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REVIEW PAPER ON DIAGRID STRUCTURAL SYSTEMS STUDIES FOR ELEVATED STEEL BUILDINGS

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ABSTRACT

To date, a number of innovations have been made to enhance the behavior and performance of buildings. With its lattice-like aesthetics and high-efficiency structural performance, the Diagrid system is a cutting-edge structural solution for high rise buildings. The terms "diagrid" and "grid" may be literally translated as "diagonal" and "grid," respectively. In contrast to traditional structural systems like braced frames and framed-tube systems, this design eliminates all external vertical columns. A diamond-shaped structure is created by the division of the diagrid frame into repeating modules along its height.

Keywords– Diagrid structural system, Conventional system, Braced framed system, optimum diagonal angle.

1. INTRODUCTION

In the contemporary era, the shrinking amount of undeveloped land, rising land costs, and widespread urbanization have forced urban planners and architects to build cities vertically. The only way to achieve vertical growth is to build as high as you can. Making a desired structure upright and stable for the duration of its life is the responsibility of a structural designer. For tall structures, there are many different structural systems available, and the diagrid system is one among them. Diagrid is an external structural system that resists lateral stresses via the axial actions of peripherally placed diagonals. For multi-storey structures, a statistical study of tall buildings in India is conducted and reported. For symmetrical structures, a parametric analysis and comprehensive comparison of the diagrid structural system to the traditional frame is done.Wind and earthquake loads must be taken into account when designing high-rise structures since the structural system must withstand these lateral loads. Rigid frames, shear walls, wall-frames, braced tube systems, outrigger systems, diagrid systems, and tubular systems are some of the often utilized lateral load resisting systems.Due to its inherent structural and architectural benefits, a recent trend indicates that the Diagrid structural system is becoming more popular in the design of tall buildings. Diagrid is an external structural system that uses solely slanted columns on the building's façade instead of any perimeter vertical columns.

2. LITERATURE REVIEW

Khushbu Jania & Paresh V. Patelb [1] (2012)have carried out study, and a detailed design for a 36-story diagrid steel structure is offered. A standard floor layout of 36 m 36 m is taken into account. The modeling and analysis of structures are done using ETABS software. IS 800:2007 is used to design all structural elements while taking into account all load scenarios. For a 36 story structure, the load distribution in the diagrid system is also investigated.Additionally, the analysis and design outcomes of diagrid structures with 50, 60, 70, and 80 stories are presented. According to the research, the majority of lateral load is resisted by periphery diagonal columns, while gravity load is resisted by both internal columns and periphery diagonal columns. Internal columns must thus only be constructed for vertical loads. The periphery diagonal columns' increased lever arms make the diagrid structural system more efficient at resisting lateral loads. The axial force in the diagonal members on the outside of the structure resists the lateral and gravitational loads, which increases the efficiency of the system. Diagrid structural technology offers more design options for the building's interior and outside spaces. Nishith B. Panchal1 & Vinubhai R. Patel2 [2] (2014) A presentation is provided on the comparative analysis and design of a 20-storey diagrid structural system building and a simple frame building. A standard floor plan with dimensions of 18 meters by 18 meters is being considered. The ETABS 9.7.4 software is utilized for the purpose of structural modeling and analysis. The following data showcases the outcomes of the analysis, including displacement, storey drift, and storey shear. The design of both structures has been completed and the optimal member sizes have been determined to meet the requirements of the code. The study's findings indicate that the diagrid structure exhibits significantly lower top storey displacement compared to a simple frame building due to the diagonal columns' ability to resist lateral loads.The diagrid structural system exhibits significantly lower storey drift and storey shear.The design of both structures utilizes identical member sizes, however, these member sizes do not meet the design criteria for the simple frame structure, resulting in failure due to excessive top storey displacement. Larger member sizes are chosen to mitigate the risk of failure.The utilization of diagrid structure system results in greater efficiency in steel and concrete consumption in comparison to a basic frame building.

Nishith B. Panchal & Dr. V. R. Patel [3] (2014) Analyzed the diagrid from various perspectives and evaluated its performance across multiple building levels. A comparative study was conducted on a 36m x 36m plan, incorporating four distinct types of diagrid angles measuring 50.2°, 67.4°, 74.5°, and 82.1°, and four different building heights of 24, 36, 48, and 60 stories. The study's findings indicate that a diagrid angle ranging from 65° to 75° results in increased stiffness for the diagrid structural system, leading to reduced displacement in the top storey.The region of diagrid angle 65° to 75° exhibits significantly lower storey drift and storey shear results. As the structural mass decreases and stiffness increases, the time period of the structure decreases. This phenomenon is particularly evident in the diagrid angle range of 65° to 75°, indicating a higher degree of stiffness and lower structural mass.Diagonal grid (diagrid) structures with an angle ranging from 65° to 75° exhibit higher efficiency in terms of steel and concrete consumption when compared to other angles of diagrid.As the number of storeys in a building increases, the height of the building also increases. It has been observed that a diagrid angle ranging from 65° to 75° yields superior outcomes in terms of top storey displacement, storey drift, storey shear, time period, and material consumption.The implementation of a diagrid structural system yields greater cost-effectiveness and advantages when the number of floors exceeds 40, and the diagrid angle falls within the range of 65° to 75°.The range of 65° to 75° is where the optimum angle of diagrid is observed.

Ravish Khan & S.B. Shinde [4] (2015) Two structural models, namely diagrid model and braced frame model, have been taken into consideration for this study. The modeling of both structures involves the following data. A high-rise structure consisting of 20 floors, with a plan dimension of 18 meters by 18 meters, and a total height of 72 meters is being considered for two models. Each floor has a height of 3.6 meters in both models. The diagrid's dimensions consist of a 350mm pipe section with a thickness of 12mm, set at an angle of 67.4°.The braced frame model employs inverted V-type bracings consisting of a 180x180x15mm long leg back-to-back double angle section. The terrace level experiences a dead load of 5.5 kilonewtons per square meter, while the floor level experiences a dead load of 4 kilonewtons per square meter. The terrace level of both models is subjected to a live load of 1.5kN/m2, while the floor level of both models is subjected to a live load of 4kN/m2. As per IS-1893-2002, the earthquake load parameters comprise of a zone factor of 0.1, soil type II, importance factor of 1, and response reduction of 5. The process of modeling, analyzing, and designing structures is performed using the STAAD Pro V8i software. The design of columns adheres to the IS-456-2000 standard, while the design of beams, diagrids, and bracings follows the IS 800-2007 standard. The study's findings indicate that the diagrid structure exhibits similar lateral load resistance to the exterior braced structure, despite the absence of vertical columns in the periphery of the diagrid structure.The diagrid structure exhibits lower levels of storey shear compared to the braced frame structure.The differential displacement of the highest level in the diagrid system is 30.7% lower than that of the outer frame structure.The topmost level of displacement in a diagrid structure is 46.7% lower compared to an exterior frame structure.

Manthan I. Shah& Snehal V. Mevada [5] (2016) The individual has conducted an evaluation and contrast of data. The study involved the modelling, analysis, and design of seven steel buildings with varying heights using ETABS software. Two structural systems were considered, namely diagrid and conventional frame.The process of analyzing and designing structures takes into account the effects of dead load, live load, lateral earthquake load, and lateral wind load. In seismic engineering, seismic loads are evaluated through both static and response spectrum analyses. Buildings are assigned to Zone V to account for extreme lateral load conditions. The selected parameters for comparison include the fundamental time period, maximum lateral displacement of the top storey, maximum base shear, weight of steel, percentage difference in weight, maximum displacement of each storey, and maximum drift of each storey. Additionally, the regulation of lateral force is also established. Based on the quantitative analysis conducted in the current research endeavor, the following primary deductions can be made:The diagrid structural system is a superior option for resisting lateral loads due to its ability to minimize lateral displacements, reduce steel weight, and increase stiffness. The material exhibits sufficient rigidity to withstand wind loads at elevated elevations.The utilization of diagrid structure results in superior steel weight efficiency and visually pleasing aesthetics. In a 24-story building, the weight of a conventional frame is 100% greater than that of a diagrid building.bservations indicate that diagrid systems exhibit lower displacements on each storey and storey drifts in comparison to conventional frames.

Kiran Kamath & Sachin Hirannaiah [6] (2016) The objective is to conduct a nonlinear static pushover analysis to examine the performance characteristics of diagrid structures. The analyzed models exhibit a circular configuration and possess an aspect ratio denoted as H/B (where H represents the overall height and B represents the base width of the structure) that ranges from 2.67 to 4.26. Kim et al. (2010) have considered three distinct external brace angles, namely 59◦, 71◦, and 78◦. The base width is maintained at a constant value of 12 meters while the height of the structure is adjusted accordingly. The plastic hinges in the model are utilized to represent the nonlinear behavior of the elements, which is based on the moment-curvature relationship outlined in the FEMA 356 guidelines. Nonlinear static analysis was utilized to assess the seismic response of the structure in relation to base shear and roof displacement at the performance point. The findings were subsequently compared. The following observations have been derived from the current analysis.In the current study, it was observed that structures with a brace angle of 59 degrees exhibit lower base shear at performance for all aspect ratios considered, compared to other brace angles.The study found that models featuring a 71-degree brace angle exhibit greater base shear during performance in comparison to other brace angles examined.The structural performance is impacted by the angle and aspect ratio of the brace.

Dr. Gopisiddappa, M. Divyashree & Sindhuja G [7] (2017)A comparative analysis was conducted on a 30-story linear building and diagrid systems with varying diagonal angles of 45°, 63°, 73°, 75°, 78°, and 81°. A comparative analysis is conducted between linear and diagrid construction methodologies.The ETABS software is utilized for the purpose of structural modeling and analysis. The presented data includes analysis results such as storey displacement and inter-storey drift. The study yielded the following conclusions.The absence of a load resisting system in a framing building results in greater drift and displacement values when compared to a diagrid system.The diagonal bracing system with an angle of 63 degrees results in reduced displacement of the top storey.In the angular region of 63 to 75 degrees, the diagrid system exhibits superior stiffness, with reduced storey drift and storey displacement.

Snehal S. Mali [8] (2017) The seismic response of a diagrid building and a conventional frame structure has been analyzed in seismic zone IV with hard soil type. The model possesses identical parameters to both diagrid and conventional frame structures. The positioning of the diagrid has been determined for the opposing face, three faces, and all faces within the model. The ETABS software is utilized to perform Equivalent Static Analysis, Response Spectrum Analysis, and Wind Analysis. The output is expressed in terms of displacement. The findings suggest that the lateral displacement of diagrid structures is notably lower than that of conventional structures in both the X and Y directions, by 45.48% and 41.71%, 45.92%, and 42.17%, respectively, when subjected to response spectrum analysis under equivalent static conditions. The wind analysis indicates that the lateral displacement of the diagrid structure is significantly lower than that of the conventional structure, with a reduction of 45.34% in the X direction and 41.59% in the Y direction.

Mohammed Abdul Rafey & M. A. Azeem [9] (2018) The study examined various models of diagrid structures and conventional braced frame structures featuring distinct symmetric and asymmetric plan geometries. Two sets of structures, consisting of two symmetric and two asymmetric models each, were subjected to linear static analysis for the purpose of analysis. Exterior diagrids were constructed using hollow mild steel pipes, while exterior bracing was accomplished using ISA angle sections. The study found that the diagrid structures exhibited superior resistance to lateral loads compared to the conventional braced frame structure. Additionally, the member stiffness of the diagrid structure elements was significantly higher than that of the conventional braced structure, despite the absence of peripheral vertical columns in the diagrid structure. The diagrid models exhibit lower top storey displacements in comparison to the conventional braced frame models. The storey shear of diagrid models exhibits a significant reduction in comparison to conventional braced frame models due to the lower seismic weights of diagrid structures.

Amruta K.Potdar [10] (2018)A presentation is provided on the comparative analysis and design of a 20-storey building utilizing a diagrid structural system versus a simple frame building. A floor plan with dimensions of 15 meters by 15 meters is being considered. Various diagrid angle models (45°, 63°, 71°, 75°, and conventional) have been developed. The ETABS 15 software is utilized for the purpose of structural modeling and analysis. The following conclusions were reached.The utilization of diagrid structural system exhibits reduced lateral displacement and drift as compared to traditional building structures. The axial load experienced by an internal column is comparatively lower in a diagrid building when compared to a conventional building. The diagonal grid structural system exhibits a lower shear force in the interior beam when compared to a conventional building.The recommended range of diagrid angle for a 20-storey structure is approximately between 60º to 70º.Diagrid buildings exhibit superior aesthetic appeal when compared to traditional buildings, making them a crucial consideration for high-rise structures.The diagrid structural system exhibits superior lateral load resistance as a result of its diagonal columns situated on the periphery. Consequently, the inner columns experience reduced stress and are responsible solely for supporting gravity loads. In traditional construction, the inner and outer columns are engineered to withstand both vertical and horizontal forces.

Mahdi Heshmatia , Alireza Khatamia & Hamzeh Shakiba [11] (2020)I have conducted an analysis on diagrid structures consisting of 36 stories, each with a consistent story height of 4.0 meters. All archetypes exhibit symmetry and comprise of six bays measuring 6.0 meters in both directions. Exterior frames are designed with uniform diagonal angles of 53°, 69°, 76°, and 79°. The internal frames are assumed to be pin-connected and are responsible for carrying only gravity loads. Conversely, a diagonal inclination of 69 degrees is postulated for the internal diagrid framework in tube-in-tube diagrid configurations. The Diagrid structures are modular in nature, with each module consisting of 2, 4, 6, or 8 stories. The modules are stacked vertically to form the overall structure. A uniform dead load of 5 kilonewtons per square meter (KN/m2), live load of 3 KN/m2, and partition load of 1 KN/m2 are being imposed on the floors. The archetypes were created to meet the SDC Dmax requirements outlined in FEMA P695 [23], with an SDS of 1.0g and SD1 of 0.6. The diagonal components were constructed using steel of grade 50, possessing a yield strength (Fy) of 345 MPa and a tensile strength (Fu) of 450 MPa. Beams are constructed using steel material that has a yield strength (Fy) of 250 MPa and a tensile strength (Fu) of 400 MPa. The utilization of response spectrum analysis is employed for seismic analysis in accordance with the specifications outlined in ASCE/SEI 7-16 [24]. The findings from the nonlinear static analyses indicate that in cases where the diagonal angles are less than those of the core, the interior tube can serve as a secondary load-resisting system following the yielding of the perimeter tube. Furthermore, the majority of diagrid structures exhibited the ability to undergo significant deformations without experiencing sudden failure throughout the entire system. Also The utilization of an interior diagrid tube effectively delayed the onset of damage states and afforded a safety buffer for the core diagrid structures. The performance of diagrid structures was deemed satisfactory during seismic activity, with the majority of mean deformations falling within acceptable limits. Deformations were observed to be distributed vertically, and the incorporation of an interior diagrid tube improved the dispersion of forces towards higher levels, particularly in models with greater diagonal angles. The residual drift distribution analysis validated the structural integrity of the diagrid system during infrequent seismic events.

Shith B. Panchal & Dr. V. R. Patel [12] (2020) The seismic performance of diagrid structures with varying angles across 36 stories has been assessed through pushover and nonlinear time history analysis. To assess the impact of diagrid core on structural performance, diagrid frames are utilized to substitute interior gravity frames. The pushover analysis findings indicate that the utilization of diagrid core can improve the structural hardening characteristics in cases where the angles of the perimeter panels are less than or equal to those of the core, as opposed to traditional diagrids. Furthermore, the primary diagrids offer secure allowances between the impairment conditions during horizontal loading. Subsequent to this, nonlinear time history analyses are executed to evaluate the inter-story drift ratio, residual drift, energy dissipation, and distribution of hinges in structures. Empirical evidence suggests that a majority of structural models exhibit satisfactory performance when subjected to infrequent seismic activity. Additionally, the distribution of hinges is evenly dispersed throughout the height of various structural components, while diagrid structures demonstrate the ability to withstand significant deformations during rare seismic events. A significant amount of input energy is dissipated by diagonal members, and due to the exterior diagonals having a steeper slope than the perimeter tube, the diagrid core effectively contributes to energy dissipation. The performance of diagrid structures was deemed satisfactory under seismic activity, with the majority of mean deformations falling within acceptable limits. Deformations were observed to be distributed vertically, and the inclusion of an interior diagrid tube improved the distribution of forces towards higher levels, particularly in models with greater diagonal angles. The residual drift distribution analysis provided evidence that the diagrid structural system exhibited satisfactory performance during infrequent seismic events.

3. CONCLUSION

The literature review presented above demonstrates a comparative analysis of diagrid structure models with conventional frame models and braced frame models. Different structural irregularities are taken into account while considering various angles of diagrid. The utilization of various software programs such as ETABS, STAAD Pro, and SAP2000 is necessary for conducting response spectrum, time history, and pushover analyses. etc Based on the findings of the literature review, it can be inferred that the diagrid structure exhibits greater stiffness in comparison to the conventional model.

- The diagrid structural system exhibits higher resistance to lateral loads in comparison to the braced frame structural system.
- The optimal angle varies in relation to the height of the diagrid structure.
- The optimal angles are within the range of 60° to 75°, depending on the height of the structure.

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