# The comparative analysis of seismic performance on three different forms of special-shaped column frame structure

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**Abstract:** In order to improve the seismic performance of the traditional reinforced concrete special-shaped column frame structure, steel reinforced concrete and concrete-filled steel tube special-shaped column frame were served as succedaneum. In the premise of the same size of column, axial compression ratio and beam section, two span and three storey of special-shaped columns exterior frame and middle frame were modeled based on Opensees finite element software, then pushover analysis and hysteretic performance analysis were carried out based on Opensees finite element software, and compared with ordinary reinforced concrete special-shaped column frame, the numerical simulation results show that: the bearing capacity increased, the ductility is greatly improved, the seismic performance of concrete-filled steel tube special-shaped column frame is the best in the three frames, the results can provide reference for the study on the seismic behavior of special-shaped column structure
**Keywords:** special-shaped column, frame, reforced concrete, Steel reinforced concrete, concrete-filled steel tube

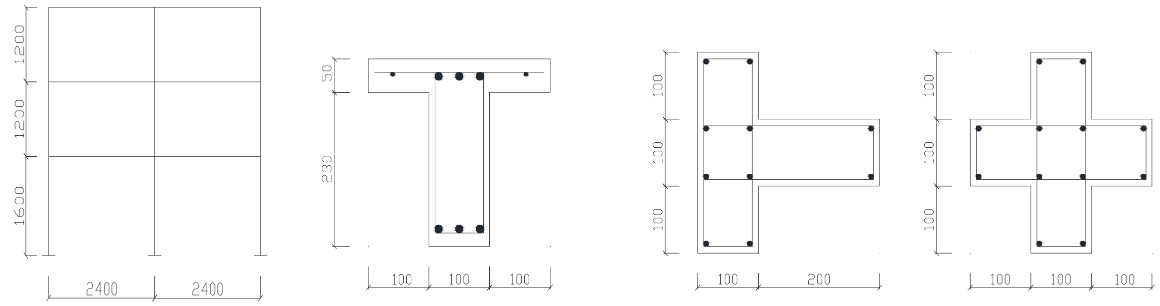
## 1. Introduction

Special-shaped column structure is the structure which column section is L-shaped, T-shaped or crisscross-shaped. In recent years, special-shaped column structure won the national attention and love of the owners because of its equal thickness of columns and wall, excellent architectural appearance and high room rate. In 2006, Ministry of Construction of the People's Republic of China has issued "Technical specification for concrete structures with specially shaped columns" (JGJ149-2006), which has been implemented since August 1, 2006 [1,2]. Accordingly, there have been a lot of research on ordinary reinforced concrete (RC) frame structure with special-shaped column, and this kind of the structure has received quite extensive application because of its great architectural functions. But in practice, there are many weaknesses for this structure such as limited loading capacity, low limit value of axial compression ratio, poor seismic performance and complex construction, which restricts its application. Steel reinforced concrete (SRC) special-shaped column structure is a new type of structural form, whose column is the combination of RC special-shaped column and the profile steel [3,4]. Xi'an University of Architecture and Technology has conducted in-depth research, which show that the loading capacity of SRC special-shaped columns is high and the seismic performance is excellent [5,6,7]. However, as the addition of the steel, resulting in an inevitable increase of the difficulty in construction. Concrete- filled steel tube structure with special-shaped column is another new type of structural form, and its construction is convenient. Based on the pseudo-static test of 7 L-shaped concrete-filled steel tube columns, Tongji University shows us that L-shaped concrete-filled steel tube column has good ductility and energy dissipation capacity under low cycle reciprocating load [8].

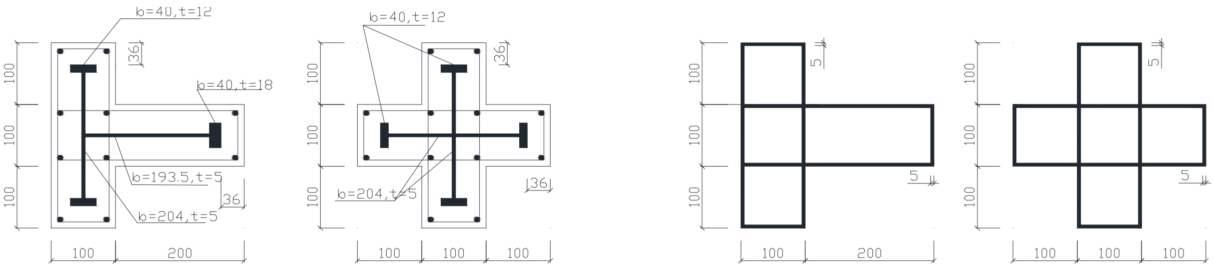
From above, the theory of RC structure with special-shaped column has been quite mature. But researches on the other two types of structures are mainly about the basic mechanical behavior and seismic performance of special-shaped column and beam-column joint, and even there is no research on concrete-filled steel tube structure with special-shaped column. In this paper, we make the comparative analysis of seismic performance on three different forms of special-shaped column frame structure. The analysis not only provides the numerical simulations for the upcoming hybrid test, but also play a role in expending the application of special-shaped column structure.

## 2. Model design

In this paper, three different forms of special-shaped column frames are used as the research object for seismic performance. They are RC special-shaped column frame, SRC special-shaped column frame and concrete-filled steel tube special-shaped column frame. In order to be able to contain the bottom, middle and top of all forms of beam-column joints, the two cross three layers middle framework model is chosen in special-shaped column frame, its side column is T-shaped column, and its interior column is cross section column. The height of framework underlying is 1.6 m, the high of the second and the third layer is 1.2 m. The scale ratio is 1:2.5.The cross-sectional area of three types of frame column is equal, the depth-thickness ratio of the limb are all 3, the depth of limb is 300 mm, the thickness of the limb is 100 mm. Beam section adopts RC beam, and the beam breadth takes 100 mm, which is equal to limb thickness of special-shaped columns, the height of beam takes 280 mm. The three mainly differ in the form of column section steel , their geometry size and section steel form as shown in figure 1 (unit: mm).




**(a) The overall geometry** **(b) Beam Section** **(c) RC special-shaped column section**




**(d) SRC special-shaped column section** **(e) Concrete-filled steel tube special-shaped column section**

**Fig.1 Structural geometry size and the column section**

On the selection of materials, the concrete uses C35,and its axial compressive strength standard value is 23.4 MPa, axis tensile strength standard value is 2.20 MPa; Steel uses HRB335, the diameter of column longitudinal reinforcement is 8 mm, that of stirrup is 6 mm, the scope of the column end 400 mm and the shear are encrypted, encryption district 40 mm spacing, unencrypted distance is 80 mm; the diameter of frame beam main reinforcement is 12 mm, that of stirrup is 6 mm, the scope of the beam end 400 mm for encryption, encryption district 40 mm spacing, unencrypted distance is 80 mm; Steel plates use Q235 and are welded together.

## 3. The establishment of the finite element model

OpenSees (Open System for Earthquake Engineering Simulation) is mainly used in the structure and geotechnical aspects of seismic response Simulation of comprehensive application software System. It includes a wealth of material, cell library, and a variety of powerful finite element solver, computational efficiency is high, the nonlinear fitting precision is good. This paper is based on the OpenSees finite element analysis software and analyzes the seismic behavior of three different forms of special-shaped column frame [9].

When modeling, use fiber element definition components section in OpenSees, and define fiber unit according to different materials. According to the concrete stirrup constraints, concrete can be divided into core concrete and protective layer concrete. On unit selection, chose based on Displacement beam-column elements to simulate the beams and columns. In order to guarantee the accuracy of the simulation results, the beam-column members are all divided for five units, each number of unit integral point is 5.

On the selection of materials, concrete uses Concrete02 Material, the constitutive relation uses Scott and others revised Kent - Park constitutive model, the skeleton curves is divided into the parabolic of rising period and the second line of falling period . This model can better reflect the constraint function of core concrete stirrup, so it doesn't need to build fiber reinforcement on the cross section. Steel and steel plates adopt Steel02 Material, the constitutive relation uses Filippou revised Menegotto-Pinto constitutive model [10], the model consider the influence of hardened steel.

## 4. Results analysis

### 4.1 Pushover analysis

Pushover analysis refers to the analysis method that put the lateral force according to horizontal or put lateral displacement of some distribution rules on calculating model, until the control points of the structure model reach the target displacement or overthrow. This method is essentially a static nonlinear analysis method, an effective evaluation of structural seismic performance.

This paper chooses applied horizontal load model in the top left column frame pillars, using the method of displacement control, gradually increase the horizontal displacement, until limit state is reached. Premise is that applied vertical load in the three pillars of the top column frame, axial compression ratio of three different types of framework are controlled, that of side column is 0.2, that of interior column is 0.4. Through Pushover analysis, we can get a framework of force-vertex displacement curve and a series of performance parameters. Calculation results are shown in figure 2 and table 1, in the table, determine the yield displacement through the general yield bending moment method, the limit displacement choses the corresponding displacement of the peak load decrease to 85%.

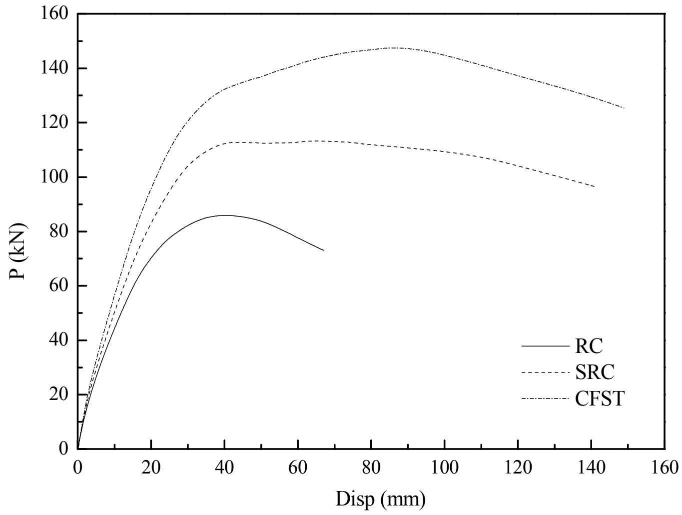



**Fig.2 Force-displacement curve**

**Table 1 Force-displacement calculation results**

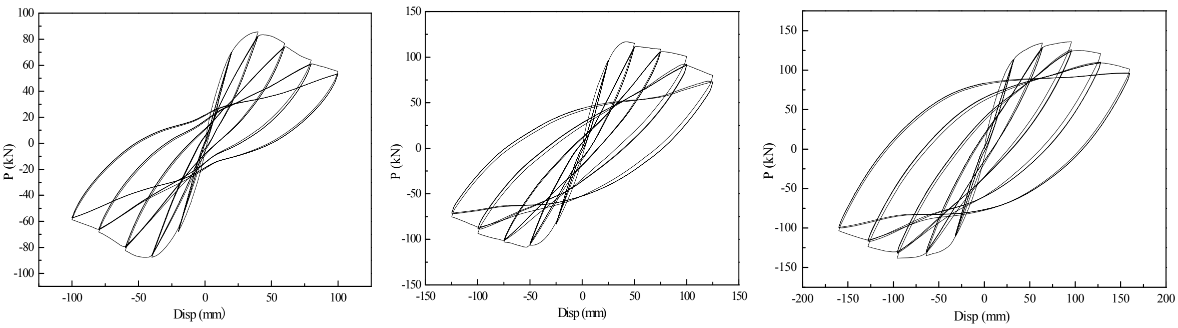
| Type of the structure | Yield displacement $\Delta_y$ (mm) | Ultimate displacement $\Delta_u$ (mm) | Displacement ductility $\Delta_y/\Delta_u$ | Shear-carrying capacity $P_u$ (kN) |
|---|---|---|---|---|
| RC special-shaped column frame | 20 | 67 | 3.4 | 86 |
| SRC special-shaped column frame | 25 | 141 | 5.6 | 113 |
| Concrete-filled steel tube special-shaped column frame | 30 | 149 | 5.0 | 147 |

In the structural seismic performance, ductility is an important indicator. The displacement ductility coefficient is commonly used to measure the frame ductility, which is the ratio of yield displacement and ultimate displacement size to judge the stand or fall of structural ductility. We can see from the above results, the ductility of SRC special-shaped column frame and concrete-filled steel tube special-shaped column frame is higher than the RC frame with special-shaped columns significantly, and increase the ductility coefficient ratio of 1.5 or so. This suggests that the appropriate configuration in the special-shaped columns steel or using a combination of concrete filled steel tube structure can greatly improve the displacement ductility of special-shaped column frame. Shear can reflect the structural ability to resist shear load bearing capacity, thus can infer structure's ability to resist horizontal seismic action. From the perspective of shear bearing capacity, three types of special-shaped column frame obviously divided into three grades, concrete filled steel tubular frame with special-shaped columns is the highest, 1.7 times as the RC frame with special-shaped columns, the SRC special-shaped column frame is in second place, 1.3 times as RC frame with special-shaped columns. So concrete filled steel tube structure has both high bearing capacity and good displacement ductility.

## 4.2 Hysteretic performance analysis

The structure bear plus or minus alternate under reciprocating load in a real earthquake action, so we can impose low cycle loading on structures to study the deformation characteristics of structure, rigidity degradation and energy dissipation capacity, and then judge the merits of the structural seismic performance.

Before making a hysteresis analysis, in the first, apply vertical load on three pillars of the top column frame, axial compression ratio of three different types of framework are controlled, that of side column is 0.2,that of interior column is 0.4, and remains the same in the whole calculation process. Then apply horizontal load in the top left column frame pillars, use the displacement control method, according to integer times of their yield displacement growing levels of cyclic loading, three times per level cycle, until the peak load decrease to around 85%. The calculation results are shown in figure 3 and figure 4.




**(a) RC frame** **(b) SRC frame** **(c) Concrete-filled steel tube frame**

**Fig.3 Hysteresis curve**

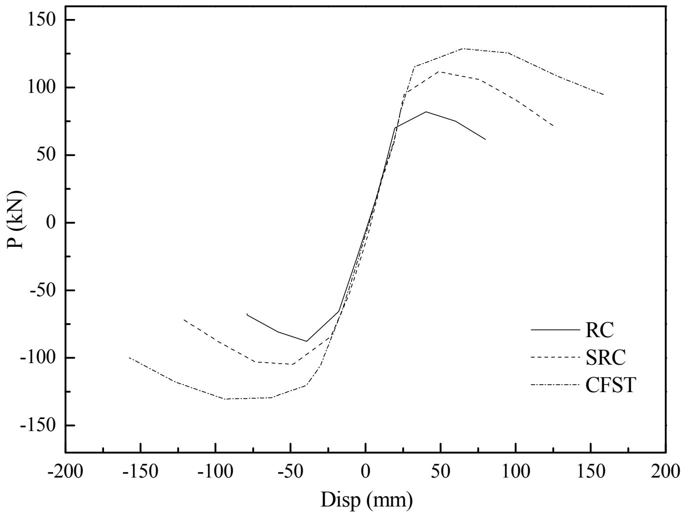



**Fig.4 Skeleton curve**

Hysteresis curve refers to force-displacement curve when the structure bear low cycle reciprocating load, the seismic performance of structure is comprehensive reflected, and it is the basis of nonlinear seismic response analysis. Skeleton curve is synthetic load peak point of every loading of the hysteresis curve successively linked, the envelope curve of get together. From figure 3, figure 4, we can see that the area of RC frame with special-shaped columns surrounded by the hysteresis curve is small, stiffness degenerate obviously and seismic performance is poor. Hysteresis curve of SRC special-shaped column frame is much plumper, stiffness degradation is relatively slow, and seismic performance is also improved. The area of concrete-filled steel tube special-shaped column frame surrounded by the hysteresis curve is the largest, the most plump hysteresis loop and stiffness degradation is slow, seismic performance is the greatest.

Structural energy dissipation ability is another important indicator of structural seismic performance, it refers to the ability of structure absorbs and dissipates energy when bearing reciprocating load. It is usually measured by the area of the hysteresis loop. In the current seismic research, the size of equivalent viscous damping coefficient he is often used to determine the structural energy dissipation capacity. The equivalent viscous damping coefficient of three frameworks are shown in table 2, and it can be seen that compared with RC frame with special-shaped column, the viscous damping coefficient of the SRC special-shaped column frame and concrete filled steel tubular frame with special-shaped column frame are improved greatly, and the viscous damping coefficient of concrete-filled steel tube frame with special-shaped column frame is more high in the three kinds of frame. So the energy dissipation ability of SRC special-shaped column frame and concrete-filled steel tube frame with special-shaped column frame is stronger, and the energy dissipation capacity of concrete filled steel tubular frame with special-shaped column frame is the best.

**Table 2 The equivalent viscous damping coefficient of the framework**

| Type of the structure | Yield point | Peak point | Breaking point |
|---|---|---|---|
| RC special-shaped column frame | 0.043 | 0.077 | 0.200 |
| SRC special-shaped column frame | 0.053 | 0.16 | 0.382 |
| Concrete-filled steel tube special-shaped column frame | 0.056 | 0.259 | 0.387 |

## 5 Conclusion

In this paper, three different forms of special-shaped column frame are used as the research object. Under the conditions of the size of column section, axial compression ratio and beam section are consistent, we use OpenSees finite element analysis software respectively conduct Pushover analysis and hysteretic performance analysis to the three, get the following conclusions:

(1) The SRC special-shaped column frame structure and concrete-filled steel tube frame with special-shaped column frame structure compare with RC special-shaped columns, the ductility is greatly improved, the displacement ductility coefficient increased to 1.5 times or so.

(2) The shear bearing capacity of concrete-filled steel tube frame structure with special-shaped column frame is significantly higher than the other two kinds of frame structure, while the ductility coefficient is slightly lower than the SRC special-shaped column frame structure, but also achieved to 5,which meets the ductility coefficient requirement of general framework is greater than 4.

(3) The hysteretic curve of concrete-filled steel tube frame with special-shaped column frame is the plumpest, energy dissipation is best, stiffness degradation is slow, seismic performance, the SRC special-shaped column frame is in second place, and seismic performance of RC frame with special-shaped columns is the worst.

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