Comparative Study on Seismic Performance of Steel Diagrid Structures with and Without Dampers

M. Vishali, S. Pradeep, and K. S. Satyanarayanan

1 Introduction

Tall buildings are fundamentally a reaction to the extreme weight on the accessibility of land. Advances in analytical technique, material, structural system for analysis, construction technology and design quickened the advancement of tall structures. The sidelong loads because of quakes and wind are the central point that causes the structure of tall business structures. The lateral loads resisting systems used widely are mainly Braced Tube System, Tubular System, Shear Wall-Frame, Outrigger System, Rigid Frame, and Diagrid Systems. Of late, the Diagrid Structural System is ending up generally famous and featuring solution in the plan of tall structures because of its Esthetically Dominant and Inherent Structural. The Diagrid is a diagonally intersecting framework of a metal, concrete or timber beams that are used for the construction of buildings and roofs. They carry both Gravity loads and Lateral loads. Because of their triangulated design, inward hub powers emerge in the part and the structure are much more effective in minimizing shear deforming [1–3]. Most diagrid structural systems are fabricated from steel and few of them are only constructed with concrete. The main principle is to eliminate the vertical segments present at the border of the building. The corner to corner converging structure goes about as both slanted segments and as propping components [4].

An early case of the diagrid structure is the IBM building (Fig. 1a) in Pittsburgh work in the mid-1960s, which has 13 storeys. The Central China Television (CCTV) (Fig. 1b) in Beijing built in 2004, it is a 51-storey skyscraper. The Swiss Re in London (Fig. 1c) is another famous example of diagrid structures all around the world, it was

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(a) (b) (c) (d) (e)

Fig. 1 **a** IBM building **b** CCTV **c** Swiss Re **d** Hearst Tower **e** Cyclone Tower

constructed in 2003 which has a 41-storey 180-m building height. Hearst tower in New York (Fig. 1d) which was constructed in 2003, has a 60 storeys and 182 m of building height. The cyclone tower in Asan, South Korea (Fig. 1e), which has 55 storeys, 284 m in height.

The major difference between a diagrid structure and a braced tube structure is that the diagrid structures carry both gravity loads as well as lateral loads and there are no vertical segments present in the border of the structure though in supported cylinder structure they convey just horizontal burdens and vertical segments are available in the edge of the structure [5]. Diagrid system can be of crystalline, planar or take on multiple curvatures and these save approximately 20% of structural steel weight when compared to conventional frame structures [6].

2 Analytical Work

2.1 Descriptions of Model and Material Properties

The modeling of the conventional structural system has been stimulated as shown in (Fig. 2a and c). The system consists of 50 storeys with a plan dimension of 40 m × 20 m as per aspect ratio (H/L) is 4.5. The system consists of an inner core and an outer perimeter column. The outer perimeter consists of a closely spaced column at 4 m to the center that forms a tube. The inner core consists of closely spaced columns. The inner core resists gravity loading while the outer perimeter column resists lateral loading. The columns are fixed at the base.

The modeling of diagrid steel structures has been stimulated as shown in Fig. 2b and d. The system consists of 50 storeys with a plan dimension of 40 m × 20 m as per aspect ratio (H/L) is 4.5. The system consists of an inner core and outer diagonal elements. The outer perimeter consists of diagrid element of angle 62° at 8 m spacing along the perimeter for the entire structure. The inner core consists of closely spaced columns. The inner core resists the gravity loading while the outer diagrid resists the lateral loading. The columns and diagrid are fixed at the base.

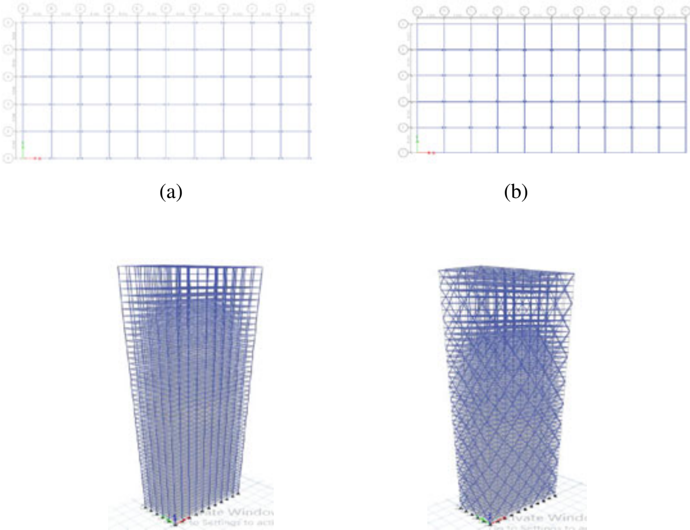

Fig. 2 **a** Plan of the conventional steel system **b** Plan of the diagrid steel system. **c** Model of the conventional steel system **d** Model of the diagrid steel system

The structural element such as beams, diagrids and columns that has the basic steel properties while the chunks are considered of RCC. In diagrid structures, there are two different behavioral characteristics that are observed as Model-A (Diagrid structures with corner columns) as shown in (Fig. 3a and c) and Model-B (Diagrid structures without corner columns) as shown in (Fig. 3b and d) [7]. Comparisons between these two models are also compared and results are analyzed based on effective structures for tall buildings and more interesting in aesthetic choice.

The modeling of diagrid steel structures with dampers has been stimulated as shown in Fig. 4a and b. The system consists of 50 storeys with a plan dimension of 40 m × 20 m as per aspect ratio (H/L) is 4.5. The system consists of an inner core and outer diagonal elements. The outer perimeter consists of the diagrid element of angle 62° at 8 m spacing along the perimeter for the entire structure. The inner core consists of closely spaced columns. The inner core resists the gravity loading while the outer diagrid resists the lateral loading. The columns and diagrid are fixed at the base. The friction dampers are introduced in the diagrid intersecting points. In damper, data properties are the total mass of the damper which is 44 kg and the weight of the damper is 250 kN.

Dampers are defined as essentialness setback in the response over the interval of time. Vitality dispersal includes factors, for example, materials, radiation of soil, and so forth. A clear comprehension of damping is required for consolidating its impact on the structure. The state of reaction bend doesn't change by damping; however, the extents are diminished. The significance of damping is the point at which the structure has much retaining limit than the seismic vitality then it can withstand the

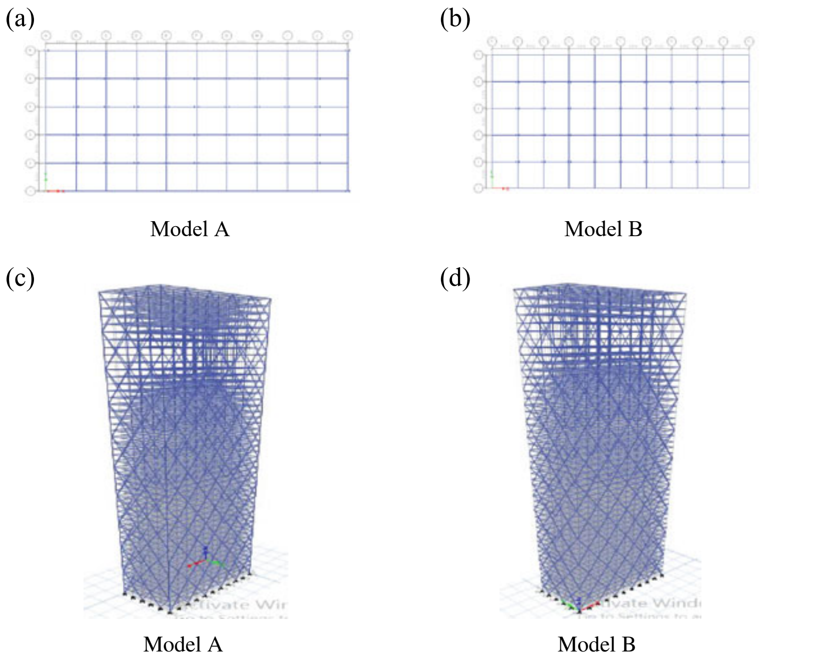

Fig. 3 **a** Plan of the diagrid structure with corner columns **b** Plan of the diagrid structures without corner columns **c** Plan of the diagrid structure with corner columns **d** Plan of the diagrid structures without corner columns

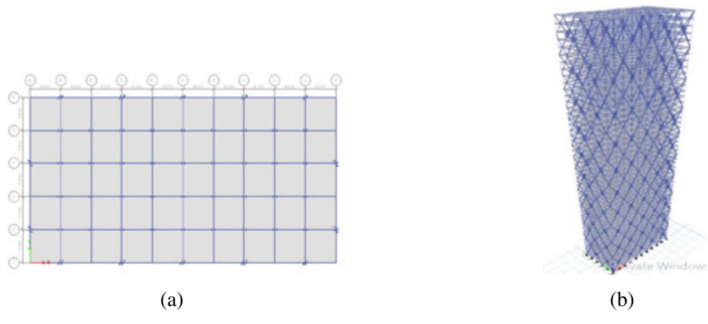

Fig. 4 **a** Plan of the diagrid steel system with damper. **b** Plan of the diagrid steel system with damper

Fig. 5 Elecentro function graph

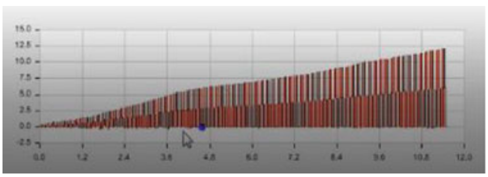

Table 1 The physical premises and information of the model

Description	Values
Storey height	3 m
Structural type	Steel frame
Types of dampers	Friction damper
Steel section	Fe250
Concrete section	M25
Column section	ISHB 450
Beam section	ISMB 400
Diagrid section	ISMB 250
Dead load	3 KN/m^2
Live load	4 KN/m^2
Floor slab	250 mm
Steel design code	IS 800:2007

auxiliary harm. Relatively soft type of damping can be utilized as a plausible method for diminishing the basic harm. Friction dampers are a kind of damper. Among others, highlights of these dampers can be delegated maintaining a strategic distance from exhaustion in served burdens and their execution free to stacking speed and surrounding temperature. These dampers are introduced in parallel to supporting. Because of direct lead and easy to present and make this sort of damper is changed over to a champion among the most sorts of crushing dampers.

The modeling and analysis are done using ETABS software. The dead loads and live loads are taken as per IS875:1987(Part1) and IS875:1987(Part 2) [8, 9]. The wind load is taken as per IS875:1978(Part 3) [10]. Response spectrum analysis has been done for two models.

The input values and earthquake load are in accordance with the Indian standard IS1893 (part 1)-2002 [11]. The structure is considered to be in Zone III with a zone factor of 0.16. Importance factor I is 1.5. Response reduction factor R is 5 as specified for special moment-resisting frames. Type 2 medium soil is selected. When the structure vibrates the amplitude decreases due to internal friction and absorbed energy. This damping is taken as 5% for steel structures. The square root of sum of squares (SRSS) method of modal combination is chosen. The physical premises and information of the model for the present study has been shown in (Table 1).

2.2 Analysis

2.2.1 Time History Analysis

In time history investigations, the auxiliary reaction is processed at various consequent time moments. To perform such an examination, an agent seismic tremor time

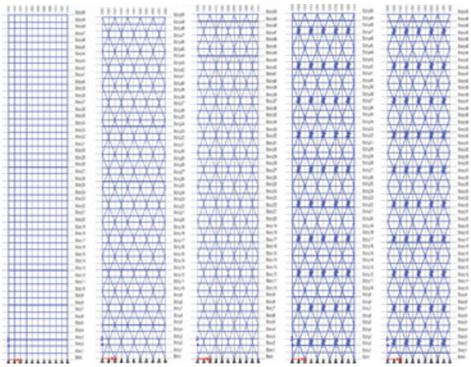

Fig. 6 Typical elevation for model 1, 2, 3, 4, 5

history is required for a structure being assessed. In this function, Elecentro is being used, because it is the most dangerous and disastrous earthquake. The values at equal intervals are 0.02. The Elecentro function for time history analysis is shown in Fig. 4.

In load case data, the initial condition should be zero. The load applied in the direction should be acceleration whereas the function is Elecentro and the scale factor has been calculated (Eq. 1).

$$\text{The scale factor } = (\mathbf{Ig}/\mathbf{R}) * (\mathbf{0.85} * \textbf{Static bases hear}/\textbf{Response} - \textbf{spectrum base shear}) \tag{1}$$

In the number of output time steps when there are a greater number of steps, the accurate values can be determined. The model damping has a constant value of 0.05 (Fig. 5).

The comparison of seismic analysis using time history analysis is going to be done between these models followed below and the typical elevation of the below models are shown in (Fig. 6).

Model 1-Conventional structure.
Model 2-Diagrid structure with corner columns.
Model 3-Diagrid structure without corner columns.
Model 4-Diagrid structure with corner columns using dampers.
Model 5-Diagrid structure without corner columns using dampers.

3 Results Comparison and Discussion

3.1 Maximum Storey Displacement

In storey displacement, it represents the correlation of the most extreme storey removals for every structure. It is observed that the general relocation esteems are very higher for traditional structures that have appeared in Fig. 7. Along these lines,

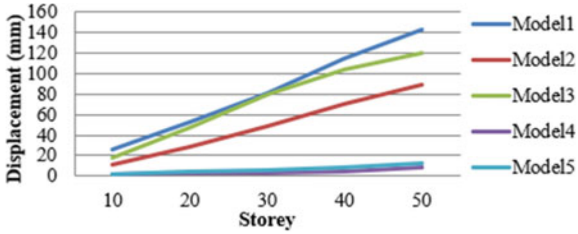

Fig. 7 Maximum storey displacement

it demonstrates the viability of diagrid structures, whereas the displacement values for the structure using dampers are lesser compared to all the structures. Hence, it is proved that the effectiveness of diagrid structures using dampers is more, which is 83% higher when compared to conventional structures.

3.2 Maximum Storey Drifts

The storey drifts of 50-storey diagrid structures with and without dampers and conventional structures are compared. It is observed that the inter-storey drifts of diagrid structures using dampers are less compared to conventional structures that has been stimulated as shown in (Fig. 8). The maximum storey drifts for conventional structures have occurred between storey 15 and 20. The maximum storey drifts for conventional systems are 0.000923. The maximum drifts for diagrid structures using dampers have occurred between storey 15 and 20. The maximum storey drifts for diagrid structures using dampers are 0.000654, which is 29% lesser than the conventional structure.

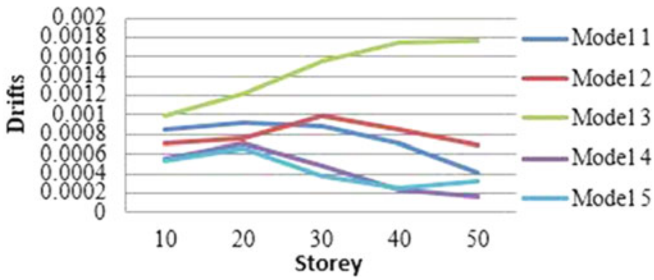

Fig. 8 Maximum storey drifts

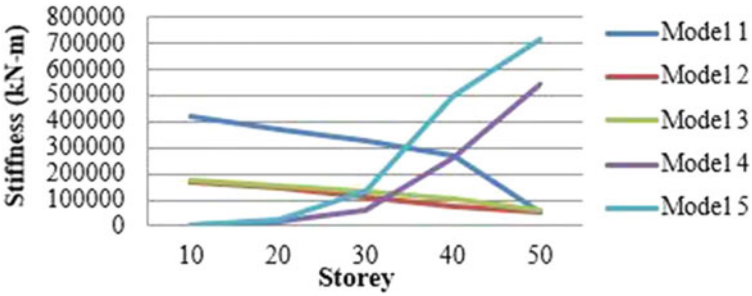

Fig. 9 Storey stiffness

3.3 Storey Stiffness

The comparison of the storey stiffness for the conventional structures and diagrid structures using with and without dampers is being observed. The stiffness of diagrid structures with dampers is gradually increased when compared to the other structures, which is 92% higher than the conventional structures. Whereas the remaining structures expect diagrid structures with dampers are gradually decreased as shown in (Fig. 9).

3.4 Storey Shear

The comparison of the storey shear for all the models have been compared. It is observed that each storey shear is taken from the bottom of the storey. The base shear is 64% more for conventional structures when compared with diagrid structures; whereas it is 93% less when compared with diagrid structures using dampers has been stimulated as shown in Fig. 10.

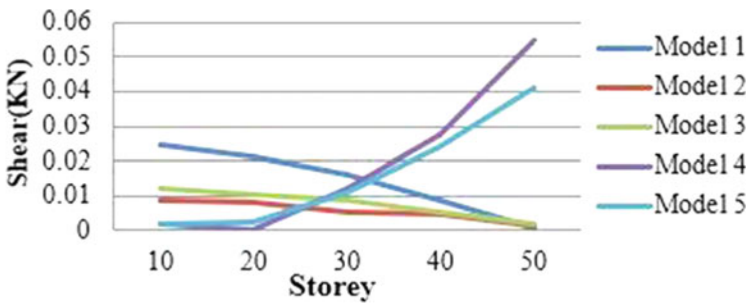

Fig. 10 Storey shear

4 Conclusion

The seismic analysis of 50-storey conventional steel structures and diagrid steel structures with and without dampers has been completed. From this result, it is clear that diagrid structure with dampers has maximum strength and lateral load resistance than a conventional structure. The stiffness of the diagrid structure with a damper is 13 times higher than the conventional structure. Diagrid structures with dampers have the minimum storey displacement and storey drift compared to the conventional structure. Thus, the seismic execution of the structure is enhanced and the basic effectiveness is expanded.

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