A Comparative Study on Seismic Analysis of Diagrid and Hexagrid Structural Systems

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Abstract. In this present era of population growth and scarcity of available land made engineers and architects to construct high rise building. Lateral loads are considered as most dominant factor in construction of high-rise building. To improve the efficiency of high-rise building, a new structural systems like diagrid and hexa-grid is introduced in this study. Diagrid structural system is the one which resist lateral load by presence of inclined columns in the periphery of the building. Another structural systems like hexa-grid also introduced in this study. Hexa-grid is the presence of hexagonal truss angulated system in the periphery of the building. Like diagrid, hexa-grid also resists lateral load and vertical load by axial action of diagonal and horizontal components in the periphery of the structure. In diagrid and hexa-grid most of the conventional columns are eliminated. In this paper a regular square floor plan of 48×48 m and irregular floor plan like C and L type base plan of diagrid and hexa-grid are studied. All structural steel members are designed as per IS 800:2007. The design earthquake load is computed based on the zone factor and their soil types, importance factor and response reduction factor as per IS:1893-2016. All models are having same 40 storey height and they are compared based on the parameters like displacement, maximum storey drift, storey shear, maximum base shear and steel consumed are considered in this study.

Keywords: Diagrid, Hexa-grid, Storey Drift, Lateral Loads, Base Shear, Steel Consumption, Displacement.

1. Introduction
The highrise buildings are constructed in response for the growing populations and scarcity of available lands. The rapid construction of highrise buildings are made possible due to the implementation of new innovative technologies, new scientific techniques, different methodologies and configuration. The conventional frame structure are widely constructed in most cities but in order to improve the efficiency and economy of high rise building, there is a need for alternative to conventional frame structure. So diagrid and hexagrid structures are one of the best alternative to conventional frame structure. The term “diagrid” is formed by blending of the word “diagonal” and “grid”. It refers to the structural system of grids that are aligned in a triangulation form. The lateral loads and gravity loads are resisted by these diagonal members. Another structural system called “hexagrid” also introduced in this paper. The term “hexagrid” describes grids that are hexagonal in shape which is inspired from the natural “beehive”. The hexagrid structural system is made by
intersecting horizontal and vertical components. Both structural system like diagrid and hexagrid resist lateral load gravity load. Most of the vertical columns are eliminated in diagrid and hexagrid structural systems. These structural system helps in reduction of material consumption and helps in distributing load in alternate path in case of failure of a member. Better aesthetic view is also achieved in both diagrid and hexagrid structural systems.

2. Literature Review

Safiya Daliya Ahammed and Shahla (2019) has reviewed that in order to improve the efficiency of a structure in tall building, a new structural system called hexagrid is introduced in the study and it consist of multiple hexagonal grids in the façade of the structure. Linear static and dynamic analysis are done to investigate the parameters like displacement, time period, storey drift and base shear are compared and studied.

Yash Bharadwaj et al., (2019) has discussed about structural properties and potential efficiency of diagrid, hexagrid and conventional frame structure are compared. The diagrid structure is more economical in terms of steel used and it saves 33% steel without affecting structural efficiency than other structures. The lateral displacement is reduced in diagrid and hexagrid pattern. The bending moment is also decreased in interior column of diagrid and hexagrid structure in comparison to the conventional structure.

Harshada Naik and Suryawanshi (2017) has discussed about the purpose of diagrid and their increased stability of a structure due to its triangulation. The results are compared on parameters like time period, top storey displacement, interstorey drift and storey shear.

Deepa Varkey and Manju George (2016) has reviewed on the comparative analysis of diagrid structure with different plan like square and complex in shape. The influence of angle in resisting lateral as well as gravity load is compared. In complex shape analysis, the building without shear wall and secondary bracing has large storey displacement compared with other two systems. The building also acts similarly in both static and dynamic analysis.

Giovanni Maria Montounni et al., (2015) has discussed about tube configuration based on hexagonal shape for tall building. The design procedure has been proposed based on simple stiffness criterion. The procedure applied to tall building case studies and assessed by varying the major geometrical parameters of the patterns.

Chonghou Zhang et al., (2012) has reviewed about preliminary design guidelines for diagrid structures with gradually varying angles. Different combination of top and bottom angles of diagrid tube structures are designed to investigate effects of angles on material usage. The optimal geometries for diagrid tube structures with different aspect ratios and optimal angles are determined.

Kyoung Sun Moon et al., (2008) has discussed about the preliminary design sizes for diagonals and optimal values for grid geometry for the design loadings. The influence of diagonal angles on displacement and steel quantity are compared. These values are useful for architects and engineers as a guidelines for preliminary design.

3. Objective

1) To plan, model and analyse conventional frame structure.
2) To plan model and analyse diagrid and hexagrid structure with plan irregularities under seismic loads.
3) To study and compare the results like base shear, storey displacement, storey shear, time period, storey drift and quantity of steel consumed.
4. Building Configuration

The plan dimension of all structures are 48 m × 48 m and it consist of 40 storey tall buildings. The total height of tall structures 160 m and each storey has a height of 4m. The design live load and floor finish are 4 kN/m² and 1 kN/m². The load combinations are based on IS 800:2007. The columns are made up of built up I section of 2 m x 2 m and beams are made up of ISWB 550 and ISWB 600 with cover plate of 220 × 50 mm on top and bottom. The spacing between the columns are 4 m each. The outer diagonal members are made up of pipe section of 750 × 75 mm and angle of inclination is 45° for diagrid and hexagrid structures. The earthquake load is based on seismic zone III, medium soil type, zone factor of 0.16 and response reduction factor of 5 and importance factor of 1.2 as per IS 1893:2016. The grade of steel is Fe345 and concrete is M30 grade. The slab thickness is 125 mm and support conditions are fixed. All 40 storey structures with symmetric plan like square plan and asymmetric plan like C and L type are considered in this study. The floor plan of conventional frame is shown in Figure 1. The floor plan of diagrid and hexagrid structures are same as shown in Figure 2. The L-type plan for both diagrid and hexagrid structures are shown in Figure 3 and C-type plan for both diagrid and hexagrid structures are shown in Figure 4. The elevation of conventional frame structures is shown in Figure 5. The elevation of C type and L type diagrid structure is same as the elevation of regular diagrid structure as shown in Figure 6. The elevation of C type and L type hexagrid structure is same as the elevation of regular hexagrid structure as shown in Figure 7. The three dimensional modelling of regular diagrid structure is shown in Figure 8 and regular hexagrid structure is shown in Figure 9. The three dimensional modelling of C type & L type diagrid structure is shown in Figure 10 and Figure 11. The three dimensional modelling of C type & L type hexagrid structure is shown in Figure 12 and Figure 13.
Figure 3. Floor Plan of Diagrid & Hexagrid L type structure

Figure 4. Floor Plan of Diagrid & Hexagrid C type structure

Figure 5. Elevation of Conventional Frame Structure

Figure 6. Elevation of Diagrid Structure

Figure 7. Elevation of Hexagrid Structure
Figure 8. 3D Modelling of Regular Diagrid Structure

Figure 9. 3D Modelling of Regular Hexagrid Structure

Figure 10. 3D Modelling of C type Diagrid Structure.

Figure 11. 3D Modelling of L type Diagrid Structure.
5. Analysis Results and Discussion

5.1 Linear Static Analysis

The linear static analysis also called as equivalent lateral force method. The design base shear are calculated and distributed across various floors along the height. These steel structures are designed as bare frame without any masonry infills and it is special moment resisting frame. In this paper linear static analysis and linear dynamic analysis is done by using SAP2000 software. The equivalent lateral force method for all structures are calculated based on IS 1893:2016. The lateral loads are resisted by exterior diagrid and hexagrid members. The vertical inner columns in the structures are used to transfer gravity loads. The design lateral loads are calculated from equivalent lateral force method are applied on the diaphragm along the height of the structure. The base shear of static analysis is more than the base shear from the dynamic analysis.

5.1.1 Storey Displacement
Figure 14. Graph represents Storey displacement due to EQX.

Storey displacement is the displacement of a storey with respect to the base of the structure. The maximum top storey displacement should not exceed H/500 as per IS 800:2007, whereas ‘H’ is the total height of the structure. The displacement results are within permissible limit. The storey displacement graph due to EQX is shown in Figure 14.

5.1.2 Storey Shear
The design lateral force applied at each floor level along the height. The storey shear graph is shown in Figure 15.
Figure 15. Graph represents Storey Shear

5.1.3 Steel Consumption
Conventional frame structure consumes more steel than any other structure. Therefore using other structural system reduces steel consumption more than 17% than conventional frame structure. The steel consumption is shown in Figure 16.

Figure 16. Bar charts represents Structural Steel Weight
5.1.4 Maximum Storey Drift
Storey drift is the displacement of one storey with respect to other storey. The storey drift should not exceed 0.004 times of storey height. Hence storey drift values are within permissible limit as per IS 1893:2016. The maximum storey drift is shown in Figure 17.

![Max Drift](image)

**Figure 17.** Bar Chart represents Maximum Drift due to EQX.

5.1.5 Maximum Base Shear

Base shear is an estimate of maximum lateral force at the base of the structure due to seismic ground motion. Storey shear is amount of lateral force due to earthquake acting at each storey. The maximum base shear values are shown in Figure 18.
5.2 Linear Dynamic Analysis

The Linear Dynamic Analysis also knowns as Response Spectrum Analysis. These structures having height of 160 m which is more than 40 m, so response spectrum analysis need to be done. In this study, there are 12 modes of vibrations are considered. The response spectrum analysis method has different modes of vibration and mass participation factor is about 90%. For each modes response spectrum analysis is checked. There are two methods of combination like (SRSS) Square Root Summation of Squares and (CQC) Complete Quadratic Combination methods. Square Root Summation of Squares (SRSS) is used for simple symmetrical structure. Complete Quadratic Combination method (CQC) is improved method of Square Root Summation of Squares (SRSS) and it gives accurate results for asymmetrical structures, so Complete Quadratic Combination method (CQC) is used.

5.2.1 Storey Displacement

The displacement due to RSX is shown in Figure 19.

**Figure 18.** Bar Chart represents Maximum Base Shear.
Figure 19. Graph represents Storey displacement due to RSX.

5.2.2 Maximum Storey Drift

The maximum storey drift is shown in Figure 20.
Figure 20. Bar Chart represents Maximum Drift due to RSX.

5.2.3 Time Period

The time period of all structures are compared in Figure 21.
6. Conclusion

The study is conducted on structural system like diagrid and hexagrid with different plan configuration. From the comparative study of these structural system, we conclude that

- Steel quantity is reduced in diagrid and hexagrid structural systems than conventional frame system.

- The base shear increased in structures having more diagonal elements and decreased in structures having less diagonal elements. The maximum storey drift and storey displacement is observed in the structure having less diagonal element.

- Storey displacement values higher for conventional frame structure and lesser for L type of diagrid and hexagrid structures.

- In terms of economy, the C and L type plan needs less steel due to less plan area. Among these, C and L type of hexagrid structural systems needs less steel than C and L type of diagrid structural system.

- By doing static and dynamic analysis, the base shear of static analysis is more than base shear of dynamic analysis.

- Time period increases with increase in height of the building. More the time period means structure is considered as less stiff. Hence conventional frame structure having more time period and considered as less stiff. L type hexagrid having lesser time period so it is stiffer than the other structures.

- The diagrid and hexagrid structural systems shows less lateral displacement and drift compared with conventional frame structural system.

- In comparision with conventional frame structural system, diagrid and hexagrid structural system have better aesthetic and it allows general amount of day lighting, thereby reducing cost and energy.

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