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SECTION DE GÉNIE CIVIL

# Assessment of resistance models according to SIA 263 and the new Eurocode 3 for lateral torsional buckling of I-shaped bridge girders


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## Scope

Bridge girders:

cross large spans and support high traffic loads

Longer elements

- High slenderness ⇒ more likely to experience instability

Deeper shapes

- Welded sections ⇒ residual stresses ↗
- Class 3 or 4 sections ⇒ elastic behaviour and reduced sections

High strength steel

- Up-and-coming type of steel
- Higher resistance ⇒ higher loads but potentially slenderer elements

Work in bending

Lateral torsional buckling

- The new version of Eurocode 3: significant modifications on the procedure of assessing member stability.

**Aim**: build a finite elements model to evaluate the necessity of these changes and their applicability on bridge girders, according a particular focus on high strength steel (HSS).

## Lateral torsional buckling in structural codes

- Lateral torsional buckling (LTB): instability phenomenon occurring in members in bending.
- Characterised by the lateral torsional buckling critical moment (expression on the right).
- Procedure for assessing the lateral torsional buckling resistance is standardised in the code (Figure 1) but differences exist.

$$M_{cr} = C_1 \frac{\pi^2 E I_z}{k_v k_\varphi l_b^2} \cdot \left[\sqrt{(C_2 z_a + C_3 \beta)^2 + \frac{I_\omega}{I_z}\left(\frac{G K k_\varphi^2 l_b^2}{\pi^2 E I_\omega} + 1\right)} + (C_2 z_a + C_3 \beta)\right]$$

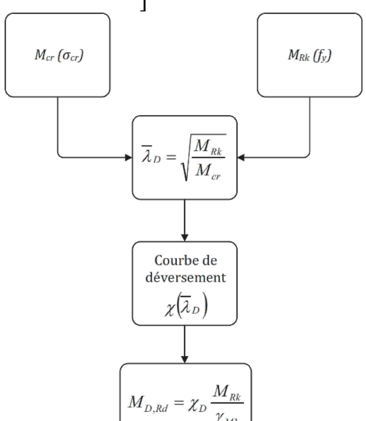



Figure 1: R. Thiébaud, 'Résistance au déversement des poutres métalliques de pont', EPFL, Lausanne, 2014. doi: 10.5075/epfl-thesis-6348.

| | $M_{Rd}$ | $\gamma_{M0}$ | $\gamma_{M1}$ | $\lambda_{LT}$ |
|---|---|---|---|---|
| SIA 263:2013 | $\frac{W_y^* f_y}{\gamma_{M1}}$ | – | 1.05 | $\sqrt{\frac{W_y^* f_y}{M_{cr}}}$ |
| EN 1993-1-1:2005 | $\frac{W_y^* f_y}{\gamma_{M0}}$ | 1.0 | 1.05<br>1.10 for bridges | $\sqrt{\frac{W_y^* f_y}{M_{cr}}}$ |
| EN 1993-1-1:2019 | $\frac{W_y^* f_y}{\gamma_{M0}}$ | 1.0 | 1.05<br>1.10 for bridges | $\sqrt{\frac{W_y^* f_y}{M_{cr}}}$ |

*$W_y = W_{pl,y}$ Class 1 or 2
$W_y = W_{el,y}$ Class 3
$W_y = W_{eff,y}$ Class 4 ⇒ reduced effective section properties

| | $\Phi_{LT}$ | $\chi_{LT}$ | $M_{b,Rd}$ |
|---|---|---|---|
| SIA 263:2013 | $0.5[1 + \alpha_{LT}(\lambda_{LT} - 0.4) + \lambda_{LT}^2]$ | $\frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \lambda_{LT}^2}}$ | $\chi_{LT}\frac{W_y^* f_y}{\gamma_{M1}}$ |
| EN 1993-1-1:2005 | $0.5[1 + \alpha_{LT}(\lambda_{LT} - 0.2) + \lambda_{LT}^2]$ | $\frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \lambda_{LT}^2}}$ | $\chi_{LT}\frac{W_y^* f_y}{\gamma_{M1}}$ |
| EN 1993-1-1:2019 | $0.5\left[1 + f_M\left(\left(\frac{\lambda_{LT}}{\lambda_z}\right)^2 \alpha_{LT}(\lambda_z - 0.2) + \lambda_{LT}^2\right)\right]$ | $\frac{f_M}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - f_M \lambda_{LT}^2}}$ | $\chi_{LT}\frac{W_y^* f_y}{\gamma_{M1}}$ |

## Conclusions

1. Difference ↗ for higher steel grade
   ⇒ Codes too conservative regarding high strength steel
   ⇒ Need of specific regulations
2. SIA estimates better than the EC & new EC better than old EC
   - Different partial factor
   ⇒ Difference ↗ 5%
3. Difference ↗ for class 4 sections
   ⇒ Reduction for class 4 sections of the SIA 263 too conservative
4. Worst differences for $\lambda_{LT} = 1.0$
   - Bridge girders range ($\lambda_{LT}$ comprised between 0.4 and 1.5) worst error

## Finite elements model

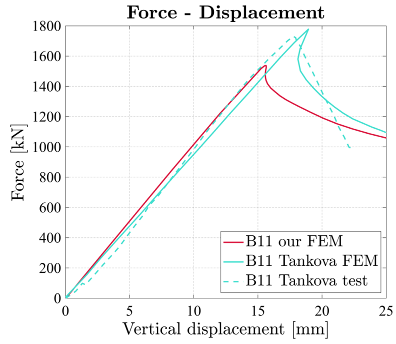
### Technical details

- Elements type: shell elements ⇒ thickness much smaller than the two other dimensions.
- Static system: four points bending with lateral restraints located at the point of load application.
- Geometric imperfections: introduced by scaling the relative buckling mode ⇒ amplitude as in the table below, from Lignos et al. studies
- Residual stresses: pattern from Thiébaud's thesis + upper limit of 500 [MPa] for HSS
- Material model: Updated Voce-Chaboce material model from Hartloper and Lignos
- Meshing: S4R elements, 10x10 mm, enhanced hourglass control
- Stiffeners thickness assumed so that section class 1
- Riks analysis performed (arc length control)

| Global out-of-straightness | Local web imperfection | Local flanges imperfections |
|---|---|---|
| L/1500 | d/2500 | $b_f$/2500 |

### Validation

Validation of the model using Tankova's paper.

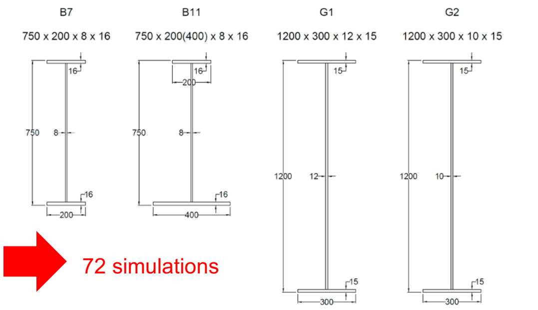



- Good estimation of the stiffness of the system
- LTB resisting force (peak in chart) underestimated ⇒ error always < 20%
  - Different residual stresses and material properties
  - Stiffeners thickness ⇒ with infinitely rigid stiffeners, LTB resistance ↗ 5-20%

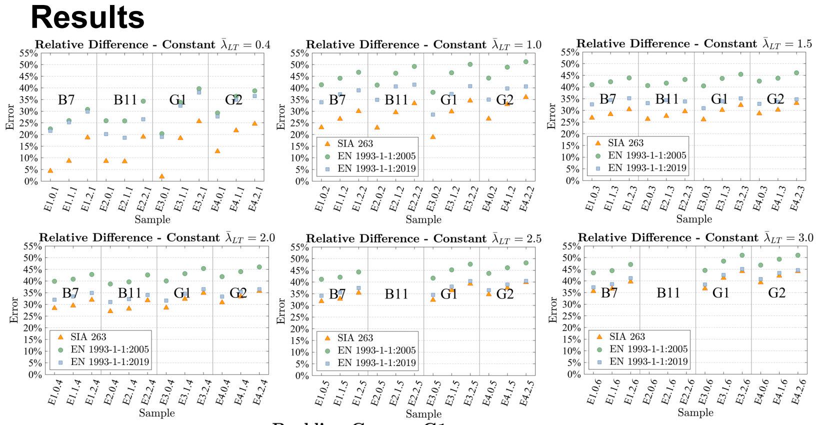
## Parametric study

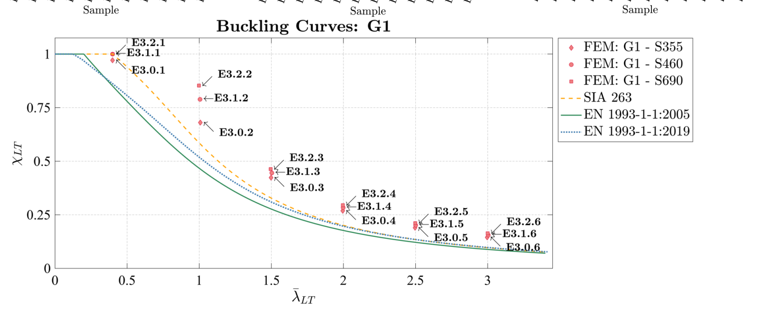
3 steel grades
(S355, S460 and S690)
x
4 cross-sections
(B7, B11, G1 and G2)
x
6 values of normalised slenderness
($\lambda_{LT}$ = 0.4 / 1.0 / 1.5 / 2.0 / 2.5 / 3.0)

⇒ 72 simulations




## Results




- Extract left reaction and vertical displacement at the point of loading for each iteration.
- Obtain the maximum reaction force ⇒ LTB bending moment resistance $M_{b,Rd,FEM}$.
- Buckling curves:
  - SIA 263 and EN 1993-1-1: 2005 depend on the normalised slenderness
  - EN 1993-1-1:2019 depend on $M_{cr}$
- Upper limit on the χLT factor of 1 was set, as specified by the codes.
- Adjustment of twice standard deviation on the curves obtained experimentally ⇒ partial explanation for this difference