Thin-Walled Structures 114 (2017) 92–106

Contents lists available at ScienceDirect

Thin–Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Web crippling behaviour of cold-formed steel channel sections with web holes subjected to interior-one-flange loading condition – Part II: parametric study and proposed design equations

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ARTICLE INFO

Keywords:
Cold-formed steel
Web crippling
Finite element analysis
Web hole
Channel section
Reduction factor
Design recommendations

ABSTRACT

A parametric study of cold-formed steel sections with web openings subjected to web crippling under interior-one-flange (IOF) loading condition is undertaken, using finite element analysis, to investigate the effects of web holes and cross-sections sizes. The holes are located either centred beneath the bearing plate or with a horizontal clear distance to the near edge of the bearing plate. It was demonstrated that the main factors influencing the web crippling strength are the ratio of the hole depth to the depth of the web, the ratio of the length of bearing plate to the flat depth of the web and the location of the holes as defined by the distance of the hole from the edge of the bearing plate divided by the flat depth of the web. In this study, design recommendations in the form of web crippling strength reduction factor equations are proposed, which are conservative when compare with both the experimental and finite element results.

1. Introduction

Most design specifications for cold-formed steel structural members provide design rules for cold-formed steel channel sections without web holes; only in the case of the North American Specification for cold-formed steel sections [1] are reduction factors for web crippling with holes presented, covering the cases of interior-one-flange (IOF) and end-one-flange loading (EOF), and with the flanges of the sections unfastened to the support. This strength reduction factor equation, however, was limited to thicknesses ranging from 0.83 mm to 1.42 mm. In addition, in the North American Specifications, the holes are assumed to be located at the mid-height of the specimen having a longitudinal clear offset distance between the edge of the bearing plates and the web hole.

In the literature, for the IOF loading condition, Yu and Davis [2] previously considered the case of both circular and square web openings located and centred beneath the bearing plate with the flange unfastened to bearing plate. It should be noted that the test arrangement reported did not use the newly established IOF testing procedure [3] in which back-to-back channel-sections specimens were loaded, but instead used two channel -sections connected through their lips. Nevertheless, these tests remain the only reported tests in the literature for the IOF loading condition where the holes are located and centred beneath the bearing plate. For circular holes a total of 10 tests were reported, all tested with a bearing length of 89 mm. A strength reduction factor equation was proposed but was limited to the aforementioned bearing length.

Again for the IOF loading condition, LaBoube et al. [4] have also considered the case of a circular hole that has a horizontal clear distance to the near edge of the bearing plate, but only for the case where the flange is fastened to the bearing plate. The strength reduction factor equation proposed by LaBoube et al. [4] was subsequently adopted by the North American Specification (NAS) [1] for cold-formed steel sections.. Other similar work described in the literature include that of Sivakumaran and Zielonka [5] who considered rectangular web openings located and centred beneath the bearing plate under the interior-one-flange loading condition, and Zhou and Young [6] who proposed strength reduction factor equations for aluminium alloy square sections with circular web openings located and centred beneath the bearing plates under end-and interior-two flange loading conditions.

Strength reduction factor equations have recently been proposed by

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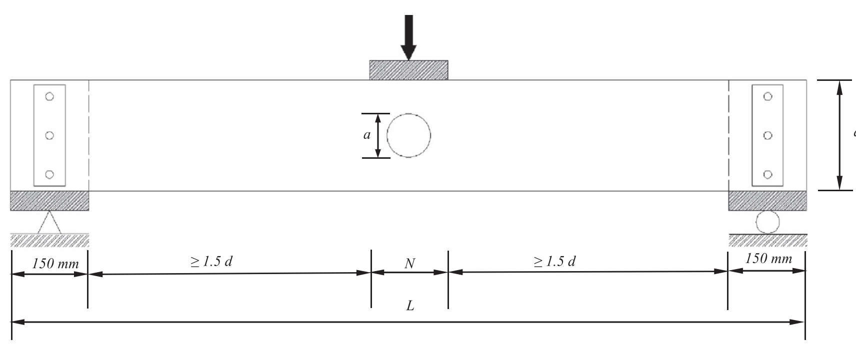
http://dx.doi.org/10.1016/j.tws.2016.10.018
Received 18 August 2016; Accepted 24 October 2016

Nomenclature

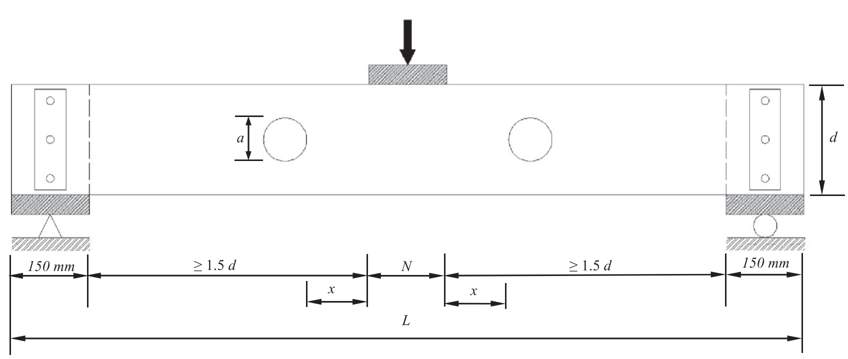
A	Web holes ratio;
a	Diameter of circular web holes;
b_f	Overall flange width of section;
b_l	Overall lip width of section;
COV	Coefficient of variation;
d	Overall web depth of section;
d_{hole}	Clear distance between holes;
d_{ed}	Clear distance between holes;
DL	Dead load;
E	Young's modulus of elasticity;
FEA	Finite element analysis;
F_m	Mean value of fabrication factor;
f_y	Material yield strength;
h	Depth of the flat portion of web;
L	Length of the specimen;
LL	Live load;
M_m	Mean value of material factor;
N	Length of the bearing plate;
P	Experimental and finite element ultimate web crippling load per web;
P_{BS}	Nominal web crippling strength obtained from British Standard;
P_{Euro}	Nominal web crippling strength obtained from European Code;
P_{EXP}	Experimental ultimate web crippling load per web;
P_{FEA}	Web crippling strength per web predicted from finite element (FEA);
P_{NAS}	Nominal web crippling strength obtained from North American Specification;
P_m	Mean value of tested-to-predicted load ratio;
R	Reduction factor;
R_P	Proposed reduction factor;
r_i	Inside corner radius of section;
t	Thickness of section;
V_F	Coefficient of variation of fabrication factor;
V_M	Coefficient of variation of material factor;
V_P	Coefficient of variation of tested-to-predicted load ratio;
x	Horizontal clear distance of the web holes to the near edge of the bearing plate;
X	Web holes distance ratio;
θ	Angle between web and bearing surface
β	Reliability index;
ϕ	Resistance factor.

Uzzaman et al. [7–10] for web crippling strength of cold-formed steel channel -sections with circular holes in the web under the end-two-flange (ETF) and interior-two-flange (ITF) loading conditions. Recent research on web crippling of cold-formed steel channel-sections, other than that by Uzzaman et al., who again considered only the two-flange loading conditions, has not covered the case of holes [11–14].

Experimental and numerical investigations have been discussed in the companion paper [15] for the IOF loading condition. In this study, non-linear finite element analysis (FEA) is used to conduct parametric studies to investigate the effect of circular holes; as shown in Fig. 1, these holes are either located centred beneath the bearing plate or having a horizontal clear distance to the near edge of the bearing plate. The cases of both flange unfastened and fastened to the bearing plate are considered. The general purpose finite element program ABAQUS [16] was used for the numerical investigation. Based on the test data found in the companion paper [15], both for the case of channel-sections without holes and with holes, and the numerical results obtained from this study, an extensive statistical analysis was per-



(a) With holes centred under bearing plate



(b) With holes offset from bearing plate

Fig. 1. Interior-one-flange loading condition.