Analysis and Design of Diagrid Structural System for High Rise Steel Buildings

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ABSTRACT: The development of tall buildings was made possible by developments in structural systems, materials, construction technology, and analytical techniques for design and analysis. Lateral loads from wind and earthquakes have an impact on the structural construction of high-rise buildings structure's lateral load resistance may be supplied by external or internal systems. Shear wall cores, braced frames, and combinations of these with frames are examples of interior structures that can withstand lateral loads. Contrarily, framed tubes are unable to withstand lateral loads from components situated outside the building's perimeter, whereas braced tubes are. Selecting the right structural system is crucial to making effective use of the structural elements while meeting design specifications. The diagrid structural system, which has become more and more common in tall structures because of its architectural flexibility and structural efficiency, has slanted columns on the outside of the building rather than the vertically aligned columns that are typical of framed tubes. The inclined columns of this design aid in lateral load resistance. The diagonals' axial movement in a framed tube structure resists stresses more effectively than the vertical columns' bending. Since the surrounding diagonals can withstand lateral shear, diagonal buildings usually don't need a core. The design and analysis of a 36-story diagrid steel skyscraper with a conventional 36 m x 36 m floor plan are presented in this paper. The structural components, which are constructed in accordance with IS 800:2007, are modelled and analysed using ETABS software, which accounts for all potential load combinations. The design and evaluation of the structure take into account dynamic elements associated with both wind directions. This 36-story skyscraper's diagrid system's load distribution is also examined. Additionally, 36-story diagrid construction analyses and plans are finished. The analytical results are compared in this work according to time period, displacement at the top storey, and inter-storey drift.

Keywords: Diagrid Structural System, Time Period, Displacement at the Top Story, Inter-Story Drift.

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1. Introduction

The city's residential development has been greatly impacted by the population's rapid rise and the resulting pressure on scarce space. The need to maintain significant agricultural production, prevent unchecked urban growth, and the high cost of land have all pushed residential building prices upward. The lateral load-resisting system gains importance over the structural system that withstands gravitational loads as building height increases. Many systems are utilized to withstand lateral loads, including tubular, braced tube, shear wall, wall-frame, rigid frame, and outrigger systems. The Diagonal Grid structural system has gained popularity in recent times for large steel buildings because of its distinct geometric design that offers both structural efficiency and aesthetic possibilities. Diagrid represents a specific type of space truss. A perimeter grid of triangulated truss systems makes up this structure. When horizontal and diagonal elements intersect, a diagrid structure is formed. The Swiss Re in London, the Hearst Tower in New York, the Cyclone Tower in Asan, Korea, the Capital Gate Tower in Abu Dhabi, and the Jinling Tower in China are a few of the world's most famous diagrid structures (Fig. 1). Complex architectural designs are supported by diagrid structural technology, as shown in the new Central China Television (CCTV) headquarters in Beijing.

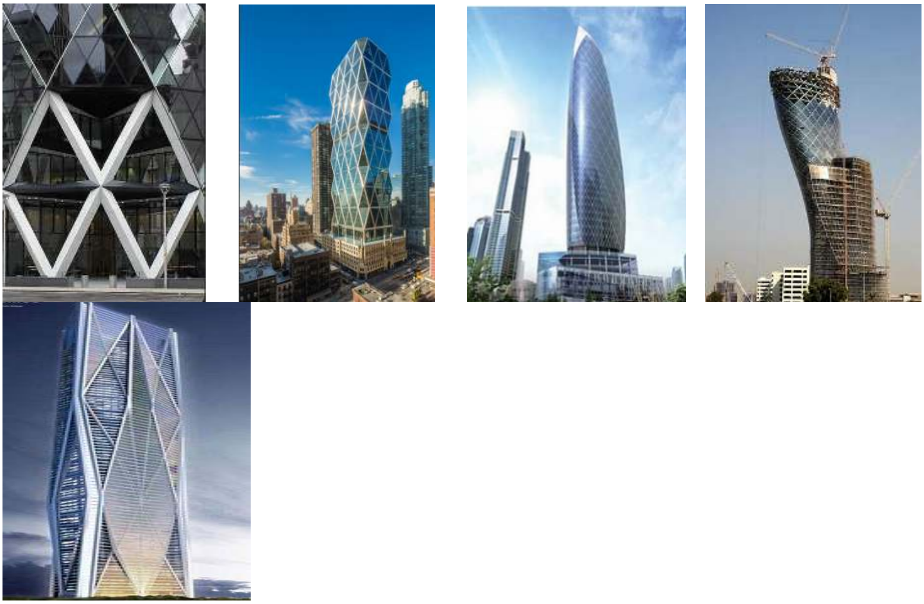

Fig. 1. Diagrid buildings (a) London Swiss Re (b) Hearst Tower, New York (c) Cyclone Tower,Asan (Korea) (d) Capital Gate Tower, Abu Dhabi and (e) Jinling Tower, China.

The diagrid system is instantly recognizable and has a pleasing appearance. Because of its efficiency and design, fewer structural components are required on a building's façade, allowing for an unhindered view. Furthermore, the diagrid system's structural effectiveness considerably increases floor plan flexibility by doing away with the necessity for interior and corner columns. In comparison to a conventional moment-frame structure, a perimeter diagrid system can also lower the weight of structural steel by roughly 20%.

The diagonal members in diagrid structural systems, due to their triangular arrangement, are able to bear both lateral forces and gravity loads. Because diagonal constructions transfer lateral shear through the axial action of their diagonal elements, they are more successful in reducing shear deformation. Since the diagonal elements on the perimeter can carry lateral shear, diagonal architectures typically do not require high-shear stiffness cores.

The analysis and design of a 36-story diagonal steel skyscraper are presented in this article. The typical 36 x 36 m floor plan is taken into account. ETABS software is used to model and analyze structural members. IS 800:2007 is used to build each structural component, accounting for all potential load combinations. For analysis and structural design, dynamics both across and along the wind are taken into account. Analyses and designs for diagrid constructions with 40, 50, 60, and 70 stories are also completed. The analysis's findings are contrasted with respect to duration of time, displacement at the top storey, and Inter-floor movement.

2. Evaluation and design of a 36-story structure

2.1. Configuration of the building.

The structure is 36 stories tall with a 36 m x 36 m plan dimension. Its storeys are 3.5 meters high. The standard elevation and plan are shown in Fig. 2. Diagrid buildings have two bracing positioned around their outside. Throughout the height, the inclination angle doesn't change. There are slanted columns spaced six meters apart around the perimeter. Only gravity loads are meant to be supported by the inner frame of the diagrid structures. The design dead load and live load on the floor slab are 3.75 kN/m^2 and 2.5 kN/m^2, respectively. The dynamic wind load along the wind direction is calculated using terrain category III and a base wind speed of 30 m/sec, following the Gust factor approach outlined in IS:875 (III)-1987 [6]. The across-wind load is determined based on the work of Gu and Quan [1]. The design earthquake load is calculated using a zone factor of 0.16, medium soil conditions, a significance factor of 1, and a response reduction factor of 5 [7]. Diagrid structures are modelled, analysed, and designed using ETABS software [9]. For linear static and dynamic analysis, braces are modelled as truss elements, while beams and columns are represented by beam elements. It is believed that the support conditions are hinged. The design of every structural member adheres to IS 800:2007[8]. Assuming a tiny difference in temperature between the interior and outside, secondary effects such as temperature variation are not taken into account in the design.

2.2. Analysis of a 36-story structure.

The analytical findings for to duration of time, displacement at the top story, and Inter-floor movement are shown in this section. Fig. 3 depicts the duration of the 36-story diagrid construction. 3.14 seconds is the diagrid system's initial mode time period. Table 1 summarizes the lateral loads caused by wind and earthquakes. The distribution of seismic and wind-induced storey Shear force along the building's height of a 36-story diagrid building is shown in Figure 4. It is discovered that dynamic wind stress causes there is more storey shear in the x direction and the y direction than in seismic forces.

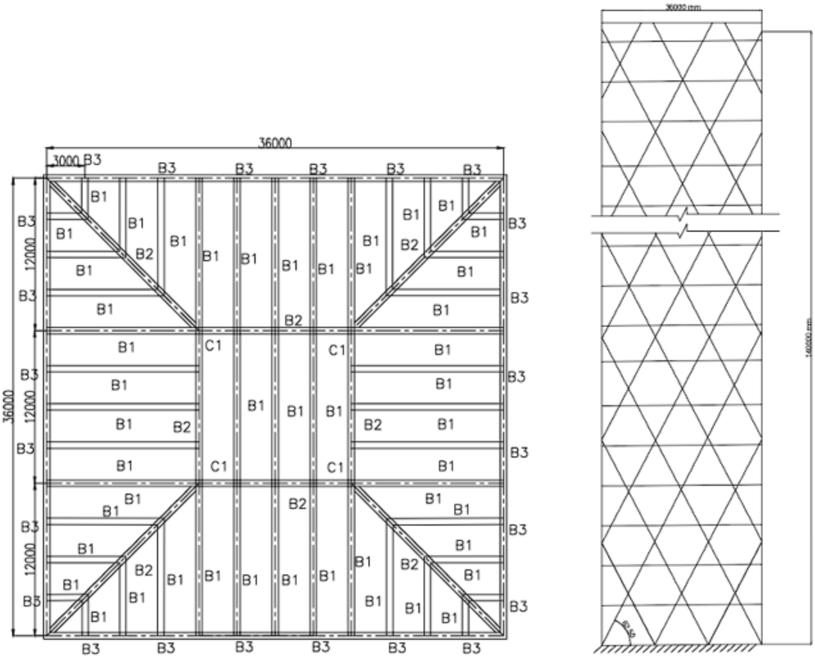

Fig. 2. (a) Floor Plan & (b) Elevation of 36-Storey Diagrid Structure

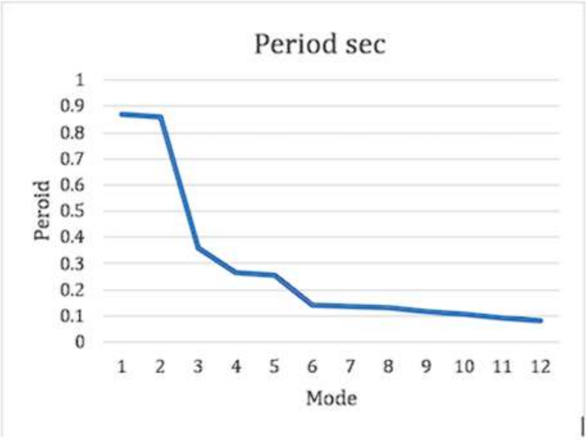

Fig. 3. A 36-story diagrid structural structure time period

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The displacement of a 36-story diagrid skyscraper is depicted in Fig. 5. It has been shown that dynamic wind load results in a larger displacement in both the x and y directions compared to seismic stress. The inter-story drift of the 36-story diagrid construction is displayed in Figure 6. It is found that inter-story drift occurs in both the x axis and the y axis is more frequently caused by dynamic wind load than by earthquake stress.

Table 1. Lateral load on a 36-story diagrid system caused by wind and earthquake

Loading	**The diagrid system's total load(kN) (ϕ= 62^0)**	**The diagrid system's total load (kN) (ϕ= 74.5^0)**
load from an earthquake in the X direction	1816.66	1794.85
load from an earthquake in the Y direction	1818.05	1826.24
As per IS:875-III:1987, static wind load along the wind direction.	3234.10	3200.26
As per IS:875-III:1987, dynamic wind load along the wind direction	3220.19	3347.60
Across wind load	722.54	719.88

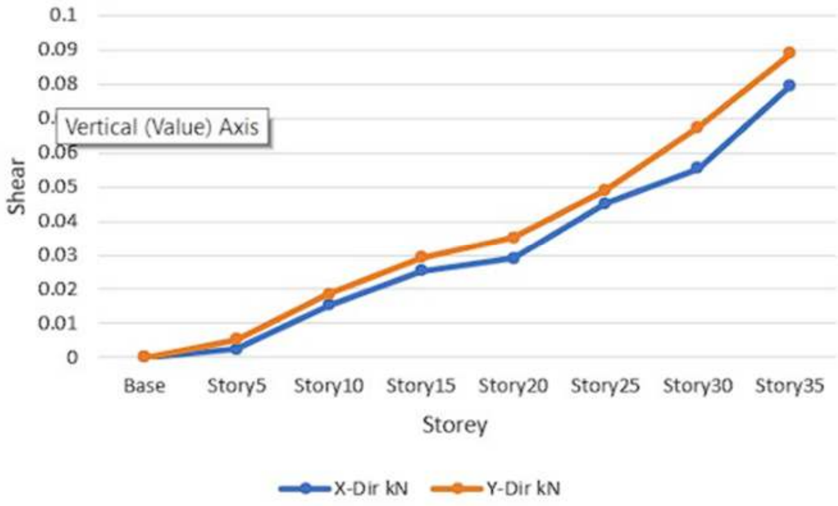


Fig. 4. 36-story diagrid structural system's storey shear

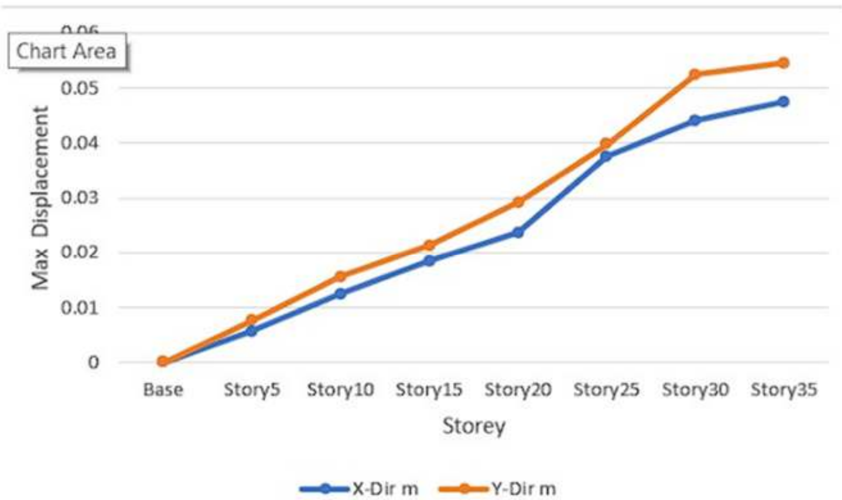


Fig. 5. 36-story diagrid structural system displacement

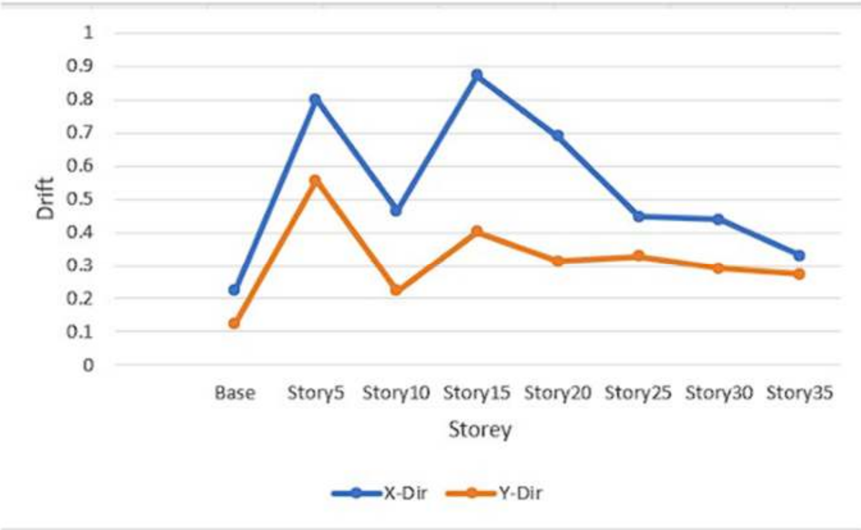


Fig. 6. 36-story diagrid structural system inter-story drift.

The two main forms of loads that the building experiences are gravity load and lateral stress from earthquakes or wind. For the 36-story diagrid building discussed in this paper, the base shear due to wind load exceeds that of the earthquake load. Consequently, wind load dictates how the building is built.

The distribution of lateral loads and gravity loads in the exterior and interior frames are displayed in Table 2. Fig. 7 displays the percentage of the total load that the outside and inner frames are able to withstand. It is found that the exterior and internal frames, respectively, withstand 96.68% and 2.31% of the lateral force. While the outer and internal frames, respectively, withstand 51.62 percent and 48.38 percent of the gravity load. As a result, the outer frame (Diagonal Columns) primarily resists lateral load, whereas the inside frame and exterior frame both resist gravity load. The results indicate that gravitational loading is mostly being resisted by the internal frame.

Table 2. Load dispersion in a Diagonal grid system of 36 stories

Load	**Diagrid System total load (kN)**	**loading on the diagonal perimeter**	**Internal Column Loading (kN)**
Lateral loading	3227.60	3152.9	74.68
loading due to gravity	3,51,264.24	1,81,332.12	1,69,932.12

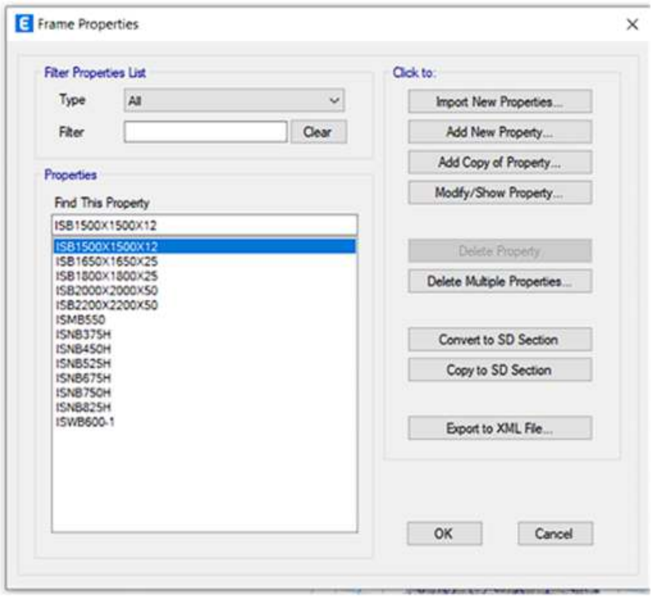


Fig. 7. Load distribution in the exterior and interior frame

3. Analysis results comparison.

Buildings with 50, 60, 70, and 80 stories are structurally designed, as was covered in the part before this one. This section compares the analytical results of 36, 50, 60, 70, and 80 stories with respect to time frame, inter-story drift, and top-story displacement. The top story's permitted lateral displacement is restricted to Height/500. Table 3 displays the first mode time periods for the 36, 50, 60, 70, and 80 story diagrid structures.

Table 3. Initial mode duration of 36, 50, 60, 70 and 80 story diagrid structure

Level	**Initial mode duration (sec) (ϕ= 62^0)**	**First mode time period (sec) (ϕ= 74.5^0)**
36		3.16
Level	2.53	
50		4.46
Level	3.57	
60		5.01
Level	4.01	
70	4.07	5.09

Level				
80			5.86	
Level	4.69			

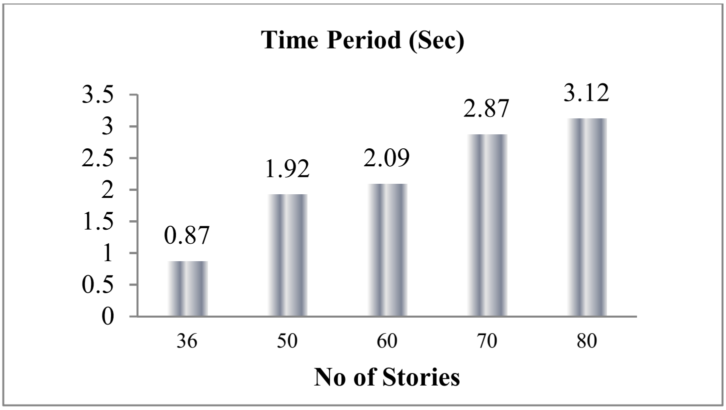


Fig. 8. Duration of 36, 50, 60, 70 and 80-storey diagonal grid structural system.

Table 4. Displacement at the Top Story of diagrid structures of 36, 50, 60, 70, and 80 stories

Level	Displacement at the Top Story caused by DYWLX in the x-direction (m) (ϕ= 62^0)	Displacement at the Top Story caused by DYWLY in the Y-direction (m) (ϕ= 62^0)	Top displacement caused by DYWLX in the x-direction (m) (ϕ= 74.5^0)	Top displacement caused by DYWLY in the y-direction (m) (ϕ= 74.5^0)
36	0.027	0.027	0.048	0.048
Level				
50			0.102	0.102
Level	0.077	0.077		
60			0.136	0.136
Level	0.11	0.11		
70			0.143	0.143
Level	0.117	0.117		
80			0.192	0.192
Level	0.168	0.168		

Figures 9, correspondingly, the displacement of storeys along the height of buildings that are 50, 60, 70, and 80 stories.

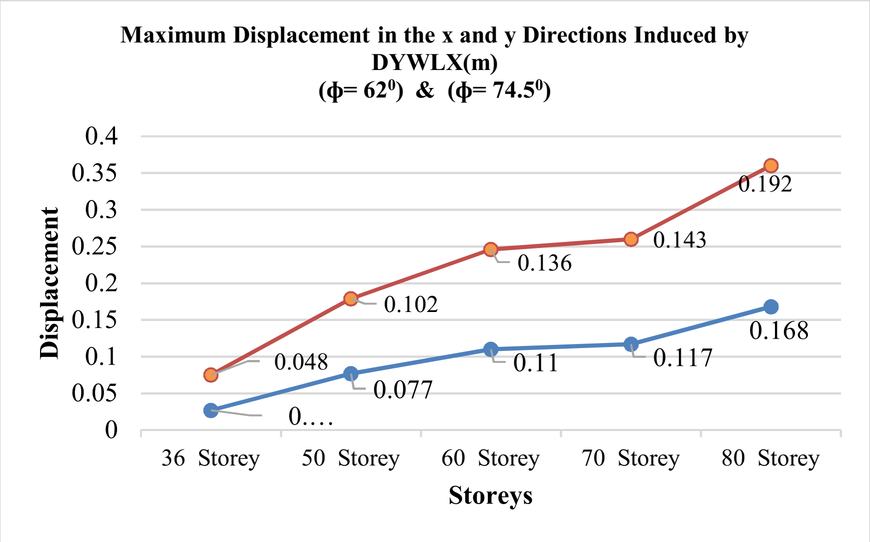


Fig. 9. **Level displacement (a) 50- Level and (b) 60-s Level (C) 70-storey (d) 80-storey.**

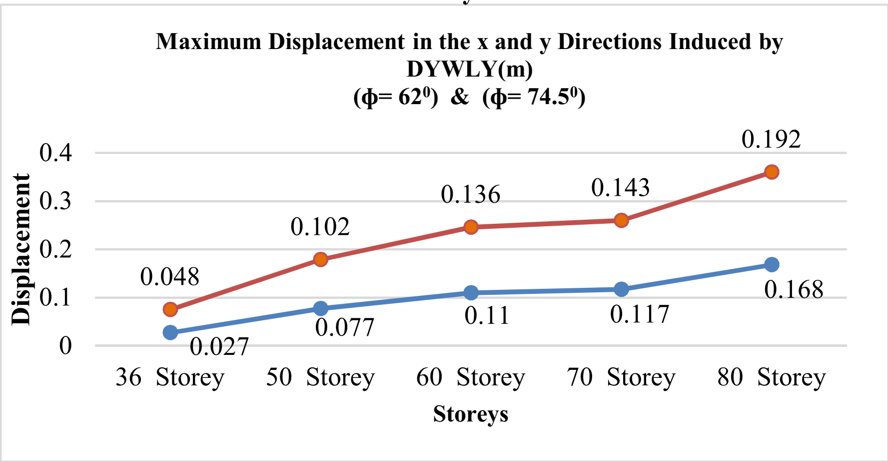


Table 5 displays the maximum inter-storey drifts caused by dynamic wind load in the X and Y directions for diagrid structures of 36, 50, 60, 70, and 80 stories.

Table 5. Inter-story drift in diagrid structures of 36, 50, 60, 70, and 80 stories

Level	DYWLX-induced Inter-floor movement in the x-direction (m)	DYWLY-induced Inter-floor movement in the Y-direction (m)
36 Level	0.000229	0.000237
50 Level	0.000491	0.000503

60 Level	0.000574	0.000585
70 Level	0.000579	0.000587
80 Level	0.000729	0.000742

Figures 10, to show how the height of buildings of 50, 60, 70, and 80 stories varies in inter-story drift, correspondingly.

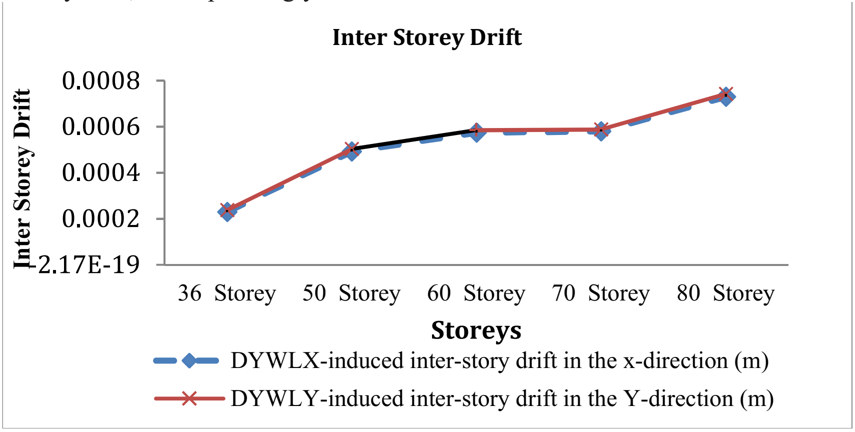


Fig. 10. Inter-floor movement (a) 50-storey (b) 60-storey (c) 70-storey and (d) 80-storey.

4. Diagrid structural system design.

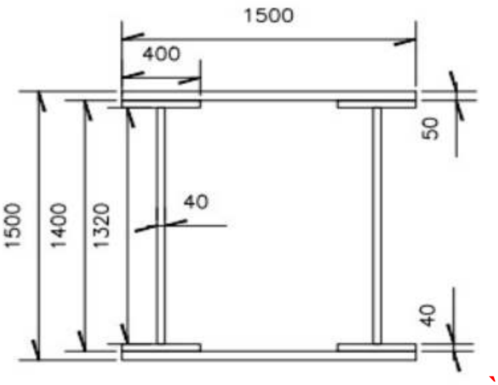
In the ETABS software, the wind-related lateral load and gravity load are integrated and given to the structure. Based on the analysis results, IS:800-2007 is followed in the design of the interior columns, floor beams, and diagonal components. Steel is thought to have a yield strength of 250 N/mm^2. The typical member sizes for the 36, 50, 60, 70, and 80 story diagonal diagrid constructions are displayed in Table 6 (10).

Table 6. Conventionall member sizes for diagrid structures with 36, 50, 60, 70, and 80 stories

Storey	Columns that are diagonal	Interior Supports	Beams (identical on each floor)
36 Stories	The pipe sections used in the structure vary in size and thickness depending on the storey. From the 19th to the 36th level, the pipe sections have a dia of 375 mm and a wall	1.5m × 1.5 m	The top and bottom cover plates, each measuring 220 mm by 50 mm, are used in the design. The beams B1 and B3 are made of ISMB 550 sections, while beam B2

	thickness of 12 mm. In contrast, from the 1st to the 18th level, the pipe sections are larger, measuring 450 mm in dia and 25 mm in thickness.		is constructed from an ISWB 600 section.
50 Stories	Sections of 525 mm pipe that are 25 mm thick	1.65m × 1.65m	
60 Stories	25 mm thick pipe sections measuring 750 mm	1.8m × 1.8m	
70 Stories	50 mm thick pipe sections measuring 675 mm	2m × 2m	
80 Stories	Sections of 825 mm pipe that are 50 mm thick.	2.2m × 2.2m	

Figures 11 and 12 depict the internal column's details that are resisting weights primarily due to gravity. By taking into account structural steel's increased yield strength, member sizes can be decreased. Fig. 13 depicts a typical 36-story structure's diagrid column and floor beam connection detail.



(a)

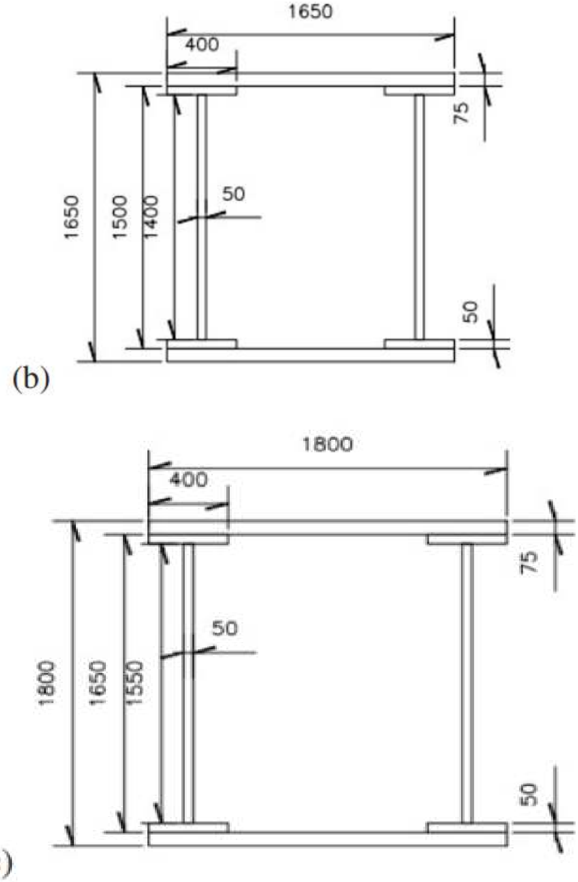
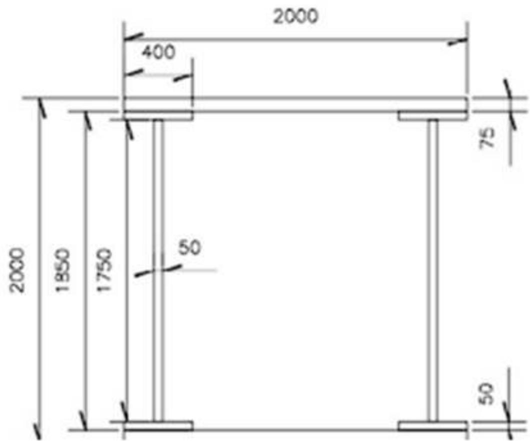


Fig. 11. Information about the interior columns of (ϕ= 74.5^0) [a] 36-stories [b] 50-stories & [c] 60-stories.



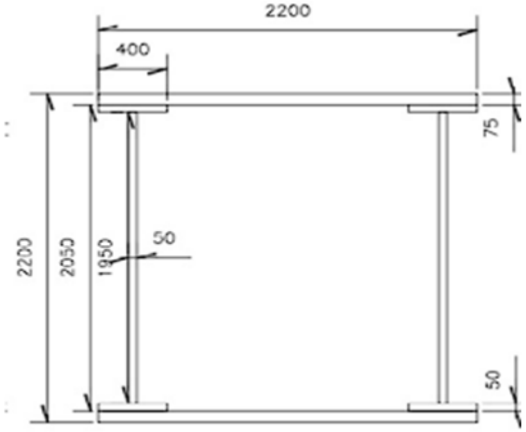


Fig. 12. Details of internal columns of (a) 70-storey and (b) 80-storey.

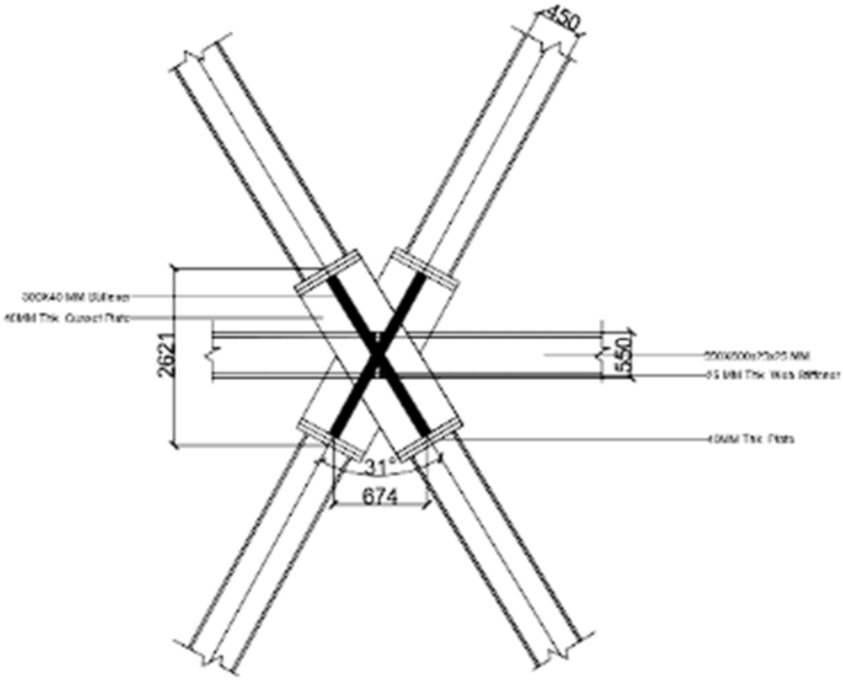


Fig. 13. Standard junction detail of the 36-story diagrid structure.

5. Conclusion

A 36-story diagrid steel skyscraper's design and analysis are presented in detail in this study. A typical Floor design measuring 36 m x 36 m is taken into account. ETABS software is employed for modelling and analysing the structure. Each structural element is designed according to IS 800:2007, considering all possible load combinations. The load distribution within the diagrid system is also examined for a 36-story building. The results of the study and design of diagrid structures of 50, 60, 70, and 80 stories are also displayed.

According to the findings, the peripheral diagonal columns withstand the majority of the lateral force, whereas the interior and peripheral diagonal columns both withstand gravity loads. Internal columns must therefore only be constructed to support vertical loads. The extension of the lever arm of the exterior diagonal columns enhances the effectiveness of the diagrid structural system in resisting lateral loads. The axial force in the diagonal elements along the building's perimeter, which withstands lateral and gravity loads, increases system efficacy. The diagrid structural framework allows for greater planning flexibility for the interior rooms and exterior façade.

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