Parametric Analysis of New Assembled Double Steel Plate-Concrete Composite Shear Wall Structure

Cheng Hong, Shuai Yi, Baohua Zhang, Kai Liu and Qiuhua Xu
1 School of Civil and Architectural Engineering, Nanchang Institute of Technology, Nanchang; 330099, China
2 Jiangxi Provincial Institute of Civil Architecture, Nanchang; 330099, China
Email: 1109687354@qq.com

Abstract. At present, China's construction industry is developing rapidly towards the goal of "design standardization and industrial production". The State Council and local governments have also issued relevant documents on the development of fabricated steel structures, the development of assembled steel structure in China has been promoted. The Shear Wall structure is one of the most important components to ensure the earthquake resistance of the whole building, which can obviously improve the overall anti-lateral stiffness of the building, so it is widely used in high-rise buildings. In this paper, the thickness of steel plate and the distance between studs are selected as the parameters of the new shear wall structure, and 9 groups of models are used for parametric analysis. Finally, the data are compared and corresponding conclusions are drawn.

Keywords. Assembled, double steel plate-concrete, shear wall structure, parametric analysis.

1. Introduction
In order to meet the increasing demand of people, high-rise building also appears, but the difficulty of high-rise building structure design lies in controlling the lateral displacement, and shear wall structure can obviously improve the lateral stiffness of the structure, so it is widely used in high-rise building. The Composite Shear Wall structure with double steel plates filled with concrete is a new type of shear wall structure in recent years. Nie Jianguo [1] and others carried out relevant loading tests on two sets of data (10 shear wall structures), and compared the failure modes and seismic performance under different axial compression ratios and shear span ratios, double Steel Plate reinforced concrete structure has the characteristics of good ductility and strong seismic performance. Jixiaodong [2] and others have carried out relevant loading tests on five double steel plate composite shear wall structures with shear-span ratio of 2.5, the failure process and failure mode of the Shear Wall are studied by controlling the factors such as steel pipe, axial compression ratio, steel plate ratio and steel bar ratio. The data show that the specimens are subjected to bending failure, huge cracks are produced in the bottom of the concrete wall, and are crushed, and buckling deformation takes place at the bottom of the steel plate and the steel tube of the concealed column. Rafiei, Hossain, et Al. [3] analysed four different tests by changing the strength of the external plate and the strength of the internal plate. The failure mode of the member is mainly as follows: the corner concrete is crushed, and the bottom steel plate produces buckling deformation. Tests have also shown that, if there is no connection between the concrete and the steel plate, the steel plate will buckle before yielding is reached. In 2014, Epackachi [4] carried out the seismic test of the Composite Shear Wall structure with two steel plates, and put forward the non-linear flexural and uncomplicated research model, which is used for the preliminary
design and discussion of the Composite Shear Wall. In 2015, Li Guoqiang et Al. [5] used the theory analysis method, at the same time combined with the finite element software analysis method, carried on the careful analysis and the contrast to the Shear Wall structure bearing mechanism and the force transmission law, in the same year, Xiong Feng et Al. [6] made a study on the scale model of the Shear Wall of a nuclear power station, and analyzed the seismic behavior of the structure by means of different stiffening rib and bolt spacing, in 2017, Wu Xiaodong et Al. [7] carried out seismic tests with the distance between studs as a parameter, and in 2017, Liu Junfei et Al. [8] studied the hysteretic behavior of shear walls with steel plate thickness, height-to-span ratio and limb-to-thickness ratio, a calculation method suitable for the structural model is proposed. In the same year, Zhao Baocheng et Al. [9] tested the seismic behavior of short-leg shear wall structures with stiffened plates.

2. Model Parameters and Loading Regime

2.1. Model Parameters

In this paper, nine models of PASCS-1-PASCS-9 are established. Figure 1 below shows a cross section of the model PASCS-1. The concrete of PASCS-1 model is f_{ck}=C30, and the steel plate is f_{y}=Q355, n=0.5 for axial compression ratio, t=10 mm for steel plate thickness, 3000 mm for front and back sides, 1500 mm for width, 3000 mm for left and right sides, 400 mm for width, the length of the steel plate is 1520 mm, the width is 400 mm, the length of the concrete plate is a=1500 mm, the width is b=200 mm, the height is H=3000 mm, and the distance between the studs is d=250 mm. The other models are all created with one parameter changed by PASCS-1, and the specific component model parameters are shown in the following table 1.

![Figure 1. Dimension Cross section of PASCS-1 model.](image-url)
Table 1. PASCS model parameter.

| Name   | Plate thickness t/mm | Spacing of studs d/mm |
|--------|----------------------|-----------------------|
| PASCS-1| 10                   | 250                   |
| PASCS-2| 6                    | 250                   |
| PASCS-3| 8                    | 250                   |
| PASCS-4| 12                   | 250                   |
| PASCS-5| 10                   | 50                    |
| PASCS-6| 10                   | 100                   |
| PASCS-7| 10                   | 150                   |
| PASCS-8| 10                   | 200                   |
| PASCS-9| 10                   | 300                   |

2.2. Model Loading Regime
In this model, the pseudo-static simulation method is used, in which the vertical axial pressure is applied, and then the horizontal reciprocating loading displacement is added. The vertical axial pressure value is determined by using the equation mentioned in the literature of Nie Jianguo et al. [10]. The equation is as follows:

\[
N = \frac{1.25N}{f_c A_c / 1.4 + f_s A_s / 1.11}
\]

where \(N\) is the vertical axial pressure, \(n\) is the axial compression ratio, \(A_c\) is the cross-section area of concrete, \(f_c\) is the axial compressive strength of concrete, \(A_s\) is the sum of the cross-section area of steel plate, \(f_s\) is the yield strength of steel.

The displacement of the horizontal load is controlled by the method of deformation control mentioned in the literature [10]. The displacement increment is \(H/400\) mm (corresponding to \(1/400\) vertex displacement angle), and the load cycle is 1 time. When the horizontal bearing capacity of the model drops below 85% of the ultimate bearing capacity, the model is destroyed and the load is stopped. The model loading regime for its horizontal displacement is shown in figure 2.

![Horizontal displacement loading system.](image)

3. Results of Parametric Analysis of the Model

3.1. Influence of Steel Plate Thickness
This section studies the effect of plate thickness on the seismic behavior of the model. Figure 3 is the model curve analysis diagram, where figure 3(a) is the model hysteresis curve diagram, and figure 3(b) is the model skeleton curve diagram. Table 2 is a table of model eigenvalues.
As can be seen from figure 3 and table 2, the influence of steel plate thickness on energy consumption of PASCS shear wall is very obvious. With the increase of the thickness of the steel plate, the energy dissipation capacity of the model is also increasing, and the difference of the energy dissipation capacity is obvious when the limit displacement is reached, the increment of energy consumption was -34.41% , -17.40% and 16.18% , respectively, and the ductility coefficient of PASCS-3 model with steel plate thickness of 8 was the highest, which was similar to that of 10 and 12, and that of PASCS-1 model with steel plate thickness of 6 was the lowest, the peak load increments of other models were -28.18% , -14.76% , and 13.35%.

### Table 2. Eigenvalues of under different thickness of steel plate.

| Name   | Yield load $\Delta_y$/kN | Yield displacement $P_y$/mm | Peak load $\Delta_m$/kN | Peak Displacement $P_m$/mm | Limit load $\Delta_u$/kN | Limit Displacement $P_u$/mm | Ductility factor $P_u/P_y$ |
|--------|--------------------------|------------------------------|-------------------------|-----------------------------|--------------------------|----------------------------|---------------------------|
| PASCS-1| 870                      | 5.88                         | 1550                    | 15.00                       | 1316                     | 37.50                      | 6.378                     |
| PASCS-2| 624                      | 5.60                         | 1113                    | 22.50                       | 1445                     | 30.57                      | 5.459                     |
| PASCS-3| 741                      | 5.74                         | 1321                    | 22.50                       | 1148                     | 37.50                      | 6.533                     |
| PASCS-4| 987                      | 5.97                         | 1757                    | 15.00                       | 1656                     | 37.50                      | 6.281                     |

3.2. Influence of Steel Plate Thickness
This section studies the effect of under different spacing of studs on the seismic behavior of the model. Figure 4 is the model curve analysis diagram, where figure 4(a) is the model hysteresis curve diagram, figure 4(b) is the model skeleton curve diagram. Table 3 is a table of model eigenvalues.
### Table 3. Eigenvalues of under different spacing of studs.

| Name     | Yield load $\Delta y$/kN | Yield displacement $P_y$/mm | Peak load $\Delta m$/kN | Peak Displacement $P_m$/mm | Limit load $\Delta u$/kN | Limit Displacement $P_u$/mm | Ductility factor $P_u/P_y$ |
|----------|---------------------------|-----------------------------|-------------------------|---------------------------|-------------------------|-----------------------------|---------------------------|
| PASCS-1  | 870                       | 5.88                        | 1550                    | 15.00                     | 1316                    | 37.50                       | 6.377                     |
| PASCS-5  | 1113                      | 7.08                        | 1869                    | 22.50                     | —                       | —                           | —                         |
| PASCS-6  | 997                       | 6.62                        | 1696                    | 22.50                     | —                       | —                           | —                         |
| PASCS-7  | 908                       | 6.14                        | 1599                    | 22.50                     | 1537                    | 37.50                       | 6.107                     |
| PASCS-8  | 888                       | 6.00                        | 1568                    | 22.50                     | 1477                    | 37.50                       | 6.250                     |
| PASCS-9  | 870                       | 5.88                        | 1551                    | 15.00                     | 1399                    | 37.50                       | 6.377                     |

Figures 4 and 3 show that the distance between studs has little effect on the energy consumption of PASCS shear wall. Compared with PASCS-1 model, the energy consumption of the other five models increased by 1.02% , 0.97% , 0.83% , 0.53% and-1.22% , respectively When the distance between studs is 50 mm ~ 150 mm, the horizontal bearing capacity increases obviously, the data in the other models did not change significantly.

### 4. Conclusion

The thickness of steel plate has a great influence on the ASEISMIC performance of the model. In the range of 6 ~ 12 mm, the energy dissipation capacity increases by about 17% and the peak load increases by about 14%, and the total energy dissipation curve increases linearly with the thickness of steel plate, although it will increase the seismic performance of the structure, but it will reduce the space occupied by the building and increase the cost of steel. The distance between studs is negatively related to the energy dissipation capacity of the model, and the decreasing rate is gradually increasing. When the total energy dissipation is below 150 mm, the curve tends to be flat, this phenomenon is also in line with the requirement in reference [10] that the maximum distance between studs should not exceed $\text{Min}(300.22 \sqrt{\frac{235}{f_y}})$.

### Acknowledgments

This project was funded by Youth Fund Project of Jiangxi Provincial Education Department (GJJ171009), Science and Technology Programme of the Ministry of Housing and urban-rural development (2020-K-009).

### References

[1] Nie J G and Hu H S 2013 Experimental study on seismic behavior of high-strength concrete filled double-steel-plate composite walls *Journal of Constructional Steel Research* **15**(3) 206-219.

[2] Ji X D and Jiang F M 2013 Seismic behavior of steel tube-double steel plate-concrete Composite walls:Experimental tests *Journal of Constructional Steel Research* **14**(3) 17-30.

[3] Rafie S, Hossain K M A, Lachemi M, Behdinan K and Anwar M S 2013 Finite element modeling of double skin profiled composite shear wall system under in-plane loadings *Engineering Structures* **56**(6) 46–57.

[4] Epackachi S 2014 Experimental, numerical, and analytical studies on the seismic response of steel-plate concrete(SC) composite shear walls *Dissertations & Theses-Gradworks* **44**(04) 22–35.

[5] Li G Q, Liu W Y, Lu Y and Sun F F 2015 Mechanical mechanism and equivalent brace model of steel plate shear wall with buckling restraint of two-side connection *Journal of Building Structure* **32**(04) 33-41.

[6] Xiong F, He T and Zhou N 2015 Study on shear strength of double steel reinforced concrete shear wall in nuclear power plant *Proceedings of the Hunan University* **42**(9) 33-41.
[7] Liu J F and Zhao B C 2015 Research on hysteretic behavior of short-leg composite shear wall filled with concrete and double steel plates *Journal of Suzhou University of Science and Technology* **28**(04) 42-46.

[8] Wu X D, Tong L W and Xue W C 2017 Finite element analysis of deformation characteristics of double steel plate-concrete composite shear wall *Progress of Building Steel Structure* **26**(01) 17-25.

[9] Zhao B C, Liu J F, Gu Q and Liu J 2017 Experimental study on seismic behavior of short-leg composite shear walls filled with double steel plates *Journal of Civil Engineering* **38**(01) 28-36.

[10] Li Y S, Nie J G and Liu F J 2013 Experimental study on seismic behavior of steel plate-concrete Composite Shear Wall with external multi-cavity *Journal of Civil Engineering* **42**(10) 26-38.