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NUMERICAL INVESTIGATION ON BEHAVIOUR OF COLD-FORMED STEEL UNLIPPED CHANNEL SUBJECT TO COMBINED COMPRESSION AND BENDING

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ABSTRACT

Cold-formed steel has become an alternative construction material solution that has many advantages compared to other construction materials including hot-rolled steel. The need for a construction material that can be manufactured easily and has a large strength-to-dimension ratio has been able to be met by cold-formed steel. In this study, the cross-section of unlipped channel cold-formed steel is subjected to a combination of compression and bending loads. Numerical analysis was carried out to see the behavior and capacity of the cold-formed steel cross-section using the effective width approach using SNI 7971-2013 or AS/NZS 4600 and using numerical analysis using the finite element method with ABAQUS. A comparison of the results of the two approaches was conducted to see whether the codes were able to give accurate results in providing cross-sectional capacity values for cold-formed steel. Numerical analysis and section capacity estimation will be carried out based on existing research in the literature.

Keywords: *Cold-Formed Steel, Unlipped Channel, Combined Compression and Bending, Finite Element Methods, ABAQUS.*

1. INTRODUCTION

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 weaknesses including a smaller strength-to-dimension ratio 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**Error! Reference source not found.**].

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 **Error! Reference source not found.**].

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 use channel cross sections, both experimental and numerical tests [2-16]. Peiris et al. [17] tested unlipped channel steel elements due to combined bending and torsion loads, element testing using the finite element method, and calculating cross-sectional 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 [18], there is not yet in the literature.

Numerical tests in 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 [18-19]. The behavior and strength of steel will be checked by modeling elements subjected to combined loads due to free eccentricities. This is the aim of this research.

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, studies [20-22] have provided results that converge to 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 get the behavior and cross-sectional capacity of an element. ABAQUS 6.14 software was used in this research to model elements and loads. The results of the visualization of the sections due to loading, boundary conditions, and mesh will be obtained from ABAQUS, besides 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 the G450 material, where the material has a fy value 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)*
200 x 75 x 5	200	75	4.7	4
180 × 75 × 5	180	75	4.7	4
150 × 75 × 5	150	75	4.7	4
125 × 65 × 4	125	65	3.8	4
100 × 50 × 4	100	50	3.8	4
75 × 40 × 4	75	40	3.8	4

Element Type and Mesh Size

Numerical tests using the finite element method must model the element in one type of finite element, in this study, it is modeled as a shell. There are many elements in ABAQUS, and the S4R element from many studies gives good results, in this study the S4R element will be used. The finite element method breaks elements into small parts called meshes, The mesh really determines the results of the analysis, in theory using a fine mesh gives good results, but the downside is that it requires a lot of computing time. This research will use a mesh size of 4 mm x 4 mm, the element size chosen has given good results in many literatures.

Boundary and Loading Conditions

The modeling of unlipped channel cold-formed steel is modeled as a shell element so that it has 6 DOFs at each node, boundary conditions are applied at 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 application location 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 load on the cross-section will be shifted in the y-axis direction from the center of gravity to the flange of the unlipped channel. Such modeling will produce an element that experiences combined loading.

The Method of Analysis

Linear analysis using linear perturbation analysis will be carried out in the first stage. This analysis is to obtain the mode shape and buckling load. The second stage carries out nonlinear analysis using data obtained from the first stage to determine the initial geometric imperfection. In stage two the modified Riks method is used as a solution for nonlinear analysis.

Imperfection is a variable that cold-formed steel has because cold-formed steel has many stages starting from formation to the construction stage at the site. Geometrical imperfection can use the values in SNI 7971 2013 or AS/NZS 4600, and the values recommended by researchers.

Schafer and Pekoz [23] suggest the imperfection value for cold-formed steel is in the range 0.14t to 0.66t, where t is the thickness of the cross-section. In the research, a local buckling geometrical imperfection of 0.25t will be used, which is also used by [3]. L/1000 will be used as the imperfection value for overall buckling or global buckling in this research.

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

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

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

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

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

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

where Nondimensional Slenderness is

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

The effective width can be calculated by the following equation

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

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

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

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

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

The unlipped channel element will be modeled as a shell element, ABAQUS software is used to carry out finite element analysis. The combined load in this study was obtained by modeling elements that were loaded with a concentrated load that shifted in the y-axis direction from the center point. Estimated cross-sectional capacity using the SNI 7971 2013 code or AS/NZS 4600 is used as a comparison for the numerical analysis results. The results of the cross-sectional capacity based on numerical analysis, the effective width method based on the code, and the results of the comparison can be seen in Table 2.

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

Section	***Length (mm)***	***P_{FEA} (kN)***	***$P_{AS/NZS}$ (kN)***	***$P_{AS/NZS}$ /P_{FEA}***
200 x 75 x 5	3000	155.77	124.32	0.80
180 × 75 × 5	3000	149.10	139.46	0.94
150 × 75 × 5	3000	139.63	106.94	0.77
125 × 65 × 4	3000	75.69	78.87	1.04

100 × 50 × 4	3000	37.29	48.47	1.30
75 × 40 × 4	3000	37.37	36.21	0.97
Mean				0.97
SD				0.193

Table 2 explains that there is a small difference between the cross-sectional capacity values based on SNI 7971 2013 or AS/NZS 4600 and numerical results using finite elements. The difference in ultimate load obtained from the two methods is 3.10% - 20.19%, based on this value, there is a good correlation between the two approaches.

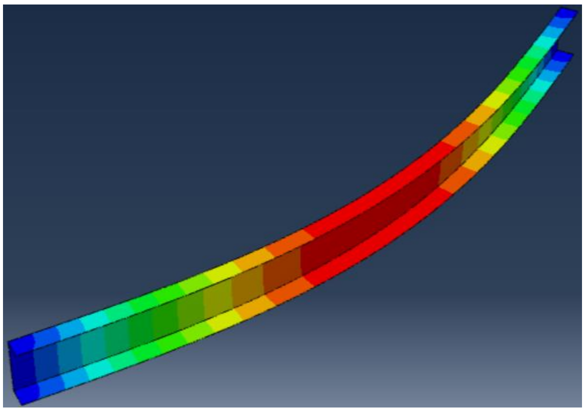

Figure 1. Buckling shape of first eigen-mode of 200 x 75 x 5 section.

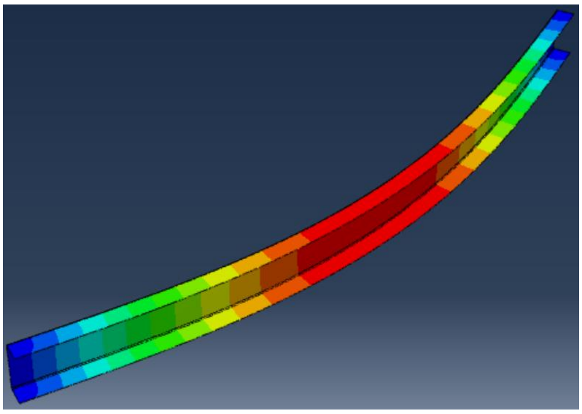

Figure 2. Buckling shape of first eigen-mode of 180 x 75 x 5 section.

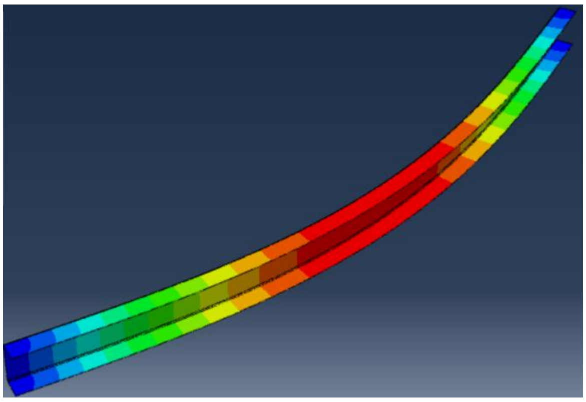

Figure 3. Buckling shape of first eigen-mode of 150 x 75 x 5 section.

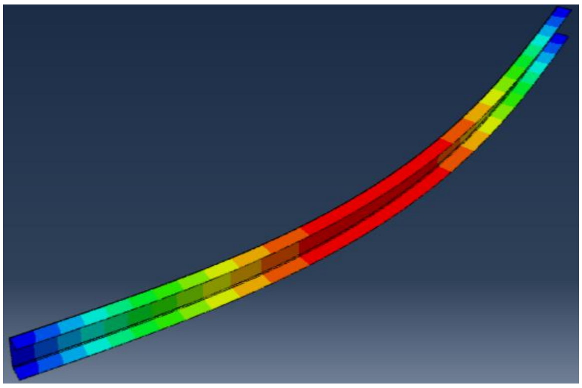

Figure 4. Buckling shape of the first eigen-mode of 125 x 65 x 4 section.

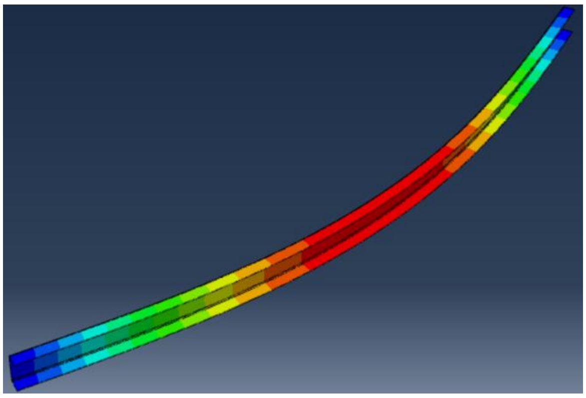

Figure 5. Buckling shape of the first eigen-mode of 100 x 50 x 4 section.

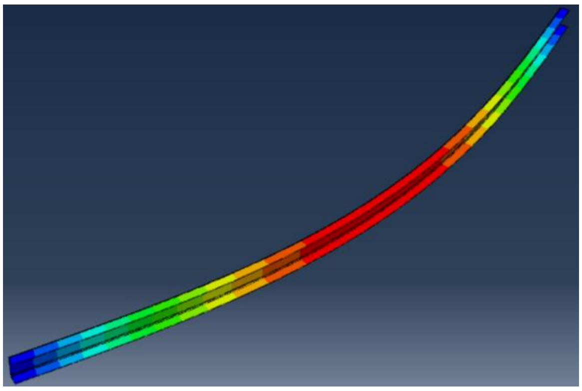

Figure 6. Buckling shape of the first eigen-mode of 75 x 40 x 4 sections.

Figure 4–8 shows that the combined load effect applied to the cold-rolled steel cross-section produces a global buckling mode. The maximum depth value in the 200x75x5 cross section does not cause the element to experience local buckling or distortion buckling.

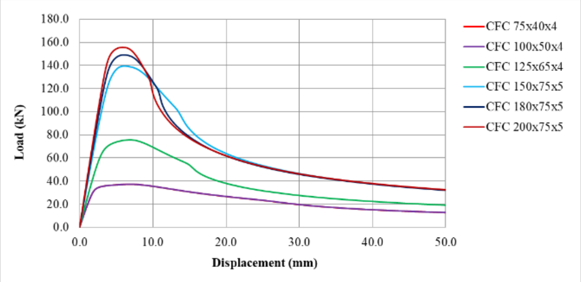

Figure 12. Load versus axial shortening behavior of the sections.

From the analysis in Figure 12, explaining the effect of the applied load on the axial shortening of all elements, the thickness of the element greatly influences the ultimate capacity that can be withheld. The level of ductility of an element can be seen from the long horizontal curve after the ultimate load is reached.

5. CONCLUSION

Analysis of the strength and cross-sectional behavior of cold-formed steel unlipped channels is carried out by placing eccentric loads on the elements using ABAQUS software. The results of the analysis show that there is a good correlation between the cross-section capacity values obtained based on the effective width method in accordance with SNI 7971 2013 or AS/NZS 4600 and numerical analysis using the finite element method. The difference in value between the two methods occurs in elements that have large dimensions, and that can be caused by the use of coarse meshing elements. Seeing the results of this research, it can be concluded that SNI 7971 2013 or AS/NZS 4600 can provide accurate values for elements subjected to combined loads.

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