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Shear Design Recommendations for Stainless Steel Plate Girders

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Introduction

Lean duplex stainless steel:

- A new grade with low nickel content (1.5%)
- Lower cost (approx. half of austenitics)
- Higher strength (approx. double austenitics)
- Adequate corrosion resistance and weldability
- Good potential for structural applications
- To date, not covered by any structural design code

Introduction

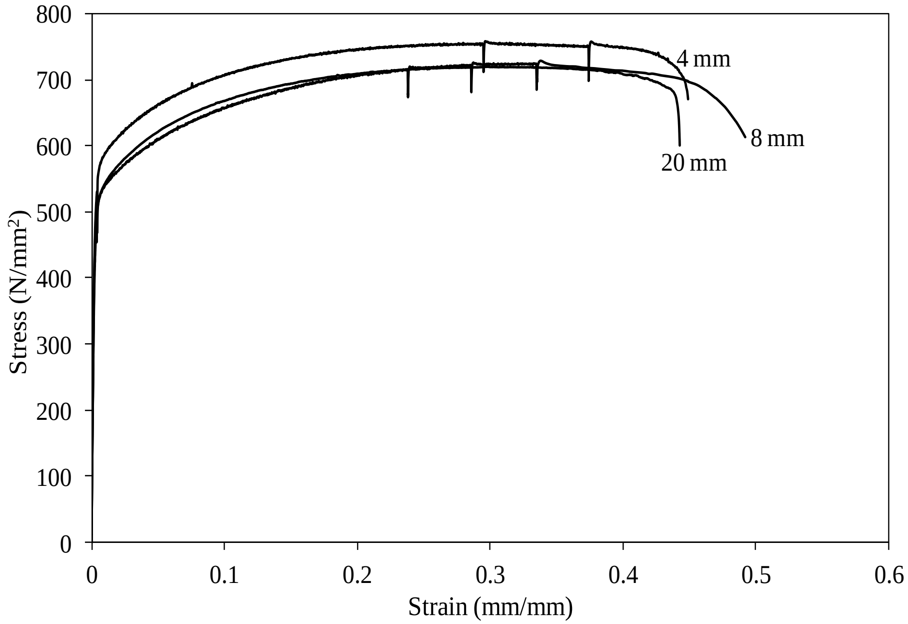
Research aim:

- Assess the structural characteristics of lean duplex stainless steel welded I-sections in:
  - *Cross-section stability: compression and bending*
  - *Plastic design: continuous beams*
  - *Shear: plate girders*
- Assess the applicability of EN 1993-1-4 to lean duplex
- Propose design guidance suitable for incorporation into EN 1993-1-4 and other standards
- Extend the continuous strength method to shear

Experimental investigation

Material tests:

- Total of 28 material tests – tensile and compressive coupons extracted from test sections
- Average $\sigma_{0.2,tests}$ = 500 N/mm^2, with $\sigma_{0.2,nom}$ = 480 N/mm^2. $\sigma_{0.2,nom}$ = 230 N/mm^2 for the most common austenitic grade, 1.4301



Experimental investigation

Shear: plate girders

- Total of 9 plate girders were tested: 4 of aspect ratio = 1.0, and 5 of aspect ratio = 2.0

Numerical Modelling

Features of numerical modelling:

- Measured geometry and material
- Non-linear stress strain response
- Initial geometric imperfections

Validation against tests:

- Initial stiffness
- Maximum load and failure mode
- Post-ultimate response

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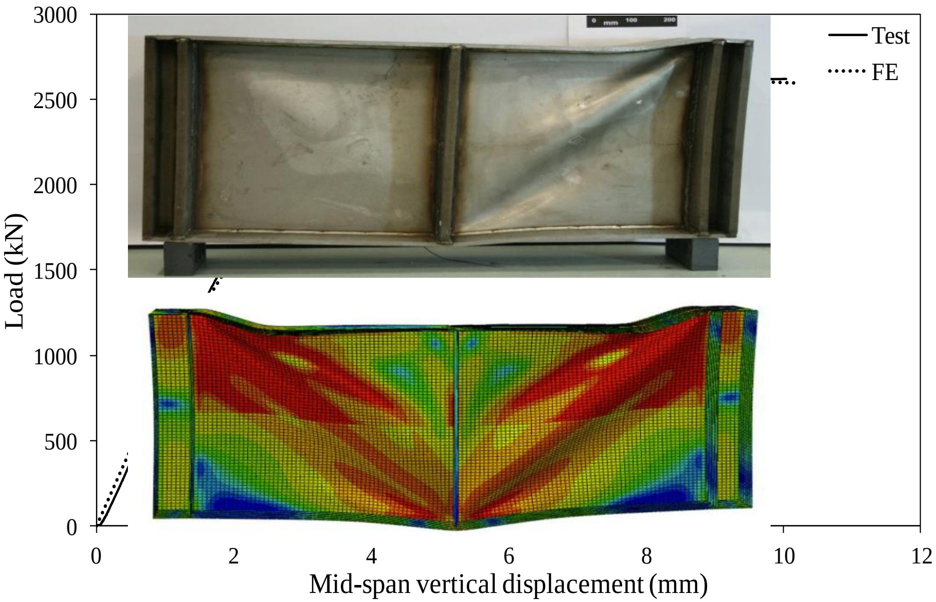
Numerical Modelling

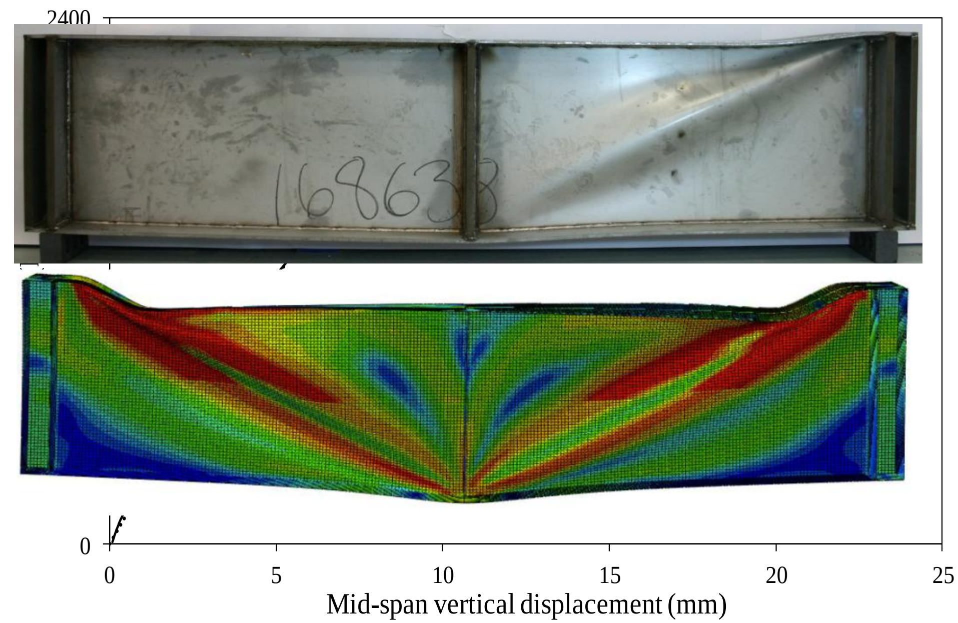
Validation:

- Shear:

aspect ratio 1.0



aspect ratio 2.0



Numerical Modelling

Parametric studies:

- Upon FE models' validation parametric studies were performed to investigate:
    - Wider range of web slendernesses
    - Different aspect ratios
    - Different end posts (plate girders)

- Extend range of structural performance data on lean duplex stainless steel

Analysis: *Plate girders*

Analysis:

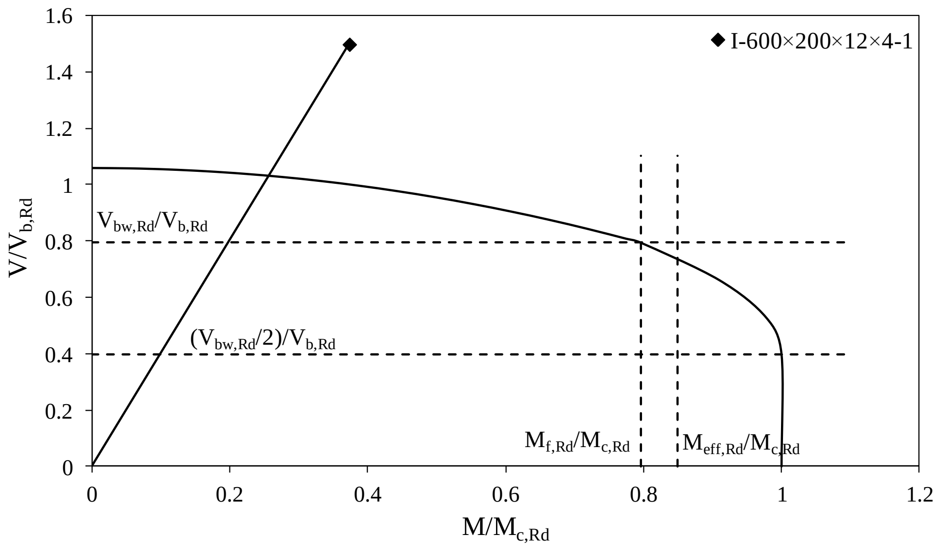
Experimental and numerical data used to assess:

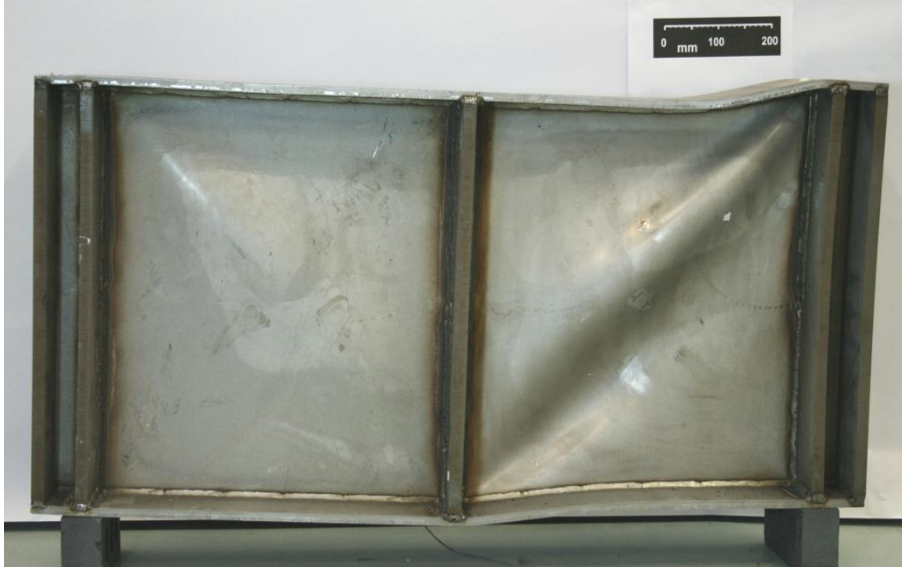
- The behaviour of lean duplex stainless steel plate girders
- EN 1993-1-4 shear resistance design model
- Effect of end post condition
- Behaviour of lean duplex stainless steel compared to other grades

Analysis: *Plate girders*

Three different failure modes observed:

Case 1: Shear dominant failure:

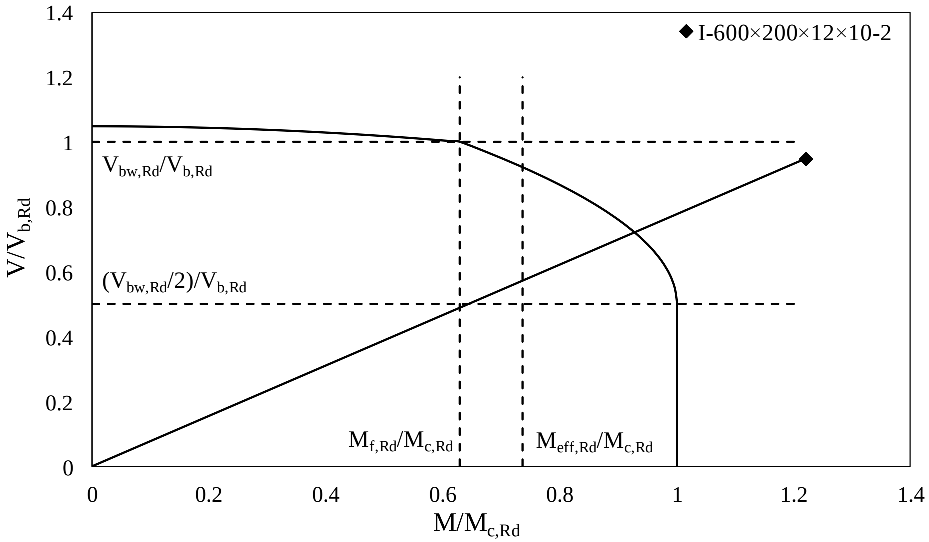




Analysis: *Plate girders*

Three different failure modes observed:

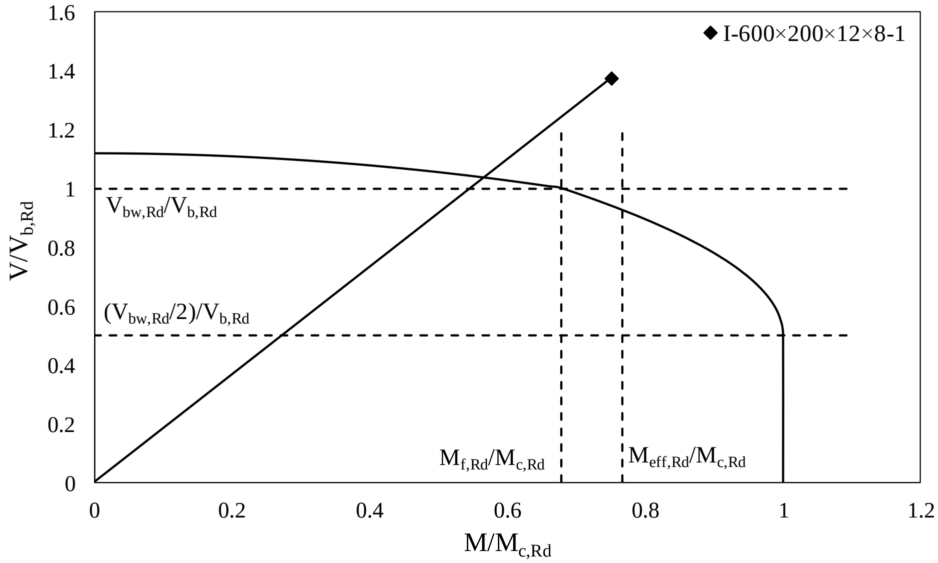
Case 2: Bending dominant failure:



Analysis: *Plate girders*

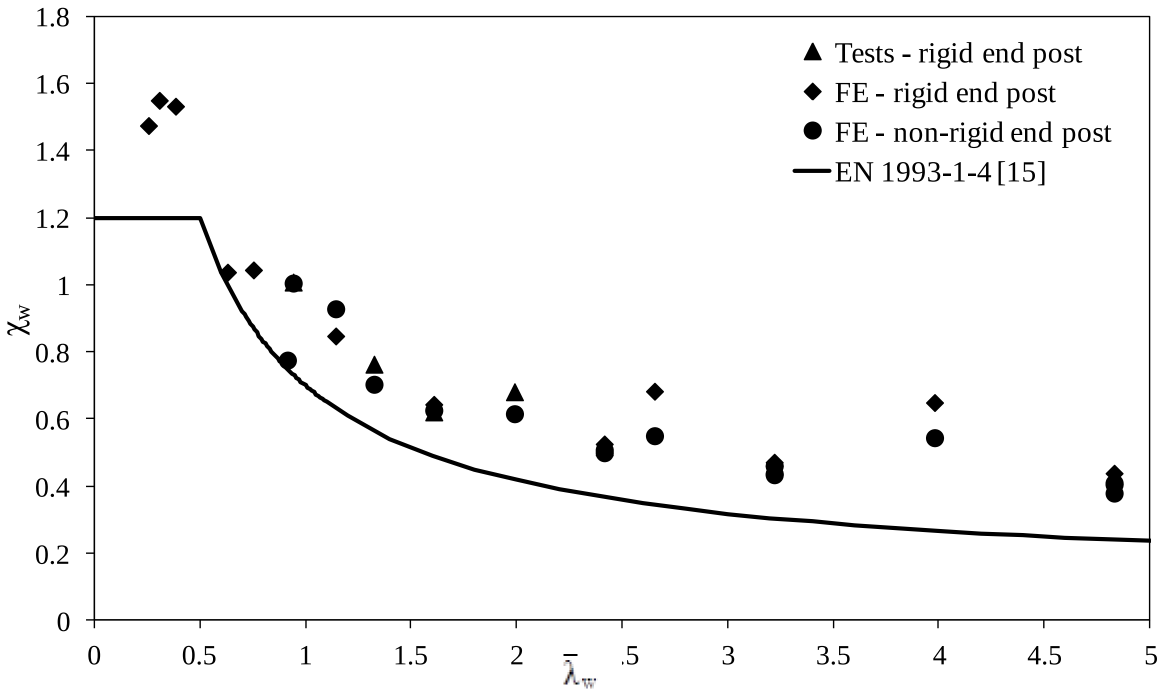
Three different failure modes observed:

Case 3: Combined bending plus shear failure:



Analysis: *Plate girders*

Comparison of test & FE shear capacities with EN 1993-1-4:

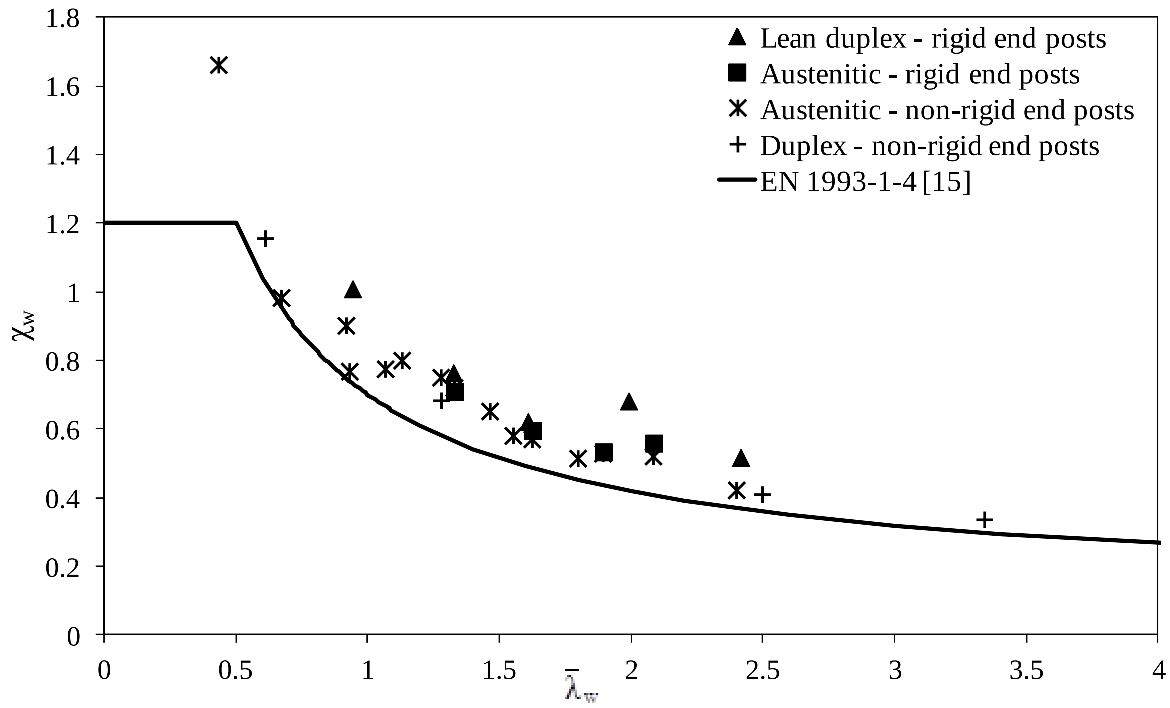


No. of tests: 41	$V_{u,test}/V_{EN1993\text{-}1\text{-}4}$
Mean	1.34
COV	0.10

No. of tests: 18	$V_{u,FE,rigid}/V_{u,FE,non\text{-}rigid}$
Mean	1.05
COV	0.05

Analysis: *Plate girders*

Comparison with other stainless steel grades:



Design recommendations

Modifications to EN 1993-1-4 design expressions:

- Comparison between test and codified design predictions:

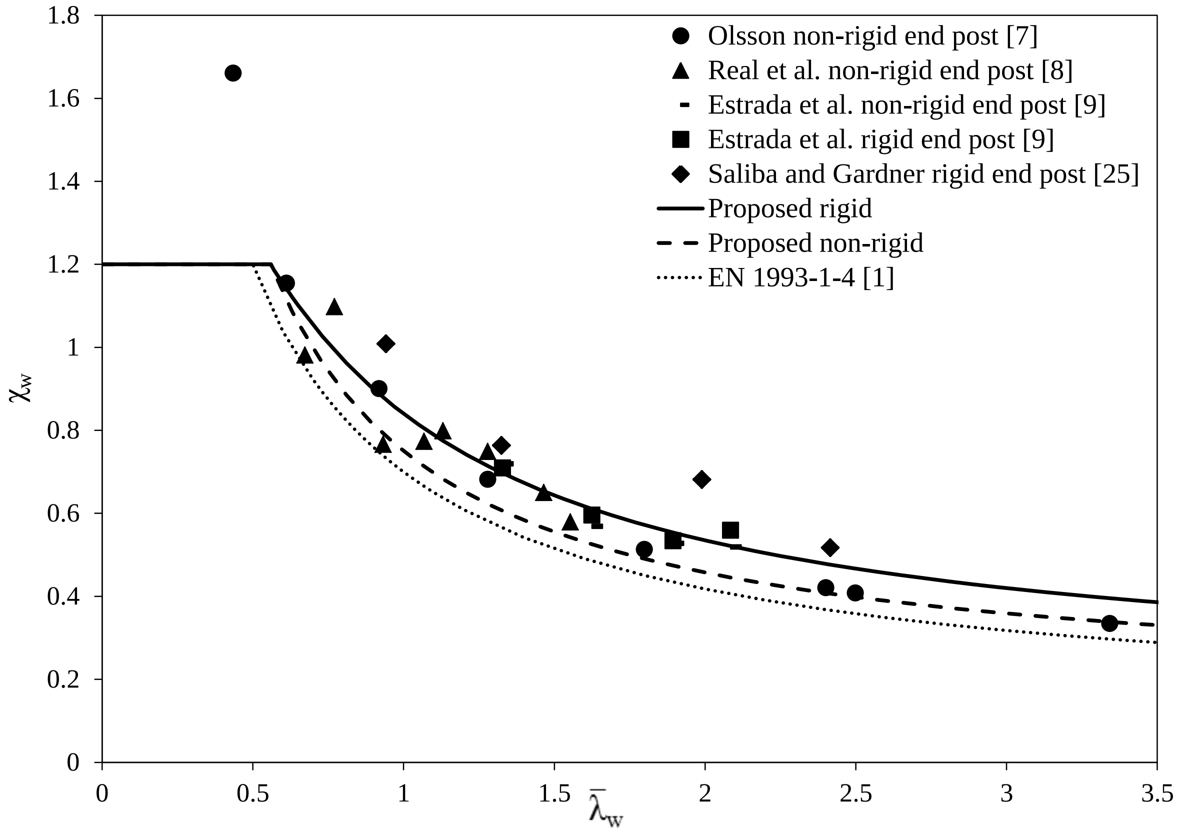
No. of tests: 34	$V_{u,test}/V_{EN1993\text{-}1\text{-}4}$	$V_{u,test}/V_{EN1993\text{-}1\text{-}5}$	$V_{u,test}/V_{Estrada\ et\ al.}$
Mean	1.22	1.13	1.12
COV	0.11	0.14	0.14

- Proposal of new design expressions:
    - Offers over 10% enhancement compared to EN 1993-1-4
    - Statistically verified by a reliability analysis according to EN 1990 (i.e. γ_{M1} < 1.1)

	χ_w for rigid end post	χ_w for non-rigid end post
$\bar{\lambda}_w \leq 0.56$	1.2	1.2
$\bar{\lambda}_w > 0.56$	$0.17 + 0.79/\bar{\lambda}_w - 0.12/\bar{\lambda}_w^2$	$0.16 + 0.60/\bar{\lambda}_w - 0.01/\bar{\lambda}_w^2$

Design recommendations

Modifications to EN 1993-1-4 design expressions:



Design recommendations

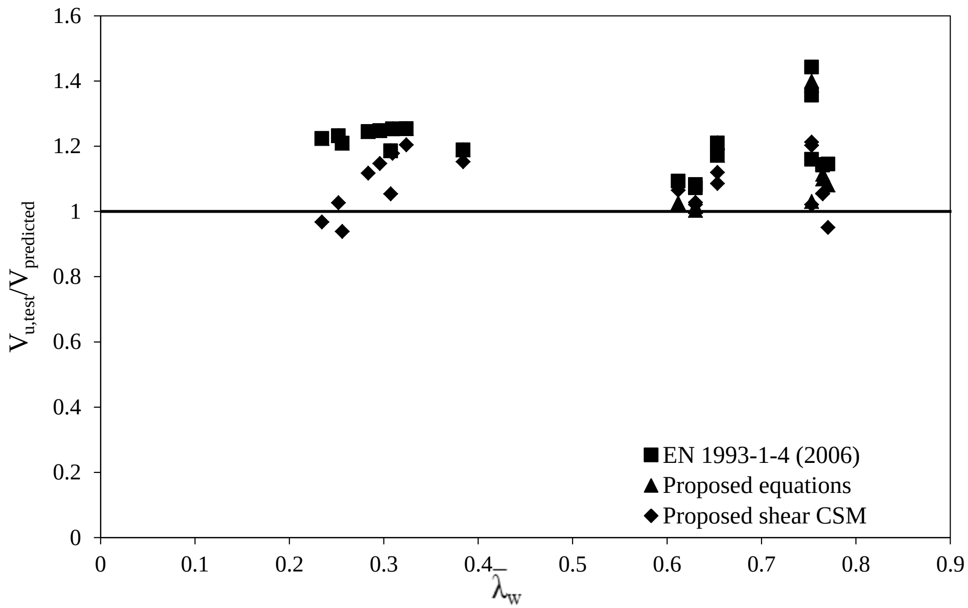
CSM for shear:

- Continuous relationship between cross-section slenderness and deformation capacity
- Accounts for the actual stress-strain behaviour of the material
- First attempt to extend CSM to shear
- Development of CSM for shear is in harmony with the original CSM but $\bar{\lambda}_w < 0.83$
- CSM offers over 11% enhancement for plate girders with $\bar{\lambda}_w < 0.83$

Design recommendations

CSM for shear:

No. of tests: 20	$V_{u,test}/V_{EN1993-1-4}$	$V_{u,test}/V_{Proposed}$	$V_{u,test}/V_{CSM}$
Mean	1.21	1.19	1.09
COV	0.07	0.10	0.07



Conclusions

- Experimental programme : 28 material tests, 9 plate girders tests
- FE models validated again test results; parametric studies conducted
- EN 1993-1-4 shear resistance equations are safe to use but unnecessarily conservative
- Rigid end post plate girders offer higher shear capacities to non-rigid end post plate girders
- Design proposals made for shear offer significant improvements over EN 1993-1-4

Thank you.