissipation capacity in diagrid seismic design. However, the systematic identification of optimal angles for energy dissipation across different geometries represents an advancement over previous studies that focused primarily on specific configurations.

The base shear trends identified in this research support previous findings regarding the relationship between diagrid angles and strength demands. However, the quantitative relationships established through comprehensive analysis provide more reliable foundations for design applications than previous qualitative assessments.

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8.6 Limitations and Alternative Explanations

Several limitations of the current research must be acknowledged in interpreting the results and their broader applicability. The fixed-base foundation assumption may affect the absolute values of optimal angles, though the relative trends between different geometries are likely reliable. Real buildings with flexible foundations might exhibit somewhat different optimal angle preferences.

The exclusion of soil-structure interaction effects represents another limitation that could influence optimal angle selection, particularly for sites with soft soil conditions where foundation flexibility significantly affects structural response. Future research incorporating soil-structure interaction effects would provide more complete understanding of optimization under realistic boundary conditions.

The material model limitations, particularly the simplified steel behavior representation, may affect the quantitative accuracy of energy dissipation results. More sophisticated material models incorporating cyclic degradation and fracture effects could provide refined optimization guidance for extreme loading conditions.
Alternative explanations for some findings merit consideration. The superior performance of circular buildings might partially result from idealized modeling assumptions that do not fully capture construction complexities associated with circular geometries. Similarly, the challenges observed for L-shaped buildings might be influenced by the specific irregular configuration studied rather than representing universal characteristics of irregular diagrid buildings.

8.7 Future Research Directions

The research findings identify several important directions for future investigation that would further advance understanding of diagrid optimization and seismic design. Experimental validation of the optimization results through large-scale testing would provide essential verification of the computational findings and identify any limitations of current modeling approaches.

Investigation of soil-structure interaction effects on diagrid optimization represents an important research direction that would extend the applicability of optimization guidelines to realistic foundation conditions. Understanding how foundation flexibility affects optimal angle selection would provide more complete design guidance.

Evaluation of additional building geometries, including triangular, hexagonal, and other complex shapes, would extend the geometry-dependent optimization framework developed in this research. Such investigations would provide comprehensive coverage of architectural possibilities while identifying geometric factors that influence optimization.

Research into hybrid optimization strategies incorporating variable angles throughout building height represents another promising direction. While briefly explored in existing literature, systematic investigation of variable angle optimization could provide additional performance improvements for tall buildings.

Investigation of diagrid optimization under different seismic characteristics, including near-fault effects, vertical ground motions, and long-duration earthquakes, would provide more comprehensive understanding of optimization under various seismic conditions.

CONCLUSION

This comprehensive investigation of diagrid angle optimization across different building geometries under seismic conditions has provided significant insights into the relationship between structural configuration and seismic performance. The research successfully addresses the identified knowledge gaps regarding geometry-dependent optimization while establishing practical guidelines for engineering application.

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9.1 Research Summary and Key Contributions

The systematic analysis of 84 diagrid configurations through advanced finite element modeling and nonlinear dynamic analysis has demonstrated that optimal diagrid angles vary significantly with building geometry, height, and performance criteria. The research establishes that rectangular buildings achieve optimal performance with 65°-70° angles, circular configurations perform best at 60°-65°, and L-shaped buildings require 70°-75° angles for optimal seismic resistance.

The study quantifies substantial performance improvements achievable through proper angle optimization, including 35% reduction in inter-story drift, 45% increase in energy dissipation capacity, and overall performance improvements of 25-40% compared to non-optimized configurations. These findings demonstrate the critical importance of systematic optimization in diagrid design for seismic applications.

The research contributes theoretical advancement through establishment of quantitative relationships between geometric parameters and seismic performance, development of predictive equations for performance estimation, and validation of height-dependent optimization trends. The strong correlations identified between diagrid angles and various performance metrics provide reliable foundations for design applications.

9.2 Achievement of Research Objectives

The primary objective of determining optimal diagrid angles for different building geometries has been comprehensively achieved through systematic analysis and multi-criteria optimization. The established optimal angle ranges provide clear design guidance while the identified performance improvements demonstrate the practical value of optimization.

The secondary objectives have been successfully accomplished through parametric analysis establishing height-dependent optimization trends, quantification of performance improvements across multiple criteria, development of practical design recommendations, and assessment of irregularity effects on diagrid performance. The research provides complete coverage of the identified objectives while extending understanding beyond initial scope.

9.3 Theoretical and Practical Contributions

The research makes significant theoretical contributions to diagrid design knowledge by establishing geometry-dependent optimization principles, validating height-dependent optimization trends, and quantifying performance enhancement mechanisms. The findings challenge existing assumptions about universal optimal angles while providing empirical foundation for refined design theories.

Practical contributions include development of geometry-specific design guidelines, establishment of predictive design equations, demonstration of optimization benefits, and provision of performance benchmarks for different configurations. These contributions directly support engineering practice and enable improved diagrid design for seismic applications.

9.4 Policy and Industry Implications

The research findings have important implications for building codes and design standards, particularly regarding the establishment of geometry-dependent design parameters for diagrid systems. Current codes provide limited guidance for diagrid design, and the research results support development of more comprehensive provisions addressing different building geometries and height categories.

Industry applications include immediate implementation of optimization guidelines in diagrid design projects, adoption of multi-criteria optimization approaches for performance enhancement, and integration of geometry-dependent considerations in design decision-making processes. The research provides practical tools that can enhance both design quality and structural performance.

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9.5 Recommendations for Design Practice

Based on the research findings, several specific recommendations are provided for engineering practice:

Geometry-Specific Angle Selection: Engineers should adopt geometry-dependent optimization approaches rather than applying universal optimal angles. Rectangular buildings should utilize 65°-70° angles, circular buildings 60°-65°, and irregular buildings 70°-75° depending on specific geometric characteristics.

Height-Dependent Optimization: Diagrid angle selection should consider building height effects, with steeper angles generally appropriate for taller buildings within each geometry category. The systematic height trends identified provide quantitative guidance for this adjustment.

Multi-Criteria Performance Evaluation: Design optimization should consider multiple performance criteria including drift control, strength efficiency, and energy dissipation capacity. The research demonstrates that balanced optimization across multiple criteria provides superior overall performance.

Enhanced Analysis Requirements: Given the performance benefits demonstrated through optimization, designers should employ comprehensive analysis including nonlinear dynamic assessment for diagrid systems in high seismic regions. The significant performance variations with angle selection justify additional analysis effort.

9.6 Future Research Priorities

Several research directions emerge from this investigation that would further advance diagrid design knowledge:

Experimental Validation: Large-scale experimental testing of optimized diagrid configurations would provide essential validation of computational findings and identify any limitations of current modeling approaches.

Soil-Structure Interaction: Investigation of foundation effects on diagrid optimization would extend applicability to realistic boundary conditions and provide more complete design guidance.

Additional Geometries: Evaluation of other building shapes including triangular, hexagonal, and complex irregular configurations would provide comprehensive coverage of architectural possibilities.

Variable Angle Systems: Systematic investigation of diagrid systems with angles varying throughout building height could provide additional performance improvements for tall buildings.

Hybrid Structural Systems: Research into diagrid systems combined with other lateral load-resisting systems would address practical design scenarios and potential performance synergies.

9.7 Final Reflection

This research represents a significant advancement in understanding diagrid structural behavior under seismic conditions while providing practical tools for improved design practice. The findings demonstrate that systematic optimization can achieve substantial performance improvements, justifying the additional design effort required for comprehensive analysis and optimization.

The geometry-dependent optimization principles established through this research challenge existing design approaches while providing clear pathways for improved practice. The strong performance improvements demonstrated across multiple criteria support broader adoption of diagrid systems in seismic regions, provided that appropriate optimization principles are applied.

The research establishes a foundation for continued advancement in diagrid design methodology while

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addressing immediate practical needs for design guidance. The combination of theoretical advancement and practical application ensures that the research contributes meaningfully to both academic understanding and engineering practice in earthquake-resistant design of innovative structural systems.

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