Study on Hear Resistance of Cold-formed Steel Composite Wall with Openings

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Abstract. In order to study the shear resistance of cold-formed steel wall with openings, a numerical model of the specimen for cold-formed steel wall with openings shear test was established using Opensees software, which was used to simulate its shear resistance under cyclic loading. On this basis, the parameters of the factors affecting the shear resistance of cold-formed steel wall with openings were analyzed. The results show that the contribution of the coupling beam to the shear performance of the whole wall is reduced with the increase of the span-depth ratio of coupling beam. When span-depth ratio of the coupling beam is greater than 5, the contribution of the coupling beam to the shear resistance of the wall is ignored. The ratio of opening to wall and the ratio of window to wall have a great influence on the shear resistance of cold-formed steel wall with openings, and the influence of each factor on the shear performance of the cold-formed steel wall with traditional side column is greater than that of the cold-formed steel wall with reinforced end studs. The stiffness of the side column has little effect on the shear resistance of the cold-formed steel wall with openings.

Keywords. Cold-formed steel wall with openings, shearing performance, numerical simulation.

1. Introduction
Cold-formed steel structure building has the advantages of light weight, high strength, high anti-seismic coefficient, good safety performance, simple construction, short construction period, etc., and it is a kind of sustainable green environmental protection building structure [1]. As the main load transfer component of the Existing Low-Rise cold-formed steel structure buildings [2] the cold-formed steel composite wall is composed of C-shaped, U-shaped cold-formed steel and skin covering plate connected by self-tapping screws.

Salenikovich [3] studied the shear resistance of the cold-formed steel composite wall with and without openings. It was found that the shear strength and rigidity of the wall with openings were lower than those of the wall without openings, but its ductility was higher than that of the wall without openings. Chao Bian et al. [4] established a numerical model to simulate the connection between the steel frame and the cladding of the composite wall by using the technology of pole element and element life and death. Nie Shaofeng [5] used ANSYS software to establish a finite element model considering the influence of material and geometric nonlinearity, and analyzed the influence of opening rate on the shear performance of cold-formed steel composite wall. Generally speaking, the research on the wall with openings is relatively less, and the hysteresis curve simulated by ANSYS software is difficult to show the “pinch effect” of the cold-formed steel wall with openings under the reciprocating load.
In this paper, OPENSEES finite element software is used to simulate the shear resistance of the cold-formed steel wall with openings. Under the condition that the model is verified, the relevant parameters affecting the shear resistance of the cold-formed steel wall with openings are analyzed, as shown in figure 1, including the span height ratio $\alpha$ of the coupling beam, the wall height ratio $\gamma$ at the lower part of the window and the rigidity of the side column, the main factors influencing the seismic performance of cold-formed steel composite wall with openings are given.

$$\alpha = \frac{l'}{d}$$
$$\gamma = \frac{h}{H}$$

![Figure 1. Analysis parameters.](image)

2. Finite Element Model

2.1. Establish Finite Element Model

The column and guide rail adopt displacement based beam element. Firstly, nodes are arranged at the connection of self-tapping screws between column and guide rail, and then nodes are defined as beam element.

In the finite element modeling, the double-layer wall panel with staggered joint arrangement is equivalent to a rigid panel, and the double-layer wall panel with flush joint arrangement is divided into blocks to establish a rigid surface, and all rigid surfaces are arranged according to the screw position. Except for the vertical joint of the rigid surface established by blocks, the other parts are connected by single row of screws.

As shown in figure 2, pinching4 material constitutive model is used to define zero length spring element to simulate the screw connection of column guide rail and wallboard keel, and the relevant displacement is coupled to coordinate the stress and relative deformation between zero length elements. The value of pinching4 material constitutive model parameter is referred to the mechanical property test of self-tapping screw connection [6].

In this paper, when building the model of cold-formed steel wall with openings, this part of the wall is simplified as a series of linear elastic beam elements distributed along the center line. As shown in figure 3a, zero length element 2 is arranged between the two ends of the coupling beam and the side column of the opening to transfer only the vertical force, so as to simulate the transfer of the self-weight of the coupling beam. By setting zero length elements 1 and 3 at both ends of the beam to transfer only the horizontal force, the simulation is carried out Moment transfer between the upper wall and the side column of the opening.

![Figure 2. Finite element modeling.](image)

![Figure 3. Finite element model of cold formed steel composite wall with strong side column.](image)
2.2. Boundary Conditions
Constrain the translational degrees of freedom out of the plane of the upper guide rail joint on the wall, coupled with the translational degrees of freedom along the loading direction of the upper guide rail joint; constrain the translational degrees of freedom of the lower guide rail joint, and couple the translational degrees of freedom of the nodes at both ends of the middle column with the corresponding guide rail joints; constrain the translational degrees of freedom out of the plane of the rigid surface and the rotational degrees of freedom around the plane. During the finite element modeling.

Newton Lapson iterative method is used to solve the nonlinear finite element analysis, and Lagrange method is used to deal with the constraints of nonlinear equations; node freedom number optimization method is used to deal with node number; data storage is used to store and calculate the nonlinear equations; energy incr convergence criterion is used, the convergence tolerance is set to 1.0e-6, and the maximum number of iterations is 5000.

3. Finite Element Model Verification
In order to verify the correctness of the model, a finite element model is established with reference to the test piece SW6 in the literature [7], the input value of the load (elastic point, yield point, peak point, failure point) of the self-tapping screw connection of the finite element model is (1002, 2022, 2433, 50), and the corresponding displacement is (0.43, 4.24, 9.59, 25). The load test value, displacement test value, ductility and stiffness coefficient of the characteristic points (yield point and peak point) of the cold-formed wall are compared with the analysis value of OPENSEES numerical simulation. The comparison results are shown in table 1. The displacement and load simulation values of the characteristic points are close to the test values, and the errors are within 15%. The comparison between the test hysteresis curve of cold-formed steel composite wall with openings and the numerical simulation results of OPENSEES is shown in figure 4. The calculated hysteresis curve in the figure is in good agreement with the test hysteresis curve, which proves that the model can simulate the hysteresis characteristics of the test piece more accurately.

| Specimen | \(F_{y}^t\) | \(F_{p}^t\) | \(\Delta_{y}^t\) | \(\Delta_{p}^t\) | \(\mu^t\) | \(k^t\) | \(\mu^0\) | \(k^0\) |
|----------|-------------|-------------|----------------|----------------|-----------|-------|-----------|-------|
| SW6      | 25.7 26.3 1.02 | 37.5 39.2 1.05 | 19.4 18.8 0.96 | 55.1 56.0 1.02 | 3.35 3.02 0.90 0.68 0.7 1.03 |

Note: \(F_{y}^t\) and \(F_{y}^0\) are respectively the test value and finite element value of yield load; \(\Delta_{y}^t\) and \(\Delta_{y}^0\) are respectively the test value and finite element value of yield displacement; \(F_{p}^t\) and \(F_{p}^0\) are respectively the test value and finite element value of maximum load; \(\Delta_{p}^t\) and \(\Delta_{p}^0\) are respectively the test value and finite element value of maximum displacement; \(\mu^t\) and \(\mu^0\) are respectively the test value and finite element value of ductility; \(k^t\) and \(k^0\) are test values and finite element values of shear stiffness respectively.
4. Parameter Analysis

In order to explore the influence of various parameters on the shear resistance of cold formed wall with openings in different side columns, two models, SWA and SWB, were set up. Based on the above model of SWA model, the side column is double jointed, the side column of SWB model is square steel tube, and the section of side column is as shown in figure 5.

![Side column section](image)

(a) double side columns  (b) square steel tube side column

Figure 5. Side column section.

4.1. Span Height Ratio of Coupling Beam

Part of the wall on the opening of the cold-formed steel opening composite wall plays a role similar to the transfer of the vertical force of the coupling beams in practice. In this paper, this part of the wall is referred to as the coupling beam. In order to explore the influence of coupling beams on the shear resistance of walls with openings, the shear resistance of walls with the ratio of span to height of coupling beams between 0 and 6 is analyzed. The opening width of SWA model is 600 mm, 1200 mm and 1800 mm, and that of SWB model is 600 mm, 1500 mm and 1800 mm, keeping other parameters unchanged. See figures 6 and 7 for rigidity curve and maximum shear bearing capacity curve of different span height ratio model of coupling beam, as you can see from the picture. With the increase of the span height ratio of the coupling beam, the shear resistance of SWA and SWB model decreases gradually. Compared with SWB model, the span height ratio of the coupling beam has a greater impact on the shear resistance of SWA model. The possible reasons are: the filling material in the square steel pipe increases the restraint ability of the side column to the self-tapping screw, and improves the integrity of the cold formed wall. The shear performance of SWA model with 1 span to height ratio of coupling beam, 600 mm width of opening and 1200 mm width of opening is basically the same. SWB model also shows this characteristic, which shows that the span to height ratio of coupling beam has obvious influence on the shear performance of opening wall. Without considering the change of height of coupling beam, the span to height ratio of coupling beam is determined by the width of opening, which affects the shear performance of combined wall. The increase of the span to height ratio of the coupling beam leads to the decrease of the shear resistance of the wall with openings, which is consistent with the fact that with the increase of the span to height ratio of the coupling beam, the
coupling beam gradually becomes a long and thin member and its contribution to the shear capacity of the wall with openings decreases. When the span to height ratio of the coupling beam is greater than 5, the difference between the shear capacity of the cold formed wall and that of the wall without opening is less than 10%. At this time, the coupling beam has little contribution to the shear performance of the wall. In engineering practice, in order to give full play to the shear resistance of the coupling beam in the wall with openings, considering the demand of lighting and ventilation, it is recommended to control the span height ratio of the coupling beam of the cold-formed steel wall with openings between 1.0 and 5.0.

![Figure 6. Maximum bearing capacity curve.](image)

**Figure 6.** Maximum bearing capacity curve.

### 4.2 Height Ratio of under Window Wall

When analyzing the influence of the height ratio of the lower wall of the window on the shear resistance of the composite wall with cold-formed steel openings, the span height ratio of the connecting beam of SWA and SWB models is 2, the hole wall ratio is 2, and the height ratio of the lower wall of SWA model window is 0, 0.1, 0.3, 0.5, 0.7, respectively.

The comparison results of the skeleton curve of the hysteretic curve of each calculation model and the changes of the bearing capacity and rigidity with the height ratio of the wall under the window are shown in figures 8 and 9. It can be seen from the figure that the shear resistance of each model increases with the increase of the height ratio of the wall under the window. Comparing the numerical results of two groups of models with different side columns, we can see that the increase of the height ratio of the wall under the window has a slightly greater impact on the SWA model than the SWB model: when the height of the wall under the window increases from 0.1 to 0.7, the maximum shear capacity of the SWA model increases by about 69%, and the SWB model increases by about 63%; the change of the height ratio of the wall under the window has a significant impact on the stiffness of the SWA model than the SWB model. When the height of the wall under the window increases from 0.1 to 0.7, the initial stiffness of the SWA model increases by about 131%, and that of the SWB model increases by about 61%; the shear capacity and stiffness of the two groups of models increase first and then decrease with the height of the wall under the window, showing an arc tangent shape, reflecting that the actual low window wall and small opening have little impact on the shear performance of the cold-formed steel opening wall. In order to give full play to the contribution of the wall under the window to the shear capacity of the wall, the height ratio of the wall under the window should be controlled between 0.1 and 0.5.
5. Conclusion

Based on the OPENSEES numerical simulation, the parameters influencing the shear performance of the cold-formed steel composite wall with openings are analyzed. The main conclusions are as follows:

1. The shear resistance of the cold-formed steel composite wall with openings decreases with the increase of the span height ratio of the coupling beams. When the span height ratio of the coupling beams is controlled between 1.0 and 5.0, the shear resistance of the coupling beams in the wall with openings can be better developed.

2. The shear resistance of the cold-formed steel wall with openings increases with the height of the lower wall of the window, and the increasing range shows the arc tangent shape of increasing first and then decreasing with the height of the lower wall of the window. It is better to control the height ratio of the lower wall of the window at 0.1~0.5 in the design.

3. The cross height ratio of the coupling beam and the height ratio of the wall under the window have more obvious influence on the shear resistance of the cold-formed steel wall with openings. Compared with the double side columns, the cold-formed steel wall with openings with square steel tube side columns has better shear resistance.

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