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Numerical Modelling and Evaluation of Hybrid Diagrid Structures

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Abstract- Advances in construction technology, material properties, structural systems and software for analysis and design facilitated the growth of high rise buildings. Structure 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. Interior structural system or exterior structural system provides the safety against lateral loads. The selected structural system should be such that it should be effectively utilized for structural requirements. Recently the use of perimeter diagonals—hence the term 'diagrid'—for structural efficiency and architectural elegance has generated renewed interest from architectural and structural designers. While comparing it with other building forms Due to inclined columns lateral loads are resisted by axial action of the diagonal members. This type of structure carries lateral wind loads more efficiently, creating stiffness that is complemented by the axial action of the diagonal member. Here Analysis and design of 36 storey hybrid diagrid-tubular building are presented. A regular floor plan of 36 m × 36 m size is considered. This project tried to explore the possibilities of hybrid structures. Mainly deals with the performance evaluation of hybrid tubular-Diagrid structure. It will conduct a comparative study on analysis results in terms of top storey displacement, storey drift. ETABS software is used for modeling and analysis of structural members. All structural members are designed as per IS 800:2007 considering all load combinations. Comparison of analysis results in terms of top storey displacement and inter-storey drift is presented in this paper.

Index Terms- Tubular structure , Diagrid Structural System , Hybrid structure

1. INTRODUCTION

The rapid growth of urban population and limitation of available land, the taller structures are preferable now a day. The number of tall building developments has been rapidly increasing worldwide, and these developments involve various complex factors such as economics, aesthetics, technology, and policies. Several structural systems have also been developed to realize mankind's dream in pursuing new heights. The steel diagrid structural system is one of them. Recently, diagrid systems Fig.1 are emerging as structurally efficient as well as architecturally pleasing structural systems for tall buildings. The diagrid systemhas been applied for structural design of axi-symmetric structures such as the Swiss-Re building in London and the Tornado Tower.

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, but in case of bracings in conventional braced frame structures carry only lateral loads.

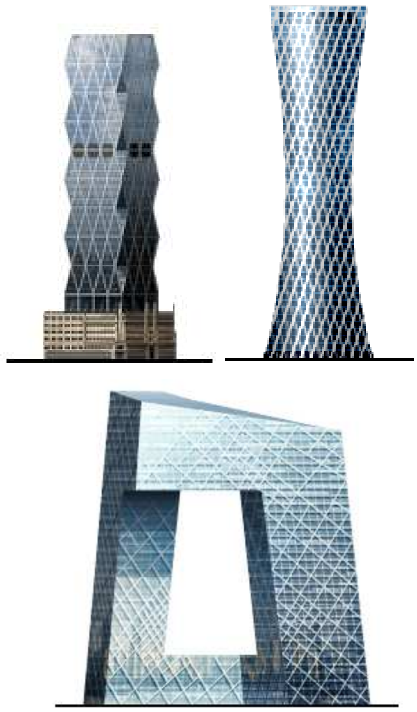


Fig.1.Example of diagrid building: (a) 42-Story Hearst Tower in New York, USA; (b) 51-Story CCTV HQ in Beijing, China; (d) 52-Story Tornado Tower in Doha, Qatar

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. Compared with conventional framed tubular structures without diagonals, diagrid structures are much more effective in minimizing shear deformation because they carry shear by axial action of the diagonal members, while conventional framed tubular structures carry shear by the bending of the vertical columns. Diagrid structures do not need high shear rigidity cores because shear can be carried by the diagrids located on the perimeter. In addition, by using diagonals, diagrid structures use a lesser amount of structural material in general than conventional structural systems composed of orthogonal members. Indeed, the structural efficiency of the diagrid system makes the number of interior columns decrease, therefore allowing much flexibility on the plan design. This is much preferred by architects and designers.

Moon is one of the researchers who has done a lot of works on diagrid structures. Moon, connor and Fernandez studied characteristics and developed a methodology for the design of diagrid buildings in 2007. Because they provide excellent shear rigidity and stiffness than tubular structures. The higher shear rigidity can avoid the need for rigid core and higher stiffness of diagrid building makes it as less susceptible to dangerous vortex shedding, and so it requires higher velocity of wind to trigger a resonant response.

Moon et al focused their study of diagrid structures on 60 storey building because majority of world's largest buildings fall between 50 and 70 stories. They discovered the optimal angle for the diagrid to be 35˚ when considering shear rigidity compared to 90˚ optimal angle any for maximum bending rigidity. So concluded that for any diagrid building optimum angle lies somewhere between this two values.

Both diagrid and tubular having certain advantages and disadvantages. Diagrid buildings are better in lateral load resisting. Diagrid structures generally do not need high shear rigidity cores because shear can be carried by the diagrids located on the perimeter. Constructability is a serious issue in diagrid structures because the joints of diagrid structures are more complicated and tend to be more expensive than those of conventional tubular structures. In order to reduce jobsite work, prefabrication of nodal elements is essential. Tubular steel sections are the best replacements to the conventional ones with their useful and comparatively better properties. It is obvious that due to the profile of the tube section, dead weight is likely to be reduced for many structural members .which derives overall economy**.** But tubular structures have a higher shear lag effect than diagrid structures. So here proposing a new hybrid form which may perform much better than other two structures

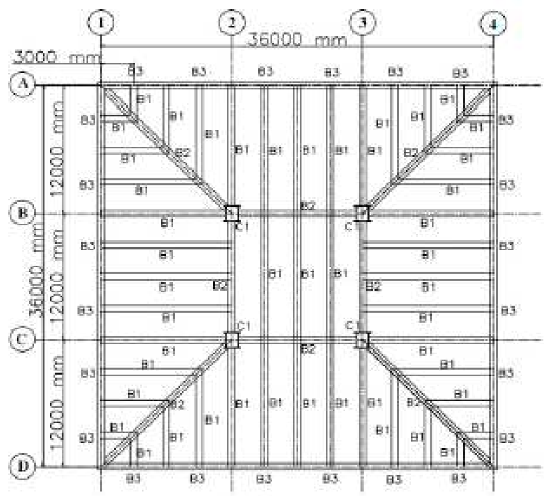
This paper trying to explore the possibilities of hybrid structures. Mainly deals with the performance evaluation of hybrid tubular-Diagrid structure. It conducted a comparative study on analysis results in terms of top storey displacement and interstorey drift.

2. MODELLING AND ANALYSIS OF HYBRID DIAGRID - TUBULAR STRUCTURE

2.1. *Building configuration*

Proposed building is a hybrid form of diagrid and tubular steel structure. Here we consider 3 type of combinations. i) 25%tubular and remaining diagrid ii) 50% tubular and 50% diagrid iii) 75% tubular and25% diagrid.

These 3 types of buildings were modelled using E-tabs 13. The 36 storey building is having 36 m × 36 m plan dimension. The storey height is 3.6 m. The typical plan and elevation are shown in Fig 2. In diagrid structures, pair of braces is located on the periphery of the building. The inclination angle is kept uniform throughout the height. The inclined columns are provided at six meter spacing along the perimeter. The interior frame of the diagrid structures is designed only for gravity load. The design dead and live loads on slab are 4 kN/m2 and 2.5 kN/m2 respectively. The dynamic along wind loading is computed based on the basic wind speed of 30 m/sec and terrain category III as per IS: 875 (III)-1987. The design earthquake load is computed based on the zone factor of 0.16, medium soil, importance factor of 1 and response reduction factor of 5.



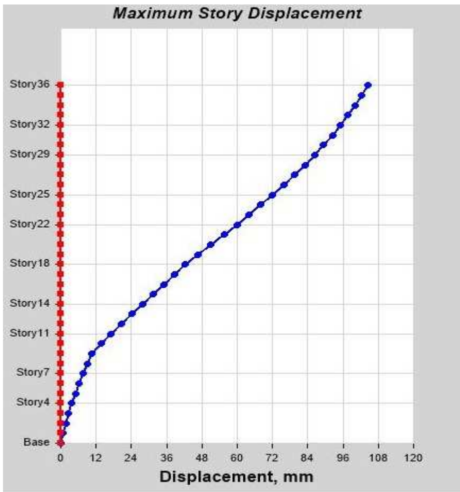
(a)

Fig. 2. Typical plan for the building

Modelling, analysis and design of hybrid structure are carried out using E-tabs software. For linear static analysis the beams and columns are modelled by beam elements and braces are modelled by truss elements. The support conditions are assumed as hinged. All structural members are designed using IS 800:2007. Secondary effect like temperature variation is not considered in the design, assuming small variation in inside and outside temperature.

2.2. *Modelling and analysis of hybrid 1*

Here 75% of the storey became diagrid structure and remaining portion by tubular structure. First 9 storey became tubular structure and after that diagrid was used. The design dead load and live loads on floor slab are 4 kN/m^2 and 2.5 kN/m^2 respectively. Analysis results shows that the obtained for wind loading maximum storey displacement is 100mm for the top storey. Maximum storey drift is found to be in between 3rd and 7th storey is 0.001257 as in fig.3. Results obtained after static analysis is given below.



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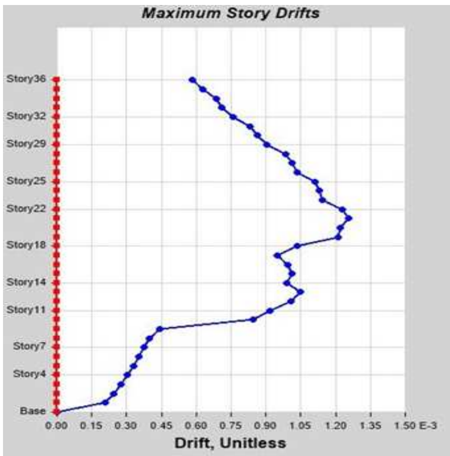
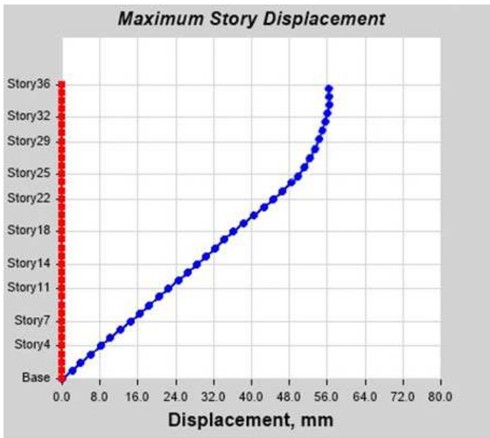


(b)

Fig. 3. (a) storey displacement plot (b) storey drift plot

2.3. *Modelling and analysis of hybrid 2*

75% portion diagrid structure with 25% braced tubular system. First 9 storey became tubular structure with bracings and after that diagrid was used. The design dead load and live loads on floor slab are 4 kN/m^2 and 2.5 kN/m^2 respectively. Results obtained for wind loading after static analysis is given below in fig.4.



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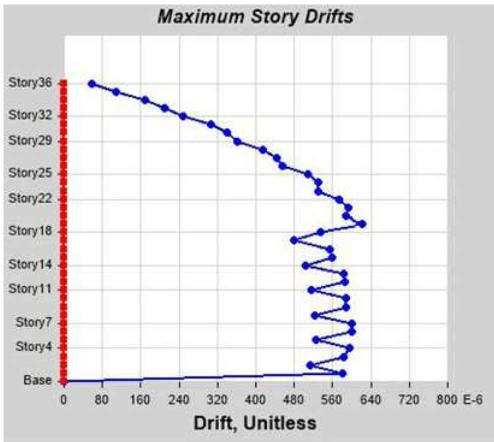


(b)

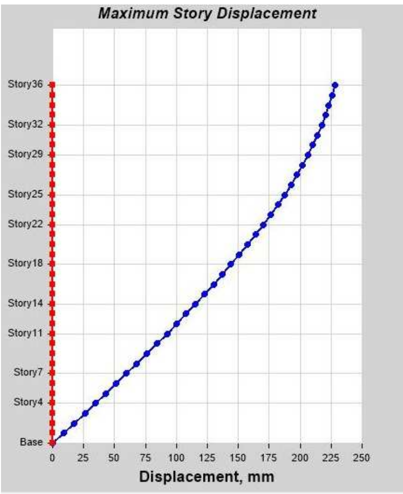
Fig. 4. (a) storey displacement plot (b) storey drift plot

Maximum top storey displacement obtained for hybrid structure is 57 mm and maximum inter storey drift obtained between 18th and 22nd storey. Maximum storey drift found to be 0.000637.

2.4. *Modelling and analysis of hybrid 3*

75% of tubular building system and remaining 25% of diagrid system.First 27 storey became tubular structure and after that diagrid was used. The design dead load and live loads on floor slab are 4 kN/m^2 and 2.5 kN/m^2 respectively. Results obtained for wind loading after static analysis is given below in fig.5.

Maximum top storey displacement obtained for hybrid structure is 227 mm and maximum inter storey drift obtained between 18th and 22nd storey. Maximum storey drift found to be 0.01331.



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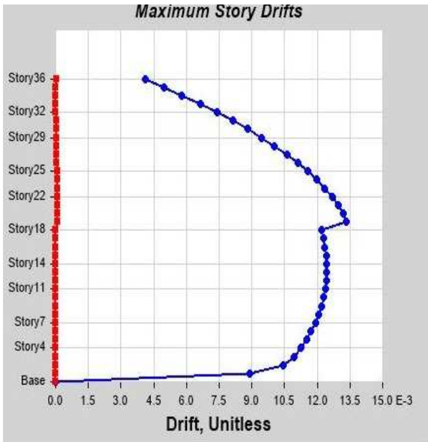
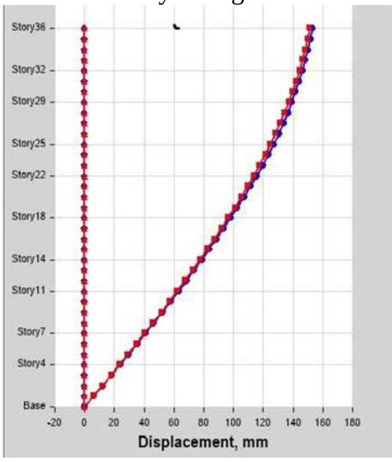


(b)

Fig. 5. (a) storey displacement plot (b) storey drift plot

2.5. *Modelling and analysis of hybrid 4*

50% of tubular building system and remaining 50% of diagrid system.First 18 storey became tubular structure and after that diagrid was used. The design dead load and live loads on floor slab are 4 kN/m^2 and 2.5 kN/m^2 respectively. Results obtained for wind loading after static analysis is given below.



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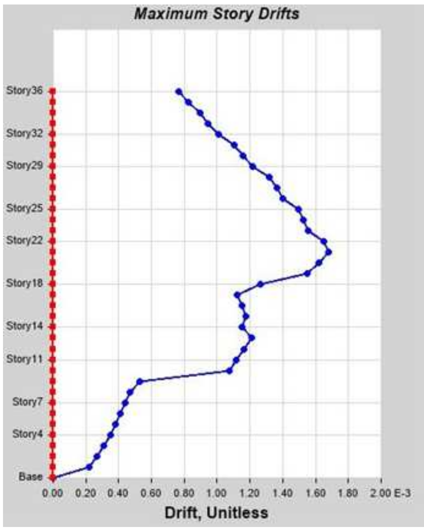

(b)

Fig:6 (a) storey displacement plot (b) storey drift plot

Maximum top storey displacement obtained for hybrid structure is 154 mm and maximum inter storey drift obtained between 18th and 22nd storey. Maximum storey drift found to be 0.001682.shown in fig.6

3. COMPARISON OF ANALYSIS RESULTS

3.1. *Comparative study*

Obtained values for maximum displacement and interstorey drift are given below in table 1.

Table 1: Analysis Results- Comparison

Building type	Maxi. Top storey displacement(mm)	Maximum inter story drift(m)
Hybrid 1	100	0.001257

Hybrid 2	57	0.000637
Hybrid 3	227	0.013310
Hybrid 4	154	0.001682

It is observed that maximum top storey displacement obtained for braced hybrid structure (Hybrid2) is comparatively lower than other type structures. Maximum top storey displacement obtained for a 36 storey Diagrid structure is found to be 61.5mm [Khushbu Jani , Paresh V. Patel]. Here hybrid type having lower displacement than diagrid structure. Inter storey drift for Diagrid structure is 0.000634.

3.2. *Material consumption*

The consumption of steel is calculated for all buildings. It is observed that the consumption of material for hybrid 2 and 3 is higher than the usual diagrid structure building. The consumption of a normal Diagrid structure and the braced hybrid2 structure is around 2000MT. Steel consumption for hybrid 3 and 4 is much higher than this value.so from the proposed models, one of the hybrid models consumes a lesser quantity of steel and we can say it can be better replacement for diagrid.

4. CONCLUSION

In this paper, a new proposal of hybrid of diagrid-tubular structure is presented here. A regular floor plan of 36m x 36m size is considered. ETABS 13 software is used for modelling and analysis of structure. Analysis results like displacement, storey drift for wind loading are presented here. Also comparison is done on the basis of material consumption.

We conclude from the study that,

- Hybrid 2 shows the better performance under wind loading. It having less top storey displacement than diagrid structure.
- Hybrid 2 possess almost same interstorey drift as diagrid structure.
- Bracing system very effective in providing resistance against lateral loading.
- Hybrid Diagrid structure system provides more economy in terms of consumption of steel as compared to other structural system.
- Diagrid structural system provides better flexibility in interior space planning and façade of the structure.

So the proposed hybrid modelling like 25% braced tubular building system and 75% diagrid building system is effective than Diagrid structure in terms of maximum top storey displacement and inter storey drift.

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