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Diagridstructural Systems Studies for Elevated Steel Buildings

***Sahil Nandal*[1], *Sheela Malik*[2], *Shivender*[3]**

[1] **M.Tech Scholar, Ganga Institute of Tech. & Management, Jhajjar, India** sahilnandal999@gmail.com
[2] **Assistant Professor, Ganga Institute of Tech. & Management, Jhajjar, India** sheelamalik2209@gmail.com
[3] **Junior Engineer, CADA (Irrigation Dept) Haryana, India** shivender3333@gmail.com

ABSTRACT

The utilization of diagrid systems is increasing due to their robustness and visually appealing characteristics as a substitute for high-rise buildings. In comparison to conventional structures, it has enhanced the rigidity and reduced the weight of the construction. The study concludes that concrete filled steel tubes (CFST) are a suitable choice for columns in diagrid structural systems for tall structures, based on their favourable performance. The seismic performance of diagrids with buckling restrained braces (BRBs) was evaluated. A study was conducted to analyze the seismic resilience of diagrid structural systems.

Keywords: Diagrid Structural Systems, Tall Buildings, Seismic Reliability, Buckling Restrained Braces, Concrete Filled Steel Tubes.

1. INTRODUCTION

The diagrid structural system is a novel structural system that has emerged as a significant structural and architectural element in high-rise buildings. In contrast to traditional structures, this particular architectural blueprint eliminates vertical columns, distributes both gravitational and lateral loads throughout the frame, and minimizes the utilization of steel. The diagrid structural system has garnered interest from structural scholars and engineers due to its effective lateral and torsional rigidity. The utilization of the innovative diagrid technique in the construction of tall buildings with unique designs can be attributed to the benefits of the triangular pattern. The present design methodology has led to a diverse range of architectural structures, encompassing contorted, conical, inclined, and unstructured forms. Swiss Re located in London, Hearst Tower situated in New York, Cyclone Tower in Asan (South Korea), Abu Dhabi's Capital Gate Tower, and China's Jinling Tower are notable examples of buildings featuring diagrid structures. The employment of a diagrid structural system to maintain a complex form is exemplified by the recently constructed Central China Television (CCTV) headquarters in Beijing. CFST (Concrete-Filled Steel Tube) columns exhibit exceptional seismic resistance structural characteristics, such as high tensile strength, ductility, and capacity for energy dissipation. Composite Fibre Reinforced Polymer (CFRP) and Steel Tubular (CFST) components are ideal for diagrid structural members due to their composite nature that incorporates both concrete and steel. The compressive strength of the CFST column allows for a significant reduction in its cross-sectional size. The high strength-to-weight ratio and stiffness of the concrete-filled steel tube (CFST) column render it a suitable choice for incorporation into diagrid structural systems. The implementation of buckling constrained braces, as suggested, could enhance the seismic performance factors of diagrids by partially substituting the diagonal components. Diagrid structures are a type of architectural construction that utilizes reduced material quantities compared to traditional methods for supporting high-rise buildings. Additionally, they provide increased flexibility in terms of design options due to their ability to function without a plan. Diagrid structural systems exhibit superior material efficiency compared to other tall building support systems, and they provide enhanced plan flexibility by eliminating the need for interior or corner columns. This technological solution offers exceptional resistance to lateral loads, wind loads, and seismic loads. It also provides greater flexibility in architectural design for tall buildings with intricate and non-uniform geometries.


(a) Hearst Tower in New York (b) Swiss Re building in London (c)International Finance Center in Guangzhou

Figure 1: Example for Diagrid Structures.

2. OBJECTICES

The objective is to evaluate the present status of seismic reliability analysis pertaining to steel diagrid structural systems and pinpoint deficiencies in the current knowledge base.

The objective is to assess the efficacy of existing design codes and guidelines in managing the seismic dependability of steel diagrid structural systems.

1. The objective is to analyze the failure modes of steel diagrid structural systems when subjected to seismic loading and devise methods to alleviate these failure modes.
2. The objective is to conduct a seismic performance analysis of steel diagrid structural systems using advanced numerical simulation techniques like finite element analysis. The obtained results will be compared with experimental data.
3. The objective is to suggest alterations to the existing design codes and guidelines, if deemed necessary, with the aim of enhancing the seismic dependability of steel diagrid structural systems.
4. The objective of this study is to propose suggestions for prospective research avenues in the domain of seismic dependability assessment of steel diagrid structural systems.

3. METHODOLOGY

EFFECT OF HEIGHT

Due to their high structural efficiency and potential for architectural aesthetics, digrid systems are frequently utilized in contemporary skyscrapers. Kyoung Sun Moona conducted a study on the structural efficacy of diagrid systems implemented in high-rise structures featuring atypical geometries, such as contorted, inclined, and non-linear towers. The structure is subjected to two primary types of loading, namely gravity load and lateral load. The structural design of tall buildings is governed by lateral loads induced by wind or earthquakes. As the height of a building increases, the lateral load resisting system becomes more important than the structural system that resists gravity stresses. With an increase in structure height, the lateral load resisting system exhibits superior resistance to gravity loads compared to the structural system. In a framed tube structure, the axial action of the diagonal in inclined columns is utilized to resist lateral loads, as opposed to the bending of vertical columns. Due to the diagonal members present on the perimeter of the building, diagrid structures are capable of resisting lateral shear forces without the need for a central core. According to the study conducted by Khushbu Jani et al. [7], the wind load's base shear is higher than the earthquake load for the 36-story diagrid structure. The design of the structure is determined by the wind load. The optimal building height is determined by the net return percentage, which is the most cost-effective option. As per the analysis conducted by Clark and Kingston in 1930 to assess diverse height designs, it was concluded that constructing a 63-storey skyscraper in Manhattan would be the most economical choice. The majority of the world's 200 tallest buildings, specifically 76 percent, are within the range of 60 to 70 stories. This indicates that this particular range is still the most economically efficient.

SEISMIC RELIABILITY WITH FIXED DIAGRID ANGLE

The two primary parameters that significantly affect the lateral stiffness and structural efficiency of a diagrid are its topography and the angle of its diagonals with respect to the horizontal. Designers must aim for precise ideal benchmarks in contrast to the progressively significant matter of visual appeal. After defining the optimal criteria, the determination of the optimal angle involves considering several factors such as the building's design, storey height, aspect ratio, lateral load distribution, and location. In the study conducted by Neha Tirkey et al. [16], it was determined that a diagrid angle of 63° yielded optimal outcomes for the construction of the G+20 storey skyscraper. Per the findings of Moon et al. [1], The optimal range of diagrid angles is frequently observed to be between 55° and 75°, based on the height and aspect ratio of the diagrid structures. The study conducted by Kim and Lee [5] revealed that diagrid configurations featuring a bracing angle ranging from 60° to 70° exhibited optimal performance in terms of load resistance against both lateral and gravitational forces. In the construction of diagrid structures with a fixed diagonal angle, it is necessary to adjust the ideal angle in order to achieve the desired design while minimizing material usage and lateral displacements, as outlined in the Moon [3] study. The optimal angles determined in this inquiry were within the range of 60 to 70 degrees. Per the findings of Sadeghi and Rofooei [18], As the diagonal angles increase from 45° to 63.4°, there is a gradual increase in both the ductility reduction factor (R) and the response modification factor (R). The diagonal angles of 63.4° were found to be optimal for both R and R in 12-story models, including those equipped with buckling restrained braces. This was observed in both initial models and subsequent analyses. The diagrid structure featuring a diagonal angle of 63.4° exhibits the greatest PI value with respect to collapse intensities. The collapse intensities of 8 and 12 storey models with a diagonal angle of 63.4° experienced an average increase of 60%. Upon reaching a specific threshold of the height to width aspect ratio, it has been established that utilizing a uniform diagonal angle aids in achieving an optimal design solution. Asadi and Adeli [15] conducted a study on the seismic performance characteristics of low- to moderate-rise diagrid buildings. In their research, it was suggested that conventional steel diagrid structures ranging from 8 to 30 stories should have an R-factor of 4 to 5. A seismic response coefficient (R factor) ranging from 3.5 to 4 is deemed appropriate for low-rise steel diagrid structures, specifically those with a height of less than 8 stories. In a subsequent investigation, Heshmati and Aghakouchak [14] employed the FEMA P695 methodology to ascertain the R factor for diagrid structures and observed that a value of 4.5 typically yields satisfactory outcomes. Moreover, as the inclination of the peripheral diagonal components increases, the ratios of over strength and collapse margin decrease, while the ductility of the system enhances. According to the findings of V. Mohsenian et al. in their research paper [19], diagrid systems having a response modification factor of 4 are capable of retaining a suitable safety margin to meet the performance levels required for life safety during seismic events that occur as per the design basis. For seismic events with the highest level of consideration, this reaction modification factor value frequently guarantees performance levels that exceed the threshold of life safety.

CONCRETE FILLED STEEL TUBES [CFST]

The seismic resistance properties of Concrete-filled steel tubular (CFST) columns are exceptional, owing to their high strength, flexibility, and energy absorption capacity. CFST diagrid structures typically employ a configuration of four CFST columns that intersect obliquely for their connections. HAN Xiaolei et al. [2] suggested a new type of connection, which was tested using two specimens at a scale of 1/5.5 under monotonic axial loading. The experimental analysis involved the measurement and examination of the deflection, stress, failure mechanisms, and capacity of the specimens. The experimental conditions involved utilizing column separation angles of 20° and 35°. The deformation of the tube in the connecting region resulted in the malfunction of the specimens having a separation angle of 20°. Specimens featuring a 35° separation angle experienced failure due to the extrusion of the tube beyond the connecting zone. The mechanical characteristics of the connections were verified to be similar to those of short columns made of concrete-filled steel tubes (CFST). The failure scenarios are significantly influenced by the interconnecting angle of the CFST columns. The behaviour of the connection remains invariant with respect to the loading type of the connection. The compressive strength of the CFST column enables a significant reduction in its cross-sectional dimensions. The characteristics of the Concrete Filled Steel Tube (CFST) column render it appropriate for implementation in diagrid structural frameworks. The study of joints in different forms has led to the conclusion that a lining plate with a ring reinforce plate joint of CFST can fulfill the requirement for a stronger connection and weaker component. The steel tube serves as a confinement element for the concrete in CFST joints, thereby enhancing the compressive strength of the concrete and mitigating the risk of buckling failure of the steel tube. The production of joints poses certain challenges owing to the amalgamation of two distinct materials.

BUCKLING RESTRAINED BRACES

In cases where diagrid members are utilized as super members for multiple stories or modules, it may be necessary to implement an internal load-bearing system, such as a moment-resisting or concentrically braced frame, in conjunction with the primary external diagrid system. Based on empirical evidence, Base Isolation Systems (BRBs) have been identified as a viable mechanism for mitigating structural harm and dispersing seismic forces. High-rise mega braced frame systems exhibit distinct characteristics in their construction and behaviour, including prolonged periods and increased mode effects, which differ from those observed in medium and low-rise structures. The results indicate that the implementation of Buckling Restrained Braces (BRBs) in place of diagonal elements can enhance the seismic performance of diagrid structures. This is due to the ability of BRBs to rapidly accumulate plastic damages and prevent buckling of the remaining diagonals. The implementation of Buckling Restrained Braces (BRBs) on the diagonals results in a more uniform distribution of plastic behaviour throughout the structure. Several modifications have been suggested by experts to enhance the ductility of diagrid and mitigate the risk of brittle fracture in the event of significant seismic activity. The utilization of a buckling restrained brace element, which includes a low yield-point steel core material located at the centre, enables the attainment of adequate plastic deformation when subjected to axial loading. The implementation of Buckling Restrained Braces (BRBs) results in an increased uplift in the collapse drifts of diagonal angles that are wider in Digrid structures. The inner brace core exerts a negligible effect on the global stiffness of the diagrid system. To the best of the authors' knowledge, the design of diagrid structures lacks sufficient attention to a crucial aspect, namely the requirement of bracing for multi-storey diagrid modules. Certain scholars have proposed enhancements to improve the ductility of diagrid and prevent brittle fracture of the structure during seismic events of significant magnitude. Utilizing a buckling restrained brace element, which incorporates a low yield point steel core material at its centre, will yield adequate plastic deformation when subjected to axial loading.

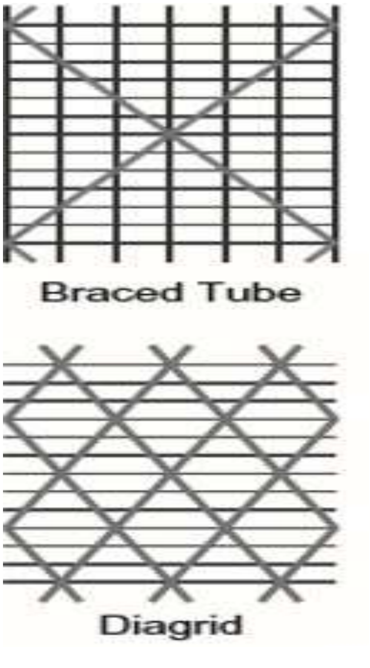

Figure 2: Braced Tube vs Diagrid Structure

4. CONCLUSION

Diagrid structural systems have witnessed a surge in their application in high-rise constructions over the past ten years. Due to their superior lateral stiffness and aesthetic properties, they have the potential to be a more widely utilized structural system in mid- and high-rise buildings. A comparative study was conducted using ETABS software to assess the stiffness and flexibility of high-rise structures with different diagrid designs. The study examined the performance of CFST diagrid structure connections under axial monotonic compression loads. The generalizability of the outcomes to other connections is uncertain. The results indicated that diagrid structures exhibit satisfactory seismic performance.

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