HOLLOSSTAB – Overall-Slenderness Based Direct Design for Strength and Stability of Innovative Hollow Sections

Summary

Recent construction practice has seen a rise in the use of structural hollow sections, due to their appealing aesthetics as well as better awareness of the advantages in terms of strength and stiffness. To meet increasing demands for sustainable and economic construction typologies and methods, the European steel industry, particularly the producers of structural hollow sections, are aiming for a reduction of weight and emissions through the use of more thin-walled sections and/or higher strength steel grades (with yield stress fy ≥ 460 MPa). These innovations increase the economy and sustainability of construction projects through the reduction of weld volumes, erection times and foundation costs. Especially the introduction of higher strength steel grades can be seen as a relevant industrial goal for the European steel industry, offering chances for new product development, research and innovation, and thus market advantages.

However, the introduction of slenderer construction typologies (for hollow sections) leads to a number of scientific and engineering challenges: higher material strength, with different constitutive laws (shorter or inexistent plastic plateau, diminished ultimate strain), combined with thinner plates leads to an increased significance of instability phenomena, especially of local buckling phenomena and their interaction with the "global" flexural buckling instability mode.

Preliminary studies have shown that the application of current design codes (e.g. the Eurocodes) is either ineffective, uneconomical or, in some cases, altogether impossible for combined instability phenomena in slender, high-strength hollow sections:

- At the level of cross-sectional resistances, an increase of yield strength leads to an increase of the (local) normalized slenderness. This means that more sections will fall into the non-compact (class 3) or slender (class 4) range and are thus more sensitive to local buckling. The classification system is quite often not suitable for capturing the actual cross-sectional behaviour in terms of strength: i. it predicts a sudden and not realistic decrease of strength at the class 2 to 3 transition, ii. the classification is based on c/t limits and in turn on bifurcation stresses for individual plates, omitting all mutual supporting effects of adjacent components, iii. plasticity is totally omitted in the non-compact and slender range, while strain hardening is omitted in the compact range, iv. the strength for class 4 sections is usually calculated by separating the load components (axial force and bending moments) and determining "effective cross-sections" for these individual load cases, creating an artificial separation of the stress state, and v. for circular (CHS) and elliptical (EHS) hollow sections, point iv is altogether inapplicable, as no definition of effective areas for CHS is given in current design codes such as the Eurocode (reference to EN 1993-1-6 is made instead, which is largely inapplicable and inconsistent with applications for CHS members.
- Point i. has already been partly addressed (for mild steel sections) in the RFCS project "SEMICOMP". However, points ii. to v. were not addressed in that project, making an immediate code implementation easier, but rendering them less suitable for innovative applications as the ones envisioned in this project proposal.
- Beyond the cross-sectional level, instability phenomena become more prevalent also at a global level (flexural buckling) and in terms of the local-global interaction. These effects are treated in structural design codes in a manner that is potentially too conservative for the high-strength, slender hollow sections studied in this project.
- The peculiarities of high-strength materials and sections (lower residual stresses, different production and thus imperfection levels) are only superficially studied and addressed in design codes.
- Generally, the treatment of local, global, and interactive local-global instabilities in the Eurocode and other design codes is seen as too cumbersome by many designers and does not take full advantage of available numerical computational methods.

Combined, these drawbacks represent a hindrance to the further development and market introduction of slenderer hollow section members in Europe. In order to overcome them, innovative design methods must be introduced and the corresponding scientific background and knowledge must be gathered.

In recent years, new design approaches and analysis techniques have emerged in the steel research, which have the potential to help overcome the above-mentioned challenges: the direct strength method, established in North America, Australia and New Zealand for cold-formed steel design; the continuous strength method, established in North America for structural stainless steel design; and the Generalised Beam Theory (GBT), which offers an efficient numerical means of studying the

Project Reference

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Leading Institution

UniBw M – Bundeswehr Munich University, (Germany)

Partners

Imperial College of Science Technology and Medicine (United Kingdom), IST – Instituto Superior Técnico (Portugal), ECCS – Convention Européenne de la Construction Métallique (Belgium), CTICM – Centre Technique Industriel de la Construction Métallique (France), ULaval – Université Laval (Canada), Conducciones Y Derivados S.L.U (Spain)

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CERIS

147 163.00€

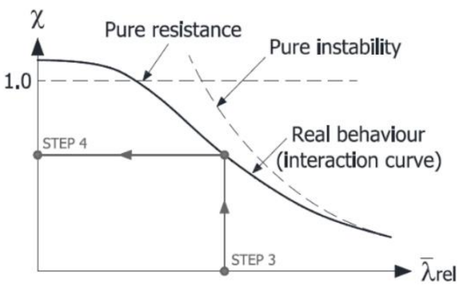
Project Website

www.steelconstruct.com/eu-projects/hollosstab buckling and nonlinear response of members and frames. Furthermore, the advantages of representing buckling strengths within the framework of the "Overall Interaction Concept" (OIC) are progressively being appreciated. The academic applicants were heavily involved in these developments.

The OIC-type "direct" representation of buckling strength makes use of advanced analysis techniques for the (theoretical) cross-sectional and member resistances. It relates the plastic resistance obtained from a materially non-linear (geometrically linear) analysis to the elastic bifurcation load, defining an "overall" slenderness. In a subsequent step, "overall" reduction factors are used to reduce the plastic resistance to account for elasto-plastic instability phenomena and imperfections; in doing so, this approach represents an expansion of the current design methods for members under pure compression or pure bending in Eurocode 3 or other international codes. The procedure is schematically represented in Figure 1.

The advantages of OIC-based methods specifically for the design of structural hollow sections would be manifold, as these sections i. are particularly suitable for slender "instability-sensitive" construction, ii. have a pronounced support effect of adjacent cross-sectional parts, iii. are not susceptible to torsion and iv. could quickly be brought to market in high strength steel grades as soon as appropriate design rules are available, as European steel producers are already capable of developing this type of product. The following scope and goals of this research project can be defined:

- Development of new, "direct" design rules for the cross-sectional capacity of slender hollow sections, on the basis of the OIC, to obtain a continuous strength function throughout the slenderness ranges, thereby eliminating the discontinuities between different cross-section classes. "New generation" design & analysis methods will be used to obtain the OIC strength curves. CHS, EHS, RHS and SHS sections are to be treated.
- Expansion of the developed "direct design" functions for the applications in beam-columns. This will allow treating global, local and local-global buckling in one design equation.
- The elastic buckling behaviour of hollow sections will be studied in a semi-analytical way using GBT; this will allow gaining insight in the characteristic behaviour of (very) slender hollow sections.
- The safety level of the newly developed design rules will be ascertained using EN 1990, making use of the test data, material properties and geometric tolerances provided in the project.
- The fields of industrial application and of possible product improvement will be studied in a systematic technical/scientific way by a major European hollow section producer (Condesa), ECCS and CTICM. Case-studies will be examined to determine the economic and technical advantages of the new design rules and developments in steel grades/shapes/wall thicknesses.
- Design tools and guidelines will be developed.



$STEP\ 1: R_{RESIST}$

$STEP\ 2: R_{STAB}$

$STEP\ 3: \bar{\lambda}_{rel} = \sqrt{\frac{R_{RESIST}}{R_{STAB}}}$

$STEP\ 4: \chi = f\ (\bar{\lambda}_{rel})$

$STEP\ 5: R_{REAL} = \chi \cdot R_{RESIST}$

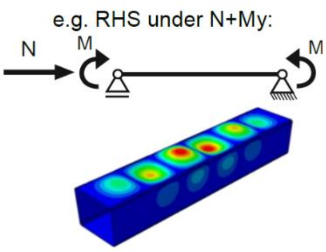


Figure 1. Representation of the "direct", OIC-based design procedure.