Design Method and Finite Element Analysis of a New Prefabricated Steel Special-shaped Lattice Column

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Abstract. A new steel special-shaped lattice column (SSLC) was proposed, which can be used in prefabricated steel structure residence. The finite element models of four SSLC with different cross-section (L-shaped, T1-shaped, T2-shaped and X-shaped) were established under cyclic loading by using ABAQUS, in which the strength, lateral resist capacity and hysteretic behavior were analyzed. The results indicate that SSLC has adequate strength, stiffness and safety redundancy. Among the four SSLC, the SSLC with X-shaped has the best structural performance and seismic behavior.

1 Introduction

Special-shaped columns mainly exist in the residential buildings with reinforced concrete frame structure [1]. Scholars at home and abroad have done extensive research on special-shaped columns. Joaquin Marin [2] carried out force-deformation analysis on L-shaped special-shaped columns, and a practical design calculation diagram was provided. Chen Qian and Feng Jianping [3, 4] conducted an eccentric compression test of L-shaped column. The calculation formulas for the bearing capacity of L-shaped and T-shaped special-shaped columns were proposed. Huang chengkui [5, 6] researched the shear performance of the special-shaped columns. The results show that the flange has a greater horizontal bearing capacity and has a greater impact on the shear bearing capacity of special-shaped columns. Zhang Ailin, Xu Min et al. [7-9] studied the seismic performance of X-shaped steel special-shaped columns, in which the hysteretic behavior and ductility performance of the special-shaped column are analysed. The combined limit of flange width-thickness ratio and web height to thickness ratio is proposed.

The special-shaped column has some shortcomings, such as low bearing capacity and poor seismic resistance, which makes its use range limited. In this paper, a new prefabricated steel special-shaped lattice column was proposed as a solution, in which the strength, lateral resist capacity and hysteretic behaviour were analysed.

2 Steel special-shaped lattice column (SSLC) structure

2.1. Design of SSLC

SSLC (Fig. 1) is composed of channel steel and square steel tube columns. The channel steel is connected by lace bars. The cross section is shown in Fig. 2. SSLC can be divided into T-shaped SSLC, L-shaped SSLC and X-shaped SSLC according to the shape of the section.

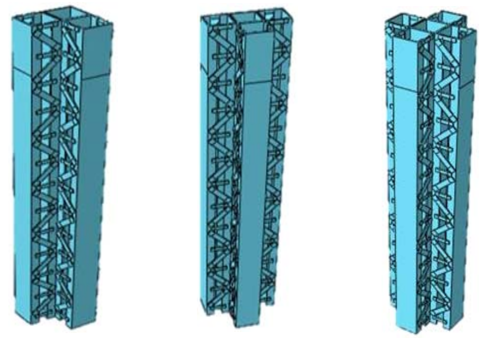
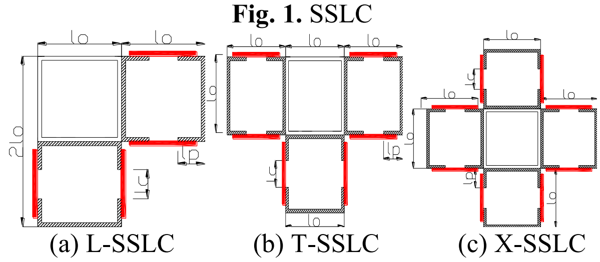


Fig. 1. SSLC



(a) L-SSLC (b) T-SSLC (c) X-SSLC

Fig. 2. Section of SSLC

2.2. SSLC connection design

The channel steels is connected by lace bars, as shown in Figure 3. In Figure 4, the square steel tube column and the channel steel web are connected by high-strength bolts.

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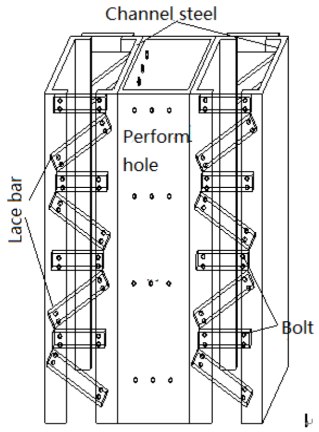


Fig. 3. Lacing structure

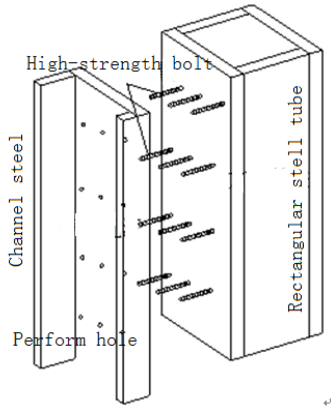


Fig. 4. Screw connection structure

3 Establishment of finite element model

The SSLC proposed in this paper is an elastic-plastic structure. The bilinear Kinematic (Figure 5) is selected.

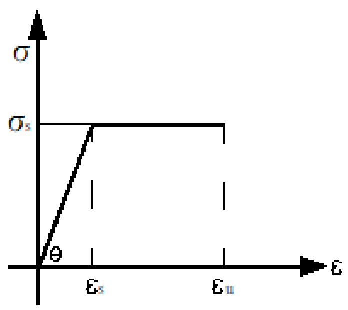


Fig. 5. Material constitutive relation

Q235 steel is used for channel steel and square steel tube column, and Q345 steel is used for lace bars. The mechanical properties of the materials are shown in Table 1.

Table 1. Mechanical properties of the material

Steel grade	E/(N/mm^2)	f_y/(N/mm^2)	Poisson's ratio
Q235	206000	235	0.3
Q345	206000	345	0.3

During finite element analysis, the lace bar is bound to the channel steel by the Tie command so that no slip occurs between the contact surfaces. The loading methods include monotonic loading and cyclic loading, which are controlled by displacement.

3.1. Analysis of lateral resistance of SSLC

L-shaped SSLC, T-shaped SSLC and X-shaped SSLC models were established by finite element software ABAQUS. Due to the different force directions of T-shaped model, the T-shaped SSLC is defined as T-SSLC-1 when the force is applied along the symmetric axis and the T-shaped SSLC when the force is applied along the asymmetric axis is defined as T-SSLC-2. Four SSLC models were loaded in a monotone horizontal manner. The load-displacement curve of the SSLC model is shown in Figure 6.

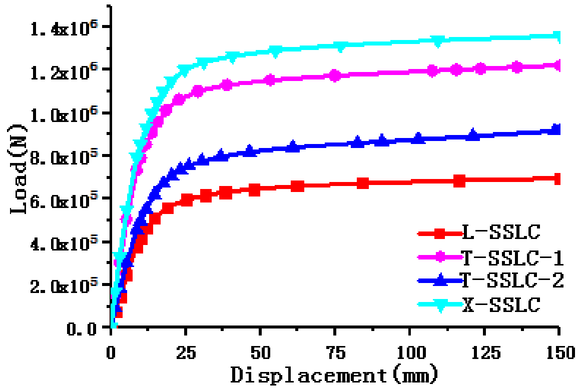


Fig. 6. Load-displacement curve of SSLC

Table 2. Indexes of SSLC under monotonic loading

Model name	Vmax/(KN)	Vy/(KN)	Δu/(mm)	Δy/(mm)	μ
十-SSLC	1361	1202.41	150	20.3	7.38
T-SSLC-1	1223.2	1063.25	150	22.7	6.61
T-SSLC-2	919.08	672.52	150	23.1	6.52
L-SSLC	697.19	573.44	150	25.3	5.93

It can be seen from the above chart that the load-displacement curves of the four models have obvious rising and strengthening section. In the two models of T-shaped SSLC, T-SSLC-1 has greater lateral stiffness than T-SSLC-2. The yield displacement and ductility coefficient of T-SLC-1 and T-SLC-2 are similar. The ultimate bearing capacity of X-shaped SSLC model is the highest. The X-shaped SSLC model has the highest ultimate bearing capacity, better plastic deformation capacity and more obvious energy dissipation capacity.

3.2 Hysteresis performance

The displacement control method was used to load the model, and the loading system was shown in Figure 7.

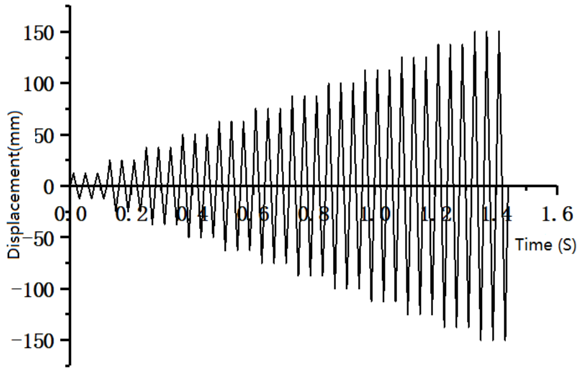
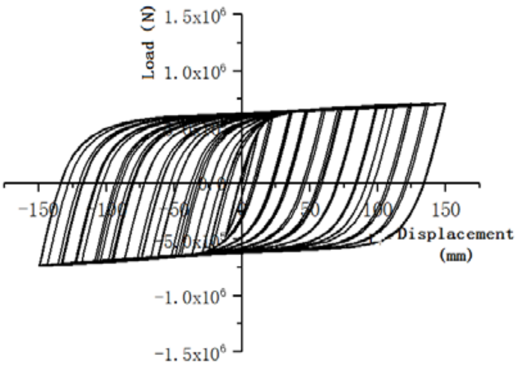
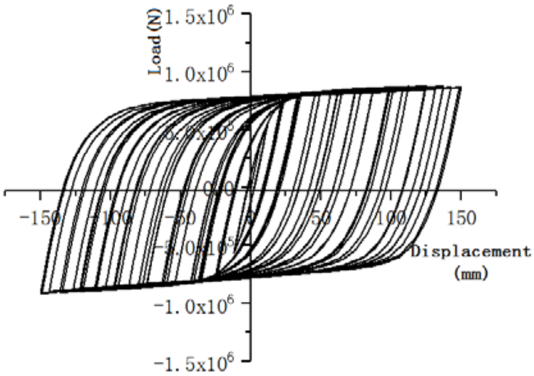


Fig. 7. Cyclic loading system

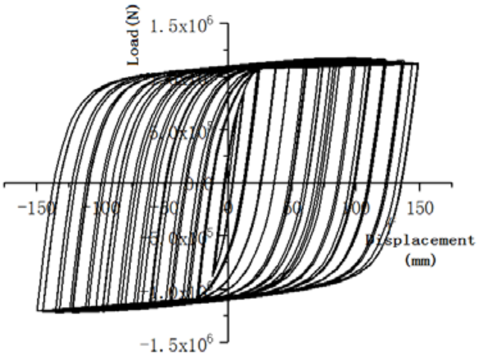
In order to study the hysteretic behavior of SSLC, four groups of models were cyclically loaded to obtain hysteretic curves (Figure 8). The skeleton curves (Fig. 9) were obtained by selecting the positive and negative peak values.



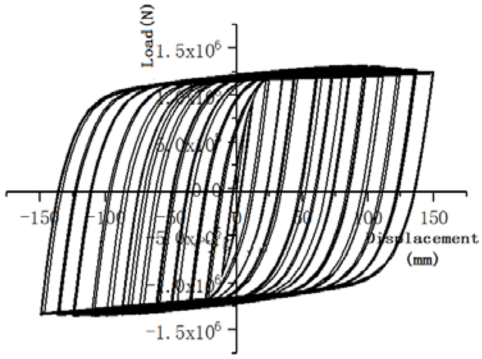
(1)L-SSLC



(2)T-SSLC-2



(3)T-SSLC-1



(4)X-SSLC

Fig. 8. Comparison of hysteretic curves

Analysis of hysteretic curve: the hysteretic curves of each SSLC were relatively full. The initial stiffness of X-shaped SSLC is the largest, and the forward bearing capacity reaches 1372KN, the reverse ultimate bearing capacity is 1446KN. In the elastic stage and the plastic development stage, the stiffness decreases uniformly.

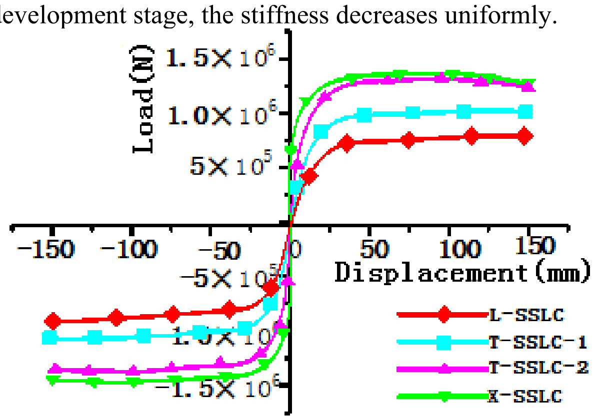


Fig. 9. Comparison of skeleton curves

The analysis of skeleton curve shows that the forward ultimate bearing capacity of L-shaped SSLC is 773KN, and the reverse ultimate bearing capacity is 812KN, which is 43.65% and 43.84% lower than X-shaped SSLC. T-SSLC-1 and T-SSLC-2 decreased by 6% and 7.2% respectively compared with X-shaped SSLC. SSLC has high stability in positive and negative directions and is suitable for use as fabricated frame columns.

4. Conclusion

The finite element models of four SSLC were established under the horizontal and cyclic loading by using ABAQUS, in which the lateral resist capacity and hysteretic behavior were analyzed. The following conclusions were drawn:

(1)SSLC has adequate strength, stiffness, ductility, and safety redundancy. It is suitable to be used as frame seismic column.

(2)When the SSLC reaches the yield ultimate bearing capacity, there is an obvious plastic strengthening stage, which is beneficial to structural energy dissipation.

(3)Among the four types of SSLC, the SSLC with X-shaped has the best structural performance and seismic behavior. The stress direction of T-shaped SSLC has little effect on the plastic deformation, but has a great influence on the bearing capacity.

Acknowledgments

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