DESIGN OF FLAT OVAL LDSS STUB COLUMNS OF SLENDER CROSS-SECTIONS

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Contents:

Introduction: Flat oval hollow steel sections

Flat Oval Section = Curved elements + Flat elements

Introduction: Flat oval steel hollow sections

https://sc01.alicdn.com/kf/HTB1tWOFGXXXXXbBXFXXq6xXFXXXr/200632358/HTB1tWOFGXXXXXbBXFXXq6xXFXXXr.jpg

https://www.taiwantrade.com/product/erw-flat-oval-steel-tube-pipe-1334808.html

Available in various sizes

Introduction: Lean Duplex Stainless Steel (LDSS) ~ *constructions*

***LDSS ~ Less expensive (due to low nickel content), good corrosion resistance, high temperature properties, adequate weldability and fracture toughness** (e.g. Theofanous and Gardner, Saliba & Gardner, 2013).*

Sölvesborg Bridge

Sant Fruitos Bridge, Spain

Añorga railway bridge

Footbridge of Ruffolo, Siena

New Doha International Airport

LDSS ~ a promising construction material

Introduction: Lean Duplex Stainless Steel (LDSS) ~ *Material properties*

METALCOR

1.4162

Trade name	LDX 2101®, Lean Duplex

Standards

Material No.	EN Designation	UNS
1.4162	X2CrMnNiN22-5-2	S32101

Description	1.4162 is a LEAN-DUPLEX chromium stainless steel with additional manganese, nickel, molybdenum and copper.
Special properties	Very good corrosion resistance. Good mechanical characteristics. Good endurance strength. Good weldability.

Chemical Composition

C %	Si ≤ %	Mn ≤ %	P ≤ %	S ≤ %
≤ 0.04	1.00	4.00-6.00	0.04	0.015
Cr %	**Mo %**	**Ni %**	**N %**	**Cu %**
21.0-22.0	0.10-0.80	1.35-1.70	0.20-0.25	0.10-0.80

Mechanical Properties 20°C

Hardness HB 30 ≤ HB	0.2% Yield strength R_p ≥ N/mm²	Tensile strength R_m N/mm²	Elongation A_5 ≥ %	Modulus of elasticity kN/mm²
290	450	> 650	30	200

Physical Properties 20°C

Density g/cm³	Specific heat capacity J/kg K	Thermal conductivity W/m K	Electrical resistivity Ω mm²/m
7.7	500	15	0.8

Suitable welding filler materials	CN 24/9 LDX PW-FD
Application	Chemical, pulp and cellulose industry, oil and gas industry

Available forms for 1.4162 /

Sheets/Plates	Bars	Tubes/Pipes	Fittings
			

p://www.metalcor.de/en/datenblatt/4/

Introduction: Lean Duplex Stainless Steel (LDSS) ~ *EN 1993-1-4:2006+A1 (2015)*

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1993-1-4:2006+A1

June 2015

Type of stainless steel	Grade	Product form							
		Cold rolled strip		Hot rolled strip		Hot rolled plate		Bars, rods and sections	
		Nominal thickness t							
		$t \leq 8$ mm		$t \leq 13{,}5$ mm		$t \leq 75$ mm		$t \leq 250$ mm	
		f_y	f_u	f_y	f_u	f_y	f_u	f_y	f_u
		N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
	1.4547	320	650	300	650	300	650	300	650
	1.4318	350	650	330	650	330	630	-	-
Austenitic-ferritic steels	1.4062	530 [e]	700 [e]	480 [f]	680 [f]	450 [g]	650 [g]	380 [b]	650 [b]
	1.4162	530 [e]	700 [e]	480 [f]	680 [f]	450	650	450 [b]	650 [b]
	1.4482	500 [e]	700 [e]	480 [f]	660 [f]	450	650	400 [b]	650 [b]
	1.4662	550 [e]	750 [e]	550	750	480	680	450 [b]	650 [b]
	1.4362	450	650	400	650	400	630	400 [b]	600 [b]
	1.4462	500	700	460	700	460	640	450 [b]	650 [b]

[a] The nominal values of f_y and f_u given in this table may be used in design without taking special account of anisotropy or strain hardening effects.

[b] $t \leq 160$ mm

[c] $t \leq 25$ mm

[d] $t \leq 100$ mm

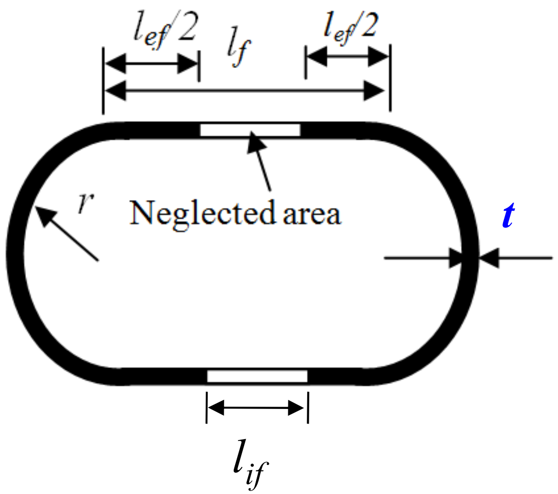
[e] $t \leq 6{,}4$ mm

[f] $t \leq 10$ mm

[g] $t \leq 50$ mm ($f_y = 430$ N/mm^2 and $f_u = 625$ N/mm^2 for 50 mm $< t \leq 75$ mm)

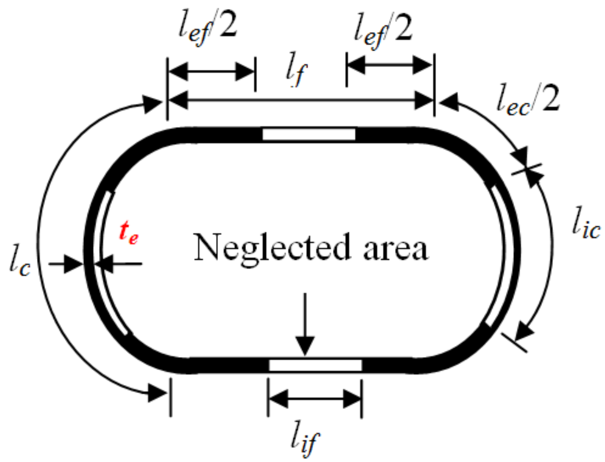
Introduction: Flat oval section ~ *Effective area*

Zhu and Young, (2011, 2012)



Curve element: **Full** effective

ASDM (2002)



Curved element: **Partially** effective

No guideline to compute effective area for composite curved and flat sections in codes e.g. EN, ASCE, AS/NZS

Introduction: Flat element effective area / length ~ *ASDM*

Flat element effective length

$$\lambda = \left(\frac{1.052}{\sqrt{k}}\right)\left(\frac{l_f}{t}\right)\left(\sqrt{\frac{f}{E}}\right)$$

$$f = f_{yrs} = \left(1 - 0.2\sqrt{\frac{l_f}{t}}\sqrt{\frac{f_y}{E}}\right)f_y$$

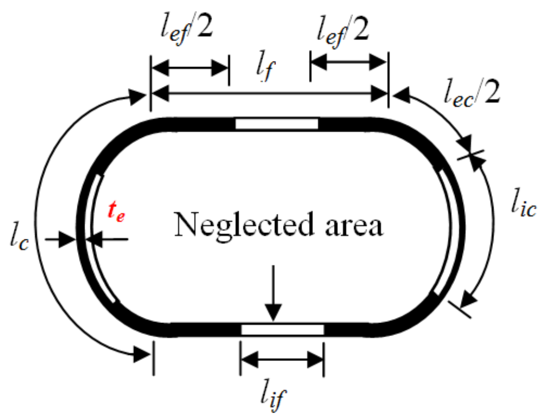
For f_y > 552 MPa, a reduced yield strength (f_{yrs}) is substituted for limiting value of f *(i.e.* $f = f_{yrs}$*, for* f_y = 657 MPa, for LDSS*)*

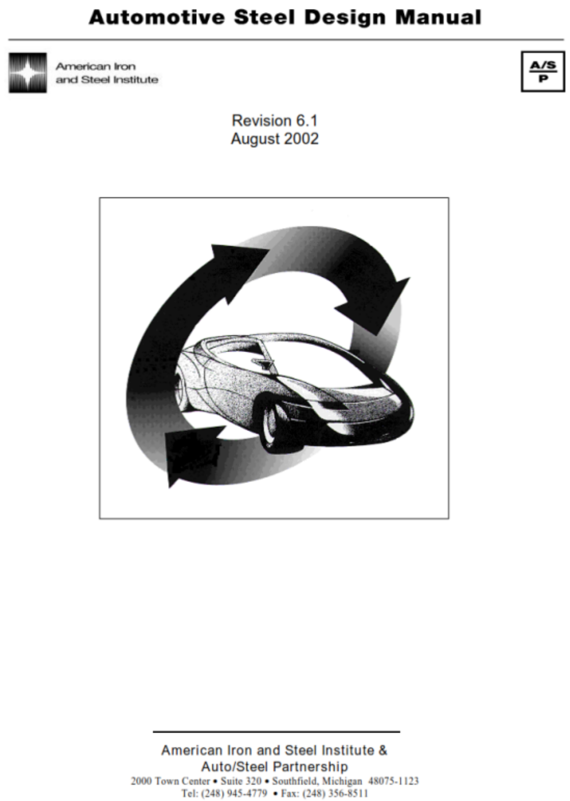
The value of k is conservatively taken as 4.0

For $\lambda \le 0.673,\ l_{ef} = l_f$

For $\lambda > 0.673,\ l_{ef} = \rho l_f,$

$$\rho = \frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda} \le 1.0$$




Automotive Steel Design Manual

American Iron and Steel Institute

A/S P

Revision 6.1
August 2002

American Iron and Steel Institute &
Auto/Steel Partnership
2000 Town Center • Suite 320 • Southfield, Michigan 48075-1123
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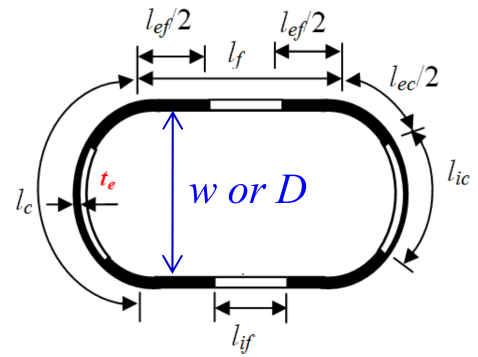
Introduction: Curved element effective area / length ~ *ASDM*

Curved element effective length (l_{ec})

$$l_{ec} = ts\left(1.486 - \frac{0.486S}{\frac{l_c}{t}}\right) \qquad s = 1.28\sqrt{\frac{E}{f_y}}$$

$$t_e = \left(\frac{A_o}{A}\right)\left(\frac{f_y}{f}\right)t$$

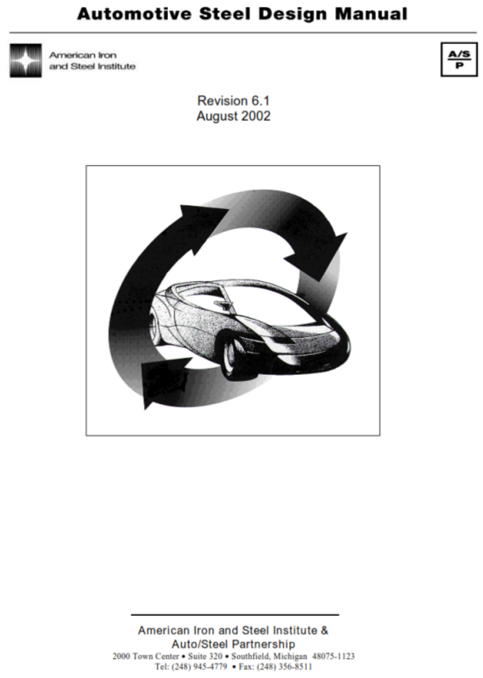


$$A_o = A\,; \qquad \frac{D}{t} \le 0.114\,\frac{E}{f_y}$$

$$= \left(\frac{2}{3} + \frac{0.038\frac{E}{f_y}}{\frac{D}{t}}\right)A \qquad 0.114\frac{E}{f_y} < \frac{D}{t} \le 0.448\frac{E}{f_y}$$

$$= \left(\frac{0.336\frac{E}{F_y}}{\frac{D}{t}}\right)A \qquad \frac{D}{t} \ge 0.448\frac{E}{F_y}$$

$D/t \le 34.22$ for
$E = 197200$ N/mm^2
$f_y = 657$ N/mm^2.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$$P_{ASDM} = f_y A_e$$

$$A_{ec} = 2(l_c - l_{ec})t_e + 2tl_{ec}$$

$$A_{ef} = 2tl_{ef}$$

$$A_e = A_{ec} + A_{ef}$$

$\frac{D}{t}$ or $\frac{w}{t} \ge 40$ ***Slender Curved element***

Objectives: Flat oval hollow LDSS stub columns

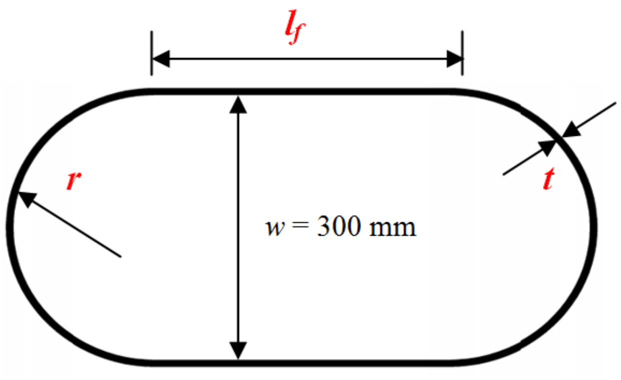
Lean Duplex Stainless Steel ***Flat Oval Hollow Stub Columns*** ***Slender Cross-Sections*** ***Compression*** ***Design***

Objectives

❑To investigate the structural behaviour of fixed ended LDSS flat oval hollow stub columns of ***slender*** cross-sections, by varying l_f (flat element length), r (radius of curved element), and t (thickness).

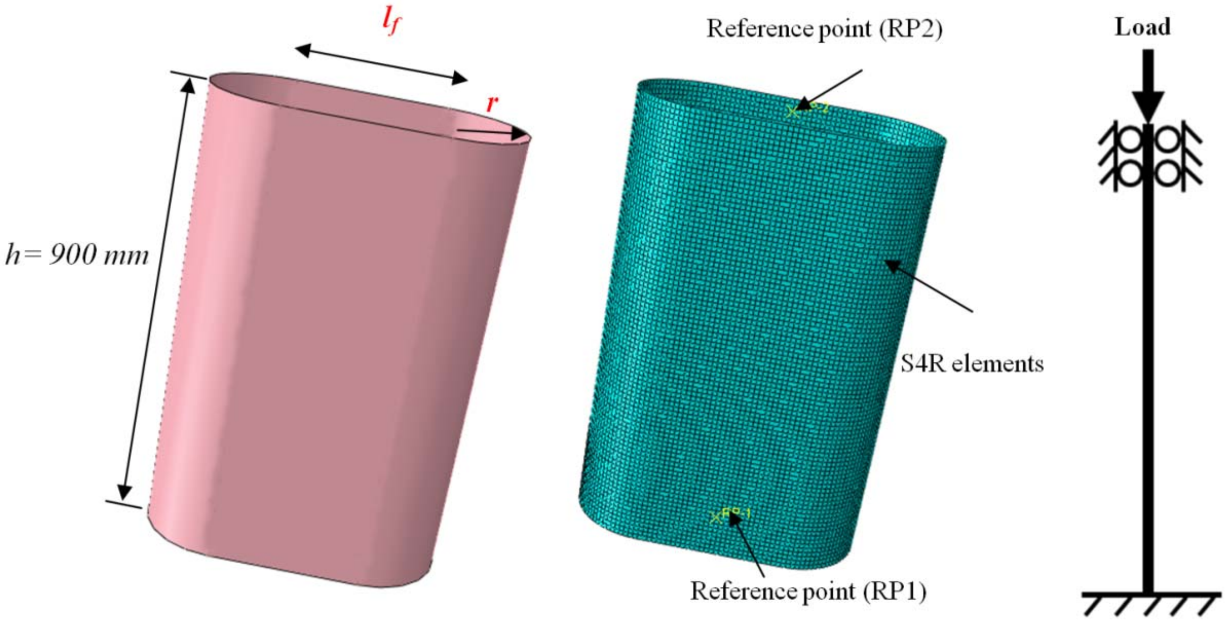
➢ To assess the applicability of current standards/codes for the design of LDSS flat oval hollow stub columns of ***slender*** cross-sections.

FE Modelling: Geometry, mesh, boundary conditions, loading…



$$\frac{D}{t} \text{ or } \frac{w}{t} \geq 40$$

Slender Curved element



l_f (mm)	r (mm)	w (mm)	t (mm)	h (mm)	Nos.
50-150	**25-100**	300	**3-7.5**	900	33

FE Modelling: Validation ~ LDSS *Square hollow stub columns*

LDSS square hollow stub column *(Theofanous and Gardner, 2010)*

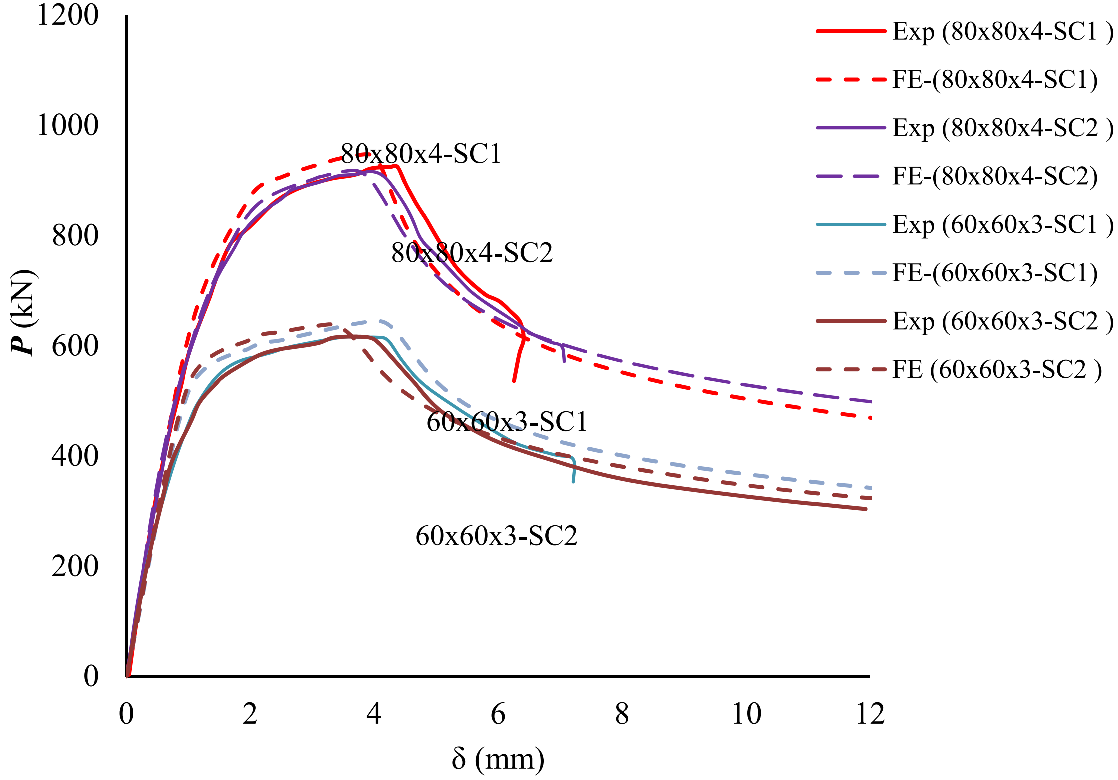
Cross-section	E (MPa)	$\sigma_{0.2}$ (MPa)	$\sigma_{1.0}$ (MPa)	Compound R-O coefficients	
				n	$n'_{0.2,1.0}$
80x80x4	197200	657	770	4.7	2.6
60x60x3	206400	711	845	5.0	2.7

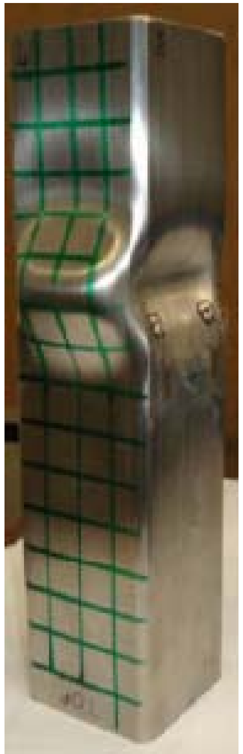
Specimen	L (mm)	B (mm)	h (mm)	t (mm)	r_i (mm)
80x80x4-SC1	319.7	80	80.5	3.88	3.8
80x80x4-SC2	332.2	80	80	3.81	3.6
60x60x3-SC1	239.8	60	60	3.09	2.3
60x60x3-SC2	240.0	60	60	3.17	2.1

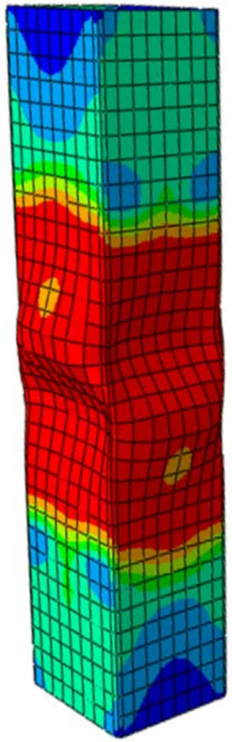
L = Length, B = Width, h = height, t = thickness, r_i = internal corner radius

FE Modelling: FE Validation ~ *Square beam, Plate girder*

LDSS square hollow stub column *(Theofanous and Gardner, 2010)*

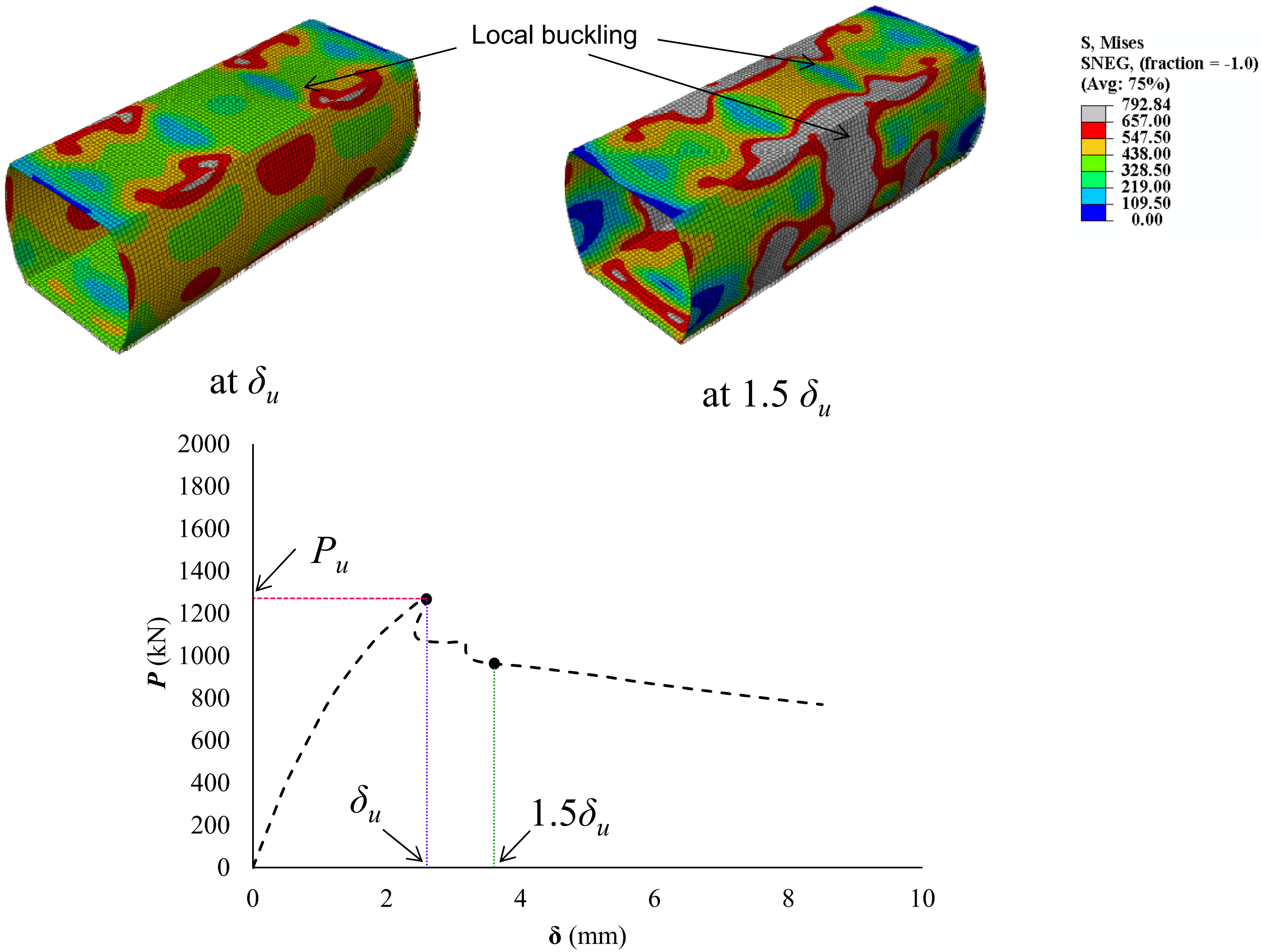




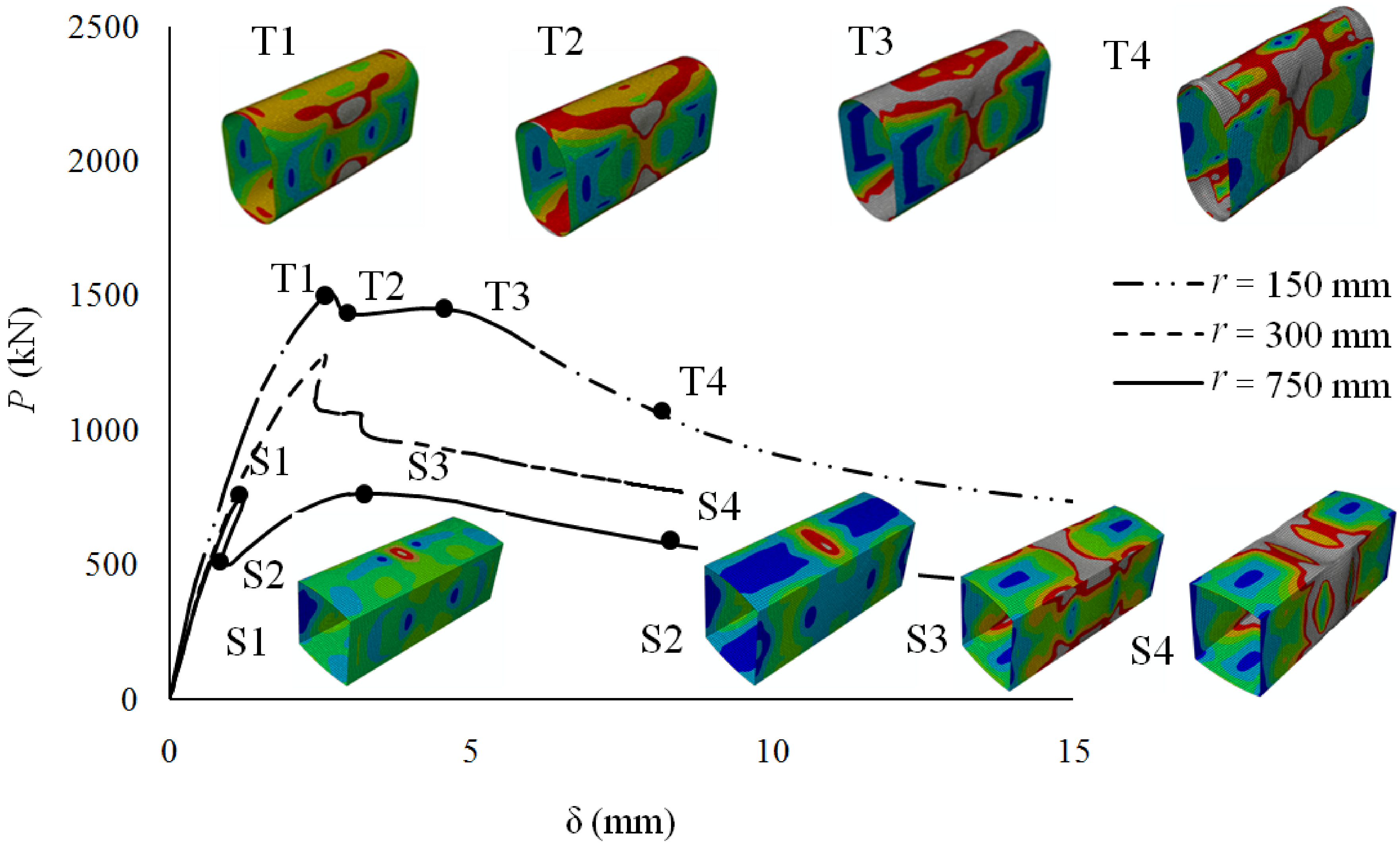


❖ ***Good agreement with experimental results***

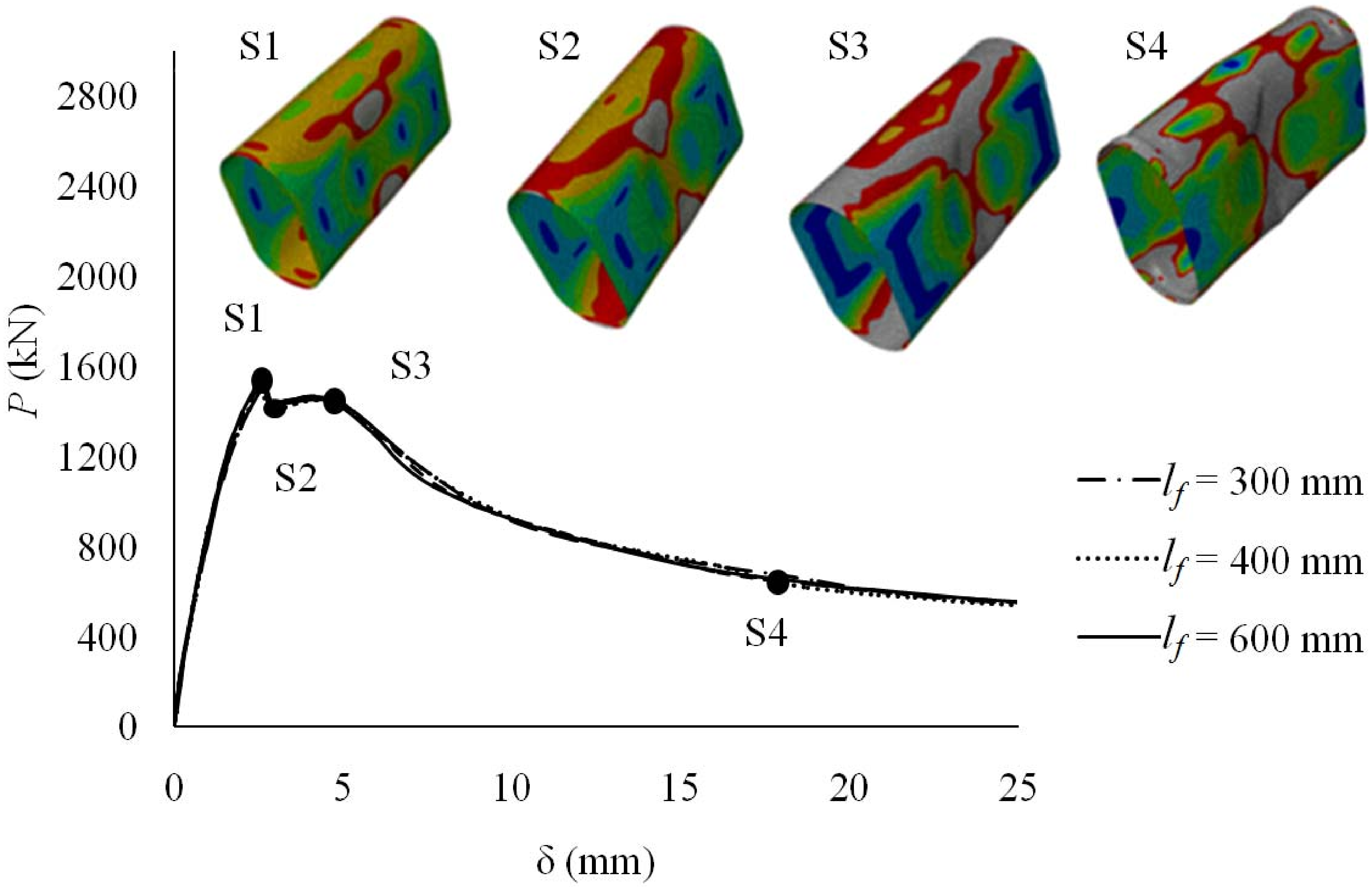
Results: Deformed shapes ~ l_f = 300 mm; r = 300 mm, t = 3 mm



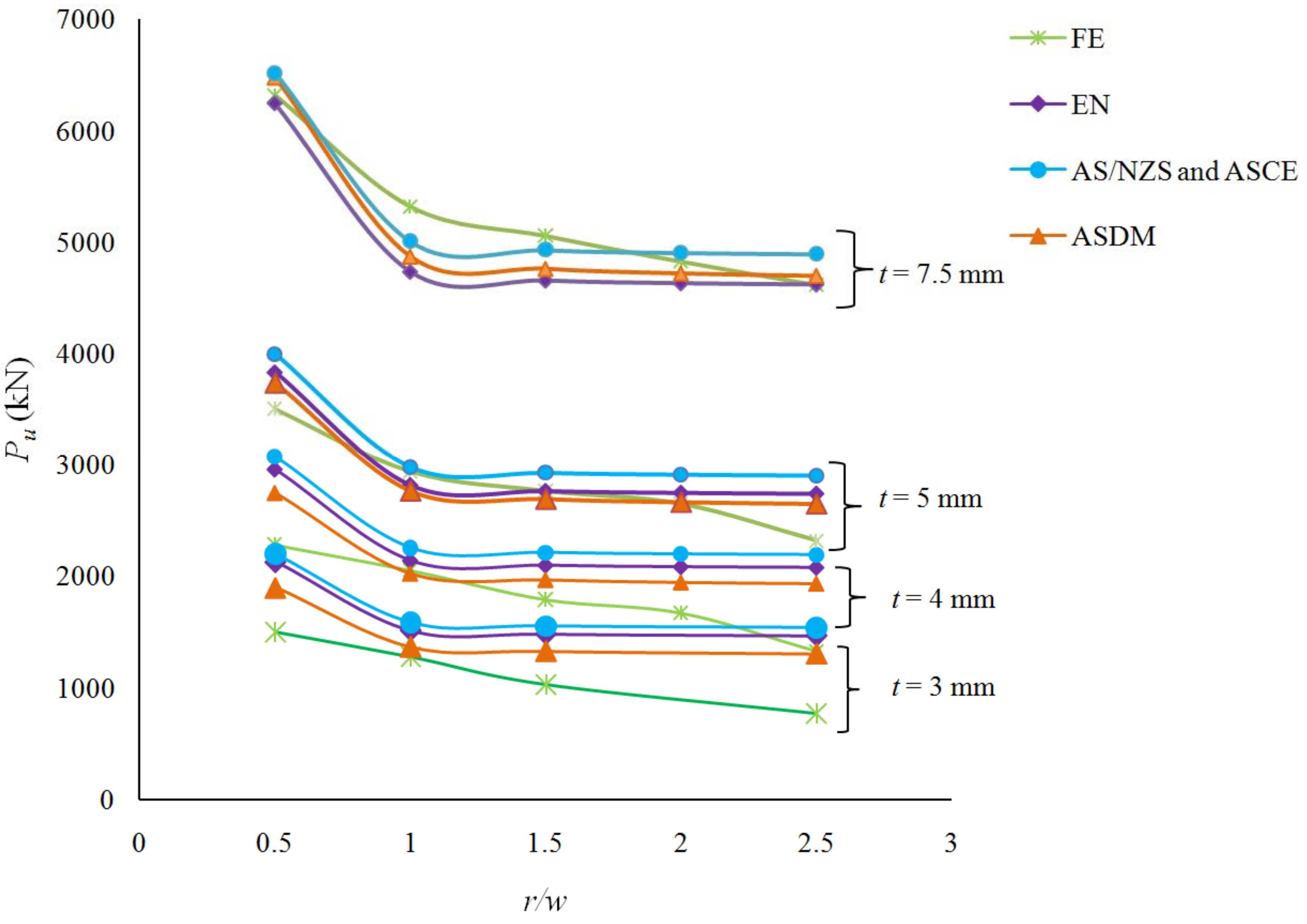
Results: Effect of curved element radius (r) ~ Deformed shapes (l_f = 300 mm, t = 3 mm)



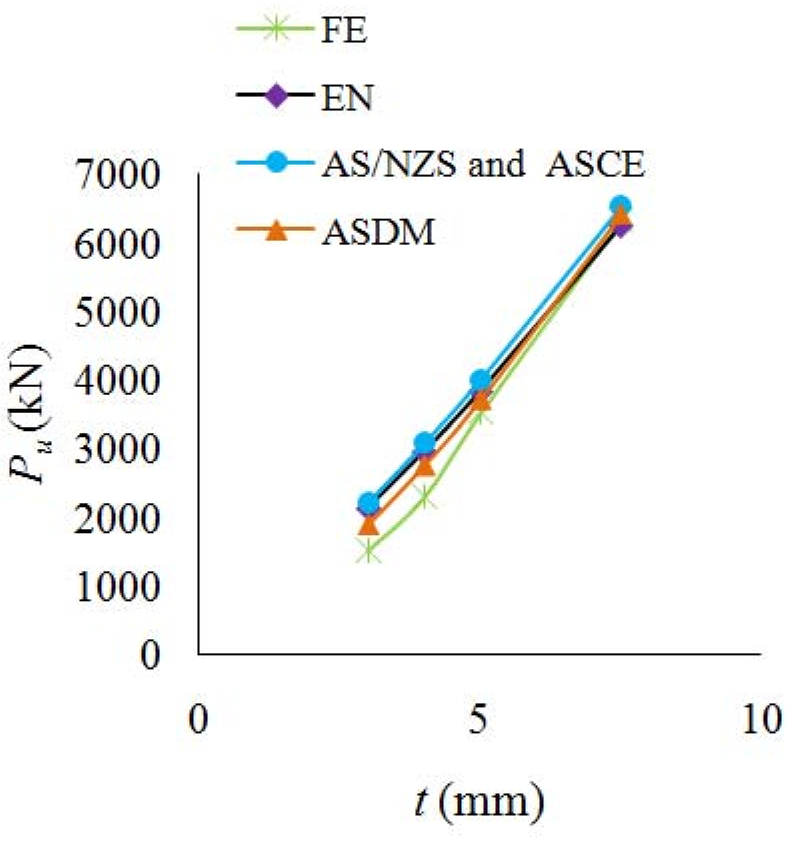
Results: Effect of flat element length (l_f) ~ Deformed shapes (r = 150 mm, t = 3 mm)



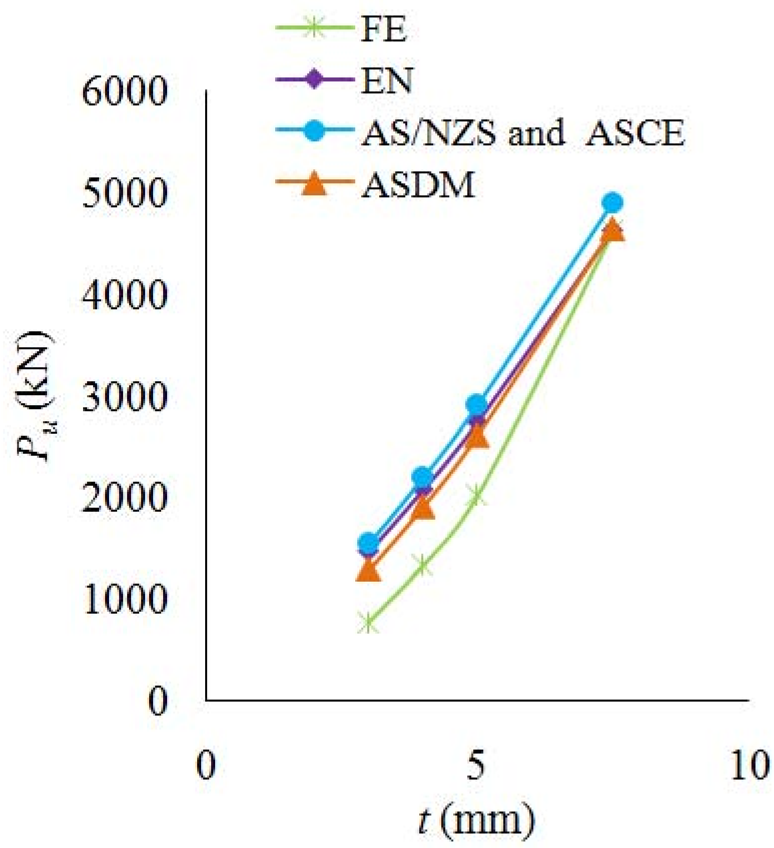
Results: Effect of curved element radius (r) ~ l_f = 300 mm



Results: Codal comparison ~ r = 150, 750 mm, l_f = 300 mm

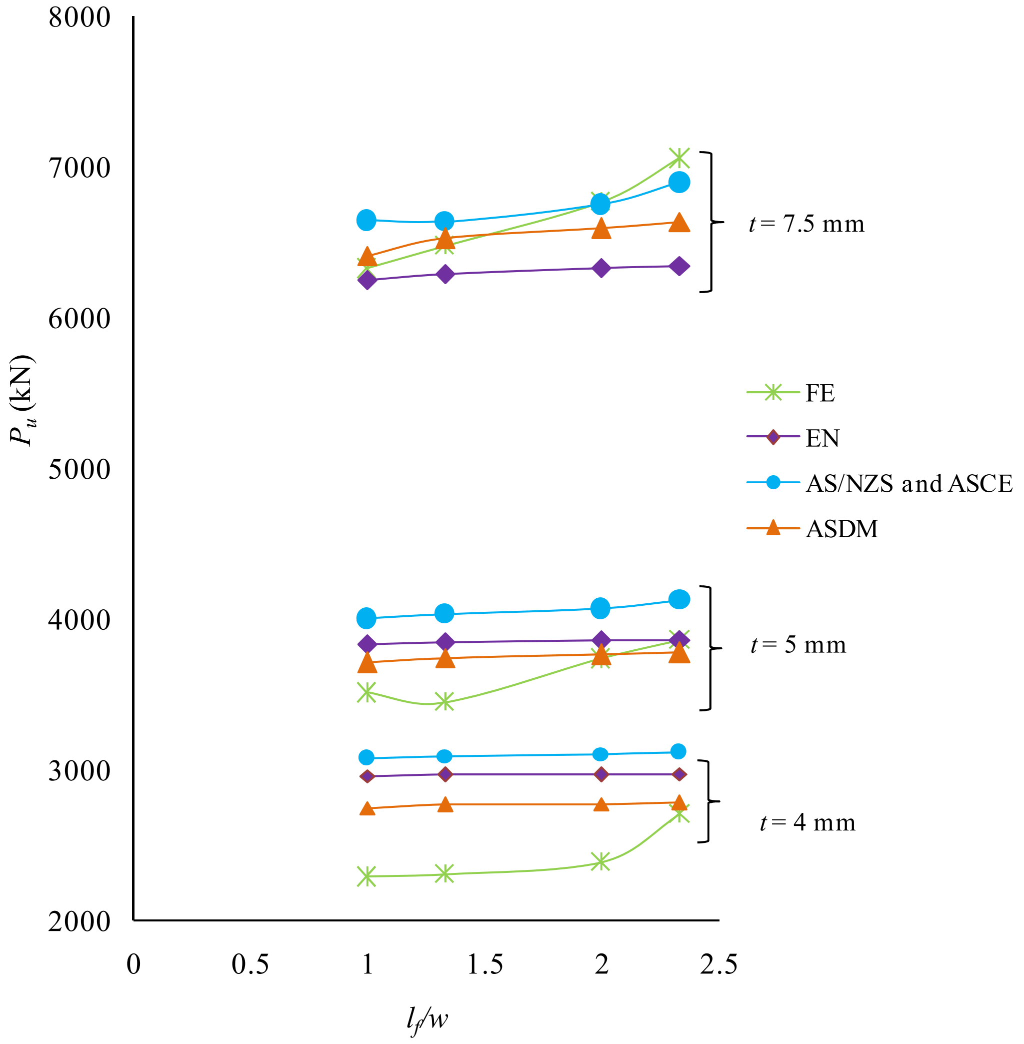


r = 150 mm

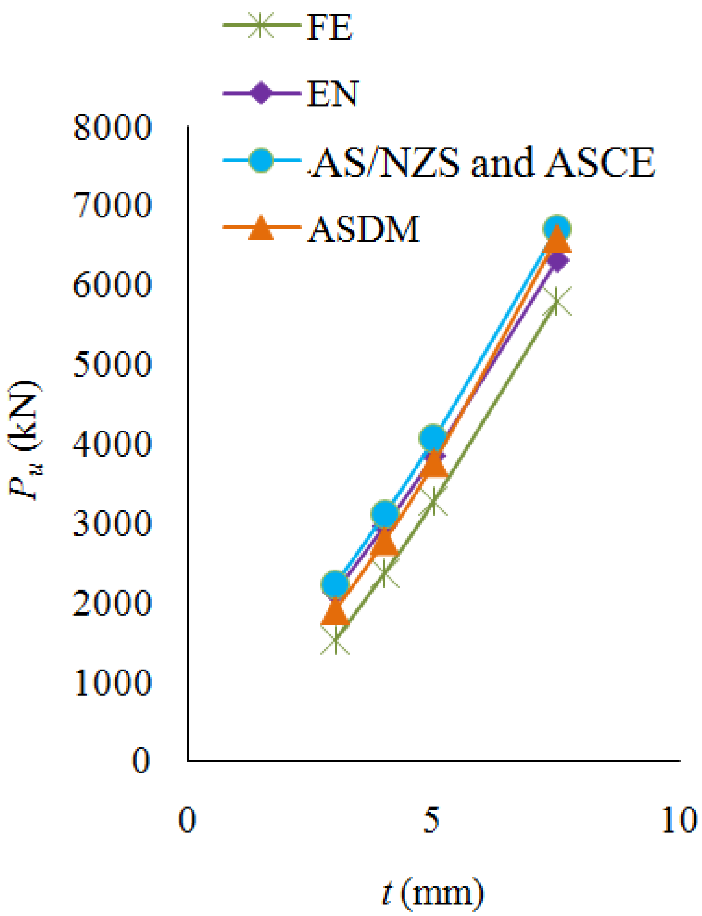


r = 750 mm

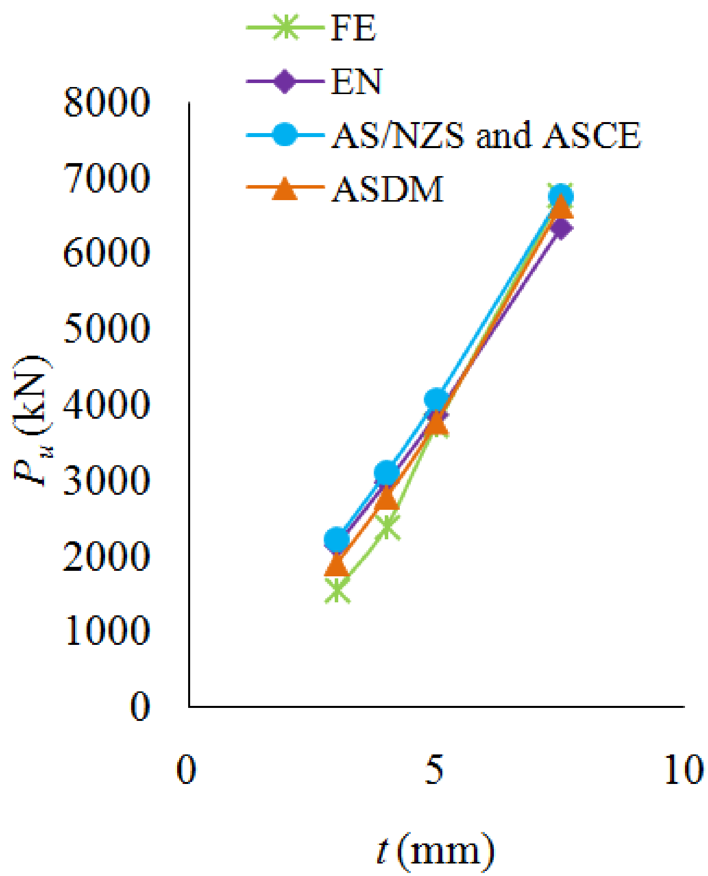
Results: Effect of flat element length (l_f) ~ r = 150 mm



Results: Codal comparison ~ l_f = 500 and 600 mm, r = 150 mm



l_f = 500 mm



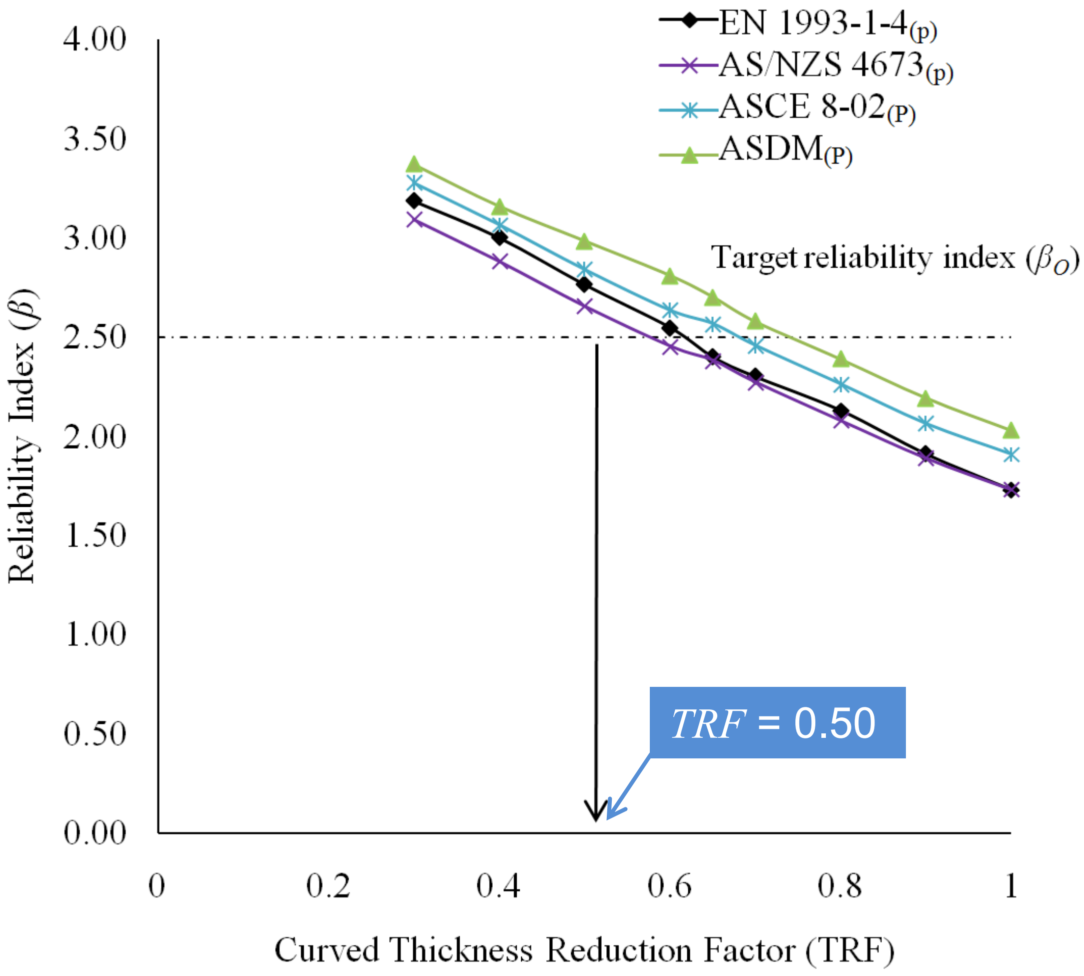
l_f = 600 mm

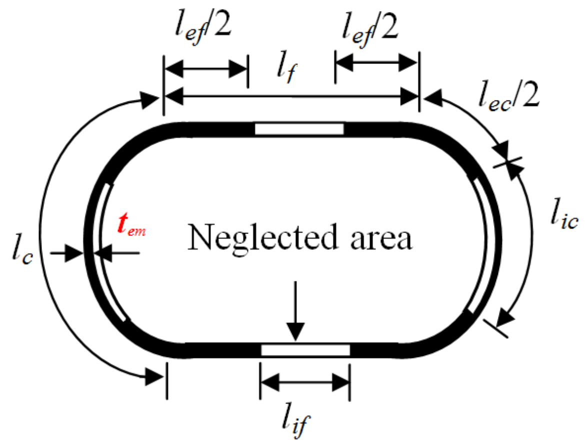
Results: Comparison with codes

Specimen	Current codes			
	$\frac{P_{FEA}}{P_{EN}}$	$\frac{P_{FEA}}{P_{AS/NZS}}$	$\frac{P_{FEA}}{P_{ASCE}}$	$\frac{P_{FEA}}{P_{ASDM}}$
l300w300r150t3	0.70	0.68	0.68	0.79
l300w300r150t4	0.77	0.74	0.74	0.82
l300w300r150t5	0.91	0.87	0.87	0.94
l300w300r150t7.5	1.01	0.97	0.97	0.98
l300w300r300t3	0.84	0.80	0.80	0.93
l300w300r300t4	0.96	0.91	0.91	1.01
l300w300r300t5	1.04	0.98	0.98	1.06
l300w300r300t7.5	1.12	1.06	1.06	1.09
l300w300r450t3	0.69	0.66	0.66	0.77
l300w300r450t4	0.85	0.81	0.81	0.91
l300w300r450t5	1.00	0.94	0.94	1.03
l300w300r450t7.5	1.09	1.02	1.02	1.06
l300w300r600t5	0.96	0.91	0.91	0.99
l300w300r600t7.5	1.04	0.98	0.98	1.02
l300w300r750t3	0.52	0.50	0.50	0.59
l300w300r750t4	0.64	0.61	0.61	0.69
l300w300r750t5	0.74	0.69	0.69	0.84
l300w300r750t7.5	1.00	0.94	0.94	0.98
l400w300r150t3	0.70	0.69	0.69	1.05
l400w300r150t4	0.78	0.75	0.75	1.08
l400w300r150t5	0.84	0.80	0.80	1.12
l400w300r150t7.5	1.11	1.05	1.05	1.35
l500w300r150t3	0.72	0.69	0.69	0.80
l500w300r150t4	0.80	0.77	0.77	0.84
l500w300r150t5	0.85	0.81	0.81	0.86
l500w300r150t7.5	0.92	0.86	0.86	0.87
l600w300r150t3	0.73	0.70	0.70	0.80
l600w300r150t4	0.80	0.77	0.77	0.84
l600w300r150t5	0.97	0.91	0.91	0.97
l600w300r150t7.5	1.07	1.00	1.00	1.00
l700w300r150t4	0.91	0.87	0.87	0.95
l700w300r150t5	1.00	0.94	0.94	1.00
l700w300r150t7.5	1.11	1.02	1.02	1.04
Mean (P_m)	0.88	0.84	0.84	0.94
COV (V_p)	0.18	0.17	0.17	0.15
Reliability index (β)	$\boxed{1.44}$	$\boxed{1.50}$	$\boxed{1.67}$	$\boxed{2.14}$

$\boxed{\beta < 2.5\text{: Not reliable}}$

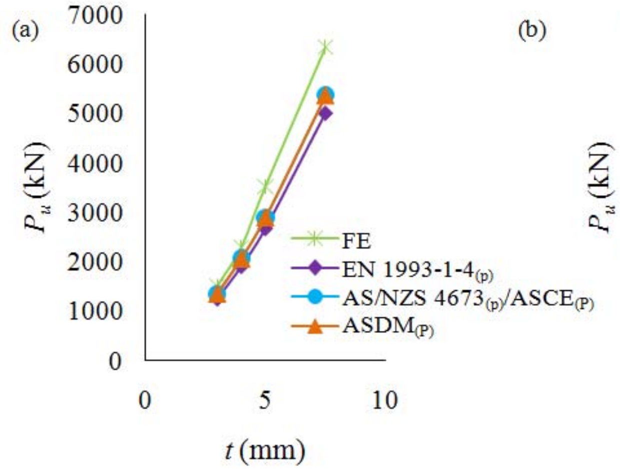
Results: Proposed effective width for curved element ~ TRF



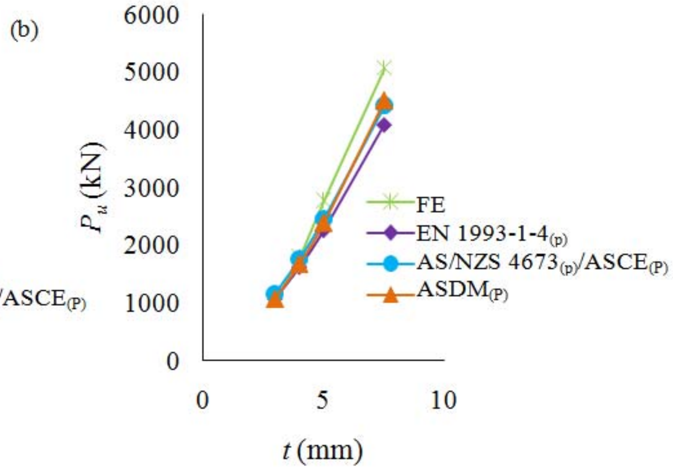


$$t_{em} = TRF\left(\frac{A_o}{A}\right)\left(\frac{f_y}{f}\right)t$$

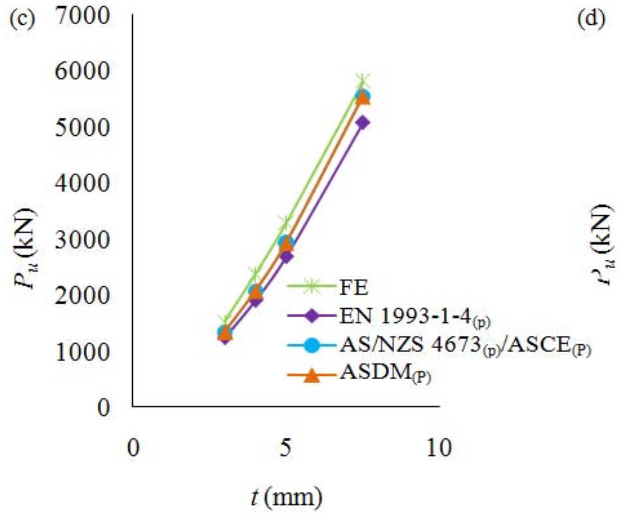
Results: Comparison with proposed modified codes



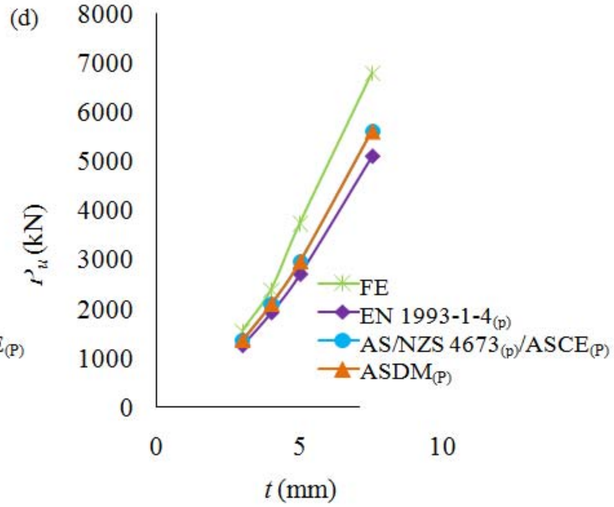
(a) $l300w300r150$



(b) $l300w300r450$



(c) $l500w300r150$



(d) $l600w300r150$

Specimen	Proposed modified codes			
	$\frac{P_{FEA}}{P_{EN(p)}}$	$\frac{P_{FEA}}{P_{AS/NZS(p)}}$	$\frac{P_{FEA}}{P_{ASCE(p)}}$	$\frac{P_{FEA}}{P_{ASDM(p)}}$
l300w300r150t3	1.21	1.13	1.13	1.13
l300w300r150t4	1.20	1.11	1.11	1.11
l300w300r150t5	1.32	1.22	1.22	1.22
l300w300r150t7.5	1.26	1.18	1.18	1.18
l300w300r300t3	1.18	1.09	1.09	1.18
l300w300r300t4	1.25	1.15	1.15	1.21
l300w300r300t5	1.37	1.25	1.25	1.22
l300w300r300t7.5	1.29	1.19	1.19	1.17
l300w300r450t3	0.96	0.89	0.89	0.96
l300w300r450t4	1.11	1.02	1.02	1.07
l300w300r450t5	1.23	1.13	1.13	1.16
l300w300r450t7.5	1.24	1.15	1.15	1.12
l300w300r600t5	1.18	1.08	1.08	1.12
l300w300r600t7.5	1.16	1.07	1.07	1.08
l300w300r750t3	0.72	0.67	0.67	0.72
l300w300r750t4	0.83	0.76	0.76	0.80
l300w300r750t5	0.99	0.91	0.91	0.94
l300w300r750t7.5	1.11	1.03	1.03	1.03
l400w300r150t3	1.21	1.12	1.12	1.12
l400w300r150t4	1.21	1.11	1.11	1.11
l400w300r150t5	1.21	1.11	1.11	1.11
l400w300r150t7.5	1.38	1.27	1.27	1.27
l500w300r150t3	1.24	1.14	1.14	1.14
l500w300r150t4	1.25	1.14	1.14	1.14
l500w300r150t5	1.22	1.12	1.12	1.12
l500w300r150t7.5	1.14	1.05	1.05	1.05
l600w300r150t3	1.25	1.15	1.15	1.15
l600w300r150t4	1.25	1.14	1.14	1.14
l600w300r150t5	1.39	1.26	1.26	1.26
l600w300r150t7.5	1.33	1.21	1.21	1.21
l700w300r150t4	1.42	1.29	1.29	1.29
l700w300r150t5	1.43	1.30	1.30	1.30
l700w300r150t7.5	1.38	1.25	1.25	1.25
Mean (P_m)	1.21	1.11	1.11	1.12
COV (V_p)	0.13	0.13	0.13	0.11
Reliability index (β)	2.77	2.66	2.84	2.98

$\beta > 2.5$: Reliable

Conclusions:

Parametric study of the structural behaviour of fixed ended LDSS flat oval section stub columns of slender cross-sections, by varying l_f (flat element length), r (radius of curved element), t (thickness), is presented. Based on the study, the following conclusions have been obtained:

- ❑ LDSS flat oval sections with semicircular elements on either sides of the flat elements (i.e. r/w = 0.5) provided the maximum column strength (P_u), with increasing P_u for increasing l_f/w.

- ❑ EN 1993-1-4, AS/NZS 4673, ASCE 8-02, and ASDM design rules are unconservative for the design of non-compact LDSS flat oval stub column sections.

- ❑ An expression has been proposed for calculating the effective thickness of curve elements of flat oval LDSS sections with $w/t \geq 40$, which can provide reliable load capacity predictions when used with EN 1993-1-4 (2015), AS/NZS 4673 (2001), ASCE 8-02 (2002) and ASDM (2002) equations.

Thank you very much for your patience