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Resistance of cold-formed steel sections to combined bending and web crippling

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Abstract Web crippling is a common failure mode in cold formed sections. Interaction between bending and web crippling reduces the load carrying capacity and may control the design. In this research, numerical study on web crippling and interaction between bending and web crippling are performed considering the material and geometric nonlinearities. The study is performed on channel sections subjected to web crippling under interior one flange (IOF) loading conditions. Finite element models are verified against experimental tests, and then extended to predict the web crippling strength of the studied channel sections. FE is used to investigate the interaction between bending and web crippling in C-sections. FE results are employed to investigate the effect of different parameters on sections resistance. It was found that, the strengths predicted by design codes are generally inadequate for channels with a practical web slenderness range. Therefore, modifications were proposed to improve the strength predicted by codes.

1. Introduction

Cold formed steel sections are special sections which have high strength to weight ratio. The cold-formed steel C- and Z-sections are the most common sections used in building construction. These sections can be used as secondary beams (purlins) to support the light weight roof covering systems, also can be used as side girt, cassettes, etc. Many criteria govern the design of such sections such as, moment capacity, deflection, web shear resistance, web crippling, combined bending and shear and combined bending and web crippling.

Flexural capacity of a cold-formed steel beam in general is limited either by the effective section capacity or the lateral buckling capacity, especially when supported laterally at large intervals. On the other hand, web crippling of such beams depends on the cross section parameters (web slenderness ratio, web thickness and inside bend radius to thickness ratio) in addition to the material yield stress and the bearing length to web thickness ratio. Although, the webs of such sections have high depth to thickness ratio, using stiffeners under the concentrated loads is not practical in this type of construction.

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List of symbols

C, C1: 20	non-dimensional coefficients
C	calibration coefficient
CH	web slenderness coefficient
CN	bearing length coefficient
CP	correction factor
CR	inside bend radius coefficient
$C\theta$	non-dimensional coefficient;
d, D	overall web depth
h, hw	flat web depth
E	Young's modulus, 21,000 N/mm^2
F	extreme compression or tension fiber at design stress
$F_{0.2}$	proof stress
F_m	mean value of fabrication factor
F_u	ultimate strength of steel
F_W	concentrated web load or reaction (kN)
F_y	design yield stress
Fyc	rounded corner yield stress
k	web crippling coefficient
L	specimen total length
M	bending moment at the point of application the concentrated load P
m	conversion coefficient
$\overline{M}$, M, M_u	the corresponding ultimate bending moment at the point of the applied ultimate concentrated load or reaction, $\overline{P}$ or P_u respectively
M_C	moment capacity determined as Se F
M_m	mean value of material factor
M_{nxo}	nominal flexural strength about the x-axis
N	bearing load length
n	number of tests or models
$\overline{P}$,, P, P_u	the ultimate concentrated load or reaction in the presence of bending moment.
PC-Exp	ultimate test load accompanied by bending moment
PFE	predicted finite element load
P_m	mean value of professional factor for tested component
P_n	nominal ultimate web crippling load or reaction per web
Pult	ultimate crippling load (kN)
P_w	concentrated load resistance of single web
py	design strength in N/mm^2
R	inside bend radius
R_n	average value of all test results
Se	elastic section modulus of effective section
t	web thickness
β	target reliability index
θ	angle between plan of web and plan of bearing surface
Φ_b	resistance factor for bending
Φ_w	resistance factor for web crippling

Therefore, the web crippling is a governing criterion that may control the design.

Theoretical study of web crippling is very complicated because many factors should be considered. These factors are the non-uniform stress distribution under the applied load, the local yielding at the loaded area, the bending due to eccentric loading, elastic and inelastic behavior of the web element, the different web flange restraint and the initial imperfections of the web element, Yu [16]. That is why most of researches on web crippling and combined bending and web crippling are experimental. Recently, with the progress achieved in the field of computer programming, the numerical analysis using an approved finite element tool is a good alternative to the experimental work.

Interaction between bending and web crippling is a common behavior in cold formed steel construction and will be also studied carefully in light of the continuous modifications of web crippling strength prediction. The adequacy of the web crippling and bending interactive formulae of the design codes will be also investigated.

This research is focused on the behavior of cold formed steel C-sections subjected to web crippling and interaction of bending and web crippling under interior one flange loading condition as indicated Fig. 1.

The parameters range of the studied channel dimensions are: web heights (D = 100, 150, 200 and 250 mm); web thicknesses (t = 2 and 3 mm); inside bend radiuses (R = 6 and 9 mm) and constant flange width (b = 50 mm). The bearing lengths are (N = 25, 50 and 75 mm) in addition to using two different steel yield stresses (F_y = 240 and 360 N/mm^2).

In addition to the mentioned parameters range, two different span lengths are used (L = 1000 and 2000 mms) for studying the interaction of bending and web crippling strengths. In this study four different design specifications are included in comparisons, the Australian/New Zealand Standard (AS/NZS-4600), British Standard (BS:5950-5), Egyptian Code of Practice (ECP-LRFD) and North American Specification (NAS).

2. Literature review

Due to its complexity, most researches on web crippling are mainly experimental and numerical. In this section, reviews of the experimental and numerical researches on web crippling and combined bending and web crippling are presented.

Experimental researches on web crippling of cold formed steel sections started in 1939 at Cornell University. Based on the results of these researches, the first American Iron and Steel Institute design code was published (AISI-1946). The first Canadian code for cold formed steel design was presented in 1963, while the first European code was published in 1970s. Experimental researches continued and the design provisions of AISI were updated in 1956, 1960, 1962, 1968, 1980, 1986, 1991 and 1996, while the Canadian code was updated in 1974, 1984, 1989 and 1994 (S136-94) [7]

In most of the current design codes, there are four different load cases considered in design against web crippling. The difference between the four load cases is based on the applied load location and whether the applied loads acting on both flanges or not. The different four load cases are shown in Fig. 2.