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Web crippling studies of SupaCee sections under two flange load cases

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ABSTRACT

Cold-formed steel channel sections are generally used as flexural members in light weight steel construction. Improved channel section profiles such as SupaCee sections with longitudinal web stiffeners and curved lips are also used instead of the conventional lipped channel sections. Web crippling capacities of these innovative sections can be different from those of conventional lipped channel sections. However, the web crippling behaviour and strength of these high strength SupaCee sections has not been investigated yet. Current web crippling design methods given in cold-formed steel design standards do not include any design procedures for SupaCee sections. Hence an experimental study involving 36 web crippling tests was first undertaken to investigate the web crippling behaviour and strengths of SupaCee sections under two flange load cases with their flanges unfastened to the supports. Comparison of experimental results showed that the web crippling capacities of SupaCee sections are reduced in comparison to lipped channel sections. Therefore the current web crippling design equations in the American and Australian/New Zealand cold-formed steel design standards were modified by including suitable web crippling coefficients for SupeCee sections. Finite element models of tested SupaCee sections were also developed and validated using the experimental results. This paper presents the details of the experimental and numerical web crippling studies of SupaCee sections under two flange load cases and the results. It also presents the details of direct strength method based design equations developed in this research.

1. Introduction

Cold-formed steel thin-walled members are omnipresent in the modern building industry due to their inherent enhanced characteristics over conventional thicker hot-rolled sections. Their usage in building construction has grown rapidly, particularly in the last few decades due to the availability of more innovative cold-formed steel products, which allows direct replacement of masonry and timber products with cold-formed steel sections. These cold-formed steel products are also faster to fabricate and construct compared to the traditional building products. Versatility of the different shapes and sizes of cold-formed steel sections that are currently available allow them to be used effectively as floor joists, roof trusses, roof purlins and partition walls.

Cold-formed steel beams are susceptible to web crippling failures at the concentrated loading points or supports. Most of cold-formed channel sections are not stiffened to resist this action and thus are subject to web crippling failures. A theoretical approach for web crippling strength predictions has not been developed yet due to highly complicated nature of web crippling behaviour such as non-uniform stress distribution in the web-flange juncture and adjoining web portions, elastic and inelastic web buckling, non-linearity of steel properties (strain hardening), web plane eccentricity to loading or reaction points at flanges (due to corner radius), initial imperfections and flange curling (specially for unfastened flange to support conditions).

Design equations in the current cold-formed steel design standards for web crippling are based on experimental data obtained from many research studies conducted in the past. However, comparisons and reviews reveal that current design equations are often inaccurate and limited to a range of sections controlled by geometric and material properties of experimental data used to calibrate the design equations. Inaccuracy in the design capacity predictions is mainly due to the inconsistency in the test set-up and specimen length used in the past experimental studies.

As shown in Fig. 1, SupaCee sections are relatively new sections when compared to conventional lipped channel sections. These web stiffened channel sections with a ribbed web and curved lips are considered to be more economical and provide increased strength in comparison with traditional channel sections due to their unique ribbed web element. They are commonly used in roof

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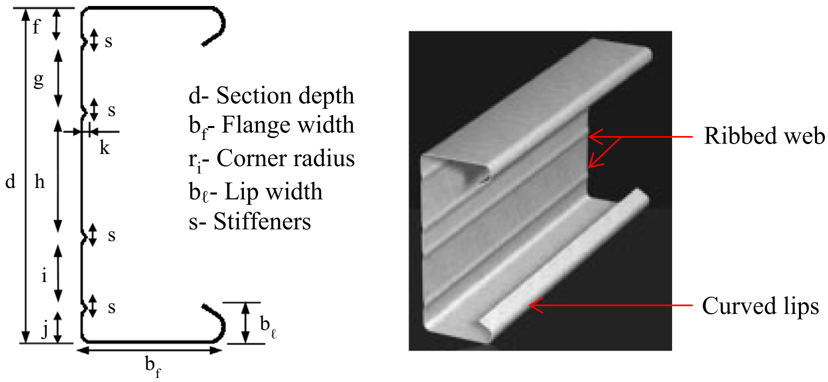

Fig. 1. Web Stiffened Channel Section (SupaCee Section).

and floor systems. For this purpose, they should have adequate bending, shear and bearing (web crippling) capacities. However, despite the presence of a ribbed web with four stiffeners they are vulnerable to localized web crippling failures at the point of transverse concentrated loading or supports. Past research has not considered the web crippling behaviour and capacities of SupaCee sections. Therefore, an experimental web crippling study was undertaken for SupaCee sections subject to two flange load cases, ie. End-Two-Flange (ETF) and Interior-Two-Flange (ITF) load cases. Finite element models were also developed and analysed using quasi-static analysis. This paper describes the experimental and finite element studies of SupaCee sections whose flanges were unfastened to their supports, and compares the web crippling capacities with the capacities predicted by the cold-formed steel design standards AISI S100 [1] and AS/NZS 4600 [2]. Based on the results from these studies, suitable design rules including those based on the direct strength method (DSM) are proposed and their details are presented in this paper.

2. Standard test methods and current design rules

2.1. Standard test method [3]

Web crippling failures are defined into four categories depending on the location of applied load or reaction force. They are End-Two-Flange (ETF), Interior-Two-Flange (ITF), End-One-Flange (EOF) and Interior-One-Flange (IOF). Many experimental web crippling studies of cold-formed steel sections conducted in the past had variations among their test arrangement and specimen lengths. To overcome this issue, a standard test method with details of suitable web crippling test set-ups and procedures was published by the American Iron and Steel in AISI S909 [3]. Fig. 2 shows the web crippling test method for two flange load cases (ETF and ITF) as given in AISI S909 [3]. The minimum test specimen lengths (L_{min}) given in AISI S909 are as follows: ETF Load case: $L_{min} = 3d_1$ ITF Load case: $L_{min} = 5d_1$, where d_1 = Flat portion of the web depth.

2.2. AISI S100 [1] and AS/NZS 4600 [2]

A unified equation (Eq. (1)), is given in AISI S100 [1] and AS/NZS 4600 [2] for the calculation of the web crippling capacities (R_b) of a range of cold-formed steel sections under ETF, ITF, EOF and IOF load cases with their flange fastened or unfastened to supports. This web crippling capacity equation was initially developed by Prabakaran [4,5] based on four web crippling coefficients (C, C_r, C_l and C_w) and the coefficients were improved later by Beshara and Schuster [6] based on past experimental studies [4,5]. Table 1 presents the web crippling coefficients for unfastened channel sections with stiffened flanges under ETF and ITF load cases. However, this design equation does not consider sections such as SupaCee sections with web ribs or curved lips.

$$R_b = Ct_w^2 f_y \sin\theta \left(1 - C_r\sqrt{\frac{r_i}{t_w}}\right)\left(1 + C_\ell\sqrt{\frac{\ell_b}{t_w}}\right)\left(1 - C_w\sqrt{\frac{d_1}{t_w}}\right) \quad (1)$$

where;
t_w = Thickness
f_y = Yield strength
ℓ_b = Bearing length.
d_1 = Flat web depth
r_i = Inside bent radius
Θ = angle between the web plane and bearing surface plane, 90° $\geq \Theta \geq$ 45°
C = Overall coefficient
C_w = Web slenderness coefficient (d_1/t_w)
C_r = Inside bent radius coefficient (r_i/t_w)
C_ℓ = Bearing length coefficient (ℓ_b/t_w)

2.3. Eurocode 3 Part 1-3 [7]

Eurocode 3 Part 1-3 [7], gives different web crippling equations that were developed using past experimental studies [4,5]. It includes Eqs. (2) and (3) for the calculation of the web crippling

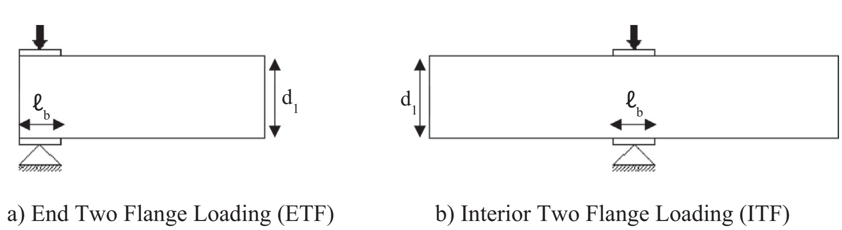

Fig. 2. ETF and ITF Load Cases (AISI S909, 2008).