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Assessment of resistance models according to SIA 263 and Eurocode 3 provisions for lateral-torsional buckling of I-shaped hot-rolled members

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Introduction & work description

Context and motivation:
- Strong differences between the Swiss and European provisions both in terms of formulation and estimated LTB resistances,
- New formulation in the reviewed European standard, different from the existing ones, based on a specific analytical, semi-empirical derivation.

Scope of study:
- Hot-rolled industrial profiles: IPE-HEA-HEB-HEM,
- Reference case: simply supported beam, uniform bending moment, end-fork boundary condition (warping-free).

Goals:
- Assess the Lateral-Torsional Buckling (LTB) resistance models,
- Investigate the influence of the imperfections by using refined models.

Methodology:
- Development of a Finite-Element Model (*ABAQUS 2019* Software),
- Model validation with prior numerical simulations and experiments,
- Automation of the GMNIA simulations,
- Analysis of the results, comparison with the codes' curves,
- Limitations, conclusions & recommendations.

Standards

SIA 263 (2013)	EN1993-1-1 (2005)		EN1993-1-1 Draft (2020)
	General case	Specific case	
§4.5.2	§6.3.2.2	§6.3.2.3	§8.3.2.1

Finite-Element Model (FEM) features

- Element: S4R shell element with reduced integration and hourglass control
- Meshing: 16 transversally in the flange, 16 transversally in the web (32 if h/b > 3,0), 100 longitudinally (200 if L/h > 100,0), found to be sufficient based on a convergence study (*Figure 1*).
- Parts: web and flanges without overlapping, additional Quadratic Hollow Section (QHS) 1D elements to account for the contribution of the fillet radius, calibrated to match the section characteristics with the tabulated values (*Figure 1*), all linked with Tie constraints.
- Material constitutive law *(Figure 2):*
  - ECCS model (1978, widely used),
  - Updated Voce-Chaboche (UVC) model (2021, more refined).
- Interactions: Coupling interactions at the edges to allow the section to warp and avoid any stress or strain concentration (*Figure 3*).
- Loads: couples of concentrated forces equivalent to a bending moment (*Figure 4*).
- Boundary conditions: concentrated at the web center (*Figure 4*).
- Geometric imperfection: deformed shape of the first LTB mode saved from a Linear Buckling Analysis, maximum lateral amplitude L/1'000 (*Figure 5*).
- Residual stress: predefined equilibrated stress field *(Figure 6):*
  - ECCS model (1984, widely used in Europe),
  - EPFL model (2021, more refined).

Figure 1: parts & meshing

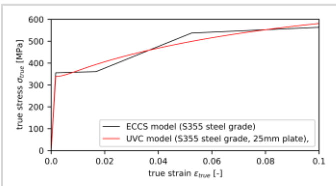


Figure 2: constitutive laws

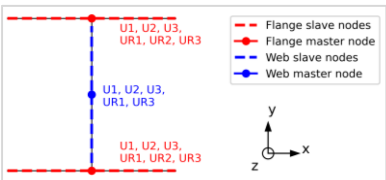


Figure 3: edge coupling

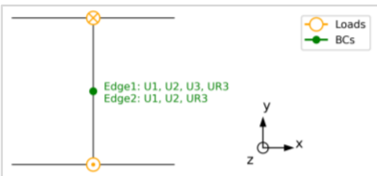


Figure 4: loads and BCs

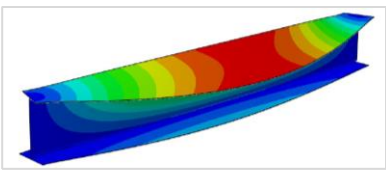


Figure 5: geometric imperfection

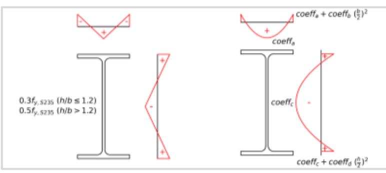
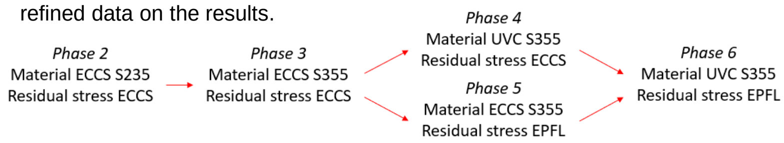


Figure 6: edge coupling

Implementation and automation of the simulations

Due to the large amount of simulation to be carried (more than 6'000), the process is automated with Python codes. The main code writes specific scripts to be run by ABAQUS (slenderness from 0,5 to 2,0 every 0,1), extract the results of interest (resistance) and save them in a separated file. First, the usual assumptions, material data and residual stress profiles are used. Then, successive changes are made to investigate the effect of the use of more refined data on the results.



Results

In each phase, the results are systematically compared to the estimations from the standards. For each code, the minimum, average and maximum differences with the numerical values are computed and plotted graphically (*Figure 8*). Also, the curves are plotted for several cases to illustrate (*Figure 7*). Due to the large amount of data, only examples are given (see full paper for exhaustivity).

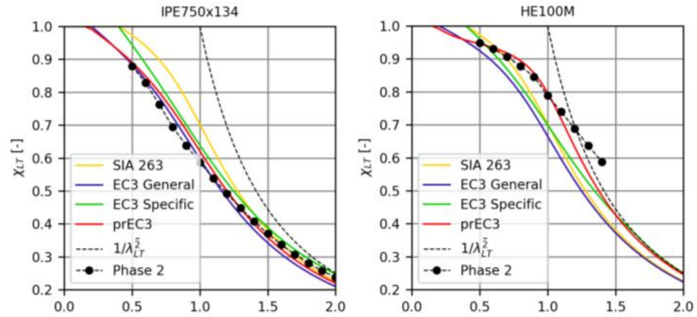


Figure 7: Example of results, LTB curves, numerical vs. standards (Phase 2)

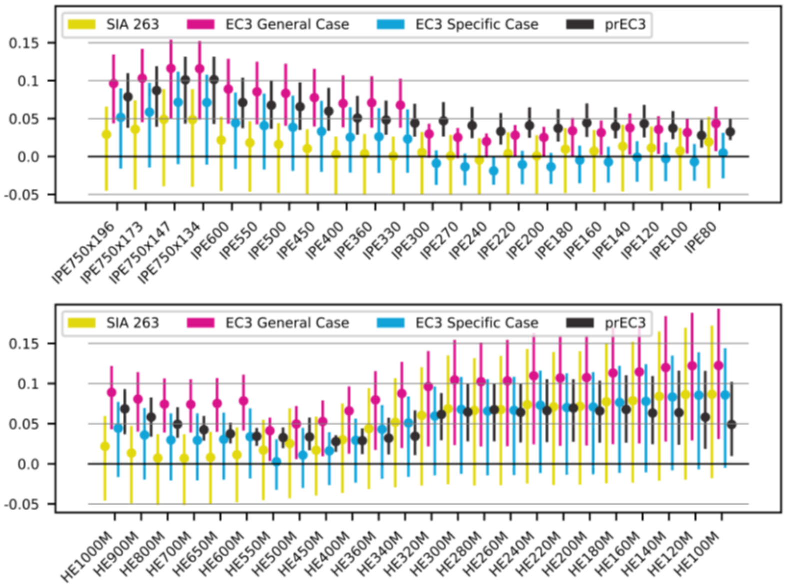


Figure 8: Example of results, min./max. (bars) & average (points) differences (Phase 6)

Limitations, conclusions & recommendations

Limitations:
- UVC model calibrated for specific specimens only, strong variability,
- Some parameters not investigated (imperfection shape and amplitude),
- Absence of values below 0,5 slenderness (model limitation),
- Model: it is a representation, contains approximations & assumptions.

Conclusions:
- The new provisions' superiority is unquestionable when the same parameters are used than in the new model development (Phase 2),
- The superiority fades when more accurate parameters are used,
- The new provision could benefit from a recalibration of its parameters by using more recent and accurate models in the numerical simulations,
- The new provision has a better ability to follow the numerical curves.

Recommendations:
- SIA 263 and EC3 specific case have shown to be unsafe for various cases. EC3 general case should be used waiting for the new provision.