

# Design and bearing capacity analysis of cold-formed thin-walled steel-timber composite members

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**Abstract.** Cold-formed thin-walled steel has light weight, large width thickness ratio, good economy and seismic performance. It is easy to realize standardization of design, and is very suitable for the development of prefabricated buildings. Due to the large width thickness ratio of cold-formed thin-walled steel, the steel plate is prone to local buckling when it is compressed, which will reduce the ductility and bearing capacity of the structure, which also leads to the limitation of the use of cold-formed thin-walled steel structure system in medium and high-rise buildings. In this paper, a kind of cold-formed thin-walled steel-timber composite members is designed. The section steel and the board are closely linked by bolts to work together. The thickness of the board and the spacing of the bolts are designed respectively, so as to provide reference for engineering design.

## 1 Introduction

Compared with ordinary hot-rolled section steel, the processing of cold-formed thin-walled steel is more simple, fast and efficient, so it is widely used in villas, multi-storey residential buildings and light steel plants<sup>[1]</sup>, as shown in Fig.1. The steel can be completely recycled to meet the requirements of environmental protection and sustainable development.



Fig. 1. Cold-formed thin-walled steel structure residence

Cold-formed thin-walled steel has light weight, open section, large width thickness ratio, good economy and seismic performance. At the same time, it reduces the requirements for the bearing capacity of the foundation, and can reduce the cost. The cold-formed thin-walled steel has the characteristics of cold processing industrial production and flexible cross-section, which makes it easy for the cold-formed steel structure to realize the standardization of component design and factory

production. Prefabricated stairs in prefabricated buildings are shown in Fig.2. The processing quality is easy to be guaranteed and transported to the site for assembly, which meets the requirements of building industrialization and adapts to the highly integrated requirements of industrialized light steel integrated building.



Fig. 2. Prefabricated stairs in cold-formed thin-walled steel structure buildings

## 2 Development and application of cold formed thin wall steel structure

Cold-formed thin-walled steel is widely used in North America, Europe and Japan. At present, British light steel structure system (British Standard), Italian light steel structure system (Italian standard), Finnish light steel structure system (Finnish standard), Australian light steel structure system (Australian standard), Japanese light steel structure system (Japanese standard) and

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American light steel structure system (American Standard) have become the six major light steel structure systems in the world.

In recent years, China has vigorously promoted prefabricated construction technology in the field of traditional construction industry, and even intelligent construction technology based on building integration<sup>[2]</sup>. The development of cold-formed thin-walled steel structure building system and the progress of corresponding design theories and methods have been greatly accelerated, and the policy system and industrial body of coordinated development of intelligent construction and building industrialization in China have been gradually established department.

### 3 Research status of cold-formed thin-walled steel structure

Due to the large width thickness ratio of cold-formed thin-walled steel, thin-walled and flexible members are often formed. When the plate is compressed, it is prone to local buckling, which will reduce the energy dissipation performance of the members, thus lead to the structural stiffness degradation, and then reduce the ductility and bearing capacity of the structure, which also leads to the limited use of thin-walled steel structure system in medium and high-rise buildings.

In order to actively promote the application of thin-walled steel in structure, many scholars have studied its static performance and seismic performance. Jing Zhao<sup>[3]</sup> carried out experimental research and finite element analysis on the seismic performance of thin-walled flexible H-section steel columns. It was found that the failure of specimens was caused by local instability. Flange width thickness ratio, web height thickness ratio and axial compression ratio were the three major factors affecting the seismic performance of thin-walled steel columns. Yiyi Chen<sup>[4]</sup> pointed out that the plastic energy dissipation capacity of thin-walled flexible H-section steel columns with large width thickness ratio was lower. The monotonic and repeated loading tests of ten specimens were carried out. The results show that, in the slenderness ratio range of general low multi-storey frame structure, The width thickness ratio of flange and web plate and the axial compression ratio of member are the key factors to determine the thickness of thin flexible section steel. Xi Lu<sup>[5]</sup> studied the seismic performance of single leg C-shaped steel through finite element analysis software, and found that axial compression ratio and width thickness ratio have great influence on the seismic performance of cold-formed thin-walled steel members, and premature local buckling is the main reason for the serious deterioration of the seismic performance of members, so the width thickness ratio of cold-formed thin-walled steel members can be limited. In order to improve the seismic performance of steel members, the intermediate stiffener is used to delay the local buckling. Ailin Zhang<sup>[6]</sup> put forward some suggestions for further study on the correlation between local buckling and global buckling of thin-walled flexible section steel members, distortional buckling of thin-

walled steel members, local buckling of steel members under horizontal earthquake and reasonable control of plastic hinge.

It can be seen that for cold-formed thin-walled members, the reduction of bearing capacity and ductility of members and even the whole structure caused by local buckling due to large plate width thickness ratio becomes the application of restraining thin-walled steel in multi-storey and high-rise light steel structures.

At present, the widely used cold-formed thin-walled steel housing structure system is a "box" structure<sup>[7]</sup>, which is composed of composite wallboard, floor and roof truss. The horizontal load of this structure is borne by the shear wall, and the vertical load is borne by the columns in the bearing wall. The "box" type cold-formed thin-walled steel housing structure system is a non frame structure with relatively low bearing capacity, and the section type of bearing members is too single to meet the use requirements of multi-storey and high-rise buildings. In order to improve the bearing capacity and seismic performance of cold-formed thin-walled steel frame structure, the beam column with steel wood composite section is used as the main load-bearing member, and the board is used to restrain the overall instability and local buckling of cold-formed thin-walled steel. The cold-formed thin-walled steel-timber composite section member is assembled by cold-formed thin-walled steel members by adding wood plates and adopting bolt connection, as shown in Fig.3.



Fig. 3. Cold-formed thin-walled steel-timber composite column

For this kind of cold-formed thin-walled steel-timber composite structure, there are relatively few studies in the world, and there is a lack of mature design methods. Therefore, it is particularly important to analyze the mechanical performance of its main load-bearing components, joints and frame structure. In this paper, section design and bearing capacity analysis of cold-formed thin-walled steel-timber composite columns are studied.

## 4 Application of cold-formed thin-walled steel-timber composite members

Because of its unique physical characteristics of heat preservation and humidity control, sound insulation and absorption, and its affinity with the surrounding environment and traditional culture, wood structure buildings are closer to nature and people. However, an obvious disadvantage of wood is that the design strength is low. The design load of the same size of wood and steel plate is very different under the premise of ensuring material damage of both. Therefore, for some large space, high-rise buildings, the use of wood structure is limited.

Cold-formed thin-walled steel-timber composite members combine the advantages of these two kinds of building materials, using high-strength steel to bear the external load, wood as the surface material to provide lateral stiffness for the steel plate and prevent the instability of the steel plate. The steel-timber composite structure is based on the tradition, and combined with the mechanical properties of wood and steel to innovate the structural system, using the structural system, components and node details to achieve the perfect combination of architecture and structure.

It shows a gymnasium whose main structure is V-shaped hollow steel arch in Fig.3., which meets the requirements of building space and visual effect. The steel arch is covered with wood, and the interior architectural style is unified<sup>[8]</sup>.

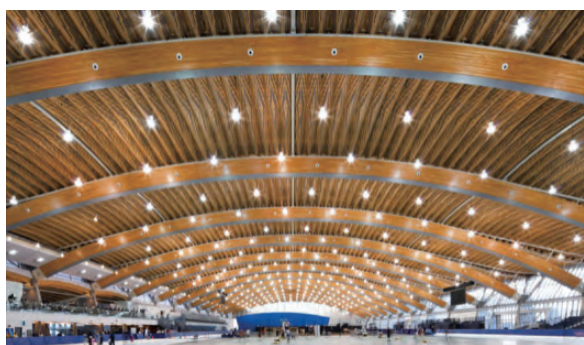


Fig. 4. Arched steel-timber composite structure

## 5 Design of cold-formed thin-walled steel-timber composite members

For the cold-formed thin-walled steel-timber composite member, the design idea is to use the section steel to bear all external loads, and the board to provide enough lateral stiffness for the steel plate, so as to restrain the overall instability of the section steel. At the same time, the appropriate bolt spacing can effectively restrain the local buckling of the steel.

### 5.1. Board thickness

In this paper, the design of double leg cold-formed thin-walled steel-timber composite member is carried out. The board does not bear any external load, just to effectively restrain the overall instability of the steel. In order to achieve this goal, it is necessary to make the

buckling critical load of the composite member exceed the yield load of the composite column and satisfy the condition of formula (1).

$$P_{cr} \geq P_y \quad (1)$$

Where:  $P_{cr}$  —the buckling critical load of the composite column,  $P_y$ —the yield load of the composite column.

The calculation of buckling critical load and yield load of cold-formed thin-walled steel-timber composite column are shown in formula (2) and formula (3) respectively.

$$P_{cr} = \frac{\pi^2 E_w I_w}{H^2} \quad (2)$$

$$P_y = f_y A_s \quad (3)$$

Where:  $E_w I_w$  —the lateral stiffness of the board,  $H$  —the calculated height of the composite column,  $f_y$ —the design value of yield strength of the cold-formed thin-walled steel,  $A_s$  —the cross sectional area of the cold-formed thin-walled steel.

Substituting formula (2) and formula (3) into formula (1), we can get the following result, as shown in formula (4):

$$I_w \geq \frac{f_y A_s H^2}{\pi^2 E_w} \quad (4)$$

### 5.2 Bolt spacing

For cold-formed thin-walled steel-timber composite members, when there is no vertical load but only horizontal load, the upper and lower flanges of the steel are subjected to compression stress and tensile stress respectively, and the web has both tensile stress and compression stress. When the axial compression ratio of composite column increases gradually, the upper flange still bears compression stress, while the lower flange and web may bear tensile stress or compression stress. Under the action of compression and bending load, three kinds of plates may appear in the composite column, as shown in Fig.5.

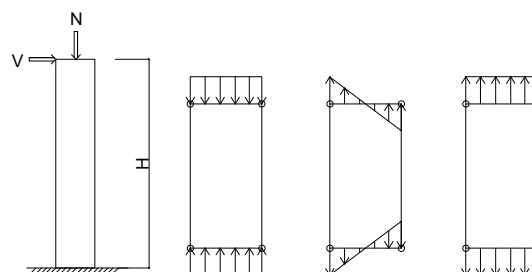


Fig. 5. Stress states of cold-formed thin-walled steel compression-bending member

There is no local buckling of steel in tension. Therefore, in order to avoid local buckling of section steel under vertical load, the small deflection theory of thin plate is used to calculate the bolt spacing. The bolt spacing is determined by the most unfavorable upper

flange plate under uniform compression. It is necessary to make the buckling critical load of the composite column exceed the yield load of the composite column and satisfy the condition of formula (5).

$$P_{cr} \geq P_y \quad (5)$$

Where:  $P_{cr}$ —the buckling critical load of thin steel plate,  $P_y$ —the yield load of thin steel plate.

The calculation of buckling critical load of thin plate and the yield load of thin plate are shown in formula (6) and formula (7) respectively.

$$P_{cr} = \frac{\pi^2 E_s I_s}{m^2} \quad (6)$$

$$P_y = f_y A_s \quad (7)$$

Where:  $E_s I_s$ —the lateral stiffness of thin steel plate,  $m$ —the longitudinal spacing of bolts,  $f_y$ —the design value of yield strength of the cold-formed thin-walled steel,  $A_s$ —the cross sectional area of the thin steel plate.

Substituting formula (6) and formula (7) into formula (5), we can get the following results:

$$m \leq \pi \sqrt{\frac{E_s I_s}{f_y A_s}} \quad (8)$$

$$A_s = n \times t \quad (9)$$

$$I_s = \frac{1}{12} n t^3 \quad (10)$$

Where:  $n$ —the transverse spacing of bolts,  $t$ —the thickness of section steel.

## 6 The calculation of compression-bending capacity of cold-formed thin-walled steel-timber composite columns

Research on the bearing capacity of cold-formed thin-walled steel-timber composite columns under compression and bending. It is mainly made of C-shaped section steel and U-shaped section steel by means of screw or spot welding, with various combinations. According to the Chinese code, the effective width method is used to check the bearing capacity of compression bending members.

In this example, Q235 steel is selected. The size of single leg C-shaped cold-formed thin-walled section steel is: the web height is 200 mm, the flange width is 70 mm, the hemming height is 20 mm, and the section steel thickness is 2 mm. The calculated height of the column is assumed to be 2000mm. According to the calculation formula of plank thickness and bolt spacing, the plank thickness is 20 mm, the bolt longitudinal spacing is 50 mm, and the transverse spacing is 60 mm. The section parameters of single leg C-shaped cold-formed thin-walled steel are shown in Table 1.

**Table 1.** The section parameters of single leg C-shaped cold-formed thin-walled steel.

| $f_y / N / mm^2$ | $A_s / mm^2$ | $I_{sx} / mm^4$   | $I_{sy} / mm^4$   |
|------------------|--------------|-------------------|-------------------|
| 205              | 727          | $4.4 \times 10^6$ | $4.6 \times 10^5$ |

The bearing capacity of double leg C-shaped cold-formed thin-walled steel columns and double leg C-shaped cold-formed thin-walled steel-timber composite columns under different axial compression ratios are checked.

According to the Chinese code, the effective width method is used to check the bearing capacity of compression bending members.

For stiffened plate, partially stiffened plate and non stiffened plate, the effective width ratio is calculated according to the formula (11) to formula (13) :

$$\text{when } \frac{b}{t} \leq 18\alpha\rho,$$

$$\frac{b_e}{t} = \frac{b_c}{t} \quad (11)$$

$$\text{when } 18\alpha\rho < \frac{b}{t} < 38\alpha\rho,$$

$$\frac{b_e}{t} = \left( \sqrt{\frac{21.8\alpha\rho}{\frac{b}{t}}} - 0.1 \right) \frac{b_c}{t} \quad (12)$$

$$\text{when } \frac{b}{t} \geq 38\alpha\rho,$$

$$\frac{b_e}{t} = \frac{25\alpha\rho}{\frac{b}{t}} \cdot \frac{b_c}{t} \quad (13)$$

Where:  $b$ —the width of cold-formed thin-walled steel sheet;  $t$ —the thickness of cold-formed thin-walled steel sheet;  $b_e$ —the effective width of cold-formed thin-walled steel sheet;  $\alpha$ —the calculation coefficient,  $\alpha = 1.15 - 0.15\phi$ , when  $\phi < 0$ ,  $\alpha = 1.15$ ;  $\phi$ —unevenness coefficient of compression stress,  $\phi = \frac{\sigma_{\min}}{\sigma_{\max}}$ ;  $b_c$ —the height of compression zone of cold-formed thin-walled steel sheet;  $\rho$ —calculation coefficient.

For the cantilever column, the horizontal thrust is determined under the condition that the edge material of the double leg C-shaped cold-formed thin-walled steel member yields. The calculation formula is shown in formula (14) and (15) .

$$\frac{N}{A_s} + \frac{M_x}{W_x} = f_y \quad (14)$$

$$M_x = V \cdot H \quad (15)$$

Where:  $N$  —the axial pressure;  $A_s$  —the cross sectional area of the cold-formed thin-walled steel;  $V$  —horizontal thrust;  $H$  —Calculation height of the cold-formed thin-walled steel.

The horizontal thrust of double leg C-shaped cold-formed thin-walled steel columns with axial compression ratio of 0 and 0.1, as well as the effective width of compressed flange,web and compressed edge curl under the action of horizontal thrust and axial pressure are calculated respectively.The effective width of tension flange and tension edge curl is its actual width.The calculation results are shown in Table 2.

**Table 2.** Calculation of effective width of cold-formed thin-wall steel

|  |       |        |
|--|-------|--------|
| Axial compression ratio                        | 0     | 0.1    |
| Horizontal thrust/ $kN$                        | 10.34 | 9.306  |
| The effective width of compressed flange/ $mm$ | 51.85 | 50.75  |
| The effective width of edge curl/ $mm$         | 16.72 | 16.73  |
| The effective width of web/ $mm$               | 80.16 | 106.69 |

It can be seen from the calculation results in the table that the change of axial compression ratio has less influence on the effective height of compression flange and compression crimp, and has greater influence on the effective width of web. Under the two axial compression ratios, the effective width of the web is only half of the actual length, which greatly reduces the bearing capacity of the column.

## 7 Conclusion

Cold-formed thin-walled steel housing has been widely used in foreign countries, but it is still in its infancy in China. In order to make the cold-formed thin-walled steel structure more widely used, this paper designs a kind of cold-formed thin-walled steel-timber column, carries out the preliminary design of the composite column, and analyzes some design methods, which provides a reference for the engineering application and design of this kind of structure. We can get the following results and some problems to be solved:

1) A certain thickness of wood plate can provide enough lateral stiffness for steel plate to restrain the overall instability of section steel. At the same time, the appropriate bolt spacing can effectively restrain the local buckling of the steel.

2) The effective width of cold-formed thin-walled steel column is calculated by using Chinese code. The results show that the effective width of the steel column is only half of the actual width, and the bearing capacity and seismic performance are significantly reduced.

3) With the constraints of wood plate, the bearing capacity and seismic performance of cold-formed thin-walled steel-timber composite columns will be greatly improved.

4) The seismic behavior of cold-formed thin-walled steel-timber composite members needs further experimental study.

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