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# Comparative Analysis of a Diagrid Structure and a Conventional Structure with Chevron Bracing

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## Abstract

This work investigates models of diagrid structures and conventional braced frame structures with different symmetric and asymmetric plan geometries. For the purpose of analysis, two symmetric and two asymmetric structures were modeled and analyzed using linear static method for each of the two structural types. Hollow mild steel pipes were considered as exterior diagrids whereas ISA angle sections were considered for exterior bracing. It was observed that the diagrid structures' performance against the lateral loads was much better than that of the conventional braced frame structure and that the member stiffness in diagrid structures' elements were of much greater magnitude than the conventional braced structure despite the fact that all peripheral vertical columns are eliminated from the diagrid structure. The top storey displacements in the diagrid models are less compared to the conventional braced frame models. The storey shear for diagrid models is much less than that of conventional braced frame models which is because the seismic weights of diagrid structures are less than the seismic weights of the conventional braced frame structures.

**Keywords:** Chevron bracing, Diagrid structures, Seismic Analysis.

## INTRODUCTION

There have been numerous innovations being carried out by architects in order to plan a good looking and an unconventional building which will be regarded as more than ordinary. In order to plan a good looking and an unconventional building, architects are trying many new challenging models and are giving them a distinct feature both internally as well as on its facade. Now it's the duty of a structural engineer to design such models safely and also consider economical nature of the same. Diagrid models are one of those wherein all the vertical columns get eliminated and diagrids are installed on its facade which gives a pleasant look architecturally but when structural point of view is concerned, there is an immediate urge to figure out and analyse the pros and cons which will be into occurrence and also to clearly differentiate the structural behaviour of such diagrids and regular conventional structures indulging with bracings on its facade. The nature of building perimeters has more structural significance in tall buildings than in any other building type due to their very tallness, which means greater vulnerability to lateral forces, especially wind loads. Thus, it is quite desirable to concentrate as much lateral load-resisting system components as possible on the perimeter of tall buildings to increase their structural depth, and, in turn, their resistance to lateral loads [1]. One of the most typical exterior structures is the diagrid structures which provides both bending and shear rigidity.

## LITERATURE REVIEW

Moon, K.S. et. al. [2] presented a simple methodology for determining preliminary member sizes. They examined the influence of the diagonal angle on the behaviour of diagrid type structures. Based on the studies, they concluded that the structural and architectural decisions at the early stage of design can be made in a more integrative and efficient way and the characteristics and methodology for preliminary design of diagrid structural systems were discussed. Moon, K.S. [3] illustrated a paper which presents a stiffness-based design methodology for determining preliminary member sizes of steel diagrid structures for tall buildings. Based on the design studies, it was suggested to use a varying angle diagrid structure for a very tall building with its aspect ratio bigger than about 7 and a uniform angle diagrid for a tall building with its aspect ratio smaller than about 7 as to save structural materials and, in turn, to create more sustainable built environments. Kim, J. et. al. [4] analysed model diagrid structures of 36-story. According to the analysis results the diagrid structures showed higher over strength with smaller ductility compared with the tubular structure. It was also observed that as the slope of braces increased the shear lag effect increased and the lateral strength decreased. Both the strength and ductility of diagrid structures increased significantly when the diagonal members were replaced by buckling-restrained braces.

The above mentioned studies are carried on various aspects with respect to the architectural, aesthetical, angular aspects of the diagrid structure. They also involve the seismic effects that indulge in a diagrid structures' behaviour[5-8]. The proper angle of inclination of the diagrid is studied and furthermore the complexity of the node construction has been emphasized [9]. Primarily, the various studies focus on strategies to enhance the performance of a building against lateral forces especially earthquake [10]. There was an urge to study the significant effects of various parameters on the governing lateral and gravity loads being carried out by the interior and exterior portions of the structure and also the behaviour of the structure which would come into picture if the diagrid on the exterior is being replaced by simple bracing using ISA angle sections, and to consider the parameters such as story drift, displacement, distribution of storey shear developed due to various loading patterns and various loading combinations.

## METHODOLOGY

Two structural models are taken into account for this study, which are Diagrid model and Conventional model with Chevron Bracing. The work is divided into two parts, 2 models of each type, in total there are 4 models named D-1, D-2, B-1, and B-2. The categorization of the models is as shown in Table 1. The geometric details are shown in Table 2. The properties of diagrid and bracing frame are indicated in Table 3. The loading is given as per Indian Standards [11-17] and are indicated in Tables 4-5. The plan and 3D elevations of the building models used in the study are as depicted in Figures 1-8.

**Table 1:** Categorization of the models used in the study

| Model Notation | Category of Model |
|---|---|
| D-1 | Diagrid Structure corresponding to a Symmetric base plan |
| B-1 | Chevron Braced Conventional Structure corresponding to a Symmetric Base plan |
| D-2 | Diagrid Structure corresponding to an Asymmetric base plan |
| B-2 | Chevron Braced Conventional Structure corresponding to an Asymmetric Base plan |

**Table 2:** Geometric Details of the building models

| Item Description | Criteria |
|---|---|
| Plan Dimension | 24x24 m |
| No. of Stories | 16 storey |
| Height of each Storey | 3.6 m |
| Depth of Foundation | 3.5m |
| End Condition of Footing | Fixed Support |
| Support condition of Diagrid connecting node | Pin Support |
| RCC Slab thickness | 120 mm |
| Span between two successive columns | 3 m |
| Panel size obtained | 3x3 m |
| Size of RCC Columns | 0.6 x 0.6 m |
| Size of RCC Beams | 0.23 x 0.38 m |
| Grade of Concrete adopted | M40 |
| Grade of Steel adopted | Fe550 |

**Table 3:** Properties of Diagrid and Bracing Section

| Item Description | Criteria |
|---|---|
| Size of Diagrid | 350 mm |
| Thickness of Diagrid | 12 mm |
| Angle of Diagrid | 74.9° |
| Section of Diagrid | Hollow Mild Steel Pipe section |
| Chevron Bracing section | ISA Steel Section |
| Size of Bracing section | 150x150x15 mm |

**Table 4:** Details of the loading applied on models

| Item Description | Criteria |
|---|---|
| Dead Load on terrace level | 5 KN/sq.m |
| Dead Load on Floor level | 4 KN/sq.m |
| Live Load on terrace level | 1.5 KN/sq.m |
| Live Load on floor level | 4 KN/sq.m |

**Table 5:** Seismic and Wind load parameters

| Item Description | Criteria |
|---|---|
| Seismic Zone considered | Zone 5 |
| Zone Factor | 0.36 |
| Importance Factor | 1 |
| Rock and Soil type factor | 2 |
| Response Reduction factor | 3 |
| Basic Wind speed considered | 44 m/s |
| Terrain Category | 3 |
| Class of structure | Class C |
| Probability factor | 1 |
| Topography factor | 1 |

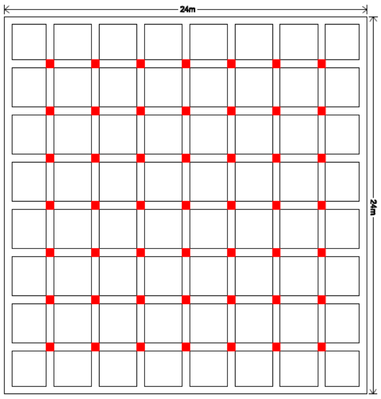


**Figure 1:** Floor Plan for model D-1

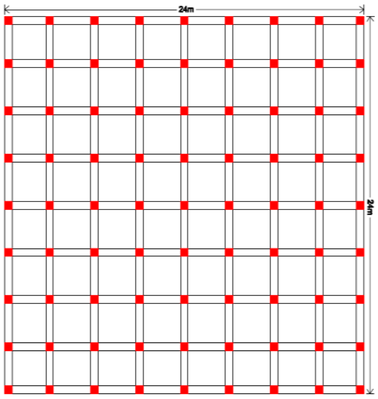


**Figure 2:** Floor Plan for model B-1

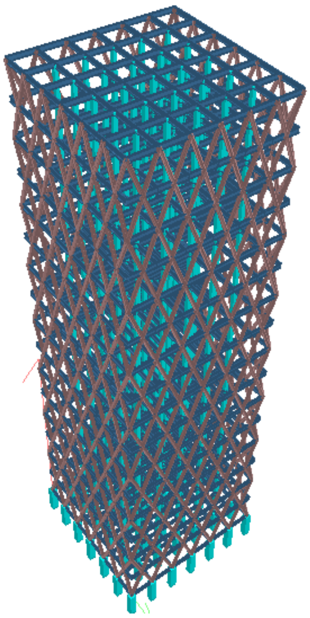

**Figure 3:** 3-D elevation for model D-1

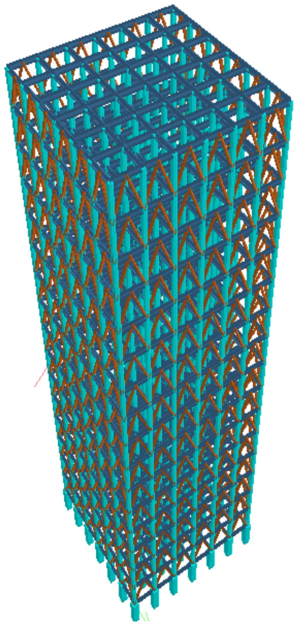

**Figure 4:** 3-D elevation for model B-1

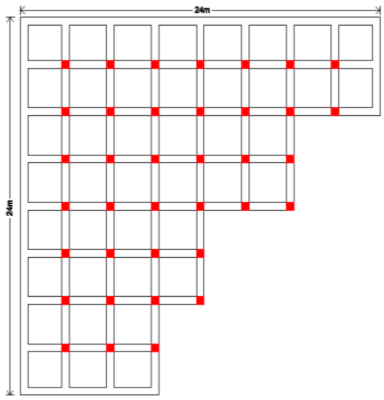


**Figure 5:** Floor Plan for model D-2

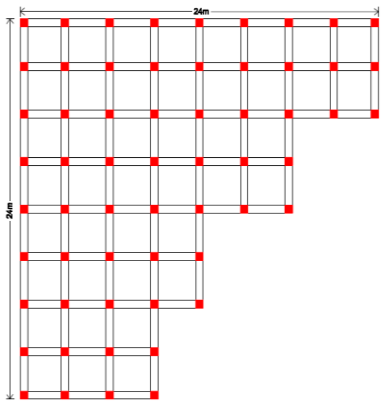


**Figure 6:** Floor Plan for model B-2

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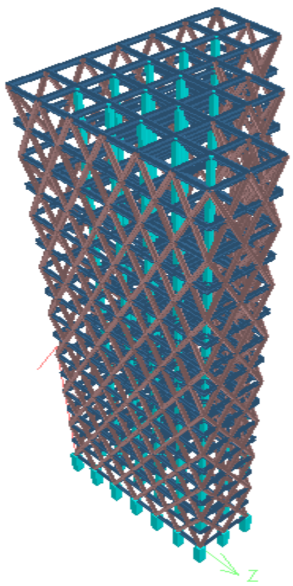

**Figure 7:** 3-D elevation for model D-2

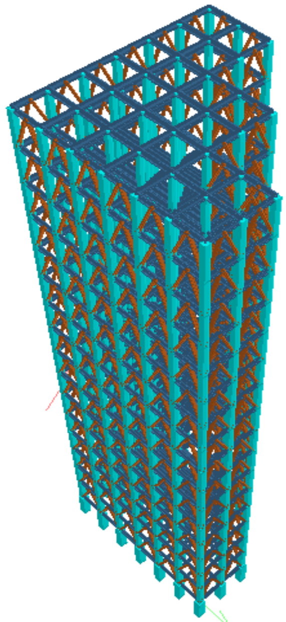

**Figure 8:** 3-D elevation for model B-2

## RESULTS AND DISCUSSION

### Distribution of Loads on Structural Models

The gravity load and lateral load distribution in exterior frame and interior frame of the models D-1 and B-1 is shown in Table 6. Figure 9 shows the percentage of loading carried by exterior and interior frames of both the models. Despite that all the vertical columns in the periphery are eliminated in the Diagrid structure D1, exterior frame takes maximum amount of lateral load whereas for the braced structure B1, interior frame takes more lateral load. For the gravity loading, in both models D1 and B1, the interior frame takes the maximum amount of the loading. The model D1 takes 94% of lateral load on the exterior frame without any exterior columns as compared to model B1 taking 39% along with presence of all exterior verticalcolumns, while interior frames of model D1 and model B1 take 6% and 61 % of lateral load respectively. The amount of gravity loads taken by exterior and interior

**Table 6:** Distribution of loads in exterior and interior frame of both structural models D-1 and B-1

| Type of Loading | Diagrid building D1 | | | Conventional Braced building B1 | | |
|---|---|---|---|---|---|---|
| | Total loading (KN) | Loading on Interior frame (KN) | Loading on Exterior frame (KN) | Total loadin g (KN) | Loading on Interior frame (KN) | Loading on Exterior frame (KN) |
| Gravity loading | 76,825 | 47,135 | 29,690 | 49,953 | 44,263 | 5,690 |
| Lateral loading | 16,716 | 996 | 15,720 | 55,980 | 34184 | 21,796 |

**Table 7:** Distribution of loads in exterior and interior frame of both structural models D-2 and B-2

| Type of Loading | Diagrid building D2 | | | Conventional Braced building B2 | | |
|---|---|---|---|---|---|---|
| | Total loading (KN) | Loading on Interior frame (KN) | Loading on Exterior frame (KN) | Total loading (KN) | Loading on Interior frame (KN) | Loading on Exterior frame (KN) |
| Gravity loading | 48,632 | 20,453 | 28,178 | 54,159 | 17,549 | 36,610 |
| Lateral loading | 31,206 | 3860 | 27,346 | 38,176 | 2631 | 35,545 |

frame are 39% and 61% respectively in model D1 while that in model B1 it is 11% and 89% respectively.

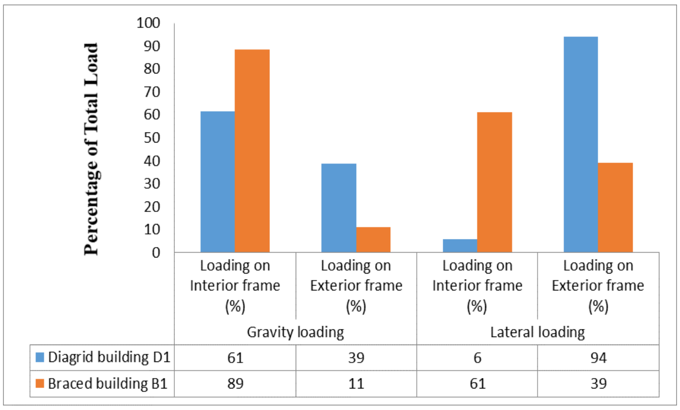


**Figure 9:** Percentage of loading carried by exterior and interior frames of both the models D-1 and B-1

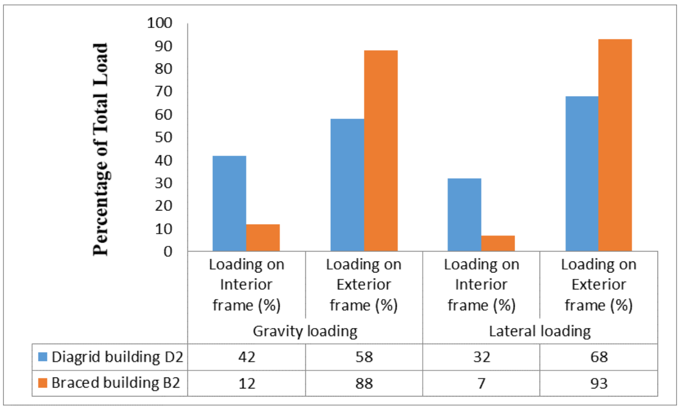


**Figure 10:** Percentage of loading carried by exterior and interior frames of both the models D-2 and B-2

## Storey Shear

Figures 11 – 12 shows the distribution of storey shear (Q) with respect to the number of storeys and Figures 13 - 14 shows the distribution of base shear (V) with respect to the number of storeys for the building models considered.

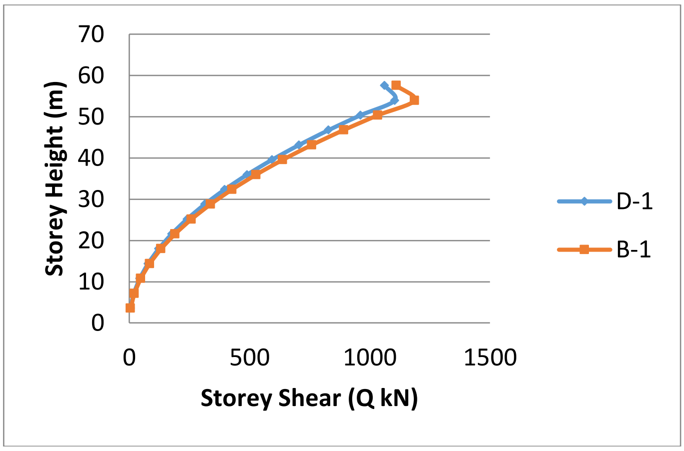


**Figure 11:** Storey shear of model D-1 and B-1

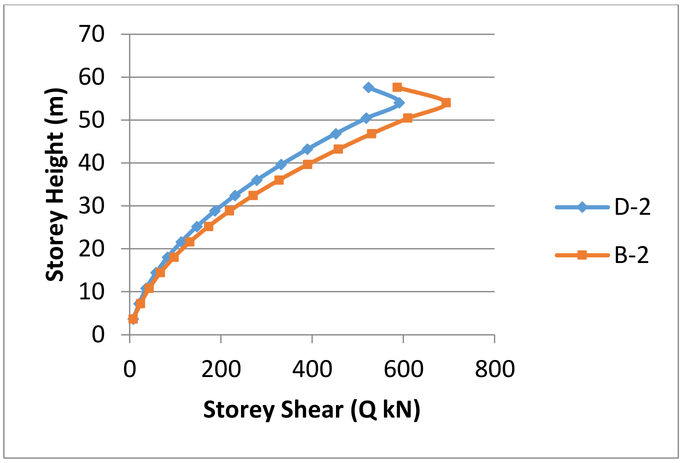


**Figure 12:** Storey shear of model D-2 and B-2

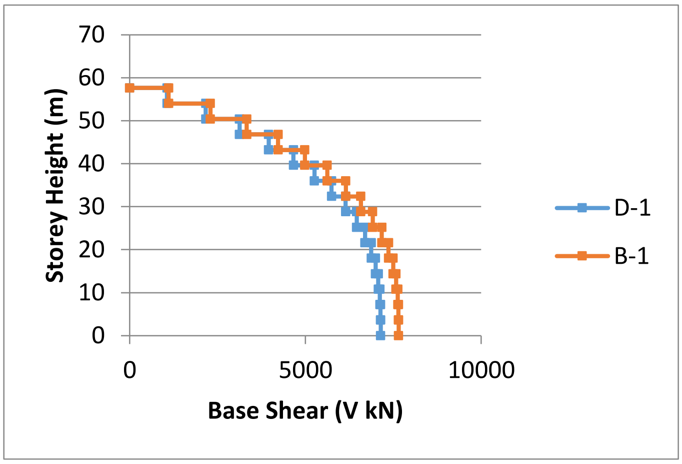


**Figure 13:** Base shear of model D-1 and B-1

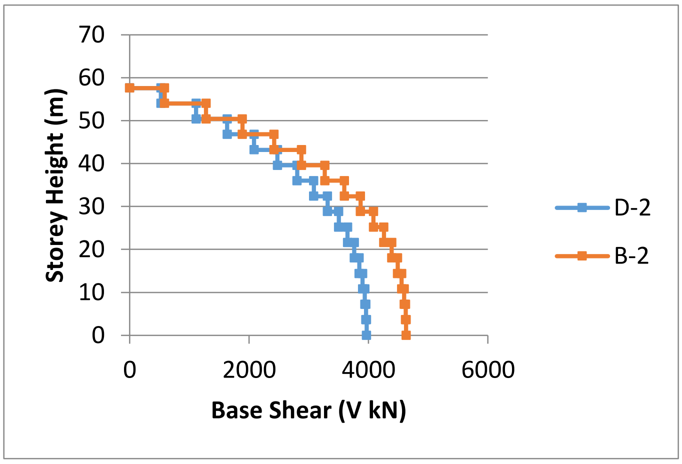


**Figure 14:** Base shear of model D-2 and B-2

The storey shear in the models D-1 and D-2 is much less than that of the models B-1 and B-2. This is because the seismic weights of diagrid structures are less than the conventional braced frame structures due to the absence of peripheral columns. But conventional braced frame structures have peripheral columns, thus there is more added weight of those structural elements and hence it has more values of design lateral force or storey shear.

**Storey Displacement**

The graphical representation of displacements of diagrid models and braced frame models are shown in Figures 15 – 16. It is noted that top storey displacement of diagrid structure is less as compared to that of braced frame structure.

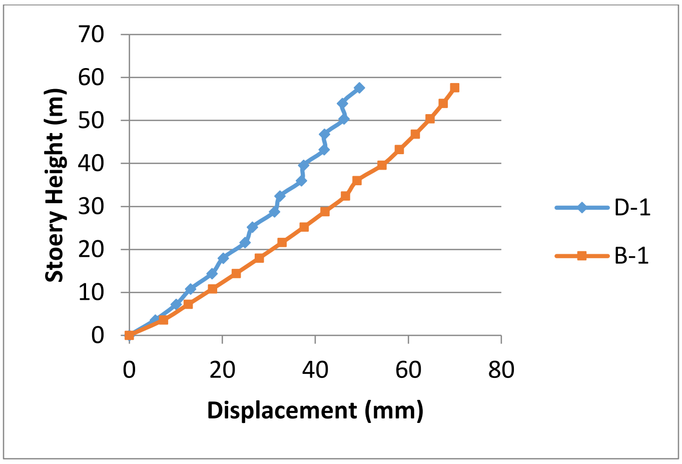


**Figure 15:** Displacement of model D-1 and B-1

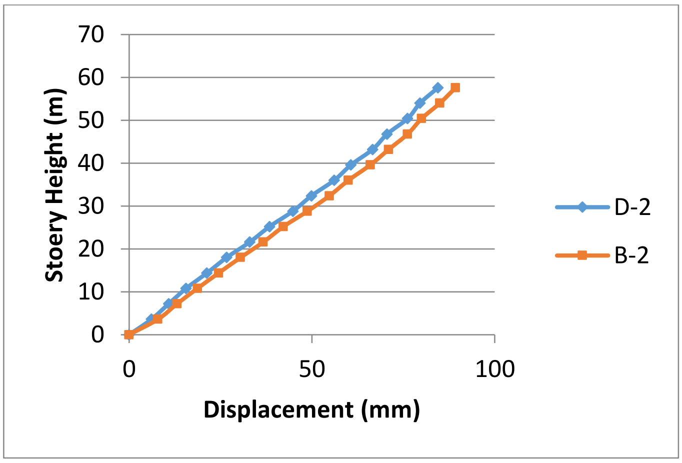


**Figure 16:**Displacement of model D-2 and B-2

When lateral storey displacement is concerned, the top storey displacements in the models D-1 and D-2 are less when compared to the models B-1 and B-2. In D-1 model, displacement is 49.5mm while in B-1 it is 70mm. The displacements in the models D-2 and B-2 are 84.5mm and 89.3mm respectively. Allowable lateral displacement of top storey is limited to Height/500. All values are well within the allowable limits.

**Storey Drift**

The Figures 17 – 18 depict the storey drift of the diagrid and braced frame models. The top storey drift values for models D-1 and D-2 are more than that for B-1 and B-2. In D-1 model, the drift is 3.6 mm while in B-1 it is 2.5mm. In models D-2 and B-2 the drift is 4.9 mm and 3.9mm respectively. Allowable top storey drift is 0.004*$h_s$. All values are well within the allowable limits.

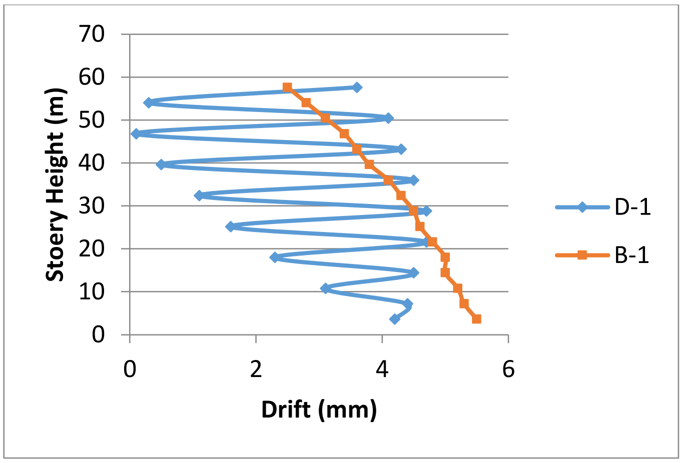


**Figure 17:**Storey Drift of model D-1 and B-1

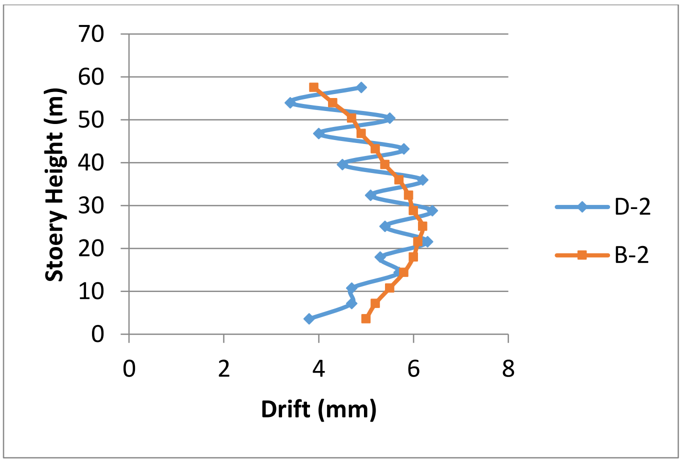


**Figure 18:**Storey Drift of model D-2 and B-2

It is observed that there is a steep fluctuation of storey drift values for both the diagrid models at every passing level but there is a gradual flow of pattern observed in conventional braced frame model for the same. The major reason for the fluctuation of storey drift at every passing storey of both the diagrid models is the fact that the diagonal grid is a 2-storey module and it has its ends supported on a particular storey. But in the next immediate storey, the diagrid makes an intersection into each other and that intersection is being connected to a design plate on the beam which makes it even more firm. Therefore, in this way, multiple supports are being connected to the beam level in the form of a design plate and the intersecting conjunction of two different mild steel pipe sections which makes that particular storey level even more stiff and firm. Then for the next particular storey, those two diagonal sections meet separately at a joint between two perpendicular beams and not in the centre of beam unlike the previous case. Therefore, the first level is prone to have a lesser storey drift and the second level has a greater storey drift.

Then immediately the storey drift for third level will fall down drastically due to the presence of design plates and intersecting conjunction of two different mild steel pipe sections at the centre of the beam and subsequently, the fourth level will have a greater storey drift as the diagonals are meeting at the ends at joints of two perpendicular beams and also they are meeting in the form of a single entity. Therefore, when there is a design plate and two mild steel pipe sections intersecting at the centre of the beam, the storey drift for that particular storey is less, whereas, when the pipe sections are meeting as a single unit into the perpendicular beam joint at the ends for the next immediate level, the storey drift tend to increase drastically.

## CONCLUSIONS

The diagrid elements give sufficient efficiency to lateral loads considering the fact that all the peripheral vertical columns from the diagrid structures have been eliminated. Thus, without the presence of the peripheral columns, the diagrids are able to take a gradual amount of lateral loads. We can also conclude that diagrids give more resistance to lateral displacements when compared to conventional braced frame structures. By observing these results, we can also make a statement that the diagrids are giving more member stiffness than the conventional braced structures. In the end, diagrid structures give more aesthetic look and gives more interior space due to less columns and facade of the building can also be planned more efficiently.

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