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Cold-formed ferritic stainless steel tubular structural members subjected to concentrated bearing loads

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ABSTRACT

The behaviour and design of cold-formed ferritic stainless steel tubular structural members subjected to concentrated bearing loads are presented in this paper. A total of 37 web crippling tests was conducted on cold-formed square and rectangular hollow sections of grade EN 1.4003 ferritic stainless steel. The tests were conducted under end loading and interior loading conditions, which closely simulated the support conditions of floor joist members seated on solid foundation. Finite element (FE) models were developed and validated against the experimental results. Upon validation of the FE models, a parametric study comprised 160 FE analyses was performed using the validated models. The web crippling strengths obtained from experimental and numerical investigations were compared with the nominal strengths calculated using the current American, Australian/New Zealand and European specifications for stainless steel structures. Furthermore, the North American Specification (NAS) and the Australian Standard AS4100 for carbon steel structures as well as the suggested design rules in the literature for stainless steel structures were also compared. Improved design rules are proposed for ferritic stainless steel tubular structural members subjected to concentrated bearing loads by means of modified NAS and Direct Strength Method. The reliability of the proposed design rules has been assessed through reliability analysis.

1. Introduction

Cold-formed stainless steel tubular sections are becoming an attractive choice in structural applications due to their attractive physical and mechanical characteristics in terms of aesthetic appearance, structural efficiency and durability [1]. Tubular structural members are not easy and uneconomical to be stiffened by transverse stiffeners. The unstiffened webs of tubular sections may cripple due to high localized transverse forces subjected to concentrated bearing loads. Therefore, web crippling check is important in the design of such members. The current American Society of Civil Engineers (ASCE) Specification [2], Australian/New Zealand Standard (AS/NZS) [3] and European Code (EC3) [4] for stainless steel structures provide web crippling design provisions for flexural members. Note that the web crippling design provisions in the ASCE Specification [2] are adopted from the 1986 edition of American Iron and Steel Institute (AISI) Specification for cold-formed carbon steel structures. This is due to no research work was carried out in the Cornell project to investigate web crippling of beams made of cold-formed stainless steels, as mentioned in the Commentary of the ASCE Specification [2]. The AS/NZS [3] has adopted the web crippling design provisions from the ASCE Specification. Thus, the web crippling nominal strengths predicted by the ASCE Specification [2] and AS/NZS [3] are identical. In addition, the web crippling design rules in the EC3 Part 1–4 [4] for stainless steel structures refer to the provisions of the EC3 Part 1–3 [5] for cold-formed carbon steel structures. Hence, the web crippling design provisions in the aforementioned specifications for stainless steel structures are all adopted from the web crippling design provisions for carbon steel structures.

The studies on stainless steel sections undergoing web crippling were pioneered at Rand Afrikaans University, where web crippling tests were conducted on cold-formed stainless steel lipped channel sections brake-pressed from austenitic and ferritic stainless steel sheets [6]. Web crippling tests were carried out by Talja and Salmi [7] on cold-formed austenitic stainless steel rectangular hollow sections. Zhou and Young [8–10] carried out a series of tests to examine the web crippling behaviour of austenitic, high strength austenitic and duplex stainless steel tubular sections, and design rules were proposed based on the unified web crippling equation in the North American Specification (NAS) [11] for cold-formed carbon steel structures with newly calibrated coefficients for cold-formed stainless steel sections. A numerical investigation on

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Notation

B Overall width of cross section
E Young's modulus
E^C Young's modulus obtained from transverse compression flat coupon test
E^T Young's modulus obtained from longitudinal tensile flat coupon test
E_{corner} Young's modulus obtained from longitudinal tensile corner coupon test
H Overall depth of cross section
L Specimen length
N Bearing length
P^C Nominal web crippling strength per web calculated using transverse compression flat coupon material properties
P^T Nominal web crippling strength per web calculated using longitudinal tensile flat coupon material properties
P_{304} Nominal web crippling strength per web obtained from suggested design rules for cold-formed austenitic stainless steel type 304 sections
P^C_{304} Nominal web crippling strength per web obtained from suggested design rules for cold-formed austenitic stainless steel type 304 sections using $\sigma^C_{0.2}$
P^T_{304} Nominal web crippling strength per web obtained from suggested design rules for cold-formed austenitic stainless steel type 304 sections using $\sigma^T_{0.2}$
P_{AS4100} Nominal web crippling strength per web obtained from Australian Standard
P^C_{AS4100} Nominal web crippling strength per web obtained from Australian Standard using $\sigma^C_{0.2}$
P^T_{AS4100} Nominal web crippling strength per web obtained from Australian Standard using $\sigma^T_{0.2}$
P_{ASCE} Nominal web crippling strength per web obtained from ASCE Specification
P^C_{ASCE} Nominal web crippling strength per web obtained from ASCE Specification using $\sigma^C_{0.2}$
P^T_{ASCE} Nominal web crippling strength per web obtained from ASCE Specification using $\sigma^T_{0.2}$
P_{DSM} Nominal web crippling strength per web obtained from proposed direct strength method
P^C_{DSM} Nominal web crippling strength per web obtained from proposed direct strength method using $\sigma^C_{0.2}$
P^T_{DSM} Nominal web crippling strength per web obtained from proposed direct strength method using $\sigma^T_{0.2}$
P_{EC3} Nominal web crippling strength per web obtained from European Code
P^C_{EC3} Nominal web crippling strength per web obtained from European Code using $\sigma^C_{0.2}$ and E^C
P^T_{EC3} Nominal web crippling strength per web obtained from European Code using $\sigma^T_{0.2}$ and E^T
$P^C_{EC3\#}$ Nominal web crippling strength per web obtained from European Code using actual bearing length and compression material properties
$P^T_{EC3\#}$ Nominal web crippling strength per web obtained from European Code using actual bearing length and tensile material properties
P_{Exp} Experimental web crippling strength per web
P_{FEA} Web crippling strength per web obtained from finite element analysis
$P_{HSA\&duplex}$ Nominal web crippling strength per web obtained from suggested design rules for cold-formed high strength austenitic and duplex sections
$P^C_{HSA\&duplex}$ Nominal web crippling strength per web obtained from suggested design rules for cold-formed high strength austenitic and duplex sections using $\sigma^C_{0.2}$
$P^T_{HSA\&duplex}$ Nominal web crippling strength per web obtained from suggested design rules for cold-formed high strength austenitic and duplex sections using $\sigma^T_{0.2}$
P_{NAS} Nominal web crippling strength per web obtained from North American Specification
P^C_{NAS} Nominal web crippling strength per web obtained from North American Specification using $\sigma^C_{0.2}$
P^T_{NAS} Nominal web crippling strength per web obtained from North American Specification using $\sigma^T_{0.2}$
$P_{NAS\#}$ Nominal web crippling strength per web obtained from modified North American Specification
$P^C_{NAS\#}$ Nominal web crippling strength per web obtained from modified North American Specification using $\sigma^C_{0.2}$
$P^T_{NAS\#}$ Nominal web crippling strength per web obtained from modified North American Specification using $\sigma^T_{0.2}$
P_{cr} Nominal bearing buckling strength per web
P_m Mean value of test and finite element strength to design prediction ratios
P_u Test or finite element strengths per web
P_y Nominal bearing yield strength per web
R Outer corner radius
V_P Coefficient of variation of test and finite element strength to design prediction ratios
f_y Yield stress
h Depth of web flat portion
t Web thickness
β Reliability index
ε^T_f Elongation after fracture from longitudinal tensile flat coupon test based on gauge length of 50 mm
$\varepsilon_{f,corner}$ Elongation after fracture from longitudinal tensile corner coupon test based on gauge length of 25 mm
ϕ Resistance factor
$\sigma_{0.2}$ 0.2% proof stress (yield stress)
$\sigma^C_{0.2}$ 0.2% proof stress obtained from transverse compression flat coupon test
$\sigma^T_{0.2}$ 0.2% proof stress obtained from longitudinal tensile flat coupon test
$\sigma_{0.2,corner}$ 0.2% proof stress obtained from longitudinal tensile corner coupon test
σ^T_u Tensile strength from longitudinal tensile flat coupon test
$\sigma_{u,corner}$ Tensile strength from longitudinal tensile corner coupon test

cold-formed stainless steel tubular and hat sections was performed by Bock et al. [12], and design rules that considered the strain hardening of stainless steels were proposed based on the design provisions in the EC3 [5]. A strength curves based design approach was proposed by Bock and Real [13] for austenitic and ferritic stainless steel hat sections. It should be noted that the previous studies on web crippling behaviour of stainless steel sections were mainly focused on the four loading conditions, i.e., the End-One-Flange (EOF), End-Two-Flange (ETF), Interior-One-Flange (IOF) and Interior-Two-Flange (ITF), as specified in the ASCE Specification [2] and AS/NZS [3]. Up to date, the investigation on behaviour and design of cold-formed ferritic stainless steel tubular structural members subjected to concentrated bearing loads is very limited, which is the focus of this study.

In the present study, a total of 37 web crippling tests was conducted on cold-formed square and rectangular hollow sections of