

# Analytical Evaluation of Most Effective Diagrid Angle Considering Severe Earthquake Time Histories

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## Abstract:

High rise structures and their structural mechanisms are evolving rapidly due to an exponential growth of urbanization. Few conventional structural systems have been efficient in withstanding heavy wind gusts as well as earthquakes. A newcomer in the list of sustainable high-rise structures is the *Diagrid*. A diagonal grid or *Diagrid* structure is a framework of diagonally intersecting inclined column sections. Due to higher resilience and robustness, the trend is rapidly shifting towards *Diagrid*. *Diagrid* structures are adopted as they take into account a number of factors like structural stability, aesthetic appearance and economic considerations. The triangulated formation of columns and ring beams transform all the external forces into direct axial forces. The effectiveness of the diagrid mechanism depends on the angle of the diagrid. In this project, analysis of symmetric diagrid building, with various diagrid angles has been carried out using software SAP2000. The analysis results for top storey displacement, base shear and modal frequency are considered for evaluating the optimal range of diagrid angle considering earthquake time histories.

**Keywords:** *Diagrid structure, Tall buildings, Time history Analysis, Optimal angle*

## 1. Introduction

From the end of the 20th century, the construction of the tall buildings is increasing day by day with a very fast rate all over the globe. Lack of available ground mainly in urban areas & appealing architectural facade views and are one of the main reasons for the exponential increase in numbers of Tall buildings or High-Rise buildings. The structural design of high-rise building is mainly governed by lateral loads (wind loads and seismic loads) along with gravity loads (dead loads & live loads). With the increase in height, the severity of lateral loads increases unavoidably [1]. For high-rise structures, lateral loads are generally resisted by external or internal load resisting systems. Generally, internally braced frame, bracing tube system having elements in the outer periphery, shear wall system are few most used lateral load resisting systems globally [2]. In the new era of super tall structures, the emerging *Diagrid* system is adopted. *Diagrid* means *Diagonal GRID* structure of columns. As shown in fig. 1, *Diagrid* system transfers all loads from ring beams to the foundation in a diagonal path through nodes of diagonal columns.

This system brought evolution in the construction of high rise structures because of its higher stiffness, suitability for any shape of the building and very prosperous architecture view. *Diagrid* eliminates large no of interior columns, providing large floor spaces. When diagrids are compared with other prevailing lateral load resisting systems, it has proved to be safer for all types of loading consideration [3]. For transferring lateral as well as gravity loads, the major considered component is the *node and the angle of diagonals* ( $\theta$ ). A typical load transferring mechanism in *diagrid* module is shown in fig.2.

An angle of *Diagrid* with reference to the horizontal is defined as the *optimal angle* for *Diagrids*. With a change in angle, load transferring capacity for gravity load and lateral load changes. For deciding the balance between gravity load transfer and lateral load transfer, optimising the angle is the most important design parameter. The Optimal angle considering wind load along with gravity load ranges between 60 degrees to 70 degrees [4].

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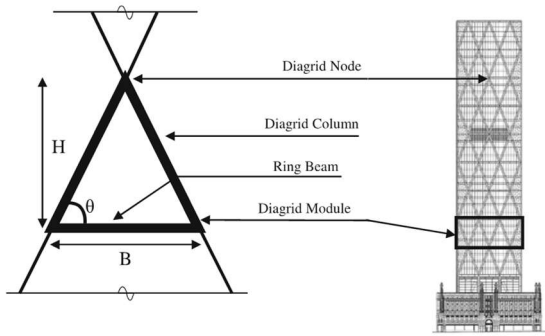
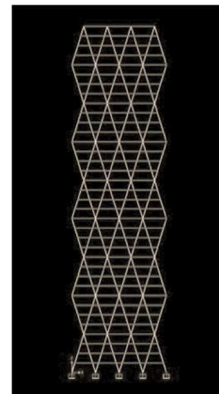


Fig. 1. A typical Diagrid building and its components



- Storey Height: 4 m
- Module width (B): 13.2 m
- Module Height: Varying
- No. of storeys per module: Varying from 2 to 12

Fig. 3. Elevation of FEM model of angle 67.58°

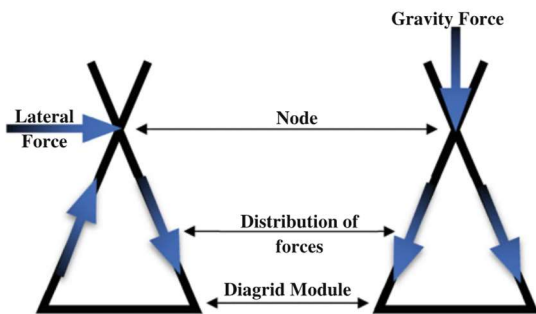


Fig. 2. Distribution of the external forces among the diagonals

This study mainly targets the behaviour of varying heights of *Diagrid* structures under seismic forces for the evaluation of most effective *Diagrid* angle. The seismic forces considered are the few severe earthquake time histories that has occurred in various countries in the past.

## 2. Modelling of Diagrid structure

In the study, the modelling of *Diagrid* structure is done using FEM software SAP2000. Plan Dimensions of models are decided by referring the Hearst tower situated in Manhattan, NY [5] (also seen in fig.1). Structural steel sections (beams & columns) are taken as same as used for the Hearst Tower [6][7]. Original building is of rectangular plan shape but for ease in analysis and modelling square dimensions are taken as 52.8 m x 52.8 m having 36 storeys in each model (as similar to presented in [9]).

Different angles of diagrid are decided considering 2-storeys, 4-storeys, 6-storeys, 8-storeys, and 12-storeys per module. Thus, the *Diagrid* angles being considered are 31.21° (2-storeys), 50.47° (4-storeys), 61.19° (6-storeys), 67.58° (8-storeys), and 74.62° (12-storeys), as shown in Fig. 4.

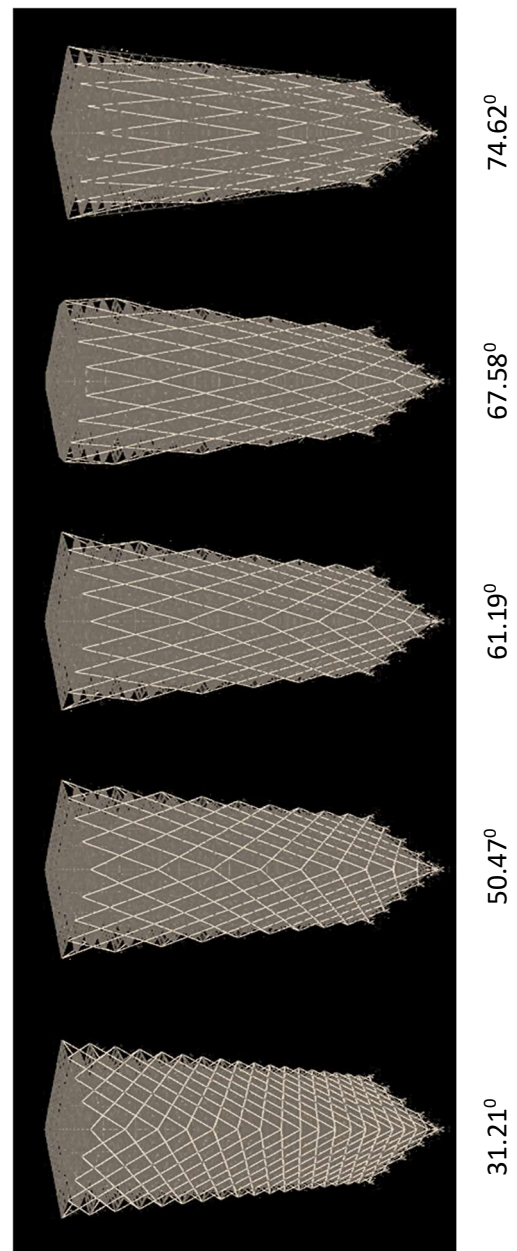


Fig. 4. FEM models considered for the study

Table 1. Considered earthquakes with their total duration & magnitude

Earthquake	Magnitude	Duration (s)
Chile	8.2	280
Bhuj	7.7	90
El Centro	6.9	54
Landers	7.3	49.5
Uttarkashi	7	41

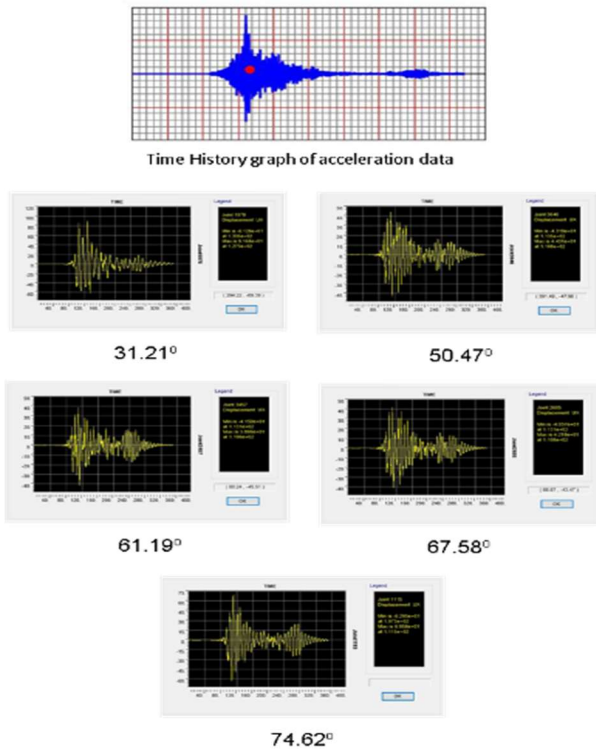


Fig. 5. Time History and plot function (top displacement) of models for Bhuj Earthquake

### 3. Analysis Process

The analysis is aimed at the optimal angle, for which various time history data of past severe earthquakes have been applied (see table 1).

Moreover, a static earthquake input according to IS 1893(2002) with considering the building in zone 5 with medium soil condition and response reduction factor as 5 has also been applied

For analysis purpose, a centre point of top storey from each model has been selected and the values of Displacement and Base shear with Plot function for all given earthquakes have been observed from SAP2000.

### 4. Results and Discussions

The typical displacement v/s time values are shown for Bhuj & Chile earthquakes in fig. 5 & 6. Similarly the analysis is obtained for all the considered earthquakes

loads. The study also compares 1<sup>st</sup> modal frequencies of all the considered building models to evaluate the optimal angle. The results for (i) top storey displacement (ii) base shear & (iii) 1<sup>st</sup> modal frequencies, are shown in chart 1, chart 2, chart 3 respectively.

The top storey displacement values (see chart 1) show that for all the considered earthquake time histories, the model with the angle 61.19° shows minimum displacement values compared to other models for the same earthquakes. Also, it is observed that for each earthquake models with lowest (31.21°) & highest (74.62°) angle, the top storey displacements are much higher.

The base shear values (see chart 2) show that the model with 61.19° gives highest base shear values compared to other angles meaning, being stiffer than other models.

Looking to the modal frequency values (see chart 3), it is observed that the diagrid angle 61.19° gives highest value of modal frequency compared to other models, meaning the highest performance with reference to lateral stiffness.

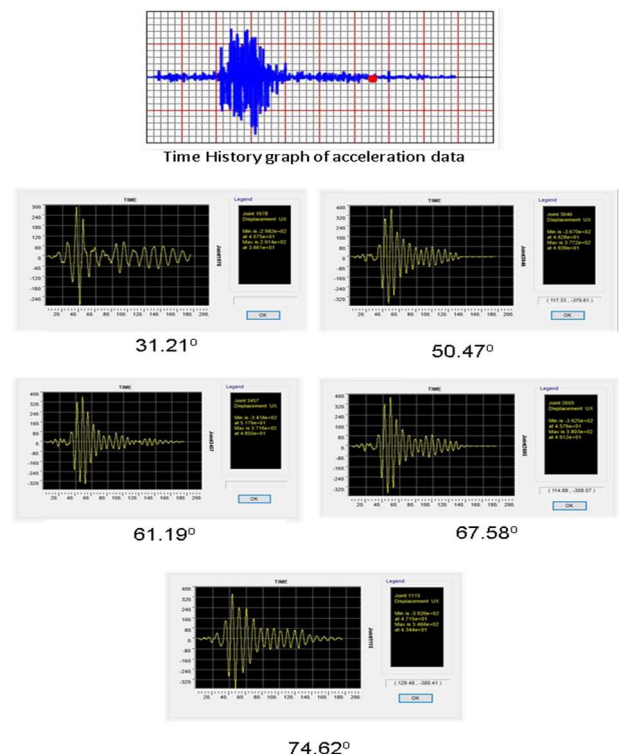


Fig. 6. Time History and plot function (top displacement) of models for Chile Earthquake

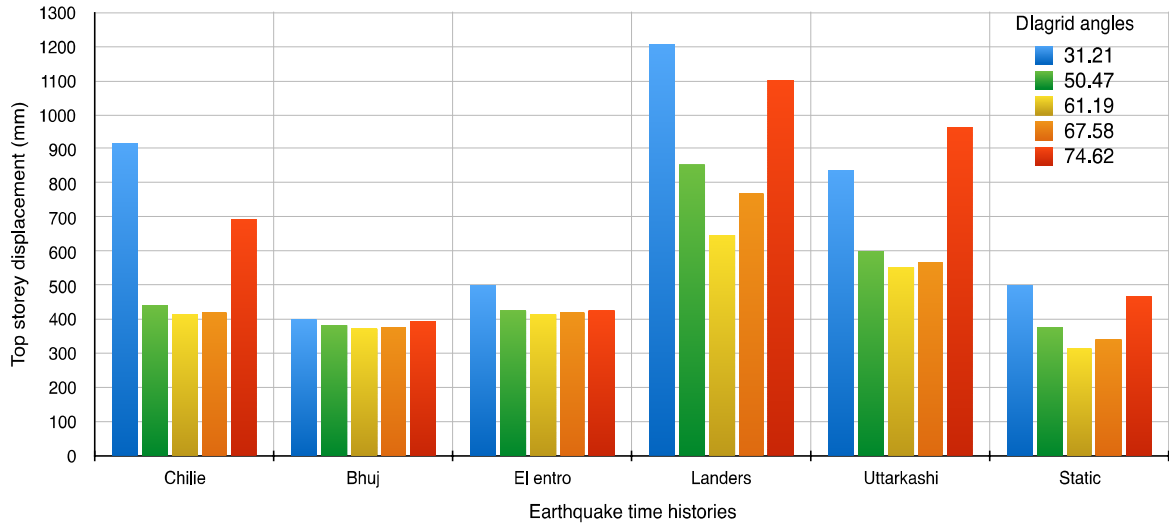


Chart 1. Top storey displacement for different models

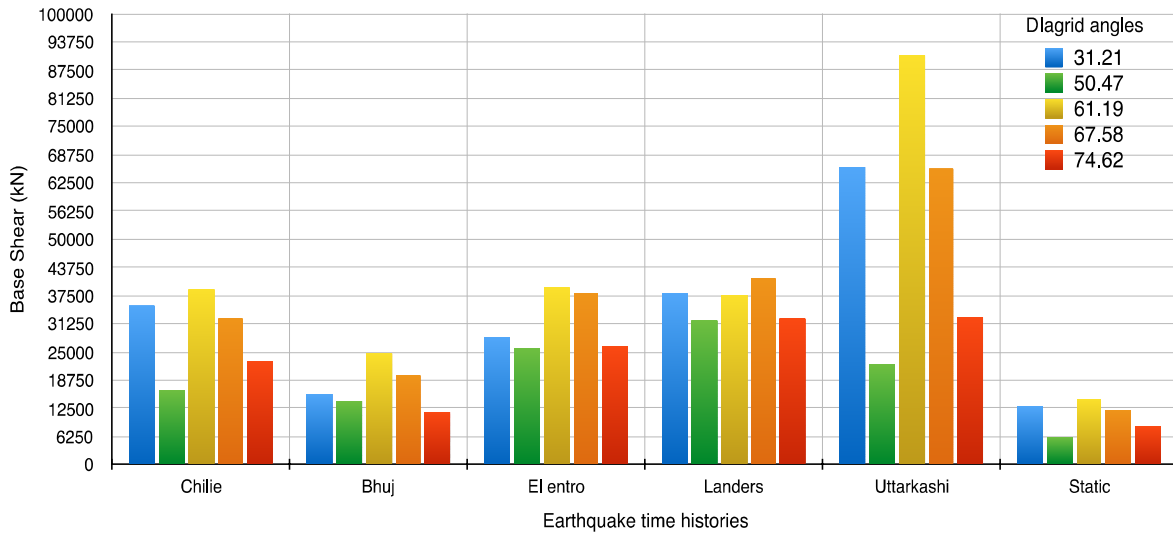


Chart 2. Base shear values for different models

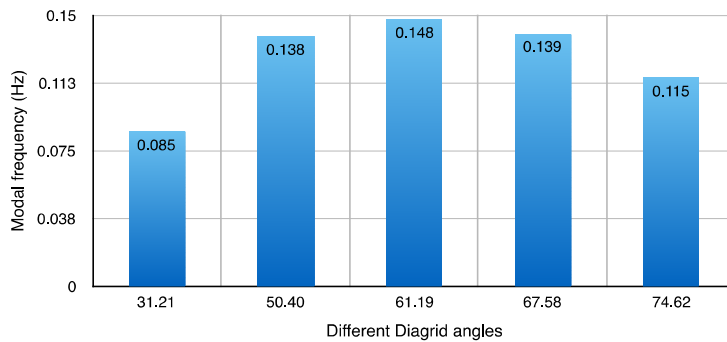


Chart 3. Modal frequency values for different model

## 5. Conclusion

*Diagrid* structural system has a very unique concept to resist lateral & gravity loads, mainly by deciding the optimal diagrid angle.

The wide range of results obtained for each model shows that, just by deciding the correct angle for the diagrid columns, one can achieve most desirable results. Among the possible diagrid angles it can be concluded that least top storey displacement with higher stiffness can be achieved by deciding the angle in the range of 61.19° to 67.58° i.e 6 to 8 storeys per module.

Also the same can be concluded w.r.t. base shear values and modal frequency values.

Considering the static seismic forces as per IS codes, similar results are obtained, which shows that the conclusion of the study is for significant w.r.t. the static loads too.

It is observed that if the optimised diagrid structure is to be constructed, it must possess the optimal diagrid angle in the range between 60° to 70°.

The optimal angle not only affects the structural optimisation and performance but results in optimisation in the material usage & ultimately the cost. Further elaborate analysis can be performed for various symmetric as well as non-symmetric *Diagrid* models.

Authors are hopeful that similar results can be achieved for the wind loads too if similar elaborate study of the same models under various wind gusts is performed.

The behaviour of the *Diagrid* models can be understood and well analysed using FEM software like SAP2000.

## Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

## 6. References

1. Sarkisian, M. P. (2016). Fazlur Khan's legacy: towers of the future. *Structure and Infrastructure Engineering*, 12(7), 802–821. <https://doi.org/10.1080/15732479.2015.1064969>
2. Moon, K. S. (2011). Sustainable Structural Systems and Configurations for Tall Buildings. *Aei 2011*, (203), 196–203. [https://doi.org/10.1061/41168\(399\)24](https://doi.org/10.1061/41168(399)24)
3. Moon, K. S. (2015). Comparative Efficiency between Structural Systems for Tall Buildings. *Journal of Structural Engineering*, (Connor 2003), 111–119.
4. Moon, K. S. (2008). Optimal grid geometry of diagrid structures for tall buildings. *Architectural Science Review*, 51(3), 239–251. <https://doi.org/10.3763/asre.2008.5129>
5. Ragette, F. (1971). Building on Tradition.
6. *Saudi ARAMCO Magazine*, 22(3), 9.
7. Osness, E. (2008). Green Giant. *New Yorker*, 1–20. <https://doi.org/10.1353/dss.2011.0097>
8. Volpicella, F. (n.d.). Hearst Tower History. <https://www.hearst.com/newsroom/history>
9. Swaral, N., & Satish, D. (2019). Diagrid building model: Design, fabrication and 1:75 scale testing for experimental seismic analysis. *Disaster Advances*, 12(7).
10. Naik, S. R., & Desai, S. N. (2019). Evaluation of lateral stability of the diagrid tall structure under different earthquake forces. In *Advances in Intelligent Systems and Computing* (Vol. 757, pp. 171–181). Springer Verlag. [https://doi.org/10.1007/978-981-13-1966-2\\_1](https://doi.org/10.1007/978-981-13-1966-2_1)