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Seismic behavior analysis of steel-concrete composite frame-RC core tube structures

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ABSTRACT. *In this paper, the 30-storey composite structures with outer steel-concrete composite frame and inner RC core tube were studied. The aseismic behaviors of the four structural models with different connections of coupling beams were analysed And behaviors of the deformation and the bearing force were coMPared. The results show that the shear-bearing ratio is laiyer and the cooperative working performance is better, with hinged connections between coupling beams and the RC core tube and fixed connections between coupling beams and RC columns or the fixed connections of the two ends. And the shear-bearing ratio is less and the cooperative working performance is poorer, with fixed connections between coupling beams and the RC core tube and hinged connections between coupling beams and RC columns or the hinged connections of the two ends. By discussing the behaviour of the structures, some conclusions can be help for the design of this kind of structure.*

KEYWORDS: *Composite frame-RC core wall; Concrete filled square steel tubular column; Steel - concrete composite beam; Connection type of the coupling beams; Aseismic behavior*

1. Introduction

With the in-depth study of concrete filled square steel tubular column[1-2] and steel-concrete composite beam[3], the steel-concrete composite frame with exterior consists of concrete filled steel tubular column and composite beam, and the frame-core tubular composite structural system with interior consisting of reinforced concrete core tube has been rapidly developed and applied in China in recent years[5]. At present, although systematic research has been carried out on the overall Aseismic behavior of the steel-concrete composite frame[6-8], the study on the steel-concrete composite frame-reinforced concrete core tubular structural system is less[9]; Especially, compared with the study of reinforced concrete frame-core and steel frame-core tubular structural systems, it is more necessary to study the overall performance of this new structural system in order to better apply it in practical engineering.

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Therefore, in this paper, general finite element analysis software SAP2000 is used to carry out modal analysis and elastic seismic response analysis on a typical steel-concrete composite frame-reinforced concrete core tubular model, and the deformation performance and mechanical performance of the structure under four different connection forms of connecting beams are compared, thus providing a reference for the design of this type of structure.

1. Structural model

The structural diagram of the calculation model is shown in Figure 1. The plane dimension of the structure is 30m×30m, and the core tubular dimension is 12m×12m, accounting for 16% of the plane area. The structure has 30 layers, in which the height of layer 1 to layer 8 is 4.5m, and the height of layer 9 to layer 30 is 3.6m, and the total height is 115.2m. The frame columns are concrete filled square steel tubular, and the beams are steel-concrete composite, and shear connectors are designed according to complete shear connection. The seismic fortification intensity of this building is 8 degree, and the site soil category is Class II, and the seismic degree is in first group. Dead load standard values are all 5.5kN/m2, and live load standard values are all 2.0kN/m2. See Table 1 for the sectional dimensions and material characteristics of the components.

Table 1. Section and Material Characteristics of Main Structural Components

Layer	Height of layer	Type	Cross section (mm)	Concrete strength grade	Type of steels
1F ～8F	4.5m	Thickness of the outer wall	800	C60	
		Thickness of inner wall	400	C60	
		Frame beam	1000×30	C50	Q345
		Frame beam	HN700×300	—	Q345
		Concrete floor	140	C30	
9F ～30F	3.6m	Thickness of the outer wall	600	C50	
		Thickness of inner wall	400	C50	
		Frame column	800×30	C50	Q345
		Frame beam	HN700×300	—	Q345
		Concrete floor	140	C30	

The outer frame beam and column around the structure are rigidly connected. Since the connection models of connecting beams with concrete core tubes and frame columns are different, four calculation models are established. Model 1-connecting beams with core tubes and frame columns are rigidly connected; Model

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2-connecting beams with core tubes and frame columns are hinged connected; Model 3-the connecting beam is rigidly connected with the core tube and hinged with the frame column; Model 4-the connecting beam is hinged with the core tube and rigidly connected with the frame column.

2. Influence of Connection Models on Structural Deformation Performance

Modal analysis and elastic response spectrum analysis are respectively carried out on the four calculation models. The first 10 vibration models of the four models are given in Table 2. The first three vibration models of the model are all X-direction translational vibration, Y-direction translational vibration and torsional vibration. It can be seen from the numbers in the table that the ratio of the first natural vibration period dominated by structural torsion (the value marked with * in the table) to the first natural vibration period dominated by translational motion is less than 65%, which meets the requirement of not more than 0.85 in the specification, and the torsional effect of the structure is limited. Because the structure is bi-axisymmetric, the first two periods of the model are equal.

Table 2. First 10 Cycles of Model (Unit: s)

Cycle	Model 1	Model 2	Model 3	Model 4
1	2.207	2.413	2. 328	2. 329
2	2.207	2.413	2. 328	2.329
3	1.393*	1.344*	1.342*	1.344"
4	0.561	0.576	0. 569	0. 569
5	0.560	0.576	0. 569	0. 569
6	0. 459	0.446	0. 446	0. 446
7	0. 268	0.263	0. 262	0. 263
8	0. 252	0.254	0.253	0. 253
9	0.252	0.254	0.253	0. 253
10	0. 207	0. 232	0.226	0. 226

It can be seen from Table 2 that the structural cycle is the smallest when both ends of the connecting beam of the steel-concrete composite frame are just connected (Model 1); When both ends are hinged (Model 2), the structural cycle is the largest, increasing by about 9.3%; When one end is hinged and the other end is rigidly connected (Models 3 and 4), the structural period is basically equal, wherein the first 3-order period of Model 4 hinged to the core tube and rigidly connected to the frame column is slightly larger than the first 3-order period of Model 3. Since the dead weight and load of the four models are the same, the overall stiffness and stiffness characteristic value of the structure are the largest when the two ends of the connecting beam are rigidly connected. When the two ends of the connecting beam

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are hinged, the overall stiffness of the structure is the smallest, and the stiffness characteristic value of the structure is also the smallest.

The elastic response spectrum of the structure under 8-degree frequent earthquake is analyzed in the X direction. According to Article 5.2.1 of Technical Specification for Concrete Filled Rectangular Steel Tubular Structures (CECS 159: 2004), the damping ratio is 0.04 under frequent earthquakes. The vibration mode decomposition response spectrum method is used to calculate the seismic response of the structure. In order to ensure the calculation accuracy, the first 60 vibration models obtained from the model analysis are used for the vibration models involved in the calculation. Lateral displacement and interlayer displacement angle of structural elastic layer are shown in Figs. 2 and 3 respectively.

Under the action of horizontal earthquake, the connection mode of Model 1 has the smallest lateral shift and interlayer displacement angle, while the hinged connection mode of Model 2 has the largest lateral shift and interlayer displacement angle. The deformation of Model 3 and Model 4 are basically the same.

Judging from the shape of the lateral displacement curve, the shape of the lateral displacement curve of the four models is basically the same. Except that the lower part is slightly bent, the overall lateral displacement belongs to the typical "bending shear" deformation, which is mainly because in the lower part of the composite structure, the concrete cylinder plays a major role and the deformation has the characteristics of bending. The maximum interlayer displacement angle of the core barrel with the main bending deformation at the upper part of the structure usually appears at the upper part[10], while the maximum interlayer displacement angle of the outer composite frame with the main shearing deformation usually appears at the bottom of the structure. The cooperative work of the two makes the structural deformation have the characteristics of shearing type.

The shape of the interlayer displacement angle curve between the composite frame and the core tube is different from that of the composite frame structure, which has the largest interlayer displacement angle in the middle and upper part of the structure and the deformation tends to be uniform. Table 3 gives the values of the maximum interlayer displacement angle and the number of layers in the four models. It can be seen from the table that the position of the maximum interlayer displacement angle of the structure moves to the upper part of the structure as the connection form rigidly connection to hinged connection. The interlayer displacement angles of the four structures all meet the limit requirement of 1/800 in the Technical Specification for Concrete Structures of High-rise Buildings.

Table 3. Maximum value and position of structural interlayer displacement angle under small earthquake

Project	Model 1	Mode 2	Model 3	Model 4
Maximum interlayer displacement	1/1378	1/1098	1/1191	1/1190

angle				
The layer where displacement appears	Layer 20	Layer 22	Layer 21	Layer 21

3. Influence of Connection Model on Mechanical Properties of Structures

3.1 Structural Internal Force Analysis

The total layer shear force and bending moment of the structure under different connection forms are not different, and generally increase with the decrease of the structure height.

The shear force and bending moment of the composite frame of Model 1 (the connecting beam is rigidly connected with both ends) and Model 4 (the connecting beam is hinged with the core tube and rigidly connected with the frame column) are similar, which are greater than the calculation results of Model 2 and Model 3. The shear forces of the four model composite frames are small in the lower part of the structure. With the increase of height, the supporting effect of the frame on the core tube increase, and the shear forces of the frame gradually increase. Model 1 has the maximum shear force on Layer19, Model 2 has the maximum shear force on Layer 21, Model 3 and Model 4 have the maximum shear force on Layer 20, and then gradually decrease. When reaching the top two layers, the shear force of the frame has obvious turning point and reaches the maximum in the top layer. The bending moment of the composite frame is the largest at the bottom of the structure. With the increase of height, the bending moment decreases, and the bending moment changes abruptly at the section mutation. It can be seen from Model 1 and Model 4 that the percentage of shear force of the outer composite frame is larger than that of Model 2, and the percentage of shear force and bending moment of the outer frame of Model 3 is the smallest.

Overall, the internal force sharing rate of Model 4 and Model 1 is similar to that of Model 2 and Model 3, which is greater than them. The shear sharing ratio of the four models increases with the structure height. In Layer 1 to Layer 10 of the structure, the seismic shear force of the steel-concrete composite frame is smaller than 10% of the corresponding total layer shear force, and the core tube accounts about 90% of the shear force. On the top layer of the structure, shear force accounts about

From the above analysis, it can be seen that Model 1 (the two ends of the connecting beam are rigidly connected) and Model 4 (the connecting beam is hinged with the core tube, and rigidly with the frame column) have strong structural integrity, and the peripheral frame takes more part in the joint work of the structure. These two connection models are recommended in actual engineering design. However, Model 3 (the connecting beam is rigidly connected to the core tube and

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hinged to the frame column) is not recommended because its outer frame and core tube have poor cooperative ability.

3.2 Comparison of Axial Forces of Outer Frame Columns

For the frame-tube or tube-in-tube structural system, the overturning moment under the action of horizontal force causes one side flange frame column of the frame tube to be pulled, the other side frame column to be pressed, and the web frame column to be pulled and pressed. The axial force distribution of each column in the flange frame column is not uniform. The axial force of the corner column is greater than the average value, the axial force of the middle column is less than the average value, and the axial force of each column in the web frame is not linearly distributed, which is the shear lag phenomenon[11]. However, for the frame-core tube structure, its mechanical performance is different from that of the frame-tube structure and similar to that of the frame-shear wall structure due to the increase of the peripheral column spacing. Next, the comparison of axial force distribution of flange frame columns under different connection models is discussed.

In Model 1, in which the two ends of the connecting beam are rigidly connected, the absolute value of the axial force of the central column B and C is greater than that of the corner column, while the absolute value of the axial force of the other three models is less than that of the corner column. This is mainly because the lateral stiffness of the frame-shear wall on axes B and C in Model 1 is much higher than that of the frame on axes A and D, while the other three models are opposite. The absolute values of axial forces of the four models are all along the height direction and tend to be average from top to bottom.

4. Conclusion

From the modal analysis of steel-concrete Composite frame-RC core wall structure under different connection models of upper connecting beams and the response spectrum analysis under frequent earthquakes, the following conclusions can be obtained:

(1) The two ends of the connecting beam are fixedly connected, so that the natural vibration period of the structure is minimum, the structural deformation is minimum, and the overall lateral stiffness of the structure is maximum; When the two ends of the connecting beam are hinged, the natural vibration period of the structure is the largest, increasing by about 9. 3%, resulting in the largest deformation and the smallest lateral stiffness of the structure.

(2) Under the action of horizontal earthquake, the structural deformation is curved and shear, and the interlayer deformation tends to be uniform in the middle and upper part of the structure.

(3) The internal force of the structure (including bending moment and shear force) generally shows an increasing trend from top to bottom, while the internal

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force sharing rate of the outer frame generally shows a decreasing trend from top to bottom, which is less than 10% at the bottom of the structure. Therefore, the internal force of the core tube at the bottom of the structure is relatively large. In actual engineering design, the bottom of the core tube needs to be strengthened.

The shear force of the outer frame is smaller in the lower part of the structure, larger in the range of about (0. 55~0. 75) f/(H is the total height of the structure) in the upper part of the structure, then slightly reduced, reaching the maximum in the top layer. The bending moment of the outer frame is the largest at the bottom layer of the structure. Generally, the bending moment decreases with the increase of height. At the abrupt change of section, the bending moment changes abruptly.

When both ends of the connecting beam are rigidly connected, or when the connecting beam is hinged with the core tube and is rigidly connected with the frame column, the horizontal shear force and bending moment shared by the outer frame are larger, and the cooperative work ability of the outer frame and the core tube is stronger; However, when the connecting beam is rigidly connected to the core tube and hinged to the frame column, the horizontal shear force and bending moment shared by the outer frame are the smallest. Therefore, in practical engineering, it is recommended to rigidly connect the two ends of the beam or hinged connect the beams with the core tube and rigidly connect the beams with the frame column.

The frame-core tubular flange frame of different connection models have different axial forces. When the two ends of the connecting beam are rigidly connected, the absolute value of the axial force of the center column is greater than that of the corner column, while in other connection models, the absolute value of the axial force of the center column is less than that of the corner column.

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