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A Review on Diagrid Structural System in High- Rise Buildings

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Abstract –Construction of high rise buildings in populated cities is rapidly increasing. Various lateral loads are acted on high rise buildings. Different types of lateral loads are acted on high rise building such as wind load and earthquake load. For resisting these loads various lateral loads resisting system are used such as rigid frame, brace tube, shear wall, wall frame, diagrid system and outrigger system. Lateral load resisting system is divided into two parts: exterior system, interior system. The diagrid system is one the most effective and efficientexterior structural system. Diagrid means diagonal grids which are presented along the periphery of structure and it is also having unique triangular configuration. Diagrid structure can carry both gravity loads and lateral loads due its triangular geometry pattern.This paper reviews researches published on diagrid structural system in high- rise buildings. This paper also deals with comparison of diagrid system with conventional building frame system in terms of different parameters like story displacement, story drift story shear, time period, material consumption. This paper shows that various analysis methods performed on diagrid structure analysis software, diagrid module and optimum angle.

Key Words: Diagrid system,Story displacement, Story drift Story shear, diagrid module, optimum angle, dynamic analysis

1. INTRODUCTION

The trend of high rise buildings is rapidly increasing because lack available land for horizontal construction development. As the height of building increases, effect of lateral loads increases. Many lateral loads resisting structural systems are used for high rise buildings like rigid frame, brace tube, shear wall, wall frame, diagrid system and outrigger system. The diagrid system is efficient and effective technique for lateral load resisting system. Diagrid consists of series of triangular space truss available along periphery of structure. The configuration and efficiency of a diagrid system reduce the number of structural element required on external side of the buildings. In diagrid system both shear and bending stiffness are provided by diagonal because diagrid system eliminates all external columns that are replaced by diagrids only.
Diagrid system minimizes shear deformation because it carries shear by axial action of the diagonal member. 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 (k. moon-2011).

2. DIAGRID STRUCTURAL SYSTEM

Diagrid structure is series of triangulated space trusses located along perimeter of structure which is shown in figure-1

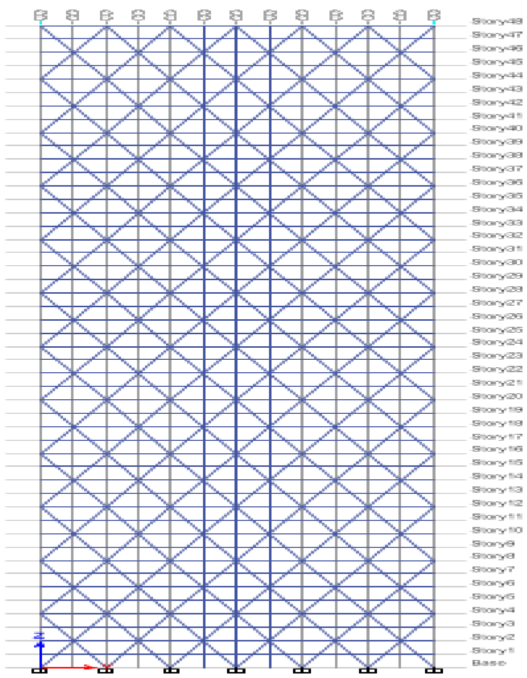

Fig -1: Diagrid module

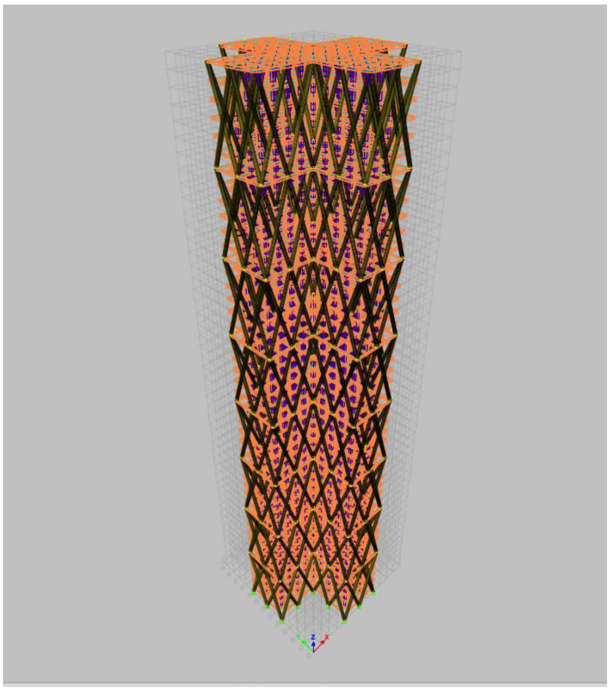

Fig -2: 3D view of diagrid building

Diagrid structure made of different modules. Diagrid structure may be storey module (1, 2, 3, 4 etc.) or sometime diagrid with varying density is used. Diagrid material can be concrete or steel. During analysis process the ends of diagrids are assumed as hinged. The support conditions are assumed as fixed. Diagrid module angle can be calculated from the height of the storey module to the base width of diagrid, that is

Angle (θ) = $\tan^{1}$ (height of module / base width)

For example: Base width is given as 8 m and floor height is 3.5 m. Diadrid module 4.

Angle (θ) = $\tan^{1}$ (14 / 8)

= 60.25^{0}

The optimal angle of the columns for maximum bending rigidity is 90^{0} and that of the diagonals for maximum shear rigidity is about 35^{0}, it is expected that the optimal angle of diagonal members for diagrid structure falls between these angles.

Vladimir shukhov, a Russian engineer built the first diagrid structure known as hyperbiod structure. The tower is known as shukhov tower.Some existing diagrid structure all around the world are shukhov tower (Moscow),PRADABoutique (Japan, Tokyo), Swiss Re (London),Hearst Tower (New York, USA), Atlas Building (Wageningen, Netherlands), Tornado Tower(Doha, Qatar),Al Dar Headquarters (Abu Dhabi, United Arab Emirates) and Capital Gate (Dubai)


Fig -3:shukhov tower**Fig -4**: PRADA Boutique


Fig -5 Swiss Re**Fig -6** Hearst Tower


Fig -7 Atlas Building**Fig -8** Tornado Tower


Fig -9 Al Dar Headquarters**Fig -10**Capital Gate

(Images source:Sepideh Korsavi &MohammadRezaMaqhareh-2014)

3. LITERATURE REVIEW

Various research papers are studied here to understand the necessity and importance of diagrid structural system in high rise buildings.Following review of literature give brief summary of diagrid structural system in high rise buildings and another important things that the performance and behaviour of this system against the lateral loads.

M. M. Ali and K. Moon (2007) emphasized on current trends of tall buildings such as outrigger, digrids and future structural development. This paper reviews the evolution of tall building's structural systems and the technological driving force behind tall building developments. It explains interior structures and exterior structures. This paper also discussed the auxiliary damping systems controlling building.This paper demonstrates that structural systems have come a long way since the late nineteenth century when they were conceived as framed systems. There is a need for creating a comprehensive database of structural systems for tall buildings throughout the globe. The innovative and emerging systems can be placed within the classification scheme presented in this paper and can be continuously updated for the benefit of the practicing professionals and researchers.

Barry Charnish and Terry Mcdonnell (2008) explained the features of 'Bow Tower' 59 story (247meters) building located in Calgary and western Canada in which diagrid structural system for lateral support system. 6 story diagrid modules are used along the periphery of building. The gravity columns of this building were steel. This system eliminates need of shear wall and provides inner space. It also focuses on a decrease in energy consumption as associated with conventional towers.

K. Moon (2009) explained a stiffness-based design methodology fordetermining preliminary member sizes which are used in tall buildings. The methodology can be applied to diagrids of various heights and grid geometries to determine the optimal grid configuration of the diagrid structure within a certain height range. This paper also discusses ofConstructabilityin diagrid structures. This paper studies, various strategies to improve constructability of diagrids through prefabrication of the nodes. In this study design methodology is applied to a set of diagrid structures 40, 50, 60, 70, 80 stories.

K. Jani & P. V. Patel (2013) considered36 m × 36 m floor plan for analysis and design. ETABS software is used for modeling and analysis of structure.IS 800:2007 is used for designing structural members. Along with that the analysis and design results of 50, 60, 70 and 80 storey diagrid structures are presented. Comparison of analysis in terms of time period, top story displacement and story drift is presented in this paper.From the study it is observed that most of the lateral load is resisted by diagrid columns on the periphery while gravity load is resisted by both the internal columns and peripheral diagonal columns so internal columns need to be designed for vertical load only.

Sepideh Korsavi & Mohammad Reza Maqhareh(2014)represented 30 cases of diagrid structure and their quantitative and qualitative features in all over the world. The different thirty case studies were carried out for finding the evolution process of diagrid structures in architectural, structural & sustainability concepts. This study also explains different concepts likediagrids' materials, height of diagrid structures,modules in diagrid structures,diagrids' angles andDiagrid' plans forms. Research shows that uniform angle design produces more efficient structural solution using less amount of structural material. Some modifications are done in high rise building to reduce the impact of wind load.

Ravi K Revankar and R.G.Talasadar(2014)performed pushover analysis ondiagrid System of 12 storey. Pushover is non- linear static analysis method. Diagrid building is analyzed by using SAP 2000. FEMA 356 hinges are assigned to the same building and conducted Nonlinear Static (Pushover) and find out the performance points that is Immediate Occupancy, Life Safety, and Collapse Prevention of diagrid elements. This study explains capacity method in which maximum inelastic deformation of non- linear SDOF system can be approximated from maximum deformation of linear static SDOF with an equivalent period and damping.

Nikesh Ganesh Rath and P. Saha (2015)compared different diagrid structure with conventional structures and effect of the change in the angle of twist, angle of tilt, tampered shaped structure, freeform etc. are investigated in this paper. This study explains brief summary of Steel diagrid andConcrete diagrid. The conclusion was made thatoptimal angle of diagonal increases with the increase in height of structure.Lateral stiffness of the twisted tower is smaller than that of the straight tower if structures considered are of many framed members. The structural performance of a tilted tall building is dependent upon its structural system and angle of tilt. If the angle of tilt is ranging from 0 to 13 degrees, it do not influence lateral stiffness of tilted diagrid. Tapered tall buildings are less susceptible to severe across-wind direction vibrations caused by vortex-shedding.

Femy Mariya Thomas et al. (2015) described the objectives aimed to find out the optimal angle for diagrid structure. ETABS software was used for modelling, analysis, design etc. different building configurations like, square, circular, rectangular in the plan were taken for analysis. Dissimilar diagrid modules are used such as 2, 4, 6, 8, 12 storey modules. 36 storey building was analyzed for inner storey drift, storey displacement.

Saket Yadav and Dr. Vivek Garg(2015)studied a normal steel building G+15 storey and plan of size 18 m x 18 m & seismic zone V was taken for analysis & design. STAAD Pro Software was used for analysis purpose. All the members were analyzed& designed as per IS code IS 800:2007 and as per IS 1893:2002 Part-1 the seismic forces were taken. In the diagrid arrangement, the most part of lateral loads was resisted by external diagonal members, which releases the forces in remaining members of the structure. The diagonal components decrease maximum shear force and bending moment in internal & external peripheral components. That reduces the size of sections required for beams and columns in diagrid structures. An economy was achieved approximately equal to 12 percent into diagrid structures as compared to the normal structure.

Manthan I. Shah et al. (2016) studied seven steel structures of defined plan area and various loads on various heights were analysed & designed for optimum sections for the conventional and diagrid structure frame in ETABS. For comparing results parameters such as maximum base shear, maximum top storey displacement, the difference in the percentage of steel, maximum storey drift, and fundamental time period were considered. Diagrid arrangement performs more than conventional frame system and increases in the percentage of steel with an increase in height of the building was a smaller amount in diagrid arrangements.

Nimisha P.and Namitha Krishan(2016)studied the tubular and diagrid building structures were equated on the basis of study the structural efficiency. The models were prepared of tubular type structure and diagrid building structure for comparison. Both tubular and diagrid building structures of 24, 30, 36, 42, 48, 54, 60, 66 storeys were modelled in ETABS software and analysis was done. For the loads IS 875-1987 used & for earthquake load IS 1893-2002 used. The analysis results, parameters like storey displacement, storey drift, time period & storey shear were compared. For the same loading conditions, the result values for tubular building structures were greater than the diagrid building structures. From that comparison, it was found that diagrid building structure was more efficient structurally than tubular building structure.

Denet Priya Mascarenhas and Deepthishree S. Aithal (2017) work carried out for diagrid structures arrangement with various aspect ratios such as 1:1, 1:2, 1:3 and 1:4. G + 60 storey diagrid building the structure with diagrid angles of 33.69°, 53.13°, 63.43°, and 69.44° were considered. The study was done for the behaviour of diagrid building structure under the wind load action. Also, the optimum angle of diagrid for G + 60 storey model was studied. The modelling, analysis, and design of model were done using ETABS software.

Trupti A. Kinjawadekar and Amit C. Kinjawadekar (2018) worked on the two set of models were taken as 18 storey and other 36 storey models with three different angles namely, 45°, 64° and 72°. Number of storeys in each type of module is decided the angle of diagrid. The conventional building model of 90° angle of diagrid is also prepared. The geometry of model is taken as bay width of 12m and storey height as 3m. To study the seismic behaviour of diagrid members SAP-2016 software is used. Dynamic analysis is carriedout on both types of model for the terms like, Storey displacements, storey drifts, time period and base shear.

Sawan Rathore and Sumit Pahwa (2019) compared analysis of G+12 and G+18 stories diagrid structural building and diagrid at 2 story diagrid (at angle 38.60), 3 story diagrid (at angle 50.20) and 4 story diagrid (at angle 58) are taken. ETABS 2016 software is used for modelling and analysis of structure. The static analysis, Response spectrum analysis and time history analysis are carried out in terms of story displacement, base shear, story drift and time period using ETABS software. Then comparative study is done between models of different angled diagrid building and results are presented.

4. SUMMARY AND CONCLUSION

The above literature study shows that diagrid structural system is effective structural system for high rise buildings. Diagrid system is exterior structural system in which all perimeter columns are replaced by diagonal grid. In many researches diagrid system is compared with conventional building and result are compared in terms of storey displacement, story drift, story shear, time period and material consumption. Modeling and analysis have been done in ETABS, STAD PRO and SAP 2000. Both static and dynamic analysis have been performed. From above study it is concluded that,

- Story displacement, story drift and story shear are less in diagrid system as compare to conventional building.
- Optimum diagrid angle depends on height of the building.
- Diagrid structure does not require high shear rigidity.
- Both shear and bending are taken by peripheral diagonal grids so internal columns are designed for gravity loads only.
- The diagrid structure performs well in all the parameters such as performance, expression and stability and due to a smaller number of columns, effective and efficient planning of the façade is possible.

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