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Optimization of lip length and aspect ratio of thin channel sections under minor axes bending

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ABSTRACT

Cold-formed steel members are used as structural members in a wide range of applications because of their simpler fabrications and high strength-to-weight ratios. Though high width-to-thickness ratio of such sections make them vulnerable to local buckling under compressive stresses, past studies have shown that these members possess inelastic reserve strengths at the ultimate stage under flexural loading. This study explore the influence of width-to-thickness ratio, lip lengths and depth-to-width (aspect) ratio on the ultimate flexural strengths of cold-formed channel sections bending about their minor axes. Finite element (FE) analyses have been conducted on 216 numbers of channel sections with varying geometric properties to investigate their ultimate resistance and mode of failure under flexural loading. The ultimate flexural strengths of these sections are theoretically predicted using the current code provisions and are compared with the exact values obtained from FE analyses. An experimental investigation has also been performed on five specimens of channel sections with and without lips to validate the FE analyses results. Based on the analysis and experimental results, the limiting values of lip lengths, aspect ratios, and width-to-thickness ratios of channel sections are discussed.

1. Introduction

Thin cold-formed steel members have a wide range of applications in construction, transportation, and manufacturing industries. The ease of fabrication and high strength-to-weight ratio properties of thin cold-formed steel members make them suitable for such a wide range of applications. These structural members can be easily produced economically by cold-forming thin plates into various types of cross-sections. However, the main disadvantage of these members is that they are more prone to local buckling under flexural/axial loading because of their high width-to-thickness ratios. Therefore, the optimization of geometric properties of these thin sections is necessary for their efficient use under a particular loading condition. During the last decades, many optimization studies have been conducted on cold-formed steel members for different loading conditions and member cross-sections, such as, hat-, I-, Z-, Σ-shapes. Seaburg and Salmon [1] used a gradient-based search technique for the optimization of hat-shaped members. This study was focused on minimizing the member weight for a given loading condition by varying the thickness of cross-sections, keeping all other parameters as constant. Adeli and Karim [2] developed a computational neural network model for optimization of three different cross-sectional shapes, i.e., hat-, I-, and Z-shapes. Karim and Adeli [3] used computational neural network model [2] to perform a comprehensive parametric study for global optimization of cold-formed steel hat-shape beams. Accordingly, different design curves were developed for global optimum values of the thickness, the web-depth-to-thickness ratio, and the flange width-to-thickness ratio for unbraced hat-shape beams. Tashakoria and Adeli [4] adopted neural dynamics model for the optimization study for minimizing the weight of available cold-formed shapes for several space trusses. Tian and Lu [5] demonstrated a combined theoretical and experimental study for open-channel steel sections subjected to axial compressive loads. The authors have optimized the weight and the associated geometrical dimensions of both channel section with and without lips. Lu [6] conducted an optimization study on Z- and R-shaped purlins with the help of genetic algorithm (GA) and finite strip analysis techniques. Liu et al. [7,8] demonstrated the knowledge-based global optimization such as the feature-space-based method for three cross- sectional shapes: hat-, I-, and Z-shapes subjected to compression loading. Lee et al. [9,10] used an improved Genetic Algorithm and micro Genetic Algorithm (μ-GA) techniques to optimize the cross-section of cold-formed beam members subjected to uniformly distributed loading. Authors also optimized the cross section of cold-formed steel channel and lipped channel columns subjected to axial compression. The μ-GA generates the optimum values of the thickness and the web

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flat-depth-to-thickness ratio for beam, optimum values of the thickness, the web flat-depth-to-thickness ratio, and the flange flat-width-to-thickness ratio for columns. Tran and Li [11] have presented global optimization method using trust-region method (TRM) for channel section beams subjected to uniformly distribute transverse loading. The trust-region method was based on different modes of failure which includes yielding strength, deflection limitation, local buckling, distortional buckling and lateral-torsional buckling.

Magnucki and Paczos [12] have done theoretical shape optimization on cold-formed thin-walled channel beams with open or closed profile of drop flanges subjected to pure bending load. Magnucka-Blandzi and Magnucki [13] have reviewed the simple analytical solutions and conducted numerical analysis as well as laboratory tests some selected beams. Blandzi et al. [14] performed optimization study for effective shaping of cold-formed thin-walled channel beams with double-box flanges subjected to pure bending by using dimensionless objective functions as a quality measure. Leng et al. [15] demonstrated application of formal optimization tools and implement it for maximizing the strength of an open cold-formed steel section without predefining cross section shape. The authors have used finite strip method for reviewing stability and Direct Strength Method for evaluating strength to get full solution space to explore any shapes of cold-formed steel. Maduliat et al. [16] have investigated inelastic bending capacity of cold-formed channel sections and developed design guidelines simple channel sections, channel sections with simple edge stiffeners, and channel sections with complex edge stiffeners. Though several studies have been conducted to optimize the geometric properties of cold-formed sections, there is a still need of further research to study the influence of several geometric parameters on the flexural behavior of these members bending about their minor axes.

2. Scope and objectives

In this study, both analytical and experimental studies have been conducted to understand the behavior of thin channel sections under flexural loading about their minor axes. The main objectives of this study are as follows; (i) to carry out a parametric study on thin channel sections by varying the section properties to analytically predict their load resisting capacities and mode of failure under minor axis loading, (ii) to compare the analytically obtained ultimate strengths with the code-based predictions considering the inelastic reserve strengths of cold-formed channel sections, (iii) to experimentally verify the behavior of channel sections with and without lips under flexural loading, and (v) to determine the limiting values of width-to-depth ratio, depth-to-width ratio and lip lengths of channel sections under stress gradient for validating the design provisions as per current codes.

3. Calculation of flexural capacity of channel sections

A member made of channel section subjected to the bending moment about its minor axis develops compressive in the some portion of flanges and tensile stress in the web. Fig. 1(a) shows the approximate stress distribution over the cross-section. The thin flange elements under compression may suffer from local buckling under the action of compressive stress. Therefore, the load-resisting capacity of compression flange should be computed based on the compression portion of the effective flange width (B_e) rather than the flange width (B). The value of B_e is computed as the product of effective width factor (ρ) times the flange width. The strength of a compression element susceptible to the local

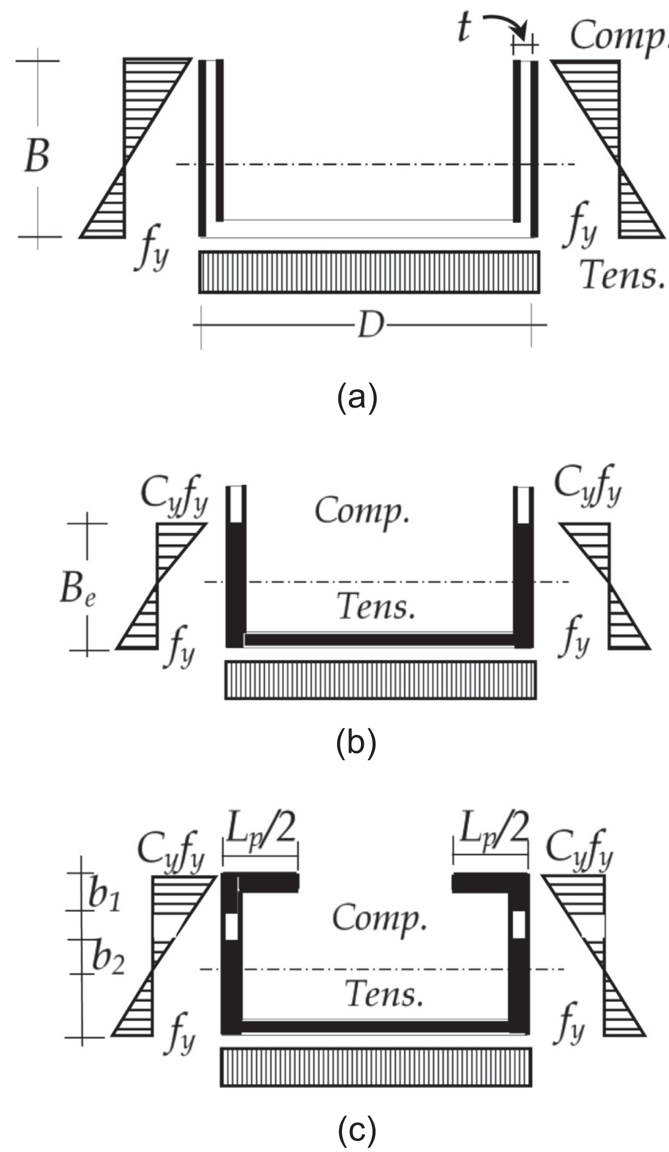

Fig. 1. Stress distribution in channel section with unstiffened flanges: (a) Gross section, (b) effective section for section without lip, (c) effective section with lip.

buckling can be related to a normalized slenderness ratio (λ) derived from the plate tests with applicable boundary conditions. The value of λ for a compression element of width as 'b' and thickness as 't' can be expressed as follows:

$$\lambda=\sqrt{\frac{f_y}{f_{cr}}} \quad (1)$$

$$f_{cr}=\frac{kE\pi^2}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2 \quad (2)$$

Where, f_{cr}=elastic critical buckling stress, f_y=yield stress, k=buckling coefficient, E=Young's Modulus, and ν=Poisson's ratio. The value of k depends on the plate boundary conditions and the state of stress. For instance, the value of k is assumed as 0.43 for an unstiffened element with uniform compression. Bambach and Rasmussen [17] conducted plate tests on cold-formed sections to establish the value of k for various stress gradients. American Iron and Steel Institute (AISI) Specifications [18] provide the different expressions for k to determine the effective width of flanges