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Web crippling behaviour of cold-formed steel channel sections with offset web holes subjected to interior-two-flange loading

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ABSTRACT

Cold-formed steel sections are often used as wall studs or floor joists; such sections often include web holes for ease of installation of the services. Cold-formed steel design codes, however, do not consider the effect of such web holes. In this paper, a combination of experimental tests and non-linear elasto-plastic finite element analyses are used to investigate the effect of such holes on web crippling under interior-two-flange (ITF) loading conditions; the cases of both flange fastened and flange unfastened are considered. A good agreement between the experimental tests and finite element analyses was obtained. The finite element model was then used for the purposes of a parametric study on the effect of different sizes and position of holes in the web. 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, and the ratio of the distance from the edge of the bearing to the flat depth of web. Design recommendations in the form of web crippling strength reduction factors are proposed, that are conservative to both the experimental and finite element results.

1. Introduction

Cold-formed steel sections are often used as wall studs or floor joists; such sections often include web holes for ease of installation of the electrical or plumbing services. These holes are usually pre-punched in the factory.

Web crushing or crippling at points of concentrated, or localised, load or reaction in thin walled beams is well known to be a significant problem, particularly in the case of beams with slender webs, and is of high importance in the field of cold-formed steel members, as such members are generally not stiffened against this type of loading. At points of concentrated loading and supports, severe lateral loading can result in a local buckling in the web [1]. For sections with holes, such web crippling needs to be taken into account.

There has been little research on the web crippling of cold-formed steel sections with web holes. Yu and Davis [2] described 20 tests investigating the web crippling strength of back-to-back channel sections with an interior-one-flange loading condition. The test programme comprised both circular and square holes; the holes were located and centred beneath the bearing plate. Strength reduction factors were proposed. Sivakumaran and Zielonka [3] described 103 tests on single lipped channel sections, but again for the interior-one-flange loading condition and with the circular holes located and centred beneath the bearing plate. Again, strength reduction factors were proposed.

LaBoube et al. [4] described 168 tests on single lipped channel sections, covering both interior-one-flange and end-one-flange loading conditions but with the circular holes positioned offset, next to the bearing plate. Strength reduction factors were again proposed. Similar tests were also described by Langan et al. [5], but with rectangular holes. Lagan et al. demonstrated that the main factors influencing the web crippling strength are the ratio of the hole depth to the depth of the web, and the ratio of the distance from the edge of the bearing to the flat depth of web.

More recently, Zhou and Young [6] conducted 84 tests on aluminium alloy square hollow sections with circular holes located at the centre beneath the bearing plates. The web crippling tests were conducted under loading conditions of end-two-flange (ETF) and interior-two-flange (ITF). Reduction factor equations were also proposed.

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 [7] 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. 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.

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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
DL	dead load
D	overall web depth of section
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_{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	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
β	reliability index
ε_f	elongation (tensile strain) at fracture
ϕ	resistance factor
$\sigma_{0.2}$	static 0.2% proof stress
σ_u	static ultimate tensile strength

In this paper, a combination of experimental tests and non-linear elasto-plastic finite element analyses (FEA) are used to investigate the effect of offset circular web holes on the web crippling strength of lipped channel sections for the interior-two-flange (ITF) loading condition, as shown in Fig.1; the cases of both flange fastened and flange unfastened to the support are considered.

The general purpose finite element program ANSYS [8] was used for the numerical investigation. A good agreement between the experimental tests and finite element analyses was obtained. The finite element model was then used for the purposes of a parametric study of the effect of different sizes and position of holes in the web. Design recommendations in the form of web crippling strength reduction factors are proposed, that are conservative to both the experimental and finite element results.

2. Experiment investigation

2.1. Test specimens

A test programme was conducted on lipped channel sections, as shown in Fig. 2, with circular web holes subjected to web crippling. The size of the web holes was varied in order to investigate the effect of the web holes on the web crippling strength. The circular holes with nominal diameters (a) ranging from 40 to 240 mm were considered in the experimental investigation. The ratio of the diameter of the holes to the depth of the flat portion of the webs (a/h) was 0.4. All the test specimens were fabricated with web holes located at the mid-depth of the webs. The horizontal clear distance of the web holes to the near edge of the bearing plate (x) is shown in Fig. 1.

Channel sections without holes were also tested. The test specimens comprised five different section sizes, having the nominal thicknesses ranging from 1.3 to 2.0 mm; the nominal depth of the webs and the flange widths ranged from 142 to 302 mm. The measured web slenderness (h/t) values of the channel sections ranged from 116 to 176. The specimen lengths (L) were determined according to the NAS Specification [7]. Generally, the distance from the edge of the bearing plate to the end of the member was set to be 1.5 times the overall depth of the web (d) rather than 1.5 times the depth of the flat portion of the web (h), the latter being the minimum specified in the specifications. Tables 1 and 2 shows the measured test specimen dimensions for the flange unfastened and fastened conditions, respectively, using the nomenclature defined in Figs. 1 and 2 for the ITF loading condition. The bearing plates were fabricated using with high strength steel having a thickness of 25 mm. Two lengths of

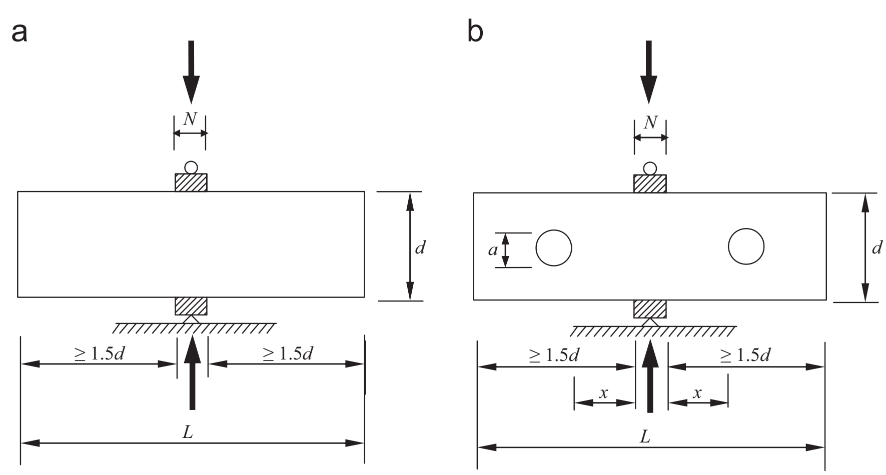

Fig. 1. ITF loading condition: (a) without holes and (b) with holes.