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# NUMERICAL MODELLING ON BEHAVIOUR OF COLD-FORMED STEEL UNLIPPED CHANNEL UNDER COMBINED COMPRESSION AND BENDING ACTIONS

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## *ABSTRACT*

*Research and development of construction materials continue to be carried out, getting materials, cross-sectional shapes, and manufacturing methods that are more efficient than before. Cold-formed steel is a material breakthrough in construction that has advantages over hot-rolled steel. In this paper, the cross-section of cold-rolled steel unlipped channel will be analyzed which is subjected to a combination of axial and bending loads. Investigating elements will be carried out using the finite element method on ABAQUS, and the results of the analysis produce a visualization of the behavior and capacity of the cold-rolled steel section. The cross-section capacity results obtained from the numerical test results will be compared with the predictions given by SNI 7971-2013 or AS/NZS 4600. Existing research in the literature will be used as a reference in conducting numerical analysis and calculating ultimate capacities.*

***Keywords:*** *Cold-Formed Steel, Unlipped Channel, Combined Axial and Bending Load, Finite Element Method.*

## 1. INTRODUCTION

In steel structure construction, there are two types of structural steel elements that are commonly used, namely hot-rolled steel and cold-formed steel. Hot-rolled steel is formed When the temperature is high while cold-formed steel is made at cold temperatures through several forming methods, the forming of cold-formed steel can be done by bending or pressing [1]. Hot-rolled steel was earlier and is commonly used in building construction, while cold-formed steel was originally and is generally used in household appliances, electronics, and the automotive industry. Hot-rolled steel has several drawbacks including the strength-to-dimension ratio being smaller than cold-formed steel, to overcome this the researchers propose several cross-sections that are more efficient so that the limitations of hot-rolled steel can be overcome [1].

The use of cold-formed steel in construction is based on the fact that cold-formed steel has several advantages such as High strength and rigidity, quick and easy installation, more precise shapes, and easy fabrication. Cold-formed steel is available in a variety of cross-sectional shapes including the commonly used C and Z shapes. unlipped channel cross-section is one of the most commonly used profiles because it can be used in many places such as beams, columns, and purlins [2].

The cross-section of cold-formed steel has thinner dimensions than hot-rolled steel, as a result, there are some special problems including distortion buckling, local buckling, joints, cold working, and fatigue. Many studies on cold-formed steel have used channel sections, both experimental and numerical tests [3]-[11].

Janartahan & Mahendran [12] tested unlipped channel steel elements due to combined bending and torsion loads, element testing using the finite element method and calculation of cross-section capacity using regulations obtained close results. In research on testing unlipped channel steel elements against combined axial and bending loads using the finite element method and capacity calculations based on SNI 7971-2013 [13] there is no in the literature.

Numerical testing in the ABAQUS software will be carried out by modeling unlipped channel steel elements to obtain several variables, one of which is cross-sectional capacity. The results of the numerical analysis are compared with the predicted results obtained from SNI 7971-2013 or AS/NZS4600 [14]. The behavior and strength of steel will be examined by modeling the elements which are subjected to combined loads due to free eccentricity, which is the aim of this study.

## 2. FINITE ELEMENT MODELLING

The numerical method is one of the solutions when the elements to be analyzed have complex shapes, and are not optimal when using analytical analysis. Numerical methods are used when the analytical solution does not give good results. One of the commonly used numerical methods is the finite element method. This method uses a discretization technique on elements that divides the continuous structure into a series of small objects called finite elements which are only connected at nodes. Among the many studies on buckling using finite elements, the study by Budiman [15] gave results that converged with the results in the literature.

Experimental tests and numerical tests using finite elements with the help of software are some of the ways that researchers do to get the behavior and cross-sectional capacity of an element. ABAQUS 6.14 software is used in this study to model elements and loadings. The results of the visualization of the sections due to loading, boundary conditions, and mesh will be obtained from ABAQUS, besides that the capacity of the sections which will be compared with regulations will also be obtained.

### Material properties and The Geometrics of Section

The numerical test due to the combined load in this study uses G450 material, where the material has a value fy of 450 and 500 for the value of fu. The type of cross-section to be used is 6 cold-formed steel unlipped channels consisting of 3 variable thickness elements, these elements have an overall depth ranging from 100 to 300 mm. The dimensions of the unlipped channel steel can be seen in table 1.

Table 1. Nominal dimensions of unlipped channel sections..

| *Section* | *d (mm)* | *$b_f$ (mm)* | *t (mm)* | *$r_i$ (mm)* |
|---|---|---|---|---|
| 300 x 90 x 6 | 300 | 90 | 6 | 8 |
| 250 × 90 × 6 | 250 | 90 | 6 | 8 |
| 200 × 75 × 5 | 200 | 75 | 4.7 | 4.5 |
| 150 × 75 × 5 | 150 | 75 | 4.7 | 4 |
| 125 × 64 × 4 | 125 | 64 | 3.8 | 4 |
| 100 × 50 × 4 | 100 | 50 | 3.8 | 4 |

### Boundary Conditions and Loading Application

Modeling cold-formed steel unlipped channel is modeled as a shell element so that it has 6 DOFs at each node, boundary conditions are applied to each end of the element, rotational movement in the z direction, and translational movement in the x, y, and z directions will be restrained, except at the location of application loads where the z-direction translation is not resisted. MPC (multi-point constraint) is used to relate the boundary conditions at one reference point. The application of boundary conditions is bound together at one reference point using the MPC (multi-point constraint). Obtaining a combination of axial and bending loads, the location of the loading on the cross-section will be shifted in the direction of the y-axis from the center of gravity to the wing of the unlipped channel, such modeling will result in an element experiencing combined loading.

### Element Type and Mesh Size

Numerical tests using the finite element method must model an element on one type of finite element, in this study it is modeled as a shell. There are many elements in ABAQUS, and the S4R elements from many studies give good results, in this study the S4R elements will be used. The finite element method breaks the elements into small parts called meshes. The mesh greatly determines the analysis results. In theory, using a fine mesh gives good results, but the drawback is that it requires a lot of computation time. In this study, a mesh size of 4 mm x 4 mm will be used, the selected element size has given good results in much of the literature.

### Analysis Method

Linear analysis using linear perturbation analysis will be carried out in the first stage. The analysis is to get the shape mode and buckling load. The second stage performs nonlinear analysis using the data obtained from the first stage to determine the initial geometric imperfection. In the second stage, the Riks modification method is used as a solution for nonlinear analysis. Imperfection is a variable that is owned by cold-formed steel because cold-formed steel has many stages starting from forming to the construction stage at the site. Geometrical imperfections can use the values in SNI 7971 2013 or AS/NZS 4600, and the values recommended by researchers. Schafer and Pekoz [16] suggest that the imperfection value for cold-formed steel is in the range of 0.14t to 0.66t, where t is the thickness of the cross-section. In this study, local buckling geometrical imperfection of 0.25t was used, which was also used by [3]. L/1000 will be used as an imperfection value for overall buckling or global buckling in this study.

## 3. EFFECTIVE WIDTH METHOD

This paper will briefly explain the calculation of the capacity of unlipped channel steel sections according to SNI 7971-2013. SNI 7971-2013 which refers to AS/NZS 4600 is used to determine the capacity of elements due to the combined load of the design axial force (N*) and design bending moment (Mx* and My*) about the x and y axes of the effective cross-section, must comply with the following

$$\frac{N^*}{\phi_c N_c}+\frac{M_x^*}{\phi_b M_{bx}}+\frac{M_y^*}{\phi_b M_{by}}\le 1.0 \quad \text{when} \quad \frac{N^*}{\phi_c N_c}\le 0.15 \tag{1}$$

$$\frac{N^*}{\phi_c N_c}+\frac{C_{mx}M_x^*}{\phi_b M_{bx}a_{nx}}+\frac{C_{my}M_y^*}{\phi_b M_{by}a_{ny}}\le 1.0 \quad \text{when} \quad \frac{N^*}{\phi_c N_c}\ge 0.15 \tag{2}$$

Where $N_s$ is the nominal cross-sectional capacity of the member in compression

$$N_s = A_e f_y \tag{3}$$

The notation $N_c$ is the nominal structural member of the structural member in compression

$$N_c = A_e f_n \tag{4}$$

Where $f_n$ is the critical stress

$$f_n = (0,658^{\lambda c^2}) f_y, \text{when} \quad f_n \le 1,5 \tag{5}$$

$$f_n = (0,877 / \lambda_c{}^2) f_y, \text{when} \quad f_n > 1,5 \tag{6}$$

where Nondimensional Slenderness is

$$\lambda_c = \sqrt{\frac{f_y}{f_{oc}}} \tag{7}$$

The effective width can be calculated by the following equation

$$b_e = b, \quad \text{ketika} \quad \lambda \le 0,673 \tag{8}$$

$$b_e = \rho b, \quad \text{ketika} \quad \lambda > 0,673 \tag{9}$$

The notation $b$ is the flat width of the element, and the slenderness is

$$\lambda = \sqrt{\frac{f^*}{f_{cr}}} \tag{10}$$

Where $f^*$ is the flat width of the element, and slenderness is the design stress in the compression element based on the effective design width, and $f_{cr}$ the elastic buckling stress of the plate

$$\frac{f^*}{f_{cr}} = \frac{k\pi^2 E}{12\left(1-\nu^2\right)}\left(\frac{t}{b}\right)^2 \tag{11}$$

coefficient of plate buckling, k=4 for both sides supported elements, effective width factor

$$\rho = \frac{\left(1-\frac{0,22}{\lambda}\right)}{\lambda} \le 1 \tag{12}$$

$M_{bx}, M_{by}$ design bending moment

$C_{mx}$, $C_{my}$ coefficients for unequal end moments, $C_m = 0$ for compression members in a frame system that are subject to joint translation (sway), For compression members with restraints in a frame system that are braced against translational joints and do not receive a transverse load between their supports in the plane of bending can be determined by the equation

$$C_m = 0.6 - 0.4(M_1 / M_2) \tag{13}$$

## 4. RESULT ANALYSIS

Numerical modeling using the finite element method is carried out at ABAQUS by modeling the unlipped channel element as a shell element, the element will be given a combined load by providing a concentrated load that shifts in the y-axis direction from the center point, due to such loading the unlipped channel cold-formed steel element will experience a load combination. Estimation of sectional capacity by SNI 7971 2013 or AS/NZS 4600. Used as a comparison from the results of numerical analysis.

Table 2. Comparison of finite element analysis (FEA) and the code

| ***Section*** | ***Length (mm)*** | ***$P_{FEA}$ (kN)*** | ***$P_{AS/NZS}$ (kN)*** | ***$P_{AS/NZS}/P_{FEA}$*** |
|---|---|---|---|---|
| 300 x 90 x 6 | 1500 | 377.31 | 367.65 | 0.97 |
| 250 × 90 × 6 | 1500 | 347.86 | 346.40 | 0.99 |
| 200 × 75 × 5 | 1500 | 209.34 | 208.29 | 0.99 |
| 150 × 75 × 5 | 1500 | 189.49 | 189.48 | 1,00 |
| 125 × 64 × 4 | 1500 | 116.49 | 112.89 | 1.05 |
| 100 × 50 × 4 | 1500 | 109.21 | 99.95 | 0.92 |
| **Mean** | | | | 0.98 |
| **SD** | | | | 0.05 |

The results of numerical analysis and capacity calculations using the finite element method give good results. There is a good correlation between the results of the ultimate capacity of the section obtained from numerical analysis and the results of the approach using SNI 7971 2013 or AS/NZS 4600. The difference in ultimate load obtained from the two methods is 0.01% - 8.48%.

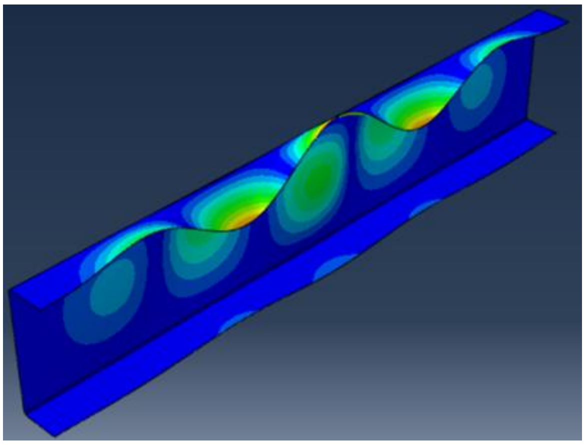

Figure 1. Buckling shape of the first eigenmode of 300 x 90 x 6 section.

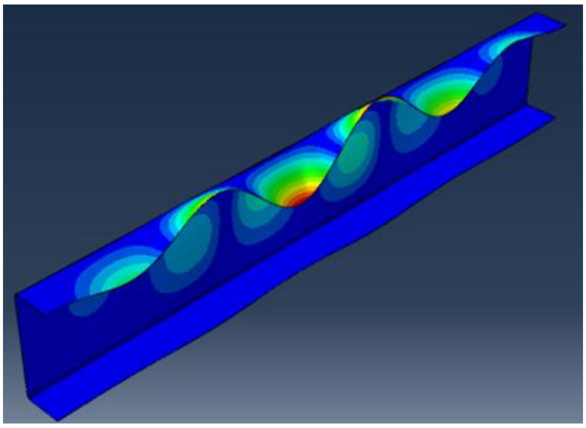

Figure 2. Buckling shape of the first eigenmode of 250 x 90 x 6 section.

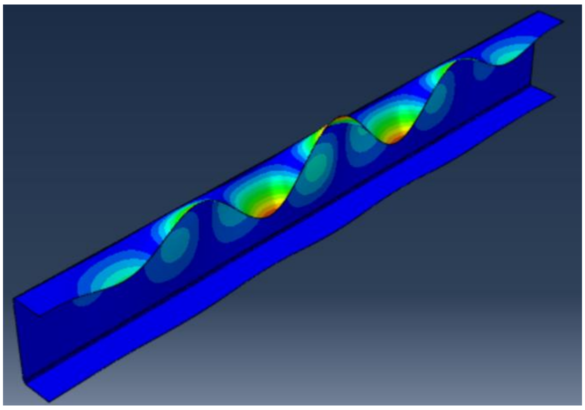

Figure 3. Buckling shape of the first eigenmode of 200 x 75 x 5 section.

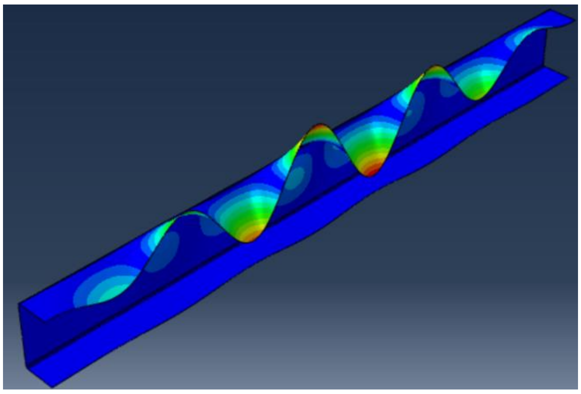

Figure 4. Buckling shape of the first eigenmode of 150 x 75 x 5 section.

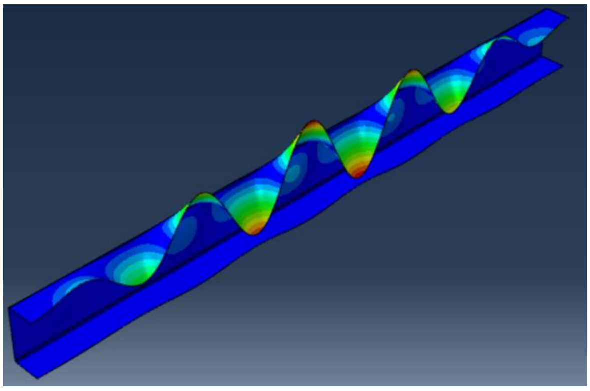

Figure 5. Buckling shape of the first eigenmode of 125 x 64 x 4 section.

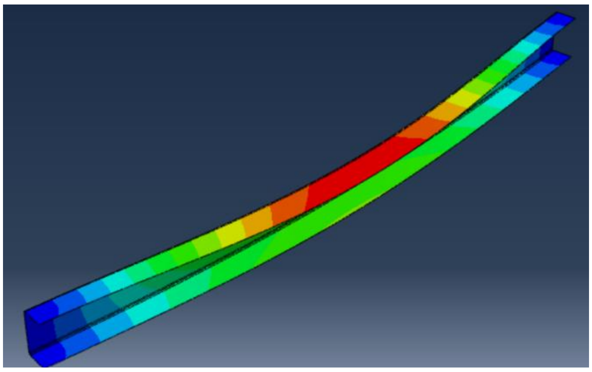

Figure 6. Buckling shape of the first eigenmode of 100 x 50x 4 section.

Figure 1 – 6. Explains that under combined load conditions where loading is carried out on one of the flanges of unlipped channel steel, the dominant mode shape is local buckling, except for the 100x500x40 element which is experiencing global buckling. The combined loading pattern does not result in the dominant element experiencing global buckling.

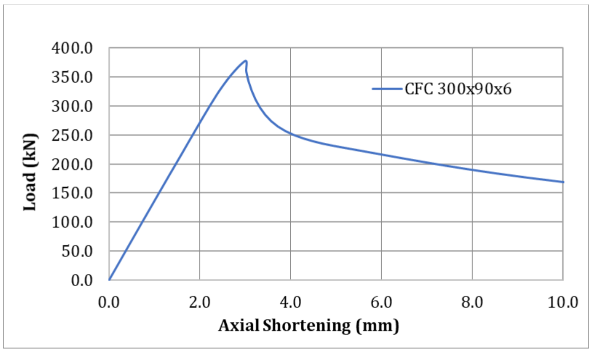

Figure 7. Axial shortening behavior of 100 x 50x 4 sections.

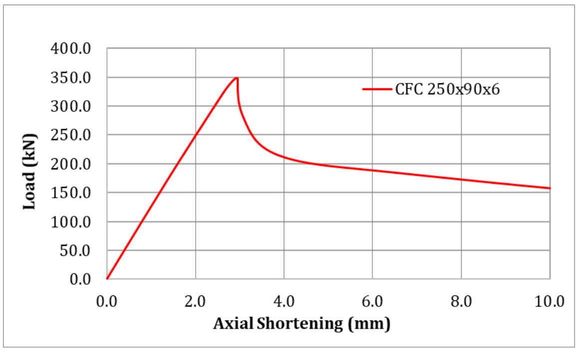

Figure 8. Axial shortening behavior of 125 x 64 x 4 sections.

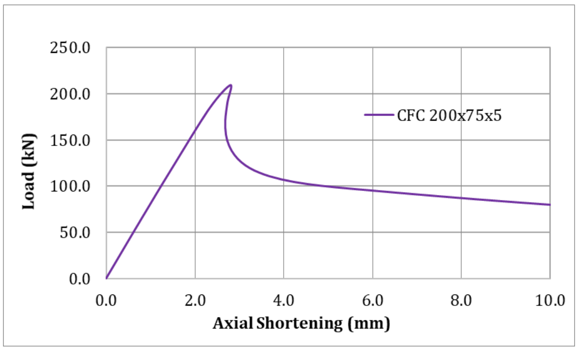

Figure 11. Axial shortening behavior of 150 x 75 x 5 sections.

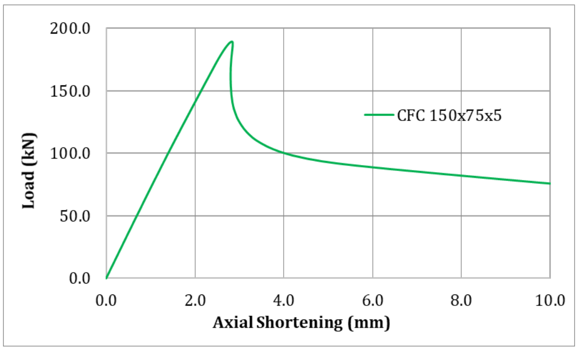

Figure 12. Axial shortening behavior of 200 x 75 x 5 sections.

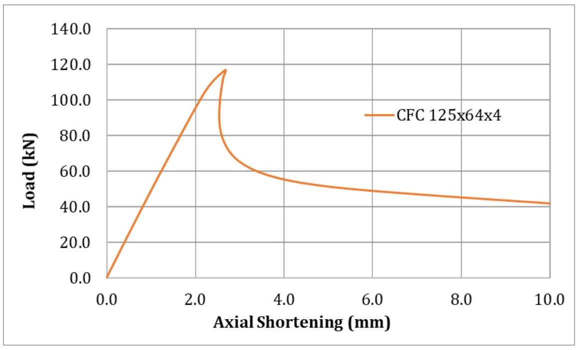

Figure 13. Axial shortening behavior of 250 x 90 x 6 sections.

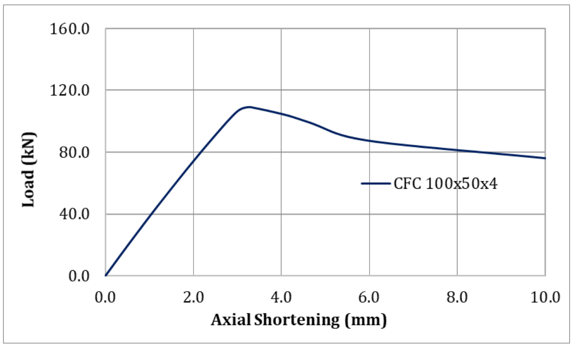

Figure 14. Axial shortening behavior of 300 x 90 x 6 sections.

From Figure 7-14 it can be seen that as the load continues to increase there will be a decrease in the stiffness of the structure, the structure will continue to maintain its integrity according to its ductility which is described as a long line after buckling occurs.

## 5. CONCLUSION

Numerical analysis of cross sections of cold-formed steel unlipped channel subjected to a combined load at ABAQUS, the combined load is obtained by providing a concentrated, eccentric force. The results of the analysis show that SNI 7971 2013 or AS/NZS 4600 can predict the capacity of the section, this is shown by the existence of a good correlation with numerical analysis. In combined load conditions, the largest difference occurs in the smallest elements due to the large ratio of length to the height of the cross-section, and also the eccentricity of the applied load. In this study, it can be concluded that elements that experience combined loading can be predicted using SNI 7971 2013 or AS/NZS 4600.

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