DIAGRID STRUCTURAL SYSTEM FOR R.C.FRAMED MULTISTOREYED BUILDINGS

Harshita Tripathi, Dr. Sarita Singla

Abstract- One of the evocative structural design solutions for tall buildings is recently embraced by the diagrid (diagonal grid) structural system. In tall buildings, the main problem that governs the design is lateral loads, instead of the gravitational loads in shorter building. Thus, systems that are more efficient in achieving stiffness against lateral loads are considered better options in designing tall buildings. The diagrid system is one of the most efficient lateral resisting systems, and this feature is caused by its triangular configurations. The diagrid structural system has been widely used for recent tall buildings due to the structural efficiency and aesthetic potential provided by the unique geometric configuration of the system. This paper presents a stiffness-based design methodology for determining preliminary member sizes of r.c.c diagrid structures for tall buildings. The methodology is applied to diagrids of various heights and grid geometries to determine the optimal grid configuration of the diagrid structure within a certain height range.

A regular floor plan of 36 m × 36 m size is considered for the structures. ETABS 2015 software is used for modelling, analysis and design of structural members. All structural members are designed as per IS 456:2000 and load combinations of seismic forces are considered as per IS 1893(Part1):2002 considering all load combinations. Dynamic along wind and across wind are considered for analysis of the structure as per IS 875-1987 (part 3). The design methodology is applied to a set of diagrid structures which consist of 24, 36, 48 stories. Dynamic Analysis of 24, 36 and 48 story building with perimeter diagrid with different story module is carried out by Response spectrum method. The comparison of analysis of results in terms of top story displacement, story drift, story shear, time period, angle of diagrid, spectral acceleration coefficients, base reactions for seismic and wind forces is done with in the same story height for different story modules and for different story heights.

Index Terms- Diagrid structural system, story displacement, story shear, time period, story drift.

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1 INTRODUCTION

INNOVATION in design trends in tall buildings pose new challenges to structural designers, in addition to the traditional requirements for strength, stiffness, ductility and system efficiency.

Following the recent trends in tall buildings design practice, the innovative structural scheme being used is the Diagrid Structural system, a perimeter structural configurations characterized by a narrow grid of diagonals members which are involved both in gravity and lateral load resistance. Ever increasing heights and complexity of form, there is a need for robustness coupled to economy, awareness of limited material resources and sustainability in addition to its structural efficiency and aesthetic potential which is provided by the unique geometric configuration of the Diagrid Structural system. The diagrid structural system is known for its redundancy, continuous and uninterrupted load paths. The diagrid structural system is becoming increasingly popular in the design of tall buildings due to its inherent structural and architectural advantages. Hence, the diagrid, for structural effectiveness and aesthetics has generated renewed interest from architectural and structural designers of tall buildings.

1.1 Diagrid System

A diagrid structure is a type of structural system consisting of diagonal grids connected through horizontal rings which create an elegant and redundant structure that is especially efficient for high-rise buildings. A diagrid structure is different from braced frame systems, since diagonals as main structural elements participate in carrying gravity load in addition to carrying lateral load due to their triangulated configuration, which eliminates the need for vertical columns. The column free structure of a diagrid system offers several advantages such as high architectural flexibility and elegancy, and enormous day lighting due to its large free facade surface.

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1.2 Design Methodology

With the rapid advancement of materials science and consequently produced higher strength materials, building structures are more often governed by stiffness requirements because of the lag in material stiffness versus material strength [1]. A diagrid structure is modeled as a vertical cantilever beam on the ground, and subdivided longitudinally into modules according to the repetitive diagrid pattern. Each module is defined by a single level of diagrids that extend over multiple stories [2]. Fig.1 illustrates the case of a 6-story module. Depending upon the direction of loading, the faces act as either web planes (i.e., planes parallel to wind) or flange planes (i.e., planes perpendicular to wind). The diagonal members are assumed to be pin-ended, and therefore resist the transverse shear and moment through axial action only. With this idealization, the design problem reduces to determining the cross-sectional area of typical web and flange members for each module.

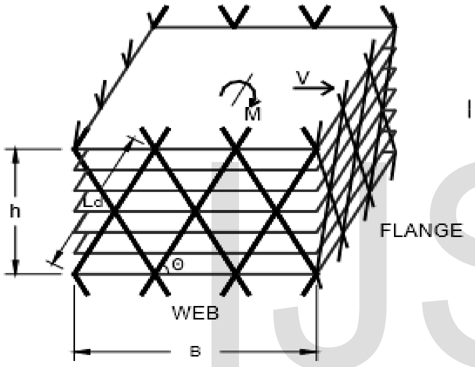


Fig. 1. Typical Diagrid Module

1.3 Structural Benefits

1. Increased stability due to triangulation
2. Combination of the gravity and lateral load bearing systems, potentially providing more efficiency.
3. Provision of alternate load paths (redundancy) in the event of a structural failure.
4. Reduced weight of the superstructure can translate into a reduced load on the foundations.

2. OBJECTIVES OF STUDY

1. To study the concept of diagrid structural system
2. To determine the optimum configuration for buildings using Etabs v.15 software.
3. To determine the optimum angle for diagrid system.
4. Comparison of results in terms of Max story drift, max story displacement, base shear in wind and seismic case, time period.

3. BUILDING CONFIGURATION

3.1 Types of Models

In this study, fifteen mathematical models (see Table 1) are modelled using Etabs v.15 software.

TABLE 1
THE NOTATIONS OF MODELS

Story Module	Angle of Diagrid		No. of Storeys		
		Module Name	24 Storey	36 Storey	48 Storey
2 Storey Module	50.2	M1	A1	B1	C1
4 Storey Module	67.4	M2	A2	B2	C2
6 Storey Module	74.5	M3	A3	B3	C3
8 Storey Module	78.2	M4	A4	B4	C4
12 Storey Module	82.1	M5	A5	B5	C5

3.2 Geometry Data

Here, the general geometry data for all the models are as follows:
1. Plan dimension- 36m X 36m
2. Storey height- 3.6m
3. Number of floors- 24, 36, 48 storeys
4. Slab thickness- 0.120m.
5. Characteristic strength of concrete: 40N/mm^2
6. Characteristic strength of steel: 500N/mm^2

As the building is assumed as office building the live load is considered as 2.5 kN/m^2. The floor load is considered as 2 kN/m^2. This load is applied on all the slab panels for all floors. A member load of 8.4 kN/m is considered on all the beams for the wall load considering the wall to be made of light weight bricks. The design earthquake load is computed based on the zone factor 0.24, soil type II, Importance factor 1, Response Reduction 5 as per IS-1893-2002 [3]. The design wind load is computed based on location Vadodara, Wind speed 44 m/s, Terrain category 2, Structure class B, Risk Coefficient 1, Topography factor 1 as per IS 875(Part 3) -1987 [4]. Modelling, analysis and design of diagrid structure are carried out using ETABS 2015 software. The end condition for diagrid is assumed as hinged. The support conditions are assumed as fixed. The design of member is carried out on the basis of IS-

456-2000 [5].

3.2 Structural Plan

Here, fig. 2 is showing the structural plan view of all the models in which the beam notations B1, B2, B3 and column notations C1, C2, C3 are shown.

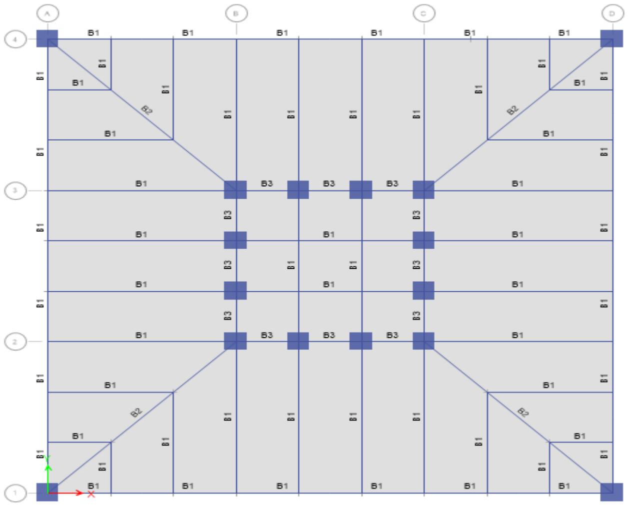


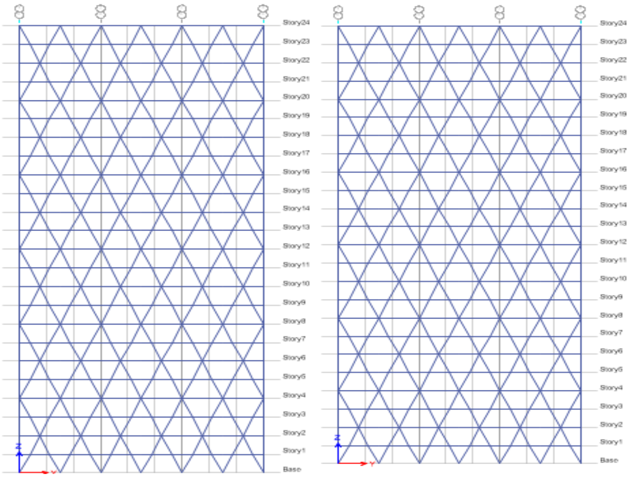
Fig. 2. Structural Plan

The angle of diagrid is decided on the basis of the storey module. The angle is obtained from the height of the storey module to the base width of diagrid. Here, in Fig.3 five different storey module is considered, that is 2-storey module, 4-storey module, 6-storey module, 8 storey module and 12-storey module.

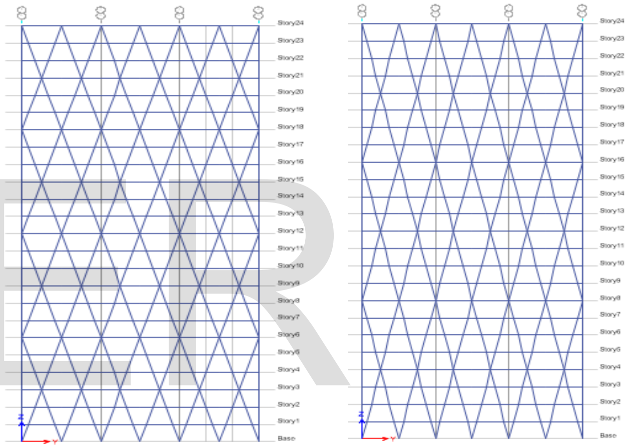
The member sizes for all the models are preliminary decided but after analysis results and designing results, the sizes are modified to prevent the failure and excessive top storey displacement. Table 2, Table 3, Table 4 is showing the member sizes for model-A, model-B, model-C.

TABLE 2
Preliminary sizes in mm for member-A

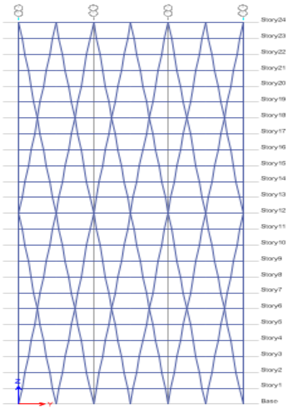
Member		Model A				
		A-1	A-2	A-3	A-4	A-5
Beam	B1	300*800	300*800	300*800	300*800	300*900
	B2	300*1100	300*1100	300*1100	300*1100	300*1100
	B3	300*800	300*800	300*800	300*800	300*800
Column	C1	1400*1400	1400*1400	1400*1400	1600*1600	1800*1800
	C2	1400*1400	1400*1400	1400*1400	1600*1600	1600*1600
Diagrid	D	500*500	500*500	500*500	500*500	600*600



a) 2-storey module b) 4–storey module



c) 6-storey Module d) 8-storey module



e) 12- storey module

Fig. 3. Elevation of different storey module

Almost all of the plans are made symmetrical as possible because it is more efficient in load-bearing and most of them are circle, ellipse or curved shape.

TABLE 3
Preliminary sizes in mm for member-B

Member		Model B				
		B-1	B-2	B-3	B-4	B-5
Beam	B1	300*800	300*800	300*900	300*900	300*1000
	B2	300*1100	300*1100	300*1100	300*1100	300*1100
	B3	300*800	300*800	300*800	300*800	300*800
Inner Column	C1	1600*1600	1600*1600	1700*1700	1700*1700	1800*1800
Outer Column	C2	1400*1400	1400*1400	1500*1500	1500*1500	1600*1600
Diagrid	D	600*600	600*600	600*600	600*600	800*800

TABLE 4
Preliminary sizes in mm for member-C

Member		Model C				
		C-1	C-2	C-3	C-4	C-5
BEAM	B1	300*800	300*800	300*900	300*900	300*1000
	B2	300*1100	300*1100	300*1100	300*1100	300*1100
	B3	300*800	300*800	300*800	300*800	300*800
INNER COLUMN	C1	1900*1900	1900*1900	1900*1900	1800*1800	1900*1900
OUTER COLUMN	C2	1700*1700	1700*1700	1700*1700	1600*1600	1700*1700
DIAGRID	D	800*800	800*800	800*800	800*800	800*800

4. ANALYSIS RESULTS

Here, the response spectrum analysis results for all the models are presented here in terms of reaction, Top storey displacement, storey drift storey shear and time period.

4.1 Time Period Results

By performing the Response spectrum analysis, time period is found out by considering 12 mode shape for all models, is presented here as shown in fig. 4, fig. 5, fig. 6.

The building's natural time period is obtained as in (1), where, m = mass of the structure and k = stiffness of the building from it can be observed that period depends upon the mass and stiffness of the structure.

$$T=2\pi*\sqrt{(m/k)} \qquad (1)$$

Where, m = mass of the structure and k = stiffness of the building, from the above equation, it can be period depends upon the mass and stiffness of the structure. If the time period is more, the modal mass is more but the stiffness of the building is less vice-versa. It can been noticed that the time period is minimum for the model A-2, B-2, C-2, so the stiffness of that models is more as compare to others.

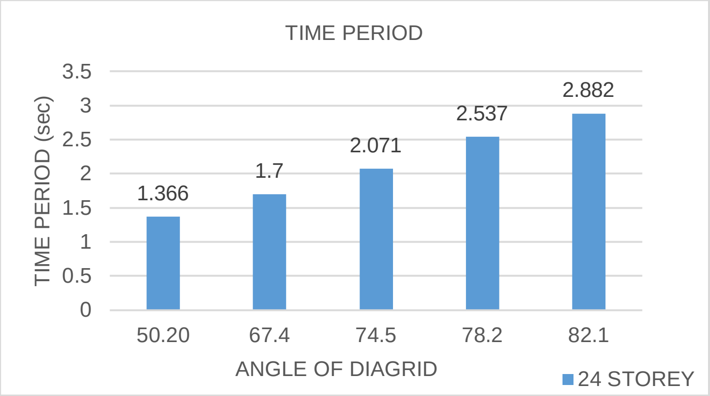


Fig. 4. Time Period for 24 Storey Model

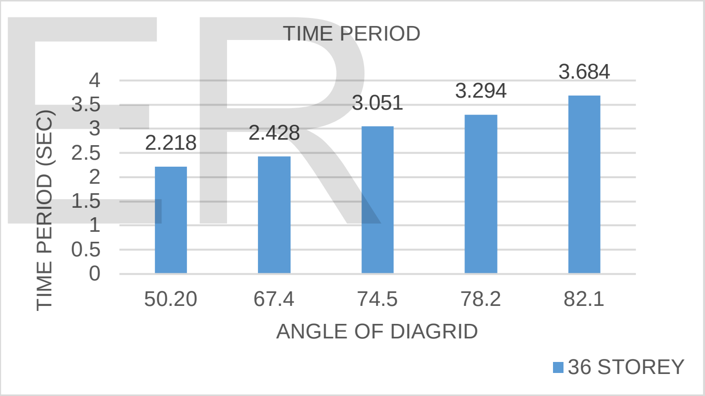


Fig. 5. Time Period for 36 Storey Model

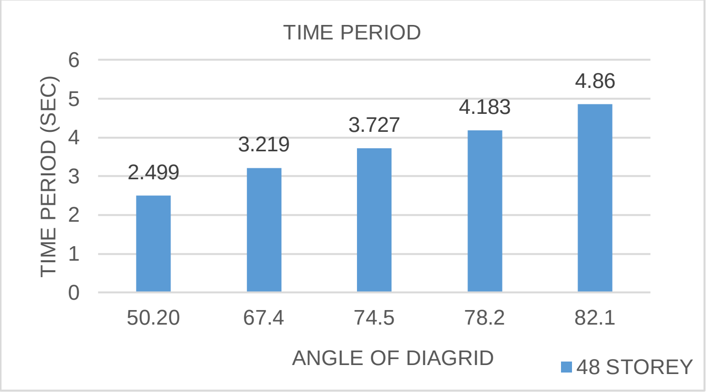


Fig. 6. Time Period for 48 Storey Model

4.2 Spectral Acceleration Coefficient

By performing the dynamic analysis of 15 mathematical mod-

els by response spectrum method, the result of spectral acceleration coefficient is as shown in Fig. 7.

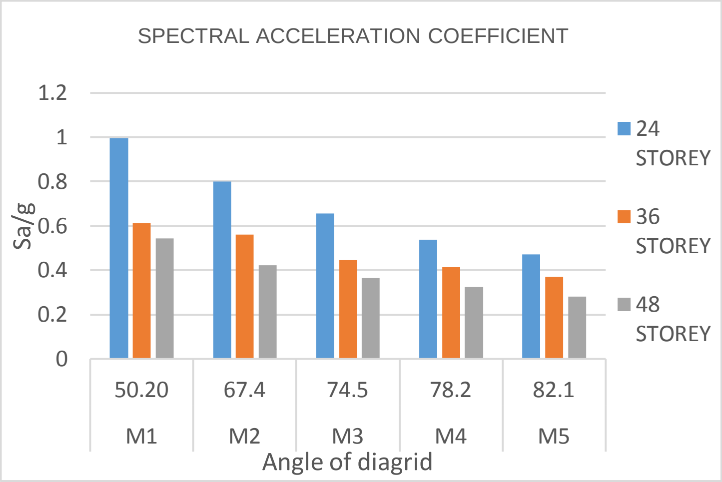


Fig. 7. Spectral acceleration coefficient for different storey module for different storey building.

4.3 Base Shear Results

The summary of reaction of lateral loads due to earthquake load and wind load for Model-A, Model-B, Model-C is as shown in Fig. 8.

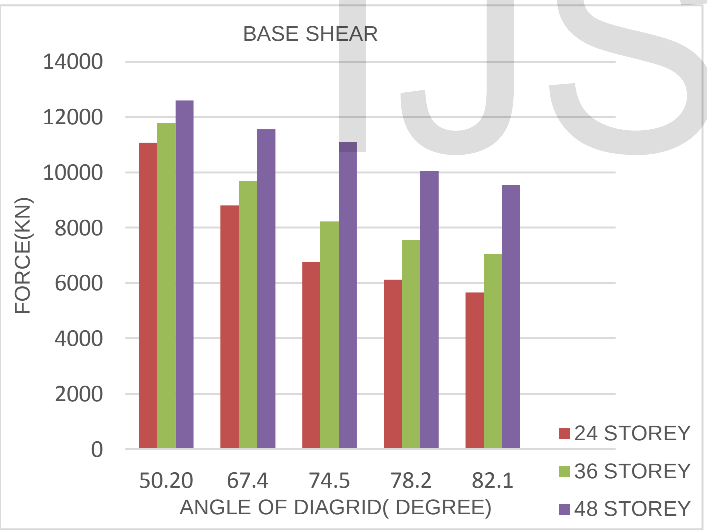


Fig. 8. Summary of base reaction for seismic loads

4.4 Displacement Results

The displacement results for Model-A, Model-B, Model-C is as shown in Fig. 9, Fig. 10, Fig. 11, Fig. 12 and Fig. 13.

Fig. 9. Displacement results for 24 storey model for seismic loads.

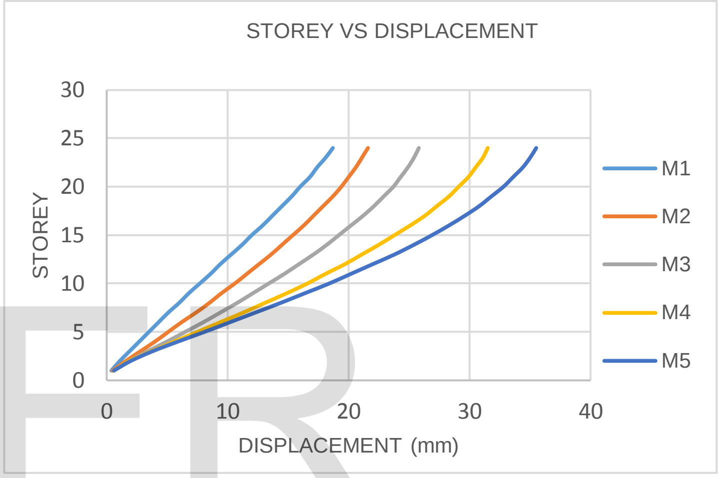


Fig. 10. Displacement results for 24 storey model for wind loads

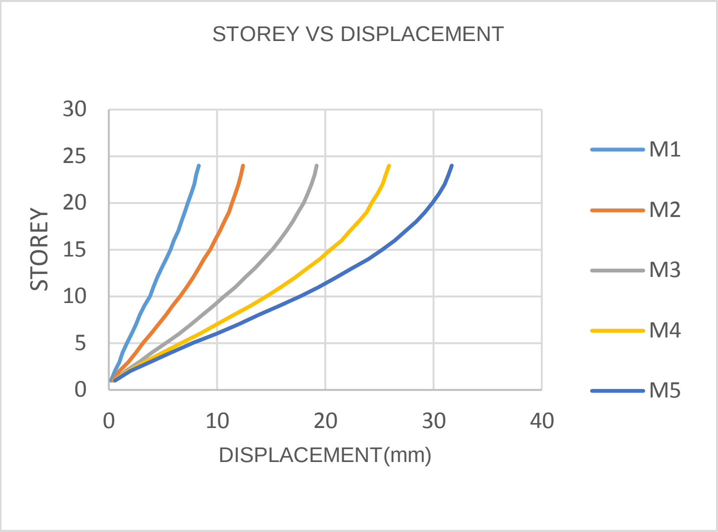


Fig. 11. Displacement results for 36 storey model for seismic loads

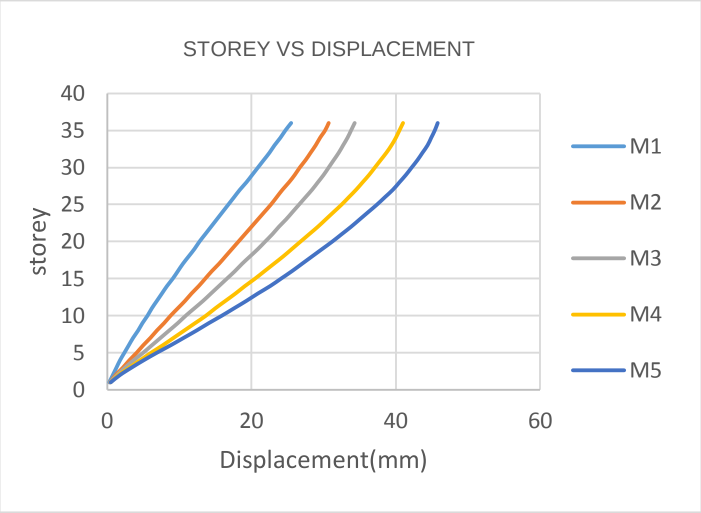


Figure 12. Displacement results for 36 storey model for wind load.

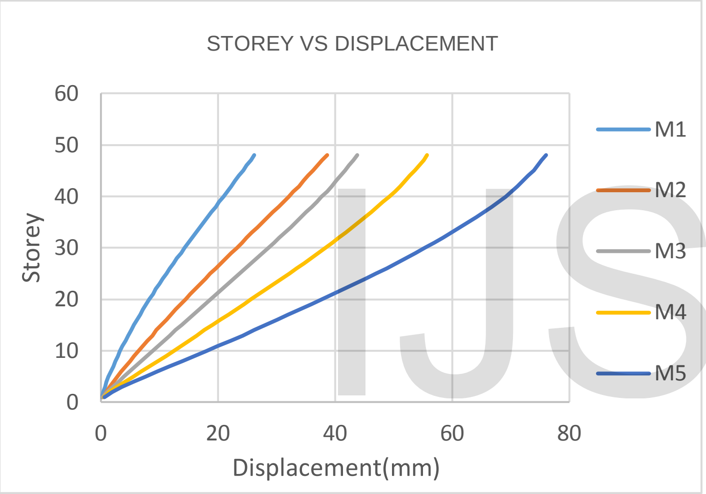


Fig. 13. Displacement results for 48 storey model for seismic load.

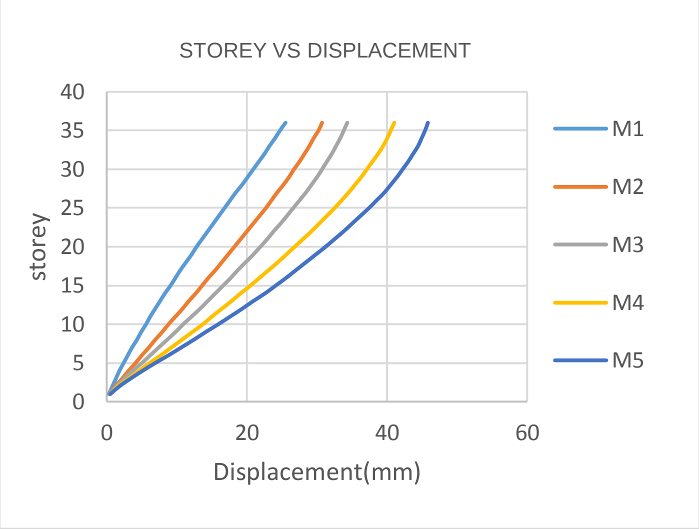


Fig. 14. Displacement results for 48 storey model for wind load.

4.5 Storey Drift Results

Here, the storey drift results in m for Model-A, Model-B, Model-C is as shown in fig. 15 for seismic loading and fig. 16 for wind loading.

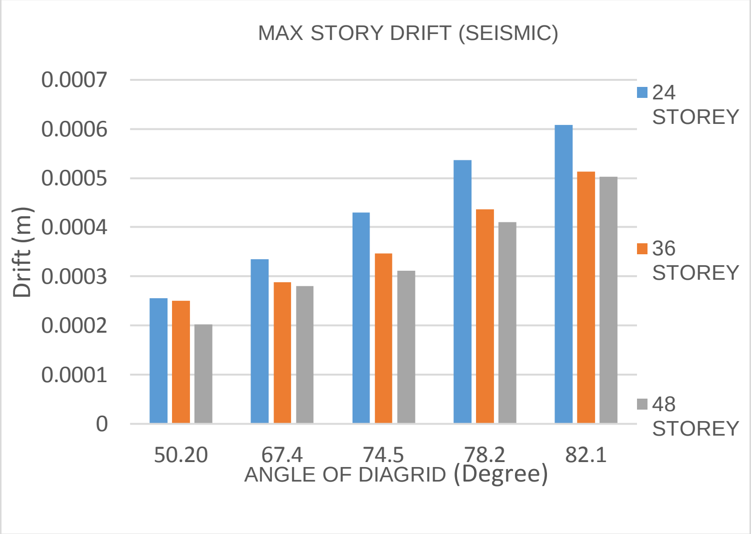


Fig. 15. Max story drift for seismic loading case.

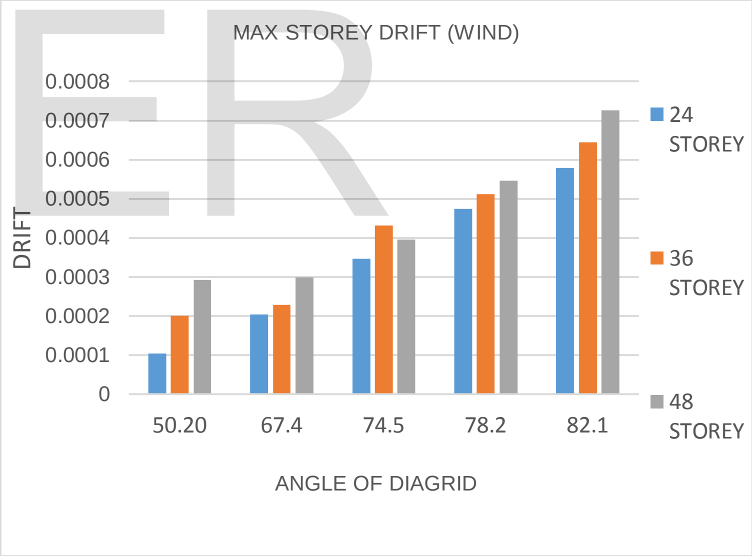


Fig. 16. Max story drift for wind loading case.

For earthquake load, as per code IS: 1893-2002, clause: 7.11.1, the storey drift in any storey due to minimum specified lateral force with partial load factor of 1.0 should not exceed 0.004 times storey height that is H/250, where H = storey height in meter. The storey drift value is within the permissible limit. It can be seen that the excessive drift for the model A-5, B-5, and C-5. Model A-2, B-2, C-2 and D-2 is giving the better results as compared to other models.

5. CONCLUSION

The current study is carried out by considering the different angles of diagrid and also different storey module of the varying building height. The proposed plan of 36m x 36m is considered with four different types of angles of diagrid that is 50.2°, 67.4°, 74.5°, 78.2° and 82.1° for 2 storey, 4 storey, 6 storey, 8 storey, 12 storey diagrid module for 24-storey, 36-storey, 48-storey building, a comparative study is carried out.
We conclude from the study that,

1. For all the 15 models, considered for the study, storey displacement and storey drift values are within the permissible limit.
2. Diagrid angle in the region of 65° to 75° provides more stiffness to the diagrid structural system which reflects the less top storey displacement.
3. The storey drift and storey shear results are very much lesser in the region of diagrid angle 65° to 75°.
4. As time period is less, lesser is mass of structure and more is the stiffness, the time period is observed less in the region of diagrid angle 65° to 75° which reflects more stiffness of the structure and lesser mass of structure.
5. It should be noticed that the results for the angle of diagrid 82.1° is quite random for the storey drift, storey shear and time period.
6. Optimum angle of diagrid is observed in the region of 65° to 75°.

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