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A Review on Design of Diagrid Structural System for High Rise Steel Buildings

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Abstract – In the current time, diagrid structural system is being approved in giant constructions due to its physical effectiveness and elasticity in architectural development. Diagrids are referred as Diagonalized grid structures that have arose as one of the utmost pioneering and adjustable methods in constructing buildings. Dissimilarities of the diagrid system have changed to the extent of making its use non-exclusive to the high-rise building. Diagrid building is also to be prevailed in a range of advanced mid-rise steel projects. The advantages of this system thus even outweigh the disadvantages which are specifically complexity in design, construction of nodes and high cost of the structure. Therefore studies related to a structure of this kind which has a huge scope in future are high.

Keywords: Diagrid Structural System, High Rise Buildings, Structural Design

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1. INTRODUCTION

There are many new design and analysis methods are available now a days for high rise buildings. Physical strategy of high rise constructions is oversaw by lateral loads which is a result of storm or earthquake. The internal or external physical scheme delivers the obstruction for lateral load. Lateral load is struggled by centrally positioned essentials in core of the shear wall, frame of brace along with their grouping, these frames are internal system. The lateral load is counterattacked by the basics delivered at the margin in the enclosed structure of tube, braced structure. In order to have healthier competency and elasticity the system of diagrid structure is accepted in the construction. The utilization of structural elements is very important in structural design. Associated to diligently space upright columns in enclosed tube, diagrid structure comprises slanted columns on the superficial of structure. In the diagrid physical structure lateral loads are counterattacked by slanted columns as long as at the external margin. Diagrid structures commonly don't need core since lateral shear can be supported by the diagonals on the edge of structure (Vijapur, 2018). It is necessary to preserve the high cost land for the agricultural, and for the transportation purpose. Therefore high rise buildings are constructed in the city. Once tall rise constructions troubles originate there must be a robust lateral load counterattacking structure for repelling shaking and wind loads, after associated to small rise buildings (Vijapur, 2018).

The Shukhov tower in Polibino is the world's leading hyperboloid diagrid building constructed in the age of 1920-1922. It was intended by Russian engineer and construction Vladimir Shukhov in 1896. The chief construction comprising Diagrids remained utilized at the frontage of the construction is in Pittsburgh, built in time around 1965. This technique of structure was not castoff over afterward this till the extra-large tasks of diagrid and their outlines were planned. The planning and building of Diagrids was ongoing over in the time 2000. The IBM construction was built through the assistance of Diagrids in which Diagrids stood synchronized by means of the curtain wall system owing to which the figures of windows become distressed and develops odd. This construction takes enclosed all-out zones of strategy phase of the diagrid buildings excluding the curtain wall system. Afterward this, diagrid building originated cutting-edge tendencies for using in tall rise structures.

The IBM construction is presently recognized by way of United Steel Workers structure. Curtis and Davis stood the creators of IBM edifice. Lesslie Robertson stayed the engineer throughout its building work. This is the primary Diagrids building during which the Diagrids were placed at the perimeter of the building. the most purpose of using Diagrids structural system is to reduce the weight of the structure by reducing steel in it which ends up in removal of maximum variety of vertical columns from the structure. There are a number of the vertical columns at the core of the Diagrids structure whose purpose is simply to

transfer gravity loads to the foundation. These columns at the core of the structure are not able to resist the horizontal load due to wind and earthquake (Singh, 2018).

When Diagrids structures were compared with standard} conventional moment resisting framed structure, it had been determined that the Diagrids structure resists a lot of lateral loads than the traditional moment resisting framed structure. By the axial action of diagonals, Diagrids structure resists additional of the shear force by that shear deformation of the structure get reduced. On the opposite side, standard structure resists shear force by the bending action that occurs in vertical columns of the structure (Singh, 2018).

(a) Shukhov Tower in Moscow (b) IBM Building in Pittsburgh

Fig.1 Diagrid buildings

Diagrid structural system is outlined as a framework made by the intersections of diagonal members made of completely different materials like concrete, steel, metals or wooden beams that are utilized in the construction work. Diagrids is employed for the construction of skyscrapers. Steel is especially used as a construction material for these structures. In these structures, a triangular truss sort structural system is made within which there's additionally a supporting beam for the diagonals at their base. Diagrids structures of steel members are usually used for increasing the strength and stiffness of the structure. However these days Diagrids are utilized in the case of high rise buildings whose span and heights are larger. Additional specially, this method is useful within the case of additional complicated patterns and profile of the structure. Diagrid structural system of tall structures has inclined columns that are called diagonal members of the structure. Because of inclination of those columns, axial force is made on the direction of the column under the action of lateral load by means of that Diagrids structural system resists the horizontal wind load and seismic load. Diagrids are set with a perfect angle at the façade of the building. With the help of those diagonal members, the building is split into variety of elements on the height of the building that are called modules. The connection between the diagonal members is considered as a pin connection (Singh, 2018).

2. LITERATURE SURVEY

(Jani and Patel, 2013) analysis and design of 36 structure diagrid steel building is conferred very well. a regular plan of 36 m ×36 m size is taken into account. ETABS software system is employed for modeling and analysis of structure. All structural members are designed using IS 800:2007 considering all load combinations. Load distribution in diagrid system is additionally studied for 36 structure building. Also, the analysis and design results of 50, 60, 70 and 80 structure diagrid structures are conferred. From the study it's determined that almost the entire lateral load is resisted by diagrid columns on the periphery, whereas gravity load is resisted by each the interior columns and peripheral diagonal columns. So, internal columns got to be designed for vertical load only. Because of increase in lever arm of peripheral diagonal columns, diagrid structural system is simpler in lateral load resistance. Lateral and gravity load are resisted by axial force in diagonal members on periphery of structure that build system simpler. Diagrid structural system provides additional flexibility in coming up with interior space and facade of the building.

(Vijapur, 2018) the Diagrid structure is offers higher leads to seismic and wind analysis than typical steel structure. The structure displacement is minimum in Diagrid structure as compared to standard frame. Structure drift is additionally less in diagrid structure, wherever it's most in typical steel structure Natural time period is minimum for diagrid structure as compared to the standard steel structure. The diagrid structure within which diagrid connecting 2 floors offers the higher leads to seismic and wind analysis as compared to alternative models. in numerous seismic and wind load analysis the model three offers the higher results, in structure displacement, structure drift, bending moment, axial force conditions.

(Singh, 2018) performed on a 60 storey diagrid high rise steel structure. The modeling and analysis is performed by using ETABS software. The structure is analyzed statically and dynamically each for seismal loads. Response spectrum analysis is performed for dynamic analysis of the structure. The results obtained by performing the analysis of the structure in terms of most level displacement, most level drift and level shear are compared and also the conclusions are drawn as follows:

- By reducing the angles of Diagrids it is observed that the lateral displacement and storey drift also reduces with a significant amount of reduction. Thus it's determined to keep the structure under permissible deformation and structural weight of steel is reduced. Hence, the structure becomes economic. There is about 20% less reduction

of steel in diagrid structure as compared to conventional structure.

- With the increase in number of diagonal elements on the web and flange façade of the structure, the top storey displacement and maximum storey drift gets reduced while base shear increases with the increase in number of diagonal elements on the web.

- Out of 20 different diagrid models and 9 different angles of Diagrids, it is found that the efficient results for geometrical diagrid pattern are in between the angles 67.38º and 71.56º.

- It is found the diagrid structure having 16 number of diagonal elements on the façade of the structure gives more efficient results than nx = 32 and nx = 8.

(Szolomicki and Golasz-szolomicka, 2017) In the design of high-rise buildings there are a large number of architectural forms, like twisted, tilted, tapered and free forms. The article describes the characteristics of the diagrid system and its applicability within the construction of tall buildings in respect to different modern construction systems: braced-tube and outrigger. The authors plan to assess the effectiveness of this technique for varied geometric forms. The characteristics of buildings with very advanced geometry which use the diagrid system are given.

(Sorathiya and Gadhiya, 2017) conclude that that diagrid structural system provides a lot of flexibility in designing interior house and facade of the building. Diagrid give a lot of resistance within the building that makes system simpler. The optimum angle vary of diagrid is 65° to 75° for many economic section. The parameter like base shear, storey drift, period of time, storey shear, prime storey displacement and steel weight is a smaller amount as compared it with typical structural system.

(Ballur and Manjunath, 2017) In trendy age, construction of high-rise buildings is speedily increasing throughout the world. Because of the decrease of accessible free land and because of the wide spread urban area, the architects and therefore the engineer have started developing the cities vertically. Recently, the diagrid structural efficiency and aesthetic potential provided by the triangulation of the systems. Compared to the traditional frame buildings having exterior vertical columns, diagrid buildings resist the lateral masses a lot of effectively because of the presence of the inclined columns. Within the present study, a 36 storey steel building is taken for the comparison. kinds of buildings thought of for comparison are as follows: diagrid frame building with rectangular set up and diagrid frame building with rectangular set up alongside chamfered edges. of these buildings are modeled and analyzed for earthquake masses and wind masses severally. The planning of structural members is completed as per IS800:2007. Comparison is completed in terms of construction displacement, construction drift, and base shear, period of time, construction stiffness and structural weight. During this study, it's found that the construction displacements and therefore the inter storey drifts reduce at the same time because the form of the building takes a curved type avoiding the edges.

(Design et al., 2016) presents a simple optimization technique for the preliminary design of steel diagrid tall buildings. The technique was applied to three building geometries which are common for diagrid structures. This work should be seen as preliminary and as a motivation for future work on the topics of diagrid optimization. In addition, the current paper discusses the topic of tall building robustness and optimization, two major fields in tall building design. Finally a future view of the diagrid structural system is provided at the end.

(Bhale and Salunke, 2016) observed that due to diagonal columns in periphery of the structures, the diagrid structure is more effective in lateral load resistance. Due to this property of diagrid structure, interior column is used of smaller size for gravity load resistance and only small amount of lateral load is considered for it. Whereas just in case of standard frame building, each gravity and lateral load is resisted by exterior similarly as interior column. the following points are complete from above study concerning diagrid structure:

- Structural performance: Diagrid building shows less lateral displacement and drift as compared to traditional building.

- Material saving property: although volume of concrete utilized in each building is approx. same, however diagrid shows additional economical in terms of steel used. Diagrid building saves concerning 33.21% steel while not affecting the structural efficiency.

- Better resistance to lateral loads: because of diagonal columns on its periphery, diagrid shows higher resistance to lateral masses and because of this, inner columns get relaxed and carry only gravity loads. Whereas in standard building each inner and outer column are designed for each gravity and lateral masses.

- Aesthetic look: as compared to traditional building, diagrid buildings are additional aesthetic in look and it becomes vital for prime rise buildings.

(Milana et al., 2015) this study arises from the impact that the construction trade has on the surroundings, in terms of use of resources and production of waste, and therefore the social want that needs work sustainable solutions, like the thought of sustainable diagrid high-rise buildings. Among the finding, the approach during which diagrid structures result in a considerable reduction of (steel) material compared to a lot of traditional structural systems like stabilizer structures is quantified. Moreover, the performance of diagrid structures has been assessed, not solely in terms of steel reduction, however additionally in terms of safety, serviceability and structural robust- ness. Completely different diagrid structures were thought of, namely, 3 geometric configurations with inclination of diagonal members of 42°, 60°and 75°. These configurations, additionally to allowing a considerable reduction of weight, offer a better performance in terms of strength, stiffness and ductility. Between the thought of diagrid structures the one with the simplest overall behavior results to be the one with 60°diagonal element inclination. For this configuration, extra analyses within the damage state are performed, assessing the general smart performance of the structure under exceptional events. even so, there are some limitations to the present study. extra loading situations ought to be accounted for, so as to own a broader insight on the structural behavior. Additionally, the outlined performance index is tag with specific constant values that highlight the property side. Finally, robustness checks ought to be applied using appropriately outlined indexes.

(Panchal, Patel and Pandya, 2014) carried out by considering the various angles of diagrid and additionally different storeys of the building. The set-up of 36m x 36m is taken into account with four differing kinds of angles of diagrid that's 50.2°, 67.4°, 74.5° and 82.1° and additionally by considering 24-storey, 36-storey, 48-storey and 60-storey building, a comparative study is allotted. It completes that:

- Diagrid angle within the region of 65° to 75° provides a lot of stiffness to the diagrid structural system that reflects the less prime construction displacement.
- The storey drift and construction shear results are significantly lesser within the region of diagrid angle 65° to 75°.
- As period of time is a smaller amount, lesser is mass of structure and a lot of is the stiffness, the period of time is discovered less within the region of diagrid angle 65° to 75° that reflects a lot of stiffness of the structure and lesser mass of structure.
- It ought to be noticed that the results for the angle of diagrid 82.1° is kind of random for the storey drift, construction shear and period of time.
- Diagrid angle within the region 65° to 75° provides a lot of economy in terms of consumption of steel and concrete as compared to completely different angles of diagrid.
- When variety of construction will increase means that height of building will increase, diagrid angle within the region 65° to 75° provides higher leads to terms of prime storey displacement, storey drift, storey shear, period of time and material consumptions.
- Diagrid structural system provides a lot of economy and a lot of advantages once no of construction is quite 40 with the diagrid angle within the region of 65° to 75°.
- Optimum angle of diagrid is discovered within the region of 65° to 75°.
- Diagrid structural system provides a lot of flexibility in designing interior area and façade of the building.

3. DIAGRID STRUCTURAL SYSTEM

Diagrids are basically an arrangement of inclined columns, as opposed to conventional vertical columns, at the perimeter of a structure making diamond shape modules along multiple floors. Leonard J. (2007) defines diagrid as a unique form of a space truss consisting of a grid made up of series of a triangulated truss system at the periphery formed by the intersection of diagonal and horizontal components. The diagrid system is not the same as the braced columns since in the former system; there are no vertical columns at the perimeter. This can be observed from the Figure 2 and 3. Figure 2 shows a conventional braced system while Figure 3 shows the diagrid system. Charnish et.al (2008) differentiated between the braced structure and the diagrid structure by stating that in braced structure, the conventional framed exterior system is aided with the diagonal bracing members as a supplementary support system. On the other hand in the diagrid system, the exterior frame is comprised exclusively of the diagonal members as the primary means of support.

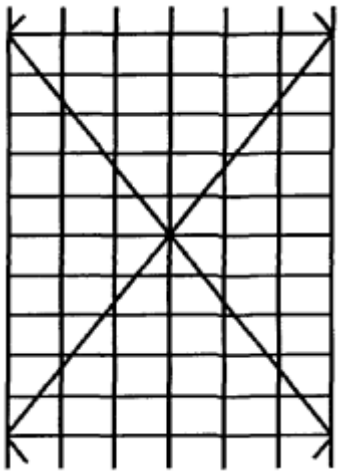

Fig.2: Braced System

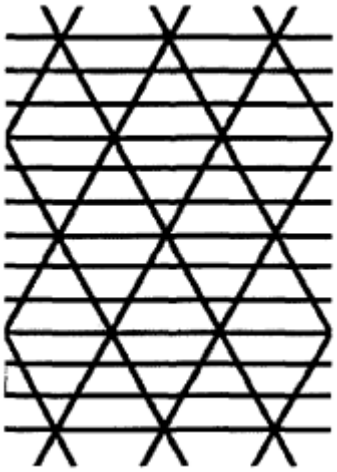

Fig.3: Diagrid System

Diagrids can be said to have evolved from braced tube structures, as the perimeter configuration provides the bending resistance and rigidity while the diagonal members are contact the facade giving rise to closely spaced diagonal parts. Here the diagonal members act each as inclined columns still as bracing parts and carry gravity loads still as lateral forces. Because of their triangulated configuration primarily the axial forces arise within the members. This may be understood from Figure 4, 5 and 6. In Fig.4, the distribution of gravity loading has been shown. One can see the vertical load is converted to axial load along the diagonal. The distribution due to the moment generated by the lateral load is shown in Figure 5. Due to the moment one side is in tension and the other side in compression thereby acting as vertical tension force on one side and compression force on the other. The last Figure 6 shows the distribution due to shearing caused by the lateral load. Horizontal load is being resisted by the diagonals along the axis**.**

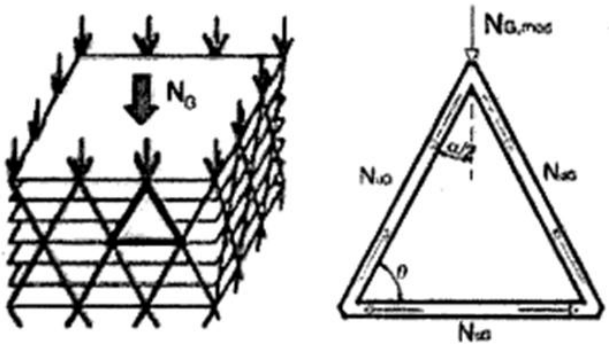

Fig.4: Effect of Gravity loading

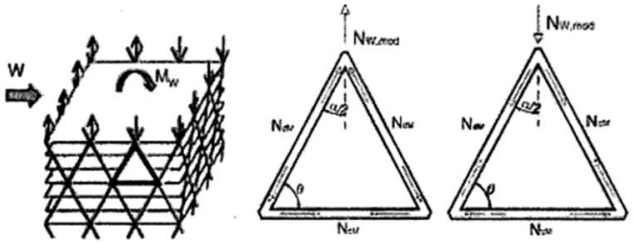

Fig.5: Effect of Lateral loading

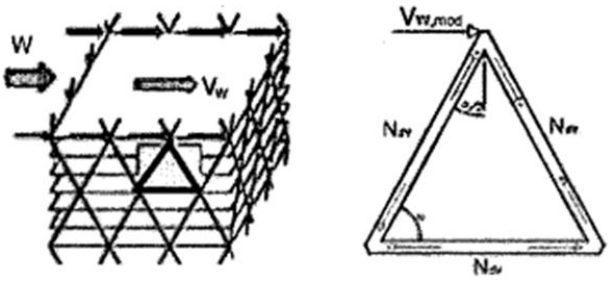

Fig.6: Effect of Shear loading

4. ADVANTAGES OF DIAGRID STRUCTURES

A lot of research has been carried out on these structures, based on that, different advantages of these structures as compared to other prevailing structures have been observed. T.M. Boake (2013) discussed that the advantage of removal of vertical columns leading to reduction of costs was major factor in the recognition and development of diagrid systems. The vertical columns were capable of carrying only gravity loads while in diagrid system due to its triangulated geometry, the inclined columns could carry gravity as well as lateral loads and thus providing high stability. Chamish et.al (2008) concluded that about 20% of steel reduction is possible in diagrid systems as compared to other conventional systems. K.S Moon (2007) stated the fact that diagrid systems are very effective in reducing shear deformations due to axial action of diagonal members. In conventional framed structures shear is resisted by bending of columns while here the diagonal members provide bending as well as

shear rigidity. Rahimian A et.al (2008) in their case study on Hearst Tower found that the diagrid system is highly efficient and redundant since it provides a structural network allowing multiple load paths important to better performance under extreme conditions. It has the advantage of stability against gravity, seismic and wind loads due to its significant lateral stiffness and strength. Structure of a diagrid system is such that, it provides unrestricted interior space hence providing flexibility in its planning and use.

5. DISADVANTAGES OF DIAGRID STRUCTURES

These structures have some limitations also. The first being the requirement of quality workmanship as the structure involves complex construction techniques. Constructability is additionally a significant issue in diagrid structures as a result of the joints of diagrid structures are a lot of difficult and tend to be more expensive than those of standard orthogonal structures. So as to reduce jobsite work, manufacture of nodal components is important.

6. CONCLUSION

Based on the review study has carried on the analysis breakthrough to the Analysis and style of Diagrid Structural System for top Rise Steel Buildings. During this paper varied analysis papers are studied associated with the Diagrid Structural System for high Rise Steel Buildings. The diagrid structural system provides a lot of flexibility in designing interior area and facade of the building. Diagrid give a lot of resistance within the building that makes system simpler. The optimum angle vary of diagrid is 65° to 75° for many economic section. The parameter like base shear, construction drift, period of time, storey shear, prime construction displacement and steel weight is a smaller amount as compared it with standard structural system.

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