Comparative Analysis Of Steel Diagrid Building and conventional Building

Kumar Saurabh **VIkesh Kumar Mewada**
M.Tech Scholar **Assistant Professor**
Department of Civil Engineering **Department of Civil Engineering**
IES Institute of Technology and Management
Bhopal, MP
IES Institute of Technology and Management
Bhopal, M.P

Abstract- Throughout the world the multi-storey building construction has been increasing day by day. The development of highly advanced structural system which has the quality of aesthetic expression, structural efficiency and most importantly geometric versatility requires the design and construction of artificial infrastructure on the lines of bio-mimicking principles. Recently, the use of diagonal members for carrying the gravity and lateral load has increased and these members are known as 'diagrid'. The unique geometrical configuration of the diagrid structural system has led them to be used for tall buildings providing structural efficiency and aesthetic potential.

In this study, the structural response of conventional and diagrid building is investigated to evaluate the structural benefits of diagrid system. A regular G+15 storey steel building with a plan size of 18 m x 18 m, located in a seismic zone V is analysed and designed by STAAD Pro. Software. All structural members are designed as per Indian standard for general construction in steel (IS 800:2007) and the seismic forces are considered as per Indian codal provision for earthquake resistant design of structure (IS 1893 (Part 1): 2002). In diagrid structure, the major portion of lateral load is taken by the external diagonal members, which in turn releases the forces in other members of the structure.

The use of diagrids significantly decreases the maximum shear force and bending moment in internal and perimeter beams. The diagrid configuration also provides a reduction in the span of perimeter beams at alternate floors, hence reducing the beam forces at alternate floors. The bending moment in internal column also decreases in diagrid building. This reduces the sectional requirement of beams and columns in diagrid building. An overall economy of nearly 12% is achieved in diagrid building compared to conventional building.

The lateral displacement and storey displacement has been reduced significantly in the diagrid building compared to the conventional building. The maximum lateral displacement in diagrid building reduces by nearly 15% compared to conventional building.

KEY WORDS: Diagrid Structure, Graphic User Interface, Codal Provisions,Lateral Displacement,Aesthetic Potential,Concentric Brace Frame, Finite Element Method, Eccentric Braced Frames

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I. INTRODUCTION

Diagrids are perimeter structural designs with a small grid of diagonal members that are used for both gravity and lateral load resistance. Although diagonalized applications of structural steel members for providing efficient solutions in terms of strength and stiffness are not new, there is a renewed interest in it and a widespread application of diagrid in large span and high rise buildings, especially when they are characterised by complex geometries and curved shapes, sometimes completely free forms

1.1 : Interior Structures

Moment-resisting frames and shear trusses/shear walls are the two most common forms of lateral load-resisting systems in this category. These systems are commonly structured in planar assemblies in two major orthogonal directions, and they can be used together as a combined system.

The moment-resisting frame (MRF) is made up of rigidly coupled horizontal (girder) and vertical (column) elements in a planar grid. The size of the columns is mostly determined by gravity loads that increase towards the structure's base, resulting in progressively bigger column diameters as the building descends from the roof. The size of the girders, on the other hand, is determined by the stiffness of the frame in order to maintain the building's tolerable lateral wobble.

Although the gravity force on all typical levels of a tall building is roughly the same, the girder diameters must be raised to maximise frame stiffness. Similarly, columns that are already sized for gravity loads must be somewhat expanded in order to increase frame stiffness. MRFs can be found in or around the core, on the façade, and along grid lines throughout the building's interior. Laterally, braced frames are supported by vertical steel trusses, also known as shear trusses, which withstand lateral loads due to the members' axial stiffness. These serve as a vertical support.

Columns serve as chord members, whereas concentric K, V, or X braces serve as web members in cantilever trusses. Concentric braced frames are the name for such frames (CBF). On the other hand, eccentric braced frames (EBF) contain braces that are attached to the floor girders that form horizontal parts of the truss and have axial offsets to bring flexure and shear into the frame. As a result, EBFs are employed in seismic zones because they reduce the stiffness-to-weight ratio while also increasing ductility

One of the most common technologies used for high-rise construction to resist lateral stresses induced by wind and earthquake loads is reinforced concrete planar solid or coupled shear walls. They are classified as fixed-base vertical cantilevers. The total stiffness of the system surpasses the sum of the individual wall stiffness when two or more shear walls in the same plane are joined by beams or slabs, as is the case with shear walls with door or window openings. Because the connecting beam restrains the individual cantilever motions of the walls, they behave as a single unit. Coupled shear walls are what they're called.. Shear walls used in tall buildings are generally located around service and elevator cores, and stairwells. In many tall buildings, the vertical solid core walls that enclose the building services can be used to stabilize and stiffen the building against lateral loads.

1.2: Exterior Structures

Tall buildings have more structural relevance than any other building style because of their height, which means greater resistance to lateral pressures, particularly wind loads. As a result, it is highly desirable to concentrate as many lateral load-resisting system components as possible on the perimeters of tall structures in order to enhance structural depth and, as a result, lateral load resistance.

The tube, which is a three-dimensional structural system that uses the entire building perimeter to resist lateral stresses, is one of the most common outside structures. The tubular concept, or a version of it, has been used in numerous recent structures with more than 50 stories. The advent of tube systems was groundbreaking because it was the first time that a building's three-dimensional response was directly related to the advantage of leaving from the traditional rigid frame system of tightly coupled flat beam-column grids. Tubular forms come in a variety of shapes and sizes, based on the structural efficiency they can give for various heights.

II. OVERVIEW OF WORK

The salient objectives of the present study have been identified as follows:

- Comparison of Column Force between conventional and diagrid building.
- Comparison of Beam Forces between conventional and diagrid building.
- Comparison of Lateral Displacement between conventional and diagrid building.
- Comparison of Weight of Building between conventional and diagrid building

III. NEED FOR THE PROPOSED WORK

There are several functional and economic advantages that underlie the use of this system:

- Increased the stability due to triangulation
- Combination of the gravity and lateral load-bearing systems, potentially providing more efficiency.
- Provision of alternate load paths (redundancy) in the event of a structural failure (which lacks in case of conventional framed building).
- Reduced weight of the superstructure can translate into a reduced load on the foundations.
- Reduced use of structural materials translating into environmental savings.
- It has ability to reduce dependency on the core for achieving lateral stability.

IV. LITERATURE REVIEW

A large number of papers has been published in the field of diagrids. Following are the few notable outcomes of the related literature:

- The most efficient rehabilitation technique for a low-rise building to reduce drift is column strengthening.
- The X bracing and single bracing systems are the most effective for inelastic behaviour and characterising the hysteric response owing to cyclic stress.
- For a 60-story skyscraper, the most ideal diagrid angle is between
- 53 and 76, with 63 as a viable option.
- A cost-effective material-saving design for systems having diagonals, such as braced systems.
- In resisting lateral and gravitational loads, braced tube and diagrid structures were discovered at an angle of 40 to 50 for braced tube and 60 to 70 for diagrid.
- In terms of shear lag ratio and lateral displacement, diagrid buildings outperform framed tube buildings by three times.
- Utilizing the performance-based method to design a building is preferable to using the traditional method.
- Self-centering energy dissipating frames with advanced bracing systems show a reduction in residual building deformation.
- When compared to tubular structures, the diagrid construction has more strength and ductility.
- Complex-shaped tall buildings, such as twisted, tilted, and so on, can be erected thanks to diagrids structural efficiency and architectural aesthetic potential.
- Over the recent decade, countries such as China, Dubai, Qatar, and England have developed more interested in diagrid constructions.
- When compared to traditional buildings, the RCC diagrid construction has a steel reinforcement benefit of 33%.

It is observed that analysis and design of diagrid structure is carried for high rise steel building only.

Moon (2008) investigated a stiffness-based design process, focusing on systems with diagonals such braced tubes and diagrid structures. A material-saving, cost-effective design was created, along with recommendations for optimal geometry. The usefulness of diagrid on tall structures was studied, and it was shown that the best angle for braced tube was 40 to 50 degrees, whereas the optimum angle for diagrid was 60 to 70 degrees.

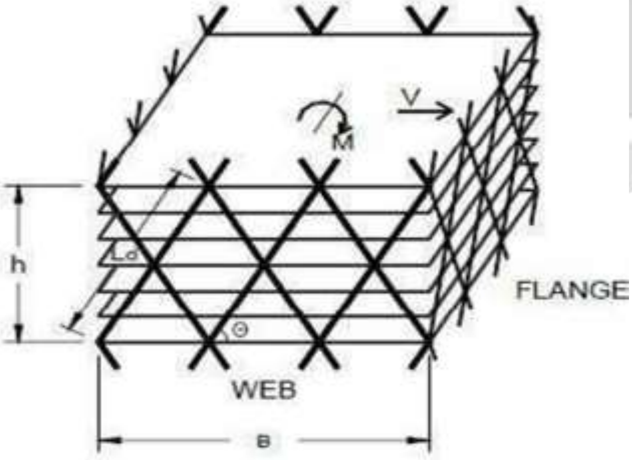

Fig – 1 Typical diagrid module

Vishwanath (2010) examined a four-story building in seismic zone 4. The building's performance is measured in terms of storey drift. The study is then expanded to eight and twelve stories. The most efficient type of steel bracing has been discovered to be X.

Kim et.al (2010) studied the seismic performance of diagrid building. Design and Analysis of the building was carried at different angle. The analysis model structure was a 36-storey diagrid structure with various slopes (50.2o, 61.0o, 67.4o, 71.6o, 74.5o and 79.5o) of external braces having a 36m X 36m plan. The diagrid structure showed higher over strength with smaller ductility compared with the tubular structure. An increase was seen in both the strength and ductility. The diagrid with braced angle between 60o and 70o proved to be most efficient in resisting the lateral and gravity load both.

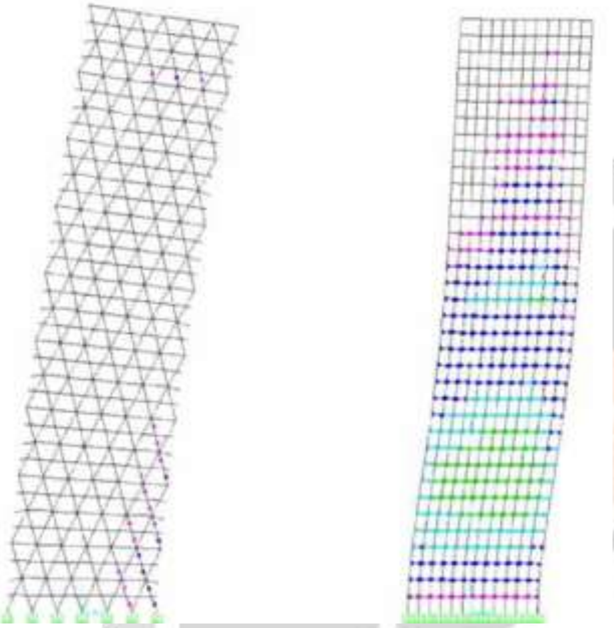

Fig – 2 : Plastic hinge formation in the model structures obtained by nonlinear static analyses. (Diagrid structure (67.4°) & Tubular structure)

Jani and Patel (2013) looked at the study and design of a 36-story steel diagrid building with a plan dimension of 36m X 36m and a floor height of 3.6m. The diagrid angle was maintained throughout the height, and the inclined columns were spaced at 6m intervals around the perimeter. The load distribution in diagrid systems, as well as the analysis and design of 50, 60, 70, and 80-story diagrids, were investigated.
structure. Top storey displacement, time period and inner storey drift was also compared.

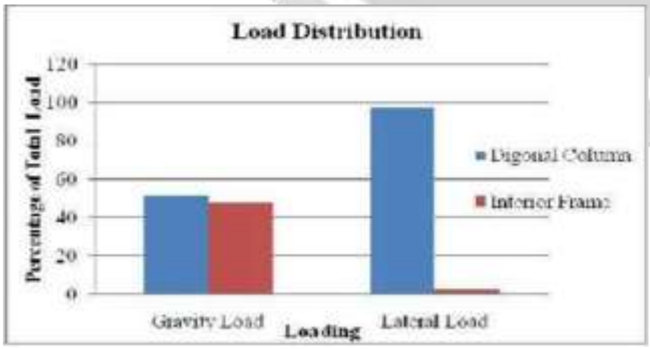

Fig – 3: Load distribution in exterior and interior frame

From the above study, it is clear that lateral study is resisted by outer periphery columns and internal column is designed only for vertical loads only.

Panchal and Patel (2014) studied the usage of diagrid structural solutions in high-rise structures to reduce lateral forces. For top storey displacement, storey drift, and material consumption, ETABS 9.7.4 software was used to compare a 20-story basic frame building to a diagrid building with a plan dimension of 18m x 18m. They came up with a difference of 57.9% in terms of steel use.

Korsavi and Maqhareh (2014), the evolutionary process of diagrid structures and their developments leads to significant breakthroughs in architectural, structural, and sustainability principles. The constructions met the bulk of the design requirements, according to the findings. According to the data, countries like China, Dubai, Qatar, and England have been increasingly popular in diagrid structures during the last decade.

V. DESCRIPTION OF STRUCTURAL MODEL

The modelling, analysis and design of a G+15 storey conventional and diagrid building is done with the help of STADD Pro. software. The geometric parameters of conventional and diagrid both the building are shown in below

1	Number of Storey	G+15
2	Plan Size	18m x 18m
3	Storey Height	3.0m
4	Number of Bays along X and Z direction	3
5	Length of each bay	6m
6	Dead Load:	
a)	Floor load	3 kN/m2
b)	Wall	
(i)	Parapet wall	2.6 kN/m
(ii)	Other wall	8.5 kN/m
7	Live Load:	
a)	At roof	2 kN/m2
b)	Other floors	4 kN/m2
8	Seismic Zone as per IS 1893(Part 1):	V
9	Response Reduction Factor	5
10	Importance Factor	1.5
11	Soil Type	Hard
12	Structure Type	Steel frame
13	Diagrid Angle	63.43 o
14	Diagrid Module	4

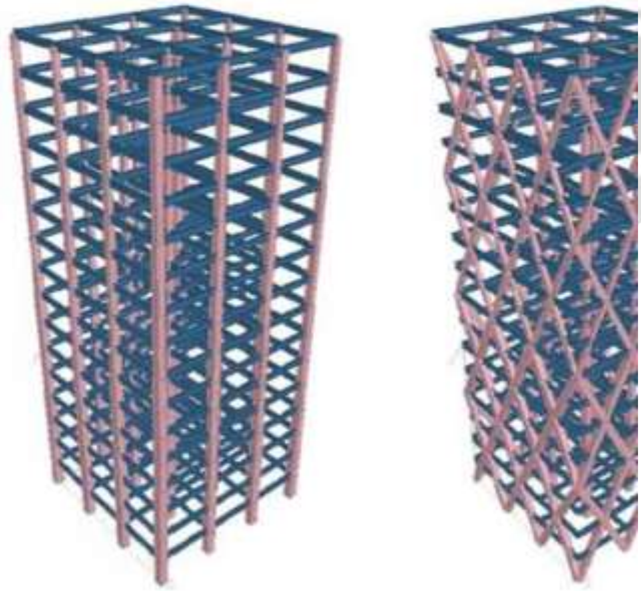

Fig- 4 : Isometric view of Conventional building and Diagrid building

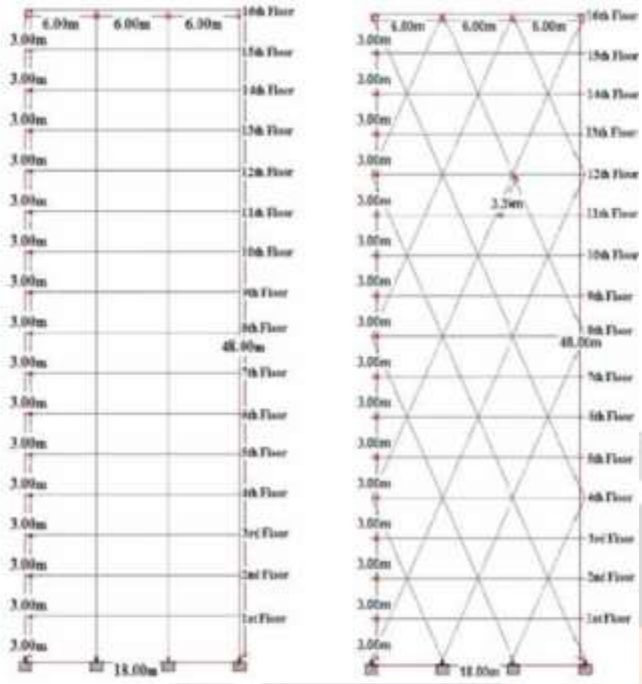

Fig – 5: Sectional view of conventional and diagrid building at 1-1

VI. RESULT

Axial Force:-

The comparison of axial force in interior columns between conventional and diagrid building at location A and B .

The use of diagrid has increased the column axial force in all the column for the considered load cases at location A. The maximum axial force is found to be 7374.05 kN at the bottom column (101) and the minimum is found in top most column (1601) to be 69.09 kN in case of conventional building, where as in case of diagrid building the maximum axial force is found to be 9617.89 kN in the bottom column (101) and the minimum is found in top most column (1601) to be 113.48 kN.

Bending Moment:-

The comparison of bending moment in interior columns between conventional and diagrid building at location A and B.

Diagrids has effectively reduces the bending moment in columns of location A. The maximum bending moment at the bottom column (member 101) is found to be 765.83 kN-m which has been reduced to 408.22 kN-m in diagrid structure.

Diagrids reduces the bending moment in column at location B significantly. The maximum value of 772.42 kN-m (member 102) is reduced to 396.81 kN-m in diagrid structure. The pattern of bending moment can be seen for interior column.

Although the axial force in interior columns of diagrid building increases in comparison to conventional building but there is a significant reduction in bending moment. This reduces the sectional requirement of columns in diagrid building.

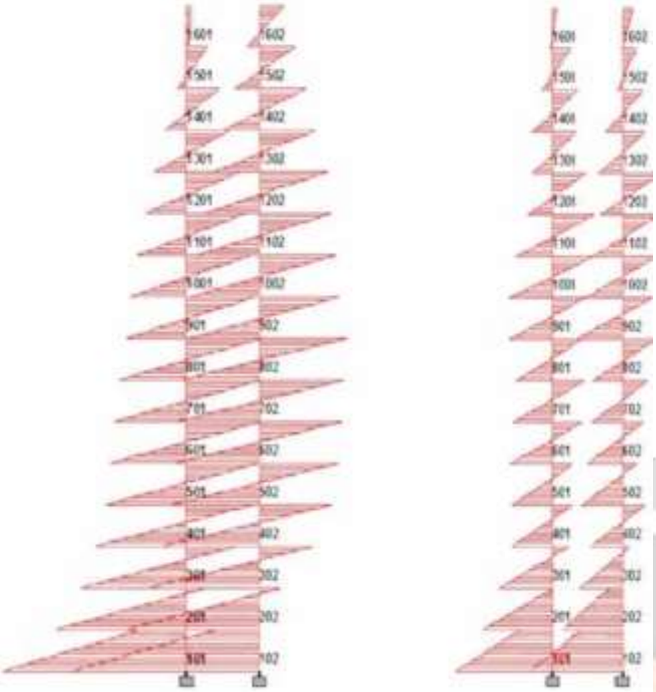

Fig – 6 : Bending moment in interior column (Conventional building & Diagrid building)

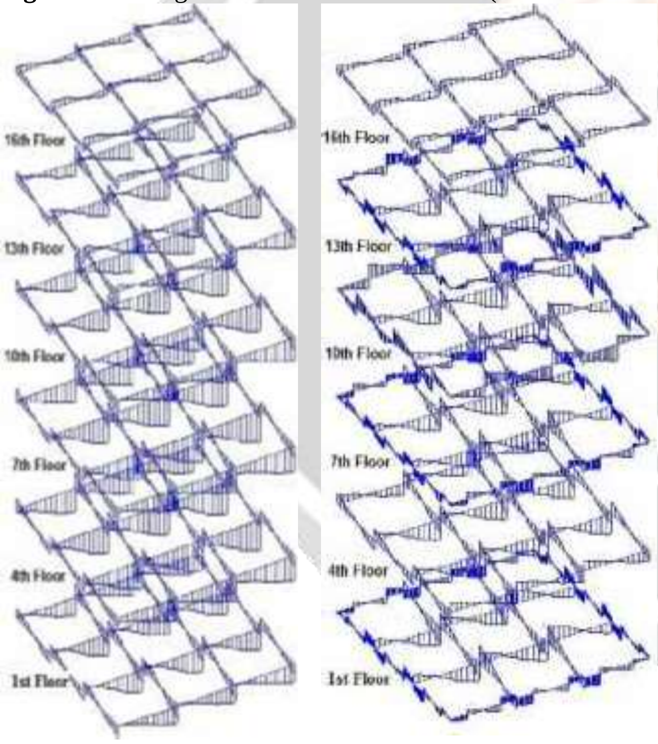

Fig – 7: Shear force diagram of selected floor beams for conventional and diagrid building (Conventional building & Diagrid building)

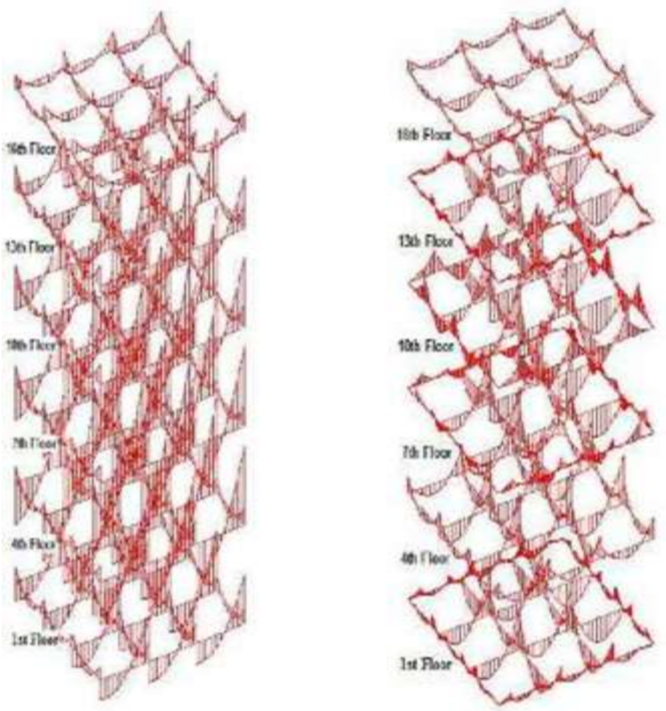

Fig – 8: Bending moment diagram of selected floor beams for conventional and diagrid building (Conventional building & Diagrid building)

Lateral displacement:-

The diagrids have efficiently controlled the lateral displacement, as seen in the table. The diagrid to conventional building ratio ranges from 0.55 to 0.82. The greatest displacement in a conventional building was 73.59 mm, whereas in a diagrid construction it was 60.43 mm. Below Figures depict the displacement diagram and graph between conventional and diagrid construction in section 1-1, respectively.

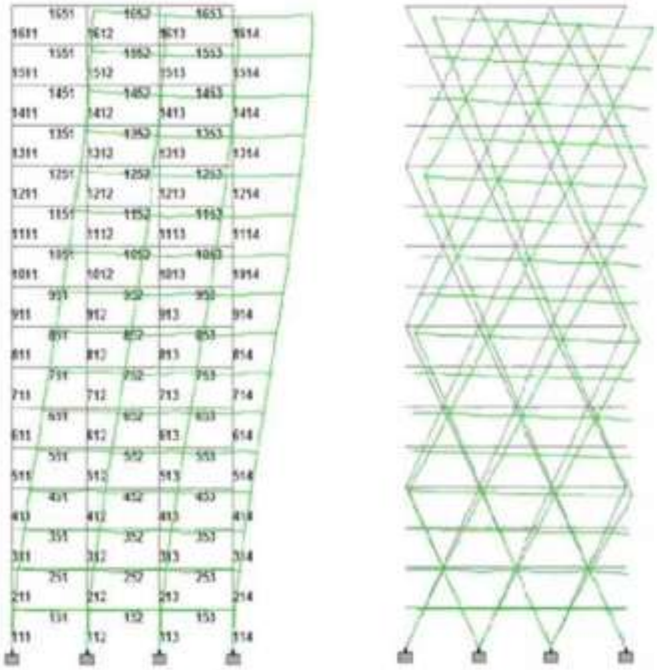

Fig – 9: Displacement diagram at section 1-1 for conventional and diagrid (Conventional building & Diagrid building)

VII CONCLUSION

The following are the main findings of the present study –

- 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.
- The sectional requirement of the members has been reduced in diagrid building when compared to the conventional building. This results in an advantage of approximately 12% in weight for diagrid building.
- The diagrid member reduces the displacement at roof. The nodes connected with the diagonal member in the direction of force have a more prominent reduction in displacement when compared to the other nodes.
- The lateral displacement and storey displacement has been reduced significantly in the diagrid building compared to the conventional building. The maximum lateral displacement in diagrid building reduces by nearly 15% compared to conventional building.

VIII. SCOPE FOR FUTURE WORK

Worldwide today, the diagrids is being used for tall and complex building construction. The unique characteristics of diagrid is to provide greater structural efficiency for tall buildings. Due to increase in population, the multi-storey building construction will continue on a larger scale. This work can be advanced and improved with consideration of following parameters:

- It is possible to investigate the performance of diagrid buildings at various height/base ratios.
- Different building shapes, such as spherical, hexagonal, and paraboloid, can be considered as well.
- A comparison based on different diagrid module sizes is also possible.
- Tubular sections are being investigated for beams and columns in the current work. Other portions to examine are the I-section, channel section, and so on.
- For more precise analysis and design, dynamic analysis might be used.
- Different seismic and wind zones can be investigated.
- It is possible to investigate the design of diagrid node connections and their impact on the overall economy of a building.
- It is also possible to compare the diagrid system to other lateral load resisting systems like as bracing, shear walls, and so on
- A study considering the stiffness of floor system in the analysis can be included in the design.

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