Comparative Study of Wind Analysis of High Rise Building with Diagrid and Outrigger Structural Systems Using Gust Factor Approach

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Abstract- *In recent high-rise buildings, a coupled wall system is adopted to resist lateral loads caused by wind or seismic. But as height of building increases, the structural stiffness plays significant role and the provision of outrigger system is benefited to give adequate stiffness to the structure against such lateral forces. Diagrid is recently evolved structural system resisting lateral loads due to wind or earthquake. The perimeter diagrid system creates triangular modules which are mainly responsible for resisting gravity as well as lateral loads caused by wind or earthquake.*

This study presents the comparative results of diagrid and outrigger structural system for high-rise building of height 108 m subjected to lateral wind load. The analysis includes different building models with shear wall system, diagrid system and outrigger system. By using Gust factor method as per IS: 875 (Part-3)-1987, the lateral wind load is calculated by considering dynamic 'along wind' response. Hence the aim of this study is to analyze and compare different models by varying the angle of inclination and changing the location of outrigger. Comparison of analysis results is made in terms of top storey displacement, axial forces, material consumption and time period.

Key Words: **High-rise building, Diagrid system, Outrigger system, ETABS, Dynamic Wind analysis**

1. INTRODUCTION

High rise structures are more referred now a day, due to tremendous growth of urban population and scarcity of available land. Structural analysis and design of high rise building is governed by lateral loads caused by seismic or wind. As height of structure increases, a lateral load becomes predominant. Interior structural system or exterior structural system provides lateral load resistance of the structure.

1.1 Diagrid structural system

The diagrid concept is a combination of the two words diagonal and grid. Structural effectiveness and flexibility in architectural planning is the key reason to adopt the diagrid structures in modern high rise buildings. The difference between the diagrid and closely spaced conventional columns is that, in diagrid systems all vertical columns at the periphery of building are removed and replaced by inclined columns. The inclined diagrid members are capable to carry gravity load and lateral loads due to the triangular module configuration.

Diagrid is placed with optimum angle of inclination at the periphery of the building and longitudinally divided into triangular modules. The diagonal members are considered to be pin connected, hence oppose through axial action only the transverse shear and moment. As compared with conventional structural system, diagrid system reduces nearly 20 % weight of structural steel. To satisfy both shear and bending rigidity, it is required to have the optimum angle of inclination of diagonal members for diagrid structure should fall in between 35° to 90° inclination.

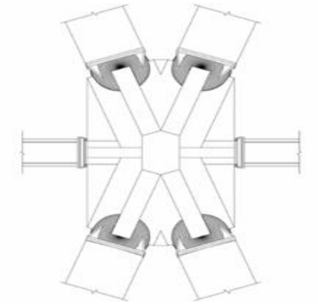

Fig. 1.1 Typical junction of diagrid structure.

1.2 Outrigger and Belt Truss Structural System

The structural configuration of an outrigger system includes central core tied to the exterior periphery column by means of rigid triangulated truss member names as outrigger truss. In outrigger and belt truss mechanism, the function of core wall is to resist lateral forces and weighty part of the loading is carried by the perimetral columns by means of axial load due to which windward columns subjected to tension and leeward columns subjected to compression.

When structure is subjected to horizontal loads, the columns connected to the outrigger resist the rotation of the central core, hence moments and the lateral deflection in the core becomes lesser as compared to core alone set apart resisted the loading. The depth of outrigger and belt truss can be taken as one or two stories deep to make it sufficiently stiff in flexural and shear. It is appropriate to locate one outrigger roughly at half of building height. The outrigger should be positioned approximately at 1/3rd and 2/3rd of height in case of structure with two outrigger system. And outrigger should be positioned roughly at 1/4th, 1/2, 3/4th of height in case of structure with three outrigger system, and so on. Generally, the outrigger located at 1/(n+1), 2/(n+2) up to n/(n+1) of height to achieve satisfactory results for an n-outrigger structure.

2. MODELING

In the present study, two different structural systems viz, Diagrid and Outrigger is taken into consideration. The building models with diagrid and outrigger is modeled and analyzed using the structural software ETABS and the results are compared.

Building configuration

- Number of stories : 30 Stories
- Height of storey : 3.6 m
- Height of structure : 108 m
- Plan dimension : 18 m x 18 m

Material Properties

- Grade of Concrete : M30
- Grade of steel reinforcement : Fe500
- Grade of steel sections : Fe345

Structural Parameter

- Floor level Column : 1000 mm x 1000 mm (Steel column)
  : 450 mm x 450 mm (Concrete column)
- Ground level column : 1000 mm x 1000 mm (Steel column)
- Floor level Beam : ISMB-600, ISWB-600 (For diagrid structure)
  : ISMB-400, ISMB500, ISWB-600 (For outrigger structure)
- Ground level Beam : 230 mm x 600 mm, 230 mm x 450 mm
- Slab thickness : 130 mm
- Diagrid section : 475 mm Pipe section with 25 mm thickness
- Outrigger : 2-ISA 200 mmX200 mmX25mm
- Outrigger belt truss : 2-ISA 200 mmX200 mmX25mm
- Core wall thickness : 450 mm
- Wall thickness : 230 mm

Loading Data

- Floor finish : 1.0 KN/m^2
- Live load on floor : 3.5 KN/m^2
- Wind zone : 4
- Basic wind speed (Vb) : 50 m/s
- Terrain category : 3
- Class of structure : A (Max. dimension < 20 m)
- Life of structure : 50 years.

2.1 : Model Considered for the Analysis

The plan and 3D view of building models with different locations of outrigger and different angle of inclination for diagrid structure are considered. Here Building with 4-Storey diagrid module (67.38° inclination) and Building with two outriggers @ 0.33H and 0.66H are presented in fig. 6.1 to 6.10.

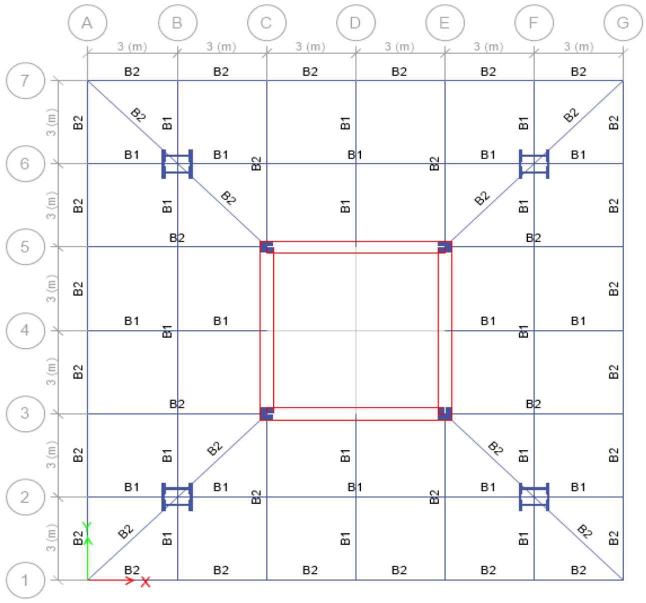

Fig. 2.1 Plan of diagrid building.

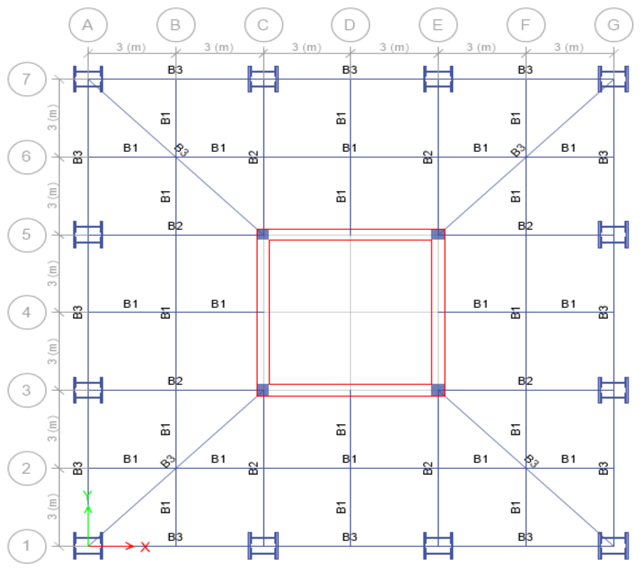

Fig. 2.2 Plan of outrigger building.

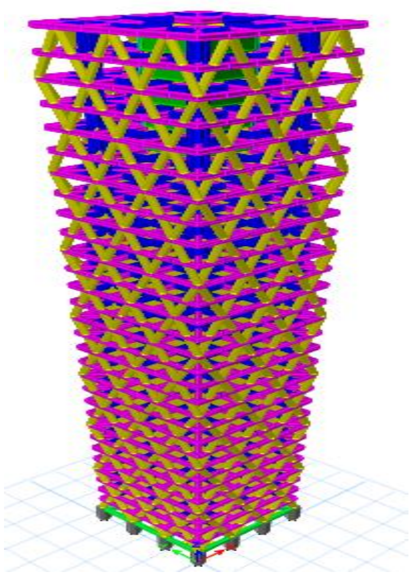

Fig.2.3 Building with 4-Storey diagrid module (67.38° inclination)

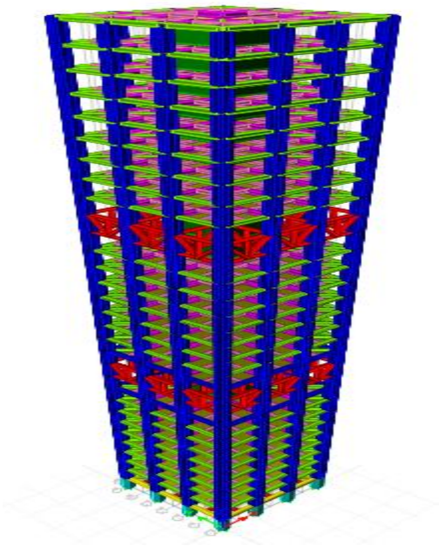

Fig. 2.4 Building with two outriggers @ 0.33H and 0.66H

3. RESULTS AND DISCUSSION

In this section, analysis results of the building structures with two outriggers at various locations and diagrid module with different angle of inclination, considered for the dynamic response of wind are presented.

Building with two outriggers at different locations:

1. Top storey displacement (mm):

Top storey displacement is one of the relevant stiffness design criteria in any high rise structural system.

Table 3.1 Top storey displacement for building having two outriggers at different locations.

Structural systems	Top Storey displacement (mm)
Building without outrigger	152.2
Building with two outrigger @ Top and 0.75H	122.9
Building with two outrigger @ Top and 0.5H	114.6
Building with two outrigger @ 0.33H and 0.66H	103.9

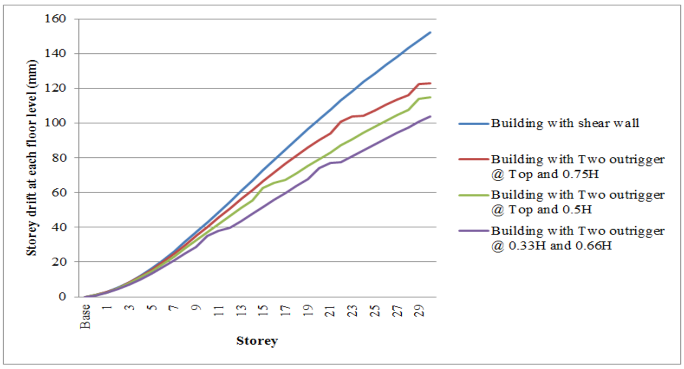

Fig. 3.1 Storey displacement at each floor level for building having two outriggers at different locations.

From table 3.1 and Fig. 3.1, it can be seen that by introducing outriggers, the top storey displacement reduces of about 31.71 % for 0.33H and 0.66H location of outrigger as compared to the building without outrigger (i.e building with shear wall only). In high-rise building, provision of outrigger at optimum location increases the shear rigidity of the structure, subsequently the structural stiffness also increases which gives the resistance to deflection under lateral loads and hence top storey displacement will be less.

2. Axial force (kN):

The axial force results in structure provided with two outriggers at different locations are tabulated in table given below and represented in fig. 3.2

Table 3.2 Axial force (kN) in column for building having two outriggers at different locations.

Structural systems	Axial force in column no. C5 (kN)
Building without outrigger	12637.33
Building with two outrigger at top & 0.75H	11512.66
Building with two outrigger at top & 0.5H	11495.03
Building with two outrigger at 0.33H & 0.66H	11463.95

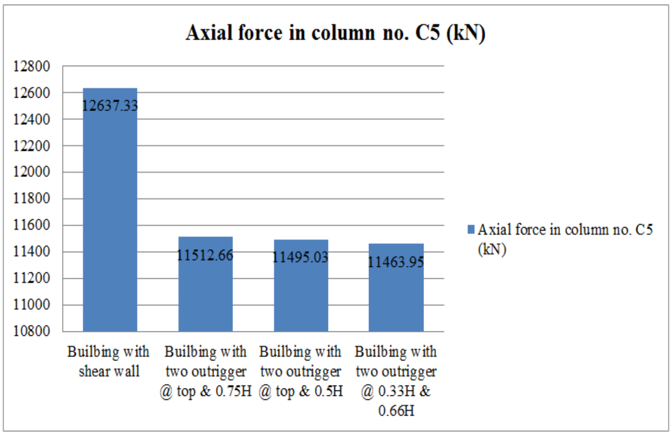

Fig. 3.2 Axial force (kN) in column for building having two outriggers at different locations.

It can be observed that the Provision of outrigger in the high rise structure decreases the displacement of the building as well as axial force in the column reduces by 9.28% for the building with outrigger location is at 0.33H & 0.66H as compared with the building model without an outrigger (12637.33 kN)

2. High-rise Building with diagrid system at different angles of inclination:

In order to obtain the optimum angle of inclination as well as minimum deformation mode for a given height of building, a set of structures having four different storey modules with different angles of inclination are as shown in the Fig. no. 3.3.

Table 3.3 Top Storey displacement for building having different storey diagrid modules.

Structural systems	Top Storey displacement (mm)
Building with shear wall	152.251
Building with 6-Storey diagrid module (74.47° inclination)	96.63
Building with 5-Storey diagrid module (71.56° inclination)	93.812
Building with 4-Storey diagrid module (67.38° inclination)	93.72
Building with 3-Storey diagrid module (60.94° inclination)	97.355

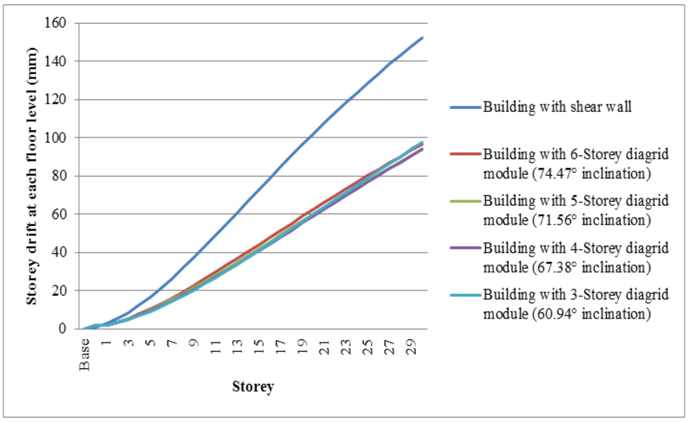

Fig. 3.3 Storey displacement at each floor level for building having different diagrid modules.

It can be seen that, the top storey displacement of Building with 4-Storey diagrid module (67.38° inclination) reduces of about 38.45 % as compared to the building without outrigger (i.e building with shear wall only). In high-rise building, diagrid structure with optimum inclination of diagonal member increases the shear rigidity of the structure, subsequently the structural stiffness also increases.

3. Comparison of storey displacement for buildings with diagrid, outrigger and shear wall structural system:

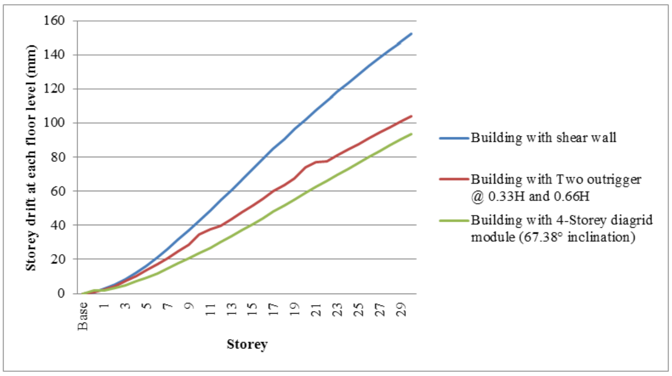

Fig. 3.4 Top storey displacement for Building with 4-Storey diagrid module (67.38°), Building with two outriggers @ 0.33H and 0.66H, and building with shear wall.

From fig. 3.4, it can be seen that, the top storey displacement of Building with 4-Storey diagrid module (67.38° inclination) reduces of about 10 % as compared to the Building with two outriggers @ 0.33H and 0.66H. Thus it may state that, the shear rigidity of diagrid structure is much more than outrigger structure which gives higher stiffness value. Hence perimeter diagrid system is stiffer than the outrigger system.

4. Material Consumption:

The consumption of steel for diagrid and outrigger structural system is calculated and presented in table. It can be observed that the consumption of steel material for outrigger structural system is higher than the diagrid structural system. The percentage increase in steel material for outrigger structure is 17% more than diagrid structure.

Table 3.4 Consumption of steel material for diagrid and outrigger structural system.

Material Consumption	Steel consumption in Diagrid (ton)	Steel consumption in Outrigger (ton)
Column	763.47	2311.20
Beam	888.06	554.16
Braces	763.90	54.11
Total	**2415.43**	**2919.47**

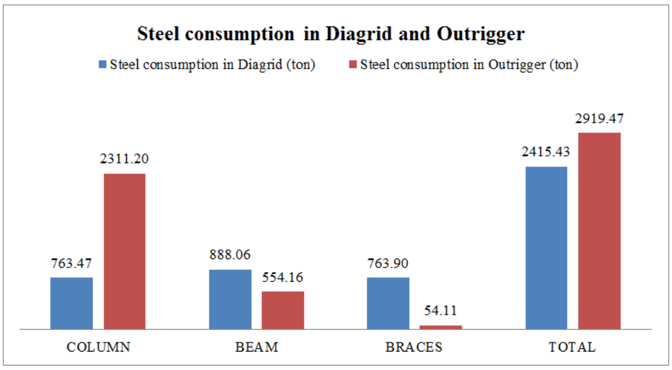

Fig. 3.5 Variation of quantity of steel material consumed for diagrid and outrigger structure.

5. Natural Time period:

The natural time period of 30 storey high-rise building corresponds to first mode for diagrid structure with 67.38° inclination, outrigger structure with provision of two outriggers at 0.33H and 0.66H location and shear wall structure are shown in fig. 3.6

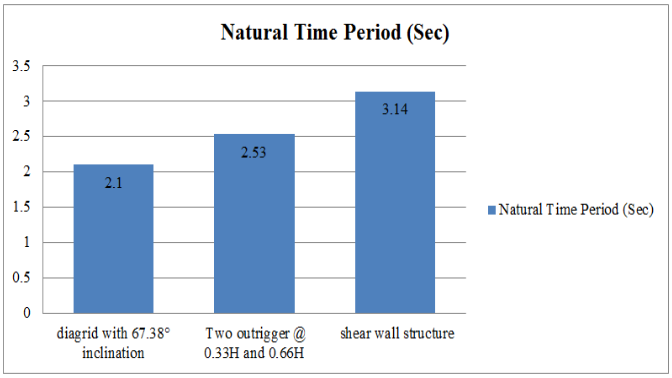

Fig. 3.6 Natural time period for diagrid, outrigger and shear wall structure.

Stiffness is inversely proportional to time period. As time period decreases stiffness of the structure increases. It can be observed from figure that, the time period of diagrid structure is less as compared to outrigger structure due to perimetral diagonal member the stiffness of diagrid structure increases (2.1 Sec). Thus it can state that, the diagrid structural system is much stiffer than the outrigger and shear wall structural system.

5. CONCLUSIONS

Following conclusions are drawn from the present study

1. The provision perimeter diagrid system in high rise buildings enhance the structural stiffness and make the structural system effective under lateral load as well as they are effective in reducing the lateral displacement.
2. The top storey displacement of Building with 4-Storey diagrid module (67.38° inclination) reduces of about 10 % as compared to the Building with two outriggers @ 0.33H and 0.66H. Hence it can be conclude that for high rise building, perimeter diagrid system is the convenient structural system.
3. The consumption of steel material for outrigger structural system is 17% higher than the diagrid structural system. Hence it can be conclude that for high rise buildings, provision of diagrid structural system will be economical.
4. The time period of diagrid structure is less as compared to outrigger structure (2.1 Sec). Thus it can be conclude that, the diagrid structural system is much stiffer than the outrigger and shear wall structural system.
5. Diagrid structure gives more feasible system in architectural planning as well as higher structural efficiency for high-rise buildings.

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