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# SEISMIC EVALUATION OF BRACED AND DIAGRID STRUCTURES

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**ABSTRACT**

**Now a days Day by day the construction of tall building increases, hence for tall buildings safe analysis and construction should be carried out, and as the height of the structures increases, the Lateral load resistance system becomes very important as the structural resistance system that withstands gravity loads. The widely used internal lateral load resisting structural systems include rigid frame, braced frame, shear wall and outrigger structure whereas the exterior systems constitute tubular, diagrid, pentagrid, hexagrid and octagrid structures. The Diagrid structure is more economical and suitable for high-rise buildings compared to conventional buildings. A constructed system called the Braced Frame was created to withstand the effects of wind and earthquake forces. It is forbidden for members of a braced frame to swing laterally. In This papers the work is done to know the behavior of seismic forces on bare frame, braced frame and diagrid with varying different angles with symmetric plan of 24x24m. An G+15 storey is investigated in which 6 models are prepared out of which one is bare frame, one is braced frame and rest of 4 models are diagrid angles. The equivalent static and time history analysis method are carried out in terms of displacement, storey drift ratio, base shear and time period using ETABS 2020 software. Then comparative study is carried in between bare frame, braced frame and diagrid structure with different angle variations and results are presented. After observation it was found that the diagrid models performing better resistance against the seismic force in terms of all parameters compare to bare and braced frame structure.**

**Keywords: Bare Frame, Braced Frame, Diagrid Structural System, Equivalent Static Method, Time History Method, Displacement, Base Shear, Drift Ratio, Time Period, ETABS**

## I. INTRODUCTION

Day by day the construction of tall building increases, hence for tall buildings safe analysis and construction should be carried out, and as the height of the structures increases, the Lateral load resistance system becomes very important as the structural resistance system that withstands gravity loads. The widely used internal lateral load resisting structural systems include rigid frame, braced frame, shear wall and outrigger structure whereas the exterior systems constitute tubular, diagrid, pentagrid, hexagrid and octagrid structures. The Diagrid structure is more economical and suitable for high-rise buildings compared to conventional buildings. A constructed system called the Braced Frame was created to withstand the effects of wind and earthquake forces. It is forbidden for members of a braced frame to swing laterally.

### 1.1 DIAGRID STRUCTURE



**Figure 1 - Example of Diagrid Structural System**

The term “diagrid” could be a combination of 2 words that's diagonal and grid. The diagrid structural system can be defined as a diagonal members formed as a framework made by the intersection of different materials like metals, concrete or wooden beams which is used in the construction of buildings and roofs. The triangulation members like steel tube round, pipe , precast pipes ,and inclined concrete columns are used which connected diagonally to one another forming a complete net which spread the lateral loads equally to the foundation of tall building. The diagrid building helps in elimination of the vertical column around the periphery of the structure as the major part of lateral loads as taken by externally provided diagonal member. Diagrid structure consist of inclined columns on exterior surface of the building. Due to this inclined columns the lateral load are resisted by the axile action of the diagonal member. Vertical columns in the core are designed for carrying gravity load only The diagrid structure is use full for both gravity and lateral loads. This intern make the diagrid structure most efficient than conventional structure. The steel use in diagrid structure is 20% less compare to steel use in conventional structure.

### 1.2 BRACED STRUCTURE

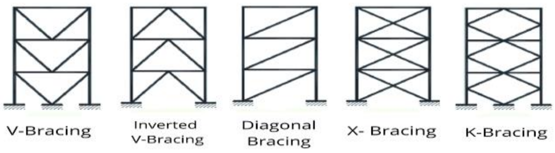



**Figure 2 - Types of Bracing Structural System**

Structures subject to lateral loads, such as wind and seismic pressure, frequently employ the very robust braced frame structural system. A braced frame's members are often constructed of structural steel, which functions well in both tension and compression. The bracing system supports the lateral loads, while the beams and columns that make up the frame carry the vertical loads. However, the placement of bracing can be challenging because they can obstruct opening placement and façade design. This has led to the bracing being expressed as an interior or external architectural component in high-tech or post-modernist architecturally inspired structures. Bracing system plays a important role in structural behavior during earthquake. Steel bracing frame work, improves the strength, stability, ductility and stiffness of the RC building frame and reduces the deformation.

### 1.3 SEISMIC EVALUATION

Seismic analysis is a branch of structural analysis that calculates the response of a building (or other structure) to earthquakes. It is a step in the structural design, earthquake engineering, or structural assessment and retrofit process in earthquake-prone areas (see structural engineering). It is a crucial tool for earthquake-prone regions like Japan, the Philippines, Nepal, the North-East of India, and many more. This kind of analysis is crucial for designing RCC building components such beams, columns, and slabs that adhere to IS 13920:2016. The dynamic nature of seismic forces allows them to be tested for mass, stiffness, wetness, ductility, and load carrying capacity. For seismic analysis of multi-story buildings, IS 1893:2016 is employed.

### 1.4 TIME HISTORY METHOD

Time history is a more detailed analysis involving the time instant. In time history analyses the structural response is computed at a number of subsequent time instants. In other words, time histories of the structural response to a given input are obtained ad a result

## II. LITERATURE REVIEW

**Abhijeet Baikerikar, Prof Kanchan Kanagali (2014).[1]:** They studied on “seismic analysis of Reinforced Concrete frame with steel bracing” In this study G+9 storey is investigated and compared under various circumstances. They considered 3 models of, bare frame, bracing in middle, bracing in corner, have used the square grid of plan 20m in each direction and the seismic analysis response spectrum as per IS: 1893 (Part 1):2002. is carried out using etabs software. The response parameters of these models are examined in relation to lateral displacements, lateral drifts, time period, base shear and lateral load resistance. After analysis it is observed that the bare frame produces large displacements and drifts compared to other 2 cases, overall bracing in middle performs the maximum least drifts and displacements compared to both bare frame and bracing in corner.

**Mohammed Ibrahim, Veena Narayankar (2016).[2]:** They have studied on “Comparative study of performance of conventional RC framed structures and Diagrid structures subjected to ground motions”. a 31-

story conventional building and three other buildings with inclines of 36.86°, 56.30° and 66.03° were modelled according to the specifications of IS 1893 (Part 1): 2002 provision and analyzed using nonlinear static analysis in ETABS 2015. The response parameters of conventional buildings & diagonal buildings are examined in relation to ground displacement, ground drift, membrane drift, spectral acceleration, spectral shift and base shear, whereby after analyzing the result it is found that the values of all above parameters are at least at a diagonal angle of 66.03° was found, so this angle is considered to be the optimum screen angle at which the Building performed its best.

**Trupti A. Kinjawadekar, Amit C. Kinjawadekar (2018).[3]:** This article presents a "Comparative Study of Seismic Characteristics of Diagrid Structural System in High Rise Construction". In this study different heights models are considered 18-storey and 36-storey with different angles respectively and analysis is done as two-dimensional plane frames as dynamic analysis using software SAP-2016.The response parameters of all models are examined in relation to storey displacements, storey drifts, time period, base shear and stiffness. Results primarily based totally on numerical fashions display that those systems can meet maximum present day layout requirements. whereby it is found that the values of all above parameters are at least with diagrid angle range of (45° to 64° ) in both 18 and 36 storey structures. The optimum angle is observed as 64°.The numerical fashions and seismic residences of the Diagrid contributors had been tested.

**Sawan Rathore, Prof. Sumit Pahwa (2019).[4]**: This articles presents the "Dynamic Analysis of diagrid structural system for RC Building Structure". In this study G+12 and G+18 Storey building structure are investigated at different angle of diagonals such as diagrid at 2 story (at angle 38.6°), diagrid at 3 story (at angle 50.2°) and diagrid at 4 story (at angle 58°) were modelled. The static and Dynamic responses are done by using Etabs software. The study parameters in terms of storey displacement, base shear, story drift and time period. After the Study It was found that the diagrid Structural system is producing least displacement, drift, and story Shear compared to the bare frame Structure. In both static and dynamic analysis methods the 3 story diagrid (50.2°) angle models is giving best results compare to other cases.

**Mr. Abhishek Admane prof. Sharif H. Shaikh (2021).[5]:** They study is carried on "Comparative Study of diagrid structure with conventional building having different heights". An G+7 G+11 and G+16 Story building with different heights is investigated. The total 6 models were prepared for every height one normal frame building and diagrid buildings with same angle for all diagrid models as 67.40° is considered. All these models have been analysed by linear static and non-linear static analysis using Etabs software. The results are to be discussed interms of study parameters such as drift, time period, base shear and displacement. After the study they made the Conclusion that diagrid is performing the least in difts, time period, displacement when compared with the Conventional building. The diagrid structure is more efficient in resisting greater capacity forces against seismic forces compare to normal structure and more economical upto G+11 story.

**OVERALL OUTCOMES OF THE LITERATURE**

- From the above observation diagrid scores better performance compared to conventional building in all criteria, such as efficiency, expressiveness, stiffness, aesthetic looks and durability.
- Based on above study bracing structural system performs better results compared to conventional building.
- Among the types of bracings the X-bracing system shows more promising results it reduces displacements and storey drift more than any of bracing system.
- In literatures comparative study on braced and diagrid structures are limited.
- Given that all of the diagrid constructions' peripheral vertical columns have been removed, the diagrid elements effectively support lateral loads.

## III. OBJECTIVES OF STUDY

- To analyse a (G+15) storey diagrid structure for seismic forces by equivalent static and time history analysis.
- To analyse a (G+15) storey braced structure for seismic forces by equivalent static and time history analysis.
- Comparison of seismic performance for both diagrid and braced structure
- To study behavior of building and compare the results with respect to base shear, displacement, story drift and time period and to check which structural system is efficient.

## IV. METHODOLOGY

This particular study begins with the development of 3D model of reinforced concrete building structure. The analysis and design of the building is taken with considering DL, LL, &EL for the proposed structure. All the loads will be taken from IS codes and the design and analysis for the models is carried out using Etab software. The square shape of a high-rise building for the diagrid and braced system is compared with the Etabs software.

- In this thesis the work is done to know the behavior of seismic forces on bare frame, building with bracing and building with different angle of diagrid. An G+15 story building is selected for the seismic analysis with the Etabs software.
- Total 6 models are prepared, out of which one is bare frame and one is brace frame and others are 4 different models with different angle of diagrid.
- The loading is applied as per Indian Standard codes.
- Equivalent static and time history method is performed using by Etabs software.
- The results obtained in terms of displacement, storey drift time period and base shear is discussed.

## V. MODEL DESCRIPTION

In this project total six models are prepared.

**Model-01**: Regular G+15 storey conventional Reinforced Concrete frame building (i.e bare frame).

**Model-02**: Regular G+15 storey conventional Reinforced Concrete frame building with bracing.

**Model-03**: G+15 story Reinforced Concrete frame building with no column at periphery taking diagrid section as concrete section with a diagrid angle of $46.84^0$.

**Model-04**: G+15 story Reinforced Concrete frame building with no column at periphery taking diagrid section as concrete section with a diagrid angle of $57.99^0$.

**Model-05**: G+15 story Reinforced Concrete frame building with no column at periphery taking diagrid section as concrete section with a diagrid angle of $64.88^0$.

**Model-06**: G+15 story Reinforced Concrete frame building with no column at periphery taking diagrid section as concrete section with a diagrid angle of $69.44^0$.

**Table 1: GEOMETRIC DETAILS OF THE STRUCTURE**

| Sl.No | Description | Values |
|---|---|---|
| 01 | Plan Dimension | 24mx24m |
| 02 | Total Storey Number | 16 |
| 03 | Each storey ht | 3.2m |
| 04 | End Footing condition | Fixed support |
| 05 | Condition of the diagrid connecting node's support | pinned |
| 06 | Successive distance between two column | 6m |
| 07 | Panel size | 6mx6m |
| 08 | RCC Column Size | 675x675mm<br>500x500mm |
| 09 | RCC Beam size | 300x550mm |
| 10 | Slab thickness | 150mm |
| 11 | Concrete grade used | M40 |
| 12 | Rebar grade used | Fe500 |
| 14 | Diagrid member | 450x600mm |
| 15 | Diagrid angle considered | $46.84^0$,$57.99^0$, $64.88^0$ and $69.44^0$ |
| 16 | Bracing member (x-type) (from steel table) | ISHB 450 2 |

**Table 2: DETAILS OF LOAD APPLIED AND SESIMIC PARAMETERS**

| Sl.No | Description | Values |
|---|---|---|
| 01 | DL (dead load) | Self weight of structure |
| 02 | Live Load | 3.5kN/m$^2$From (IS 875 PART-2) |
| 03 | Wall Load | 12kN/m (230mm thick wall) |
| 04 | Floor finish | 1.0kN/m$^2$ |
| 05 | Structure type | SMRF |
| 06 | Earth quake zone | V as per (IS 1893 PART-1 2016) |
| 07 | Zone factor | 0.36 |
| 08 | Type of soil | Medium (type 2) |
| 09 | Response Reduction factor | 5 |
| 10 | Importance factor | 1.2 |
| 11 | Load combination | (As per IS 1893 part-1 2016) |
| 12 | Earthquake data for Time History Analysis | BHUJ Earthquake record data |

## MODELING AND ANALYSIS

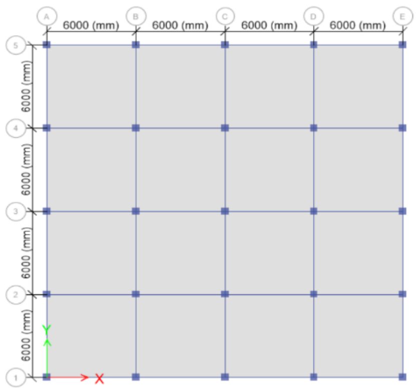



**Figure 3 – Plan for Bare Frame and Braced Frame Building**

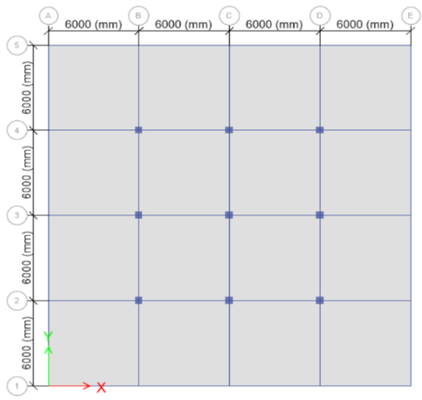



**Figure 4 – Plan for Diagrid Structural Building**

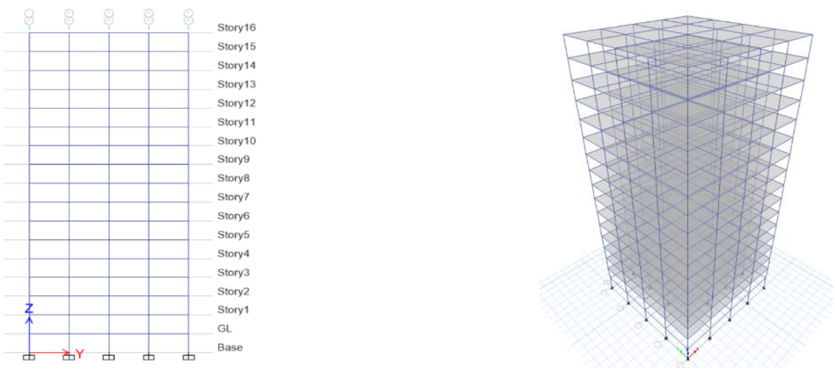



**Figure 5 – Elevation and 3D View of Bare Frame Structure Model 1**

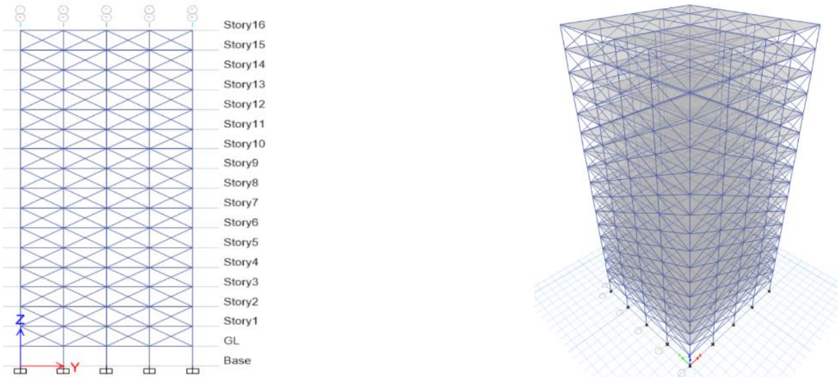



**Figure 6 – Elevation and 3D View of Braced Frame building Model 2**

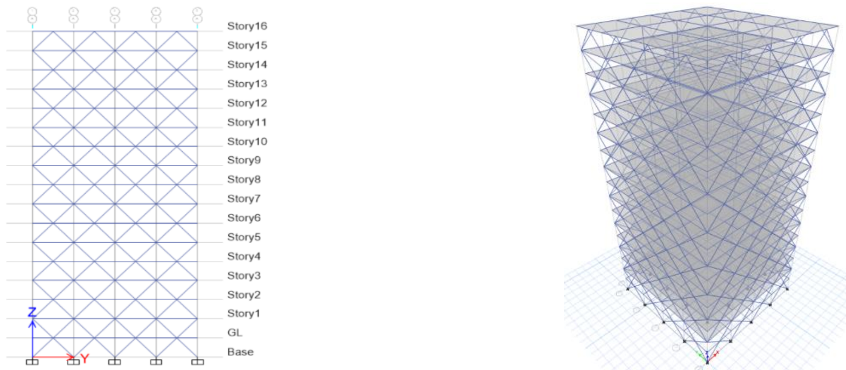



**Figure 7 – Elevation and 3D View of Diagrid Frame Structure Model 3 with angle as 46.84$^0$.**

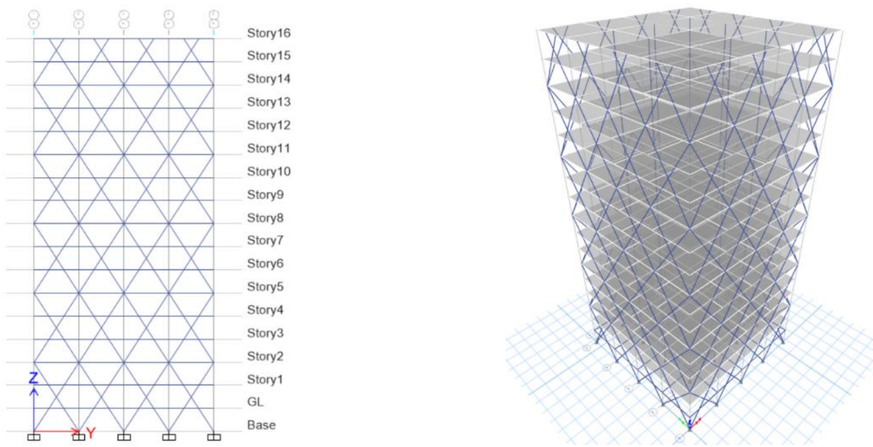



**Figure 8 – Elevation and 3D View of Diagrid Frame Structure Model 4 with angle as 57.99$^0$.**

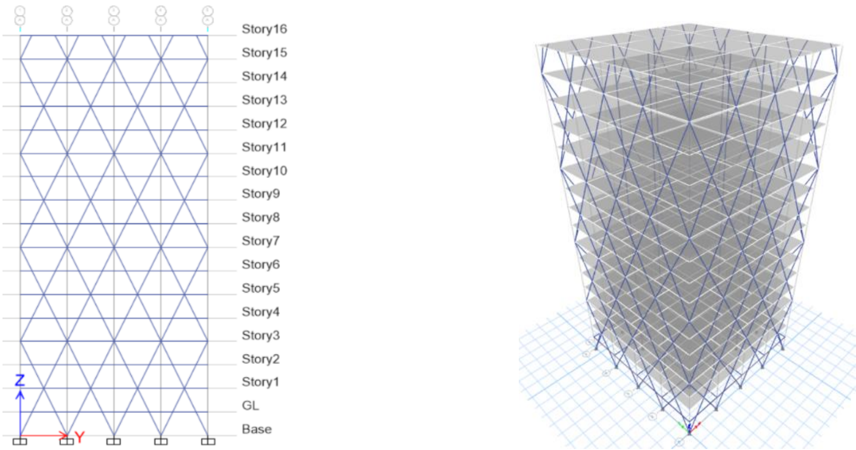



**Figure 9 – Elevation and 3D View of Diagrid Frame Structure Model 5 with angle as 64.88$^0$.**

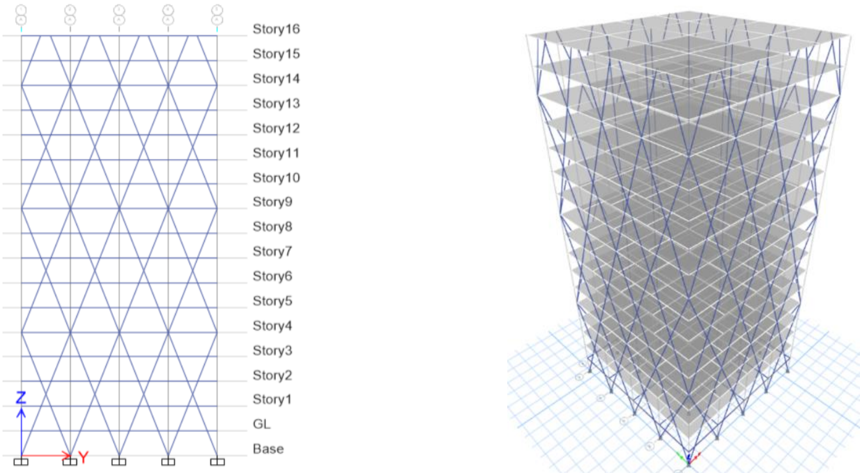


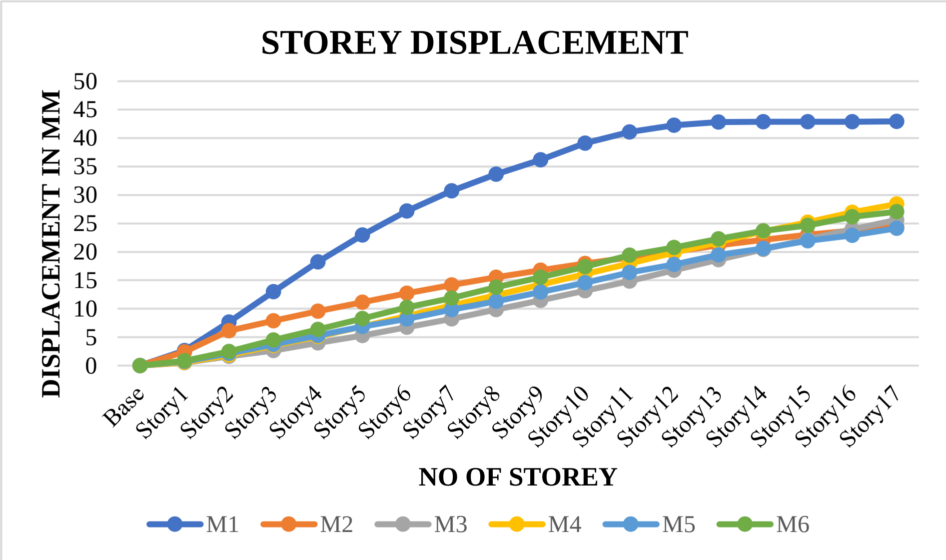

**Figure 10 – Elevation and 3D View of Diagrid Frame Structure Model 6 with angle as 69.44$^0$.**

## VI. RESULTS AND DISCUSSION

For the evaluation of all six models seismic load that is equivalent static method and time history method is applied. The analysis of the all the distinct building fashions is finished via the usage of ETABs 2020 software program. The evaluation effects along with displacements, storey drifts, time period and base shear of all constructing models are presented and compared.

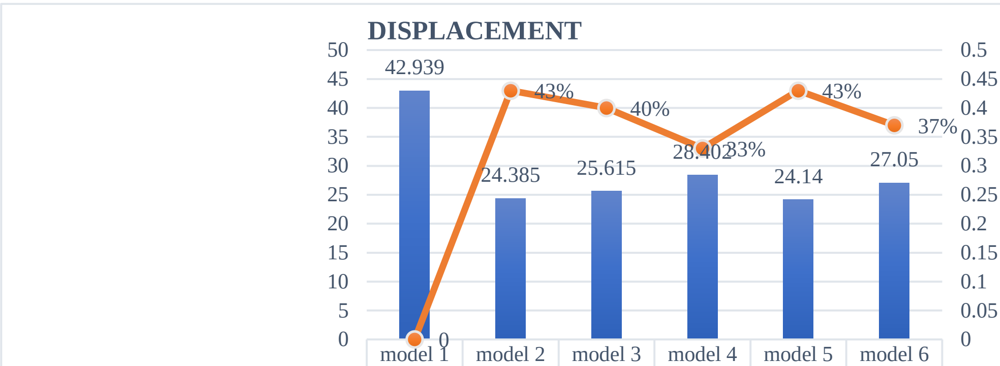
### STORY DISPLACEMENT

Story displacement is described as the movement of a floor relative to a structure's foundation, which is often the building's ground. According to clause 5.6.l of IS 800-2007, the maximum deflection is H/500, where H is the height of the building. Deflection that is permitted is 54.4/500 = 0.108m = 108mm.




**Graph 1: Displacement in mm due to time history analysis for all models along x & y-direction**

**STOREY WISE MAX DISPLACEMENT FOR ALL MODEL**

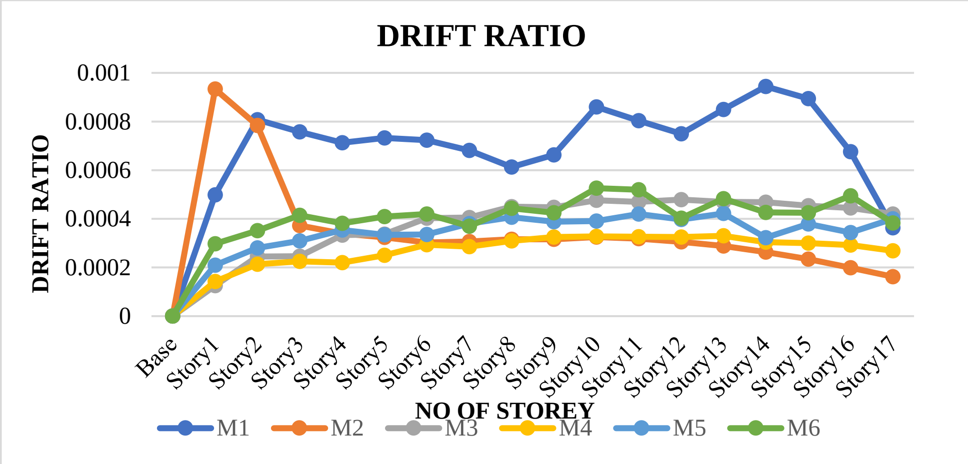



| | model 1 | model 2 | model 3 | model 4 | model 5 | model 6 |
|---|---|---|---|---|---|---|
| MAX DISPLACEMENT IN MM | 42.939 | 24.385 | 25.615 | 28.402 | 24.14 | 27.05 |
| REDUCATION COMPARED TO MODEL 1 | 0 | 43% | 40% | 33% | 43% | 37% |

According to the graph, model M1 has the most displacement compared to any model. The bracing system was used for the RC frame building in model M2, which resulted in a displacement reduction of 43.21% as compared to M1. The displacement in the model M5 is reduced by 43.78% in comparison to the M1 due to the existence of a diagrid frame structure and is almost the same for the M2 bracing system.

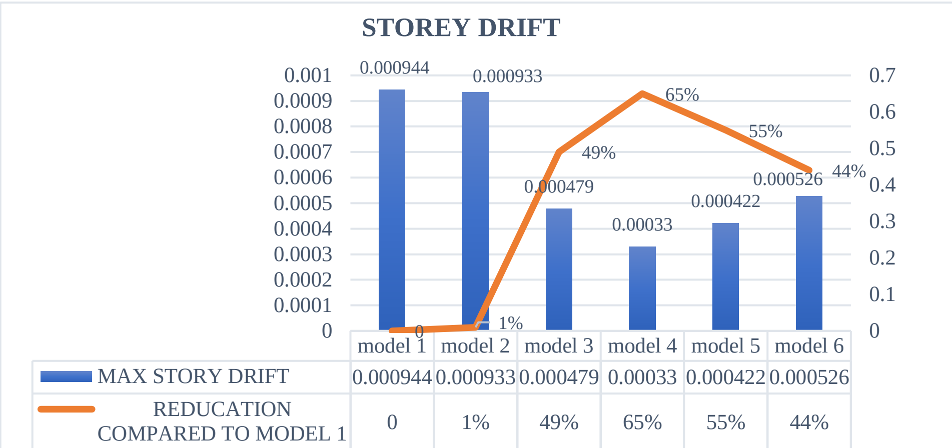
**STORY DRIFT**

Because of the quantitative relationship between the movement of two succeeding floors and the height of that floor, it is outlined. Using time history analysis, the drift ratios for bare frame, braced frame, and diagrid structures are displayed below. According to I.S. 1983:2016, the drift values cannot be higher than 0.004 times storey height.




**Graph 2: Storey drift due to time history analysis for all models along X & Y-Dir.**

**STOREY WISE MAXIMUM STORY DRIFT FOR ALL MODEL**

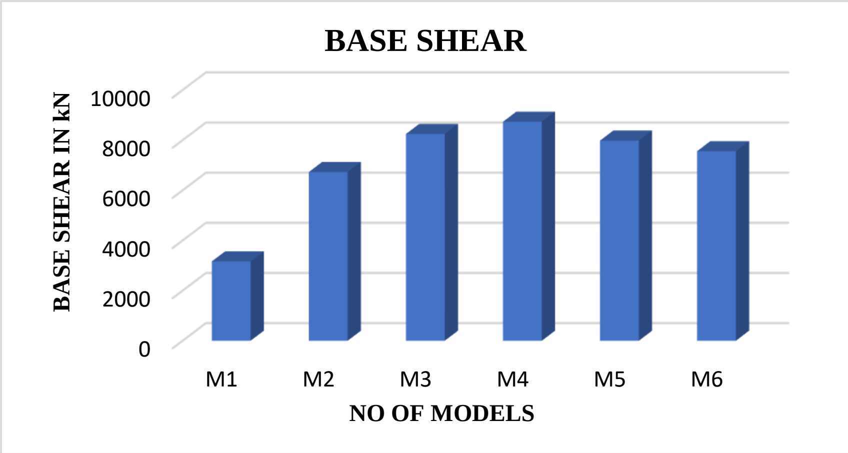



Model M1 has the highest amount of drift among all the models. As the diagrid system and bracing were installed for models M2 & M3, M4, M5, and M6, As a result, drift values continue to decline. Among the diagrid structural systems, the model M4 exhibits the lowest drift ratio values due to presence of the diagonal elements along the structure's perimeter, which boosts the structure's strength, durability, and stiffness. We learned from the aforementioned finding that, when compared to other models, the diagrid system M4 exhibits the least results against drift. In Above all model anaylsis model 4 gives more stability and less drift for the seismic analysis.

**BASE SHEAR**

**Table 3** - Comparison of Base shear in kN for different models using Time History Analysis.

| BASE SHEAR | |
|---|---|
| MODEL NO | Base Shear in kN |
| model 1 | 3164 |
| model 2 | 6728 |
| model 3 | 8246 |
| model 4 | 8734 |
| model 5 | 7980 |
| model 6 | 7558 |



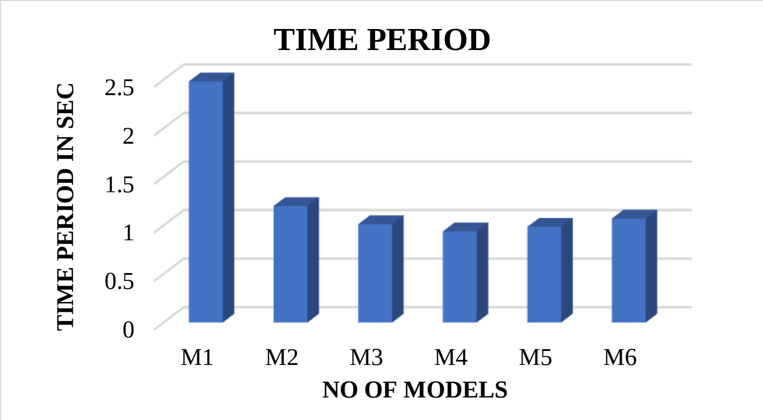

**Graph 3: Base shear in kN for all models in the x and y directions by time history analysis.**

It has been seen from the aforementioned graphical representation that model M1 has the lowest base shear when compared to all other models. As the bracing system is added to model M2, the seismic weight of the building increases. As a result, base shear increases by 53% when compared to model M1's bare frame. When compared to bare and braced frame structures, the base shear of model M3, M4, M5, and M6 is increased because diagonal members are present around the structure's perimeter. Among these diagrid models M6 has the less base shear because the base shear is goes on reducing as the angle of inclination of diagonal member is increased. The base shear in model M4 is higher in comparison to bracing model M2 and higher in comparison to the bare frame model, increasing by 22.96% and 63.79%, respectively.

**TIME PERIOD**

**Table 4 - Comparison of Time Period in Sec for different models using Time History Analysis**.

| TIME PERIOD | |
|---|---|
| **Model No** | **Time Period in Sec** |
| model 1 | 2.484 |
| model 2 | 1.20 |
| model 3 | 1.013 |
| model 4 | 0.939 |
| model 5 | 0.986 |
| model 6 | 1.071 |




**Graph 4: Time period in Sec of all models due to Time History Analysis.**

From the chart it is observed that the time period for model M1 is highest and M4 is least compare to the all models. The time period for model M2 is 51.69% decreases compare to model M1. It is because the bracing system plays a important role in structural behavior during earthquake which improves the stiffness and strength of Reinforced Concrete frame building and also reduces deformation. From the diagrid structural models the M4 is performing the least time period as base shear is high for this model hence stiffness increases it may leads to reduces fundamental time period. From the above observation we can say that the time period for M4 has been decreased by 62.19% when compare to M1 bare frame model and also decreased by 21.75% when it is compared with the M2 bracing system.

## VII. CONCLUSION

- This analytical study concludes that the diagrid structural system has greater capacity resisting seismic forces compare to bare frame and bracing structural system.
- Among all the diagrid structural system models, model 6 having angle as 69.44° is showing the less base shear compare tp other diagrid models.
- From this study the diagrid model 5 of angle $64.88^0$ and model 4 of angle $57.99^0$ is best suitable for particular displacement and story drift ratio case.

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