Study on the Influence Factors of the Seismic Performance with Specially Shaped Columns Under Rare Earthquake

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Abstract. Based on the structural analysis software ANSYS, a three-dimensional dynamic analysis model of frame structure with specially shaped columns is established. The influence of ratio of section height to section thickness on the seismic performance of the frame structure with specially shaped columns is studied, and the relative ratio of section height to section thickness is determined. On the basis of ratio of section height to section thickness, the energy dissipation properties and failure mechanism of frame structure with the specially shaped columns under the rare earthquake are studied. The results show that the ratio of section height to section thickness has a certain influence on the seismic performance of the structure, and seismic performance of the structure is better when the ratio is close to 4.

1. Introduction
Specially shaped column is the abbreviation of special-shaped column. It refers to the column with L-shaped T shape and cross-shaped shape adopted according to the requirements of architectural design and layout under the premise of meeting the requirements of structural stiffness and bearing capacity. Because of the small thickness of the special-shaped column, the higher the height of the column, the lower the torsion resistance, the stress concentration at the intersection of the special-shaped column is concentrated, and even serious warping is produced[1~2]. In engineering design, the design and calculation method of special-shaped column frame structure has not been unified, most of them are designed by the existing structural design software. In the calculation, the special-shaped column is considered approximately by shear wall or rectangular column. But the reliability of the results is difficult to understand. Especially in the analysis of seismic performance of frame structures with special-shaped columns, there are many influencing factors, including the ratio of limb height to limb thickness, aspect ratio and axial compression ratio, etc[3~4]. In this paper, the ratio of limb height to limb thickness is the main objective. Dynamic time history analysis method is used to calculate and analyze three kinds of reinforced concrete special-shaped column frame structures with different ratio of limb height to limb thickness. The influence of the ratio of limb height to limb thickness on the seismic behavior of frame structures with special-shaped columns is studied, and the optimum ratio of limb height to limb thickness is selected, which provides a reference for future engineering design.

2. Analysis model
High limb segments refers to thickness ratio of each limb special-shaped columns column limb section height and thickness ratio, according to the structural design of reinforced concrete special-shaped columns "(JGJ 149-2017)[5] : the geometry of the section as L shape, T shape and cross, and the cross
section of each limb segments high thick limb than not greater than 4 column. Therefore, the establishment of a high limb segments were 2.7, 3.2, and 4.0 thickness ratio of three kinds of special-shaped column frame structure model, the engineering prototype of six layer reinforced concrete frame structure with special-shaped columns, fortification intensity of 7 degrees (0.15 g), site group in the first group, class II (feature period of 0.35 s). The structure is 5 span and the column distance is 7.2m. Horizontal 3 span, edge span of 6.0m, medium span 3.0m, the plane layout of the model is shown in figure 1, and the section size of the cross-section of the height of different limbs is shown in table 1, with the shape of L, T and cross. The structure height is 3.0m and the total structure height is 18.0m. The strength grade of the beam and column concrete in the structure is C40, and the strength of the stress longitudinal bar is HRB400. The concrete strength grade of floor slab is C40, its thickness is 120mm, and the distribution of reinforcement is arranged in two directions. The filling wall is made of concrete hollow block. All columns in the longitudinal reinforcement are 16, 20 φ stirrup for φ 10 @ 100, all along the column high encryption.

| Table 1. Column section size |
|-----------------------------|
| ratio of section height to section thickness | 2.7 | 3.2 | 4.0 |
| section height (mm) | 800 | 800 | 800 |
| section thickness (mm) | 300 | 250 | 200 |

In ANSYS finite element software, the element Beam189 is selected to simulate the beam and column of the special-shaped column frame. Unit Shell63 simulates the floor board of the special-shaped column frame. The reinforcement processing in beams, columns and plates is modeled after the adjustment of elastic modulus, and the foundation is simplified as a fixed-end constraint. Considering the nonlinearity of the structural material, the stress-strain relation of the material adopts the ideal elastoplastic relationship and is subject to the Von Mises yield criterion and its related flow law. According to the above conditions, the frame structure is simplified to a certain extent to form an analytical model. The calculation model of the special-shaped column structure in ANSYS finite element software is shown in Fig. 2.

3. Analysis results
The seismic waves selected in this paper are two natural seismic wave El-centro waves and Taft waves, an artificial wave, then amplitude modulation of its acceleration(The maximum earthquake acceleration at 7 degrees (0.15g) under rare earthquakes is 310 cm/s²), Seismic wave duration is taken as 20s and the time interval is 0.02s. Then, the dynamic time history analysis under the rare earthquake was performed. The results of dynamic analysis were based on the average of three waves.
3.1. Acceleration
Under the rare earthquake, the maximum acceleration of each floor of the three special-shaped column frame structures is shown in Table 2. The ratio of the maximum acceleration of each floor to the maximum acceleration of the ground is the acceleration amplification factor, and the coefficient curve is shown in Fig. 3.

Table 2. The max acceleration of each floor under rare earthquake

| acceleration (cm/s²) | floor | 0     | 1     | 2     | 3     | 4     | 5     | 6     |
|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| 2.7                  | 310.0 | 258.4 | 242.9 | 278.6 | 293.7 | 365.2 | 390.1 |
| 3.2                  | 310.0 | 229.8 | 253.2 | 255.1 | 280.5 | 326.0 | 373.6 |
| 4.0                  | 310.0 | 213.5 | 240.1 | 243.4 | 265.2 | 287.5 | 362.8 |

Figure 3. This is a figure with acceleration magnification curve.

For the special-shaped column frame structure model with three different cross-section heights and cross-sectional thickness ratios, the change trend of the floor acceleration amplification factor is as follows: From the first floor to the second floor, the trend is decreasing, and three or more layers begin to increase. The structural model with the ratio of section height to section thickness equal to 4.0 has the most uniform structural change. This is due to the fact that the structural model with a ratio of section height to section thickness of 4.0 is deeper into the plasticity, the plastic development in the middle of the structure is more uniform, and the overall plastic development trend is more obvious.

3.2. Displacement and Drift angle
The maximum displacements and drift angles of each floor of frame structure with specially shaped columns under rare earthquake are shown in Tables 3,4 and Fig. 4.

Table 3. The maximum displacement of each floor under rare earthquake

| displacement (mm) | floor | 1     | 2     | 3     | 4     | 5     | 6     |
|-------------------|-------|-------|-------|-------|-------|-------|-------|
| 2.7               | 8.07  | 25.24 | 45.62 | 66.87 | 85.70 | 100.20|
| 3.2               | 8.58  | 24.16 | 44.50 | 64.33 | 81.95 | 94.07 |
| 4.0               | 8.26  | 25.60 | 45.78 | 68.22 | 87.33 | 102.03|

Table 4. The maximum story drift angle of each floor under rare earthquake

| drift angle       | floor | 1     | 2     | 3     | 4     | 5     | 6     |
|-------------------|-------|-------|-------|-------|-------|-------|-------|
| 2.7               | 1/286 | 1/168 | 1/135 | 1/137 | 1/149 | 1/197 |
| 3.2               | 1/322 | 1/178 | 1/137 | 1/138 | 1/160 | 1/228 |
| 4.0               | 1/335 | 1/187 | 1/139 | 1/141 | 1/145 | 1/194 |
Figure 4. These two figures have been placed with the maximum displacement and story drift angle of each floor

In Tables 3, 4 and Fig.4, under the rare earthquake, the maximum story drift angle of the three model occurred in the third layer, which indicates that the third layer is the weak layer of the structure. The maximum story drift angles of the ratio of section height to section thickness equal to 2.7, 3.2, and 4.0 are 1/135, 1/137, and 1/139. The story drift angle of the frame structure with specially shaped columns in which the ratio of section height to section thickness is 4.0 is smaller than that in which the ratio of section height to section thickness are 2.7 and 3.2. It can be seen that the special-shaped column frame structure with a ratio of the cross-sectional height to the cross-sectional thickness is 4.0 is good in seismic performance.

3.3. Shear force

Under rare earthquakes, the shear forces between the floors of the three special-shaped column frame structures are shown in Table 5 and Fig.5.

Table 5. The max shear force of each floor under rare earthquake

| shear force (kN) | floor 1  | floor 2  | floor 3  | floor 4  | floor 5  | floor 6  |
|------------------|---------|---------|---------|---------|---------|---------|
| ratio of section height to section thickness | 2.7     | 5787    | 4968    | 4370    | 3736    | 3314    | 2903    |
|                  | 3.2     | 5671    | 4828    | 4176    | 3513    | 3115    | 2725    |
|                  | 4.0     | 5597    | 4784    | 4110    | 3421    | 3063    | 2672    |

The interlaminar shear force of the frame structure with specially shaped columns with the ratio of section height to section thickness of 2.7 is the largest. The frame structure with specially shaped columns with the ratio of section height to section thickness of 3.2 and 4.0 has little difference in inter-layer shear force. The maximum values of the inter-story shear forces at the ratios of section height to section thickness of 2.7, 3.2, and 4.0 were 5787 KN, 5671 KN, and 5597 KN, respectively. With the increase of the ratio of the height of the section and the thickness of the section, the overall stiffness of the structure decreases, so the shear force of the structure decreases under rare earthquake.

The shear stress curve of the special-shaped column frame structure with a ratio of section height to section thickness of 4.0 is relatively flat. This shows that the structure with ratio of section height to section thickness equal to 4.0 is more more evenly affected by the earthquake and the seismic performance is better.
3.4. Energy consumption

In the Engineering aseismic test, Energy dissipation coefficient is used to quantify energy dissipation capacity of the structure. The energy dissipation coefficient $E$ can be calculated as follows:

$$E = \frac{S_{(ABC+CD)} + S_{OE}}{S_{(OBE+ODF)}}$$

As shown in the figure 6, Area ABCD is the energy dissipated in a week of hysteretic curve. The area OBE is the imaginary elastic line OB that is surrounded by the same displacement OE (That is the energy absorbed). The ratio of energy dissipated to the equivalent elastomer produces the same displacement as the input energy is expressed by the ratio of the curve ABC area to the triangle area OBE. The higher the ratio, the greater the energy dissipation coefficient, the stronger the dissipation capacity of the structure.

Based on this, a comparative analysis was made on the energy dissipation capacity of the special-shaped column frame structures with the section height to section thickness ratio of 2.7, 3.2 and 4.0 respectively. In the case of the rare earthquake, the energy dissipation energy of the frame structure with the section height to section thickness ratio of 4.0 was 708.83KN•m, the energy dissipation energy of the frame structure with the section height to section thickness ratio of 3.2 and 2.7 was 637.99KN•m and 588.79KN•m respectively. It is shown that the energy dissipation energy is larger and the structure is more earthquake-resistant when the frame structure of the special-shaped column with the section height to section thickness ratio is 4.0.

3.5. Plastic development

The plastic development cloud picture of three special-shaped column frames in the rare earthquake is shown in Fig. 7.

It can be seen from figure 7, the plastic development trend of the special-shaped column frames structure of different ratio of section height to section thickness is basically the same, This is because the three structures are the same as the frame structure. However, for the special-shaped frame structure of different ratio of section height to section thickness, there will be some difference in plastic development. When the ratio of section height to section thickness was 2.7, plastic development is the most uneven, the plastic hinge is mainly concentrated in the third layer of the structure, corresponding to the data obtained from the displacement Angle between layers; When the ratio of section height to section thickness was 3.2, the plastic development was better than the ratio of section height to section thickness was 2.7; but when the ratio of section height to section thickness was 4.0, the plastic development most uniform, compared to the other two structures, the plastic development is better, corresponding to the above interlayer displacement Angle. This illustrates when the ratio of
section height to section thickness was 4.0, not only the minimum displacement Angle, but also the most uniform plastic development. Therefore, the special-shaped column frames with the ratio of section height to section thickness was 4.0 was better.

4. Conclusions
In this paper, the influence of the ratio of section height to section thickness on seismic performance of the special-shaped column frame structure is studied. Under the rare earthquake, the three six-story frame with specially shaped columns has been established by selecting the ratio of section height to section thickness to 2.7, 3.2 and 4 respectively. Through dynamic time analysis, this thesis gets the following conclusion: the floor displacement and drift angle of the frame with specilly shaped columns with the ratio of section height to section thickness for 4.0 were smaller than that of the special-shaped column frame structure with the ratio of section height to section thickness for 2.7 and 3.2; The plastic development trend is basically the same of the special-shaped column frame structure of the different the ratio of section height to section thickness, the plastic development was better than that of the other two structures when the ratio of section height to section thickness was 4.0. As a whole, the special-shaped column frame structure with the ratio of section height to section thickness was 4.0 has better seismic performance.

Acknowledgments
This work was financially supported by the Natural Science Foundation in Jiangxi Province (Grant NO. 20161BAB206148 ) and Undergraduate scientific research fund project in Jiangxi Science &Technology Normal University (Grant NO. 201711318018 ).

References
[1] Li Jie, Wu Jianying, Zhou Deyuan, Experimental study on L shaped and Z shaped wide limb special-shaped columns under low cyclic loading[J], Journal of architectural structure, 2002, 23(01) :9-15.
[2] Rong Xian, Liang Yan, Wang Tiecheng, Experimental study on seismic behavior of reinforced concrete special-shaped column frame structure[J], Journal of natural disasters, 2006, 15(3):135-138.
[3] Tiecheng Wang, Lei Zhang, Hailong Zhao et al., Progressive collapse resistance of reinforced-concrete frames with specially shaped columns under loss of a corner column, Magazine of Concrete Research, 2016, 68 (9): 435-449.
[4] Peiqi Ren, Yi Li, Yulong Zhou et al., Experimental Study on the Progressive Collapse Resistance of RC Slabs, Structures Congress 2014: ASCE, 2015, 868-879.
[5] JGJ149-2017. Technical specification for concrete structures with specially shaped columns[S]. Beijing: Planning Press of China, 2017.