Design of Hollow Section Joints using the Component Method

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ABSTRACT: The component method is a design approach for the characterization of the mechanical properties of structural joints. Initially the component method has been developed for joints between open sections and it is referred to in Eurocode 3 Part 1.8. It allows a theoretical evaluation of the resistance, stiffness and ductility properties based on mechanical models. However, the design of joints between tubular hollow sections follows a different approach. A joint (or more precisely a joint configuration, i.e. a zone where two or more members are connected) is considered as a whole when determining its resistance(s). Existing design rules for joints between tubular hollow sections are based on simple theoretical mechanical models and they are then fitted through comparisons with experimental tests. As a consequence, their field of application is often restricted to the domain for which the rules have been validated. Under the umbrella of CIDECT, a project is being carried out to develop a unified design approach for steel joints independent of the type of section of the connected elements by extending the field of application of the "component method". To achieve this objective, rules recommended for hollow section joints have to be "converted" into a component format. The present paper presents ways and means for the development of such a unified design approach. Components have been identified in typical hollow section joints in lattice girder structures. The paper presents also design rules (component resistances and assembly rules) for some hollow section joints as examples.

1 INTRODUCTION

1.1 *Objective*

The so-called component method is a design approach for the characterization of the mechanical properties of structural joints. Initially it has been developed for joints between open sections. The application of this design approach for joints in tubular construction has been initiated in CIDECT. As an outcome of first projects, the possibility to extend this method to hollow section joints has been demonstrated and the advantage of its use has been pointed out:

- Unified approach for all joints
- Applicability to any constitutive material(s) and combinations of profiles (tubular sections, open sections, rolled, cold-formed, hot-finished, built-up sections ...)
- Applicability to any connection system (bolts, rivets, welds ...) and connecting devices (plates, cleats, gussets, splices ...)
- Applicability to joints in any structural system (frames, trusses, masts ...)
- Applicability to joints under static loading but also fire, earthquake, fatigue, exceptional events, etc.

Furthermore, in the last years CIDECT has carried out some gap analysis in order to highlight further research and development needs. Resulting from this work, CIDECT has asked the authors of this paper to reformat the contents of EN 1993-1-8 chapter 7 into a component format compatible with the one used in the EN 1993-1-8 chapter 6 so as to profit from the above-listed advantages and to allow later on an easy application to joints between members with tubular and open sections.

1.2 *Design approaches*

In the last decades, much research work has been devoted in all parts of the world to the design of joints in steel structures. All these efforts led to the development of new connection types and new design rules which have been progressively implemented in design recommendations and national or international codes.

These actions have been extended by other ones aimed at preparing design handbooks for practitioners as well as appropriate simplified design tools, so facilitating the transfer of new technologies to the constructors and designers.

A quick look at the outcome of these different initiatives is enough to understand that two separate ways have been followed by researchers as far as the type of connected members is concerned:

- joints between tubular hollow sections
- joints between hot-rolled or built-up I or H sections

This divergence results from two different design approaches which are briefly described below. EN 1993-1-8, for instance, is revealing in this regard since chapters 6 and 7, referring respectively to the design of joints between I or H sections and joints between RHS or CHS tubular hollow sections, address these two different philosophies.

1.2.1 *CIDECT approach (failure mode approach)*

The design rules for joints between tubular hollow sections are based on simple theoretical mechanical models and they are then fitted through comparisons with experimental tests. As a consequence, their field of application is often restricted to the domain for which the rules have been validated.

For different failure modes observed in the experimental tests, the design formulae generally give a resistance value for the joint as a whole, for specific loading cases and specific joint configurations; this restricts the field of application and hence the freedom to modify the joint detailing. It has also to be mentioned that usually no information is provided with regard to the stiffness or the ductility of the joints.

1.2.2 *Component method approach*

In the case of joints between open sections, a new theoretical approach based on the so-called "component method" has been developed. It allows a theoretical evaluation of the resistance, stiffness and ductility properties based on mechanical models. It may be applied to a wide range of joint configurations and connection types in steel structures and has been extended to composite steel-concrete joints. Research activities are in progress in view of its application to timber joints or joints between concrete precast elements, but also to various loading situations (fire, earthquake, impact, robustness…). Besides its theoretical background, the component method provides the user with information about the relative stiffness, resistance and ductility of all the constitutive parts of the joints (called components), so allowing:

- to show how the stiffness and resistance are "distributed" between the joint components
- to derive the actual failure mode
- to assess the related level of ductility
- to give indications on how to stiffen or strengthen the joint in an easy and economic way when needed

1.3 *The component method*

1.3.1 *A basis for a unified approach*

In Europe both design approaches are reflected by Eurocode 3 in the latest version of EN 1993 Part 1.8. For "mixed" joint configurations, i.e. where hollow and open sections are connected together, EN 1993 Part 1.8 provides some guidelines for welded connections but not for bolted connections, i.e. structural solutions with mixed types of sections are difficult to apply for practitioners as they are not directly covered in the design rules. Rules for some "mixed" bolted connections were covered by the ENV version of EC 3, but they disappeared in the EN version. Those rules are of course found in the various CIDECT design guides (e.g. Packer et al.1992, Wardenier et al. 1991).

The present paper reports on the development of a unified design approach for steel joints independent of the type of connected elements by extending the field of application of the component method to tubular joints.

The component method is a three step procedure which may be defined as follows:

- identification of the constitutive individual components of the joint
- determination of the stiffness/resistance properties of all these components by using appropriate design formulae
- combination or "assembly" of the single components so as to derive the stiffness/resistance properties of the whole joint

The properties of joints to be evaluated in practice strongly depend on the type of global frame analysis and design process which is followed by the designer; for instance:

- for an elastic analysis combined with an elastic verification of the members and joints, the stiffness and the elastic resistance of the joints should be derived
- for an elastic analysis combined with a plastic verification of the members and joints, the stiffness and the plastic resistance are required
- for a rigid-plastic analysis, only the plastic resistance and the rotational capacity of the joints will have to be evaluated

This approach is very comprehensive and, as already said, the objective of the ongoing project is to extend it to joints involving other types of sections and, in particular, hollow sections. Practically speaking, this requires:

- to define and characterize the relevant components;
- to verify that the available "assembly" procedures (which are based on general principles like equilibrium, compatibility of displacements, ...) are general enough to be considered as independent of the actual nature of the constitutive components and are therefore still relevant.

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 has to 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 favor 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 the most efficient. Many already exist and are used in practice for joints with open sections.

1.3.2 *Basic joints components*

As explained above, any joint is considered as a set of individual components. Therefore, in agreement with the principles of the component method, the first step of the work will consist in establishing the list of components required to cover the present scope of chapter 7 of EN 1993 Part 1.8. Not only the geometrical configuration of the studied joints will have to be taken into consideration, but also the type of loading to which the joint is subjected (axial forces, bending moments, shear forces, combinations of axial forces and bending moments, ...). In a next step, design resistance formulae for each of the constitutive individual components in shear, tension or compression will have to be derived from chapter 7 of EN 1993 Part 1.8 through an appropriate "conversion" process to be specified.

1.3.3 *Assembly - Determination of joint properties*

Once the components will be identified and characterized, the way on how to assemble the latter will have to be derived.

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 in equilibrium 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 joint resistance.

2 FIELD OF APPLICATIONS

In its section 7.1, EN 1993-1-8 provides the scope of chapter 7 and its general field of application. Within these limits, the clauses provided by chapter 7 may be used for the evaluation of the design resistance of the hollow section joints.

In section 7.2, EN 1993-1-8 explains that six failure modes can be identified for any hollow section for joints between hollow and open sections and basically that the design resistance of a joint may be evaluated as the minimum of the six design resistances corresponding to these six failure modes.

Further to these quite general statements, EN 1993-1-8 points out that not all these six failure modes are always relevant and therefore that simplification may be achieved, when possible, by disregarding failure modes which could be recognized as irrelevant. In order to turn this conclusion into reality, EN 1993-1-8 specifies successively for:

- welded joints between CHS members (section 7.4)
- welded joints between CHS or RHS brace members and RHS chord members (section 7.5)
- welded joints between CHS or RHS brace members and I or H section chords (section 7.6)
- welded joints between CHS or RHS brace members and channel section chord members (section 7.7)

the specific limited fields of application in which some of the failure modes may be disregarded, so reducing the number of computations to be achieved by the designer.

For the "remaining" (relevant) failure modes to be checked, formulae are then provided, but again with some more further "local" limitations on joint geometry. These ones reflect usually the domain in which the design rule has been validated.

3 GENERALITIES ABOUT THE CONVERSION PROCESS

3.1 *Definitions of connection, joint and joint configuration in EN1993-1-8 chapter 6*

Chapter 6 of EN 1993-1-8 addresses the design of joints between members with open cross-sections and applies in priority to building frames; the latter consist of beams and columns, usually made of H or I shapes that are assembled together by means of connections. These connections are between two beams, two columns, a beam and a column or a column and the foundation (Figure 1).

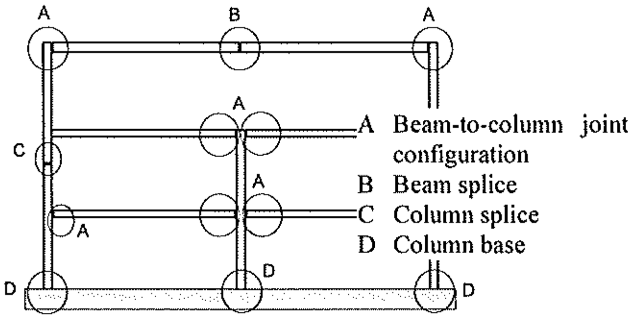
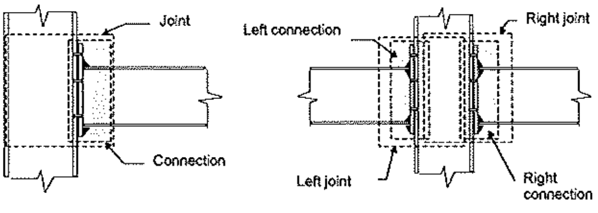


Figure 1. Different types of joint configurations in a building frame

A connection is defined as the set of the physical components which mechanically fasten the connected elements. One considers the connection to be concentrated at the location where the fastening action occurs, for instance at the beam end/column interface in a major axis beam-to-column joint. When the connection as well as the corresponding zone of interaction between the connected members are considered together, the wording joint is used (Figure 2a).



(a) Single sided joint configuration

(b) Double sided joint configuration

Figure 2. Joints and connections

Depending on the number of in-plane elements connected together, single-sided and double-sided joint configurations are defined (Figure 2). In a double-sided configuration (Figure 2b), two joints - left and right - have to be considered.

The definitions illustrated in Figure 2 are also valid for other joint configurations and connection types.

To point out the need for distinguishing connections from joints, reference is here made to one-sided and double-sided joint configurations illustrated in Figure 2.

In these ones, the left (if any) and right connections are subjected to the forces respectively in the left (if any) and right beams while the shear force applying to the column web panel results from the equilibrium of all the forces acting on it. The shear force in the panel V_{wp} may be evaluated as follows:

$$V_{wp} = \frac{M_{b1} - M_{b2}}{z} - \frac{V_{c1} - V_{c2}}{2} \qquad (3.1)$$

Another formula to which it is sometimes referred, i.e.:

$$V_{wp} = \frac{M_{b1} - M_{b2}}{z} \qquad (3.2)$$

is only a rough and conservative approximation of Eq. (3.1).

In both formulae, z is the lever arm of the resultant tensile and compressive forces in the connection(s).

Both above-mentioned formulae are given in EN 1993-1-8 chapter 5.

As a direct outcome, it is concluded that the connection response depends only on the forces acting in the corresponding beam and therefore that it is the same in both joint configurations; but also that the response of the joints is influenced by that of the column web panel in shear which depends on how the joint configuration is loaded. For its computation, the designer may decide, according to EN 1993-1-8: (i) to model separately the column web panels and the connections or (ii) to model the joints.

A similar concept applies to minor axis beam-to-column joints (beam connected to the web of the column) or to 3-D joint configurations (beams connected to the flange and the web of the column).

In daily practice, it is used to refer to the "joint" concept and not to model separately the column webs panels and the connections and, in order to facilitate the application, so-called "transformation parameters β" are defined. These ones allow to easily account for the influence of the column web panels on the response of the joints. Chapter 5 of EN 1993-1-8 provides the user with accurate or approximate values of these β parameters.

3.2 *Application to EN 1993-1-8 chapter 7*

Even if it is not explicitly said, EN 1993-1-8 chapter 7 refers also to the concept of joints, and therefore implicitly to the concept of transformation factors.

In fact, in chapter 7, a joint configuration is constituted of as many joints as there are braces connected to the chord (see Figure 3). The verification of the resistance of the joint configuration is achieved through the successive check of the resistance of all the constitutive joints. For symmetry reasons, the number of joints to check may be reduced (as an example, for DK joints in Table 7.15 of EN 1993-1-8 where the four actual joints reduce to two).

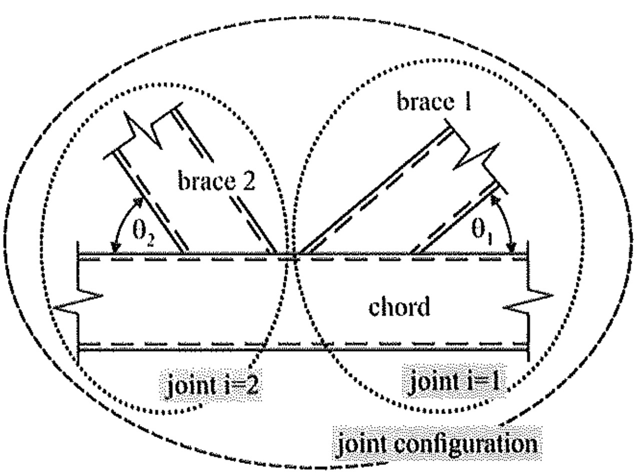


Figure 3. Example of a joint configuration including two joints

This means that, in a later stage of revision of the Eurocodes, a rewording of section 5.3 of EN 1993-1-8 chapter 5 could be easily achieved so as to extend its scope from "beam-to-column joints" to "joints" and so to cover the whole scope of EN 1993-1-8.

3.3 *Design checks for joint configurations involving tubular members*

As already said above, to check the resistance of a joint configuration consists in checking successively the resistance of all its constitutive joints. And for the verification of a joint named i, the following general formula is provided in chapter 7:

$$\frac{N_{i,Ed}}{N_{i,Rd}}+\frac{M_{ip,i,Ed}}{M_{ip,i,Rd}}+\frac{M_{op,i,Ed}}{M_{op,i,Rd}}\leq 1{,}0 \tag{3.3}$$

In this expression:

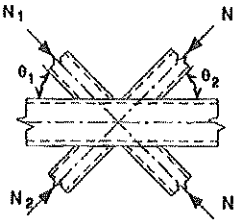
- $N_{i,Ed}$, $M_{ip,i,Ed}$ and $M_{op,i,Ed}$ are the forces acting in the brace of the considered joint i, respectively the design axial force, the design in-plane moment and the design out-of-plane moment;
- $N_{i,Rd}$, $M_{ip,i,Rd}$ and $M_{op,i,Rd}$ are the design resistances of the considered joint i, respectively the design axial resistance, the design in-plane moment resistance and the design out-of-plane moment resistance.

For welded joints between CHS members, formula (3.4) is substituted by the following one:

$$\frac{N_{i,Ed}}{N_{i,Rd}}+\left[\frac{M_{ip,i,Ed}}{M_{ip,i,Rd}}\right]^2+\frac{M_{op,i,Ed}}{M_{op,i,Rd}}\leq 1{,}0 \tag{3.4}$$

Obviously, possible interactions between joints belonging to the same joint configuration may occur and should be considered in the verification procedure. This fact is well recognized in EN 1993-1-8 chapter 6 and chapter 7.

In chapter 6, most of the relevant interactions are considered at the component level while in chapter 7, these ones lead more generally to additional checks for the whole joint configuration. An example is provided in Figure 4 for a DK joint.



Additional check: $N_{1,Ed}\sin\theta_1+N_{2,Ed}\sin\theta_2\leq N_{x,Rd}\sin\theta_x$

where $N_{x,Rd}\sin\theta_x=\max\{|N_{1,Rd}\sin\theta_1|,|N_{2,Rd}\sin\theta_2|\}$

Figure 4. Additional design check to cover interactions

Through the conversion process of chapter 7 to a component style, it will be seen that some of these "joint configuration" extra checks may be turned into a "component" modified check, so decreasing the number of verifications to be effectively achieved, but without changing the resistance of the joint configuration presently provided by the application of chapter 7.

3.4 *Design checks for joints involving tubular members*

For each joint belonging to a joint configuration, Eq. (3.3) has to be applied, what requires first to evaluate its three individual resistances $N_{i,Rd}$, $M_{ip,i,Rd}$ and $M_{op,i,Rd}$.

To derive these individual resistances, reference is made to the component approach. Its application is described in the following sections, first for a particular joint and then in more general terms.

3.4.1 *Component approach – particular example*

According to the component method, the joint may be conceptually considered as a system of springs, each of these ones representing a specific component. Figure 5 illustrates the concept for a T joint between RHS profiles under axial force. In this graph, the notations "a" to "e" relate to the relevant active components which may be identified as follows:

a.(chord) face in bending
b. (chord) side wall(s) in tension or compression
c.(chord) side wall(s) in shear
d. (chord) face under punching shear

e.(brace) flange or web(s) in tension or compression

In Figure 5, the axial forces is seen to be carried out from the brace to the chord through four loading zones located at the corners of the brace sections. This assumption, once it is agreed, has to be respected all along the design process. For each brace cross-section type, the number and the location of the load transfer zones will have to be carefully defined.

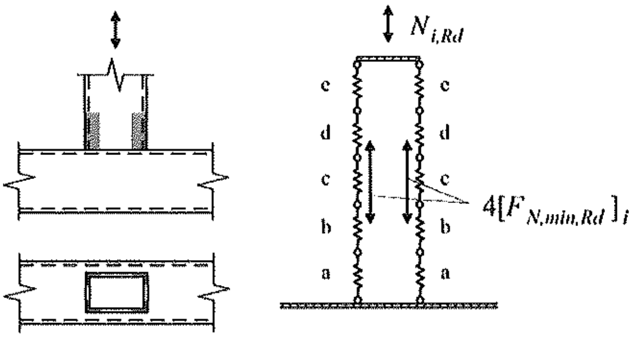


Figure 5. Example of joint representation by means of the component approach

In this particular case, the design resistance of the joint under axial force may be derived as:

$$N_{i,Rd} = 4 \cdot \left[F_{N,\min,Rd}\right]_i \tag{3.5}$$

where $\left[F_{N,\min,Rd}\right]_i$, the minimum resistance of the active components (a)..(e) for joint i under axial force, is expressed as:

$$\left[F_{N,\min,Rd}\right]_i = \min\left[F_{a,N,Rd}; F_{b,N,Rd}; \dots; F_{e,N,Rd}\right]_i \tag{3.6}$$

The procedure may be extended similarly to all loading situations and so, at the end, the design resistances of the joint under $N_{i,Ed}$, $M_{ip,i,Ed}$ and $M_{op,i,Ed}$ are given by:

$$N_{i,Rd} = 4 \cdot \left[F_{N,\min,Rd}\right]_i \tag{3.7}$$

$$M_{ip,i,Rd} = 2 \cdot \left[F_{M_{ip},\min,Rd}\right]_i z_{ip} \tag{3.8}$$

$$M_{op,i,Rd} = 2 \cdot \left[F_{M_{op},\min,Rd}\right]_i z_{op} \tag{3.9}$$

where $\left[F_{N,\min,Rd}\right]_i$, $\left[F_{M_{ip},\min,Rd}\right]_i$ and $\left[F_{M_{op},\min,Rd}\right]_i$, respectively the minimum resistance of the active components for joint i under axial force, the minimum resistance of the active components for joint i under in-plane moment and the minimum resistance of the active components for joint i under out-of-plane moment are expressed as:

$$\left[F_{N,\min,Rd}\right]_i = \min\left[F_{a,N,Rd}; F_{b,N,Rd}; \dots; F_{e,N,Rd}\right]_i \tag{3.10}$$

$$\left[F_{M_{ip},\min,Rd}\right]_i = \min\left[F_{a,M_{ip},Rd}; F_{b,M_{ip},Rd}; \dots; F_{e,M_{ip},Rd}\right]_i \tag{3.11}$$

$$\left[F_{M_{op},\min,Rd}\right]_i = \min\left[F_{a,M_{op},Rd}; \dots; F_{e,M_{op},Rd}\right]_i \tag{3.12}$$

where z_{ip} is the relevant lever arm under in-plane moment and z_{op} is the relevant lever arm under out-of-plane moment

These lever arms result from the assumption made on the location of the loading transfer zones within the joint.

3.4.2 *Component approach – generalization*

The conversion of EN 1993-1-8 chapter 7 into a "component style" requires therefore, for each joint in each joint configuration covered in the normative document, to:

- identify the active components
- derive the resistance of these active components
- assemble the components

successively for each individual loading situations (axial force, in-plane bending moment and out-of-plane bending moment).

When this is achieved, the resistance of each joint may then be checked through Eq. (3.3).

In terms of assembly, it may be shown that the above-mentioned Eqs. (3.7) to (3.9) may be generalized to all joints under the scope of EN 1993-1-8.

4 FROM FAILURE MODES TO COMPONENTS

Six failure modes are listed in chapter 7 of EN 1993-1-8 to be possibly relevant to determine the resistance of hollow section joints:

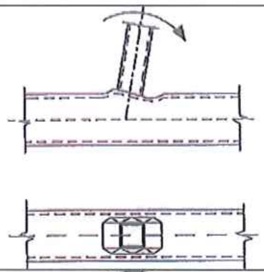
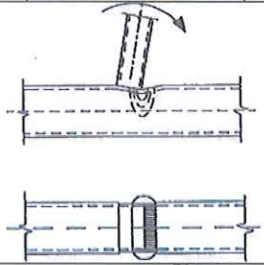
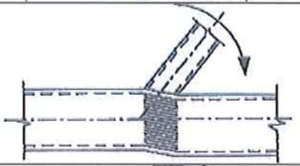
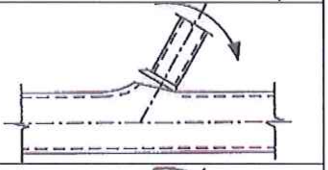
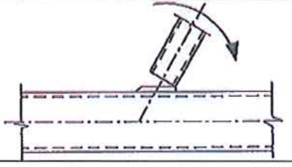
- Chord face failure (yielding);
- Chord side wall failure (yielding and/or instability);
- Chord shear failure (yielding and/or instability);
- Chord punching shear;
- Brace failure;
- Local buckling failure (brace or chord).

In the ongoing CIDECT project, five failure modes have been considered so far. In full agreement with the component method principles, five corresponding components are identified:

a: Chord face in bending;
b: Chord side wall(s) in tension or compression;
c: Chord side wall(s) in shear;
d: Chord face under punching shear;
e: Brace flange and web(s) in tension or compression component.

The names of these components are chosen so as to respect the terminology used in EN1993-1-8 chapter 6. These basic components are illustrated in Table 1. Local buckling failure will be investigated in a later step.

Table 1. Illustration of basic components

a: Chord face in bending	
b: Chord side wall(s) in tension/compression	
c: Chord side wall(s) in shear	
d: Chord face under punching shear	
e: Brace flange and web(s) in tension or compression	

5 COMPONENT DESIGN RESISTANCE FORMULAE

5.1 *"Chord face in bending" component*

The chord face in bending component (a) for a CHS chord is here selected to present the way on how the contents of EN 1993-1-8 Chapter 7 is "transferred", without any change in the level of design resistance, into a component format.

Let's consider first the case of a X joint made of a CHS chord and two IPE braces, the latter ones being subjected to compression forces N_i^* shown in Figure 6.

According to the well-known Ring Model initially developed by Togo (1967):

- It is assumed that most of the loading is transferred at the saddles of the brace, since the chord behaves most stiffly at that part of the connection perimeter.
- The load N_i^* in the brace can be divided into two loads of $0.5 \cdot N_i^*$ perpendicular to the chord at the saddles (at a distance noted $c_1 d_1$).
- These loads are transferred by an effective length B_e of the chord.

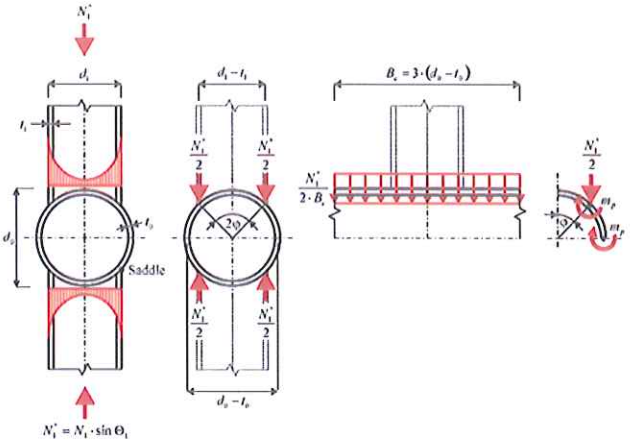


Figure 6. Ring model

- The load $0.5 \cdot N_i^*$ is considered as a linear distributed load over the effective length B_e.
- To take into account the influence of the axial load in the chord, a chord stress function k_n is used. This one has been determined by experiments and numerical investigations.
- The width ratio β is defined as equal to d_1 / d_0.
- Neglecting the influence of axial and shear stresses on the plastic moment resistance $m_{pl,Rd}$ of the chord per unit length allows, if it is assumed that $d_0 - t_0 \approx d_0$, to derive an evaluation of the design resistance N_{Rd} of the joint as follows:

$$N_{Rd} = \frac{8B_e / d_0}{1 - c_1\beta} k_n m_{pl,Rd} \tag{5.1}$$

- The effective length B_e has been determined experimentally and depends on the β ratio. An average value is $B_e = 2.5d_0 \div 3.0d_0$

In reality, much more complex yield patterns develop in the chord face when it is subjected to tension/compression transverse forces; and these ones differ significantly according to the specific way on how the transverse load is transferred to the CHS chord. From that point of view, the four situations illustrated as examples in Figure 7. have each individually to be considered as particular ones and specific design resistance formulae have consequently to be suggested.

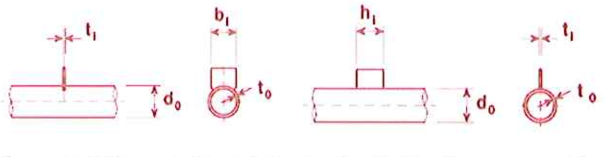


Figure 7. Different "load introduction" situations in a welded T joint (left: gusset plate perpendicular , right: gusset plate longitudinal)

In EN 1993-1-8, for instance, the following design resistances are suggested (see Figure 7):

Gusset plate perpendicular:

$$
\begin{aligned}
N_{Rd} &= k_p f_{y0} t_0^2 \left(4+20\beta^2\right)/\gamma_M \\
&= 4k_p\left(4+20\beta^2\right) m_{pl,Rd}
\end{aligned}
\tag{5.2}
$$

Gusset plate longitudinal:

$$
\begin{aligned}
N_{Rd} &= 5k_p f_{y0} t_0^2 \left(1+0,25\eta\right)/\gamma_M \\
&= 20k_p\left(1+0,25\eta\right) m_{pl,Rd}
\end{aligned}
\tag{5.3}
$$

Whatever is the case, the general format of the equations is as follows:

$$N_{Rd} = \left(\sum \bar{l}_{eff,i}\right)\cdot k_n \cdot m_{pl,Rd} \tag{5.4}$$

where $\sum \bar{l}_{eff,i}$ designates the total equivalent (effective) length coefficient characterizing the yield line pattern actually developing in the chord face. The meaning of $\sum \bar{l}_{eff,i}$ may be highlighted through the following interpretation of the basic Ring Model formula:

$$
\begin{aligned}
N_{Rd} = \frac{8 \cdot {}^{B_e}\!/_{d_0}}{\left(1-c_1\cdot\beta\right)}\cdot m_{pl,Rd}\cdot k_n &= {}^{\sum l_{eff,i}}\!/_{d_0}\cdot m_{pl,Rd}\cdot k_n \\
&= \sum \bar{l}_{eff,i}\cdot m_{pl,Rd}\cdot k_n
\end{aligned}
$$

In Figure 8, for an joint between a CHS chord and a longitudinal gusset plate, the actual yield lines developing in the chord are illustrated; moreover, it shows how the different zones of the yield line pattern contribute individually to $\sum l_{eff,i}$. In this figure, the thickness t_1 of the gusset has been voluntary exaggerated.

From Figure 8 it can be seen that the total effective length is the sum of the effective length of the "inner part" (Ring model) and the external part. For compatibility with the typical definitions of components in chapter 6 of EN 1993-1-8 it is suggested to subdivide the axial force acting on the gusset is into four equal forces, in this particular case two forces at the same location. The distance between the two pair of forces is equal to h_1. Therefore one has:

$$N_{Rd} = 4\cdot\left[F_{a,Rd}\right] \tag{5.5}$$

The design resistance of the "chord face component in compression" (or of the "chord face component in tension") may finally be expressed as follows:

$$F_{a,Rd} = \left(0,5\bar{l}_{eff,1}+\bar{l}_{eff,2}\right)k_n m_{pl,Rd} \tag{5.6}$$

With Eqs. (5.2) to (5.6) the values for $\bar{l}_{eff,1}$ and $\bar{l}_{eff,1}$ can be derived. More details can be found in Weynand (2014)

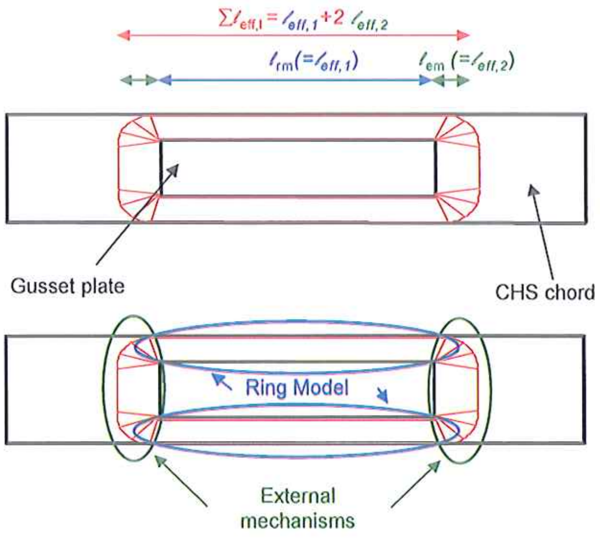


Figure 8. Yield line pattern and effective lengths

5.2 *Other components*

For the other components, a similar procedure is used:

- Select an analytical expression representing the physics of the studied phenomenon;
- Compare the EN 1993-1-8 to the selected analytical expression and so calibrate effective length(s) or the effective width(s) according to the case.

6 ACKNOWLEDGEMENT

Financial support for the work reported in this paper is provided by CIDECT.

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