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Structural Behaviour of Hexagrid and Diagrid Comparison System in Staadpro

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***Abstract*- Development of tall buildings have been rapidly increasing in number worldwide. The trends in tall building design is now towards the integration of optimal building form with the structure to produce an efficient design. Diagrid system is an innovative technology that is widely used now a days which promise better lateral load efficiency. Hexagrid system is an extension to the diagrid structural system which also efficient in lateral load resisting system. In these systems, the lateral loads are resisted by the axial action of diagonal columns compared to bending of vertical columns. Analysis of 48 storied Steel building with diagrid system and hexagrid system is presented. Modelling and analysis of structural member is done using finite element software ETABS. Loads, load combinations and seismic data are provided according to IS 875:1987and IS 1893:2002 respectively. Comparison of analysis results with conventional system is done in terms storey displacement, storey shear, storey drift and time period. We also find the durability of 98.5% for per day analysys.**

***Keywords*- Diagrid structural system, Hexagrid structural system, Lateral load resisting system, Storey displacement, Storey drift, Storey shear, Time period.**

I. INTRODUCTION

Tall building development involves various complex factors such as economics, aesthetics look, technology, municipal regulations, and politics. Among these, economics has been the primary governing factor. For a very tall building, its structural design is generally governed by its lateral stiffness. Comparing with conventional orthogonal structures for tall buildings such as framed tubes, diagrid structures carry lateral wind loads much more efficiently by their diagonal member's axial action. A Diagrid structure provides great structural efficiency without vertical columns have also opened new aesthetic potential for tall building architecture. Diagrid has a good appearance and it is easily recognized. The configuration and efficiency of a diagrid system reduces the number of structural element required on the façade of the buildings, therefore less obstruction to the outside view.

The structural efficiency of diagrid system also helps in avoiding interior and corner columns, and therefore allowing significant flexibility with the floor plan. "Diagrid" system around perimeter saves approximately 20 percent of the structural steel weight when compared to a conventional moment-frame structure. The diagonal members in diagrid structural systems carry gravity loads as well as lateral forces due to their triangulated configuration. Diagrid can save up to 20% to 30% the amount of structural steel in a high-rise building. The term "diagrid" is a combination of the words "diagonal" and "grid" and refers to a structural system that is single-thickness in nature and gains its structural integrity through the use of triangulation. Diagrid systems can be planar, crystalline or take on multiple curvatures, they often use crystalline forms or curvature to increase their stiffness. Perimeter diagrids normally carry the lateral and gravity loads of the building and are used to support the floor edges.

II. DIAGRID STRUCTURAL SYSTEM

Diagrid, or exodiagonal systems, is a perimeter structural configurations characterized by a narrow grid of diagonal members which are involved both in gravity and in lateral load resistance. It is worldwide recognized that "This is the moment of diagrid". Diagonalized applications of structural steel members for providing efficient solutions both in terms of strength and stiffness are not new: rather, triangulation can be considered the first, most natural and always fresh (the oldest and the newest solution) design strategy in steelwork applications.

Fig. 1. Diagrid Structural System.

While in the past, the designers considered diagonals highly obstructive and usually embedded them within the building interior cores, with the diagrid system the multiple and variegated use of triangulation brashly characterizes the aesthetics of the buildings. On the contrary, nowadays a renewed interest in and a widespread application of diagrid is registered.

A multiple and variegated use of triangulation which brashly characterizes the aesthetics of important building is the new trend in tall buildings. The diagrid concept offers the structural possibility of combining high efficiency and aesthetic connotation. A major reason for this "diagrid craze" is undoubtedly the structural efficiency of the triangulated patterns: in fact "… diagrid speaks a reassuring language of stability, a message qualified by its real physical economy and resilience …. Diagrid looks like it should work, and it does.

III. DIAGRID STRUCTURAL BEHAVIOR

The diagrid structures can be seen as the latest mutation of tube structures, which starting from the frame tube configuration, have increased structural efficiency thanks to the introduction of exterior mega-diagonals in the braced tube solution; in this case the significant improvement in terms of lateral stiffness and shear lag reduction also reflects in the building architecture, strongly connoted by the clear and disciplined structure, "the honesty of the structure", in the words of the architect Bruce Graham.

The diagrid system can be considered as a further evolution of the braced tube structures, since the perimeter configuration still holds for preserving the maximum bending resistance and rigidity, while, with respect to the braced tube, the mega-diagonal members are diffusely spread over the façade, giving rise to closely spaced diagonal elements and allowing for the complete elimination of the vertical columns; thus the diagonal members in diagrid structures act both as inclined columns and as bracing elements, and carry gravity loads as well as lateral forces; due to their triangulated configuration, mainly internal forces arise in the members, thus minimizing shear racking effects. Despite the large number of applications and proposed projects, design criteria for the diagrid system are not yet consolidated as in the case of more traditional structural types, and also building codes do not provide explicit guidelines and provisions for diagrid structures.

1. Hexagrid Structural System

The Hexagrid structural system recently evolved, rarely executed is inspired by the 'Beehive' (one of the stable structure of nature). This structural system is made by arranging several hexagons of height equal to story height in a unique way as in Beehive.

Fig. 2. Hexagrid System.

Hexagrid system rests on a regular polygon with six elements system. This system has an advantage of uniform distribution of stresses in itself due to uniform angle of 120 degree between any two elements but has disadvantage of very less lateral stiffness.

1.1. Hexagrid; Nodes + Load Path Transference

The Hexagrid system offers several advantages in addition to eliminating perimeter columns. Most notably it optimizes each structural element. Typically, columns are used to provide vertical-load-carrying capacity, and diagonals or braces provide stability and resistance to large forces, such as wind and seismic loads. But here hexagons and diagonals are participating in the vertical load transfer, and the lateral load under ideal assumptions in a typical high-rise. In a hexagrid system the two functions are working together, such as couple. The hexagons and diagonals are all one.

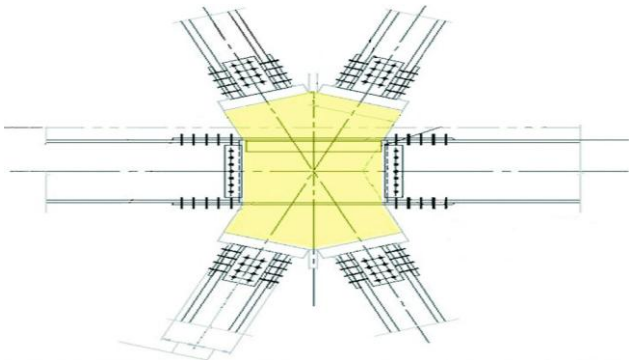

Fig. 3. Nodes & Load Path.

1.2. Hexagrid; Architectural

Here is an example of the design research project, Beehive Tower's Design at London, Designed by Rory Newel & Lucy Richardson, the 220 m high Beehive Towers. It's a vertical farm inspired by the hexagonal forms of the honeycomb in Heron Quay, London. Each hexagon is 8 stories high and contains 8 duplex apartments. A number of the hex cavities are dedicated to gardening and face in different directions so that each

element gets a fair share of sun. The structure features a number of sustainable systems such as an army of wind turbines that sits atop it and a rainwater collection system to water the crops within it.

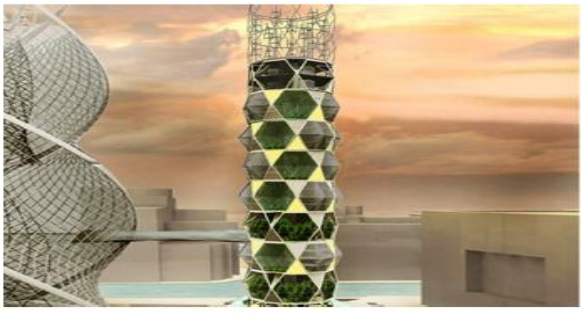

Fig. 4. 3D Model of Beehive Tower, London.

1.3. Hexagrid; Structural System

- Temporarily ignoring the box shape, one can simplify the structure shown here into a series of hexagons – connected at 'nodes' - and rings - that intersect the hexagons at the 'nodes.' What can be see then is a hexagonated, ring perimeter framed system - the HexaGrid.
- In the above image the Hexagrid is rendered in different colors (due to the different young modulus and section for the structure)
- It acts as a rigid shell, and for structural purposes can be considered a very thin, deep beam".
- Both the hexagons and the rings are here formed from wide flanged rolled sections that are welded or bolted for full restraint (they can be constructed from other materials as well).

2. Advantages of Hexagrid System

The Hexagrids are redundant and load path following.

- The Hexagrids combines the benefits of a hollow tube with those of a truss and its chords.
- The angled setting of the columnar elements allows for a natural flow of forces through the structure.
- In this manner, both gravity loads and laterl loads are transferred through the Hexagrid to the ground below
- Loads are able to follow the hexagons through the structure as it naturally resists vectors of forces through its hexagonal shapes.
- Load paths are continuous and uninterrupted.
- Vertical gravity loads follow the structure of the tube from top to base along the hexagonal members of said tube.
- The same vertical gravity loads are able to transfer from one columnar element to another in the rare or designed case of an interruption.
- The exploitation of steel's compressive and tensile abilities creates a need for less steel in a building using the Hexagrid system.
- Materially, there are multiple choices of material for use when employing a HexaGrid, such as; Steel (the most common), Wood, Composite (Concrete & Steel). But Steel is the typical material of choice due to its high abilities to resist both tensile and compressive forces.
- Less Material, Roughly %10 to %15 reduction in steel possible.

3. Hexagrid: Disadvantage

- Construction crews can be an issue, having little or no experience of creating a hexagrid.
- It is hard to design windows that create a regular language from floor to floor.
- Execution, the Hexagrid is heavy-handed if not executed properly.

IV. RESEARCH SIGNIFICANCE

Recent design trends in tall buildings pose new challenges to structural designers, in addition to the traditional requirements for strength, stiffness, ductility and system efficiency. Structural configurations best addressing the traditional requirements of strength and stiffness for tall buildings are the ones employing the tube concept, whose efficiency is strictly related to the involved shear resisting mechanism, and in fact the historical evolution of the tube concept has been marked by the attempts of reducing the occurrence of efficiency loss due to shear deformations. More recently, the diagrid structural system with tubular behaviour is being employed as structurally efficient as well as architecturally satisfying structural system for tall buildings. Perimeter diagonals act as a facade, which governs the aesthetics of the building to a great degree. In order to improve the efficient of tube-type structures in tall buildings, a new structural system called Hexagrid (Beehive) is introduced in this paper. In the hexagrid structure system, almost all the conventional vertical columns are eliminated. Hexagrid structural system consists of Hexagrid perimeter which is made up of a network of multi-storey tall hex-angulated truss system. Hexagrid is formed by intersecting the diagonal and horizontal components. The project is focused to horizontal hexagrid pattern which aims to investigate the optimal angle and a topology of diagonal members in a hexagrid frame using finite element analysis and to study the structural properties of hexagonal structures so as to compare their potential efficiency with the conventional systems.

The topology of the hexagrid system is an important design variable since the degree of an angle between diagonal members consisting of hexagrid determines stress distribution resisting internal forces. Therefore the effects of diagonal angles in the hexagrid system should be considered in order to obtain an optimal hexagrid topology with the highest stiffness in design phases. The unit cell of the hexagrid module is extending over

multiple floors, which repeats horizontally along the building perimeter and stacks vertically along elevation. The geometrical parameters of the module are: the diagonal angle, the diagonal member length, the module height, the number of storeys covered by a single module, the number of modules along elevation and the number of modules along the perimeter. This research should help the structural designers to obtain more insight in the complex behaviour of the special structures like free-formed structures and should offer the structural designers more design freedom in the end of the design process.

V. LITERATURE REVIEW

1. General

This chapter presents a review of the current literature on Diagrid Structural System. The advanced construction technologies, evolution of efficient structural system, necessity of vertical growth because of scarcity of urban land and rapidly increasing population caused the development of the high rise buildings all over the world. Lateral loads i.e. earthquake loads and wind loads require special attention in design of high rise buildings along with gravitational loading. Lateral loads can be taken care by interior structural system or exterior structural system.

Generally shear wall core, braced frame and their combination with other frames are interior structural systems where lateral load is borne by centrally located structural elements. While framed tube, braced tube structural system bear lateral loads by the elements provided on periphery of the buildings. It is very much important that the selected structural system must be optimized and should utilize structural elements effectively while satisfying design requirements. In the past decades, the Diagrid Structural system is widely adopted and used for the construction of tall steel buildings due to its structural efficiency and aesthetic potential provided by the unique geometric configuration of the system. Compared to closely spaced vertical columns in framed tube, Diagrid structural system consists of inclined grid members on the exterior surface of building. Due to inclined grid members lateral loads are resisted by axial action of the diagonals, compared to bending of vertical columns in framed tubular structure. Diagrid structures generally do not require gravity core because lateral shear can be managed by the diagonals on the periphery of building.

2. Review of Past Research

Akshat and Gurpreet Singh (2018) reviewed research published on the structural performance of diagrid system. A first step toward a systematic and comprehensive study is that regular patterns are compared to alternative geometrical configurations, obtained by changing the angle of diagonals (variable-angle, VA) as well as by changing the number of diagonal (variable-density, VD) along the building height. Further it discusses about the different diagrid patterns generated and designed for an assumed building; and how the resulting diagrid structures are assessed under gravity and wind loads and various performance parameters are evaluated on the basis of the analyses results.

Md. Arman (2018) analysed the performance of high-rise buildings, it is especially important that an effective modelling technique be involved because of the complexity of the real structural behaviour and the difficulties of full scale measurement. The lateral performance of multi-storey buildings under different loading conditions is greatly influenced by various parameters such as structural stiffness and base to height ratio of the building. Optimization and refinement of such performance has become the focus as well as the constraint for structural engineers in their design practice.

Avnish Kumar Rai & Rashmi Sakalle (2017) analysed a regular eleven storey RCC building with plan size 16 m × 16 m located in seismic zone V & III is considered for analysis. STAAD. Pro software is used for modelling and analysis of structural. Seismic zone is considered as per IS 1893(Part 1): 2002. The Comparison between the diagrid and conventional building analysis results presented in terms of a node to node displacement, bending moment, storey drift, shear forces, an area of reinforcement, and additionally the economical aspect.

Kona Narayana Reddy and Dr. E. Arunakanthi (2017) studied on the Oblique columns of different shapes in high rise building. In this work a high rise building with Normal Columns & with different locations of Oblique columns is considered for analysis. In this paper, response spectrum & Linear Static analysis were executed combined with a Numerical Building Model by this program, which were also compared following the analysis results. The results of the analysis on the Axial forces, Base shear, Time period, Storey drift and Displacements are compared. The results are presented in tabular and graphical form. The results on the displacement are checked with serviceability conditions and are compared and presented in tabular form.

Ravi Sorathiya and Prof. Pradeep Pandey (2017) presented a stiffness-based design methodology for determining preliminary member sizes of RCC diagrid structures for tall buildings. A G+24, G+36, G+48, G+60 storey RCC building with plan size 18 m × 18 m located in surat wind and seismic is considered for analysis. STAAD.Pro software is used for modelling and analysis 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(Part 1): 2002. Comparison of analysis results in terms of beam displacement, Storey Drift, Bending Moment. This cause economical design of diagrid structure compared to conventional structure.

VI. RESULT AND ANALYSIS

Table 1. MSE Analysis of Neural Network.

Layers	MSE Analysis Without Neural Network	MSE Analysis With Neural Network
1Layer Training	2.53	0.2678
2Layer Training	1.59	-0.127
3Layer Training	3.01	0.739
4Layer Training	2.13	-0.1447

Table 2. Accuracy and Precision of base paper and our proposed work.

S.N.	Accuracy Base paper	Proposed ANN based Accuracy
1.	96.2(GA)	98.24

The previous chapter introduces the proposed methodology. This chapter describes the related future work and schedule plan of excursion.

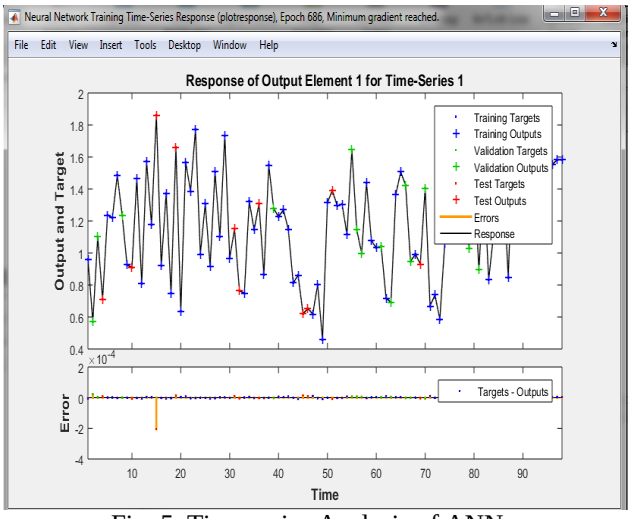

Fig. 5. Time series Analysis of ANN.

This curve is show the load based building durability in days with also find maximum accuracy of optimization.

VII. CONCLUSION AND FUTURE SCOPE

1. CONCLUSION

The following points are concluded from above study about diagrid and hexagrid structure.

- Study shows that diagrid structure decreases bending moment which in results decreases reinforcement requirement. Hence we find maximum accuracy 98.3% for day based durability.
- It shows that lateral displacement can be minimized by using diagrids.
- Although volume of concrete used in building is different, but diagrid shows more economical in terms of steel used. Diagrid building saves about 33.21% steel without affecting the structural efficiency.
- Due to diagonal columns on its periphery, diagrid shows better resistance to lateral loads and due to this, inner columns get relaxed and carry only gravity loads. While in conventional building both inner and outer column are designed for both gravity and lateral loads.
- A significant decrease of bending moment in interior columns of diagrid building is found in comparison to conventional building.
- The use of diagrids significantly decreases the maximum shear force and maximum bending moment in internal and perimeter beams. The sign of maximum bending moment also changes in perimeter beams of diagrid building.
- The diagrid configuration provides a reduction in the span of perimeter beams at alternate floors, hence reducing the beam forces at alternate floors.
- So from results and comparison with conventional building, one can adopt hexagrid structure for better lateral load resistance and this becomes important for seismic zone IV

2. FUTURE SCOPE

- Higher storey buildings can be studied in R.C.C symmetrical building for diagrid and hexagrid structure.
- Asymmetrical building with different angel study for hexagrid and diagrid structure
- Study with and without outer column for diagrid structure.
- Steel building can also studies diagrid structures.

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