CEN TECHNICAL SPECIFICATION FOR DESIGN OF HOLLOW SECTION JOINTS ACCORDING TO THE COMPONENT METHOD

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The European normative document entitled Eurocode 3 Part 1-8 (EN 1993-1-8) provides design rules for structural steel joints. For joints between open sections, reference is made to the concept of the "component method" while it is not the case for joints between tubular sections. Further to recent research works funded by CIDECT, the concept of the "component method" has been extended to joints in tubular construction. A CEN (European Normalisation Committee) Technical Specification (TS) document complementing Part 1-8 and detailing the application of the component method to tubular construction is in preparation through a further CIDECT funding. It is planned to be available end of 2019. Resistance values determined through this new TS will be the same as those obtained through EN 1993-1-8. As a next step, this change of direction will have to be progressively implemented in practice. This requires, similarly to what has been previously done for open section joints, the development of specific design tools: design tables, simplified design procedures for specific joints, software and worked examples. In the present paper, the new TS will be presented, and a brief review of forthcoming practical design tools will be achieved.

Keywords: Tubular profiles, joints, component method.

1 Introduction

Based on a systematic review of the published Eurocode(s), the European standards for the design of steel structures (Eurocode 3) are currently under a full revision.

In this context, CIDECT decided to fund an ambitious research project (16F project) on the development of a "full consistent design approach for bolted and welded hollow section joints"; this report is available upon request on the CIDECT website (Weynand et al. 2015). In fact, in the European normative document for the design of steel joints, known as Eurocode 3 Part 1-8 (EN 1993-1-8), design rules for joints connecting profiles with tubular, on one side, and open sections, on the other side, are not based on the same philosophy. For joints between open sections, reference is made to the "component approach" while it is not the case for joints between tubular sections. Therefore, the initiative of CIDECT, through the funding of the 16F project, was based on the wish to convert the existing design rules for tubular joints into the "component" format. This approach is adopted in the Eurocodes not only for the design of steel but also of composite joints between members made of open sections. Nowadays it is used worldwide by researchers developing design rules for new joint typologies under static loading,

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but also more and more for joints under seismic loading, fire and exceptional events (robustness).

Such a harmonization of the design procedures inside Eurocodes would facilitate the daily life of the designers faced henceforth to a single design approach for joints, but would also open the door to the combined use of open and tubular sections in steel structures and more generally to innovation in terms of joint typologies, what was widely used these last years to develop new joint configurations for energy dissipation in seismic zones, as in Landolfo et al. (2018) or Francavilla (2017).

Through this CIDECT project, it has been demonstrated that this conversion was totally possible. “Component method” reformatted design rules have been proposed and, in addition, first design guidelines for their practical application to tubular joints have been proposed. It has to be mentioned that, for sake of consistency, the so-reformatted rules provide exactly the same resistance values than the “original ones” given in EN 1993-1-8.

Besides that, the adoption of the component format for the design of tubular joints has been discussed by CEN (European Committee for Standardisation) and, as a result, the following decision has been taken for the next issue of the European regulations:

- the present rules for tubular joints would be kept in EN 1993-1-8;
- a Technical Specification (TS 801) complementing EN 1993-1-8 and in which the design rules for tubular joints converted into the component format would be included.

According to the current time schedule of CEN, the forthcoming revised EN 1993-1-8 and its related TS should replace the current version from 2005 in around 2023/2024. Besides that, technical changes are also regularly incorporated in EN 1993-1-8 and its current available draft cannot be seen as the “really” final one. As a consequence, the draft of the complementary Technical Specifications, which is presented in the present paper, has to be seen as a continuous process.

In fact, the application of the component method for the design of hollow section joints has been globally presented a few years ago at the ISTS 15 by Jaspart et al. (2015). In this paper, the general approach and the aspects of assembly, i.e. the determination of the joint properties on the basis of the resistances of individual components, was described in detail. Therefore, in Section 2, only a short summary of the related essential aspects is provided before, in Section 3, addressing in a more detailed way the characterisation of the component design rules and, briefly in Section 4, the development of practical design guidelines.

2 The Component Method

2.1 *A general approach*

The component method is a design approach for the characterization of the mechanical properties of structural joints. In few words, the component method can be explained as a three-step procedure which may be defined as follows:

- identification of the constitutive “individual (basic) components” of the joint;
- determination of the stiffness/resistance properties of all these components by using appropriate design formulae;
- “assembly” of the individual components to derive the stiffness/resistance properties of the whole joint.

2.2 *Basic joints components*

As explained above, any joint is considered as a set of individual components. Therefore, the list of specific components met in hollow section joints has been established so as to cover the present scope of application of EN 1993-1-8. Then, design resistance formulae for each of the constitutive individual components in shear, tension or compression have been derived. These ones differ according to the geometrical configuration of the studied joint, but also according to the type of loading to which the joint is subjected (axial forces, bending moments, shear forces, combinations of axial forces and bending moments …).

2.3 *Determination of joint properties*

To assemble the components means to express the fact that the forces acting on the whole joint distributes amongst the constitutive components in such a way that:

- the internal forces in the components are distributed so that equilibrium is reached with the external forces applied to the joint;
- the resistance of a component is nowhere exceeded;
- the deformation capacity of a component is nowhere exceeded.

As far as the resistance of the whole joint to external forces is concerned, the fulfilment of these three rules is enough to ensure that the evaluated design resistance is smaller than the actual one.

2.4 *Stiffness evaluation*

With regards to the application of the component method for the design of hollow section joints, the actual stiffness of individual components and hence the stiffness of the joints are not (yet) considered. Because appropriate models to predict the stiffness of hollow section joints are not available, the general approach to design hollow section joints is based on the assumption that the joints are either nominally pinned (i.e. the modelling assumes no transfer of moments and a rotational stiffness equal to zero) or rigid (i.e. the modelling assumes a transfer of moments and the rotational stiffness of the joint is assumed to be infinite). In the case of nominally pinned joints (an assumption which is simple in terms of structural modelling and global frame analysis but which does not reflect the actual rotational response) specific requirements concerning ductility must be followed. As an example in Eurocode 3 Part 1-8 for tubular joints, member sections should be of class 1 or class 2 and welds should be designed as full-strength.

2.5 *Resistance evaluation*

According to the component method approach, the joints are represented as a system of springs, each of these ones representing a specific component. When external forces are applied to this system, these ones distribute amongst the springs according to their respective stiffness, resistance and ductility. To express the relation between external forces on the joint and internal forces in the constitutive components is nothing else that what has been here above called the “assembly of components”. Figure 1 illustrates the situation for a T joint between RHS under axial force. In this graph, the notations “(i)” to “(v)” relate to the relevant active components which may be identified as follows:

(i) (chord) face in bending
(ii) (chord) side wall(s) in tension or compression
(iii) (chord) side wall(s) in shear

(iv) (chord) face under punching shear
(v) (brace) flange or web(s) in tension or compression

For obvious reasons of symmetry, all the components are in this specific case subjected to a force equal to one fourth of the external applied load. So the resistance of the joint is simply obtained when the resistance of the weakest component ($\left[F_{\text{N,min,Rd}}\right]_i$) is reached i.e. for an applied axial load $N_{\text{i,Ed}}$ equal to $N_{\text{i,Rd}} = 4\left[F_{\text{N,min,Rd}}\right]_i$. Other loading situations were addressed in Weynand et al. (2015).

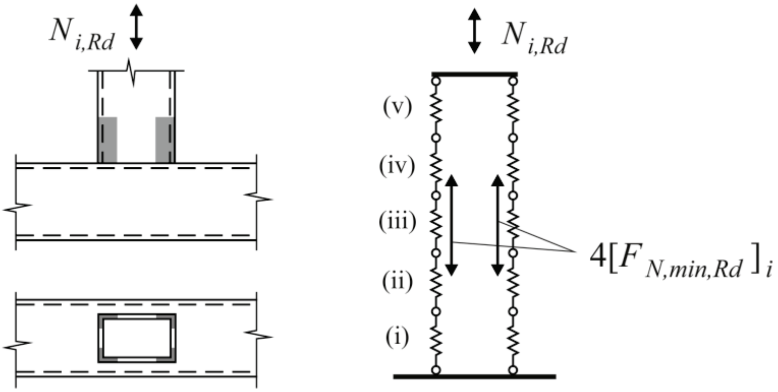

Figure 1. Joint representation by a system of springs.

3 Determination of the design resistances according to TS 801

3.1 *General*

The design rules included in EN 1993-1-8 for hollow section joints are mainly based on the exploitation of numerous experimental results (fitting) performed on joints, and not on components. In order to draft the Technical Specification TS 801, these rather empirical design rules have to be "converted" into a component format. This means that each design rule in EN 1993-1-8 has to be "decomposed" in a way to identify the design resistance of the components, on one hand, and the assembly procedure respecting the requirements expressed in Section 2.3, on the other hand. Furthermore, for sake of consistency with the design rules given in EN 1993-1-8 for joints between members made of open sections, the wish is to provide expressions based on mechanical models and reflecting as much as possible the influence of the physical parameters.

Technically speaking, for a specific component, the design resistance formula provided by EN 1993-1-8 has so to be compared to the formula as it results from the application of the component method (an example of such a formula is reproduced in Figure 1). In Sections 3.2 to 3.8, the mathematical physically-based expressions selected for each component are provided. As the assembly procedures have already been presented in ISTS'15, they will no more be described here. Finally, by identification of the semi-empirical formulae of EN 1993-1-8 and the physically-based formulae associated to the component approach, the constitutive parameters of the component formulae presented in Sections 3.2 to 3.8. can finally be evaluated and mathematically expressed.

All conversion works are extensively reported in Weynand et al. (2015), as well as the detailed definition of the constitutive parameters. It has to be mentioned that the information to be found in Weynand et al. (2015) and partly reproduced here below is based on the design rules given in the current Eurocode version (CEN EN 1993-1-8, 2005). For sake of concision in the present paper, all variables used in the next sections are not all defined in a detailed way, but the interested reader will find all necessary information in (CEN EN 1993-1-8, 2005).

3.2 *Component "Chord side wall(s) in shear"*

The following format is proposed for the design plastic resistance $V_{\mathrm{wp,Rd}}$ of a chord side wall subjected to a design shear force $V_{\mathrm{wp,Ed}}$:

$$V_{\mathrm{wp,Rd}} = \frac{\kappa_{\Theta,\mathrm{wp}} \cdot k_{\mathrm{wp}} \cdot f_{y,0} \cdot A_{\mathrm{v}}}{\sqrt{3} \cdot \gamma_{\mathrm{M5}}} \tag{1}$$

where:

- A_{v} is the shear area of the chord;
- $\kappa_{\Theta,\mathrm{wp}}$ is a factor to account for brace inclination, $\kappa_{\Theta,\mathrm{wp}} = 1/(4\sin\Theta)$;
- γ_{M5} is a safety factor defined in EN 1993-1-8;
- k_{wp} is a reduction factor to allow for possible stress interaction effects (coexistence of the shear force $V_{\mathrm{wp,Ed}}$ with axial forces $N_{0,\mathrm{Ed}}$ in the chord); for RHS, k_{wp} is, for instance, determined as follows:

$$k_{\mathrm{wp}} = \begin{cases} 1{,}0 & N_{0,\mathrm{Ed}} \le \left(A_0 - A_{\mathrm{v}}\right) f_{\mathrm{y},0} / \gamma_{\mathrm{M}5} \\ \sqrt{1 - \left(\dfrac{N_{0,\mathrm{Ed}} - \left(A_0 - A_{\mathrm{v}}\right) f_{\mathrm{y},0} / \gamma_{\mathrm{M5}}}{A_{\mathrm{v}}\, f_{\mathrm{y},0} / \gamma_{\mathrm{M}5}} \right)^2} & N_{0,\mathrm{Ed}} > \left(A_0 - A_{\mathrm{v}}\right) f_{\mathrm{y},0} / \gamma_{\mathrm{M}5} \end{cases} \tag{2}$$

In Eq. (2), A_0 is the total area of the chord and $f_{\mathrm{y},0}$ is its yield strength. The physical meaning of Eqs. (1) and (2) appears as rather obvious.

3.3 *Component "Chord side wall(s) in transverse compression"*

The design resistance of chord side wall(s) subjected to transverse compression should be determined from:

$$F_{\mathrm{c,wc,Rd}} = k_{\mathrm{wc}}\, \kappa_{\Theta,\mathrm{wc}}\, b_{\mathrm{eff,c,wc}}\, t\, f_{\mathrm{y},0} / \gamma_{\mathrm{M5}} \quad \text{but} \quad F_{\mathrm{c,wc,Rd}} \le k_{\mathrm{wc}}\, \kappa_{\Theta,\mathrm{wc}}\, \rho\, b_{\mathrm{eff,c,wc}}\, t\, f_{\mathrm{y},0} / \gamma_{\mathrm{M5}} \tag{3}$$

where:

- $b_{\mathrm{eff,c,wc}}$ is the effective width of chord side wall(s) in compression defined in Weynand et al. (2015);
- ρ is a reduction factor for plate buckling, see Weynand et al. (2015);
- k_{wc} is a reduction factor accounting for possible stress interaction with the axial stresses in the chord, see Weynand et al. (2015);
- $\kappa_{\Theta,\mathrm{wc}}$ is a reduction factor to account for the layout of the joint configuration, and more especially for brace inclination;
- t is a reference thickness defined as equal to the chord wall thickness $t = t_0$ or $t = t_0 + t_{\mathrm{p}}$ for hollow chords reinforced with side plates

In the case where no buckling develops and no interaction takes place in the side walls and the brace and the chord are perpendicularly connected, Eq. (3) simply reduces to the plastic resistance of the side walls expressed as

$$F_{\mathrm{c,wc,Rd}} = b_{\mathrm{eff,c,wc}}\, t\, f_{\mathrm{y,wc}} / \gamma_{\mathrm{M5}} \tag{4}$$

3.4 *Component "Chord side wall(s) in transverse tension"*

The design resistance of the chord side wall in tension component may be expressed in a similar way than for "Chord side wall(s) is compression", but without a ρ factor, as plate buckling is not likely to occur:

$$F_{\mathrm{t,wc,Rd}} = k_{\mathrm{wc}}\, \kappa_{\Theta,\mathrm{wc}}\, b_{\mathrm{eff,t,wc}}\, f_{\mathrm{y,wc}}\, t / \gamma_{\mathrm{M5}} \tag{5}$$

3.5 *Component "Chord face in bending and transverse shear"*

In EN 1993-1-8, T-stub connections are considered as a result of their particular interest for the evaluation of the mechanical properties of bolted beam-to-column connections. Indeed T-stub may closely represent the response of endplate or column flanges subjected to bolt forces. Three failure modes are identified which respectively correspond to the full yielding of the T-stub flange (Mode 1), the failure of the bolts in tension (Mode 3) and the partial yielding of the T-stub flange combined with a failure of the bolts in tension (Mode 2). The design resistance $F_{\mathrm{fc,1,Rd}}$ of a chord face in bending is similar to a Mode 1 failure of a classical T-stub (flange in bending) and a similar resistance formula may therefore also be proposed:

Mode 1:
$$F_{\mathrm{fc,1,Rd}} = k_{\mathrm{fc}} \left(0{,}5\, \bar{l}_{\mathrm{eff,1}} + \bar{l}_{\mathrm{eff,2}}\right) m_{\mathrm{pl,Rd}} \tag{6}$$

The non-dimensional effective lengths $\bar{l}_{\mathrm{eff,1}}$ and $\bar{l}_{\mathrm{eff,2}}$ are defined in Weynand et al. (2015). Flange reinforcing plates may be used to increase the resistance of a RHS chord face. The plastic moment resistance of the chord face per unit length is equal to:

$$m_{\mathrm{pl,Rd}} = 0{,}25\, t_0^2\, f_{\mathrm{y0}} / \gamma_{\mathrm{M5}} \tag{7}$$

Mode 2 and Mode 3 are here not relevant.

Besides the yielding of the chord face, also punching shear failure must be considered as a possible failure mode. This failure needs not to be checked for bolted T-stub because it is already checked in an implicit way through the proposed resistance formulae. However, for a hollow section chord flange, the failure needs to be check as Mode 4:

Mode 4:
$$F_{\mathrm{fc,4,Rd}} = b_{\mathrm{eff,s,fc}} \frac{f_{\mathrm{y,0}}}{\sqrt{3}}\, t_0 / \gamma_{\mathrm{M5}} \tag{8}$$

$b_{\mathrm{eff,s,fc}}$ values are defined in Weynand et al. (2015). Flange reinforcing plates may be used to increase the resistance of a RHS chord face.

3.6 *Component "Brace parts in compression"*

The design resistance of beam or brace parts in compression is given by:

$$F_{\mathrm{c,pb,Rd}} = b_{\mathrm{eff,c,pb}}\, t_{\mathrm{c,pb}}\, f_{\mathrm{y,i}} / \gamma_{\mathrm{M5}} \qquad (9)$$

$b_{\mathrm{eff,c,pb}}$ is given in Weynand et al. (2015). $t_{\mathrm{c,pb}}$ is a reference thickness. For CHS, RHS or plate section braces $t_{\mathrm{c,pb}} = t_{\mathrm{i}}$ and, for I or H braces, $t_{\mathrm{c,pb}} = t_{\mathrm{fb}}$. $f_{\mathrm{y,i}}$ is a yield strength of the braces.

3.7 *Component "Brace parts in tension"*

In a lattice structure joint, the design resistance of brace parts with properly formed welds is generally higher under tension than under compression. However, the design resistance of brace parts in tension is taken as equal to the design resistance of brace parts in compression, so as to avoid the possible excessive local deformation or reduced rotation capacity or deformation capacity which might otherwise occur.

4 Design tools

The field of application of this unified design procedure is wide as the number of components may be enlarged to cover any new joining solution that could be proposed by designers or fabricators. This is one of the main advantages of the procedure. But it must be recognized that its practical application may sometimes, when the number of components become significant, be rather long and cumbersome. That is why, for daily practice, the user will favour practical design tools much more in line with his request for efficiency. Amongst the practical design tools allowing a quick and easy characterization of the joints, software or sometimes design sheets and tables of standardized joints appear to be most efficient. Such tools have been in the last years prepared and widely disseminated in different countries, for example see Weynand et al. (2011) or Feldmann et al. (2019).

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