Common Framework—Study on Mechanical Properties of Frame—Grid Frame Structure

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ABSTRACT

Grid frame is a new structural system with mechanical properties between shear wall and frame. Grid frame is introduced into frame structure. Compared with a practical project, it is shown that grid frame can improve the overall stiffness of frame structure, reduce the story drift, and weaken the sudden change of structural stiffness. The better mechanical properties of the frame provide the foundation for the practical application of the grid structure in the future.

KEYWORD

Frame, Grid frame, Mechanical Properties

INTRODUCTION

Frame structure is the most widely used structural form at present, when the overall lateral stiffness is small, it is difficult to be used in high-intensity, high-rise systems [1]. The space structure team headed by Academician Ma Kejian has studied the frame and its related systems for many years[2]. He put forward a new system "grid frame structure" and successively developed assembled integral steel grid frame structure, new reinforced concrete grid box-in-tube structure, new assembled integral space steel etc. Mesh frame plays an important role in all systems with excellent performance, and has achieved good mechanical properties and economic benefits. The lattice frame is introduced into the ordinary frame to

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improve the mechanical properties of the ordinary frame by taking advantage of its high stiffness, good energy dissipation and good ductility. This system is called the ordinary frame-grid frame hybrid structure system.

GRIDFRAME STRUCTURE

Reinforced concrete grid frame is the same as general frame in form, both are composed with the beams and columns, which are the basic stressed components of reinforced concrete, but when composing basic frame system, it is different from Common frame structure. Firstly, There is not only one frame beam is arranged at the height of the story in grid framework, but also one to three frame beams are arranged between the stories. The spacing of the lattice frame columns is generally three times as large as that of the ordinary frame columns, so that the single grid formed by the ordinary frame beams and columns is changed into N small grids. As shown in Figure 1.

![Figure 1. Schematic diagram of frame and grid frame.](image)

The results[3-6]show that: the grid frame has the advantage of large lateral stiffness when the same material amount is used with the common frame. In engineering practice, the displacement angle and the vertex displacement between stories are smaller than those of the ordinary frame, and the lattice frame has more super-static under earthquake action. Under rare earthquakes, the lattice frame columns have less plastic hinges, most of them are in the bottom floor, and the development is not very serious”. In this paper, the common frame-grid frame hybrid structure is studied from the mechanical properties, technical indicators and other aspects, hoping to obtain some excellent performance key control factors of the new structural system, laying a good foundation for the further engineering application of the system.
MECHANICAL PERFORMANCE OF FRAME-GRID FRAME STRUCTURE

Based on the design of an office building, this paper studies its mechanical performance through comparative analysis of frame structure and frame-grid frame structure.

Project Profile

The office building is rectangular, whose X direction length is 50.4m with column spacing 8.4m and Y direction length is 19.8m with column spacing 8.4m\3m\8.4m. Its height is 20.7m with story height 4.2m on first floor and 3m on second to sixth floor. Whose seismic precautionary intensity is 8 degrees, design basic acceleration of ground motion is 0.20 gal, site-class is II, and design earthquake group is 1st group. The damping ratio of the structure is 0.05. The reference wind pressure is 0.45 kN/m2. Main loads on the floor include dead load (not including the slab weight, considering partition of rooms locating arbitrary) and active load. The value of dead load is 3.0 kN/m2, and the value of active load is 2.5 kN/m2.

Structural Models

Models of Frame structure and frame-grid frame structure are established.

FRAME STRUCTURE MODEL

The frame structure takes 6 spans along X direction, with column spacing 8.4m and 3 spans along Y direction, with column spacing 8.4m\3m\8.4m.

In the first story, the section size of the inner frame columns is 650mm x 650mm, while the section size of the outside frame columns is 600mm x 600mm. And, the section size of main beams is 350mm x 600mm and 250mm x 600mm. In the second story, the section size of the frame columns is 600mm x 600mm. And, the section size of main beams is 300mm x 650mm and 250mm x 700mm. In the third story, the section size of the frame columns is 550mm x 550mm. And, the section size of main beams is 250mm x 650mm and 250mm x 700mm. In the fourth story, the section size of the frame columns is 500mm x 500mm. And, the section size of main beams is 250mm x 650mm and 250mm x 600mm. In the fifth story, the section size of the inner frame columns is 400mm x 400mm, while the section size of the outside frame columns is 500mm x 500mm. And, the section size of main beams is 250mm x 600mm. In the sixth story, the section size of the frame columns is 400mm x 400mm. And, the section size of main beams is 250mm x 600mm. Otherwise, the section size of secondary beams of all floors is 250mm x 500mm. The concrete strength grade of beam, column and slab are all C30, and the steel bar is all HRB400. See Figure2 for the model diagram.
FRAME - GRID FRAME STRUCTURE

The frame-grid frame structure model has the same plane size. Specially, grid frames are located in the four corners of the structure. The spacing of grid frame columns is 2.1m. The spacing of grid frame beam is half of story height.

To ensure the better ductility and lateral stiffness of net-frame structure, the span-depth ratio of beam and column should be in the range of 4 to 5. For the first floor of building, from $2,100/4 =525$mm and $2,100/5 =420$mm, it is concluded that its section size of beam and column should be $400\text{mm} - 550\text{mm}$, the section size should be $450\text{mm} * 450\text{mm}$ for column and $250\text{mm} * 500\text{mm}$ for inter-layer beam. Considering the heavy load of floor beam, the section size of floor beam at the top grid frame is $250\text{mm} * 600\text{mm}$. Considering the larger torsion of the structure corners, the section size of corner columns is $600\text{mm} * 600\text{mm}$. Similarly, on the other floor, the section size is $250\text{mm} * 500\text{mm}$ for inter-layer beam and $250\text{mm} * 600\text{mm}$ for floor beam, the section size of column is $450\text{mm} * 450\text{mm}$ or $400\text{mm} * 400\text{mm}$, the section size of corner column is $500\text{mm} * 500\text{mm}$ or $400\text{mm} * 400\text{mm}$.

In the first story, the section size of the frame columns is $600\text{mm} \times 600\text{mm}$. In the second story, the section size of the inner frame columns is $550\text{mm} \times 550\text{mm}$, while the section size of the outside frame columns is $500\text{mm} \times 500\text{mm}$. In the third story, the section size of the inner frame columns is $500\text{mm} \times 500\text{mm}$, while the section size of the outside frame columns is $450\text{mm} \times 450\text{mm}$. In the fourth story, the section size of the inner frame columns is $450\text{mm} \times 450\text{mm}$, while the section size of the outside frame columns is $400\text{mm} \times 400\text{mm}$. In the fifth and sixth story, the section size of the frame columns is $400\text{mm} \times 400\text{mm}$.

Otherwise, the section size of main beams of all floors is $250\text{mm} \times 600\text{mm}$, and the section size of secondary beams of all floors is $250\text{mm} \times 500\text{mm}$. The concrete strength grade of beam, column and slab is all C30, and the steel bar is all HRB400. See Figure3 for the model diagram.

For the convenience of comparison, in the two models, the slab span is $4.2\text{m} \times 3\text{m}$ and $4.2\text{m} \times 4.2\text{m}$, and the slab thickness is $110\text{mm}$. 
**Main Performance Index**

**NATURAL VIBRATION CHARACTERISTICS**

Table 1 shows the first three natural frequencies of the two structures. As can be seen from the following table, the period of frame structure is longer than that of frame-grid frame structure for 36.71 percent.

The first two periods of the two structures are translational, and the third period is torsional. The ratio of torsional period to the first period is 0.85 for frame structure, and 0.657 for frame-grid frame structure. It can be seen that the torsional stiffness of frame-grid structure is larger and the its torsional performance is better. The cycle ratios of the two structures both meet the code requirements.

<table>
<thead>
<tr>
<th>Structure System</th>
<th>Mode</th>
<th>Period</th>
<th>Dynamic Characteristics</th>
<th>Period Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame Structure</td>
<td>T1</td>
<td>1.199</td>
<td>X translation</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>1.172</td>
<td>Y translation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>1.0195</td>
<td>torsion</td>
<td></td>
</tr>
<tr>
<td>Frame-Grid Frame Structure</td>
<td>T1</td>
<td>0.874</td>
<td>X translation</td>
<td>0.657</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>0.846</td>
<td>Y translation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>0.576</td>
<td>torsion</td>
<td></td>
</tr>
</tbody>
</table>

It can be seen from the above table that the period of frame-grid frame structure is smaller and the stiffness is larger.

**SHEAR-WEIGHT RATIO OF STRUCTURE**

According to the current code for seismic design of buildings (GB50011-2010), in areas with seismic precautionary intensity of 8 degrees, the minimum seismic shear force of each floor shall not be less than 3.2% of the floor representative values of gravity load (minimum shear factor). As shown in table 2, both systems comply with the code requirements.

<table>
<thead>
<tr>
<th>Structure System</th>
<th>Level</th>
<th>Floor Shear (X Direction)</th>
<th>Seismic Shear Factor %</th>
<th>Floor Shear (Y Direction)</th>
<th>Seismic Shear Factor %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame Structure</td>
<td>1</td>
<td>3143.48</td>
<td>5.603</td>
<td>3471.7</td>
<td>5.699</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3139.11</td>
<td>6.204</td>
<td>3194.59</td>
<td>6.313</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2754</td>
<td>6.805</td>
<td>2805.52</td>
<td>6.932</td>
</tr>
<tr>
<td>Frame-Grid Frame Structure</td>
<td>1</td>
<td>4627.89</td>
<td>7.382</td>
<td>4765.14</td>
<td>7.601</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4293.72</td>
<td>8.245</td>
<td>4428.98</td>
<td>8.505</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3807.79</td>
<td>9.103</td>
<td>3933.4</td>
<td>9.403</td>
</tr>
</tbody>
</table>
STORY DRIFT ROTATION OF STRUCTURE

The story drift rotation mainly limits the horizontal displacement of the structure under regular service condition, ensures that the structure has sufficient stiffness, and avoids excessive displacement which will affect the bearing capacity, stability and use requirements. The story drift rotation of the frame structure and frame-grid frame structure in this project are shown in Figure 4.

It can be seen from the above figure that the story drift rotation of frame structure just meets the requirements of seismic code, while the story drift rotation of frame-grid frame structure is 44.2% less than that of frame structure, and the stiffness is much larger than that of frame structure. Thus the mixed structure can reduce its column size and save material consumption. The maximum story drift curves of the two structures under earthquake action are shown in FIG. 5.

As can be seen from the above figure, the maximum displacement of the frame structure is 31.6mm in X-direction and 30.9mm in Y-direction, while that of the frame-grid frame structure is 21.8mm in X-direction and 20.8mm in Y-direction. Displacement curve of frame-grid frame structure is different from the shear type of frame structure or bend type of shear wall, but similar to linear type. As shown in figure 7, drift curve is similar to linear type at the bottom part and shear type at the upper part. It shows that grid framework plays more important role in a frame-grid frame structure, similar to the role of shear walls in frame-shear wall structure.

Calculations suggest that the maximum story drift ratio is 1.03 in x-direction and 1.19 in Y-direction. The maximum story drift ratio is 1.02 in x-direction and 1.12 in Y-direction.
Y-direction. It can be seen that the two structures neither have sudden change in stiffness nor weak points. The stiffness of frame-grid frame structure is more uniform compared with frame structure.

CONCLUSIONS

Firstly, the frame structure has a smaller natural period and a better anti-seismic performance. Secondly, the story drift rotation of frame-grid frame structure is 44.2% less than that of frame structure, and the stiffness is much larger than that of frame structure. Thirdly, story drift curve is similar to linear type at the bottom part and shear type at the upper part, it shows that grid framework plays a more important role in the bottom part of frame-grid frame structure.

REFERENCES