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The Continuous Strength Method of Cold-formed Stainless Steel Equal-leg Angle Section Stubs

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Abstract: Structural stainless steel requires appropriate recognition of its beneficial properties such as material nonlinearity and significant strain hardening. The recently proposed Continuous Strength Method (CSM) exploits those benefits through a strain based approach for both stocky and slender cross-sections, and is shown to yield a higher level of accuracy and consistency, as well as design efficiency, in the capacity predictions of stainless steel cross-sections. Although there have been extensive and comprehensive studies on SHS, RHS, round tubes and H-sections stubs, but research into cold-formed stainless steel equal-leg angle section stubs remains scarce. In this paper, the scope of the CSM is extended to cover the design of cold-formed stainless steel equal-leg angle section stubs. Developed FE models included material nonlinearities as well as initial geometric imperfections. A comprehensive parametric study has been carried out covering a wide range of slenderness with different cross section geometries for the considered angle stubs. Cross-section resistances obtained from the numerical study were used to assess the performance of the current Continuous Strength Method (DSM) guidelines and EC3 when applied for stainless steel equal-leg angle section stubs; obtained comparisons showed considerable conservatism. A modified design method for cold-formed stainless steel equal-leg angle section stubs is proposed herein following CSM techniques, which provides considerably more accurate predictions for the considered cold-formed stubs. Reliability of the proposed design equations is also presented showing a good agreement with both experimentally and numerically obtained results.

Keywords: Stainless Steel, Cold-formed, Equal-leg Angle, The Continuous Strength Method, Cross Section Strength

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1 2 2*

1
2

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(CSM)
H
EC3
FE

1

-

SEI/ASCE-8[1] AS/NZS4673[2]
0.673
3(EC3)[3] 4
CECS-410[4]

-

(CSM)
Gardner
Nethercot[5,6] Gardner
Ashraf[7]
Ashraf
[8] “ ”
Gardner[9] “ ”
Afshan Gardner[10]
CSM
($\overline{\lambda}_p \leq 0.68$)
CSM

Ahmed Ashraf[11]

CSM
CSM

CSM
(RHS)
(SHS) H
Zhang
Tan[12]

CSM
CSM
CSM

CSM

2

[1]
/ [2] [3] [4]

2.1 (EC3)

EN1993-1-1[13] EC3[3]

(b/t)
$\varepsilon = \sqrt{\left(235/\sigma_{0.2}\right)/\left(E/210000\right)}$ (
)
0.2 ($\sigma_{0.2}$) (σ_y)
1-3 4 1-3
/
4

3
$\sigma_{0.2}$
$N_{c,Rd}$ (1) (2)
A_g A_{eff} γ_{M0}

1 2 3

$$N_{c,Rd} = \frac{A_g \sigma_{0.2}}{\gamma_{M0}} \tag{1}$$

4

$$N_{c,Rd} = \frac{A_{eff} \sigma_{0.2}}{\gamma_{M0}} \tag{2}$$

2.2 (CSM)

2.2.1

(CSM)[14-16]

(1 2 3)
[17-20]

2.2.2 CSM

CSM “ ”

$\bar{\lambda}_p$ ($\varepsilon_{csm}/\varepsilon_y$)
(3) ε_{csm}
$\varepsilon_y=\sigma_y/E$ (3) ($\varepsilon_{csm}/\varepsilon_y$)
15
EN1993-1-4[21]

(DSM) (CSM)
$\bar{\lambda}_p$ $\bar{\lambda}_l$
(3)
$\bar{\lambda}_p$ 0.68

$$\frac{\varepsilon_{csm}}{\varepsilon_y}=\frac{0.25}{\bar{\lambda}_p^{3.6}}\le\min\left(15,\frac{C_1\varepsilon_u}{\varepsilon_y}\right)\qquad\bar{\lambda}_p\le0.68\qquad(3)$$

CSM (C_1
C_2 C_3 C_4) E_{sh} (4)

CSM C_1
((3))
CSM C_2 (4)
E_{sh} $\varepsilon_u=C_3\left(1-\sigma_y/\sigma_u\right)+C_4$
σ_u

$$E_{sh}=\frac{\sigma_u-\sigma_y}{C_2\varepsilon_u-\varepsilon_y}\qquad(4)$$

ε_{csm} E_{sh}
CSM σ_{csm} (5)
(6) $N_{csm,Rd}$ γ_{M0}
1.1

$$\sigma_{csm}=\sigma_y+E_{sh}\left(\varepsilon_{csm}-\varepsilon_y\right)\qquad(5)$$

$$N_{csm,Rd}=\frac{A\sigma_{csm}}{\gamma_{M0}}\qquad(6)$$

CSM

[17-21]

2.2.3 CSM

CSM
0.2
CSM

- CSM

CSM
$\bar{\lambda}_p>0.68$

CSM
ε_{lb}
ε_{lb} δ_u L

CSM
[11]

CSM -

$\varepsilon_{lb,e}$
$\varepsilon_{lb,e}=N_{u,test}/\left(EA\right)$ $N_{u,test}$
(
ε_y)
(7) $N_y=A\sigma_y$
[24]
0.2
- *CSM*
$\varepsilon_{csm}/\varepsilon_y=\varepsilon_{lb,e}/\varepsilon_y$

$$\varepsilon_{csm}/\varepsilon_y=\varepsilon_{lb,e}/\varepsilon_y=N_{u,test}/N_y\qquad(7)$$

$\bar{\lambda}_p>0.68$
CSM

( ) (0.68,1)
CSM (8) $\bar{\lambda}_p$=0.68

$$\frac{\varepsilon_{csm}}{\varepsilon_y}=\left(1-\frac{0.222}{\bar{\lambda}_p^{1.050}}\right)\frac{1}{\bar{\lambda}_p^{1.050}}\qquad(8)$$

(　)

CSM (9)

$$N_{csm,Rd}=\frac{\varepsilon_{csm}}{\varepsilon_y}\frac{A\sigma_{0.2}}{\gamma_{M0}} \tag{9}$$

3

3.1

ABAQUS[22]

3.2

[23-24] S4R 2mm 6 Arrayago [25] Rasmussen[26] Ramberg-Osgood(R-O)[27]

2 [28]

3.3

1) Gardner Nethercot[29] Dawson Walker [30] 2)t/100 3)t/10 t Riks [31-32]

-

3.4

[33-34]

3.5

-

1 FE

1

		D&W	**t/100**	**t/10**
A50X6	A50X6-150	1.01	1.02	0.95
	A50X6-150R	1.01	1.03	0.94
A100X6	A100X6-300	0.93	0.98	0.89
	A100X6-300R	1.00	1.05	0.94
		0.99	1.02	0.93
		0.04	0.03	0.03

1 A50-150 A100-300 FE - FE FE Dawson Walker [12]

2 A100×100×6

4

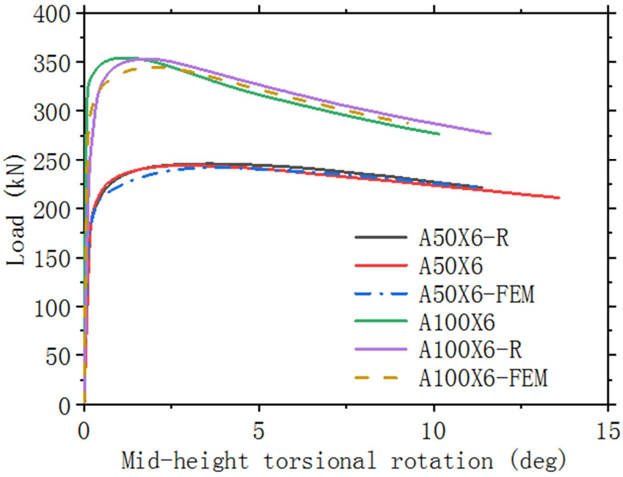
470 25-200mm 2-6mm 0.25-3.0 (1.4420) [12] A50×50×6

2 Dawson Walker

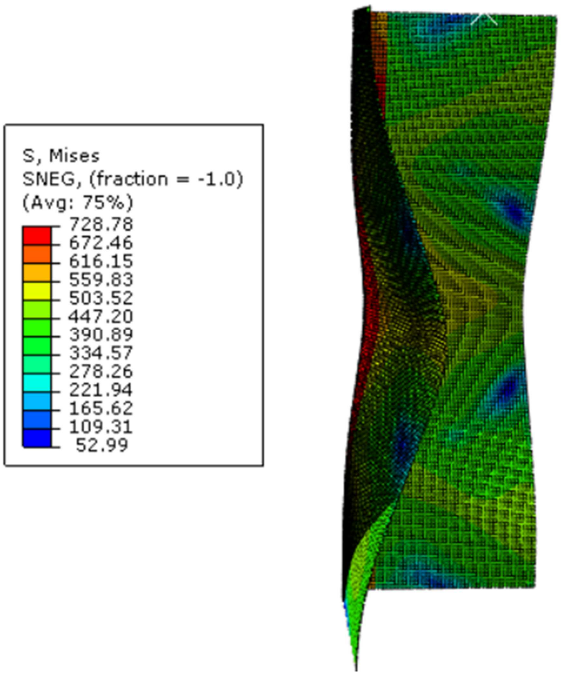
[12] (EC3)[3] CSM

2 [12]

	E(GPa)	**$\sigma_{0.2}$(MPa)**	**σ_u(MPa)**	**R-O (n)**
A50X6	198.2	278.2	637.0	6.8
	187.1	619.4	880.5	2.2



1 [12] -



2 A100×100×6

5 (EC3) CSM

N_u

$N_{u,pred}$

3 EC3 CSM

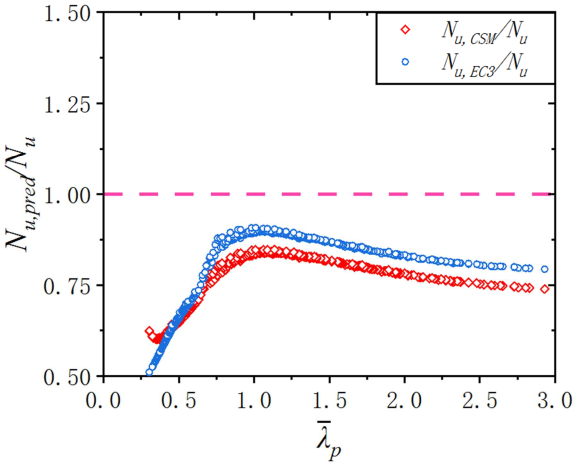
CSM

EC3 CSM EC3

CSM EC3

0.74 0.77 CoV 0.09 0.12

CSM EC3



3 CSM

6 CSM

(10) δ_u

L 4

CSM (11)

4 (11) CSM

CSM

$$\varepsilon_{csm}=\varepsilon_{lb}-0.002=\frac{\delta_u}{L}-0.002 \tag{10}$$

CSM CSM ((3) (8))

CSM (

(11))

$$\varepsilon_{csm}=\frac{0.0013}{\bar{\lambda}_p^{0.73}} \quad \frac{\varepsilon_{csm}}{\varepsilon_y}\leq \min\left(15,\frac{C_1\varepsilon_u}{\varepsilon_y}\right) \tag{11}$$

$$\sigma_{csm}=\mathrm{E}\varepsilon_{csm} \tag{12}$$

$$N_{csm,Rd}=\frac{\sigma_{csm}A}{\gamma_{M0}} \tag{13}$$

(11) (11)

(12) CSM

(13)

$\bar{\lambda}_p=0.68$

CSM

$N_{u,pro}$ FE N_u

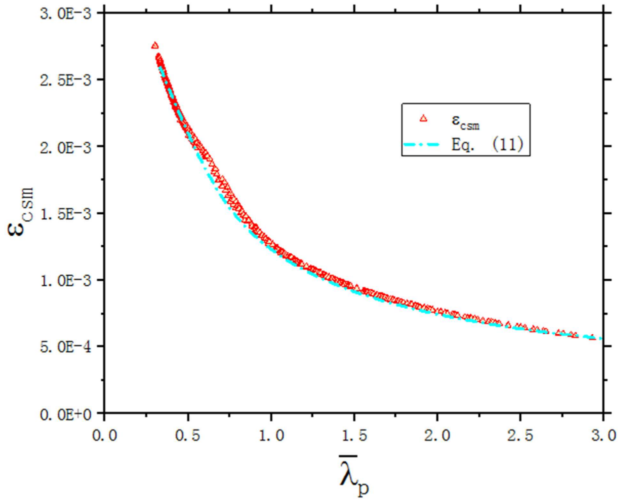
5 $N_{u,pro}/N_u$ 1.01

0.03 CSM

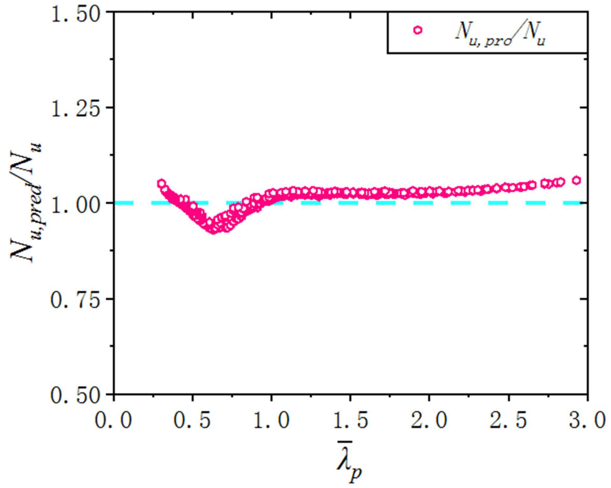
(EC3) CSM

1.0

CSM



4



5 CSM FE

7

EN 1990 - Annex D[35]
CSM 3
n FE $k_{d,n}$
n ( ) b
FE
V_δ FE
V_r
γ_{M0} [36]
1.3
0.06 0.05
CSM
γ_{M0} EC3[3]

1.10
CSM
1.15
CSM

3

n	Kd,n	b	V_δ	V_r	γ_{MO}
470	3.04	1.01	0.06	0.05	1.12

8

FE
470
(EC3) CSM
(EC3) CSM

FE CSM CSM
CSM
CSM

1.15
CSM

(2018JM5123)

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