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Effect of web holes on web crippling strength of cold-formed steel channel sections under end-one-flange loading condition – Part I: Tests and finite element analysis

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ABSTRACT

Web openings could be used in cold-formed steel beam members, such as wall studs or floor joints, to facilitate ease of services in buildings. In this paper and its companion paper, a combination of tests and non-linear finite element analyses is used to investigate the effect of such holes on web crippling under end-one-flange (EOF) loading condition. The present paper includes a testing programme on web crippling of channel section and material tensile coupons, followed by a numerical study, where the models are firstly validated against the performed experiments. The results of 74 web crippling tests are presented, with 22 tests conducted on channel sections without web openings and 52 tests conducted on channel sections with web openings. In the case of the tests with web openings, the hole was either located centred above the bearing plates or having a horizontal clear distance to the near edge of the bearing plates. A non-linear finite element model is described, and the results compared against the laboratory test results; a good agreement between the tests and finite element analyses was obtained in term of both strength and failure modes.

1. Introduction

Cold-formed steel sections are increasingly used in residential and commercial construction as both primary and secondary framing members. Web crippling at points of concentrated load or reaction is well known to be a significant problem, particularly in thin walled beams. To improve the buildability of buildings composed of cold-formed steel channel-sections, openings in the web are often required, for ease of installation of electrical or plumbing services.

Strength reduction factor equations have recently been proposed by Uzzaman et al. [1–4] for the 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. This paper extends the work of Uzzaman et al. [1–4] to consider the end-one-flange (EOF) loading condition for cold-formed steel channel sections with circular holes in the web.

In the literature, for the EOF loading condition, LaBoube et al. [5] have previously considered the case of a circular hole having a horizontal clear distance to the near edge of the bearing plates, but only for the case where the flanges are fastened to the bearing plates. The strength reduction factor equation proposed by LaBoube et al. [5] was subsequently adopted by the North American Specification (NAS) [6] for cold-formed steel sections. This strength reduction factor equation, however, was limited to thicknesses ranged from 0.83 mm to 1.42 mm. Other work described in the literature include that of Yu and Davis [7] who studied the case of both circular and square web openings located and centred beneath the bearing plates under interior-one-flange loading condition, and Sivakumaran and Zielonka [8] who considered the case of rectangular web openings located and centred beneath the bearing plates under the interior-one-flange loading condition, and Zhou and Young [9] 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. Recent research on web crippling of cold-formed steel channel sections, other than that by Uzzaman et al. [10–13] who again considered only the two-flange loading conditions, has not covered the case of holes.

The present paper and its companion paper [14] describe a

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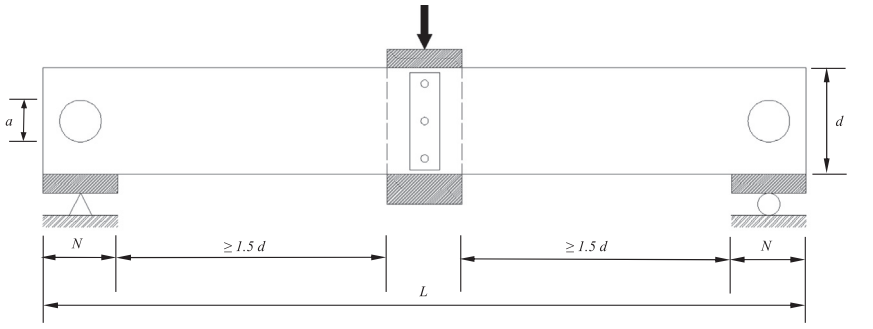
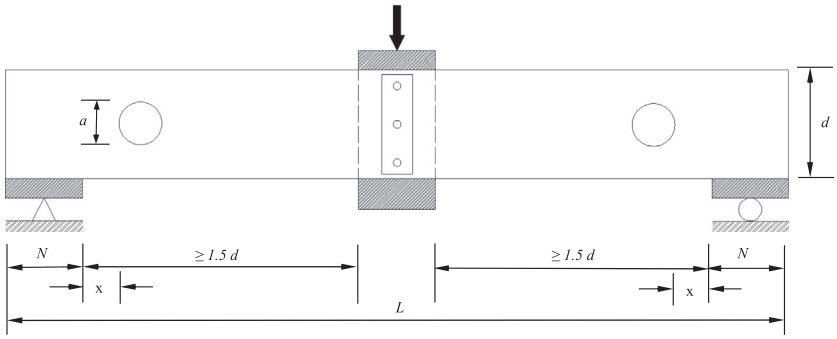
Nomenclature

A	Web holes ratio
a	Diameter of circular web holes
a_{LHS}	Diameter of circular web holes positioned left hand side of specimen
a_{RHS}	Diameter of circular web holes positioned right hand side of specimen
b_f	Overall flange width of section
b_l	Overall lip width of section
COV	Coefficient of variation
d	Overall web depth of section
E	Young's modulus of elasticity
FEA	Finite element analysis
f_y	Material yield strength
h	Depth of flat portion of web
L	Length of specimen
N	Length of bearing plate
P_{EXP}	Experimental ultimate web crippling load per web
P_{FEA}	Web crippling strength per web predicted from finite element (FEA)
P_m	Mean value of tested-to-predicted load ratio
r_i	Inside corner radius of section
t	Thickness of section
x	Horizontal clear distance of web holes to near edge of bearing plate;
$\sigma_{0.2}$	Static 0.2% proof stress
σ_u	Static ultimate tensile strength



(a) With holes centred above bearing plate



(b) With holes offset from bearing plate

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

comprehensive experimental study, numerical study and design recommendation of cold-formed steel channel sections with circular web holes under end-one-flange loading condition subjected to web crippling. In this study, a combination of tests and nonlinear finite element analyses (FEA) are used to investigate the cases of both flanges fastened and flanges unfastened to the bearing plates, of circular web holes located centred above the bearing plates and with a horizontal clear distance to the near edge of the bearing plates, on the web crippling strength of lipped channel sections for the end-one-flange (EOF) loading condition, as shown in Fig. 1. The general purpose finite element analysis (FEA) programme ABAQUS [14] was used for the numerical investigation. The finite element model (FEM) included geometric and material non-linearities; the results of the finite element analysis were verified against laboratory test results. Both the failure loads as well as the modes of failure predicted from the finite element analyses were in good agreement with the laboratory test results. Upon validation of the finite element models, a series of parametric studies are carried out; design recommendations are reported in the companion paper [14].

2. Experimental investigation

2.1. Test specimens

Fig. 2 shows details of the cold-formed steel lipped channel sections, with circular web holes, used in the web crippling test programme. As can be seen from Figs. 3 and 4, each test comprised a pair of channel sections with a load transfer block bolted between them. Washer plates of thickness 6 mm were bolted to the outside of the webs of the channel-sections.

The size of the web holes was varied in order to investigate the effect of the web holes on the web crippling behaviour. Circular holes with a nominal diameter (a) ranging from 55 mm to 179 mm were considered in the experimental investigation. The ratio of the