# Study on Torsional Irregularity in Irregular Structures and Seismic Assessment using Push Over Analysis

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**Abstract -** *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 accounts for interior system, where lateral load is resisted by centrally located elements. Recently diagrid structures which is an exterior 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. Analysis and design of 36 storey diagrid steel building is presented. A regular floor plan of 36 m × 36 m size is considered. ETABS 2017 is used for modeling and analysis of structural members. All structural members are designed as per IS: 800:2007,IS: 1893-2002 for earhquake loads and IS: 875-1987 for wind loads considering all load combinations. Dynamic along wind and across wind are considered for analysis of the structure. Load distribution in diagrid system ,comparison of analysis results in terms of time period, top storey displacement ,base shear and inter- storey drift is presented in this paper.*

***Key Words***: Diagrid Building; Lateral Load Resistance; Tall Building

## 1. INTRODUCTION

The diagrid structural system can be defined as 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. Diagrid structures of the steel members are efficient in providing solution both in terms of strength and stiffness. But nowadays a widespread application of diagrid is used in the large span and high rise buildings, particularly when they are complex geometries and curved shapes.[4]

The difference between conventional exterior-braced frame structures and current diagrid structures is that, for diagrid structures, almost all the conventional vertical columns are eliminated. This is possible because the diagonal members in diagrid structural systems can carry gravity loads as well as lateral forces due to their triangulated configuration in a distributive and uniform manner. For instance, structural performance of braced tubes and diagrid structures are very similar in a sense that both systems carry lateral loads very efficiently with their structural members axial actions. While bending rigidity in braced tubes is provided primarily by vertical perimeter columns, bending rigidity in diagrids is provided by diagonals which also provide shear rigidity because the system is typically composed of only diagonals.

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. 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. Diagrid structures are more effective in minimizing shear deformation because they carry lateral shear by axial action of diagonal members[3].

Modifying the structural pattern of a vertical building to optimize its structural efficiency has several benefit. Variation of structural pattern on the perimeter of vertical buildings has given certain aesthetics towards a ubiquitous and monotone prismatic form, especially considering that limitation of site and functional consideration usually does not allow much modification of the vertical building's form.[2] This paper examines the influence of changing the structural pattern's granularity towards the efficiency of the structure.Today's building technology prefer tubular concept for high rise buildings. But diagrid is also an important lateral load resistance system, which can be used for complex geometries of building. Hence, in this study the diagrid building are compared with different geometric patterns in order to reveal the structural advantages of diagrid building. For the comparison six models of diagrid buildings are generated in ETABS2017 software. The number of stories is taken as the criteria for the selection of models. 36storey model is used for the study.[3]

## 2. RELATED WORKS

### Optimum Angle of Diagrid Structural System

This paper involves the modeling of diagrid structures of 36 storey. 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 and to investigate the structural potential of diagrids with changing angles. In this paper, the comparison study of various geometric patterns of diagrid structural system with a diagrid angle 60.56°, 74.28° and 78.13° is presented[4].The comparison of analysis of results in terms of top storey displacement, storey drift, time period,storey shear, angle of diagrid are included in this paper. From the study it was observed that the Diagrid angle in the region of 60° to 74° provides more stiffness to the diagrid structural system which reflects the less top storey displacement, storey drift, time period and storey shear.

### Analysis and Design of Diagrid Structural System for High Rise Steel Buildings

The analysis and design of 36 storey diagrid steel building is presented in this paper. A regular floor plan of 36 m × 36 m size is considered for the study. The modeling and analysis of structural members have been done in ETABS software. 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. The analysis results are compared in terms of time period, top storey displacement and inter-storey drift. 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. So, internal columns need to be designed for vertical load only. Lateral and gravity load are resisted by axial force in diagonal members on periphery of structure, which make system more effective.[3]

## 3. MODELLING AND ANALYSIS

Building models of plan 36 m x 36 m are generated in ETABS2017. The storey height is 3.6 m. Four interior columns are used for carrying a part of gravity load. In the present study models of varying diagrid buildings are modelled. The models of varying geometric patterns in degrees ie, 60.56°, 74.28°, 78.13° are generated in ETABS 2017, which are represented by D1, D2, D3, D4, D5, D6.

**Table -1:** Geometric Patterns In Degrees

| S.No | Model Type | Number Of Story | Angle In Degrees |
|---|---|---|---|
| 1 | D1 | 36 | 60.5° |
| 2 | D2 | 36 | 74.2° |
| 3 | D3 | 36 | 78.1° |
| 4 | D4 | 1-12 | 78.1° |
| | | 13-24 | 74.2° |
| | | 25-36 | 60.5° |
| 5 | D5 | 36 | 60.5° |
| 6 | D6 | 36 | 60.5° |

The end conditions for diagonals are assumed as pinned and the support conditions as fixed. 36-storey diagrid module is used for modelling.[3]

In building models columns are placed at closer spacing of 3 m on outer periphery of the building. In order to model these buildings, the member sections are kept same as that of diagrid building for the purpose of comparison . Then the analytical results of all types of buildings are compared in terms of storey displacement, storey drift, time period and storey shear.

The characteristic strength of concrete and steel are taken as $25N/mm^2$ and $415N/mm^2$ respectively. The design of building models have been done based on Indian Standards. The design dead load and live load are taken from IS: 875 (Part 1) – 1987 [7] and IS: 875 (Part 2) – 1987 [8] respectively. The live load assigned on roof level is $1.5KN/m^2$ and that on typical floor level is $2.5KN/m^2$ [8].The earthquake loads are taken from IS:1893-2002.The earthquake design is based on zone III. Zone factor of 0.16, Importance factor of 1, Soil type II and response reduction factor 5 are adopted as per IS 1893 (Part 1): 2002[5].The dynamic along wind loading is computed based on the Wind speed 30 m/s, Terrain category 3, Structure class B, Risk Coefficient 1 and Topography factor 1 as per IS: 875 (Part 3) – 1987 . The models are generated in ETABS 2017 software and linear static analysis have been done.

The structural plan used for the present study is given in the Fig.1. The member sections used for diagrid building models are given in Table I.

Initially, preliminary member sections are assumed and modelling and analysis have been done by using ETABS 2017 software. The member sections are revised for failed members.

The Table 1 represents the revised member sections for diagrid models presented in this study. The models D1-D6 are used for the study are shown in Fig.3.

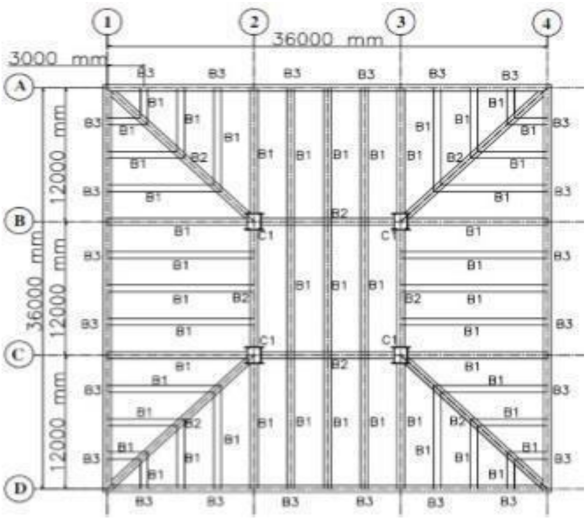


**Fig -1**: Structural Plan

### Internal Column Details:

The gravity load and lateral load due to wind are combined and assigned to structure in ETABS software. From the analysis results design of diagonal members, floor beams and interior columns is carried out as per IS:800-2007. The yield strength of steel is considered as 250 N/mm$^2$. The details of internal column resisting mainly gravity loads is shown in Fig.3 and all dimensions are in mm.

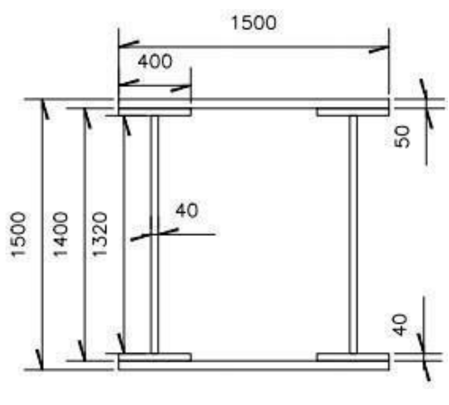


**Fig -2**: Interior Column Details

### Section properties:

The interior column details are provided as a core column and diagonal columns of different sections as provided in exterior and beams are provided with the bottom cover plate.the sizes of typical memers of 36 storey diagrid structure are mentioned below.

**Table -2:** Member Sections For Diagrid Models

| Storey | Diagonal Columns | Interior Columns | Beams |
|---|---|---|---|
| 36 storey | 375 mm Pipe sections with 12 mm thickness (from 19th to 36th storey) | 1500 mm × 1500 mm | B1,B3=ISMB500<br>B2=ISWB600 with top and bottom cover plate of 220 × 50 mm |

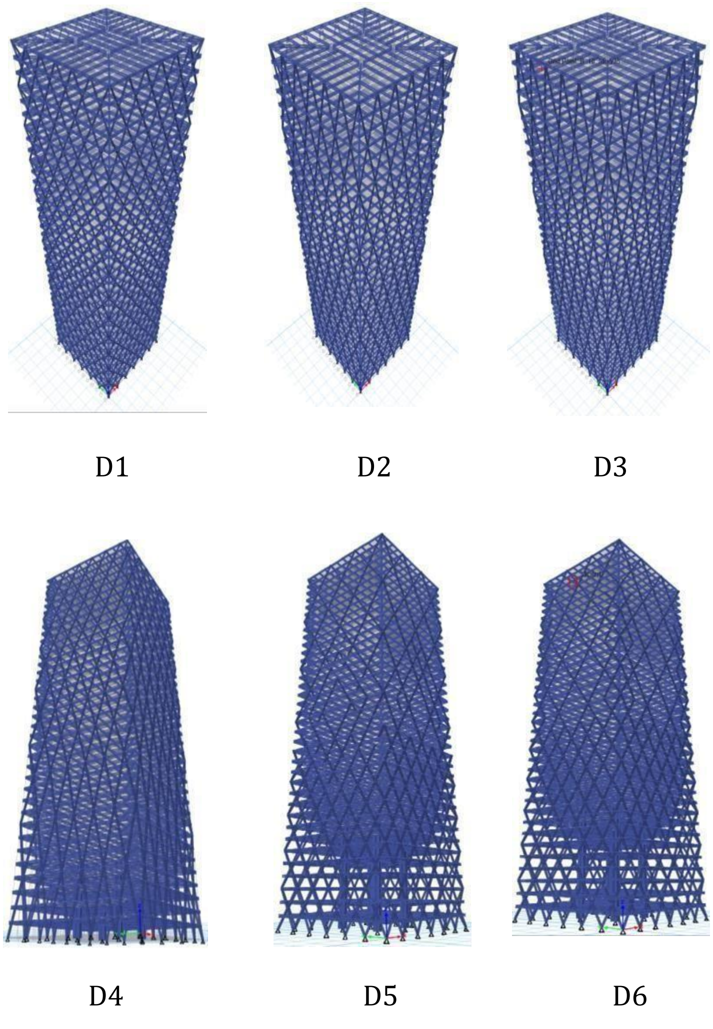


**Fig -3**: View For Diagrid Models

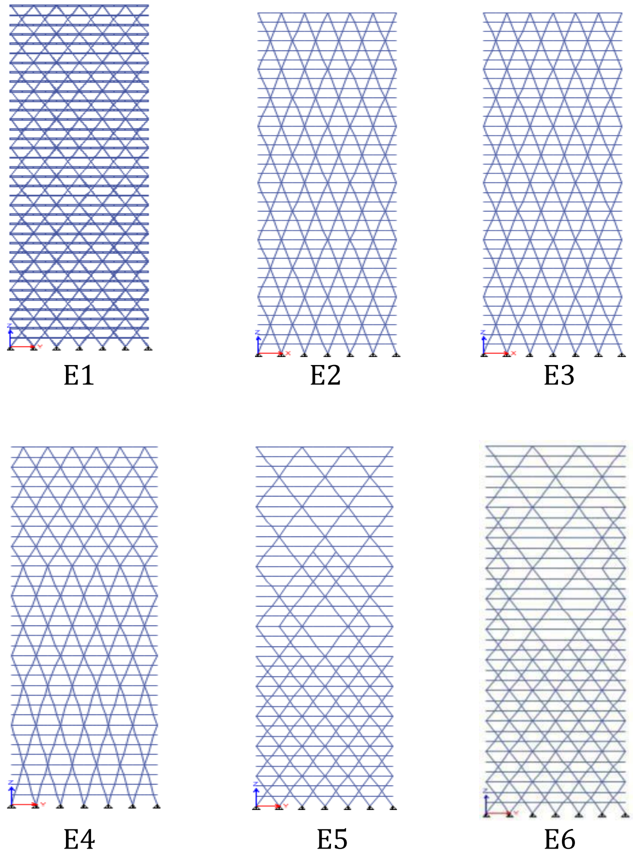


**Fig -4**: Different Geometric Patterns For Diagrid Models

Where E1, E2, E3, E4, E5, E6 are different elevational views for Diagrid models D1,D2, D3, D4, D5 and D6.

## 4. ANALYSIS RESULTS OF 36 STOREY BUILDING

### 4.1.Time Period

The time period of 36 storey diagrid structure are discussed here.The first mode time periods of diagrid structure D1,D2,D3,D4,D5 and D6 are shown in Table

**Table -3:** First Mode Time Period For Diagrid Structure

| Model | First mode time period (sec) |
|---|---|
| D1 | 3.072 |
| D2 | 3.723 |
| D3 | 4.181 |
| D4 | 3.644 |
| D5 | 3.243 |
| D6 | 3.125 |

The modal analysis results of Diagrid buildings of all models are compared in Fig.5. The time period for ten mode shapes are considered for each model and for model D1 time period results are shown below.

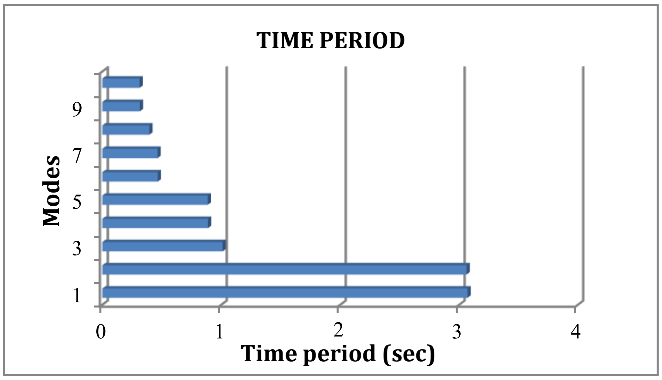


**Fig -5**: Time Period Results Of D1 Model

The building natural time period is obtained from the equation;

$$T = 2\,\Pi * \sqrt{(m/k)}$$

Where, 'T' is the time period, 'm' is the mass, 'k' is the stiffness. i.e. the time period can be related to the stiffness of the building.

### Displacement

Storey displacement is the absolute value of displacement of the storey under action of the lateral forces. The Diagrid building models are compared in terms of displacement as shown in the Fig.6.

The Diagrid models are compared under EQX load case. The displacement of model D4 are found to be less than that of other diagrid models.The Top Storey Displacement for model D4 with the combination of all the three degrees 78.13,74.28,60.56 has the lowest of 41.44 mm when compared to other models.

**Table -4:** Displacement For Diagrid Structures

| Model | Actual value (mm) | Diference in value (mm) | Displacement (%) |
|---|---|---|---|
| D1 | 46.84 | 1 | 1 |
| D2 | 42.12 | 4.72 | 10.07 |
| D3 | 54.56 | -7.72 | -16.48 |
| D4 | 41.44 | 5.4 | 11.52 |
| D5 | 48.42 | -1.58 | -3.37 |
| D6 | 47.42 | -0.58 | -1.23 |

From the above table, the percentage of displacement for diagrid model D4 is 11.52% when compared to other diagrid structures.

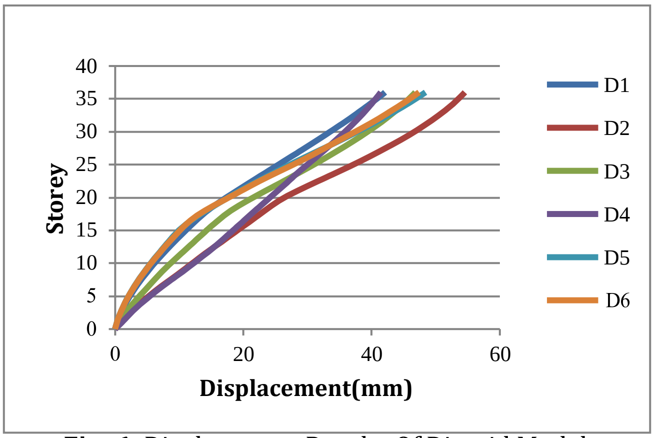


**Fig -6**: Displacement Results Of Diagrid Models

From this graph, it is found that diagrid with the combination of 60.56,74.28,78.13 Degrees ie. Model D4 controls the maximum displacement to 41.44 mm.

As per code IS: 456-2000 , clause: 20.5, page no. 33, the maximum top storey displacement should not exceed H/500, where H is the total height of the building. All the building models satisfy this criteria. But the lateral displacement of D4 building model is very larger than that of other diagrid building model. i.e. D4 building model displaces more than that of other diagrid models under same load.

### Storey Drift

The maximum inter-storey drifts of D1, D2, D3, D4, D5 and D6 diagrid structures in X-direction and Y-direction due to dynamic wind load are shown in Table IV.

**Table -5:** Inter Storey Drift For Diagrid Structure

| Model | Inter storey drift in X-direction due to DYWLX (m) | Inter storey drift in Y-direction due to DYWLY (m) |
|---|---|---|
| D1 | 0.000317 | 0.000316 |
| D2 | 0.000291 | 0.000301 |
| D3 | 0.000271 | 0.000298 |
| D4 | 0.000224 | 0.000225 |
| D5 | 0.000391 | 0.000393 |
| D6 | 0.000366 | 0.000368 |

The variation of inter-storey drift along the height of all diagrid buildings are shown in Fig. 7

For earthquake load, as per code IS: 1893-2002 , clause:7.11.1, page no: 27, the storey drift in any storey due to minimum specified lateral force with partial load factor of 1.0 should not exceed 0.004 times storey height that is H/250, where H is the storey height in meter. The storey drift values are found to be within the permissible limit.

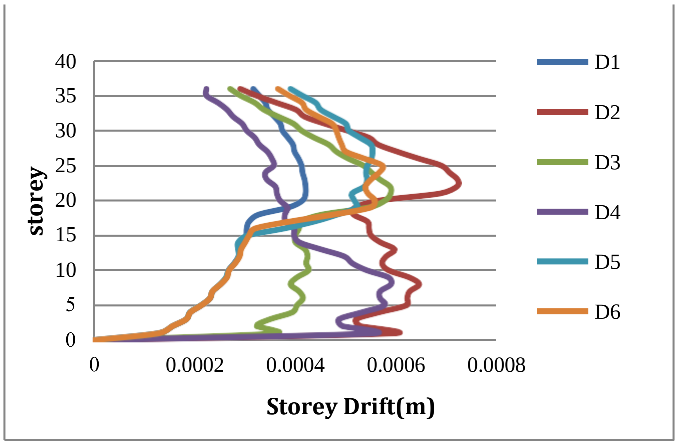


**Fig -7**: Inter Storey Of Diagrid Models

### Storey Shear

The storey shear of diagrid building models are compared under WINDX load case in the Fig.8.

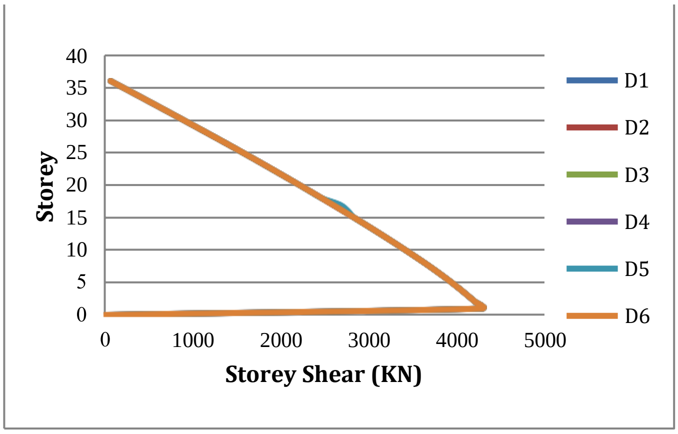


**Fig -8**: Storey shear Of Diagrid Models

From the above graph, the base shear for model D2 has the value of 4297.29 KN.

The storey shear values increases while moving from lower models to higher models for all types of diagrid buildings. i.e. the maximum storey shear increases when the height of the building increases. While comparing all the building models, the storey shear are found to be almost same for respective models.

## 4. CONCLUSION

In this paper, analysis and design of 36 storey diagrid steel building is presented in detail. A regular floor plan of 36 m × 36 m size is considered. ETABS2017 software is used for modeling and analysis of structure. All structural members are designed using IS 800:2007 considering all load combinations. The conclusions are given below,

1. Lateral loads are resisted by diagonal columns so the top storey displacement is very much less in diagrid structure as compared to the simple frame building.

2. The base shear for model D2 with the degree 74.28°has the maximum value 4297.29 KN when compared to other models.

3. The Storey Drift for model D4 with the combination of all the three degrees 78.13°,74.28°,60.56° has the maximum drift value as 0.000395 between storey 7 and 11 when compared to other models.

4. The Top Storey Displacement for model D4 with the combination of all the three degrees 78.13°,74.28°,60.56° has the lowest of 41.44 mm when compared to other models.

Diagrid structure system provides more economy in terms of steel and concrete as compared to simple conventional building. In comparison to conventional building, diagrid buildings are more aesthetic in look and it becomes important for high rise buildings. Lateral and gravity load are resisted by axial force in inclined column on periphery of structure, which make system more effective. 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 peripherial diagonal columns. So, internal columns need to be designed for vertical load only.

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