Comparison of the performance of concrete-filled steel tubular and hollow steel diagrid buildings

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Abstract. In the recent construction scenario, diagrid structures are becoming a popular high-rise building structural system. Diagrid structures consist of diagonals in the perimeter and an interior core. The corner and interior vertical columns are not required due to the structural efficiency of diagrid structural systems. Steel and concrete are commonly used material for diagrid. An alternate material for diagrid is concrete-filled steel tube (CFST). CFST incorporates the advantages of both steel and concrete. In CFST, the inward buckling of the steel tube is effectively prevented by the filled concrete. The compressive strength of concrete increases due to the tri-axial state of stress in concrete induced by the steel tube. The longitudinal as well as lateral reinforcement to the concrete core is also provided by the steel tube. This paper compares the performance of CFST and steel diagrid buildings using linear static analysis. For this purpose, a 12 storey and 36 storey building are analysed using finite element method and CFST diagrid building is found to perform better.

1. Introduction
The growth in population and urbanisation has led to the prevalence of high rise buildings in the modern era. In the case of high rise buildings, lateral load and gravity load becomes important. Based on the position of lateral load resisting elements, structures are classified into interior and exterior structures. In interior structures, lateral load resisting elements is located within the structure (e.g. outrigger structures). Diagrid structures are exterior structures wherein the lateral load resisting elements are situated at the periphery of the structure. Diagrid structures consist of diagonals in the perimeter and an interior core i.e. it consist of a network of triangular grids or number of diagrid modules. A diagrid module extends over 2 to 6 storeys. The angle of diagonal with the horizontal is known as diagrid angle. The structural action of diagrid module is depicted in figure 1(a) and (b). The advantage of diagrid is that the gravity and lateral load is transferred through the axial action of the member in contrast to the bending action in conventional buildings. Some of the examples of diagrid structures are Hearst Tower in New York, Swiss Re building in London, West Tower in Guangzhou (figure 2). Hollow steel tube and concrete are the commonly used material for the diagrids, steel being more popular. The disadvantage of hollow steel tube is that it is susceptible to local buckling which is overcome by concrete-filled steel tubes (CFST). The tri-axial state of stress induced by the steel tube also increases the compressive strength of concrete.

Hence in this paper, a CFST diagrid building is analysed and its comparison with hollow steel diagrid buildings is done in order to establish the advantage of CFST over hollow steel tube.
2. Analysis of CFST diagrid building

For the present study, a 12 storey building of plan dimension 24m x 24m and storey height 3.6m is adopted. The plan and elevation of the diagrid building are shown in figure 3. The diagrid angle is kept constant throughout. The slab thickness is 150mm. The interior frame of the diagrid structures, consisting of beams B1 (ISMB550), B2 (ISWB600 with top and bottom plates of 220 × 50 mm) and interior composite column (of dimension 1500 × 1500mm), is designed considering gravity load only. At the periphery, diagonals are CFST members of 375 mm diameter and 12 mm thick filled in with M20 concrete. A design dead load of 3.75 kN/m² and live load of 2.5kN/m² is applied on the floor slab. The specifications as per IS: 1893-2002 is used in the computation of design earthquake load, which is fixed considering zone factor 0.16, importance factor 1, response reduction factor 5 and medium soil[3]. A wind speed of 30 m/s and terrain category III is considered for computation of design wind load as per IS: 875(III)-1987 specifications. ETABS software is used for modelling and analysis of CFST diagrid building. Beam elements are used to model beams and columns and truss elements are used to model diagrids. The support conditions are assumed to be hinged. The specifications as per IS: 800-2007 is used to carry out design of members.
The results of the analysis are presented with respect to time period, storey displacement and inter-storey drift. Storey drift is the ratio of relative displacement of two adjacent stories to the storey height. The time period of 12 storey CFST diagrid building corresponding to twelve modes is given in figure 4.

![Figure 3](image_url)

**Figure 3.** Plan and elevation of 12 storey CFST diagrid building.

![Figure 4](image_url)

**Figure 4.** Time period of CFST diagrid building.

The storey displacement and inter-storey drift of CFST diagrid building is plotted in figure 5(a) and 5(b) and it is found to be more for earthquake load as compared to wind load.
3. Comparative analysis of CFST and hollow steel diagrid building

The comparative analysis between 12 storey CFST and hollow steel diagrid building is done with respect to time period, storey displacement and inter-storey drift. For this, diagrids are modelled as hollow steel tube of 375mm diameter and 12mm thick and 12 storey hollow steel diagrid building is modelled with the same plan dimensions. The columns and beams are the same as that mentioned in CFST diagrid building. The first mode time period of CFST diagrid building is 0.73 s, whereas for hollow steel diagrid building is 0.901 s. The time period of CFST and hollow steel diagrid buildings is shown in figure 6.

![Figure 6. Time period of CFST and hollow steel diagrid building.](image)

The storey displacement of CFST and hollow steel diagrid buildings due to earthquake and wind load is plotted in figure 7 (a) and 7 (b). The storey displacement of CFST diagrid building is found to be lower than hollow steel diagrid building. The top storey displacement is found to reduce by 19% and 39% in the case of earthquake and wind load respectively. The inter-storey drift of CFST diagrid building is also lower than hollow steel diagrid building.
A 36 storey CFST and hollow steel building of plan 36m x 36m is also modelled and analysed similar to the 12 storey building. The plan and elevation is given in figure 8. The dimensions of beams and columns are the same as mentioned before. Upto the 18th storey, the diagonals of diameter of 450 mm and 25 mm thick is provided and from 18th to 36th storey diagonals of diameter of 375 mm and 12 mm thick is provided.

The percentage reduction in storey displacement and inter-storey drift is used in assessing the performance of CFST and hollow steel diagrid buildings. The results of 12 and 36 storey buildings as presented in table 1 shows that CFST diagrid building perform better than hollow steel diagrid building. The graphs and plots as part of the results of the analysis are avoided for brevity.
**Table 1. Comparison of performance of different diagrid buildings**

| Parameter                  | Percentage Reduction |
|----------------------------|----------------------|
|                            | 12 storey building   | 36 storey building |
|                            | EQX                  | WindX              | EQX                  | WindX              |
| Storey displacement        | 19%                  | 39%                | 17%                  | 33%                |
| Inter-storey drift(max)    | 17%                  | 37%                | 19%                  | 35%                |

4. Conclusions
The analysis of 12 storey CFST diagrid building is carried out using ETABS and performance is compared with hollow steel diagrid building. It is found that the time period, storey displacement and inter-storey drift of CFST diagrid building is lower than hollow steel diagrid building. CFST diagrid building is more effective as indicated by the percentage reduction of top storey displacement. Similar analysis of 36 storey diagrid buildings is also carried out. In a 12 storey building earthquake load is found to be critical whereas for a 36 storey building wind load is critical. The percentage reduction in earthquake and wind load for both 12 storey and 36 storey buildings showed similar trends and it can also be inferred that diagrid buildings are more effective in case of wind loads.

5. References
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