Experimental investigation on double lipped channel cold-formed thin-wall steel column under compression loading

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Abstract. In order to investigate the compression behavior of double lipped channel cold-formed thin-wall steel column used in Box housing, a total of 12 columns with three different lengths (3000mm, 2556mm, 2000mm, respectively) and two different thickness (3mm, 4mm) were tested to investigate the ultimate load-carrying capacity and deformation behavior of cold-formed steel. It is found that the thickness has an obvious effect on compression ultimate load-carrying capacity, while the length does not have much influence. The failure modes of most specimens contain local buckling. Test analysis result simulated by finite element analysis (FEA) agreed well with the experimental data, which verified the FEA analysis method is appropriate. The analysis method provided in this paper can be referenced for the design of Box housing.

1. Introduction
In recent years, box housing has been widely used in practice for its characteristics of convenient transportation, reusable use and fast disassembly [¹]. Its main load-bearing members often adopt double lipped channel cold-formed thin-wall steel section to meet the structural requirements. However, the current standard of China GB50018 [²] for cold-formed thin-wall steel design lacks the design guidance for the asymmetric section of double axes. Up to recent, much attention has been paid on the cold bending thin-wall axial compression member [³][⁶]. Specifically, C edge of C channel steel and channel steel [⁷][⁹] has been researched very much. While, the double lipped channel cold-formed thin-wall steel has been rarely studied. The ultimate load-carrying capacity and deformation behavior of cold-formed steel are investigated in this article, and the detailed experimental study and theoretical research can provide powerful test basis for the design of Box housing.

2. Experiment design
In this experiment, a total of 12 Specimens with three different lengths (3000mm, 2556mm, 2000mm, respectively) and two different thickness (3mm, 4mm) were tested to investigate the ultimate load-carrying capacity and deformation behavior of cold-formed steel.

2.1. Test specimen introduce
Column section form of Box housing is shown in Figure 1. The component is the two edge unequal angle, with the long side B3 = 210 mm, the short side B4 = 150 mm, the first edge side B2=B5 = 50 mm, the second edge side B1=B6 = 25 mm.
Apart from the general column length 2556mm and the thickness $T=3\, \text{mm}$, the additional length $3000\, \text{mm}$, $2000\, \text{mm}$ and thickness $T=4\, \text{mm}$ were designed for comparison. Two specimens are processed for each component, so that the coherence of the whole test will not be affected by the failure of the individual specimen. Sample numbers are arranged according to the rules shown in Figure 2. The statistical table of specimens is shown in Table 1.

| Specimen batches | Length | Thickness |
|------------------|--------|-----------|
| C1L2000T3        | 2000   | 3         |
| C1L2556T3        | 2556   | 3         |
| C1L3000T3        | 3000   | 3         |
| C1L2000T4        | 2000   | 4         |
| C1L2556T4        | 2556   | 4         |
| C1L3000T4        | 3000   | 4         |

2.2. Test equipment and measuring point arrangement

2.2.1 Test equipment. The test is loaded by 100t hydraulic servo jack. Due to the section of the Specimen is a biaxial asymmetric section, certain torsion may occur at the end of the component. In order to achieve the hinge connection at the end of the Specimen, universal spherical hinge is set in this test, as shown in Figure 3. The universal hinge can rotate in any axial directions, which can be hinged approximately for calculation.

The 200t level test loading frame of China construction technology center is adopted in this experiment, as shown in Figure 4. The beam length of the loading frame is adjustable, which can meet the test requirements of different Specimens lengths.
2.2.2 Measuring point arrangement. The displacement meters to measure the axial deformation of the Specimen are set in the centroid of the section at the top and bottom supports respectively, and the direction is consistent with the longitudinal axis of the Specimen, shown in Figure 5(a). In addition to the axial deformation, the torsion deformation of the Specimen also needs to be measured. Therefore, two displacement meters with a certain distance are arranged on each side of the end plates to measure the torsion, as shown in Figure 5(b). The displacement meters perpendicular to B3 and B4 plates are set in the middle of the Specimen to measure the horizontal displacement, shown in Figure 5(c).

In the middle of B3 and B4 plates, four strain gauges are arranged to measure the stress distribution and change rules, and three strain gauges are arranged at the Specimen corners for physical alignment [11], as shown in Figure 6(a). Three strain gauges are arranged at the corners at both end of the Specimen to observe the stress value in real time, as shown in Figure 6 (b).
2.2.3 Loading strategy. This experiment uses the hierarchical load, according to the results of ANSYS simulation to control the load. In the initial phase the strategy apply the limit load by 5% per level until 80%, 0.5mm per level is loaded. Appropriately decrease the displacement increment when the Specimen appears obvious deformation, until the ultimate load is achieved. When the load is dropped to 80% of the ultimate load the test stops. The displacement loading rate should be controlled at 0.5mm/min.

3. Experiment result and analysis

3.1. Experiment result

The Experiment phenomenon can be found that most Specimens appear the phenomenon of overall bending + local buckling without obvious torsion deformation, and the local buckling occurs near the middle position, as shown in Figure7. During the loading process, the middle part of Specimen B3 plate bent inwards. With the increase of load, the bending deformation gradually increases with small amplitude. When the Specimen fails, obvious local buckling deformation occurs in the middle position, and the overall bending amplitude increases instantly, accompanied by a dull sound. Most of the specimens showed the characteristics of B3 plate bending inward and B4 plate bending outward, and a few showed the opposite pattern, which indicates that the local failure mode was related to the local defects of the specimens, and the buckling direction was uncertain. The flexural drum is elliptic, the long side of ellipse corresponds to the width direction, and the short side corresponds to the longitudinal direction.

![Figure 7. Experiment result](image)

The average value of the two same specimen test results including the limit load and the failure mode is given in the Table2. Noted that L represents local buckling, D represents distorted buckling,
and T represents overall buckling. The results showed that the Specimen ultimate bearing capacity of the same thickness and different length does not produce significant changes with length, because the different lengths of specimens damage suddenly once local stress reaches the yield stress. So within this length range, the ultimate bearing capacity does not have the direct relationship with the length, which is mainly related to the section initial defects and load error. The Specimen ultimate bearing capacity of the same length and different thickness is much related to the thickness. The ultimate bearing capacity of the Specimen with a thickness of 4mm is about 38% larger than that of the Specimen with a thickness of 3mm on average, which can be considered as the key parameter in the design of the Specimen.

Table 2. Test results including the limit load and the failure mode

| Specimen       | Limit load/(KN) | Failure mode | Specimen       | Limit load/(KN) | Failure mode |
|----------------|-----------------|--------------|----------------|-----------------|--------------|
| C1L2000T3      | 256.1           | T+L          | C1L2000T4      | 329.4           | T+L          |
| C1L2556T3      | 266.3           | T+L          | C1L2556T4      | 404.6           | T+L          |
| C1L3000T3      | 231             | T+L          | C1L3000T4      | 328.5           | T+L          |

Figure 8 plots the load-axial displacement curve. It can be seen that, before the limit load is reached, the load-axial displacement curve approximately develops linearly. When the limit load is reached, the load suddenly drops with great descent, which is consistent with the failure phenomenon of the specimen in the experiment.

3.2. Comparison of finite element analysis and experimental results

The finite element software ANSYS11.0 was used to simulate T3 specimen in this experiment. Shell181 unit was used for analysis. The simulation analysis and the experiment results are compared, as shown in Table 3. The ultimate bearing capacity of the two result are almost consistent, and the error between the finite element results and the experiment results is within 8%. The failure mode of the finite element simulation and the experiment results are the same, shown in Figure 9. It can be seen that the finite element analysis method used in this paper can satisfactorily simulate the ultimate bearing capacity and failure mode of double-flanged Angle steel Specimen.

Table 3. Comparison of The simulation analysis with the experiment results

| Specimen       | Limit load/(KN) | Ansys result/(KN) | error |
|----------------|-----------------|-------------------|-------|
| C1L2000T3      | 256.1           | 260.8             | 1.8%  |
| C1L2556T3      | 266.3           | 254.5             | -4.4% |
| C1L3000T3      | 231             | 248.6             | 7.6%  |
4. Conclusion
In order to investigate the compression behaviour of double lipped channel cold-formed thin-wall steel column used in Box housing, a total of 12 Specimens with three different lengths (3000mm, 2556mm, 2000mm, respectively) and two different thicknesses (3mm, 4mm) were tested to investigate the ultimate load-carrying capacity and deformation behaviour of cold-formed steel. It is found that the thickness has an obvious effect on compression ultimate load-carrying capacity, while the length does not have much influence. Most Specimens appear the phenomenon of overall bending + local buckling without obvious torsion deformation. Test analysis result simulated by finite element analysis (FEA) agreed well with the experimental data, which verified the FEA analysis method is appropriate. The analysis method provided in this paper can be referenced for the design of Box housing.

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