COMPARATIVE STUDY OF SEISMIC CHARACTERISTICS OF DIAGRID STRUCTURAL SYSTEMS IN HIGH RISE CONSTRUCTION

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ABSTRACT

Diagrid structural system has led to significant innovations in architectural and structural concepts. In case of high rise structures, the lateral load resistance is usually provided by interior or exterior structural systems. Adoption of diagrid structural system in high rise construction provides better structural efficiency in resisting lateral load along with flexibility in architectural planning. Such system consists of inclined columns on the exterior surface of buildings instead of closely spaced vertical columns in framed structures. This paper presents a comparative study of seismic characteristics of diagrid structural systems for multi-storey structures. The results based on numerical models indicate that these structures can address most of the present-day design requirements. The study aims to explore the applicability of diagrid structures in high rise structures, over the traditional construction systems. Numerical models and seismic characteristics of diagrid members have been studied using software SAP-2016.

Key words: Diagrid, High Rise, Optimum Angle, Stiffness.


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1. INTRODUCTION
Before the 20th century, research was carried out to analyse the effectiveness of diagonal bracing members in tall structures to resist lateral forces. The structural importance of diagonals was well recognised, their aesthetic potential was not explicitly appreciated[1].

The change in design approach took place when braced tubular structures were introduced in the late 1960s. For the 100-story tall John Hancock Building in Chicago, the diagonals were located along the entire exterior perimeter surfaces of the building to maximise their structural effectiveness and capitalise on the aesthetic innovation[2].

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. Elimination of vertical columns is possible because the diagonal members in diagrid structural systems can carry gravity loads as well as lateral forces, whereas the diagonals in conventional braced frame structures carry only lateral loads.[3][4][5]

2. BUILDING CONFIGURATION
2.1. Types of Models
In the present study, two different set of models were considered. One for 18 storeys and other for 36 storeys structure with three different angles of diagrid viz., - 45°, 64°, 72°, and 90° (simple frame). In all, eight different models were analysed. The analysis is done as two-dimensional plane frames [4][6][7].

The mathematical models based on above configurations were analysed using software SAP-2016.

2.2. Geometry Data
Following is the general information about the geometry of the models.
   i. Bay width: 12m
   ii. Storey height: 3m
   iii. Characteristic strength of steel: 450 N/mm²
The number of storeys in each type of module decided the angle of diagrid. e.g.
   a) Angle 45° is for Two-storey module,
   b) Angle 64° is for Three storey module, and
   c) Angle 72° for a Four storey module.

Based on above considerations following models were studied further.
Comparative Study of Seismic Characteristics of Diagrid Structural Systems in High Rise Construction

Figure 1. 18 Storey structures with different angles of Diagrid.

a) Simple frame. b) Diagrid at 45°. c) Diagrid at 64°. d) Diagrid at 72°

Figure 2. 36 Storey structures with different angles of Diagrid.

a) Simple frame. b) Diagrid at 45°. c) Diagrid at 64°. d) Diagrid at 72°
Table 1 Material properties

<table>
<thead>
<tr>
<th>Material</th>
<th>$F_y$ (Yield stress)</th>
<th>$F_u$ (Tensile stress)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel STY 310</td>
<td>310 N/mm²</td>
<td>450 N/mm²</td>
</tr>
</tbody>
</table>

Table 2. Loads patterns

<table>
<thead>
<tr>
<th>Type</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead Load</td>
<td>12 kN/m</td>
</tr>
<tr>
<td>Live Load</td>
<td>5 kN/m</td>
</tr>
<tr>
<td>Seismic (Earthquake) Load</td>
<td></td>
</tr>
<tr>
<td>(IS-1893-2002)[8]</td>
<td>-Seismic Zone factor: 0.10</td>
</tr>
<tr>
<td></td>
<td>-Soil Type II</td>
</tr>
<tr>
<td></td>
<td>-Importance Factor 1</td>
</tr>
<tr>
<td></td>
<td>-Response Reduction 5</td>
</tr>
</tbody>
</table>

2.3. Structural Plan

The member sizes for the different models were same. The following structural characteristics were analysed concerning different angles of the model.


Table 3 Member sizes for the 18-storey model.

<table>
<thead>
<tr>
<th>MEMBER</th>
<th>$S$</th>
<th>$F$</th>
<th>45°</th>
<th>64°</th>
<th>72°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams</td>
<td>HEB 600</td>
<td>45°</td>
<td>64°</td>
<td>72°</td>
<td></td>
</tr>
<tr>
<td>Columns 1st, 2nd, 3rd</td>
<td>500<em>500</em>36</td>
<td>500<em>500</em>36</td>
<td>500<em>500</em>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columns 4th, 5th, 6th</td>
<td>450<em>450</em>32</td>
<td>450<em>450</em>32</td>
<td>450<em>450</em>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columns 7th, 8th, 9th, 10th</td>
<td>450<em>450</em>28</td>
<td>450<em>450</em>28</td>
<td>450<em>450</em>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columns 11th, 12th, 13th, 14th</td>
<td>400<em>400</em>28</td>
<td>400<em>400</em>28</td>
<td>400<em>400</em>28</td>
<td></td>
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</tr>
<tr>
<td>Columns 15th, 16th, 17th, 18th</td>
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<td>400<em>400</em>25</td>
<td>400<em>400</em>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagonals</td>
<td>Ø244 - 8mm</td>
<td>Ø244 - 8mm</td>
<td>Ø244 - 8mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4 Member sizes for the 36-storey model.

<table>
<thead>
<tr>
<th>MEMBER</th>
<th>$S$</th>
<th>$F$</th>
<th>45°</th>
<th>64°</th>
<th>72°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams</td>
<td>HEB 600</td>
<td>45°</td>
<td>64°</td>
<td>72°</td>
<td></td>
</tr>
<tr>
<td>Columns 1st, 2nd, 3rd, 4th</td>
<td>650<em>650</em>50</td>
<td>650<em>650</em>50</td>
<td>650<em>650</em>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columns 5th, 6th, 7th, 8th</td>
<td>600<em>600</em>50</td>
<td>600<em>600</em>50</td>
<td>600<em>600</em>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columns 9th, 10th, 11th, 12th</td>
<td>600<em>600</em>40</td>
<td>600<em>600</em>40</td>
<td>600<em>600</em>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columns 13th, 14th, 15th, 16th</td>
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<td>550<em>550</em>40</td>
<td>550<em>550</em>40</td>
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<tr>
<td>Columns 17th, 18th, 19th, 20th</td>
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<td>550<em>550</em>36</td>
<td>550<em>550</em>36</td>
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</tr>
<tr>
<td>Columns 21st, 22nd, 23rd, 24th</td>
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<td>500<em>500</em>36</td>
<td>500<em>500</em>36</td>
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<tr>
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<td>500<em>500</em>32</td>
<td>500<em>500</em>32</td>
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<td></td>
</tr>
<tr>
<td>Columns 29th, 30th, 31st, 32nd</td>
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<td>450<em>450</em>32</td>
<td>450<em>450</em>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columns 33rd, 34th, 35th, 36th</td>
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<td>400<em>400</em>28</td>
<td>400<em>400</em>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagonals</td>
<td>Ø323 – 12.5mm</td>
<td>Ø323 – 12.5mm</td>
<td>Ø323 – 12.5mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 RESULT ANALYSIS

Dynamic analysis of the models is performed based on following criteria -
1) Storey Displacements 2) Storey drifts 3) Time period, 4) Base shear.

3.1. Storey Displacement

The displacement results for the 18-storey model and 36-storey model are presented. For all the models, the only lateral load considered is seismic (earthquake) load.

![Figure 4. Displacements for 18 storey structures](image)

![Figure 5. Displacements for 36 storey structures.](image)

3.2. Storey Drift

![Figure 6. Storey drift for 18 storey structures.](image)
The limitations for drift is addressed in the AISC’s Steel Design Guide Series No. 3: Serviceability Design Considerations for Low-Rise Buildings, as well as in the MBMA Metal Building Systems Manual. They recommend maximum drift is expected between H/60 and H/100 where H is the building height. \[11\][12] The storey drift value is within the permissible limit.

### 3.3. Time Period

- **Figure 7** Storey drift for 36 storey structures.
- **Figure 8** Time period for 18 storey structures
- **Figure 9** Time period for 36 storey structures.
3.4. Base Shear

![Figure 10](image)

**Figure 10** Base shear 18 storey structures

![Figure 11](image)

**Figure 11** Base shear 36 storey structures.

4 DISCUSSION OF RESULTS

4.1. Top Storey Displacement and Drift

![Figure 12](image)

**Figure 12** Top storey displacement
From above graph, it is seen that the displacement is less for the diagrid angle of 64° for the 36-storey model. It is less for the diagrid angle 45° for the 18-storey model.

The maximum drift for the 18-storey model is 540 mm, and the maximum drift for the 36-storey model is 1080 mm.

4.2. Time Period

![Time Period Graph]

**Figure 13** Time period

It can be observed that the first mode time period is minimum for angle region 45° to 64°.

4.3. Material Consumption

![Steel Weight Graph]

**Figure 14** Structure weight

It can be observed that,

- **18 STOREYS:** Diagrid angle within a range of 45° to 64° provides better economy regarding consumption of steel for such type of structures.
- **36 STOREYS:** Similar to 18 storey structures diagrid structures with angles in the range of 45° to 64° degrees provide better economy regarding the use of steel.
5. CONCLUSION

- In 18 storey structures use of Diagrid angle in the region of 45° to 64° provides more stiffness which reflects in lesser top storey displacement. For 36 storey Diagrid structures angles in the range of 64° to 72° display lesser top storey displacement.

- The storey drift and storey shear results are much lesser in the region of diagrid angle 45° to 64° to structures with 18 storeys. For structures with 36 storeys, the storey drift and storey shear results are lesser in the region of diagrid angle of 64°.

- Diagrid angles in the region 45° to 64° are more economical regarding consumption of steel as compared to other angles of diagrid.

- The optimum angle of diagrid is observed around 64°. At this angle, top storey displacement being lesser, the storey drift is also much lesser. So, it is more economical regarding consumption of steel because though it has similar weight as in the case of diagrid angle 45°, but it has lesser number of joints.

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REFERENCES


