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Numerical modelling of web crippling failures in cold-formed steel unlipped channel sections

B. Janarthanan, M. Mahendran *, S. Gunalan

Queensland University of Technology (QUT), Brisbane, Australia

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ABSTRACT

This paper presents a finite element analysis based study of web crippling failures in cold-formed steel unlipped channel sections with their flanges fastened to supports under one-flange load cases (EOF and IOF). Currently no design equations are available in the current cold-formed steel specifications to determine the web crippling capacities of unlipped channel sections with restrained flanges under one flange load cases. Hence the web crippling behaviour of unlipped channel sections was first investigated experimentally using 28 tests and suitable coefficients were proposed for the current web crippling design equation. However, the applicability of the proposed coefficients was limited to the tested channel sections. In this study advanced finite element models were developed in ABAQUS/CAE and validated in terms of ultimate failure loads, load versus deflection curves and failure modes. The developed models were analysed using nonlinear static and quasi-static analysis based on implicit and explicit integration schemes. This study addressed the effects of mesh size, element type, mechanical property model and inertia of support and loading plates. Also, the effects of two enhancement techniques of explicit analysis such as mass scaling and artificial loading rates with different thicknesses were investigated and the results are presented. A detailed parametric study was then conducted using the validated finite element models. New and improved design equations were proposed to determine the web crippling capacities of unipped channel sections using the results from both finite element analysis based parametric study and experiments.

1. Introduction

Cold-formed steel sections have gained popularity over hot-rolled steel sections because of higher strength to weight ratio, mass production and easy fabrication. Among them, unlipped channel sections are used as bearers in many floor systems. However, they are vulnerable to web crippling failures under high concentrated loads or support reactions. Theoretical study of web crippling failures is complicated due to non-uniform distribution of loading, inelastic behaviour of web element, local yielding near the load application point and initial out of plane imperfections [1]. Hence the web crippling failures of cold-formed steel sections have often been investigated experimentally. However, with significant advances in computer technology, advanced finite element models are being increasingly used following their validation using experimental results.

The AISI standard web crippling test method [2] defines web crippling failures under four types such as End-One-Flange (EOF), End-Two-Flange (ETF), Interior-One-Flange (IOF) and Interior-Two-Flange (ITF) as shown in Fig. 1, based on loading and failure locations. The load case is considered as end loading if the failure occurs within $1.5d_1$ from the edge of the specimen, otherwise, it is interior loading, where d_1 is the depth of the flat portion of the web element. Two flange loading is considered if the distance between the edges of the bearing plates of adjacent two loadings is less than $1.5d_1$, otherwise, it is one-flange loading. The web crippling failure of cold-formed steel sections also depends on support conditions (fastened/unfastened) [3–5]. The web crippling capacity (R_b) equations in the current cold-formed steel specifications such as Australian/New Zealand standard (AS/NZS 4600) [6], North American Specification (AISI S100) [7] and Eurocode 3 Part 1–3 [8] were developed based on experimental studies [3,4,9–11]. AS/NZS 4600 [6] and AISI S100 [7] use a unified web crippling equation (Eq. 1) consisting of the key parameters such as the web thickness (t_w), the yield strength (f_y), the web height to thickness ratio (d_1/t_w), the inside bent radius to thickness ratio (r_i/t_w) and the bearing length to thickness ratio (l_b/t_w) with different coefficients (C, C_w, C_r and C_l). Eurocode 3 Part 1–3 [8] uses a separate equation for each load case and does not distinguish fastened and unfastened supports. Hence Eurocode 3 Part 1–3 was

* Corresponding author.
E-mail address: m.mahendran@qut.edu.au (M. Mahendran).

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