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Comparative Study of Wind Analysis of High Rise Building With Diagrid And Outrigger Structural System Using Gust Factor Method

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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. Provision of diagrid in high-rise building increases building stiffness and often makes lighter than conventional high rise buildings. As compared to conventional structural system, diagrid structure saves approximately 15% structural steel.

Key Words: Highrise building, Diagrid ,outrigger,wind analysis ,ETAB2016…

1.INTRODUCTION

High rise structures are more preferred 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. The growth of high rise building is facilitated by enhancement in construction industry, effective materials, internal and external structural systems and advancement in analysis and design methods. Governing factor for structural design of high rise building is the lateral loads caused by wind or earthquake. It should to be noted that the assigned structural system is such that the structural components are used efficiently while ascertaining the design requirements.

Various load resisting structural systems or philosophies which are usually incorporated in multi-storied structures are discussed here. The various structural systems are;

1. Rigid frame systems
2. Braced frame and shear-walled frame systems
3. Braced frame systems
4. Shear-walled frame systems
5. Outrigger systems
6. Framed-tube systems
7. Braced-tube systems
8. Bundled-tube systems

Motion perception or vibration is the third engineering difficulty creating in the structure‟s resistance to bending and shear. If building sway increases, structural system loses human comfort criteria or it may observe that the nonstructural components such as glass fascia may crack which causes expensive destruction to the building, also causing harm to the pedestrians.

2. LITERATURE REVIEW

Smith, B. S. and Alex Coull (1991) [1] investigated the optimum outrigger location by taking into account the tentative structures whose outriggers were flexurally rigid. It is seen that, structural system with single outrigger should be positioned at around midheight of the building, the outrigger should be positioned at approximately at 1/3rd and 2/3rd of height in case of structure with two outrigger system and it should be positioned roughly at 1/4th, 1/2, 3/4th of height in case of structure with three outrigger system, and so on.

Z. Bayati, M. Mahdikhani and A. Rahaei (2008)[2]studied on reduction in displacement for uniform belted structures having rigid outrigger by means of the analysis done on sample structure constructed in Vanak Park in Tehran. From analysis results it can be seen that, the seismic response of the building can efficiently reduce by using optimized multi outrigger system. Furthermore, it shows that the dimensions of the structural elements and foundation can decreases by multi outrigger system.

Po Seng Kian, Frits Torang Siahaan (2001) [3] studies that for high-rise building, the usefulness of outrigger belt truss system under wind or seismic lateral load. Analysis is done for eight 2-D models of outrigger belt truss system having 40-storey subjected to wind load and five 3-D models having 60-storey subjected to seismic load. Analysis results are compared to ascertain lateral displacement corresponds to the different positions of outrigger system.

Abbas Haghollahi, Mohsen Besharat Ferdous, and Mehdi Kasiri (2012)[4]studied present the comparison of optimum outrigger locations for response spectrum and nonlinear time-history analysis. For response spectrum and time-history analyses, 20 and 25 storey models have been investigated and carried out against seven ground motions. The aim of this study is to ascertain optimized location of outrigger with nonlinear time history is different from response spectrum analyses and it has been located in upper levels.

Khushbu Jani, Paresh V. Patel (2012) [5] carried out analysis and design of diagrid steel building having 36-storey. Analysis and design of structural member is conducted by using ETAB software. All structural elements are designed by taking into account all load combinations as per IS 875:2007. For analysis and design of structure dynamic along wind and across wind are considered. Likewise, for fifty, sixty, seventy and eighty storey high diagrid building, analysis and design is carried out.

3. SCOPE AND OBJECTIVE OF WORK

The present study aims to establish the optimum angle of inclination for diagrid structure, optimum location of outrigger and storey displacement in high-rise buildings. Taking into account the dynamic effects by using gust factor method of wind analysis as per IS 875 (Part 3)-1987. The 3D modeling and analysis has been considered using structural analysis and design software ETABS-16 and the results such as storey displacement, column's axial forces and material consumption are acquired and compared with different building models.

OBJECTIVE OF WORK:

I. Creating 3D building models with different storey module for diagrid structure and by varying the outrigger locations.
II. The main objective of this study is to investigate the behavior of structure for different lateral load resisting systems i.e. diagrid and outrigger under wind analysis.
III. To ascertain the optimum angle of inclination for diagrid structure and optimum position of outrigger.
IV. To obtain and compare the analysis results in the form of storey displacement, axial forces, for different building models with diagrid and outrigger structural systems.

4. METHODOLOGY OF WORK

4.1. GENERAL

The present work represents the comparative study of wind analysis of high rise building with diagrid and outrigger structural systems using gust factor approach. For analysis 3 basic building models are considered in which building with shear wall (without outrigger and diagrid), building with diagrid structural system and building with outrigger structural system are included. Each building model is further modeled by making variation of angle of inclination and by providing different locations of outrigger in case of diagrid and outrigger structural systems respectively. While there is no variation in model with shear wall structure. The performance of lateral load is made by imposing the lateral wind load having wind intensity low at bottom and goes on increasing at top to the building models by using gust factor methods per IS 875-1987 (part 3). At each floor level, the obtained wind load is applied to each of building models.

DYNAMIC WIND ANALYSIS

Dynamic wind analysis is required for high rise, slender and long span structures. Large dynamic motions with oscillations produced due to fluctuating forces on the structure caused by wind gust. Damping of structure and Frequency of vibration are the two parameters on which severity of dynamic motion depends. In both along wind and across wind direction, the motions are produced.

4.2. DIAGRID STRUCTURAL SYSTEM

INTRODUCTION

The diagrid concept is a combination of the two words diagonal and grid which enhance its structural rigidity through use of triangulation. 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. As compared to conventional structures, construction of diagrid structure is more difficult due to modern structural system and complicated joints of diagrid structures.

DIAGRID MODULE

The modelling of diagrid has to be done as vertical cantilever beam fixed at base. Diagrid is placed with optimum angle of inclination at the periphery of the building and longitudinally divided into triangular modules. Each diagrid module is extended over many stories. The faces treated as either web planes parallel to direction of wind or flange planes perpendicular to direction of wind which are depends on direction of lateral loading. The diagonal members are considered to be pin connected, hence oppose through axial action only the transverse shear and moment. Diagrid structures can be easily recognized and also it has good appearance. The arrangement and effectiveness of a diagrid structure lessen the quantity of structural components necessary at the periphery of the building, thus it gives less impedance to outdoor look. As compared with conventional structural system, diagrid system reduces nearly 20 % weight of structural steel.

Fig. 3.6 Swiss Re in London

Fig. 3.7 Capital Gate Tower in Abu Dhabi

4.3. OUTRIGGER & 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. The central core can be of steel braced element or reinforced concrete core wall, and mainly situated at central location of building with outrigger connected to the exterior columns of building. The outrigger system consists of combined shear walls with outriggers that are capable to restrict inter-storey displacement subjected to wind as well as seismic loads and also reduces moment of central core and its dimension.

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. Former literature have represented that the outrigger and belt truss system can give extra lateral stiffness up to 25 to 30 % (Taranath 1988) or decreases lateral displacement of about 25 to 32 % (iyengar 1995). It is possible to directly connect each and every perimetral column to the outrigger; hence belt truss system along with outrigger is frequently implemented to tie all perimetral columns around the building.

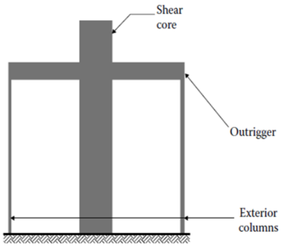


Fig. 3.10 centrally located core with outrigger and belt wall structure

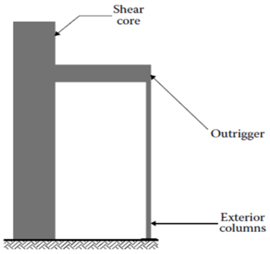


Fig. 3.11 offset core with outrigger and belt wall structure

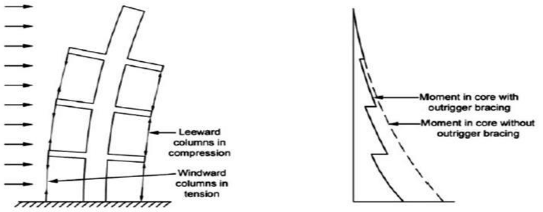


Fig. 3.12 (a) Outrigger structural system subjected to lateral load (b) Resultant core moment.

The usual structural performance of the outrigger and belt truss system is not complex. 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 [refer Fig. 4.3(a), (b)]. The exterior moment is then opposed by core bending alone as well as by exterior columns through axial tension and compression. Due to which, structural effective depth is enhanced when it moves as vertical cantilever fixed at base by means of windward columns subjected to tension and leeward columns subjected to compression. Hereafter the remaining columns which are not connected to the ends of the outrigger, also mobilize to attend in withstanding the outriggers. This can be done by providing a deep spandrel beam, or triangulated truss which is known as belt truss placed at the periphery column corresponds to outrigger level.

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. Diagonal members extending over multiple floors can also be adopted as an outrigger (refer Fig. 4.4). It has to remember that in outrigger system, the flexural stiffness of the structure is significantly increases whereas its shear resistance does not increase which is further taken by central core.

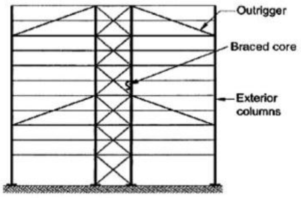


Fig. 3.13 Diagonals acting as outriggers.

OPTIMUM LOCATION OF OUTRIGGER STRUCTURE

There are more options for locating the two outriggers in different positions. Deflection reduction in building near to the optimum values may be attained with outriggers located completely diverse from optimum locations. Hence, there is some freedom to engineers and architect while ascertaining the optimum locations of outriggers. However, 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.

5. MODELING AND ANALYSIS OF STRUCTURE

In the present study, two different structural systems viz, Diagrid and Outrigger is taken into consideration. The analysis of building does not exhibit a specific existing structure that has been built. Nevertheless, the building configuration is set to satisfy the aspect ratio to perform dynamic wind analysis. The building models with diagrid and outrigger is modeled and analyzed using the structural software ETABS and the results are compared.

5.1. ANALYSIS AND DESIGN SOFTWARE

ETABS SOFTWARE

ETABS is most comprehensive software for modeling, analysis and design of building. The ETABS program comprised of finite element based linear static and dynamic analysis, nonlinear static and dynamic analysis of buildings, static and dynamic P-delta analysis, pushover analysis, response spectrum analysis, time History Analysis, construction sequence loading analysis. In this work, the effort is made to investigate the performance of the diagrid and outrigger structural system under dynamic response. At the end of analysis, the top storey displacement, column axial forces, and material comparison of different building models are gained in the analysis.

MS-EXCEL SOFTWARE

After analyzing the different structural models by including gravity as well as lateral loads with different load combinations, the excel sheet is used to show different graphs represents difference between top storey displacement, axial forces in the column, material comparison.

Structural Configuration :

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

Material Properties:

- Grade of concrete : M30
- Grade of steel reinforcement : Fe500
- Grade of steel section : Fe345

Structural Parameter:

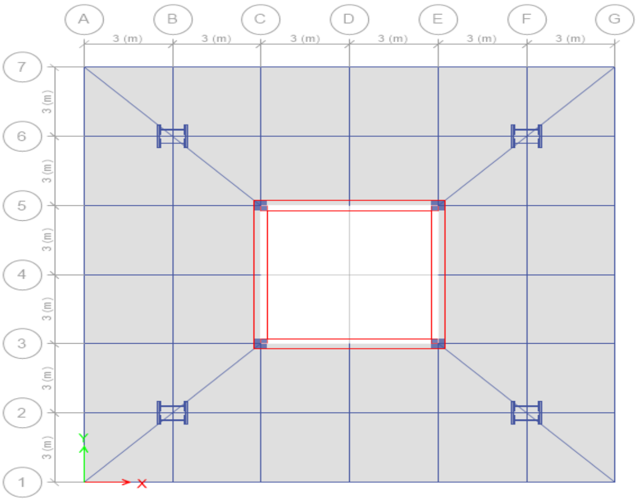
- Floor level column : 1000mmx1000mm (steel column)
  450mmx450mm(concrete column)
- Ground level column : 1000mm x 1000mm (concrete column)
- Floor level beam : ISWB 600 & builtupsection (diagrid)
  ISMB 500 & ISWB 600 (outrigger)
- Floor beam : 230mmx600mm
  (for diuagrid and outrigger)
- Slab Thickness : 130mm
- Diagrid Section : 500mm pipe section with 30mm thick
- Outrigger beam : 2ISA 200mm x 200mm x 25mm
  (Double angle section)

-Outrigger belt truss : 2ISA 200mm x 200mm x 25mm
(Double angle section)

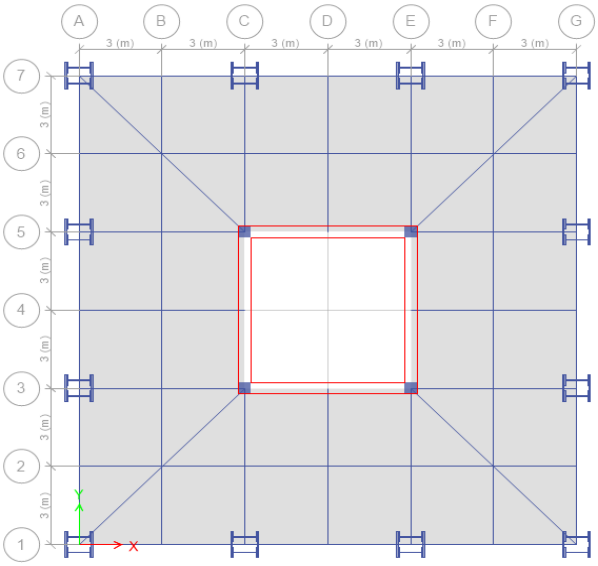
-Core wall Thickness : 450mm
-Wall Thickness : 230mm

ETABS MODEL:

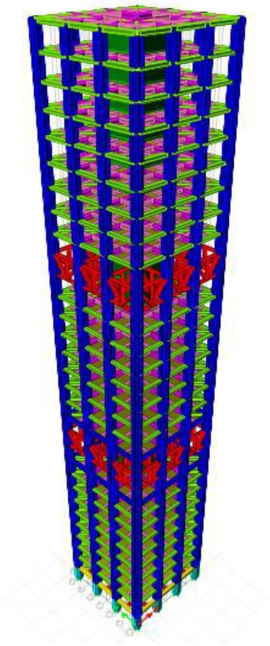
In this section, plan views and models of diagrid and outrigger buildings are presented which are analyzed in ETABS-2016.



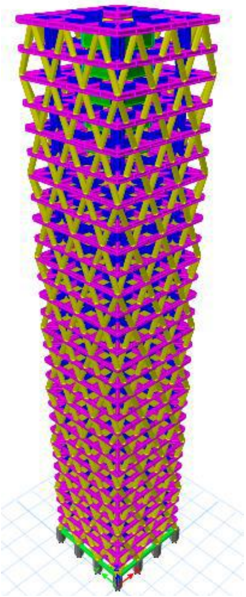
PLAN FOR DIAGRID BUILDING



PLAN FOR OUTRIGGER



Building With Two Outrigger At 0.33H And 0.66H



Building With 4-Stroery Diagrid Module

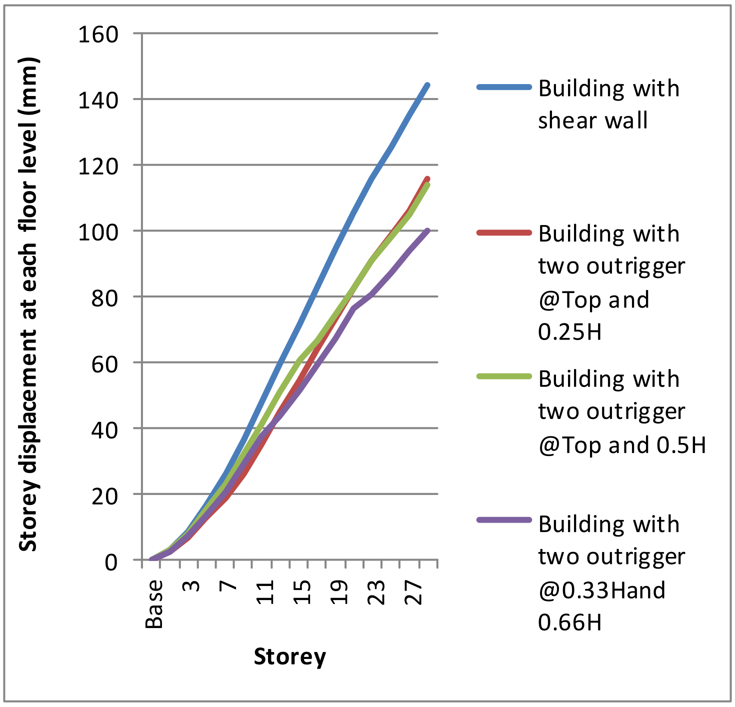
6. RESULT AND DISCUSSION

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.

Top storey displacement (mm)

Top storey displacement is one of the relevant stiffness design criteria in any high rise structural system. Permissible value of top storey displacement should be limited to the ratio Height/500. The important parameter oversee throughout the complete analysis is displacement at the top of the structure. The following table gives the results for top storey displacement for the structural models having two outriggers at different locations.

Structural system	Top storey displacement(mm)
Building with shear wall	148.582
Building with two outrigger @Top &0.25H	116.551
Building with two outrigger @Top &0.5H	114.609
Building with two outrigger @0.33H &0.66H	103.224



Storey displacement of each storey level for outrigger structure with three different outrigger locations are tabulated in table . it can be observed, as compared to shear wall structure the top storey displacement of building with two outrigger at top and 0.25H is reduced by of about 21.55 %, the top storey displacement of building with two outrigger at top and 0.5H is reduced by of about 22.86 %, and the top storey displacement of building with two outrigger at 0.33H and 0.66H is reduced by of about 30.52 %.

From table it can be seen that by introducing outriggers, the top storey displacement reduces of about 30.52 % 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.

Axial Force (KN)

The axial force results in structure provided with two outriggers at different locations are tabulated in table given below

Structural system	Axial force in column (KN)
Building with shear wall	12601.99
Building with two outrigger @Top &0.25H	11641.62
Building with two outrigger @Top &0.5H	11618.66
Building with two outrigger @0.33H &0.66H	11537.76

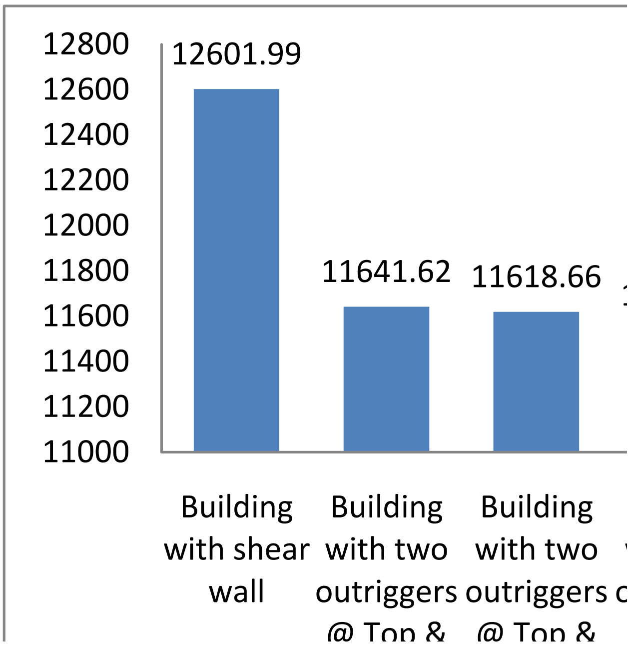


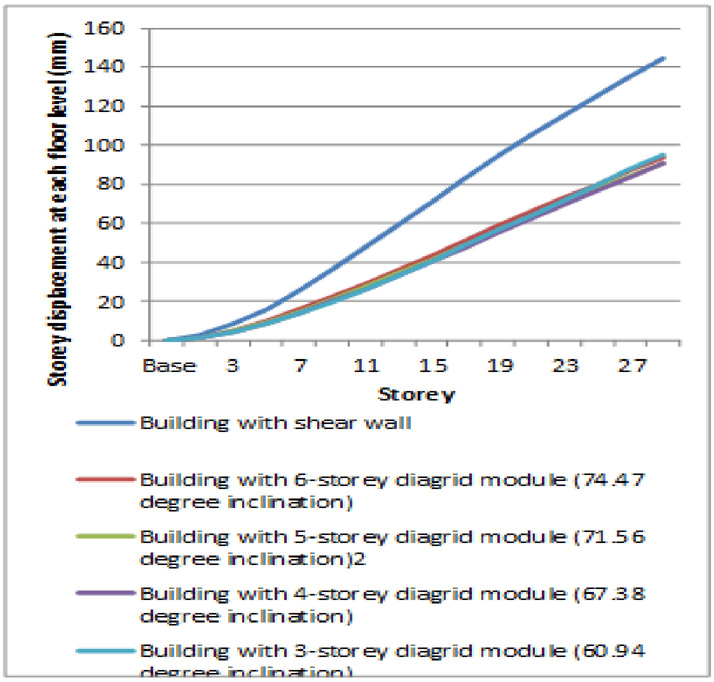
Table and fig. shows the axial force (kN) in column for building models consisting of two outriggers at different locations. It can be observed that the value of axial force in column C5 is higher (11641.62kN) for building model with outrigger location is at top and 0.25H as compared to another two outrigger models. Provision of outrigger in the highrise

structure decreases the displacement of the building as well as axial force in the column reduces by 7.62% for the building model to with outrigger location is at top & 0.25H; for the building with outrigger location is at top & 0.5H, the axial force reduces by 7.82%; and for the building with outrigger location is at 0.33H &0.66H, the axial force reduces by 8.44% as compared with the building model without an outrigger (12601.99 kN) By introducing the outrigger the stresses in the columns are reduced as compared to building without an outrigger system. Also due to provision of outriggers, the forces get evenly distributed and hence the column axial forces are also reduced.

High-rise Building with Diagrid at Different Angles of Inclination

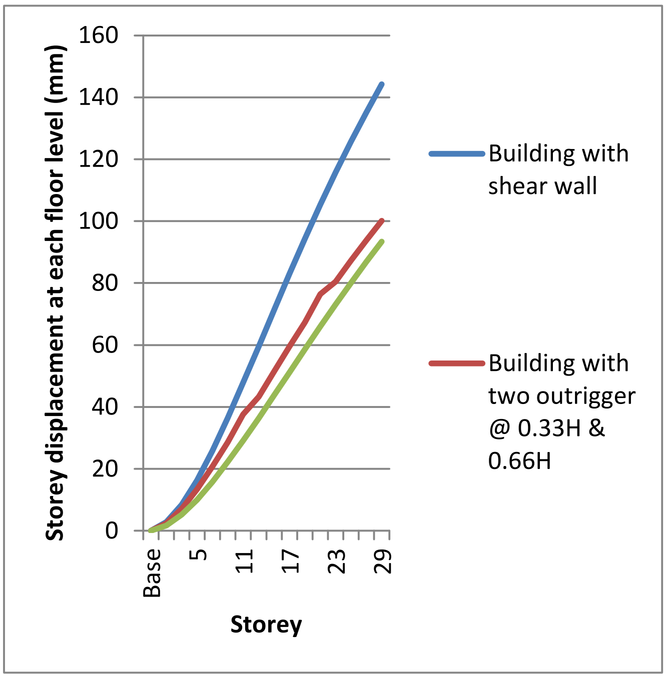
In order to obtain the optimum angle of inclination as well as minimum deformation mode for a given height of building, a set of structures having four different storey modules with different angles of inclination are as shown in the Fig. . The following table gives the results for storey displacement for the structural models having 6-storey, 5-storey, 4-storey, 3-storey diagrid module

Structural system	Top storey displacement(mm)
Building with shear wall	148.582
Building with 6- storey diagrid module	96.650
Building with 5- storey diagrid module	94.277
Building with 4- storey diagrid module	93.932
Building with 3- storey diagrid module	98.834



The displacement results for building with 6-storey diagrid module, 5-storey diagrid module, 4-storey diagrid module and 3-storey diagrid module having angle of inclination 74.47°, 71.56°, 67.38°, 60.94° respectively. it can be observed, as compared to shear wall structure the top storey displacement of Building with 6-Storey diagrid module (74.47° inclination) is reduced by of about 34.95 % ; the top storey displacement of Building with 5-Storey diagrid module (71.56° inclination) is reduced by of about 36.54 %; the top storey displacement of Building with 4-Storey diagrid module (67.38° inclination) is reduced by of about 36.78 %, and the top storey displacement of Building with 4-Storey diagrid module (67.38° inclination) is reduced by of about 33.42 %.

Comparison of Storey Displacement for Buildings with Diagrid, Outrigger and Shear Wall Structural System



The storey displacement at the top of the building is most relevant and fundamental parameter oversees throughout the analysis. The provision of outrigger, it is seen that the top storey displacement of building model with two outriggers at 0.33H and 0.66H location is satisfactory as compared with other outrigger models whereas the top storey displacement of building with 4-Storeydiagrid module (67.38° inclination) is satisfactory as compared with other diagrid models. From these results, it can be stated that the optimum location for the building with two outriggers approximately will be at 0.33H for first outrigger and 0.66H for second outrigger and the optimum angle of inclination for diagrid member will be 67.38°. , it can be observed that, the building with 4-Storey diagrid module(67.38° inclination) efficiently decreases the top storey displacements as compared tobuilding with two outriggers at 0.33H and 0.66H location. The percentage decrease in topstorey displacement for diagrid structure is about 9.00% as compared to outrigger structure.

CONCLUSIONS

In the current study, an effort is made to investigate the behavior of diagrid system and outrigger system in high rise building of about 108m height subjected to trapezoidal distribution of wind loads. The following conclusions can be made based on the analysis results

1. The provision of outrigger with belt truss system and 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 9.00 % 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 study shows that the performance of diagrid and outrigger structural systems considerably affected by the angle of inclination of diagonal members and optimum location of outrigger system respectively. Hence from analysis results, it may be conclude that the optimum angle of inclination for diagrid structure is 67.38° for 4-storey diagrid module and optimum location of outrigger structure is at 0.33H and 0.66H that is one third and two third of height to which corresponding top storey displacement is getting less.
4. By introducing the outrigger the stresses in the columns are reduced as compared to building without an outrigger system. Also due to provision of outriggers, the forces get evenly distributed and hence the column axial forces are also reduced.

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