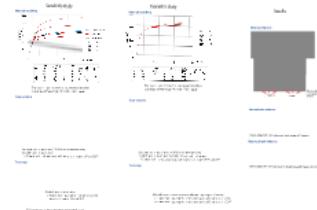


Study of web crippling in ferritic stainless steel cold-formed sections



Marina Bock Montero, I. Arrayago, E. Real and E. Mirambell



Universitat Politècnica de Catalunya

Study of web crippling in ferritic stainless steel cold-formed sections



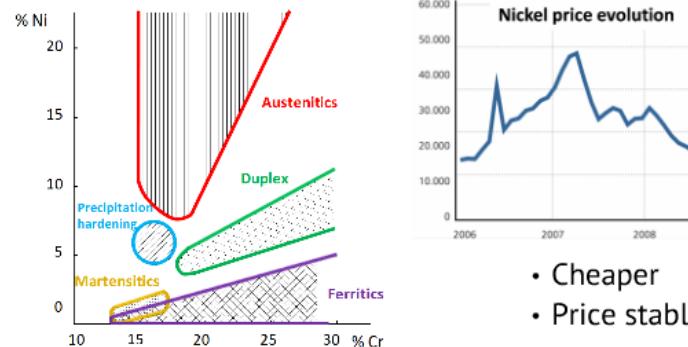
Marina Bock Montero, I. Arrayago, E. Real and E. Mirambell



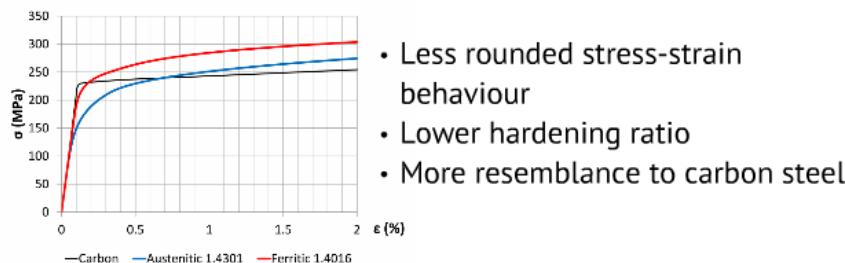
Universitat Politècnica de Catalunya

Introduction

Ferritic stainless steel

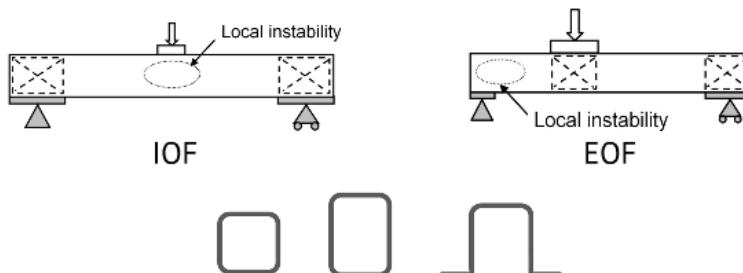


- Cheaper
- Price stable



- Less rounded stress-strain behaviour
- Lower hardening ratio
- More resemblance to carbon steel

Web crippling

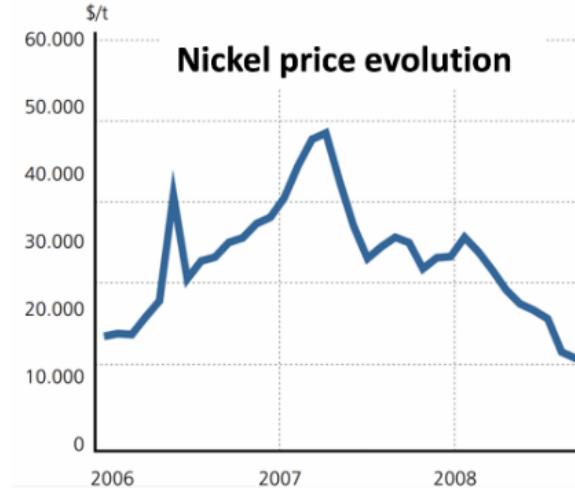
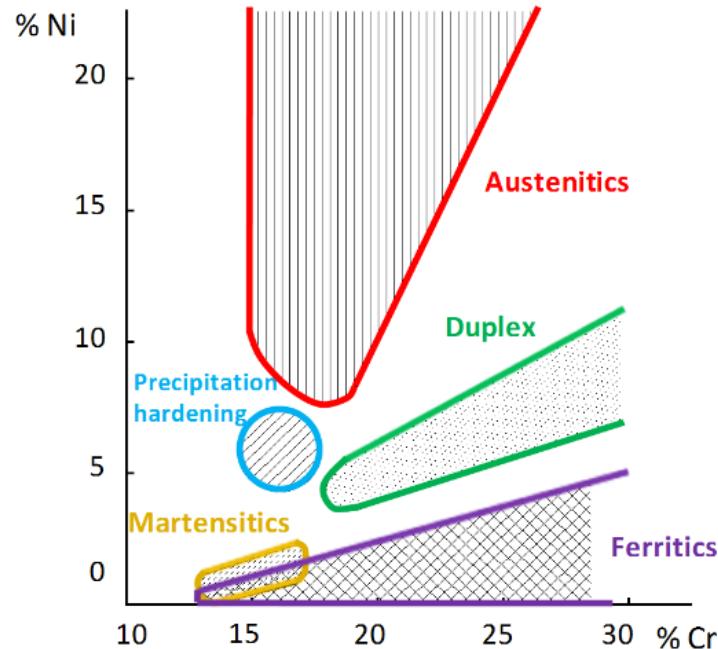


The study has focused on:

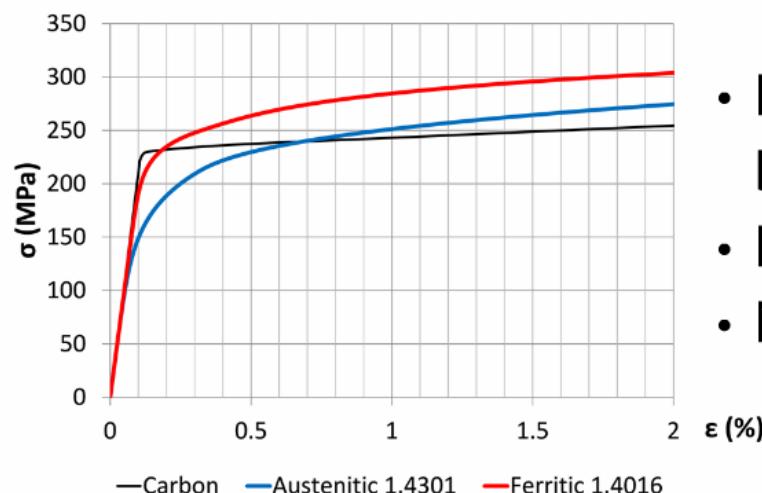
- Internal and external loads applied in one flange (IOF and EOF)
- Square hollow sections (SHS)
- Rectangular hollow sections (RHS)
- Hat sections

Introduction

Ferritic stainless steel

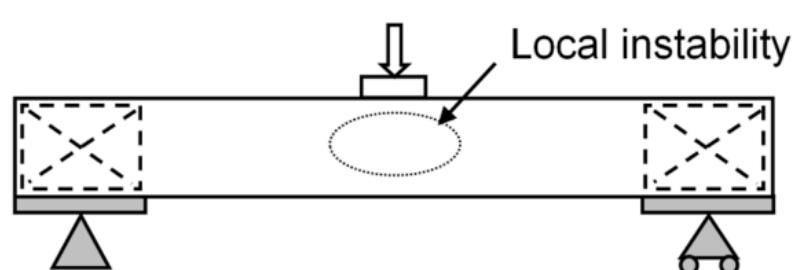


- Cheaper
- Price stable

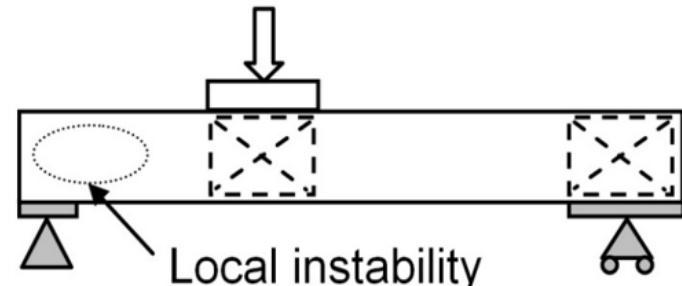


- Less rounded stress-strain behaviour
- Lower hardening ratio
- More resemblance to carbon steel

Web crippling



IOF



EOF



The study has focused on:

- Internal and external loads applied in one flange (IOF and EOF)
- Square hollow sections (SHS)
- Rectangular hollow sections (RHS)
- Hat sections

European Web Crippling formulation for stainless steel members

EN1993-1-4

Part-1-4 considers different grades of ferritics, austenitics and duplex stainless steel.

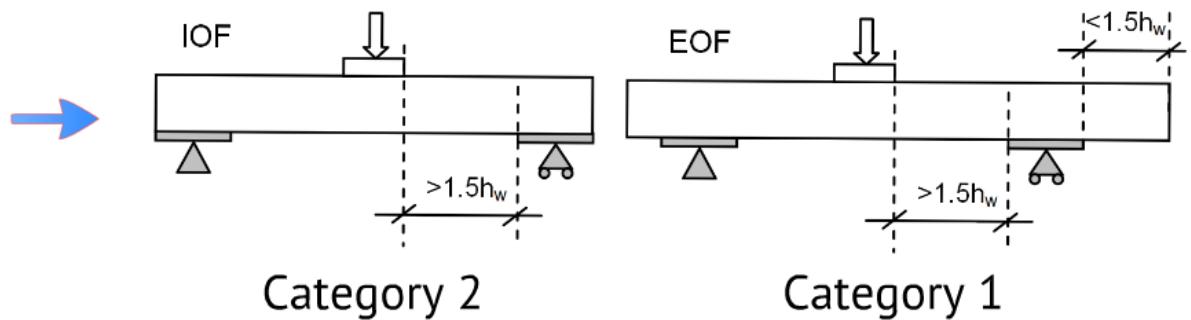
However, to calculate Web crippling strength this part refers to Part-1-3

EN1993-1-3

$$R_{w,Rd} = \underline{\alpha} \underline{t^2} \sqrt{\sigma_{0.2} E} \left(1 - 0.1 \sqrt{r/t} \right) \left(0.5 + \sqrt{0.02 l_a/t} \right) (2.4 + (\phi/90)^2) / \gamma_{M1}$$

For Category 1: $l_a = 10mm$

For Category 2: $l_a = S_s$
 $l_a = 10mm$



- Geometrical parameters: r, t and ϕ
- The bearing length: S_s
- Material parameters
- Nondimensional coefficient: α

→ Material nonlinearity is
not considered

Objectives

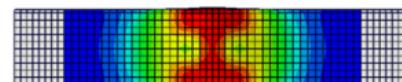
- To assess the applicability of the European Web crippling formulation to stainless steel
- To study both material and geometrical influence in web crippling strength
- Propose some amendments to consider material nonlinearities in the European web crippling formulation
- To compare the new proposal with different web crippling Eurocode formulae (sections 6.1.7.3 and 6.1.7.2)
- To validate the new proposal using experimental results of other researchers

Numerical model

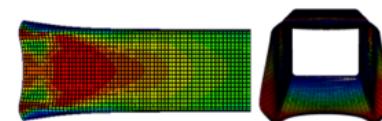
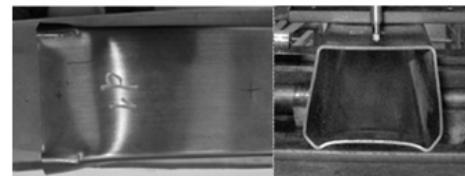
5 test configurations were developed using an ABAQUS plug-in and validated with experimental results:

- SHS and RHS undergoing IOF / EOF:

SHS/RHS - IOF

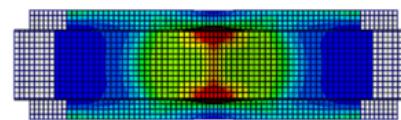


SHS/RHS - EOF

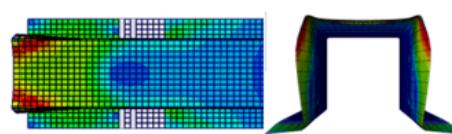
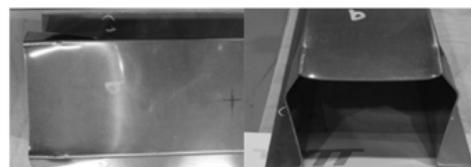


- Hat sections undergoing IOF / EOF:

Hat - IOF



Hat - EOF



SHS / RHS - IOF	Ru,exp (kN)	Ru,num (kN)
SHS_IS	43.92	37.74
SHS 100x100x3	107.1	99.96
RHS 120x80x3	108.3	96.6
RHS 140x60x3	107.5	94.95



SHS/RHS - EOF	Ru,exp (kN)	Ru,num (kN)
SHS_ES	26.76	35.37



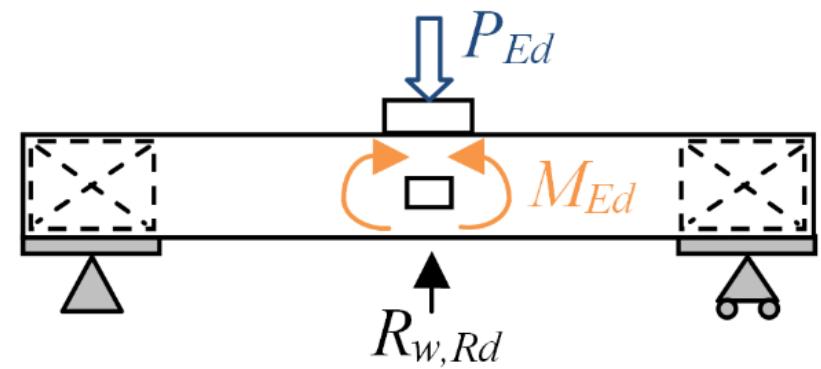
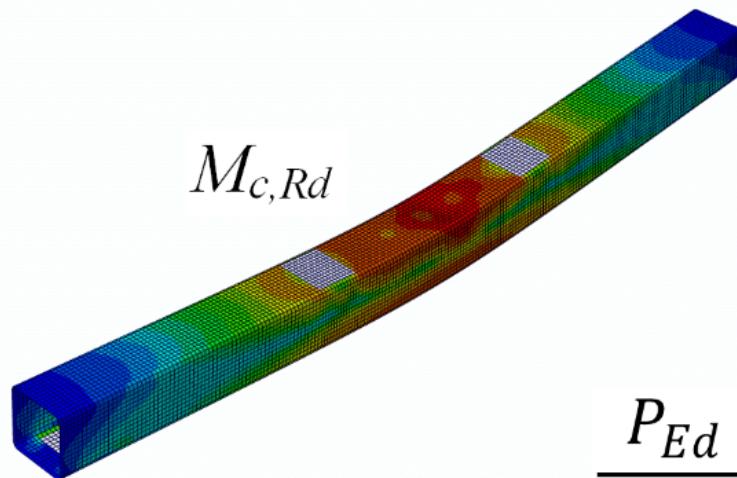
Hat - IOF	Ru,exp (kN)	Ru,num (kN)
TH_10_IS	10	9.74
TH_15_IS	20.73	19.56
TH_20_IS	34.84	32.22
TH_30_IS	55.01	49.98



Hat - EOF	Ru,exp (kN)	Ru,num (kN)
TH_10_ES	7.16	7.02
TH_15_ES	15.03	15.02
TH_20_ES	25.91	25.71



- 4-point bending test for SHS/RHS and Hat sections



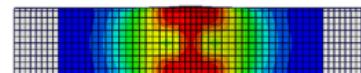
$$\frac{P_{Ed}}{R_{w,Rd}} + \frac{M_{Ed}}{M_{c,Rd}} \leq 1.25$$

Numerical model

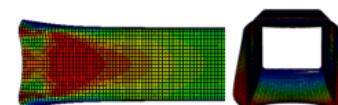
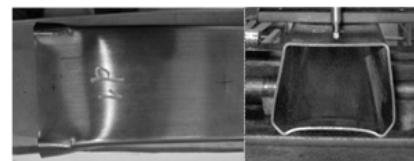
5 test configurations were developed using an ABAQUS plug-in and validated with experimental results:

- SHS and RHS undergoing IOF / EOF:

SHS/RHS - IOF

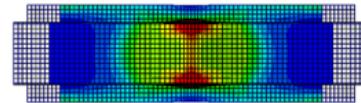


SHS/RHS - EOF

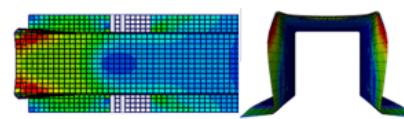
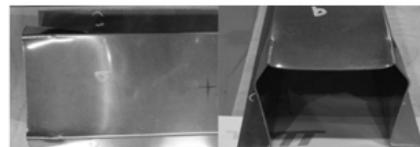


- Hat sections undergoing IOF / EOF:

Hat - IOF



Hat - EOF



SHS / RHS - IOF	Ru,exp (kN)	Ru,num (kN)
SHS_IS	43.92	37.74
SHS 100x100x3	107.1	99.96
RHS 120x80x3	108.3	96.6
RHS 140x60x3	107.5	94.95



SHS/RHS - EOF	Ru,exp (kN)	Ru,num (kN)
SHS_ES	26.76	35.37

Hat - IOF	Ru,exp (kN)	Ru,num (kN)
TH_10_IS	10	9.74
TH_15_IS	20.73	19.56
TH_20_IS	34.84	32.22
TH_30_IS	55.01	49.98

Hat - EOF	Ru,exp (kN)	Ru,num (kN)
TH_10_ES	7.16	7.02
TH_15_ES	15.03	15.02
TH_20_ES	25.91	25.71
TH_30_ES	42.06	39.55



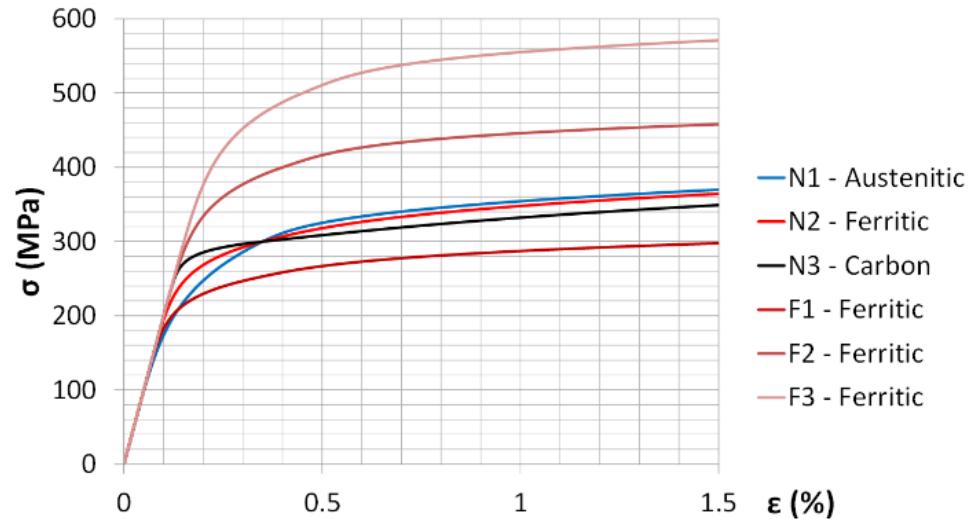
Objectives

- To assess the applicability of the European Web crippling formulation to stainless steel
- To study both material and geometrical influence in web crippling strength
- Propose some amendments to consider material nonlinearities in the European web crippling formulation
- To compare the new proposal with different web crippling Eurocode formulae (sections 6.1.7.3 and 6.1.7.2)
- To validate the new proposal using experimental results of other researchers

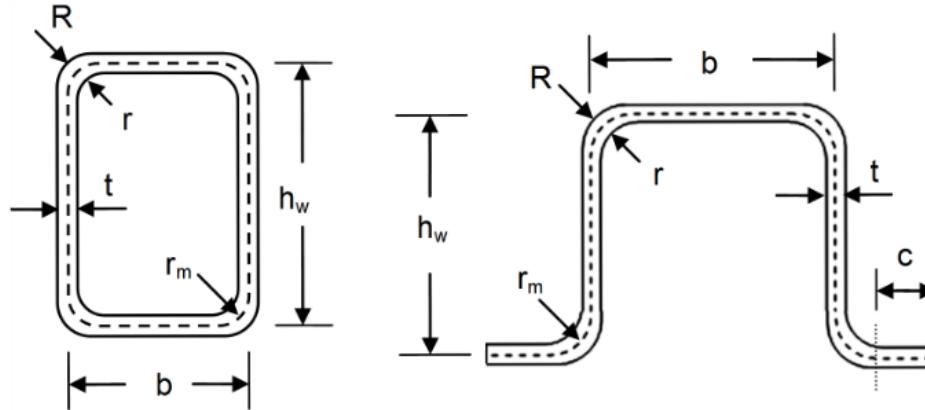
Parametric Study - Numerical database

Material modelling

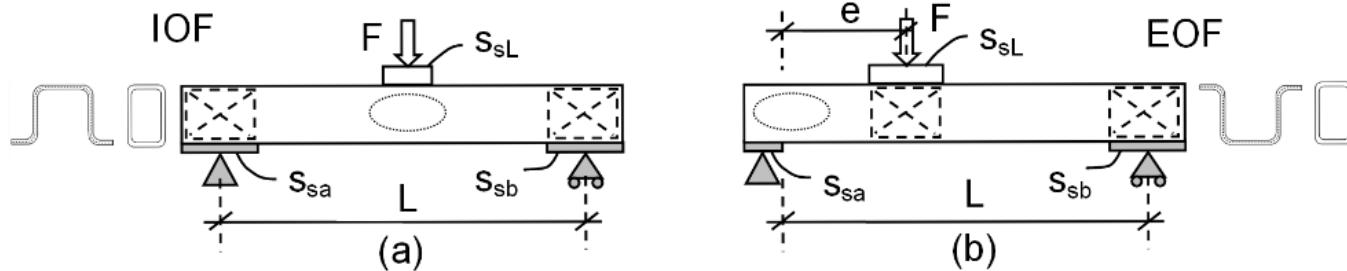
The multi-linear stress-strain curve was based on a compound two-stage Mirambell-Real model



Cross-sections



Test setup



over 350 numerical simulations

Objectives

- To assess the applicability of the European Web crippling formulation to stainless steel
- To study both material and geometrical influence in web crippling strength
- Propose some amendments to consider material nonlinearities in the European web crippling formulation
- To compare the new proposal with different web crippling Eurocode formulae (sections 6.1.7.3 and 6.1.7.2)
- To validate the new proposal using experimental results of other researchers

New proposal web crippling formula

$$R_{w,Rd} = \alpha t^2 \sqrt{\sigma_{0.2} E} \left(1 - 0.1 \sqrt{r/t} \right) \left(0.5 + \sqrt{0.02 l_a / t} \right) (2.4 + (\phi/90)^2) / \gamma_{M1}$$

Category 1: $l_a = 10\text{mm}$
 Category 2: $l_a = S_s$
 $l_a = 10\text{mm}$

$$R_{w,Rd} = \alpha t^2 \sqrt{\sigma_{0.2} E} (\xi \sigma_{1.0} / E)^k \sqrt{\beta t / r} \left(0.5 + \sqrt{0.01 l_a / t} \right) (2.4 + (\phi/90)^2) / \gamma_{M1}$$

(added)

Category 1: $l_a = 0.01 S_s$
 Category 2: $l_a = 2.2 S_s$

3 new nondimensional coefficients:

β , δ , ξ

where: $k = \delta r / t$

It's a coefficient that adjusts
the material nonlinearities
for different thicknesses

	Category 1 (EOF)		Category 2 (IOF)	
	SHS/RHS	Hat section	SHS/RHS	Hat section
α	0.07	0.085	0.13	0.14
β	2.14	1.65	0.59	0.81
δ	0.22	0.13	0.14	0.065
ξ	2200	2275	2700	2000

These coefficients were calibrated using the numerical database results

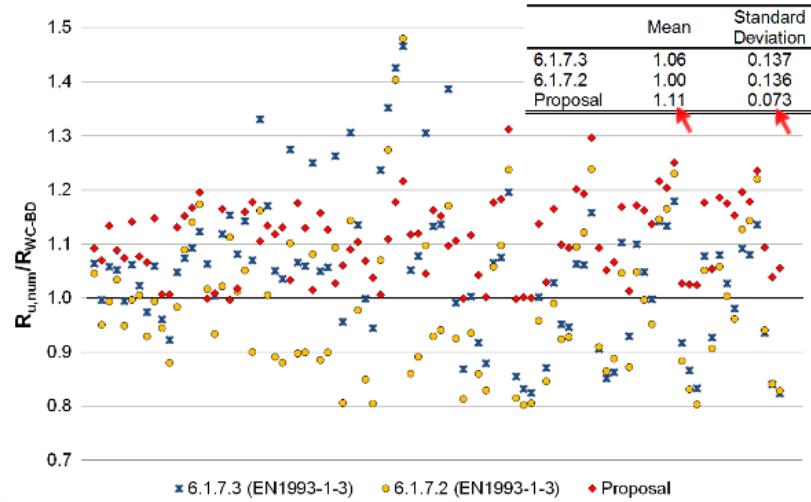
Conclusions

- This new proposal provides more accurate and less conservative results than current EN1993-1-3
- It is applicable to any stainless steel

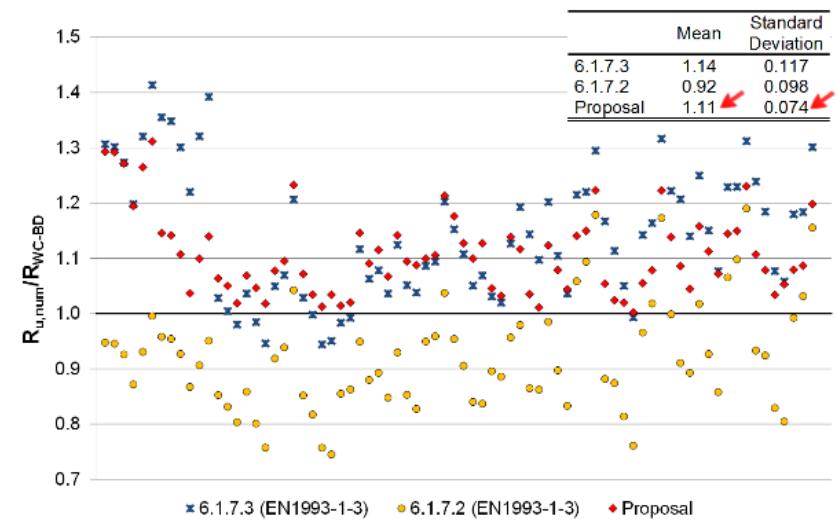
Objectives

- To assess the applicability of the European Web crippling formulation to stainless steel
- To study both material and geometrical influence in web crippling strength
- Propose some amendments to consider material nonlinearities in the European web crippling formulation
- To compare the new proposal with different web crippling Eurocode formulae (sections 6.1.7.3 and 6.1.7.2)
- To validate the new proposal using experimental results of other researchers

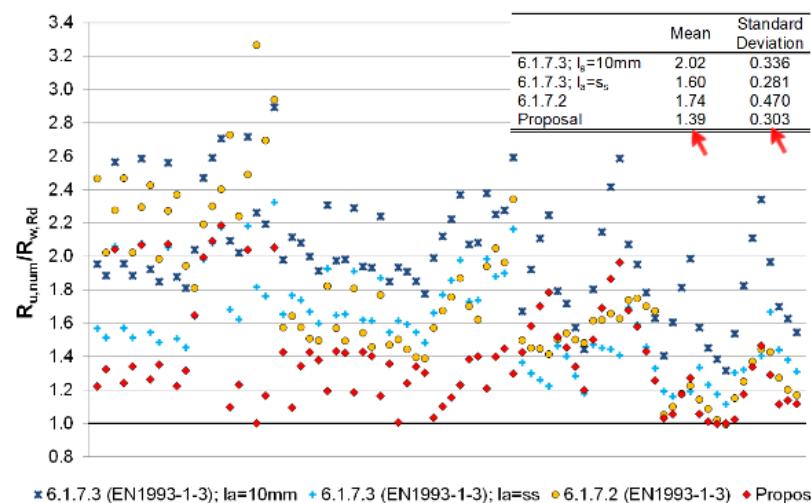
Comparison with different Eurocode formulae



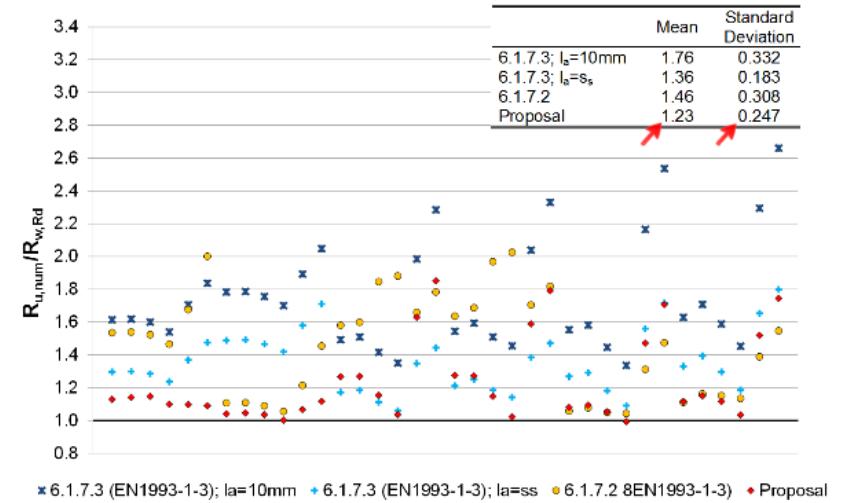
SHS/RHS sections undergoing IOF



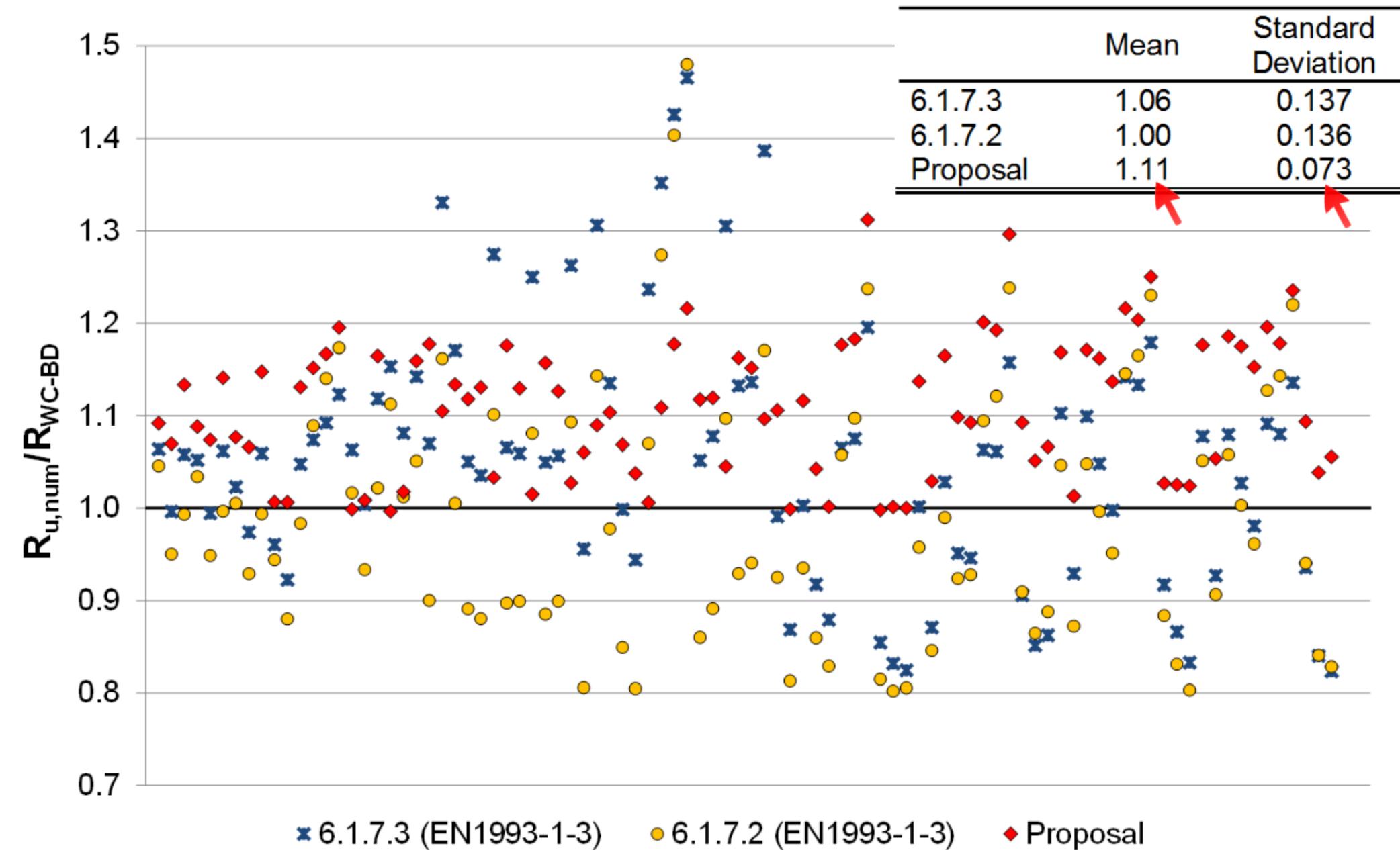
Hat sections undergoing IOF



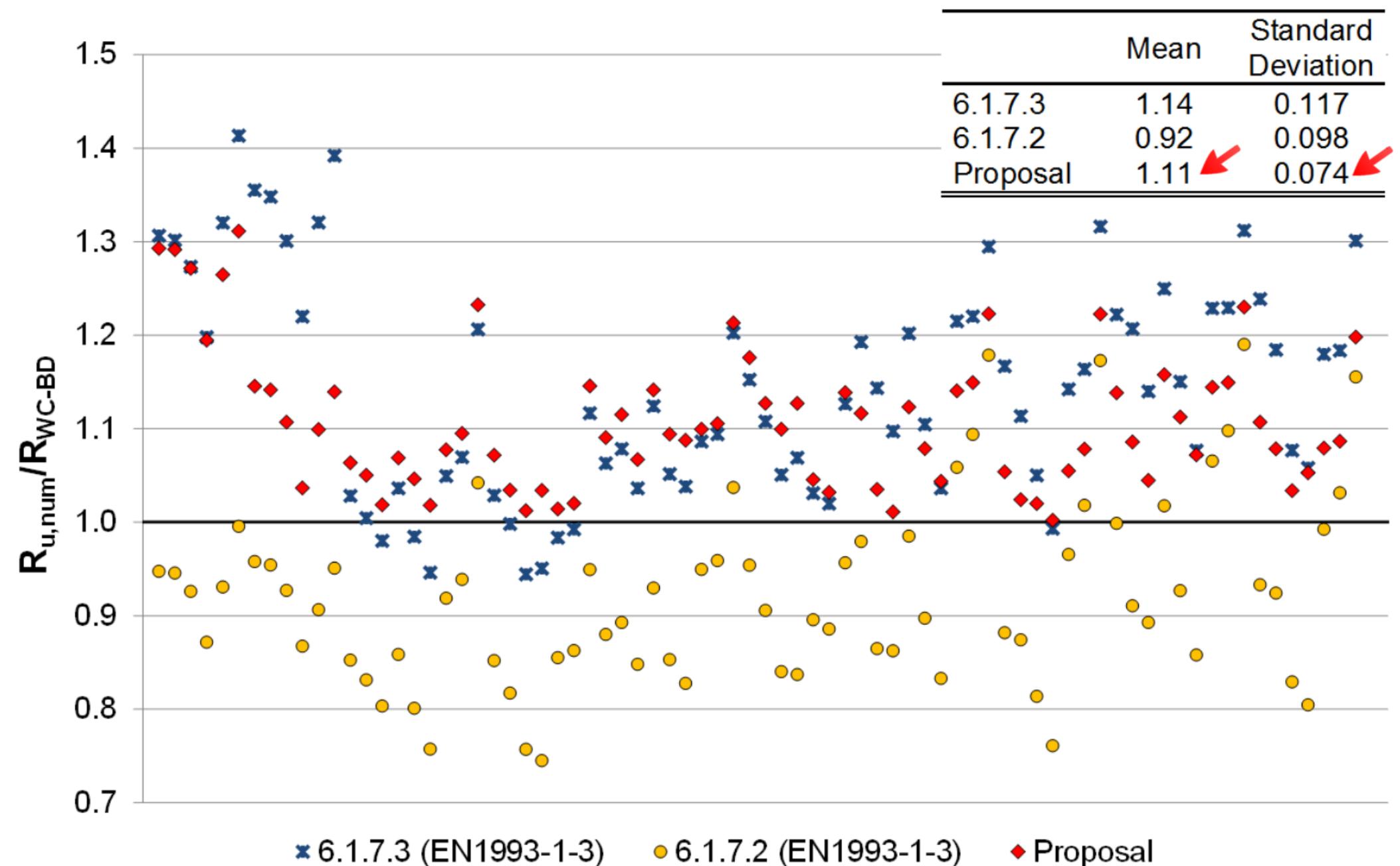
SHS/RHS sections undergoing EOF



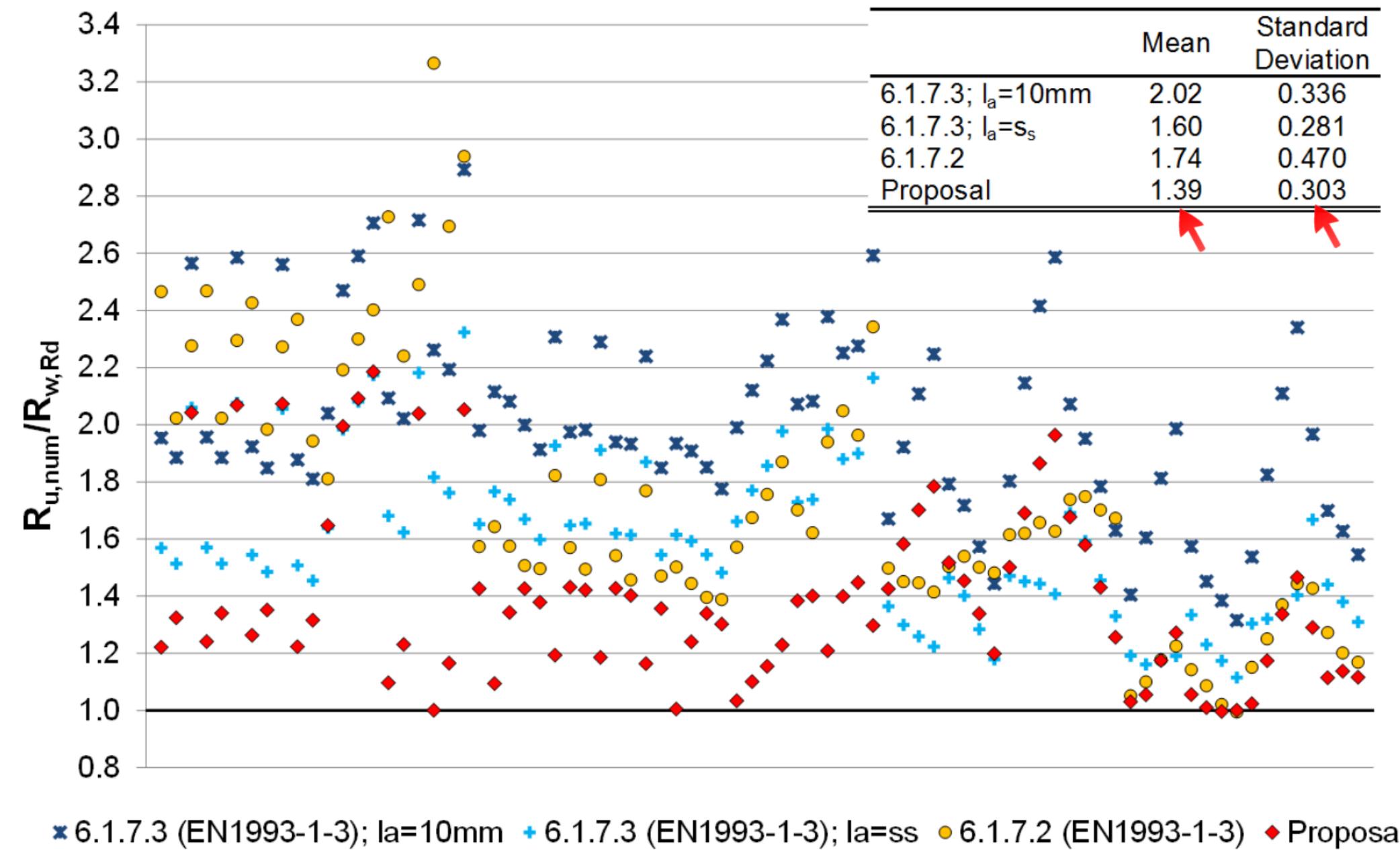
Hat sections undergoing EOF



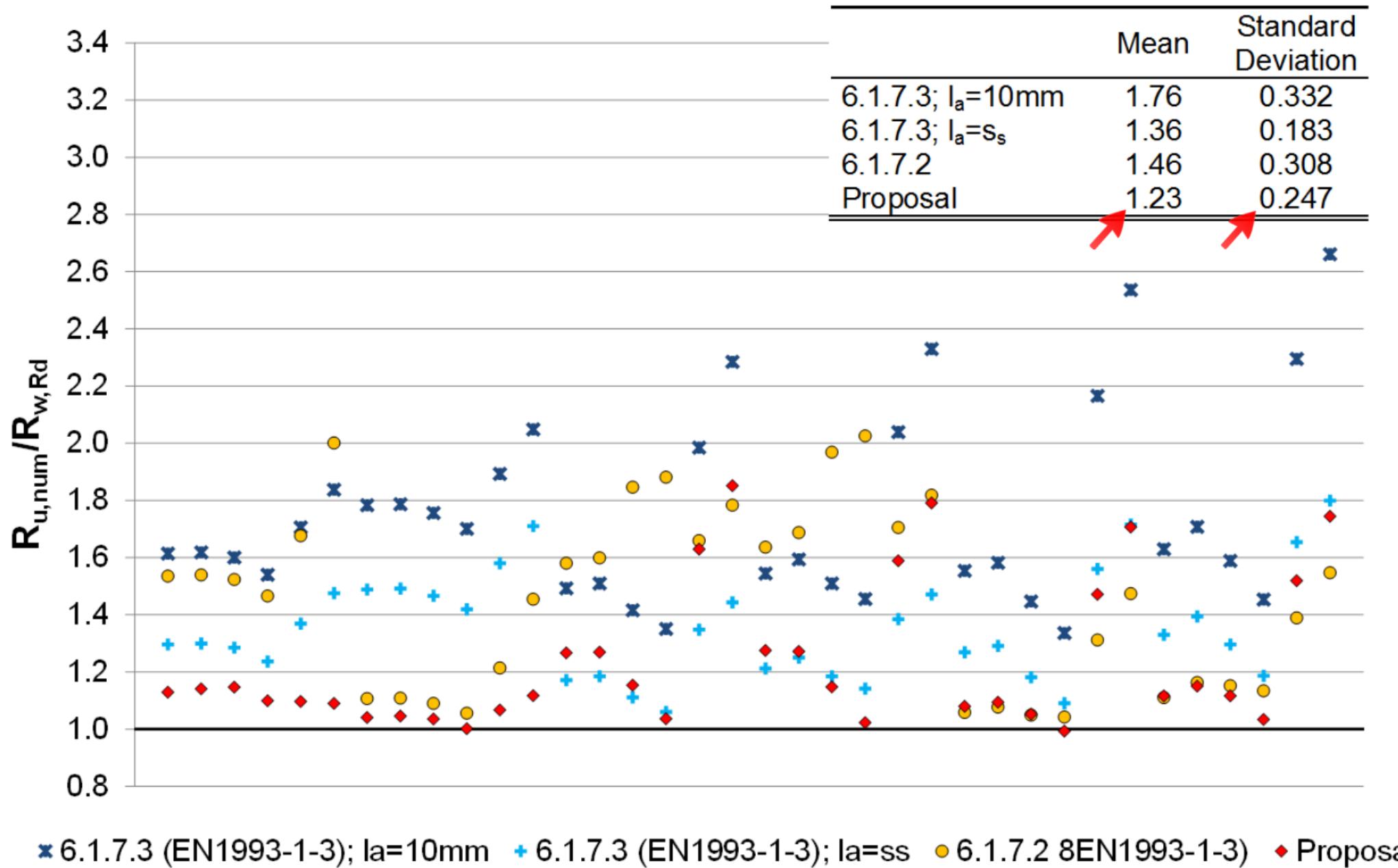
SHS/RHS sections undergoing IOF



Hat sections undergoing IOF



SHS/RHS sections undergoing EOF



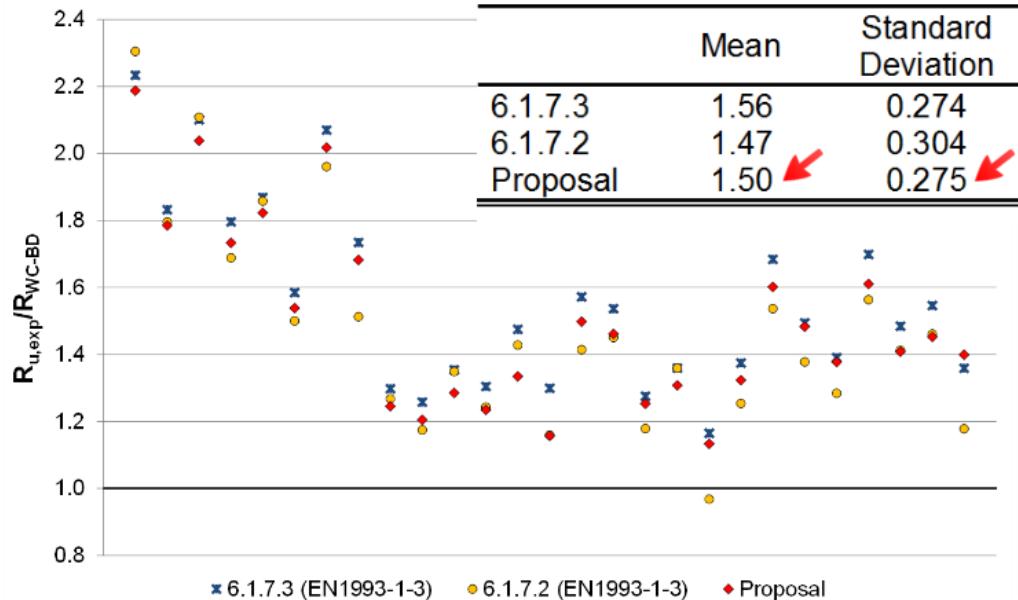
Hat sections undergoing EOF

Objectives

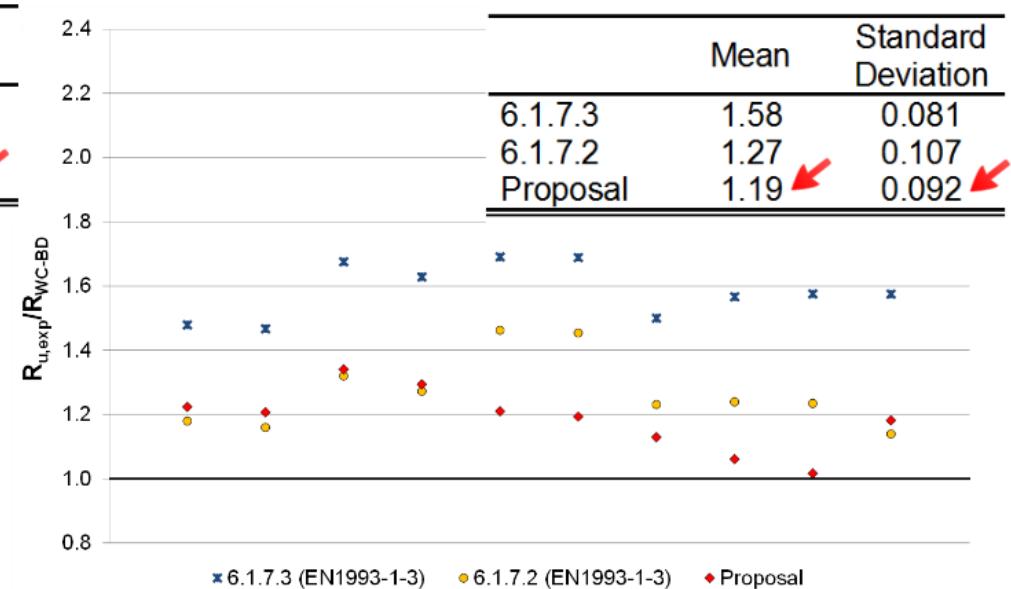
- To assess the applicability of the European Web crippling formulation to stainless steel
- To study both material and geometrical influence in web crippling strength
- Propose some amendments to consider material nonlinearities in the European web crippling formulation
- To compare the new proposal with different web crippling Eurocode formulae (sections 6.1.7.3 and 6.1.7.2)
- To validate the new proposal using experimental results of other researchers

Validation with experimental results

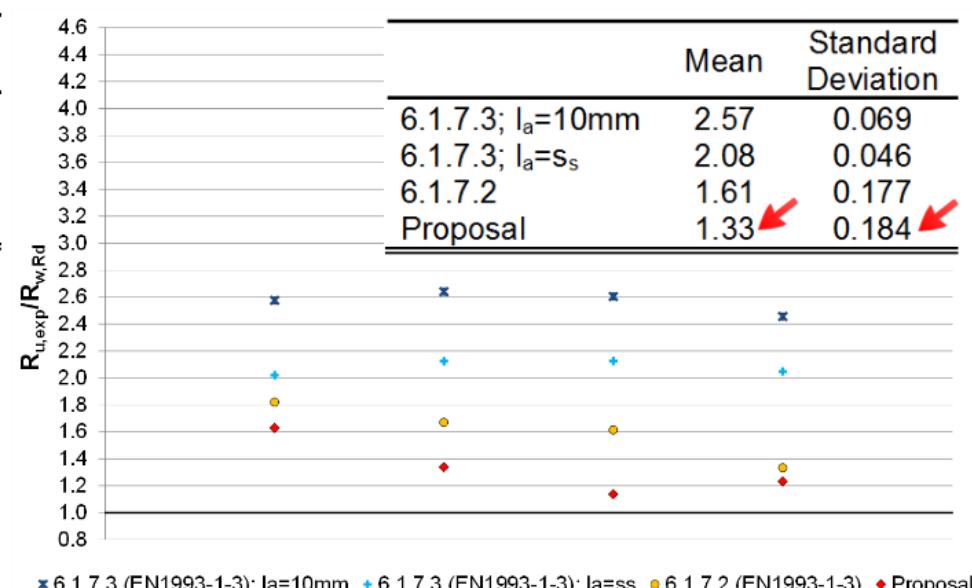
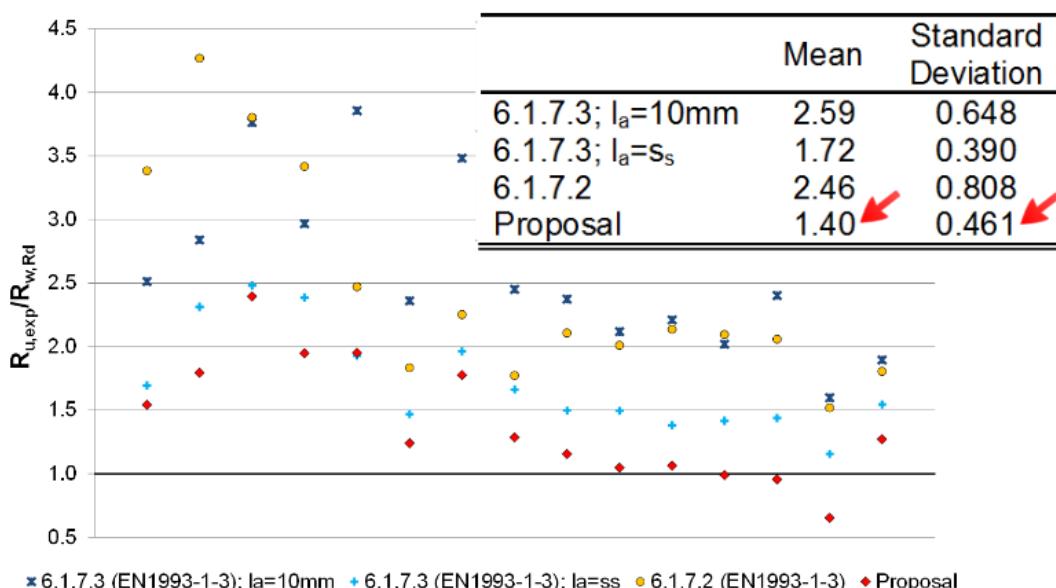
Talja and Salmi (1995), Talja (2004), Gardner et al. (2006), Zhou and Young (2007) and Talja and Hradil (2011)



SHS/RHS sections undergoing IOF



Hat sections undergoing IOF



New proposal web crippling formula

$$R_{w,Rd} = \alpha t^2 \sqrt{\sigma_{0.2} E} \left(1 - 0.1 \sqrt{r/t} \right) \left(0.5 + \sqrt{0.02 l_a / t} \right) (2.4 + (\phi/90)^2) / \gamma_{M1}$$

Category 1: $l_a = 10\text{mm}$
 Category 2: $l_a = S_s$
 $l_a = 10\text{mm}$

$$R_{w,Rd} = \alpha t^2 \sqrt{\sigma_{0.2} E} (\xi \sigma_{1.0} / E)^k \sqrt{\beta t / r} \left(0.5 + \sqrt{0.01 l_a / t} \right) (2.4 + (\phi/90)^2) / \gamma_{M1}$$

(added)

Category 1: $l_a = 0.01 S_s$
 Category 2: $l_a = 2.2 S_s$

3 new nondimensional coefficients:

β, δ, ξ

where: $k = \delta r / t$

It's a coefficient that adjusts
the material nonlinearities
for different thicknesses

	Category 1 (EOF)		Category 2 (IOF)	
	SHS/RHS	Hat section	SHS/RHS	Hat section
α	0.07	0.085	0.13	0.14
β	2.14	1.65	0.59	0.81
δ	0.22	0.13	0.14	0.065
ξ	2200	2275	2700	2000

These coefficients were calibrated using the numerical database results

Conclusions

- This new proposal provides more accurate and less conservative results than current EN1993-1-3
- It is applicable to any stainless steel

References

Talja, A. and Salmi, P. Design of stainless steel RHS beams, columns and beam-columns. VTT Research Notes 1619. Espoo, Finland: VTT Technical Research Centre of Finland, 1995.

Talja, A. Test results of RHS, tophat and sheeting profiles. Report to the ECSC Project: Structural design of austenitic cold worked stainless steel. VTT Technical Research Centre of Finland, 2004.

Gardner, L., Talja, A., Baddoo, N.R. Structural design of high-strength austenitic stainless steel. *Thin Walled Structures* 44 (2006), 5, 517-528.

Zhou, F. and Young, B. Cold-Formed High-Strength Stainless Steel Tubular Sections Subjected to Web Crippling. *Journal of Structural Engineering* 133 (2007), 3, 368-377.

Talja, A. and Hradil, P. SAFSS Work package 2: Model calibration tests – Test report. VTT Technical Research Centre of Finland, 2011.

Acknowledgments

European Community's Research Fund for Coal and Steel (RFCS) - SAFSS project

Petr Hradil from VTT Technical Research Centre of Finland who have developed the Abaqus Plug-in

Study of web crippling in ferritic stainless steel cold-formed sections



Marina Bock Montero, I. Arrayago, E. Real and E. Mirambell



Universitat Politècnica de Catalunya