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 $\sigma_{0.2,\text{tests}} = 500 \text{ N/mm}^2$, with $\sigma_{0.2,\text{nom}} = 480 \text{ N/mm}^2$. $\sigma_{0.2,\text{nom}} = 230 \text{ N/mm}^2$ 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
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:**

![Graph showing the relationship between various load factors and load ratios for plate girders.](image-url)
Analysis: *Plate girders*

Three different failure modes observed:

**Case 3:** Combined bending plus shear failure:

![Graph and image of plate girders]
Analysis: Plate girders

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

<table>
<thead>
<tr>
<th>No. of tests:</th>
<th>$V_{u,\text{test}}/V_{\text{EN1993-1-4}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>Mean 1.34 COV 0.10</td>
</tr>
<tr>
<td>No. of tests:</td>
<td>$V_{u,\text{FE,rigid}}/V_{u,\text{FE,non-rigid}}$</td>
</tr>
<tr>
<td>18</td>
<td>Mean 1.05 COV 0.05</td>
</tr>
</tbody>
</table>
Analysis: *Plate girders*

*Comparison with other stainless steel grades:*

![Graph showing analysis of plate girders with comparison to other stainless steel grades.](image)
Design recommendations

*Modifications to EN 1993-1-4 design expressions:*

- Comparison between test and codified design predictions:

<table>
<thead>
<tr>
<th>No. of tests:</th>
<th>$V_{u,test}/V_{EN1993-1-4}$</th>
<th>$V_{u,test}/V_{EN1993-1-5}$</th>
<th>$V_{u,test}/V_{Estrada et al.}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.22</td>
<td>1.13</td>
<td>1.12</td>
</tr>
<tr>
<td>COV</td>
<td>0.11</td>
<td>0.14</td>
<td>0.14</td>
</tr>
</tbody>
</table>

- 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. $\gamma_{M1} < 1.1$)

<table>
<thead>
<tr>
<th>$\lambda_w$</th>
<th>$\chi_w$ for rigid end post</th>
<th>$\chi_w$ for non-rigid end post</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_w \leq 0.56$</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>$\lambda_w &gt; 0.56$</td>
<td>$0.17 + 0.79/\lambda_w - 0.12/\lambda_w^2$</td>
<td>$0.16 + 0.60/\lambda_w - 0.01/\lambda_w^2$</td>
</tr>
</tbody>
</table>
Design recommendations

**Modifications to EN 1993-1-4 design expressions:**

![Graph showing 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 $\overline{\lambda}_w < 0.83$
- CSM offers over 11% enhancement for plate girders with $\overline{\lambda}_w < 0.83$
Design recommendations

**CSM for shear:**

<table>
<thead>
<tr>
<th>No. of tests:</th>
<th>$V_{u,test}/V_{EN1993-1-4}$</th>
<th>$V_{u,test}/V_{Proposed}$</th>
<th>$V_{u,test}/V_{CSM}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.21</td>
<td>1.19</td>
<td>1.09</td>
</tr>
<tr>
<td>COV</td>
<td>0.07</td>
<td>0.10</td>
<td>0.07</td>
</tr>
</tbody>
</table>
Conclusions

- Experimental programme: 28 material tests, 9 plate girders tests
- FE models validated against 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.