COMPARATIVE STUDY ON DIAGRID STRUCTURE WITH FRAMED STRUCTURE

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Abstract - *The construction of multi-storey buildings has increased worldwide. With an increase in structure height, the importance of lateral load-resisting elements becomes more significant. Widely used lateral load resisting systems are moment resisting frames, shear walls, braced systems, outrigger systems, and diagrid systems. Diagrid is an exterior structural system that consists of inclined columns along the periphery. The main aim of this study is to compare the performance of the diagrid structural system with a framed structural system. Comparisons are made for both R.C and steel structures. Structural models are analysed and comparisons are made to find the optimum angle of diagrid, roof displacement, storey drift, and effectiveness of the diagrid structure with the framed structure in resisting lateral loads. Based on the results of the analyses, it is found that the diagrid structure with 65° diagrid angle is more effective in resisting lateral loads and reduced roof displacements, storey drift compared to a framed structure. Diagrid R.C structure saves approximately 8% of concrete and 15% reinforcement, whereas the diagrid steel structure saves approximately 18% of structural steel.*

***Key Words*: Diagrid structure, Lateral Stability, R.C Structure, Steel Structure, Optimum angle, Lateral loads, Displacement**.

1. INTRODUCTION

Due to rapid urbanisation construction of tall buildings has rapidly increased. As the height of buildings increases, the lateral load resisting system becomes more important than the structural system that resists the gravitational loads. The lateral load resisting systems that are widely used are mainly moment resisting elements, shear walls, braced systems, outrigger systems, and diagrid systems. The diagrid structural system is becoming popular in the design of tall structures due to its structural and architectural advantages. Diagrid is an exterior structural system in which perimeter columns are replaced with diagrids. Shear and overturning moment developed are resisted by the axial action of these diagonals, compared to the bending of vertical columns in a framed structure. [1]. Optimum angles for diagrids are between 35 and 90 degrees. Diagrid members transfer both lateral and gravity load through axial action, enhancing lateral load resistance and requiring less structural material. Triangular grid pattern of diagrids adds aesthetic value to the structure.

The present study focuses on the effectiveness of the diagrid system in resisting lateral loads when compared to a framed structure. Concrete and Steel structures were analysed with both framed and diagrid systems. As the optimum angle of the diagrid depends on the geometry of the structure, analyses were made to determine the optimum angle of the diagrid. Performance of the diagrid structure is analysed based on the maximum displacement, storey drift, axial force, shear force, bending moment and saving of structural material. Analyses are performed based on IS codal provisions.

2. LITERATURE REVIEW

Many researchers have done work in the field of diagrid structures. A few studies are mentioned along with their key findings. Diagrids improve the aesthetic appearance of the structure without compromising structural integrity. The diagonal members in diagrid structural systems carry gravity loads as well as lateral forces due to their triangulated configuration. It saves up to 20% of structural material compared to a framed structure. [2]. Diagrid Structure performs better as a lateral load resisting system than shear wall and bracing systems. Diagrid Structure has the least Maximum Lateral Displacement and Maximum Storey Drift. [3]. Jani Khushbu, Patel Paresh V. [4] has done analysis and design on 36 36-storey diagrid steel building. A floor plan of 36 m x 36 m is adopted. Wind loads and Earthquake loads are considered for analysis. Load distribution for peripheral diagrids and interior columns is studied for a 36-storey building. From the results, it can be observed that diagrids resist most of the lateral loads, while gravity load is resisted by both the internal columns and peripheral diagrids.

J. Kim, Y. Jun and Y.Ho Lee [2] presented a paper on seismic performance evaluation of diagrid building. Design and analysis of a 36-storey building is carried out for different angles. The analysis model structures are 36-storey diagrid structures with various slopes (50.2°,61.0°, 67.4°, 71.6°, 74.5°, and 79.5°). The result shows that as the angle of the diagrid increased, the shear lag effect increased and the lateral strength decreased. The diagrid structures with an angle between 60° to 70° seemed to be most efficient in resisting lateral as well as gravity loads.

Divya C. Bhuta, Umang Pareekh [5] has done a study on the lateral load resisting system in tall buildings. Analysis was carried out on a 40-storey R.C structure with different lateral resisting systems like Shear walls, outriggers and diagrids. Analysis was carried out for earthquake and wind loads. Comparison of top storey displacement, storey drift and time period is done for different structural systems. It is concluded that the diagrid system shows a minimum displacement than other systems.

Manish S. Ramteke, Kirti R. Padmawar, [6] have studied the Comparative study of Conventional Framed and Diagrid with plan irregularity. The structures are analysed by the linear static method. The building is considered to be irregular in plan. Irregular plans, C-shape plans, and L-shape plans are considered. The results obtained are compared by various parameters like storey displacement, base shear, bending moment, frequency, and storey drift. The result showed that the diagrid system resists lateral loads more efficiently than the conventional system.

From the literature study, it is understood that the diagrid system performs better than framed, shear walls and outrigger systems. The diagrid angle depends on the structure's geometry.

3. METHODOLOGY

In the present study of the diagrid system with the conventional framed system, the main objective is to find the optimum angle of the Diagrid. Structural performance in terms of roof displacements and storey drift, for concrete and steel structures, is evaluated for both types of structural systems.

A floor plan for a 12 Storey Building measuring 30.8 m x 24.8 m with a storey height of 3.2 m is adopted. For R.C structures, M30 grade of concrete and Fe 550D grade steel is considered. For Steel structures, E350 Structural steel is adopted. The thickness of the slab is 150mm, and the thickness of exterior and interior walls is 230 and 115 mm.

Wind loads are calculated based on IS 875 (Part – 3). Basic wind speed is considered as 39 m/s for terrain category 3. Seismic analysis is performed based on IS 1893: 2016, earthquake Zone-3 with a zone factor of 0.16, an Importance factor(I) of 1 and a Response reduction factor of 5 for a special moment resisting frame. Equivalent Static method analysis is performed to evaluate maximum displacements and storey drift for wind and seismic loads. Based on the results of structural analysis, designs are carried out as per the IS codes of practice.

Considering Gravity loads such as dead loads and live loads as per IS 875 Part 1 & 2. Self-weight of the structure, 1.5 kN/m^2 for floor finishes and 2.5 kN/m^2 for roof finishes and Wall loads of 12.65 kN/m^2 for exterior walls, 6.5 kN/m^2 for interior walls, and 2.3 kN/m^2 for parapet walls were considered as dead loads. Live loads of 2 kN/m^2 for floors and 1.5 kN/m^2 for roofs were incorporated. Load combinations are prepared based on IS 875(part-5):1987. For R.C and steel structures, IS 456:2000 and IS 875:2007 codes are considered for general design in concrete and steel structures.

Lateral performance of the structure is evaluated based on the roof displacement and Storey drift. As per Indian standard codes of practice, the lateral sway at the top of the building shall not exceed H/500 for transient wind loads, where H is the total height of the building and under seismic loading, the lateral sway at the top should not exceed H/250, and storey drift shall not exceed 0.004 times of storey height.

4. ANALYSIS

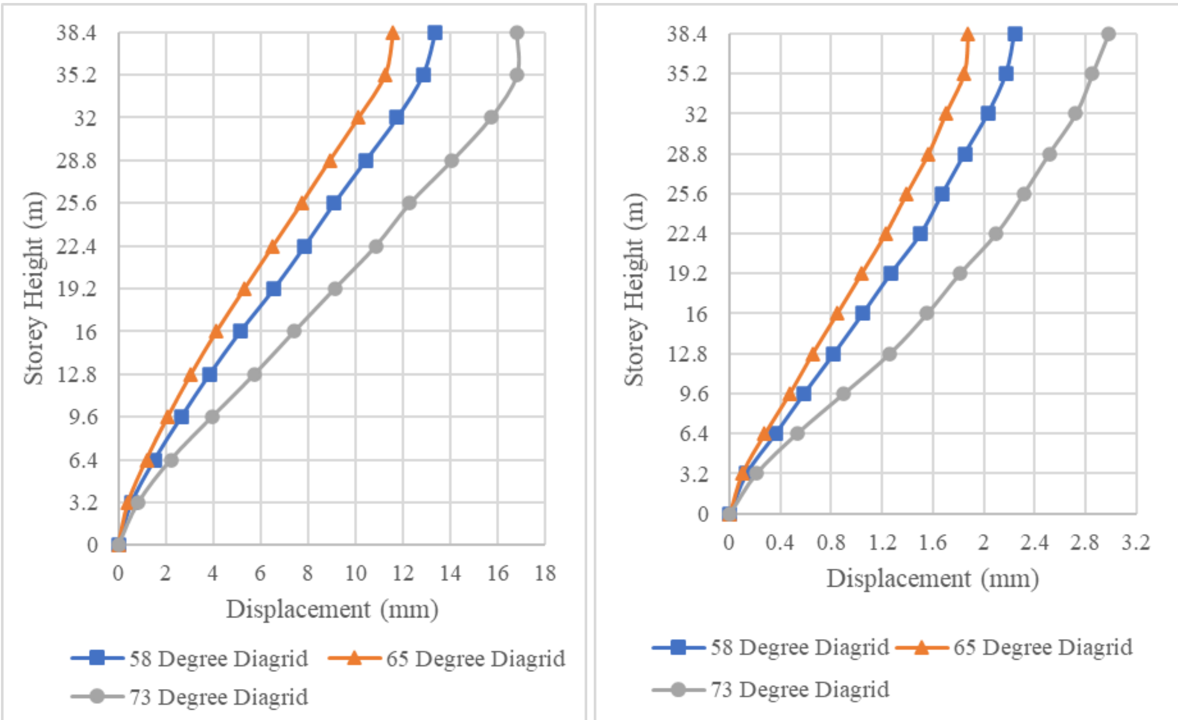
Initially, diagrid models with three diagrid angles, 58^o, 65^o, and 73^o are analysed. Diagrid angle depends on the height and width of the diagrid module. Comparisons are made for roof displacements and storey drift, based on structural performance to lateral loads. By comparing roof displacements and Storey drift, the optimum angle of the diagrid is determined.

A comparative study was then carried out for framed structures with the diagrid model using the optimum angle. Roof displacements and storey drifts are compared to analyse the structure's ability to withstand lateral loads; reduced storey drift indicates improved lateral stability and occupants' comfort. Based on the results of the analysis, it can be observed that the diagrid structure reduces the roof displacement and the storey drift. Further, the effectiveness of periphery diagrids in resisting lateral loads is analysed, and the axial load due to lateral load received by the diagrids and interior columns are compared. It is found that 86% of lateral loads are resisted by the periphery diagrids. Interior columns are selected to compare the Bending moment and Shear force due to lateral loads for the framed and diagrid structures. From the comparison of the results of the analysis, it is proven that the diagrid structures are effective in resisting lateral loads.

5. RESULTS AND DISCUSSIONS

Based on the analysis results, the following observations are made for framed and diagrid structures. The variation of storey displacements along the structure height for the three diagrid structures under the action of lateral loads is shown in Figure 1, and roof displacements are shown in Table 1.

It can be observed that the 65° diagrid model showed the least response to lateral loads among the three models.



(i) (ii)

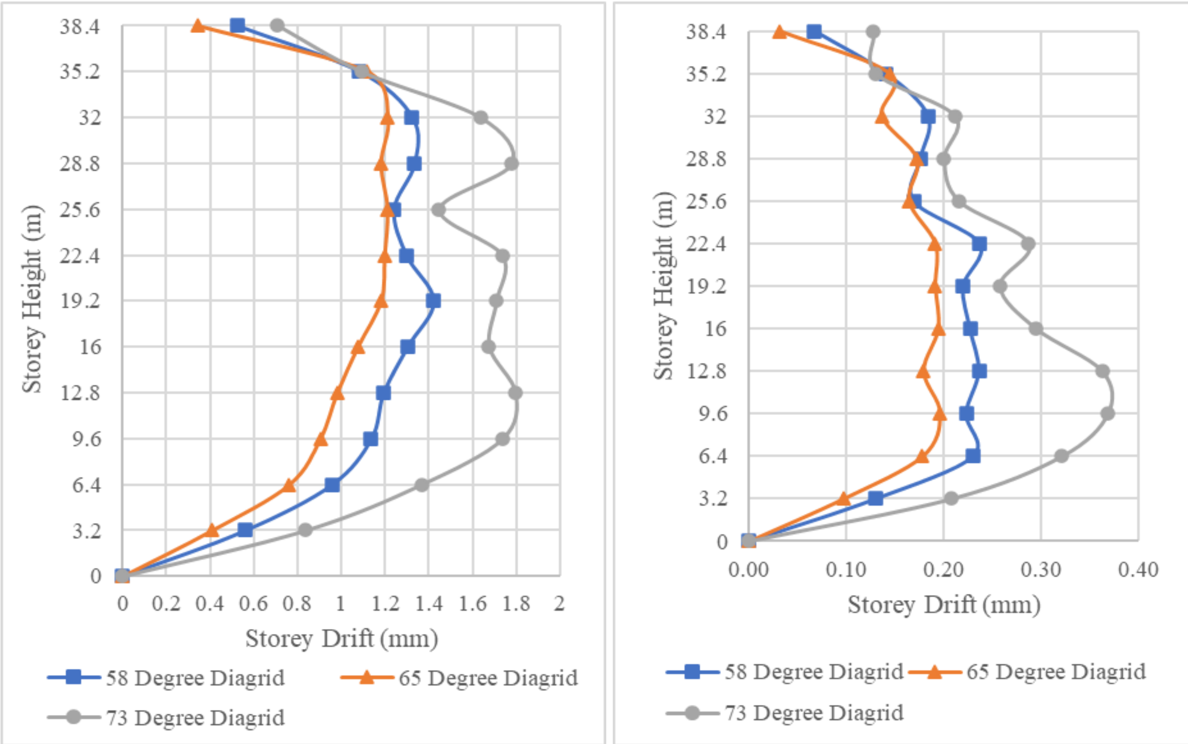
Figure -1: Variation of Storey displacements along the Height of the Structure due to (i) EQ & (ii) WL for Three Types of Diagrid Structures

Table -1: Roof displacements due to EQ & WL for Diagrid Structures

Diagrid Angle	**Roof Displacement**	
	Earthquake Load	**Wind Load**
58° Diagrid	13.37 mm	2.24 mm
65° Diagrid	11.58 mm	1.87 mm
73° Diagrid	16.79 mm	2.98 mm

Storey drift variation along the structure height under earthquake and wind loads is shown in Figure 2, and maximum storey drifts are shown in Table 2.

It can be observed that the 65° diagrid model shows the least variation to lateral loads among the three models. Hence, the optimum diagrid angle for the given structure is 65°, further comparative study will be carried out with the diagrid model using the optimum angle.



(i) **(ii)**

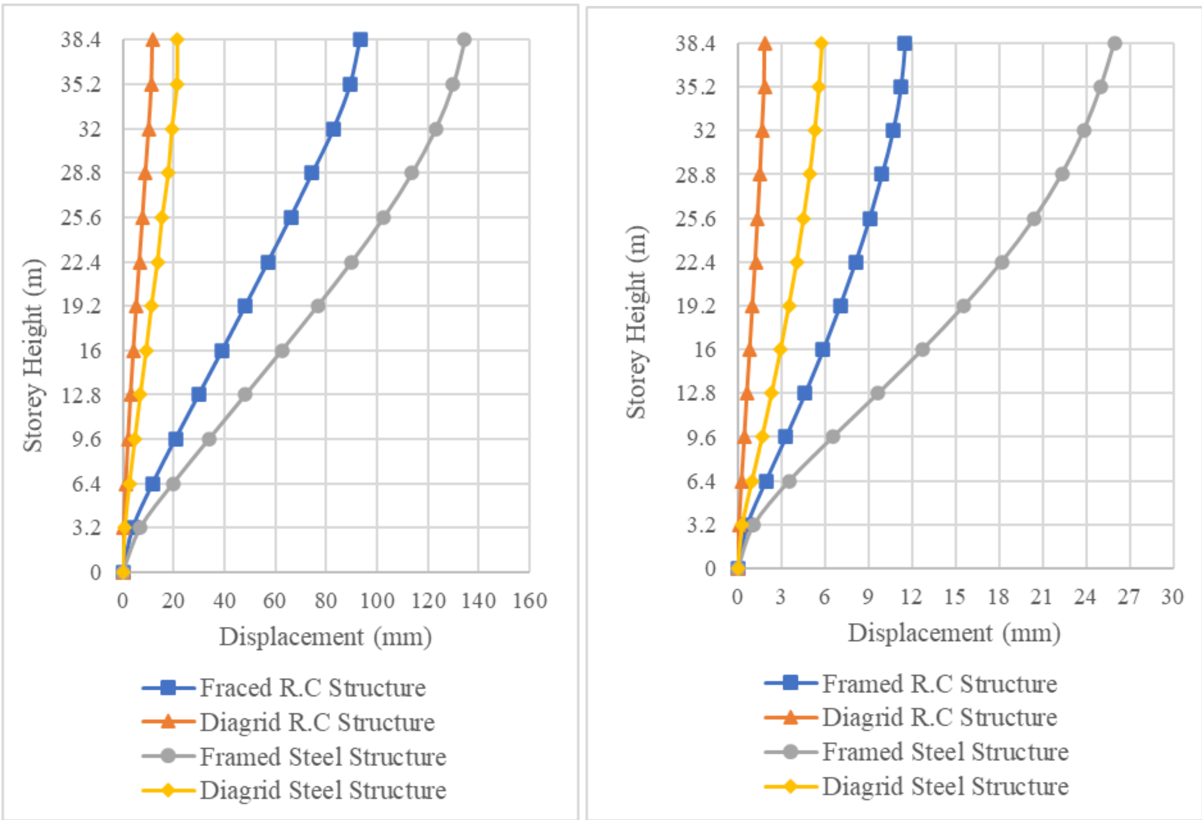
Figure -2: Variation of Storey Drift along the Height of the Structure due to (i) EQ & (ii) WL for Three Types of Diagrid Structures

Table -2: Maximum Storey Drift due to EQ & WL for Three Types of Diagrid Structures

Diagrid Angle	Maximum Storey Drift	
	Earthquake load	Wind load
58° Diagrid	1.42 mm	0.24 mm
65° Diagrid	1.21 mm	0.20 mm
73° Diagrid	1.80 mm	0.37 mm

The variation of storey displacements for R.C and steel structures with framed and diagrid systems under the action of earthquake and wind loads is shown in Figure 3. The Roof displacements for R.C and steel structures under earthquake and wind loads are shown in Table 3.

It can be observed that the R.C diagrid structure results in 87% and 84% reduction of roof displacements. Similarly, it can be observed that the steel diagrid structure shows reduced response to lateral loads when compared to the framed structure.



(i) **(ii)**

Figure -3: Variation of Storey Displacement along the Height of the Structure (i) EQ and (ii) WL for Concrete & Steel structures

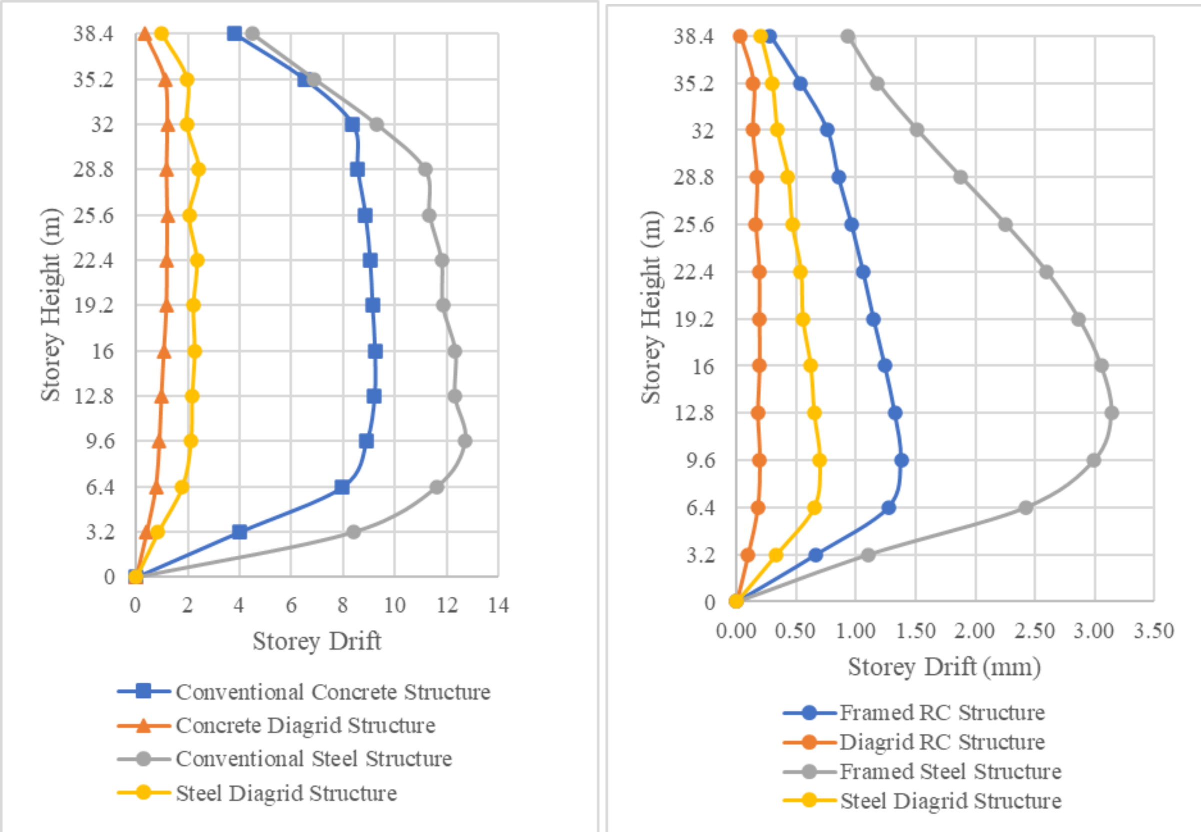
Table -3: Roof Displacements due to EQ & WL for Structural Systems

Structural System	R.C Structure		Steel Structure	
	EQ	**WL**	**EQ**	**WL**
Diagrid System	11.58 mm	1.87 mm	25.94 mm	5.8 mm
Framed System	93.21 mm	11.51 mm	134.41 mm	25.94 mm

Storey drift is a critical parameter in structural design. Limiting storey drift helps to prevent structural and non-structural damage, enhances the structural stability under lateral forces and improves occupant comfort.

The variation of storey drift along the height of R.C and steel structures with framed and diagrid systems under the action of earthquake and wind loads is shown in Figure 4. The Maximum Storey Drift for R.C and steel structures under earthquake and wind loads are shown in Table 4.

It can be observed that storey drifts are significantly reduced in diagrid structures, indicating higher resistance to lateral loading.



(i) **(ii)**

Figure -4: Variation of Storey Drift along the Height of the Structure (i) EQ and (ii) WL for Concrete &Steel Structures

Table- 4: Maximum Storey Drift due to WQ & WL for Structural Systems

Structural System	R.C Structure		Steel Structure	
	EQ	WL	EQ	WL
Diagrid System	1.21 mm	0.196 mm	2.4 mm	0.7 mm
Framed System	9.22 mm	1.38 mm	12.70 mm	3.14 mm

It can also be observed that the fundamental advantage of the diagrid system is that the peripheral diagrids carry most of the lateral load. Axial force acting on Diagrids and interior columns is shown in Figure 5.

It can be observed that the periphery diagrids receive 86% of the lateral load than interior columns, resulting in reduced axial force on interior columns.

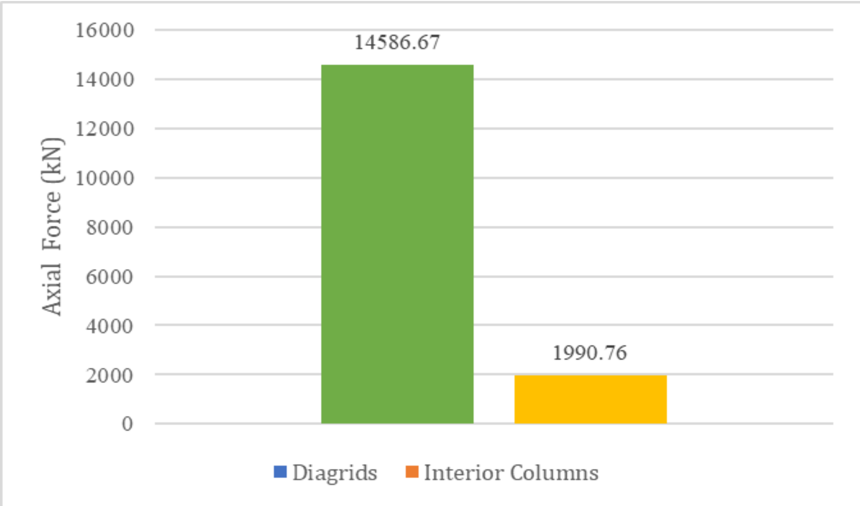


Figure -5: Axial Force due to lateral loads on Diagrids and Interior columns

Figure 6 shows the Bending moment variation under lateral loads for Interior columns in framed and diagrid systems. It is observed that approximately 89 % of the Bending moment due to lateral loads is reduced in the diagrid system.

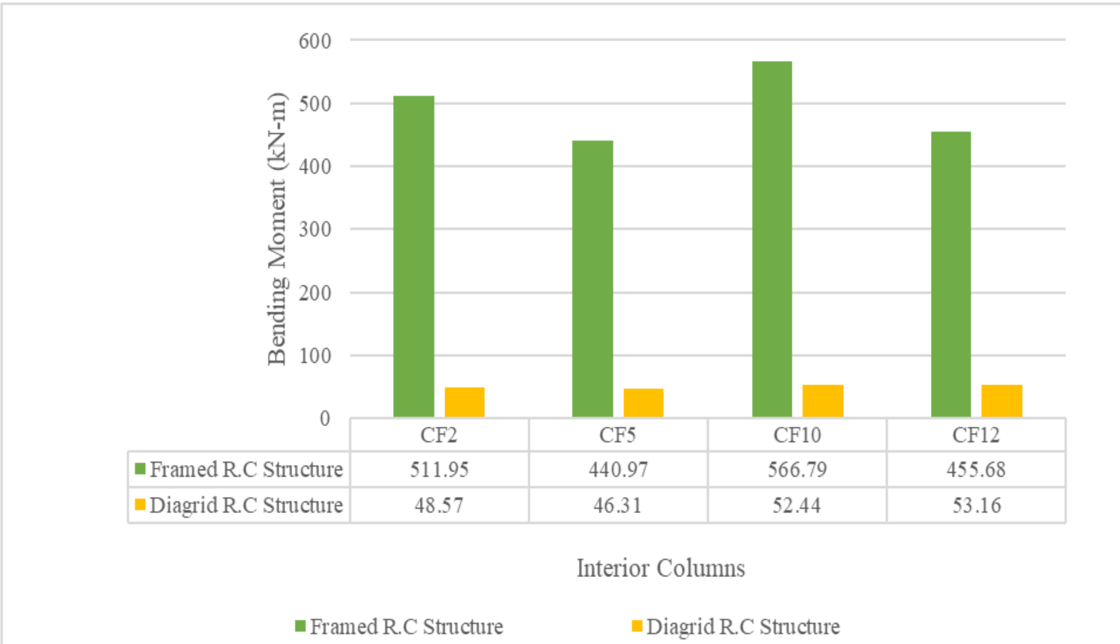


Figure -6: Bending moment Variation on Interior Columns due to Lateral Loads for two structural Systems

Figure 7 shows the variation of Shear Force for Interior columns in framed and diagrid systems due to the lateral loads. It is observed that 84 % of the shear force due to lateral loads is reduced in the diagrid system.

It can be concluded that the diagrids are the most efficient systems in resisting lateral loads acting on the structure, resulting in reduced member sizes for interior structural members.

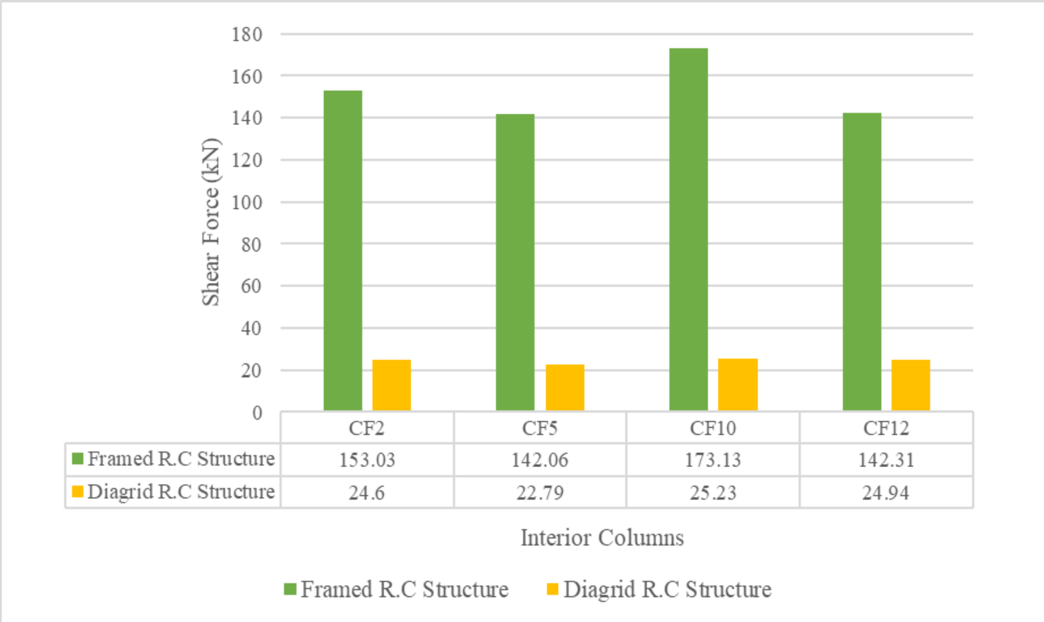


Figure -7: Shear force variation on Interior Columns due to Lateral Loads for two structural Systems

Figure 8 presents the self-weight comparison for framed steel and diagrid steel structures. Diagrid steel structure saves approximately 18% of structural steel compared to the framed steel structure.

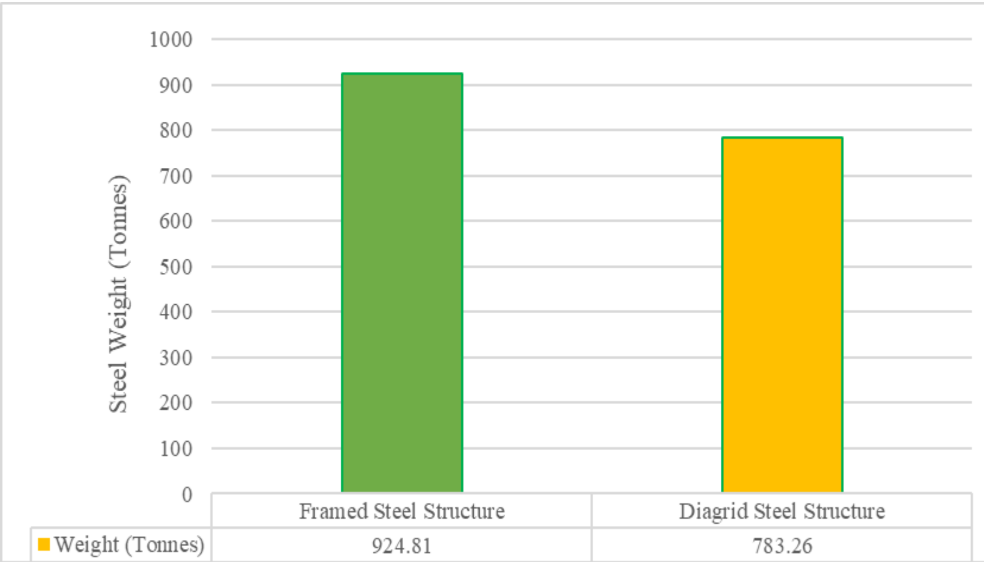


Figure -8: Comparison of self-weight for the Framed steel structure and Diagrid Steel structure

Figure 9 shows the self-weight comparison for framed R.C and diagrid R.C structures. It can be observed that the diagrid R.C. structure saves 8% of concrete compared to the framed structure.

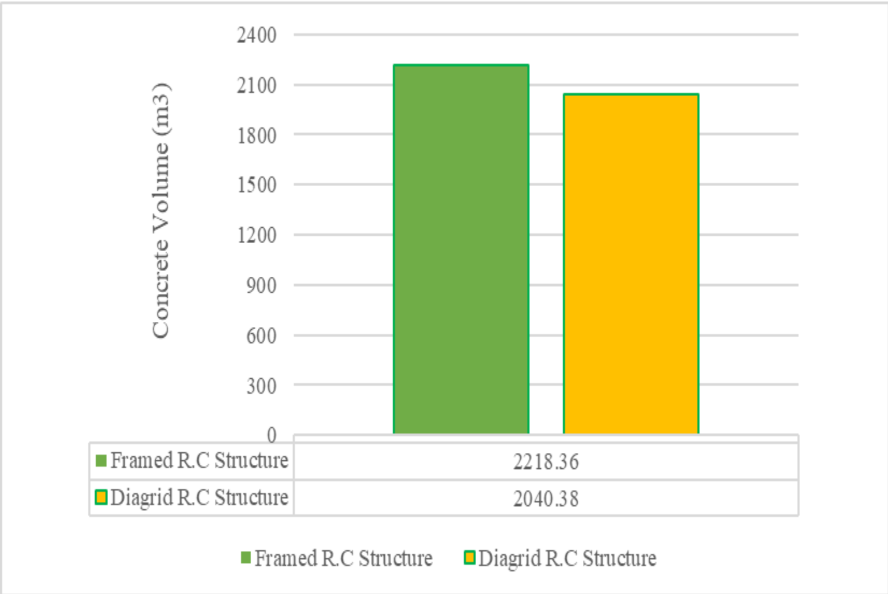


Figure -9: Comparison of self-weight for the Framed R.C structure and Diagrid R.C structure

Figure 10 shows the comparison of reinforcement required for R.C framed and R.C diagrid structures. It can be observed that the R.C diagrid structure saves approximately 15% of reinforcement compared to the framed structure.

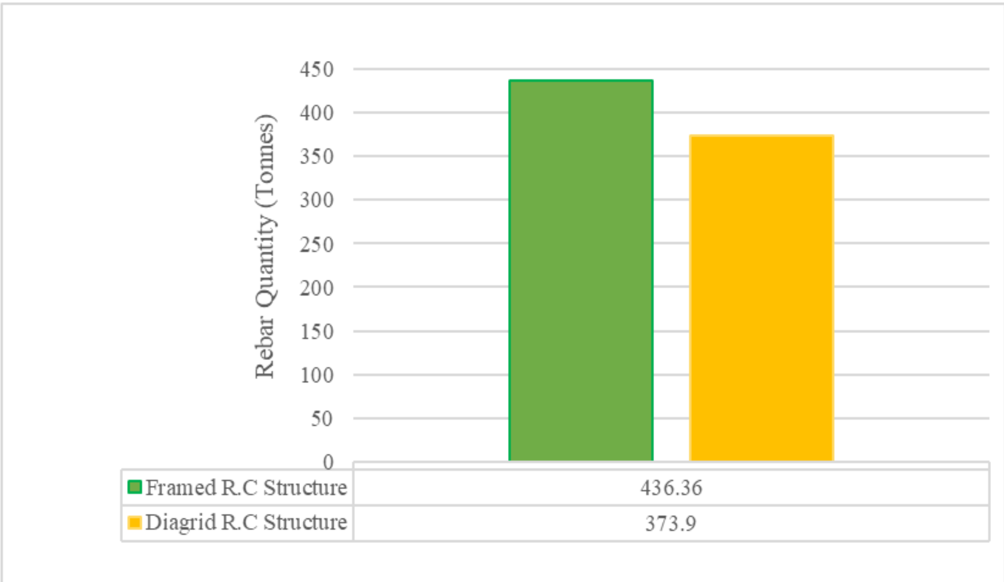


Figure -10: Comparison of reinforcement required for the Framed R.C structure and Diagrid R.C structure

3. CONCLUSIONS

The following conclusions are drawn from the comparative study of the diagrid system with the framed structural system.

- 65^0 Diagrid structure shows reduced roof displacement and storey drift compared to 58^0 and 73^0 Diagrid structures. Hence, the optimum diagrid angle for the given structure geometry is 65^0.
- The maximum roof displacement due to earthquake load in framed R.C and steel structures is 93.21mm and 134.41 mm, respectively, whereas for diagrid structures, it is 11.58 mm and 25.94 mm, respectively.
- The maximum storey displacements due to wind load in Framed R.C and steel structures are 11.51mm and 25.94 mm, whereas for diagrid structures, the maximum storey displacements are 1.873 mm and 5.8 mm.

- Compared to a framed structure, diagrid structure shows approximately 80 to 85 % reduction in roof displacements.
- Storey Drift is significantly reduced in diagrid structures, indicating increased stiffness.
- Periphery diagrids resist most of the lateral load in the diagrid system, which results in reduced axial force on interior columns.
- Bending moment and shear force due to lateral loads in the diagrid structure are reduced approximately 89% and 84 %, respectively.
- An R.C diagrid structure saves approximately 8% of concrete and 15% reinforcement. Whereas the steel diagrid structure saves approximately 18% of structural steel. Hence diagrid system is not only laterally effective but also an economic system.
- Due to the presence of diagonal columns on the periphery, the diagrid structure shows better resistance to lateral loads and due to this, inner columns carry only gravity loads. While in a framed structure, both inner and outer columns are designed for both gravity and lateral loads. Hence, Diagrid structures provide an efficient means of resisting lateral loads compared to framed structures.

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