Local correlation buckling analysis of double lipped channel cold-formed steel column

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Abstract. In this paper, the double lipped channel cold-formed steel column is analyzed by finite element method. Compared with the code both at home and abroad, convenient and practical design formulas have been figured out. The finite element model in this paper was compared with existing data analysis, and the results show that the model precision can meet the needs of the analysis. Through finite element analysis of double lipped channel cold-formed steel column, we can get the influence of a relative size, the plate width, on the bearing capacity of the local stability. The specification about plate buckling under the influence of the common effect of the different types of adjacent panel has no clear rules. Under even pressure, we get the general calculation formula under certain conditions. The conclusion can be used for reference in the standard revision.

1. Introduction
The container building is a kind of movable and revolving prefabricated construction product. Single box is the basic unit of container building, which can be used alone or be combined due to different needs. Generally, the connection between the units uses the fastener at the node. The assembly is completed in the processing plant, and the hoisting is in place at the destination. If the destination is far away, the project of bulk transportation and on-site installation is adopted for construction. This kind of building can be used for the temporary construction of the construction site, sales exhibition hall, temporary reception center and so on. Compared with the general K type building, the container building has the many characteristics: the transportation is convenient, the sealing is good, the heat insulation and warm keeping, the modularization, recyclable and so on.

The double lipped channel cold-formed steel column is the main vertical bearing member of container building. Through the study on the local buckling of this member, the suggested formula for design reference is obtained.

2. Provisions on local buckling correlation in national codes
According to the elastic stability theory, the formula for calculating the critical stress of plate failure is:

\[ \sigma_{cr} = \frac{k \pi^2 E}{12(1-\nu^2)} \left( \frac{l}{h} \right)^2 \]

In the formula, h is the width of the plate.

Relevant buckling consideration method: constraint coefficient, and combine it with the buckling
coefficient of the plate, or calculate according to the single plate\[^{[1]}\], namely:

\[
\sigma_{cr} = \frac{\chi k \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{h}\right)^2
\]  

(2)

In the formula, \(\chi\) is the restraint factor of plate.

The American code does not consider relative buckling, British design code for cold-formed steel\[^{[2]}\] adopts different calculation formulas for different stressed members and different section forms; In the Technical code of cold-formed thin-wall steel structures\[^{[3]}\] (GB50018), a unified calculation formula for the constraint coefficient of the plate group is put forward.

3. Finite element model validation

Known from the literature\[^{[4]}\], using the beam unit to analyze the buckling problem does not conform to the reality, this paper adopts shell181 element modeling calculation, material for elastomer, modulus of elasticity \(E = 206000\) Mpa, Poisson's ratio=0.3.

Unit division: web, flange and rolled edge are divided into units by size of 8mm and 30mm along column height.

The two ends of the column are hinged, the bottom constraint \(UX=UY=UZ=ROTY=0\), the top constraint \(UX=UZ=ROTY=0\).

Through the cериг command, all nodes at the top loading end are formed into a rigid domain to avoid local damage, and uniform line load is adopted.

The model was calculated and verified. The column height was 800mm and only the local bearing capacity was verified. According to the selection and calculation of components in literature\[^{[5]}\], the results were compared with those in this paper, Where P1 is the calculation result of literature\[^{[5]}\], P2 is the calculation result of this paper.

| Table 1. Comparison results of finite element calculation |
|---------------------------------------------------------|
| Sectional dimension | P1/MPa | P2/MPa | P2/P1 |
|---------------------|--------|--------|-------|
| 1 C80x40x15x2.0 | 619.00 | 628.96 | 1.016 |
| 2 C100x50x15x2.5 | 614.80 | 622.70 | 1.013 |
| 3 C120x50x20x2.5 | 436.80 | 442.01 | 1.012 |
| 4 C140x50x20x2.0 | 209.65 | 211.98 | 1.011 |
| 5 C140x50x20x2.5 | 325.44 | 329.26 | 1.012 |
| 6 C160x60x20x2.0 | 159.81 | 161.65 | 1.012 |
| 7 C180x70x20x2.0 | 125.23 | 127.43 | 1.018 |
| 8 C180x70x20x2.5 | 195.76 | 198.27 | 1.013 |
| 9 C220x75x20x2.0 | 84.61 | 86.48 | 1.022 |
| 10 C220Xx75x20x2.5 | 132.62 | 134.58 | 1.014 |

By comparison, it can be found that there is little difference of local buckling stress between the finite element analysis in this paper and reference\[^{[5]}\], which indicates that the geometric modeling, mesh dividing and constraint conditions in this paper are reasonable, and the simulation calculation of the double lipped channel cold-formed steel column on this basis should also be reasonable.

4. Analysis of the double lipped channel cold-formed steel column

The column analyzed in this paper, in which the web belongs to the stiffener plate in the standard classification of our country, and the related plate parts, one is the stiffener plate, the other is the edge stiffener plate. The code does not clearly give the calculation formula of the correlation coefficient of this plate group.
As shown in figure 1, plate 2 and plate 3 are stiffener plate, and the types of adjacent plate parts on both sides are the same, plate 1 is edge stiffener plate.

This paper studied the influence of local buckling of plate 3 on its correlation coefficient between adjacent plates, and did not discussed the influence of flanging of stiffener plate or edge stiffener plate. Suppose b1/l<1, b2/l≤1/2.03.

According to the relevant provisions in China's regulations, when b1/b2=2.03, plate 1 and plate 2 have the same constraint effect on plate 3, and the discussion is as follows.

4.1. The case of b1/b2=2.03

When b1/b2=2.03, plate 1 and plate 2 have the same constraint effect on plate 3. It is suggested to calculate the correlation coefficient according to equations (3) and (4), and then calculate by equation (2).

\[
\chi = 1.715 - \frac{0.49\eta}{0.11 + \eta} - 0.294\eta^3
\]  
(3)

\[
\eta = \frac{b}{l}
\]  
(4)

In the formula, l is the width of plate 3; b is the width of plate 1.

| l/mm | b1/mm | b2/mm | b1/l | b2/l | Buckling stress /MPa | Recommended formula /MPa | Comparison % |
|------|-------|-------|------|------|----------------------|---------------------------|--------------|
| 180  | 100   | 45    | 0.500| 0.250| 506.00               | 493.61                    | 2.45         |
| 180  | 120   | 50    | 0.556| 0.278| 502.47               | 489.13                    | 2.65         |
| 180  | 140   | 60    | 0.667| 0.333| 494.03               | 481.21                    | 2.60         |
| 180  | 160   | 72    | 0.800| 0.400| 480.00               | 472.62                    | 1.54         |
| 180  | 170   | 85    | 0.944| 0.472| 449.55               | 463.53                    | 3.11         |

1—The results of recommended formula (4mm);
2—The results of ansys (4mm);
3—The results of recommended formula (3mm);
4—The results of ansys (3mm);
5—The results of recommended formula (2mm);
6—The results of ansys (2mm);

Figure 2. Column section

Figure 2. Column local capacity when l=180mm
b2/l>0.25 is to ensure that the size of plate 1 cannot be too small, b1/l<1 is to ensure that local buckling occurs in plate 3 firstly. The value of b1/b2 is approximately 2. Due to space limitation, only partial calculation results are listed here.

On the premise of b1/b2=2.0, changing the ratio of b1/l, the deviation of the correlation coefficient between the ansys and recommended formula calculation results is relatively small. When b1/l≤0.8, the recommended formula calculation results is smaller than ansys calculated results; when b1/l close to 1, the recommended formula calculation results is slightly superior to ansys calculation results. The main reason is using the straight line instead of bending arc when modeling, thus the model section features differ with the actual situation.

4.2. The case of b1/b2>2.03
When b1/b2>2.03, plate 1 has a strong constraint effect, the correlation coefficient can be calculated by the suggested formulas (5) \(^6\), (6) \(^6\), and (7), and then calculated by formula (2).

\[
\chi_1 = 1.75 - \frac{0.45\eta}{0.11 + \eta} - 0.3575\eta^3
\]

(5)

\[
\chi_2 = 1.75 - \frac{0.5\eta}{0.11 + \eta} - 0.33\eta^3
\]

(6)

\[
\chi = 1.1 \times \frac{\chi_1 + \chi_2}{2}
\]

(7)

In the formula, \(\chi_1\) is the Constraint coefficient of plate 1 to plate 3, \(\chi_2\) is the Constraint coefficient of plate 2 to plate 3.

Table 3. Comparison of calculation results of columns when b1/b2>2.03, b2/l =0.25.

| l/mm | b1/mm | b2/mm | b1/l | b2/l | Buckling stress /MPa | Recommended formula /MPa | Comparison /% |
|------|-------|-------|------|------|----------------------|------------------------|--------------|
| 180  | 100   | 45    | 0.556| 0.25 | 503.10               | 486.69                 | 3.37         |
| 180  | 120   | 45    | 0.667| 0.25 | 496.72               | 478.51                 | 3.81         |
| 180  | 140   | 45    | 0.778| 0.25 | 487.93               | 469.74                 | 3.87         |
| 180  | 160   | 45    | 0.889| 0.25 | 471.89               | 460.07                 | 2.57         |
| 180  | 170   | 45    | 0.944| 0.25 | 457.65               | 454.81                 | 0.62         |

In the case of 4>b1/b2>2.03, b1/b2>2.03 is to ensure strong constraint effect of plate 1, 4>b1/b2 is to ensure local buckling of plate 3 under the premise of b1/b2>2.03. In the case of 0.25≤b2/l≤0.444, 0.25≤b2/l is to ensure that the size of plate 1 cannot be too small, b2/l≤0.444 is to ensure local buckling of plate 3 under the premise of b1/b2>2.03.

Under the premise of b1/b2>2.03, changing the ratio of b1/l, the deviation of the correlation coefficient between the ansys and recommended formula calculation results is relatively small.

4.3. The case of b1/b2>2.03
When b1/b2<2.03, the constraint effect of plate 2 on plate 3 is strong. It is suggested to calculate the correlation coefficient according to equations (3) and (4), and then calculate by equations (2).

Table 4. Comparison of calculation results of columns when b1/b2<2.03, b2/l =0.25.

| l/mm | b1/mm | b2/mm | b1/l | b2/l | Buckling stress /MPa | Recommended formula /MPa | Comparison /% |
|------|-------|-------|------|------|----------------------|------------------------|--------------|

...
In the case of $1 \leq b_1/b_2 < 2.03$, $b_1/b_2 < 2.03$ is to ensure the strong constraint effect of plate 2; $1 \leq b_1/b_2$ is to ensure the size of plate 3 is not too small; The condition $0.25 \leq b_2/l \leq 0.444$ is to ensure the the same discussion scope as formula (2) above.

Within the scope of the above panel dimensions, the deviation of the correlation coefficient between the ansys and recommended formula calculation results is relatively small.

When $b_1/l$ close to 1, the recommended formula calculation results is superior to ansys calculation results.

5. Example

The section of 210x150x50x50x25x4 is widely used in the market. The formulas can be verified by the example. When $b_1/b_2=150/50=3>2.03$, the section suits the third case and compares with the calculation result of ansys.

| Thickness/mm | 2    | 2.5  | 3    | 3.25  | 3.5  | 3.75  | 4    |
|--------------|------|------|------|-------|------|-------|------|
| Buckling stress /MPa | 92.47 | 143.89 | 206.34 | 242.87 | 280.82 | 321.31 | 364.30 |
| Recommended formula /MPa | 92.94 | 145.22 | 209.12 | 245.42 | 284.63 | 326.74 | 371.76 |
| Comparison /% | 0.51 | 0.92 | 1.35 | 1.05 | 1.36 | 1.69 | 2.05 |

By comparing the results of the proposed formula calculation with the results of ansys simulation, it is found that the proposed formula calculation is slightly larger, but the deviation of the proposed formula calculation results is within 2%, so the proposed formula can be used for calculation in the design.

6. Conclusion

After a large number of variable parameter simulation calculations, the proposed formula in this paper is of value of reference.

In this paper, the conclusion is applicable to the section of $0.25 < b_2/l < 0.444$. When $b_1/b_2 \leq 2.03$, the correlation coefficient can be calculated by the suggested formulas (3), (4), (2); when $b_1/b_2 > 2.03$, the correlation coefficient can be calculated by the suggested formulas (5), (6), (7), (2). The conclusion can be used for reference in the further changes to the specification.

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