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Seismic Performance of Steel Special-shaped Column-corrugated Steel Plate Shear Wall System

Min Li[1], Xiaotong Peng[1*], Yiyuan Gao[1] and Chen Lin[2]

[1] School of Civil Engineering and Architecture, University of Jinan, Jinan 250022, Shandong, China

[2] School of Architecture and Landscape Design, Shandong University of Art and Design, Jinan 250399, Shandong, China

*pengxito@163.com

Abstract. The study aimed to solve the problems of column-beam protrusion of steel structure residences and insufficient lateral stiffness resistance of high-rise steel frames. Therefore, a new steel special-shaped column-corrugated steel plate shear wall system was proposed. By establishing the finite element model, the influence of special-shaped column type, corrugated steel plate direction, and beam-column width on the seismic performance of special-shaped frame and embedded corrugated steel plate under low-cycle reciprocating load was studied. It was then compared with the traditional H-shaped steel column-flat steel plate shear wall structure model. The results show that the embedded corrugated steel plate model with transverse arrangement is the most suitable shear wall member for the stiffness ratio of the embedded corrugated steel plate and frame beam-column and the design specification. The embedded corrugated steel plate will yield before the frame beam and column under the lateral load. The geometric out-of-plane buckling characteristics of the embedded corrugated steel plate also effectively reduce its load on the frame beam and column.

Keywords: Prefabricated Steel Structure, Steel Special-shaped Column, Corrugated Steel Plate Shear Wall, Seismic Performance.

1 Introduction

Steel structure building has the characteristics of low carbon emission and high recovery rate, which has become an important development direction in the field of prefabricated building. The steel tube bundle structure [1-2] and the implicit frame system [3-4] solve the problem of the convex beam and convex column of the structure. Nevertheless, the system has problems such as poor economy and complex construction. Another more economical approach is to use narrow flange steel special-shaped columns and corrugated steel plate shear walls to form a new steel special-shaped column-corrugated steel plate shear wall system (SC-CPSW).

Relevant scholars have studied special-shaped columns and corrugated steel plates through experiments and numerical calculations. Yu [5] verified the excellent seismic

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performance of steel special-shaped columns, joints, and whole frame through the stress distribution and failure mode under rare earthquake loads. Wang et al. [6-7] derived the bending-torsional buckling correlation equation of steel special-shaped columns by using the theory of elastic thin-walled columns. Yang [8] studied the seismic performance of an L-shaped steel special-shaped column frame. The research [8] concluded that the steel special-shaped column frame structure with a smaller web height-thickness ratio has higher bearing capacity and better seismic performance. Wang [9] proposed the steel frame-sinusoidal corrugated steel plate shear wall structure. The research [9] studied its hysteretic behavior and static elastic-plastic pushover analysis. It is concluded that the new shear wall structure has good ductility and energy dissipation capacity under low cyclic loading. Tan et al. [10] derived the theoretical formula of the lateral stiffness and bearing capacity of the side-stiffened semi-circular corrugated steel plate shear wall.

In this paper, a new steel special-shaped column-corrugated steel plate shear wall system is proposed. The finite element numerical simulation is used to study its seismic performance, which provides a reference for the design and application of the structural system.

2 Finite Element Model

In order to study the influence of the arrangement direction of special-shaped frame and embedded corrugated steel plate on the seismic performance of the structure, three models of HH-transverse corrugated steel plate (SW2), LL-vertical corrugated steel plate (SW3) and LL-transverse corrugated steel plate (SW4) were designed. They were compared with the traditional H-shaped steel column-flat steel plate shear wall structure model (SW1). The specific size information of each model is shown in Table 1. The single-span, double-layer corrugated steel plate, and the surrounding special-shaped frame are taken out from the overall structure and studied separately. The corrugated steel plate is arranged in a single layer. The corrugated form is trapezoidal, and the corrugated length is 280 mm. The beam-column frame adopts Q355 B, and the embedded steel plate in the shear wall adopts Q235 B.

Table 1. Model design parameter

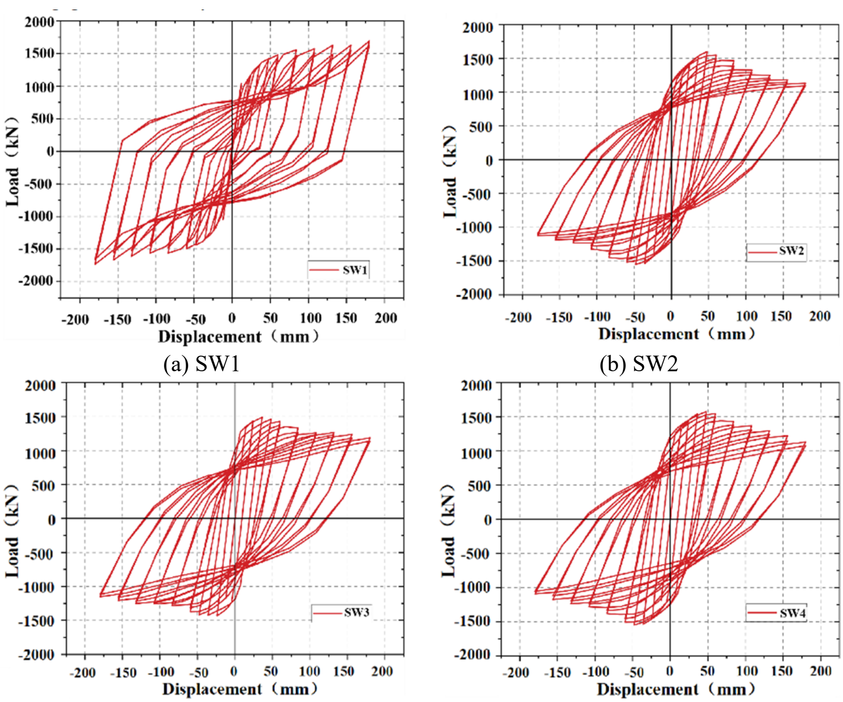
Model number	Embedded steel plate type	Plate thickness (mm)	Special-shaped frame		Beam (column) flange width (mm)
			Left	Right	
SW1	Flat steel plate	3	H	H	160 (400)
SW2	Corrugated steel plate (horizontal)	3	H	H	160 (400)
SW3	Corrugated steel plate (vertical)	3	L	L	160 (160)
SW4	Corrugated steel plate (horizontal)	3	L	L	160 (160)

Since the frame beam has little effect on the seismic performance of the structure, the four models all use I-shaped steel beams of 300 × 160 × 8 × 10 (mm). Considering that the different strengths of the external frame will affect the performance of the embedded corrugated steel plate, 400 × 400 × 12 × 14 (mm) and L-shaped steel special-shaped column 400 × 160 × 12 × 14 (mm) are taken respectively. The model uses the quasi-static method to apply cyclic load to the model. The horizontal displacement angle is used to control the loading.

3 Overall Seismic Performance

3.1 Hysteretic Performance

Fig. 1 shows the hysteresis curves of each model. The hysteresis curve of the SW1 model shows a certain pinching phenomenon due to the obvious effect of the tension band. The single hysteresis loop of the hysteresis curve of the SW2 and SW4 models is a full spindle shape, which has good energy dissipation capacity. The hysteresis curve of the SW3 model shows a slight pinch phenomenon. After reaching the peak bearing capacity in the early stage, it decreases slightly. The bearing capacity decreases slightly, showing good ductility.



(a) SW1 (b) SW2

(c) SW3 (d) SW4

Fig. 1. Hysteresis curve

The Mises stress cloud diagram of each model under low cycle reciprocating load is shown in **Fig. 2**. The embedded steel plate of the SW1 model shows out-of-plane buckling of two tension band shapes. The direction of the tension band is consistent with the lateral direction. In the later stage of loading, an X-shaped tension field is formed through the whole steel plate. At the same time, the outer flanges of the columns on both sides near the beam joints are affected by the tension band, and the local buckling is serious.

In the loading process of the SW2 model, the embedded corrugated steel plate has obvious multiple local buckling phenomena. The shape is similar to the bulging shape when the flat steel plate is buckled. However, the buckling phenomenon of the structure is more dispersed in the position. The small area yield area is also increased, mostly in the form of a cross. Additionally, there is no buckling phenomenon through the whole plate. The embedded corrugated steel plate has a great influence on the load of H-shaped steel columns on both sides. Moreover, the column ends on both sides appear to be a bending phenomenon in the later stage of loading.

The buckling of the SW3 model is that the middle part of the embedded corrugated steel plate first buckles, and then diffuses to both sides. The buckling direction buckles out of the plane with the bending direction of the corrugated plate. Reciprocating loading forms an X-shaped small tension band in the middle area of the embedded steel plate, and there is no buckling phenomenon through the whole plate. The addition of corrugated steel plate can effectively inhibit the buckling of the steel plate. The web of the embedded corrugated steel plate has a slight buckling. The embedded corrugated steel plate has a great influence on the load of the upper and lower beams.

The SW4 model is not fully developed due to the tension band, and the tilt angle of the tension band is biased towards the ripple direction. The shear yield and tension band of the embedded corrugated steel plate in the model bear the lateral load, and there is no obvious out-of-plane buckling phenomenon. The beam-column frame is subjected to the minimum load value of the embedded steel plate.

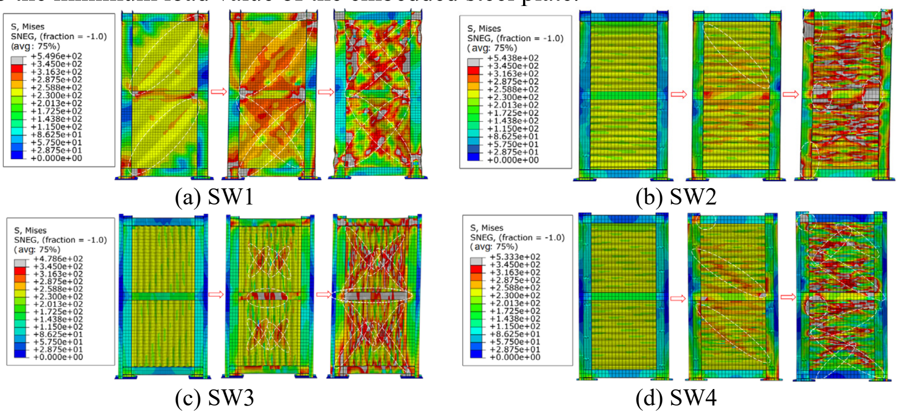


Fig. 2. Mis's stress cloud diagram

3.2 Ductility and Energy Dissipation

As shown in **Fig. 3**, the skeleton curve of the SW1 model is in the elastic stage, and the embedded steel plate remains elastic. After the elastic buckling of the embedded steel plate in the model, the skeleton curve begins to bend, but the bearing capacity of the structure continues to rise. With the lateral loading, the growth rate of bearing capacity becomes slower. The bearing capacity and stiffness of the skeleton curves of SW2, SW3, and SW4 models in the elastic-plastic stage are higher than those of SW1 when the corresponding displacement occurs. The bearing capacity begins to decrease slowly after reaching the peak point, showing good ductility. The peak bearing capacity of the SW4 model is the largest.

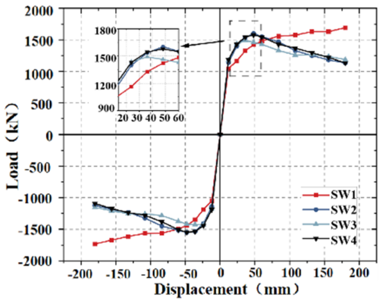


Fig. 3. Skeleton curve

As shown in **Fig. 4**, the one-cycle energy dissipation capacity of the SW2, SW3, and SW4 models is higher than that of the SW1 model in the early stage of loading. The energy dissipation capacity of the SW4 model is the highest, showing better energy dissipation performance. After loading to the failure point, the energy dissipation capacity of the SW1 model exceeds that of the corrugated steel plate shear wall model. As shown in **Fig. 5**, the energy dissipation capacity of the SW1 model is significantly lower than that of the SW2, SW3, and SW4 models in the early stage of loading. The SW2, SW3, and SW4 models show better stability after the bearing capacity reaches the peak point, showing the same energy dissipation trend and better energy dissipation capacity.

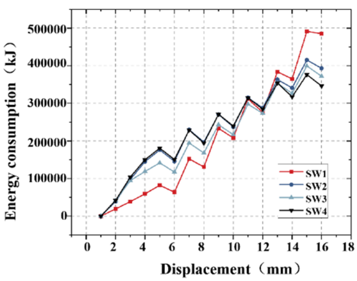


Fig. 4. Energy consumption curve

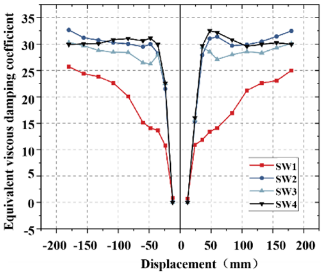


Fig. 5. Equivalent viscous damping coefficient

4 Conclusion

1) The traditional H-shaped steel column-flat steel plate model relies on the buckling of the embedded steel plate to form a tension band to bear the lateral load.

2) The transversely arranged embedded corrugated steel plate model (SW4) is the shear wall member that best conforms to the stiffness ratio of the embedded corrugated steel plate and the frame beam-column and the design specification. Under the lateral load, the embedded corrugated steel plates will yield before the frame beams and columns. The out-of-plane buckling characteristics of the embedded corrugated steel plates also effectively reduce the load on the frame beams and columns.

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