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Effect of Diagrid Systems on Seismic Performance of High Rise Buildings

Elmi Abdiaziz Abdillahi*

Hargeisa Group Hospital, Maroodi-jeh, Somalia

*Corresponding Author: Elmi Abdiaziz Abdillahi, Hargeisa Group Hospital, Maroodi-jeh, Somalia, Tel: 252614745666, E--mail: hooyo1994aabo@gmail.com

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Abstract

In the past decade, numerous research works have been conducted on diagrid buildings. Researchers and practitioners have recognized the importance of diagrid structures, and as a result, have developed advanced design strategies to improve the efficiency and economy of diagrid structural systems. The unique architectural flexibility and structural efficiency of the diagrid make it an innovative system for tall buildings. To further expand on this innovation, multiple studies have focused on joint connections and established design methodologies. Therefore, the objective of this paper is to provide a systematic summary of existing research accomplishments related to the diagrid structural system in tall buildings.

Keywords: Diagrid structural system; Optimum diagonal angle; Framed structures; bending moment; Time period; seismic forceshear force; deflection; axial force; wind pressure; shear wall

Introduction

The progression of structural systems efficiency, scarcity of urban land, advances in construction technology, and advanced computational techniques all contribute to the growth of high- rise structures. Since the last few decades, the number of high--rise structures in the world's major cities has increased. Wind and earthquake lateral loading, as well as gravitational loading, govern the design of high-rise buildings. Exterior and interior structural systems are provided for tall structures to withstand lateral loads. Resisting systems of internal lateral load that are commonly used include rigid frames, braced frames, shear walls, and outrigger structures. Tubular structure and diagrid structure are the exterior systems.

Because of its structural efficiency, the diagrid system has recently been carried out to numerous tall steel buildings. Diagrid is a type of space truss in which there are no conventional columns on the structure's exterior periphery. Diagrid is made up of a series of triangulated truss systems that are formed by intersecting diagonal columns and horizontal beams.

The Diagrid structural system allows for greater flexibility in the planning of interior space and the building's facade.

The term "diagrid" is not a new concept. It's derived from the word's "diagonal" and "grid." Diagrid structures are the most recent evolution of braced tube structures. Almost all conventional vertical columns are eliminated in diagrid structures. Because of their triangulated configuration, the diagonal members in a diagrid system can carry gravity load as well as lateral forces. The axial action of the diagonal members in a diagrid carries shear, whereas the bending of the vertical columns in a conventional framed tubular structure carries shear. Diagrid structures do not require high shear rigidity cores because shear can be carried by diagrids on the perimeter.

A diagrid system's configuration and efficiency reduce the number of structural elements required on the building's facade, resulting in less obstruction to the outside view. The structural efficiency of the diagrid system also aids in the avoidance of interior and corner columns, allowing for significant floor plan flexibility. Diagrids can be made of steel, concrete, or wood. Because of the flexibility of the triangulated shape, diagrids can be used to model any complex shaped building.

Literature Review

Khushbu Jani and Paresh V. Patel [1] operated on Analysis and Design of High-Rise Structural diagrid steel System. In their research, they have considered a 36-story diagrid steel structure that is dynamic alongside and across wind for structure's design and analysis. Displacement, time period, inter-storey drift and top storey are the results compared in this analysis. According to the findings, exterior columns effectively carry both gravity and lateral loads, whereas interior columns carry only vertical loads.

Boake (2014) [2] investigated the diagrid structures designed and built in the last few decades. It explains how the diagrid system has evolved to the point where it is no longer limited to tall buildings. According to the report, diagrid construction can also be found in a variety of innovative midrise steel projects.

Kwon and Kim (2014) [3] examined the progressive failure resisting capacities of tall diagrid buildings under various column removal scenarios, as well as the seismic load resisting capacity of diagrid buildings. The structure's analysis model was found to be harmless against progressive flop instigated by the removal of one or two diagrid pairs from the first storey.

Kyoung Sun Moon [4] carried on a project called Design Methodology based Stiffness for Braced Steel Tube Structure, A Sustainable Tactic. In this paper, they used a stiffness-based design methodology to evaluate preparatory braced tube member sizes for tall buildings. They discussed the effects of various economic designs on geometrical configurations of structural members and made recommendations for the optimal geometries. They have also investigated the impact of the diagonal angle acting on the structural design of a braced tube structure.

Moon (2009) [5] investigated 40, 50, 60, 70, and 80 storey diagrid tall structures with uniform angle and varying angle diagrids to better understand the diagrid structure design procedure. It was concluded that by configuring diagrids for tall buildings to have optimal grid geometries, the efficiency of diagrid structures for tall buildings can be maximised.

T. H. Kim et al. 2017, [6] in this study, An Iso Truss® grid (ITG) system was used to create a structure, and its behavior was compared to that of a diagrid system. Exterior columns were placed obliquely and vertically and were connected in a zigzag pattern across the building's height. The primary function of exterior columns was to allow for more free space in a building. The structural efficiency of a 64-story building was evaluated using diagrid and ITG. In addition, stiffness-based criteria were used for the structural design of the diagrid and ITG systems. Its viability was investigated by means of lateral displacement control at the top of the building and steel capacity for the columns in the peripheral frame. The structural performance of the proposed system was found to be similar to that of the diagrid system based on the outcomes of the analyses.

Kim "et al." [7] Evaluated the seismic behavior of a typical diagrid structure. He came to the conclusion that diagrid structures have higher strength and lower ductility than tubular structures. Diagrid structures can be made more ductile by substituting the diagonal members with restrained buckling braces.

Leonard “et al.” [8] Conducted research on the shear lag impact in high-rise buildings using the diagrid system and indicated that the diagrid structure conducted three times effectively than framed tube buildings.

Dentification of Gabs

1) The behavior of diagrid Systems in Steel Framed Structures has not been extensively studied through research.

2) To gain a comprehensive understanding of steel constructions, it is necessary to conduct more research into the diverse range of diagrid angles that are utilized in steel structures.

3) Different combinations of diagrid bracing systems and their behavior must be studied.

Objectives of the Study

The main objectives of this study titled: **“Analysis and Design of G+20 High Rise Diagrid Structure Using Staad Pro”** is as follows:

1) To investigate the performance of high-rise diagrid structures.

2) To investigate the behavior of a diagrid structure with a regular plan when subjected to wind and seismic loading.

3) To study the behavior of different buildings (regular and Irregular in plan) using different bracing systems

4) To check and adopt the most favorable bracing system and arrangement for a particular type of building.

5) To study the behaviour of Re-entrant corners in buildings with plan irregularities using different Bracing arrangements.

Methodology

1) The design methodology is carried out to a set of G+20 story tall diagrid structures. To find out the optimum grid structural properties of the structure within a certain height range, each storey height of diagrid building is intended with diagonals of varied uniform angles as well as diagonals of rapidly changing angles over the building height. The building’s typical plan dimensions are 36x36 meters with typical storey heights of 3 meters each.

2) Using static loading evaluate and calculate the intensity of wind pressure and Earthquake volume acting on the different heights of the structure and assign the values accordingly to the structure.

3) Analyse the structure to find out the reactions, displacements and deflections at various nodes of the structure and to compare the value of maximum node displacement, bending moment, and sheer force of beam with respect to increasing height of structure.

4) Run the Analysis command to see the reactions, displacements, deflections, axial forces, shear force and bending moments for the various members of the structure.

5) Finally, steel design is carried out for the beams, columns and diagrids as per IS 800, 2007 and concrete design is carried out for the slab in accordance with IS 456:2000 by defining appropriate design commands for various structural components.

Analysis and Results

A comparison of two different steel frame structures is carried out in this project, one of G+20 high rise diagrid structure and the other of simple frame structure. They both carrying steel and concrete design. Steel design is carried out for the beams, columns and diagrids as per IS 800, 2007 and concrete design is carried out for the slab in accordance with IS 456:2000 by defining appropriate design commands for various structural components. The results are compared in terms time period, shear force, bending moment and displacement. Fig 1 shows a comparison of the time periods of both systems. The figure shows that as the building height increases, the time period of the diagrid remains smaller than that of the conventional frame building. As a result, the diagrid structure is if far than the conventional f rame.

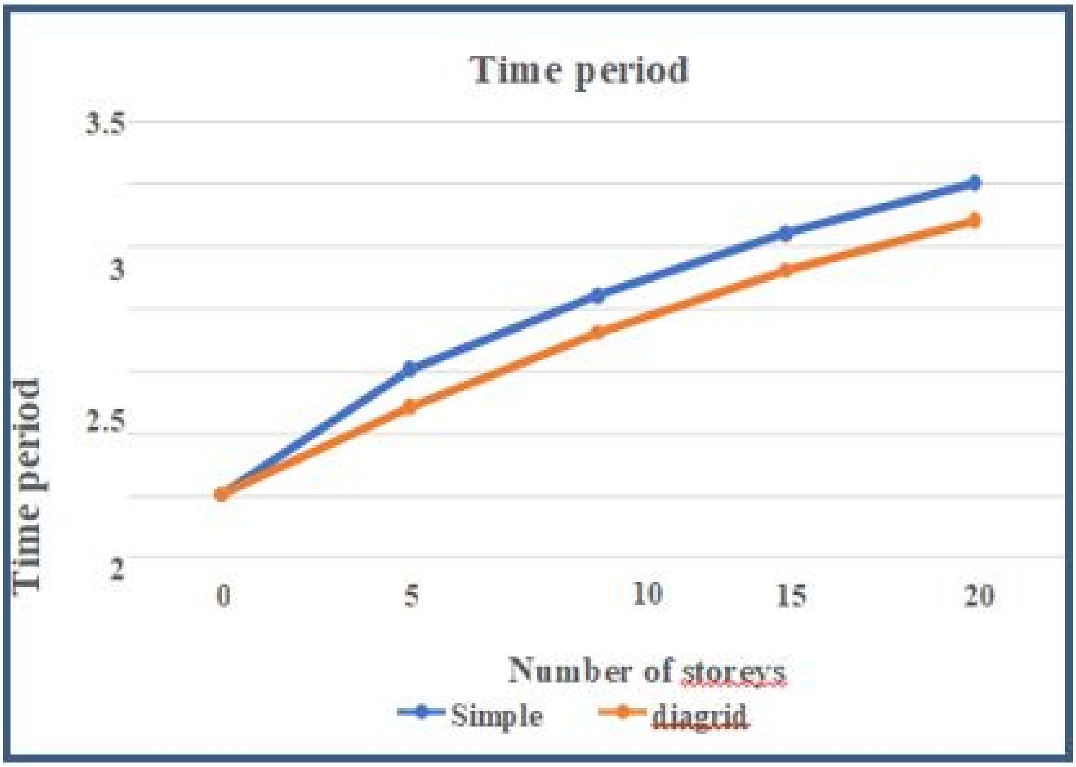

Figure 1: time period

Table 1: shear force values

Beam No	2281	2235	2175
Simple Frame	14.96	14.96	14.96
Diagrid Frame	0.66	2.98	8.5

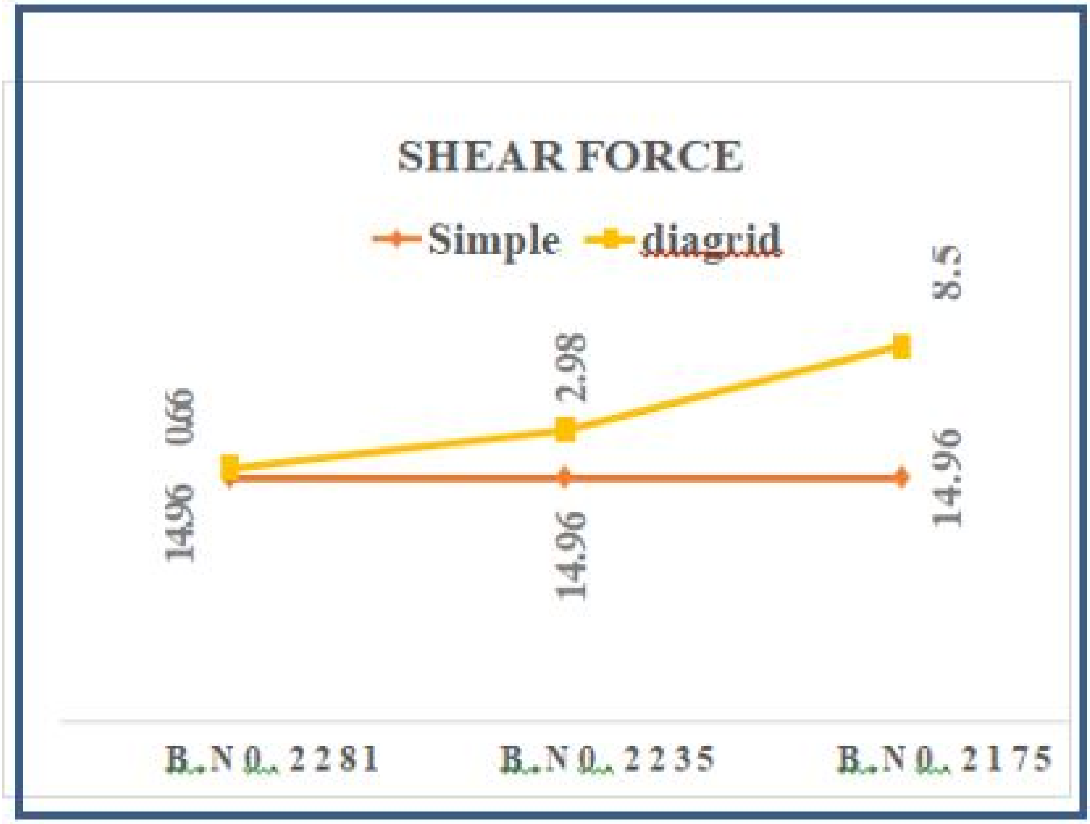

Figure 2: shear force

Table 3: bending moment values

Deflection	Diagrid frame	Simple frame
Beam no.2280	0.95	1.56
Beam no.2248	0.40	3.63
Beam no.2140	1.29	3.33

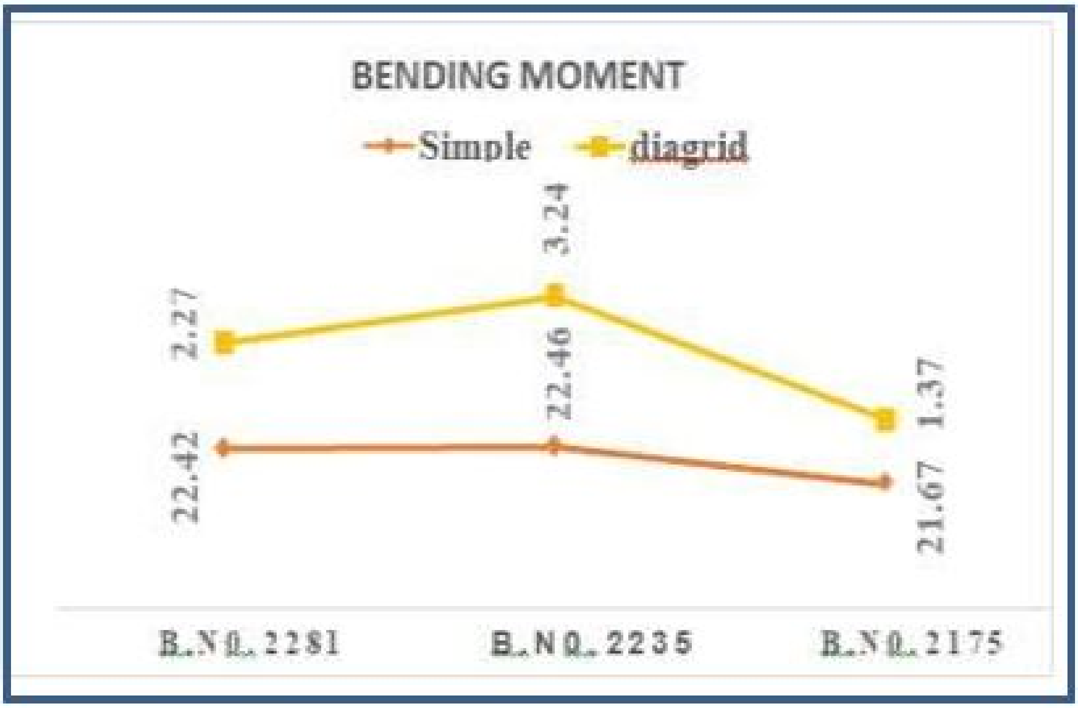

Figure 3: bending moment

Table 3: Deflection values

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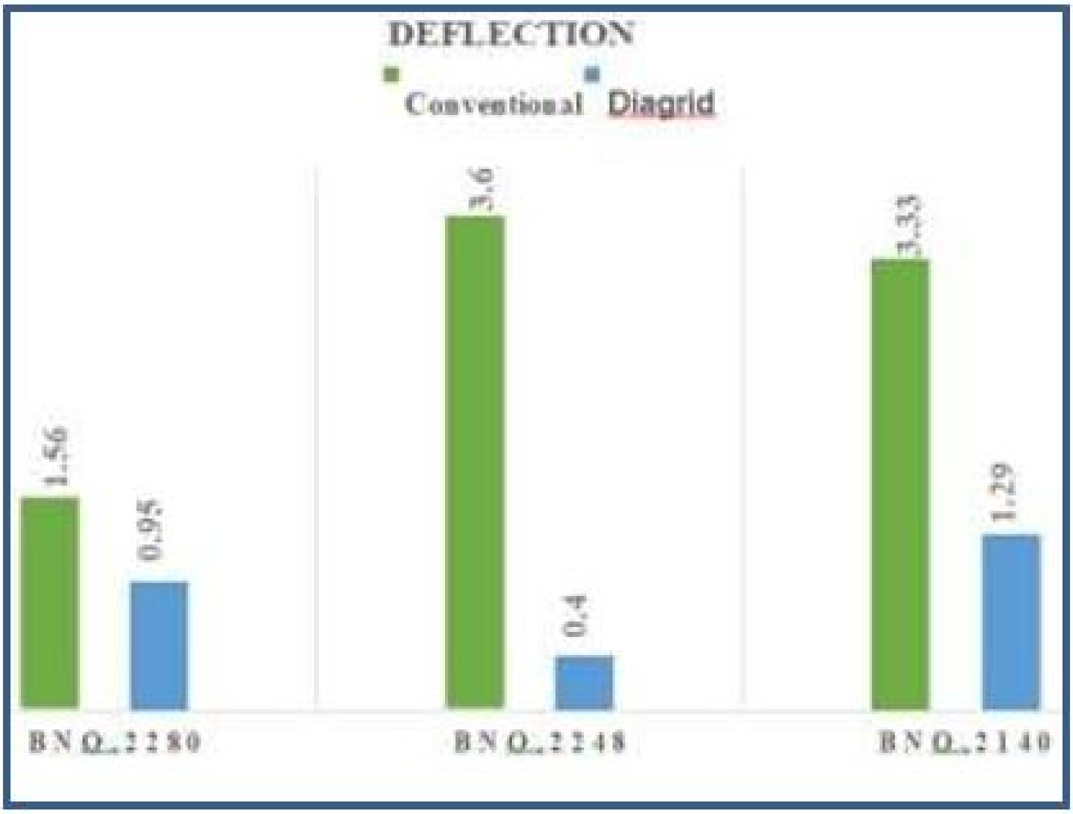

Figure 4: deflection

1) The Diagrid structural system is a type of lateral load resisting system that was introduced as a better solution for high-rise buildings. Compared to traditional systems such as braced frames or shear walls, the Diagrid system offers several advantages in terms of lateral displacements, stiffness, and steel weight.

In terms of lateral displacements, the Diagrid system provides superior performance due to its inherent stiffness and strength. The diagonal members of the system act like braces, providing resistance against lateral loads such as wind or earthquakes. This means that the building will experience less lateral deflection and sway, which can be particularly important for tall buildings that are more susceptible to wind forces at greater heights.

2) The diagrid structure is considered to be both efficient in terms of steel weight and aesthetically pleasing. One of the key advantages of the diagrid system is that it uses less steel than a conventional frame, while providing equivalent or better structural performance.

For example, studies have shown that for a typical 20-story building, the weight of a conventional frame can be up to 100% greater than that of a diagrid building. This is because the diagrid system relies on an optimized use of material by using diagonal members that are thicker at the corners of the building and thinner towards the middle. This reduces the overall weight of the structure, which can result in significant cost savings over the life of the building.

3) Displacements on each storey and storey drifts are important considerations when designing high-rise buildings. The diagrid system has been shown to have advantages over conventional framing systems in both of these areas.

In terms of displacements on each storey, the diagrid system provides superior performance due to its inherent stiffness and strength. The diagonal members of the system act like braces, providing resistance against lateral loads such as wind or earthquakes. This means that the building will experience less lateral deflection and sway, which can be particularly important for tall buildings that are more susceptible to wind forces at greater heights.

Additionally, because the diagrid system is inherently stiffer than traditional systems, it can better resist deformations due to vertical loads such as gravity and live loads. This means that the overall displacement of each storey is less than it would be in a conventional framing system.

4) The distribution of story shear along the height of a building is an important consideration when designing high-rise buildings. The diagrid system has been found to offer advantages over conventional framing systems in this area as well. Research has shown that the distribution of story shear in a building with a diagrid system is more uniform compared to a building with a conventional framing system. This means that the forces are spread out more evenly throughout the structure, which can result in a more stable and safer building. In terms of material consumption, the diagrid system is also more efficient than traditional framing systems. In fact, studies have shown that a simple frame building can consume up to 13.01% more concrete and 57.9% more steel compared to a building constructed using the diagrid system. This is because the triangulated shape of the diagrid system allows for an optimized use of materials, resulting in a lighter and more efficient building.

Conclusion

The following major conclusions can be drawn from the numerical study conducted in the current research work:

1) In terms of lateral displacements, stiffness and steel weight, the Diagrid structural system was introduced as a better solution for lateral load resisting systems. It is stiff enough to withstand wind forces at greater heights.

2) The diagrid structure is both efficient in terms of steel weight and aesthetically pleasing. The weight of a conventional frame is 100 percent greater than that of a diagrid building for a 20- story building.

3) Displacements on each storey and storey drifts are less in diagrid systems than in conventional frames.

4) From the comparison made above, it was observed that the displacement of a simple frame structure is greater than that of a diagrid frame structure in EQX, EQY, WLX, and WLX cases and in terms of inter-story drift, the conventional building outperforms the diagrid frame buildings in EQX, EQY, WLX, and WLX.

5) The same was discovered in the distribution of story shear alongside the structure's height. Similarly, in terms of material consumption, a simple frame building consumes more than a diagrid structure building; the difference in concrete for the buildings was 13.01 percent and 57.9 percent for steel because of its structural flexibility and efficiency in architectural planning and it offers more economy in terms of steel and concrete consumption than the simple frame building.

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