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Performance Analysis of the Tall Diagrid Structures for Gravity and Seismic Loading

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***Abstract*—Many structural systems are available for constructing stable tall buildings. The diagrid structural system has proved to be better performing due to its structural efficiency and aesthetic potential. As the name depicts 'Diagrid' refers to diagonalized grid arrangement of members mainly on periphery of the structure. It basically works on the principle of triangulation as a result of which the diagonal members have the ability to carry both gravity as well as lateral loads effectively. The main objective of this research is to analyse the seismic performance of diagrid building in order to find out its feasibility for high rise constructions. In this study structural analysis of 48-storey steel diagrid building with 4-storey module of diagonal member for both square and circular plan was done to evaluate their performance. The plan considered for study was 36m x 36m and the method used for analysis was Response Spectrum Method. All the members were designed as per IS456:2000 and IS1893(Part I):2016.The modelling and analysis were done by using ETABS 2017 software. The performance of both square and circular diagrid modelwas evaluated and compared from various seismic parameters i.e. time period, base shear, storey displacement, storey drift and storey stiffness. The results obtained were expressed in the form of graphs and the values were compared with the limitations as per codes.It was founded that storey displacement and storey drift lies within the permissible values as per IS1893(Part I):2016 and EU-8(2004). Comparing the specified parameters, it was observed that circular diagrid model performs better than the square diagrid model. It was observed that diagrid structural system is found to be effective for high-rise structures due to their high stiffness and aesthetic potential. Overall it was concluded that the diagrid building can be considered as sustainable solution in terms of resources and production of waste.**

1. INTRODUCTION

Diagrid structures are defined as diagonalized grid structures constructed to resist gravity as well as lateral loads in order to eliminate vertical columns. The vertical columns are provided to carry only gravity load and were incapable of providing lateral stability. On the other hand, the diagonal grid if properly spaced and configured are capable to carry gravity load as well as provide lateral stability due to its triangular configuration.Diagrids provided are considered as pin jointed truss elements making them stiffer enough to even resist wind forces for higher heights. Diagrid structures when compared with conventional framed structure without diagonals are more effective in reducing shear deformations as they carry shear by axial action of diagonal members where as in conventional framed structure shear is carried by bending action of vertical columns. Also, the difference between conventional braced frame structures and diagrid structures is that in diagrid structures almost all the vertical columns are eliminatedinvolving efficient utilization of material. Overall the diagrids can be considered as the arrangement of inclined columns at the perimeter of building resulting in diamond shape modules along multiple floors resulting in increasing significant flexibility with the floor plan of the diagrid system as well making it more aesthetic.

In diagrid structures, the diagonal members act both as inclined columns as well as bracing elements and carry both gravity aswell as lateral load. Due to the presence of triangulated configuration only axial forces arise in the members. The gravity load is converted to axial load along the diagonal members.The moment generated by lateral load is distributed along the members. Due to this distributed moment one side of the structural member is in tension and the other side is in compressionthus acting as vertical tension force on one side and compression force on the other side respectively. The shear loading is resisted by diagonals along the axis. This distribution of load is shown in **fig. 1.1.**

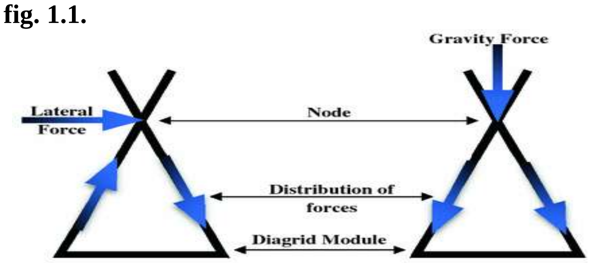

Fig 1.1 Load Transfer Mechanism [15]

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2. OBJECTIVES OF WORK

i) To analyze and compare the performance of square and circular diagrid structural model under the seismic load and gravity load.
ii) To evaluate the seismic parameters i.e. time period, base shear, storey displacement, storey drift andstiffness on the performance of both the structures.

3. DESCRIPTION OF BUILDING

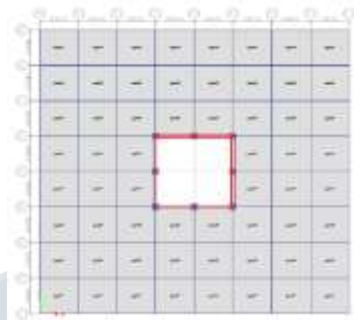
- Building type-Commercial
- Plan area-36mx36m
- Number of storeys-48
- Height of each storey-3.5m
- Total height of building-168m
- Deck thickness-150mm
- Core thickness-400mm
- Size of steel square tube section used for Diagrids-385.6mmx385.6mmx11mm
- Size of columns provided in central core-800mmx800mm (8 nos.)
- Steel section used for beams-ISMB 500
- Concrete grade used for flooring-M30
- Concrete grade used for central core and columns-M40
- Steel used for sections-Fe250
- Dead load-self weight of structure
- Live load-4kN/m^2 as per IS-875(Part 2)[17]

4. MODELLING

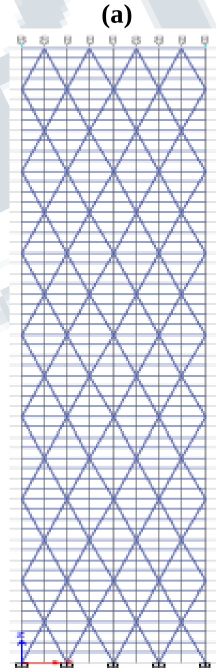
For the dynamic analysis of buildings ETABS 2017 software is used and modelswere prepared to determine the seismic performance of diagrid structure on hard soil in zone III using Response Spectrum Method.

Seismic Data[as per IS1893(Part I):2016][16]

Seismic zone=III
Zone factor (Z)=0.16(table3, clause 6.4.2)
Importance factor (I)=1.2(table8, clause 7.2.3)
Response reduction factor I=5 (SMRF) (table9, clause 7.2.6)
Soil type-I (Rock or Hard Soil)
The square and circular diagrid modelswere shown in **fig.4.1 and fig. 4.2** respectively

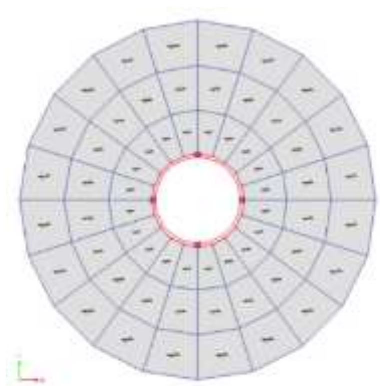


(a)

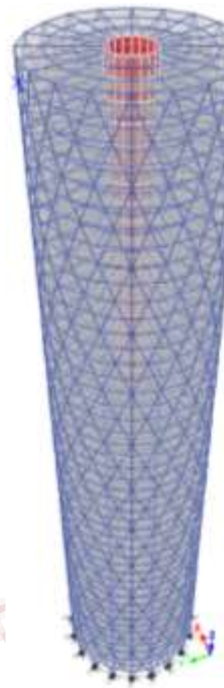


(b)

Fig. 4.1 a) Plan view, b) 2D Elevation view of 4-storey square diagrid model



(a)



(b)

Fig. 4.2 a) Plan view, b) 3D Elevation view of 4-storey circular diagrid model

5. ANALYSIS AND RESULTS

5.1 Time Period: -

More time period indicates more flexibility in structure whereas lesser time period indicates more rigidity in the structure.The maximum natural time period of one complete cycle of oscillation of square diagrid building is **5.38sec**and of circular diagrid building it is **5.11 sec.**The variation of time period for both the models is shown in **fig.5.1.**

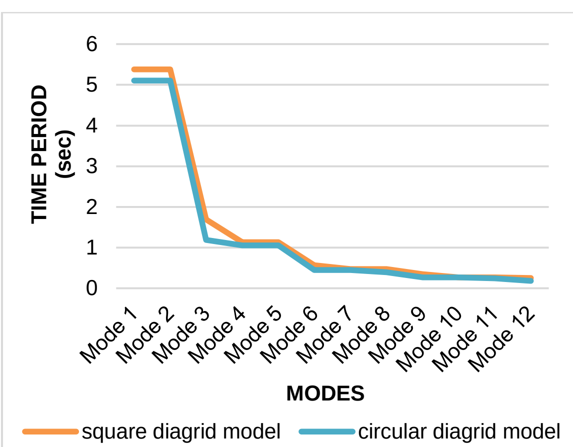


Fig. 5.1Variation of Time Period (sec)

5.2 Base Shear:-

Base shear is the maximum lateral force that will occur due to ground motion as a result of seismic activity at the base of the structure.As per **IS1893(Part I):2016**[16]**clause 7.6.1 pg. no.21**, the design base shear is given as,

$$V_B = A_h W \qquad \text{… (i)}$$

Where, 'A_h' is design horizontal acceleration coefficient

'W' is the seismic weight of building

As per **IS1893(Part I):2016**[16] **clause 7.6.3 pg. no.21,** the design base shear distribution is given as,

$$Q_i = \left(\frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2}\right) V_B \qquad \text{… (ii)}$$

Where,

'Q_i'is the design lateral force at floori

'W_i' is seismic weight of floor i

'h_i'is the height of floor i measured from base

'n' is the number of storeys in building

The maximum base shear of square diagrid model is **1887.51 kN** and of circular diagrid model it is **1813.58kN.**The base shear for both the models was distributed using equation (ii) along the height of building at each storey level as shown in **fig. 5.2.**

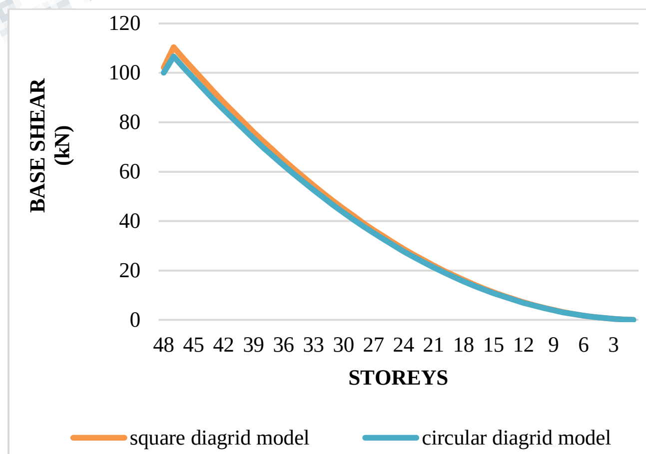


Fig. 5.2 Distribution of Base Shear along the height of building (kN)

5.3 StoreyDisplacement:-

Displacement of any storey with respect to the base due to lateral loads is known asStorey Displacement. The maximum storey displacement are**438.53mm**for square diagrid model and **396.798mm**for circular diagrid model. Thus, both the values are less than **672mm**as per **EN-8(2004)**[20]**.** The variation of storey displacement along the height of building for both the models is shown in **fig.5.3**.

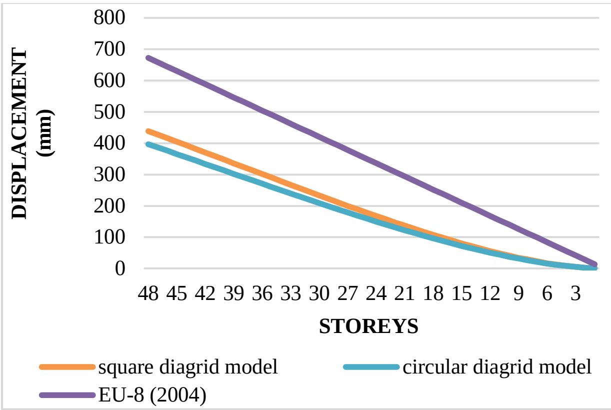


Fig. 5.3Variation of Storey Displacement along height (mm)

5.4 Storey Drift: -

Storey drift is defined as the relative displacement between storeys above and below the storey considered. The drift values observed are**11.39 mm**for square diagrid model and **10.56mm**for circular diagrid model**.**As per **IS1893(Part I):2016**[16]storey drift is **0.004x3.5= 14 mm**and as per **EN-8(2004)**[20]storey drift is **0.01x3.5= 35mm.** Thus, storey drift for both the models lie withinthepermissible limits. The variation of storey drift along the height of building for both the models is shown in **fig. 5.4**.

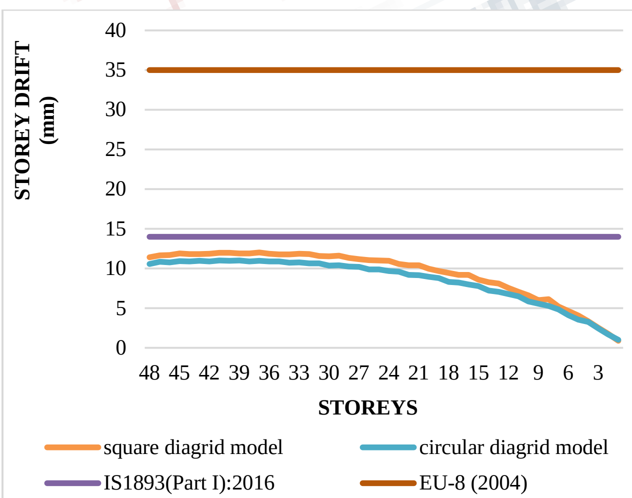


Fig.5.4Variation of Storey Drift along height (mm)

5.5 Storey Stiffness:-

For uniform distribution of lateral load deformation and lateral forces over the plan and elevation of building, the stiffness of building plays a major role. The amount of lateral load resisted by individual member of building is controlled by their lateral stiffness. Maximum value of stiffness is**22965890 kN/m** for square diagrid model and **17825598kN/m**for circular diagrid model**.**The variation of stiffness along the height of building for both the models is shown in **fig. 5.5**.

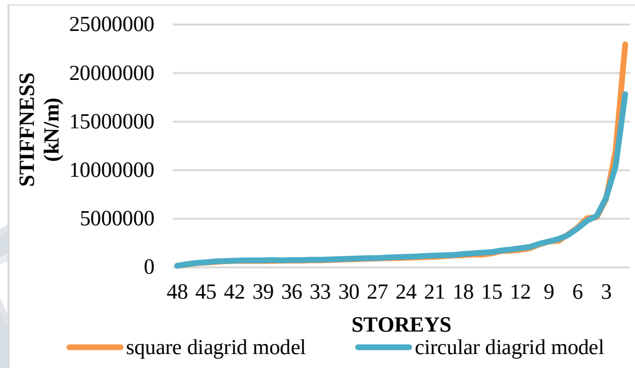


Fig. 5.5 Variation of Stiffness along height (kN/m)

6. CONCLUSIONS

The increased stiffness results in more seismic loads acting on the structure. Since diagrid structures are found to be stiffer in structural system thusit results in emphasising on investigation of seismic performance of diagrid structures.

- The storey displacement and storey drift values lies within the permissible values as per refered codes. Both the displacement and storey drift values were found minimum for circular diagrid model.
- The core provided in the diagrid structure carry majority of gravity loads while the diagonal members carry majority of lateral load.
- In both the models analysed the circular diagrid model gives better result as compared to square diagrid model. The circular diagrid model performs better than square diagrid model.
- In the diagrid buildings adequate space is presentdue to absence of the vertical columns in the structure.

Diagrid structural system are found to be more stiffer and have great aesthetic potential. Thus, it can be considered as effective structural sytem for future high rise constructions.

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