Finite element analysis of cold-formed thin-walled steel skeleton wall with rigid diagonal braces

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Abstract. In order to investigate the shear resistance of cold-formed thin-walled steel skeleton wall under monotonic load, the finite element analysis of six walls was carried out to obtain the shear capacity of different walls and reveal the wrecking mode of the wall. The results show that the arrangement of rigid cross brace and rigid diagonal brace in the wall can significantly improve the shear resistance of the wall, the vertical continuous splay layout with two spans has the largest lifting range.

1. Introduction

The cold-formed thin-walled steel house system is a new type of house structure system, which is developed from wood structure and takes galvanized cold-formed thin-walled steel frame and lightweight plate as load-bearing and enclosure structure. Compared with the traditional concrete structure and masonry structure, it has the advantages of light weight, low foundation requirements, good seismic performance, high degree of industrialization, convenient construction and installation, short period and so on. Different from the general beam column structure system, the cold-formed thin-walled steel structure system is a distributed stress system mainly composed of roof, floor and wall. Among them, the wall is the main load-bearing component, bearing the vertical load transmitted by the floor and roof, as well as the horizontal load generated by the wind load and horizontal seismic action on the structure[1].

Rigid diagonal brace is an effective way to improve the shear performance of composite wall, but there is little research on the influence of the layout of rigid diagonal brace on the shear performance of the whole structure, so it is of great significance to study the influence of different layout of diagonal brace on the shear performance of cold-formed thin-walled steel wall.

2. Finite element modeling and calculation

It is an effective way to simulate and analyze the cold-formed thin-walled steel skeleton wall by using the finite element method. Compared with the experimental research, it has the advantages of strong flexibility, short period and convenient operation. However, the difficulty is how to adopt the effective and convenient method to calculate the model quickly and accurately. Among them, how to select the appropriate element, simplify the contact element, deal with the boundary conditions, and effectively mesh are the key points of model simplification.

As shown in figure 1 – figure 2, six cold-formed thin-walled steel frame wall models are established according to the different layout of rigid cross bracing and rigid diagonal bracing[2-4], with length of 3660mm, width of 100mm, height of 2760mm, column spacing of 610mm, column and
diagonal bracing size of C97 × 38 × 12 × 1.0, top and bottom beams and cross bracing size of U100 × 42 × 1.0. Apply a constant vertical load (5T) and a horizontal monotonic load (70mm).

(a) SW-1  (b) SW-2  (c) SW-3  (d) SW-4  (e) SW-5  (f) SW-6

Figure 1 Finite element model

2.1. Unit type selection
The thickness of each component of the cold-formed thin-walled steel skeleton wall is 1mm, which is far less than its span, and the stress in the thickness direction can be ignored. Therefore, S4R element (4-node quadrilateral finite film strain linear reduction integral shell element) is used to simulate the structure. In order to simplify the analysis, the effects of fillet hardening, residual stress and initial defects of cold-formed thin-walled steel sections are ignored.

2.2. Nonlinear problems of materials
The von Mises yield criterion is adopted for all components of cold-formed thin-walled steel framework wall, and the ideal elastic-plastic model is adopted for the constitutive relationship of cold-formed thin-walled steel components. The material characteristics are: elastic modulus $E = 2.06 \times 10^5 \, \text{N/mm}^2$, yield strength $f_y = 235 \, \text{N/mm}^2$, poisson's ratio $\nu = 0.3$, thickness $t = 1.0 \, \text{mm}$.

2.3. Establishment of finite element model
Self tapping screws are used to connect the members of the cold-formed thin-walled steel frame wall. How to simulate the connection is always a difficulty in the finite element analysis. Most foreign scholars use nonlinear spring element to simulate the connection of self tapping screw. Although the results are accurate, the process is complex, time-consuming and not easy to calculate. In view of the coupling method in ABAQUS software, a rigid region can be formed at the joint by using coupling constraints. The nodes constrained have the same displacement value, ignoring the slip between the connectors and simplifying the model[5-6]. The parts which are connected by self tapping screws are connected by coupling contact, coupling the translational degrees of freedom in x, y and z directions,
that is, the members move together in three directions to simulate the constraint effect of self tapping screws.

The columns on both sides of the wall are two rolled C-steel (C97 × 38 × 12 × 1.0) with back-to-back connection by self tapping screws. The screw spacing is 200 mm. It is found in the test that the deformation between the two webs of the side columns is very small. It can be considered that the two sides are rigid connection. In the finite element study, tie contact is used to make the side columns closely connected. The bottom beam and the ground are closely connected by the ground anchor bolt, and the bottom beam is fixed to restrict all degrees of freedom of the bottom beam, i.e. \( U_1 = 0, U_2 = 0, U_3 = 0, U_{R1} = 0, U_{R2} = 0, U_{R3} = 0 \). The out of plane displacement of the top beam is constrained to simulate the role of the lateral rolling support in the test, so as to prevent its out of plane instability, that is, \( U_2 = 0 \). Hard contact is adopted for the contact between component surfaces, and the friction coefficient is 0.25, that is to say, the contact pressure transmitted by the surface of each component of cold-formed thin-walled steel is infinite, no contact pressure is generated when there is no contact, and mutual penetration is not allowed between the two surfaces. The loading point is set 150 mm above the top beam, and all the joints on the top beam are coupled with the degrees of freedom in X direction, so that the rigid body is stressed in the horizontal direction. The loading of the coupling joint is equivalent to the loading of the wall top beam, and the displacement control is adopted.

3. Analysis of finite element calculation results

Through the ABAQUS program post-processing module to extract the calculation results and analyze the processing, verify the strengthening effect of rigid cross brace and rigid diagonal brace on the shear performance of cold-formed thin-walled steel skeleton wall.
According to the analysis of figure 3 – figure 9, the wrecking mode of cold-formed thin-walled steel skeleton wall is as follows: the column is unstable, the top beam, bottom beam, rigid cross brace and rigid diagonal brace flange are locally buckled, and the connection between diagonal brace and cross brace and the end of columns on both sides are severely buckled, and the failure point is concentrated at the connection of self tapping screw.
Table 1 Wall characteristic values

| Wall number | \( P_{\text{max}}/\text{kN} \) | \( \Delta_{\text{max}}/\text{mm} \) | Increase of bearing capacity /% |
|-------------|-----------------|-----------------|-----------------------------|
| SW-1        | 0.76            | 43.25           | -52.8                       |
| SW-2        | 1.61            | 50.25           | --                          |
| SW-3        | 7.12            | 51.66           | 342.2                       |
| SW-4        | 7.14            | 54.36           | 343.5                       |
| SW-5        | 8.13            | 70.00           | 405.0                       |
| SW-6        | 11.20           | 48.76           | 595.7                       |

According to figure 10 and table 1, the setting of rigid cross brace and rigid diagonal brace makes the shear capacity of the wall increase geometrically, which significantly enhances the shear performance of the wall. Among them, the largest lifting range of diagonal braces is 6.0 times. The vertical continuous end-to-end arrangement of diagonal braces on both sides of the span takes the second place, which is 4.1 times. Diagonal braces are arranged at vertical intervals on both sides of the span, and the lifting range of diagonal braces pointing to the corner of the wall is basically the same as that of diagonal braces, which is 3.4 times.

4. Conclusions

(1) The wrecking mode of cold-formed thin-walled steel skeleton wall is as follows: the column is unstable, the top beam, bottom beam, rigid cross brace and rigid diagonal brace flange are locally buckled, and the connection between diagonal brace and cross brace and the end of columns on both sides are severely buckled, and the failure point is concentrated at the connection of self tapping screw.

(2) The results of finite element analysis show that the setting of rigid cross brace and rigid diagonal brace improves the shear performance of the wall, which makes the shear capacity increase in geometric multiple level, in which the vertical continuous splayed braces on both sides of the span have the largest lifting range, followed by the vertical continuous head to tail braces on both sides of the span.

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References

[1] Zhou X.H., Shi Y., Zhou T.H. (2005) Cold-formed steel framing system of low-rise residential building. Journal of Architecture and Civil Engineering., 22: 1-14.
[2] Xing Y.H., Wang X.W., Yu Y.Q. (2019) Simulation analysis of pseudo-dynamic test on K-braced light-gauge steel wall frame. Industrial Construction., 49: 177-183.
[3] Wang C.G., Li N., Zhang Z.N. (2017) Research on seismic behavior of cold-formed thin-walled steel residential structures with different rigid bracings. steel structure., 32: 45-51.
[4] Wang Y.H., Deng R., Yao X.M. (2019) Experiment on seismic behavior of cold-formed thin-walled steel walls with diagonal braces. Journal of Architecture and Civil Engineering., 36: 30-38.
[5] Shi Y. (2005) Research on shear capacity of composite wall of low rise cold-formed thin-walled steel structure residence. Chang’an University, Xi’an.
[6] Guo P. (2008) Experimental and theoretical study on shear performance of cold-formed steel framing walls. Xi’an University of Architecture and Technology, Xi’an.