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Web crippling behaviour of thin-walled lipped channel beams

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ABSTRACT

This paper presents the results of an investigation into web crippling behaviour—conducted on cold-formed thin-walled steel lipped channel beams subjected to Interior-One-Flange (IOF), Interior-Two-Flange (ITF), End-One-Flange (EOF) and End-Two-Flange (ETF) loading conditions as defined by the American Iron and Steel Institute (AISI). An experimental program was designed to obtain the load-deformation characteristics of beam members with varying cross-sectional and loading parameters under the three web crippling loading conditions. The results obtained from the experiments comprised of the ultimate web crippling strength values and displacements of the thirty-six beam specimens tested. Nonlinear finite element models were developed to simulate web crippling failure of the two loading conditions considered in the experimental program. Also, a combination of elastic analysis with a plastic mechanism approach was employed to investigate the load-deformation characteristics of lipped channel members subjected to the IOF loading condition. The comparison of experimental, finite element and plastic mechanism approach results revealed that the nonlinear finite element models were best capable of closely simulating the web crippling failure behaviour observed in the experiments for all ranges of displacement. Web crippling strength predicted from the Eurocode 3, Part 1.3 [1], and the Polish PN-B-0327 [2] design specifications were also compared with the experimental results and the comparisons indicated considerable underestimations for the range of specimens under EOF and ETF loading conditions.

1. Introduction

Web crippling failure may occur at places where thin-walled flexural members are subjected to high concentrated loadings or support reaction forces. Fig. 1 illustrates web crippling failure at a loading point. Web crippling deformation is defined as the decrease of cross-section height below the load-bearing plate [3].

Four different loading conditions, where web crippling may take place, have been defined by the AISI based on the number of loadings involved and the location of failure initiated, namely, Interior-One-Flange (IOF), Interior-Two-Flange (ITF), End-One-Flange (EOF) and End-Two-Flange (ETF) loading conditions [4]—Fig. 2(a)–(d), respectively.

A considerable amount of research has been carried out on web crippling over many years by numerous researchers, particularly to validate various design rules for web crippling, and the majority were based on experimental investigations. The early research work conducted by Winter and Pian [5], Ratliff [6], Hetrakul and Yu [7], etc. provided the basis for web crippling design rules that appeared in the early versions of the AISI Specification and is consequently adopted by the other major design codes including Eurocode 3, Part 1.3. In the recent past, number of investigations were carried out by Young and Hancock, Prabakaran and Schuster, and Shaojie, Yu and LaBoube, and these resulted in a more unified form of design rule which was adopted by the AISI Specification, 2001 edition.

Web crippling (crushing behaviour) of hat section beams was investigated by Hofmeyer [3] and Hofmeyer et al. [8], who implemented the yield-line analysis (plastic mechanism analysis) to the investigation of the crushing behaviour of top hat-section beams subject to three-point bending—a similar approach was applied by Bakker and Stark [9].

A research program was initiated to investigate web crippling behaviour of cold-formed thin-walled lipped channel beams under the four loading conditions. The results of the preliminary experimental investigations and the finite element analysis of lipped channel beams under IOF and ITF loading conditions were reported in previous publications [10,11]. The aim of this paper is to present the results of experimental investigations and finite element analysis carried out to investigate the web crippling behaviour of lipped channel sections under IOF, EOF and ETF loading conditions. The experimental results were also compared with the web crippling strength predictions from Eurocode 3-1.3 and with the Polish code PN-B-0327, which adopted the Eurocode

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recommendations. The results for the IOF loading condition were also compared with the analytical solution of the plastic mechanism problem approach [12,13], leading to an evaluation of the unloading path.

2. Experimental investigations

Experimental investigations were designed to examine the influence of various cross-sectional and loading parameters on web crippling strength.

Experimental tests for IOF loading conditions (Fig. 2a) were performed by Heiyantuduwa and others and described in detail in [12,14]. Two separate series of tests were performed considering EOF and ETF loading conditions. The test specimens were fixed on to load bearing plates during both series of tests to prevent flange rotations and possible lateral movements of specimens during loading. Each series comprised of eighteen test specimens manufactured from 0.78 mm thickness carbon steel sheets. The test specimens were designed to have three different corner radii and two different web heights and were loaded with three different sizes of load bearing plate. Fig. 3 illustrates the cross-sectional and loading parameters used in the specimen design.

A separate series of tensile tests was carried out prior to specimen manufacture in order to obtain the material properties of the individual steel sheets.

During the web crippling tests, applied load, displacement at the loading point and the displacement at a number of other critical points were measured. Results of the experimental investigations were used to validate the finite element models, to check the validity of web crippling strength predictions obtained from design codes and to compare with theoretical unloading paths obtained from a plastic mechanism analysis. Detailed results of material tests are given in [10,14].

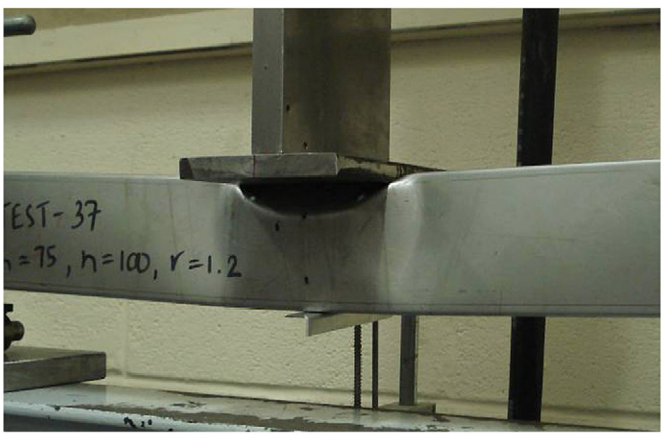


Fig. 1. Web crippling at loading point.

2.1. EOF loading tests

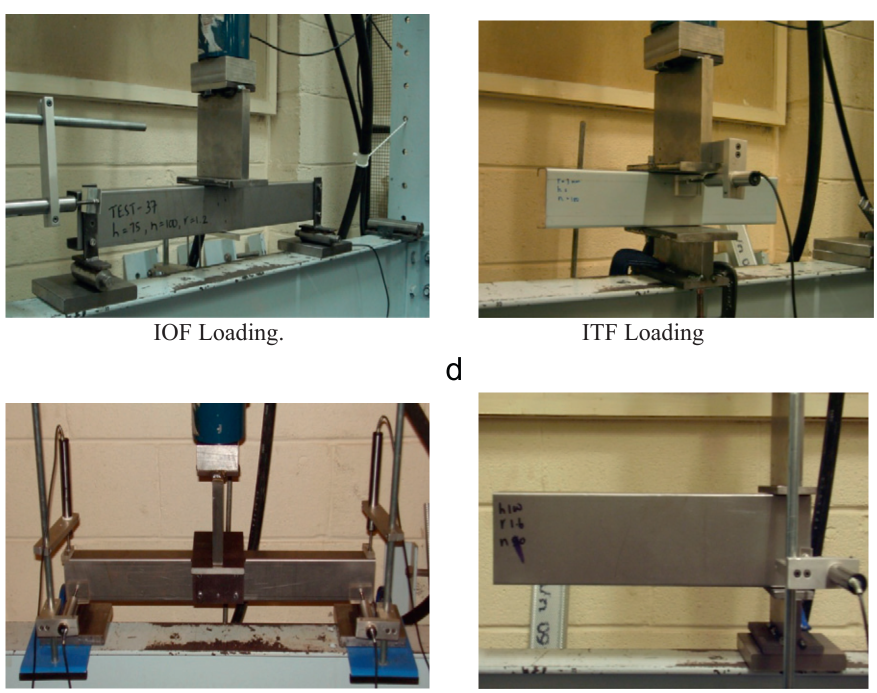
EOF loading tests were performed as three-point bending tests; however, the failure was intended to occur at the end of the beam (at supports) and the loading was applied to the mid-point of the beam.

The load bearing plate was fully fixed at the mid-point in order to prevent failure around this area. The test rig used in the EOF loading tests is shown in Fig. 4.

2.2. ETF loading tests

ETF loading tests were performed by applying a load which was directly above the support. Hence, the failure was initiated at the end of the beam due to the heavy loading and the support reaction force. The test rig used in ETF loading tests is shown in Fig. 5.

a b



IOF Loading. ITF Loading

c d

EOF Loading. ETF Loading.

Fig. 2. (a) IOF loading; (b) ITF loading; (c) EOF loading; and (d) ETF loading.