# Dynamic Analysis of Diagrid Structural System in High Rise RCC Building With Varying Geometry

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***Abstract-*** *Skyscraper 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 high rise building, the structural design is generally governed by its lateral stiffness. Diagrid structures carry lateral seismic loads much more efficiently by their diagonal member's axial action in comparing with conventional orthogonal structures for tall buildings such as framed tubes, A diagrid structure provides great structural efficiency without vertical columns have also opened the new aesthetic potential for tall building architecture. Diagrid has a good appearance and it is facilely apperceived. The configuration and efficiency of a diagrid system reduce the number of the structural element required on the façade of the buildings, therefore less obstruction to the outside view. The diagrid system structural efficiency also helps in avoiding interior and corner columns and therefore allowing significant flexibility with the floor plan. A diagrid structure is a type of structural system consisting of diagonal grids connected through horizontal rings which create an elegant and redundant structure that is especially efficient for high-rise buildings. In the present study a G+41 storey multistoried R.C.C building model is modelled using Etabs 2018 software. Response spectrum analysis is made by considering building situated in zone III.Building models are analyzed by Etabs 2018 software to study the effect storey shear, base shear, time period, base moments, maximum storey displacement and maximum storey drift etc.*

***Keywords***- Diagrid structures, G+41 storey, Response spectrum analysis, Etabs 2018 software

## I. INTRODUCTION

Skyscraper 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 high rise building, the structural design is generally governed by its lateral stiffness. Diagrid structures carry lateral seismic loads much more efficiently by their diagonal member's axial action in comparing with conventional orthogonal structures for tall buildings such as framed tubes, A diagrid structure provides great structural efficiency without vertical columns have also opened the new aesthetic potential for tall building architecture. Diagrid has a good appearance and it is facilely apperceived. The configuration and efficiency of a diagrid system reduce the number of the structural element required on the façade of the buildings, therefore less obstruction to the outside view. The diagrid system structural efficiency also helps in avoiding interior and corner columns and therefore allowing significant flexibility with the floor plan. A diagrid structure is a type of structural system consisting of diagonal grids connected through horizontal rings which create an elegant and redundant structure that is especially efficient for high-rise buildings. A diagrid structure is different from braced frame systems since diagonals as main structural elements participate in carrying gravity load in addition to carrying lateral load due to their triangulated configuration, which eliminates the need for vertical columns. The column free structure of a diagrid system offers several advantages such as high architectural flexibility and elegance, and cyclopean day lighting due to its immensely colossal free façade surface. The lateral schemes explored different type of geometry of buildings along with different type soil and seismic zones.

### Objective of the Study

- This study is aimed to analyse and design the diagrid structures for high rise building with varying geometry,
- To study the behavior of lateral forces on high rise buildings with varying geometry.
- To apply diagrid structural systems on the structures and find out the optimum performance of this systems with suitable geometry in the respective seismic zone.

- To compare the structures based on stiffness parameters, relative displacement, ductility and resistance compared with each other
- To propose a suitable, economic and optimum position of diagrid structural system suitable according to the respective lateral load.
- To study the response of buildings in terms of storey shear, base shear, time period, base moments, maximum storey displacement and maximum storey drift etc.

## II. LITERATURE REVIEW

2.1 Background

Tall commercial buildings are primarily a response to the intense pressure on the available land. Advances in materials, construction technology, analytical methods and structural systems for analysis and design accelerated the development of tall structures. The lateral loading due to wind and earthquake is the major factor that causes the design of high-rise buildings. These lateral loads are resisted by exterior structural system or interior structural system. The lateral load resisting systems that are widely used are mainly rigid frame, shear wall, wall-frame, braced tube system, outrigger system, diagrid system and tubular system. Recent trend shows that the diagrid structural system is becoming popular in the design of tall buildings due to its inherent structural and architectural advantages. Diagrid is an exterior structural system in which all perimeter vertical columns are eliminated and consists of only inclined columns on the façade of the building. Shear and over-turning moment developed are resisted by axial action of these diagonals compared to bending of vertical columns in framed tube structure. Vertical columns in the core are designed for carrying gravity loads only and the diagrid is useful for both gravity and lateral loading. Diagonalized applications of structural steel members for providing efficient solutions both in terms of strength and stiffness are not new, however nowadays a renewed interest in it and a wide spread application of diagrid is registered with reference to large span and high-rise buildings, particularly when they are characterized by complex geometries and curved shapes.

2.2 The Research Carried Out by Various Researchers

It was found that large numbers of research works were conducted on Dynamic Analysis of Diagrid Structural System in High Rise RCC Buildings with varying geometry. Mostly among all available literature and experimental work was based on the Dynamic Analysis of Diagrid Structural System in High Rise RCC Buildings with varying geometry



The following literature surveys for "Dynamic Analysis of Diagrid Structural System in High Rise RCC Buildings with varying geometry**.**

**2**.2.1 Deepika Khatri, Sumit Pahwa [Aug 2019]1

The latest trend in high rise building is diagrid structures because of structural and architectural effectiveness. In the study previous literatures are studied for Flat-slab Building and detailed analysis is carried out to check the behaviour of flat slab buildings with and without diagrid. It is very important that the selected structural system is such that the structural elements are utilized effectively while satisfying design requirements. Recently diagrid structural system is adopted in tall buildings due to its structural efficiency and flexibility in architectural planning. Structural design of high-rise buildings is governed by lateral loads due to wind or earthquake. Lateral load resistance of the structure is provided by interior structural system or exterior structural system. Due to inclined columns lateral loads are resisted by axial action of the diagonal in diagrid structure compared to bending of vertical columns in conventional building. This paper also reviews the studies on the comparison of diagrids with regular configuration and diagrids with varying angles. The analysis and comparison of diagrid and conventional structural system on the basis of consumption of steel, structural weight and displacement are also highlighted.

2.2.2. Akshat, Gurpreet Singh [Feb 2018]2

Now a days, the rate of population is increasing day by day due to which the access for land is decreasing. Due to this, tall structures are preferred. As it is known that the effect of lateral load is more on the tall structures because with the increase in height of structure, the effect of lateral load increases. The lateral load on the structure can be due to the wind and earthquake. In this paper, the study is made on the basis of lateral load due to earthquake. There are various structural systems for resisting the lateral load but the diagrid structural system is in trends nowadays and adopted for research work. In this paper, a 60-storey tall building of height 216 m is analyzed. The plan dimension of the building is 48 m × 48 m. The building is analyzed for lateral load due to earthquake in seismic zone IV. Various patterns of the diagrid were used in the dynamic analysis by varying the angles of the diagonal elements. The analysis is performed by using ETABS software. Response Spectrum Method is adopted for the dynamic analysis of the structure. The number of diagonal elements is also varied on the façade of the structure for the assessment of the economy. At last, secondary bracing system was also added to it. The results of analysis are discussed in terms of Maximum storey displacement, maximum storey drift and maximum storey shear.

2.2.3 Dipesh Joshi et.al [2017]3

As Diagrid Structure are efficient in providing solution both in terms of strength and stiffness. Therefore, nowadays widespread application of Diagrid is used in high rise building and skyscrapers, particularly when complex geometries and curved shapes are involved. As height of building rises, not only D.L and L.L are predominant forces but along with it W.L and Seismic forces equally hold a share with it. In order to provide resistance against these forces, conventional design approach might be sufficient to counteract these loads but may lead to uneconomical design, lesser F.O.S, greater stability requirement and aesthetics part may not be up to the mark. Diagrid takes into account above mentioned limitation which conventional building faces and. proves to be one of the solutions for getting optimum structure skyscrapers, particularly when complex geometries and curved shapes are involved.

2.2.4 Avnish Kumar Rai & Rashmi Sakalle [Sep. 2017]4

The diagrid system nowadays widely used for high rise buildings due to its structural efficiency. In present research work, steel diagrid structure at an outer portion of the building at 60 degrees having an inner core of R.C.C columns with R.C.C beam and the slab is analyzed and compared with a conventional concrete building. The diagonal member of diagrid structure transferred the lateral loads by axial action compared to bending of vertical columns in the conventional building system. 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 modeling 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.

2.2.5 U. A. Nawale, D. N. Kakade [ Jun. 2017]5

Now days high rise structures are rapidly grow due to limitation of available land. Structure design of high-rise buildings is governed by the lateral loads due to wind or earthquake. Lateral load resistance of structure is provided by wall frame, braced tube, shear wall, outrigger and tubular system. Recently the diagrid-diagonal grid system is widely used for tall buildings due to its structural efficiency. In this paper, study of 32-storey diagrid structural system without vertical column around periphery building is presented here. The comparison of analysis of result in terms of storey displacement, storey drifts for they are presented here

2.2.6 Jayesh Venkolath, Rahul Krishnan [ Sep 2016]6

Construction of multi-storey building is rapidly increasing throughout the world. Recently diagrid structural system is adopted in tall buildings due to its structural efficiency and flexibility in architectural planning. The diagrid structure of each storey height is designed with diagonals placed at various uniform angles as well as gradually changing angles along the building height in order to determine the optimal uniform angle for each structure with a different height. As the height of building increase, the lateral load resisting system becomes more important than the structural system that resists the gravitational loads. The lateral loads are resisted by axial action of diagonal members. The aim of this study is to find the optimal diagrid angle to minimize the lateral drift and displacement in high-rise building. Five different diagrid angle configurations (36.8°, 56.3°, 66°,77.5° and 83.6°) have been considered for 24-storey circular buildings. The results were tabulated by performing finite element analysis using ETABS software. The comparison of analysis of results in terms of lateral displacement, storey drift, storey shear and time period.

2.2.7 Anjana Elsa Alexander et.al [Aug. 2016]7

Structural design of high-rise buildings is governed by lateral loads due to wind or earthquake. As the height of building increases, the lateral load resisting system becomes more important than the structural system that resists the gravitational loads. Recently, diagrid structural system is widely used for tall buildings due to its structural efficiency and flexibility in architectural planning. Diagrid structural system is made around the perimeter of building in the form of a triangulated truss system by intersecting the diagonal and horizontal members. Diagonal members in diagrid structural systems can carry gravity loads as well as lateral loads. Lateral loads are resisted by axial action of the diagonals compared to bending of vertical columns in framed tube structure. The structural efficiency of diagrid system also helps in reducing the number of interior column and avoiding corner columns, thereby allowing significant flexibility with the floor plan. In this paper, effect of lateral loads on steel diagrid buildings are studied. Square and rectangular buildings of same plan area with diagrid structural system is considered for the study. Diagrid modules extending upto 2, 4, 6, 8 and 12 storeys are evaluated. Static analysis for the gravity loads, wind and earthquake and response spectrum analysis are carried out for these different combinations of plan shape and diagrid modules and performance of all these diagrid models i.e., storey displacement, storey drift and modal time period are evaluated and compared in this study.

2.2.8 Arpitha L M et.al [Jul. 2016]8

In this era increasing in the population limiting in the land space and high in the cost of land, to save agricultural land we go for tall buildings. When height of the building increases, the lateral loads will be increasing this cause failure of structure. In order to resist this lateral load resisting systems have been introduced. Some of lateral resisting systems are of diagrid and Braced tubes are taken for this study. The plan of square and hexagonal are modeled for both Diagrid and Braced tube structures. The models are compared for different plans of the structure, such as square and hexagonal, the maximum storey displacement, storey drift, base shear, and time period, the structure is analyzed for seismic zone III and zone V and medium soil condition as per IS 1893:2002 using ETABSv15 software. From the model braced structures is stiffer than the diagrid structures, since the columns are provided in periphery. Diagrid structures can be made effective by providing additional columns near periphery of the structure.

2.2.9 Raghunath.D. Deshpande et.al [Jul. 2015]9

Advances in materials, construction technology, analytical methods and structural systems for analysis and design-initiated development of tall Structures. Structural design for tall structures is governed by horizontal forces due to earthquake and wind load. Lateral load is resisted by exterior structural system or interior structural system. Usually braced frame, shear wall core and their combination with frames are interior system, where lateral force is resisted by centrally located elements. Diagrid structural systems adopted in tall Structures due to its flexibility in floor area and structural. Diagrid consists of inclined columns on the façade. Due to inclined columns lateral loads are resisted by axial action of the diagonal compared to bending of vertical columns in framed tube structure. Diagrid structures generally do not require core because lateral shear can be carried by the diagonals on the periphery of building. Analysis and design of 60 storey diagrid steel building is presented. A regular floor plan of 24 m × 24 m size is considered. ETABS software is used for modeling and analysis of structural members. All structural members are designed as per IS 800:2007 considering all load combinations. Dynamic along wind and across wind is considered for analysis and design of the structure. Later both Conventional and Diagrid Structural Systems are compared

2.2.10 Khushbu Jani, Paresh V. Patel [ 2013]10

Advances in construction technology, materials, structural systems and analytical methods for analysis and design facilitated the growth of high-rise buildings. Structural design of high-rise buildings is governed by lateral loads due to wind or earthquake. Lateral load resistance of structure is provided by interior structural system or exterior structural system. Usually shear wall core, braced frame and their combination with frames are interior system, where lateral load is resisted by centrally located elements. While framed tube, braced tube structural system resists lateral loads by elements provided on periphery of structure. It is very important that the selected structural system is such that the structural elements are utilized effectively while satisfying design requirements. Recently diagrid structural system is adopted in tall buildings due to its structural efficiency and flexibility in architectural planning. Compared to closely spaced vertical columns in framed tube, diagrid structure consists of inclined columns on the exterior surface of building. Due to inclined columns lateral loads are resisted by axial action of the diagonal compared to bending of vertical columns in framed tube structure. Diagrid structures generally do not require core because lateral shear can be**T** carried by the diagonals on the periphery of building. Analysis and design of 36 storey diagrid steel building is presented. A regular floor plan of 36 m × 36 m size is considered. ETABS software is used for modeling and analysis of structural members. All structural members are designed as per IS 800:2007 considering all load combinations. Dynamic along wind and across wind are considered for analysis and design of the structure. Load distribution in diagrid system is also studied for 36 storey building. Similarly, analysis and design of 50, 60, 70 and 80 storey diagrid structures is carried out. Comparison of analysis results in terms of time period, top storey displacement and inter-storey drift is presented in this paper

2.2.11 Jinkoo Kim, Young-Ho Lee [Nov 2010]11

In this study, the seismic performance of typical diagrid structures was investigated. To this end, 36-storey diagrid structures with various slopes of external braces were designed and their seismic responses were evaluated using nonlinear static and dynamic analyses. A tubular structure and a diagrid structure with buckling-restrained braces were also designed with the same design loads, and their seismic performances were compared with those of the diagrid structures. According to the analysis results, the diagrid structures showed higher overstrength with smaller ductility compared with the tubular structure. It was also observed that as the slope of braces increased the shear lag effect increased and the lateral strength decreased. Both the strength and ductility of diagrid structures increased significantly when the diagonal members were replaced by buckling-restrained braces

2.3 Summary of Literature Review

1. The review of the study indicates that there are numerous research efforts found on seismic analysis of buildings resting on sloping ground.
2. It was found that less numbers of research works were conducted on Dynamic Analysis of Diagrid Structural System in High Rise RCC Buildings with varying geometry.
3. To find the performance of diagrid buildings with different plan geometry (square and rectangular) against lateral loads in terms of Storey displacement, Storey drift, and Time period.
4. It is observed from o perform static analysis (gravity load, wind and earthquake) and dynamic analysis (response spectrum method) of diagrid buildings using Etabs software.
5. To study the performance of diagrid structures with varying angle of diagonal diagrid members and to determine the angle at which optimum performance of building can be observed.

## III. PROBLEM STATEMENT AND METHODOLOGY

The study is carried out for the behavior of G+41 storied R.C frame buildings with a regular plan having rectangular and square geometry. Floor height provided as 3.6 m. And also, properties are defined for the frame structure. Models are created in Etabs software by providing rigid outrigger structures at various positions of the buildings. Various types of load are considered. For static behavior dead load of the building is considered as per IS 875 Part 1 and live load is considered as per IS 875 Part III, lateral load confirming IS 1893(part 1)2016. The three-dimensional reinforced concrete structures with G+41 storey was analyzed by Response spectrum analysis using Etabs software. The analysis results will show effectiveness of outrigger belt truss system in terms of storey shear, storey drift, storey displacement, time period,base shear, base moments, storey displacement etc.

3.1 Problem statement

In this project, a 41-storey structure of a diagrid structures with 3.6m floor to floor height has been analyzed by Finite Element Method using Etabs software in zone (III). The plan selected is Rectangular in shape. It is not the plan of any existing or proposed building but is an architectural plan. The structure has been analysed for both static and dynamic wind and earthquake forces. Diagrid column has been provided throughout height of the structure. hard soil condition has been selected for the structure.

In this project, a 41-storey structure of a commercial building with 3.6m floor to floor height has been analyzed by Finite Element Method using ETABS software in zone (III). The plan selected is Square in shape. It is not the plan of any existing or proposed building but is an architectural plan. The structure has been analysed for both static and dynamic wind and earthquake forces. Diagrid column has been provided throughout height of the structure. hard soil condition has been selected for the structure.

**3.2 Model Description:**

**A. Preliminary data required for Rectangular Geometry Analysis**

Eight models are prepared in this study for the analysis and study. The constant parameters in all

the eight models are as below:

**Table 3.1.** Parameters to be consider for rectangular geometry analysis

| Sr. No. | Parameter | Values |
|---|---|---|
| 1. | Number of storey | G+41 |
| 2. | Floor height | 3.6 m |
| 3. | Infill wall | 150 mm thick |
| 4. | Materials | Concrete 50 and Reinforcement Fe 500 |
| 5. | Frame size | 36m X45m building size |
| 6. | Grid spacing | 3m grids in X-direction and 3m grids in Y-direction. |
| 7. | Size of column | 1000 mm x 1000 mm |
| 8. | Size of beam | 500mm x 600 mm |
| 9. | Depth of slab | 225 mm |
| 10. | Plan area | 1620 $^2$ |

### B.Load Details

**Table 3.2.** Load details for rectangular geometry analysis

| | | |
|---|---|---|
| a. | Dead load | In ETABS the software itself calculates the dead loads by applying a self-weight multiplier factor of one which is taken by the structure and the rest load cases are kept zero. Its defined in the load cases section. |
| b. | Live load on floors | 4 kN/m$^2$ as per IS:875 (part -2) |
| c. | Floor finish on roof and floors | 1.5 kN/m$^2$ as per IS:875 (part -2) |
| d. | Wall load on all levels | 9 kN/m |

### C. Seismic data required for analysis

**Table 3.3** Seismic data required for rectangular geometry analysis

| Sr. No. | Parameter | Values as per IS 1893:2016 (Part1) | Reference |
|---|---|---|---|
| 1. | Type of structure | Special RC moment resisting frame | Table 9, Clause 7.2.6 |
| 2. | Seismic zone | III | Table 3, Clause 6.4.2 |
| 3. | Zone factor (Z) | 0.16 | Table 2, Clause 6.4.2 |
| 4. | Type of soil | Rock or Hard Soil | Clause 6.4.2.1 |
| 5. | Damping | 5 % | Clause 7.2.4 |
| 6. | Response spectra | As per IS 1893 (part 1):2016 | Figure 2, Clause 6.4.6 |
| 7. | Load combinations | 1) 1.5(DL + IL)<br>2) 1.2(DL+IL+EL)<br>3) 1.5(DL + EL)<br>4) 0.9DL + 1.5 EL | Clause 6.3.1 |
| 8. | Response reduction factor (R) | 5 | Table 9, Clause 7.2.6 |
| 9. | Importance factor (I) | 1.5 (Hospital, Schools Buildings) | Table 8, Clause 7.2.3 |

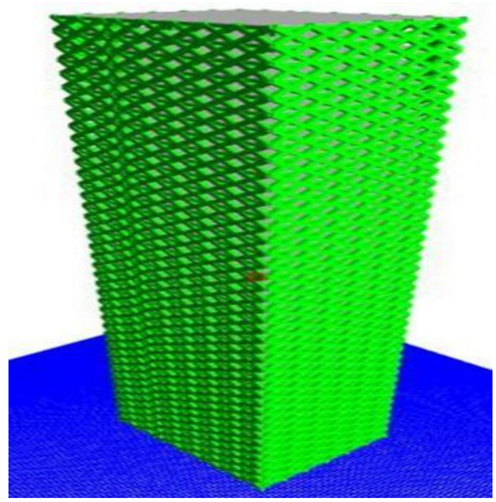

Fig. 1: 3D View of Square Geometry Analysis

## IV. CONCLUTION

The following conclusions have been drawn based on the results obtained from present study:

- Diagrid structures can be made effective by providing additional columns near periphery of the structures.
- 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.
- The dead load and beam load increases with height of structure.
- Diagrid performs better across all the criterions of performance evaluation, such as, efficiency, expressiveness and sustainability.
- Diagrid structure gives more aesthetic look and gives more of interior space. Due to less number of columns, façade of the building can also be planned more efficiently.
- Floor loads are more critical for tall structures but it is higher in conventional building structure than diagrid structure.
- Buildings should be designed for loads optimized in both directions separately for deflection and stresses in buildings.
- Time period for G+41 Storey of Rectangular geometry analysis are less as compared to and square geometry analysis frames.
- Earthquake load case of Storey shear of plinth level for G+41 Storey. of Rectangular geometry analysis are less as compared to and square geometry analysis frames.
- Earthquake load case of Base shear in kN for G+41 Storey in X-direction of Rectangular geometry analysis

are more as compared to and square geometry analysis frames.

- Earthquake load case of Base moments of plinth level for G+41 Storey of Rectangular geometry analysis are more as compared to and square geometry analysis frames.
- Earthquake and Wind load case of Maximum storey drift in mm for G+41 Storey of Rectangular geometry analysis are less as compared to and square geometry analysis frames.

## V. SCOPE AND LIMITATIONS

1) The first being the requirement of quality workmanship as the structure involves complex construction techniques.
2) 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
3) Construction crews have little or no experience creating a Diagrid skyscraper.
4) it is hard to design windows that create a regular language from floor to floor.
5) The Diagrid is heavy-handed if not executed properly. Can be brash, garish.
6) The only RC framed buildings are considered for the analysis.
7) The contribution of infill walls is considered as non-integral with RC frames.
8) The out of plane action of masonry walls are neglected in the analysis
9) The effect of the supporting foundation medium on the motion of structure gives soil structure interaction but this effect may not consider in the seismic analysis for structures supported on rock or rock like materials.
10) The Flexibility of floor diaphragms are neglected and considered as rigid diaphragm.
11) The base of the column is assumed to be fixed in the analysis.
12) Secondary effect P- shrinkage and creep are not considered.
13) The contribution of infill wall to the stiffness was not considered. Loading due to infill wall was taken into account.

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