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APPLICATION OF THE COMPONENT METHOD FOR COLD FORMED JOINTS ASSISTED BY FINITE ELEMENT ANALYSIS

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Abstract. *Previous studies presented the investigation of back-to back cold formed C beams-to-SHS column joints under monotonic and cyclic loading. Two joint types have been tested experimentally and studied using finite element methods. The first joint consists of two flange diaphragms welded to the column and fixed to the beam's flanges through 4xM20 bolts each. The second joint has T-stubs placed at the upper and lower flanges of the beam, each being fixed through 4xM20 blind bolts to the column and 4xM20 bolts to the beam's flange. The failure mechanisms have been observed, their stiffness, strength and ductility has been evaluated based on experimental and numerical studies, enabling the classification of the joints according to EN 1993-1-8. This paper presents the application of the component method for analytical evaluation of the joint performance. Since EN 1993-1-8 does not give any support for cold formed steel joint evaluation, a possible approach assisted by finite element analysis is presented, where component identification is assisted by the developed and calibrated models. Good agreement between analytical and experimental results was obtained.*

1 INTRODUCTION

Research about cold-formed steel profiles as load-bearing structural elements has increased in the last few years, due to the many advantages that it brings, which includes short erection time, cost savings and good strength to weight ratio. Lee et al. [1] and Komara et al. [2] offers a review of current research about cold-formed steel connection types and their performance. Previous studies by Nagy [3], Lim and Nethercot [4], Chung and Lau [5] and Öztürk and Pul [6] showed that bolted joints in cold formed steel portal frames have in most of the cases semi-rigid behavior. Other studies by Lim and Nethercot [7], Wong and Chung [8] have also showed that these types of joints are partially resistant. An important contribution to the global flexibility of the joints, besides the bearing effect (bolt hole elongation), is due to the deformation induced by the local buckling or distortion of the thin walled profiles.

In an unwisely configured joint, premature local buckling can cause the failure of the joint itself well below the expected load bearing capacity. In case of back-to-back bolted connections, when bolts are installed only on the web of cold formed section, the local buckling is made more critical by stress concentrations, shear lag and bearing deformations around bolt holes, as observed by Dundu and Kemp [9]. However, in case of usual cold-formed steel sections, both tests and numerical simulations shows the bearing work of bolts associated with elastic-plastic elongation of bolt-holes is by far the most important component controlling the stiffness and capacity of such type of connections, as found by Lim and Nethercot [4], Yu et al. [10] and Ho and Chung [11]. The contribution of other components, such as flanges in tension and compression due to bending action, and the web in shear due to transverse action is significantly lower. In case of non-conventional joints, where the identification of the relevant components is also difficult, FEA based on calibrated models can represent an alternative for the development of analytical solutions using the component method given in EN 1993-1-8 [12], even though the methodology does not cover the cold-formed steel joint applications. Based on tests of back-to back cold formed C beams-to-SHS column joints under monotonic and cyclic loading, which are summarized in a previous article [13], the application of the component method is used to characterize their stiffness and strength.

2 APPLICATION OF COMPONENT METHOD FOR STUDIED JOINTS

The component model method is a general procedure for design of strength and stiffness of joints in building frames, and is implemented in EN1993-1-8, 2003 [12]. The method is based on representing the joint by a number of components and evaluating the force-displacement relationship of each one. The components which are representing partially the joint behavior due to one single action are assembled based on distribution of the internal forces within the joint.

According to Jaspart [14], the application of the component method requires the following steps:

- identification of the active components for the joint
- evaluation of the mechanical characteristics of individual components: design strength and initial stiffness
- assembly of the components in order to evaluate the strength and stiffness of the whole joint

The application of component method for the considered joints is based on the previous studied cold-formed steel joints [3]. The focus of this section is to evaluate analytically the performance of the connections using the component method based on the conclusions of experimental testing [13] and the calibrated FEM analysis [15].

2.1 Case of Diaphragm Connection for Beam to Column (DCBC) joints

The DCBC joint is built up of 2xC300/3 beam and an SHS 200/12.5 column, which are connected by welding two 10 mm diaphragm plates (S235) around the column and fixing each plate to the beam’s flange using 4 x M20 bolts, as presented in figure 1.

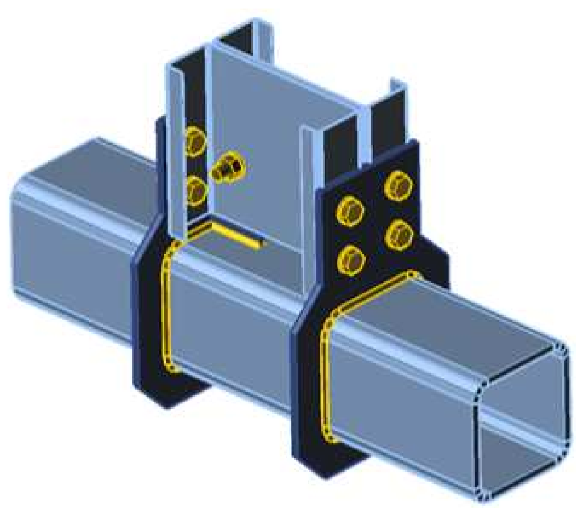


Figure 1: DCBC connection configuration.

Previously studied joints were fully covered by the components presented in EN 1993-1-8 [12]. Due to the innovative character of the DCBC joint, its strength and stiffness includes components, which are not covered by the existing rules, thus the use of the method is limited to the knowledge about the components and how they interact in order to correctly assemble the overall joint. Since the resistance of joint is given by the component with the lowest resistance, the contributions of flanges in tension and compression due to bending, web in shear due to transverse action, or bracket in bending is significantly lower than some of the other components. Furthermore, the identity of the component which defines the moment resistance of the connection is suggested by the test results and also FEM analyses. Concerning the initial stiffness of the joint, the sources of flexibilities are necessary to be identified, while every considerable flexible component is contributing to the global flexibility of the joint. Only those components which are much stiffer relatively to others can be neglected. Beside the resistance component which is identified directly in the test, those components which determine the initial stiffness can be gathered by carefully inspecting the experimental results and the pictures taken during the experiment, and as a more efficient method, increasing the deformation scale factor in the FEM analyses.

As both tests and numerical simulations on DCBC joint shows, the bearing work of bolts generating elastic-plastic bolt-hole elongations, it can be assumed that this is the most important component, governing the overall rotation stiffness. But for strength and stiffness evaluation we need to account components not covered by existing rules. The following components were identified and used to model the joint strength:

- Bracket in tension/compression
- Bracket in bearing
- Bolts in shear
- Cold-formed C profiles bearing
- Cold-formed C profiles in tension/compression

The following components were identified and used to model the joint stiffness:

- Bolts in shear
- Bolts in bearing on the cold-formed member
- Bolts in bearing on the bracket
- Lower bracket in bending

Stiffness and strength of these components are available in EN1993-1-8. The component "Lower bracket in bending" is a newly developed one for this particular connection.

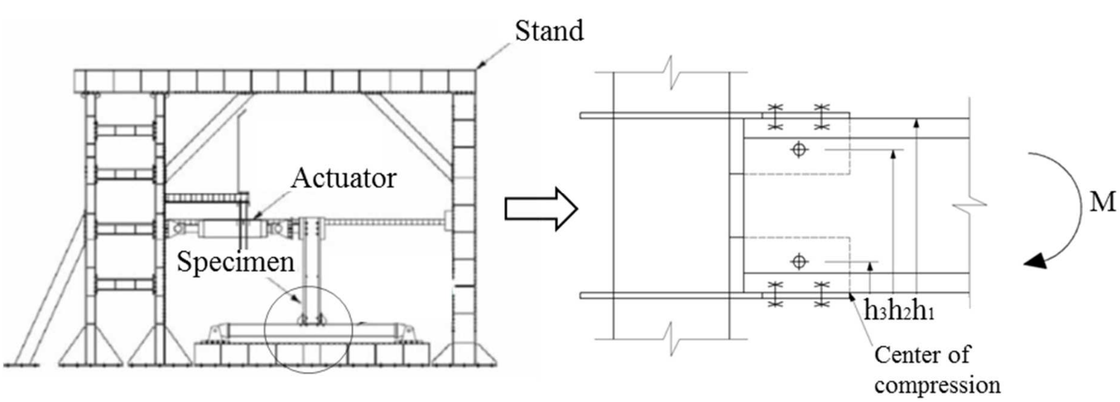


Figure 2: Experimental test setup and DCBC joint model geometry.

Figure 2 shows the studied joint geometry, while the deflection of the lower bracket of the joint from the analysis of the calibrated FE model can be observed in figure 3. The contribution of lower bracket deformation is more important than the upper one, due to the unequal reaction appearing as a result of the fixing method used for the C profiles. The lower bracket is experiencing larger deformations, since the force acting on it is distributed through the whole contact area between the C profiles and bracket, while also having unfavorable orientation for the direction of action. The initial stiffness of this component is evaluated considering the deflection of the cantilevered bracket section due to the concentrated load at the free end.

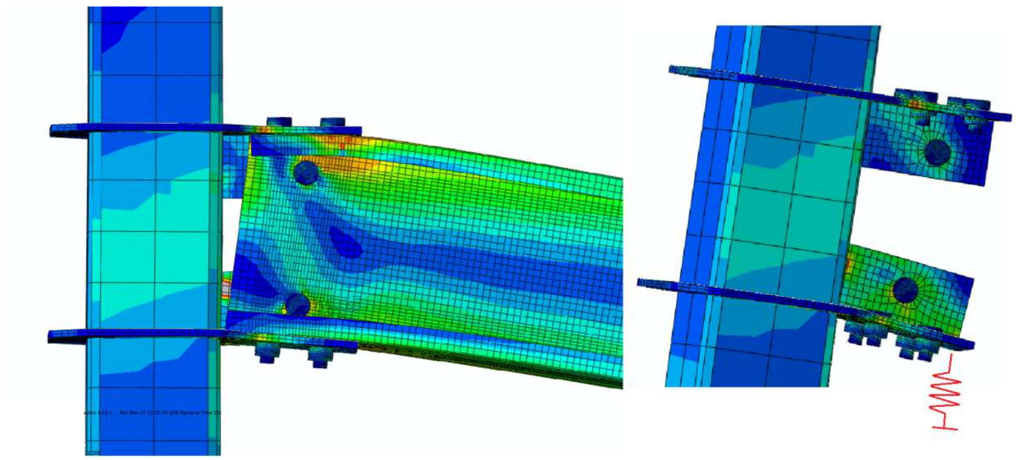


Figure 3: FEM detail with deformation of the lower bracket.

Figure 4 shows the assumption due to which the lower bracket deforms. The same force R is acting both on the lower and upper bracket. However, these have different lever arms, which results in different applied force on the bracket. Since the lever arm of the R force acting on the upper bracket is close to 0, the produced deformation is insignificant, as confirmed by the FEM results as well (see Figure 3).

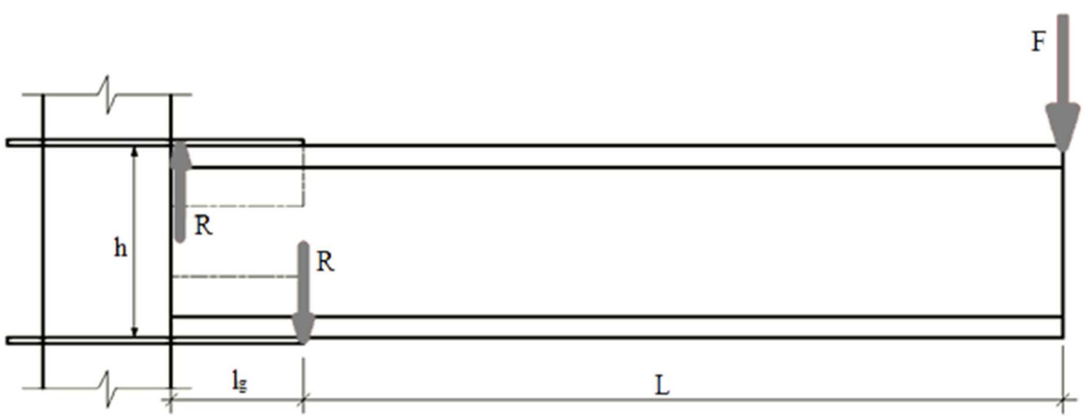


Figure 4: Geometrical details of the tested specimen.

The initial stiffness coefficient is derived from the elastic stiffness of the above described component. The force-deformation relationship of the component is given by equation (1) [16]:

$$F_{spring} = k * E * \Delta_{spring} \tag{1}$$

F_{spring} is the force in the spring which describes the component;
k is stiffness coefficient of the related component;
E is the Young modulus;
Δ_{spring} corresponds to the deformation of the spring;

Equation (2) described the force acting at the end of the cantilevered gusset:

$$R = \frac{F(L + l_g)}{l_g} \tag{2}$$

R is the reaction force acting at the end of the cantilevered gusset element;
F is the force applied by the actuator;
L is the lever arm of the actuator force as presented in figure 4;
l_g is the length of the gusset element as presented in figure 4;

The deformation of the spring is equal to the deflection of the cantilevered gusset element loaded with force R, as equation (3) describes:

$$f = \frac{R\ l_g^3}{3\ E\ I_g} \tag{3}$$

f is the deflection of the cantilevered gusset;
E is the Young modulus;
I_g is the second moment inertia of the T shaped bracket;

The k component is obtained by introducing equation (2) and equation (3) in equation (1):

$$k = \frac{3\ I_g^3}{l_g^3} \tag{4}$$

In order to combine the k component of the gusset element simply in the joint stiffness, it is converted into stiffness coefficient k_g, which describes an equivalent spring acting horizontally as presented in Figure 5. The aim is to combine this stiffness together with the other components acting at this row. Equation (5) shows the result for the equivalent spring stiffness obtained through geometrical transformation as shown in figure 5.

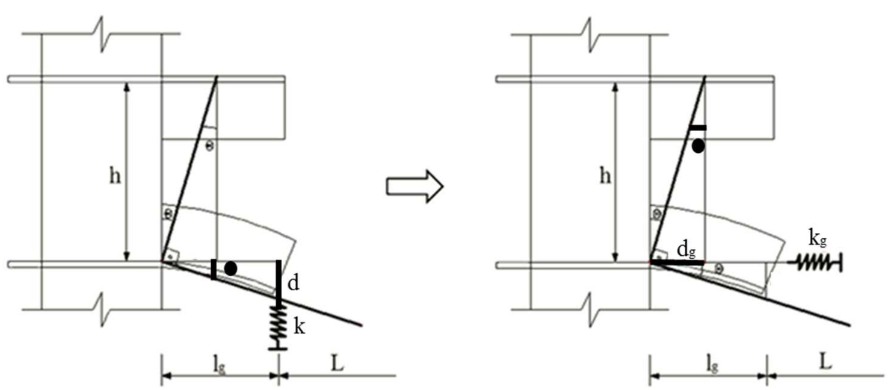
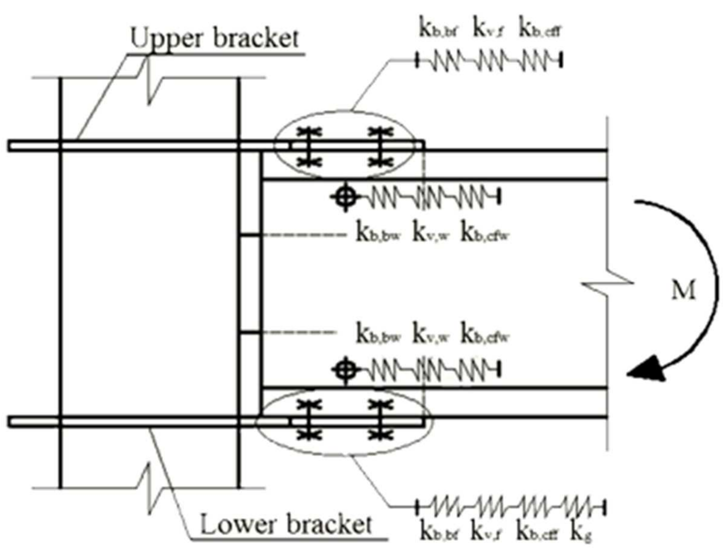


Figure 5: Component lower bracket in bending.

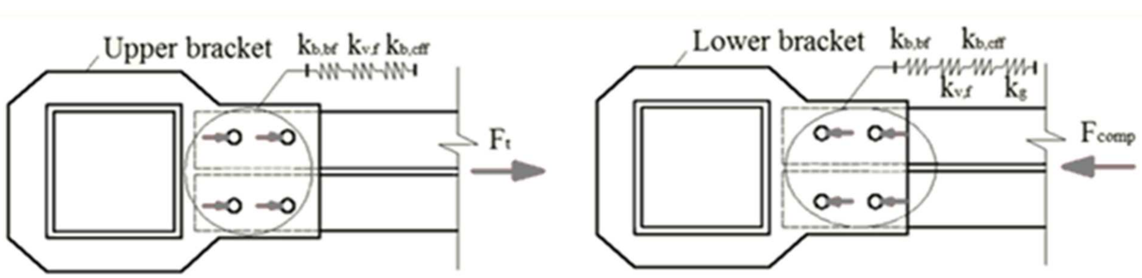
$$k = \frac{3\ I_g^3\ L}{l_g\ h^2\ \left(L + l_g\right)} \tag{5}$$

h is the height of the C section;

In order to facilitate the comparison with the numerical results, the partial safety factors were considered in all cases equal to unity. Four components were considered to contribute to stiffness of the connection: bolts in shear (denoted $k_{v,f}$ for flange bolts and $k_{v,w}$ for web bolts), bolts in bearing on cold-formed member (denoted $k_{b,cff}$ for flange bolts and $k_{b,cfw}$ for web bolts), bolts in bearing on the bracket (denoted $k_{b,bf}$ for flange bolts and $k_{b,bw}$ for web bolts) and the bracket in bending (denoted k_g).These components are presented in figure 6, from upper, lower and side view.



a)



b) c)

Figure 6: Identified components: a) side view, b) upper view, c) lower view.

Formulas to determine the stiffness coefficients are available in EN1993-1-8 [12]. For each of the bolt rows (r_1, r_2, r_3, r_4), an effective stiffness coefficient $k_{eff,r}$ is determined by combining the individual stiffness coefficients in line, following an equation from EN1993-1-8 [12], which is presented in equation (6).

$$k_{eff,r} = \frac{1}{\sum_i \frac{1}{k_{i,r}}} \tag{6}$$

$k_{i,r}$ is the stiffness coefficient representing component *i* relative to bolt row *r*;

Finally, the initial joint stiffness is determined as the procedure presented in figure 7 using equation [7]. An equivalent stiffness coefficient is calculated from the effective stiffness coefficients relative to the bolt rows which are in tension, namely bolt rows r_1, r_2 and r_3.

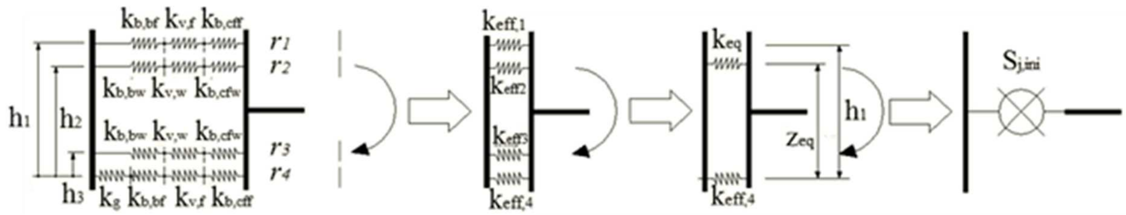


Figure 7: Proposed mechanical model and procedure for evaluating the rotational stiffness.

$$S_{j,ini} = \frac{E\, z_{eq}^2}{\frac{1}{k_{eq}} + \frac{1}{k_{eff,4}}} \tag{7}$$

z_{eq} is the equivalent lever arm;
k_{eq} is the equivalent stiffness coefficient relative to bolt rows r_1, r_2, r_3;
$k_{eff,4}$ is the effective stiffness coefficient relative to bolt row r_4;

Table 1 below presents the results of application of component method for the specimen, in terms of resistance values of the components.

Table 1: Resistance of connection components.

Bolt row	Bracket Tens/Comp [kN]	Bracket Bearing [kN]	Bolt Shear [kN]	Cold-formed member Bearing [kN]	Cold-formed member Tens/Comp [kN]	Bolt-row resistance [kN]
1	554.4	576	490	307.4	406.9	307.4
2		288	245	170.8		170.8
3		288	245	170.8		170.8
4	554.4	576	490	307.4	406.9	307.4
$M_{bC,Rd}$ = 143.46 kNm						

Table 2: Stiffness of connection components.

Bolt row	Bolts in shear [mm]	Bolts in bearing on the cold-formed member [mm]	Bolts in bearing on the bracket [mm]	Equivalent bracket deflection stiffness k_g [mm]	Bolt-row effective stiffness [mm]
1	3.809	0.860	1.697	-	0.496
2	3.809	0.915	0.771	-	0.377
3	3.809	0.915	0.771	-	0.377
4	3.809	0.860	1.697	0.299	0.186

The stiffness coefficients of the connection components are presented in table 2.

Table 3 gives a summary of the results obtained by the application of the component method, which are compared with the values obtained from the experimental testing of the joint. The comparison shows good correlation between the experimentally obtained and the analytically evaluated initial stiffness and moment resistance.

Table 3: Overall results of application of component method for the DCBC joint.

	Initial stiffness [kNm/rad]	Moment resistance [kNm
Experimental value	2107	118
Analytical value	2271	121
Deviation [%]	8%	3%

The moment resistance of the joint was determined using a two-step procedure. In the first step, only the components related to bolt resistance were included, in order to determine the moment resistance of the bolted connection $M_{bC,Rd}$. In a second step, the joint moment resistance was obtained as the minimum of the moment resistance of the bolted connection $M_{bC,Rd}$ and the moment resistance of the connected cold formed member $M_{beam,Rd}$, as in equation (8). The moment resistance of the cold-formed member was calculated taking into account experimental mechanical characteristics of the used C profiles, obtained by means of coupon tests [15].

$$M_{C,Rd} = \min\left(M_{bC,Rd}, M_{beam,Rd}\right) \tag{8}$$

2.2 Case of Hollo Bolts for Beam to Column (HBBC) joint

For the second connection two 10 mm T-stubs (S235) with 8 mm stiffeners were placed at the upper and lower flanges of the C profiles. Each T-stub was fixed with 4 x M20 hollo bolts grade 10.9 to the column, with 4 x M20 bolts to the beams flange and with 1 x M20 bolt to the beam’s web, as showed in figure 8.

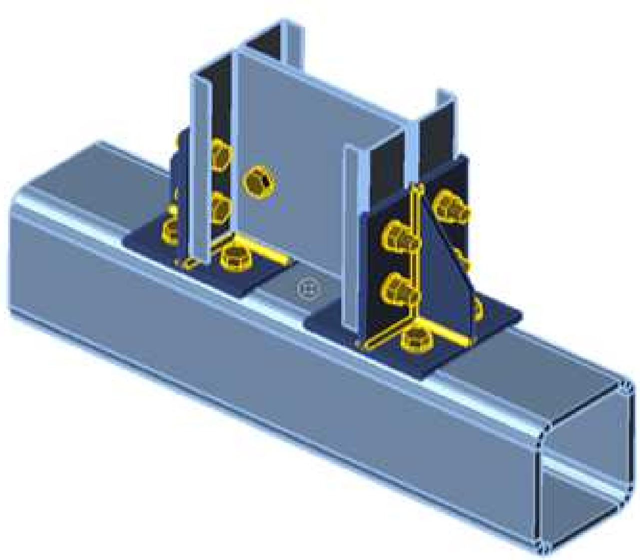


Figure 8: HBBC connection type.

In case of HBBC joint configuration there are similar components as in case of DCBC model, but supplementary components were identified and used to evaluate the joint strength:

- SHS web in shear
- SHS flange in bending
- Hollo-bolt in tension
- Bracket in tension/compression

The following additional components were identified and used to evaluate the joint stiffness:

- Hollo-bolt in tension
- SHS in transverse compression and tension: Chord face failure
- Hollo-bolt in shear
- Hollo-bolt in bearing on the SHS profile
- Hollo-bolt in bearing on the bracket

As figure 9 shows, the bolt and hollo-bolt rows were grouped in different stiffness assemblies having different bolt rows and different centers of compression. The position of the center of compression for the hollo-bolt connection was assumed to be at the lowest hollo-bolt row, as confirmed by the deformations observed in the FEM model, presented in figure 11.

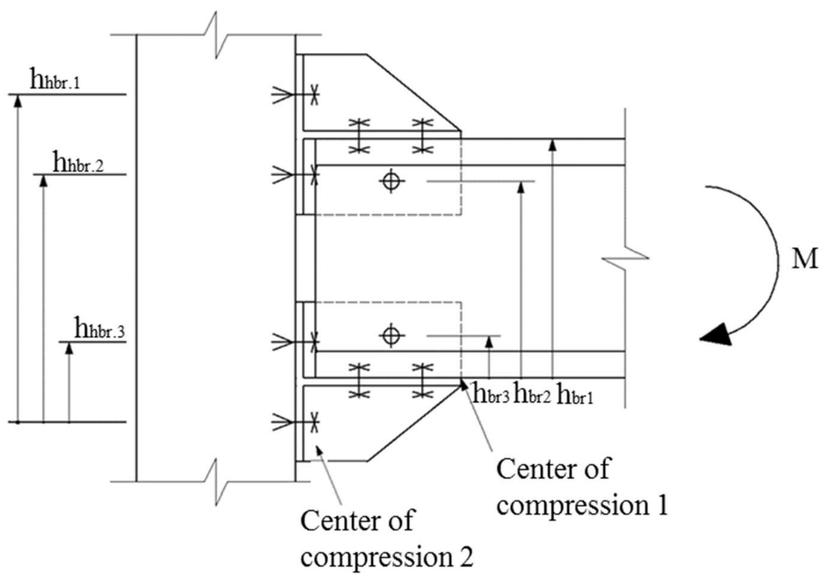


Figure 9: HBBC joint model geometry.

Figure 10 depicts the proposed mechanical model and procedure for the evaluation of the rotational stiffness of the HBBC connection, showing that the initial joint stiffness ($S_{j,ini}$) was evaluated based on three individually calculated stiffness values, namely:

- S_{gv}: the rotational stiffness of the joint, considering components active in the displacement of the lower gusset due to the shear in the hollo bolt connections (see table x);
- S_c: the rotational stiffness of the joint, considering the components active in the SHS chord face failure and the hollo bolt connection (see table x);
- S_b: the rotational stiffness of the joint, considering the components active in the deflection of the bracket in the bolt connection (see table x);

From the above mentioned three individual rotational stiffness values, the S_b term is determined by considering the same components as the components considered for the determination of the rotation stiffness of the DCBC joint, focusing on the bolted connection part. In order to obtain the overall HBBC joint rotational stiffness, this value is completed with the individual stiffness values S_{gv} and S_c, which are corresponding to the components of the hollo-bolt connection to the SHS column member.

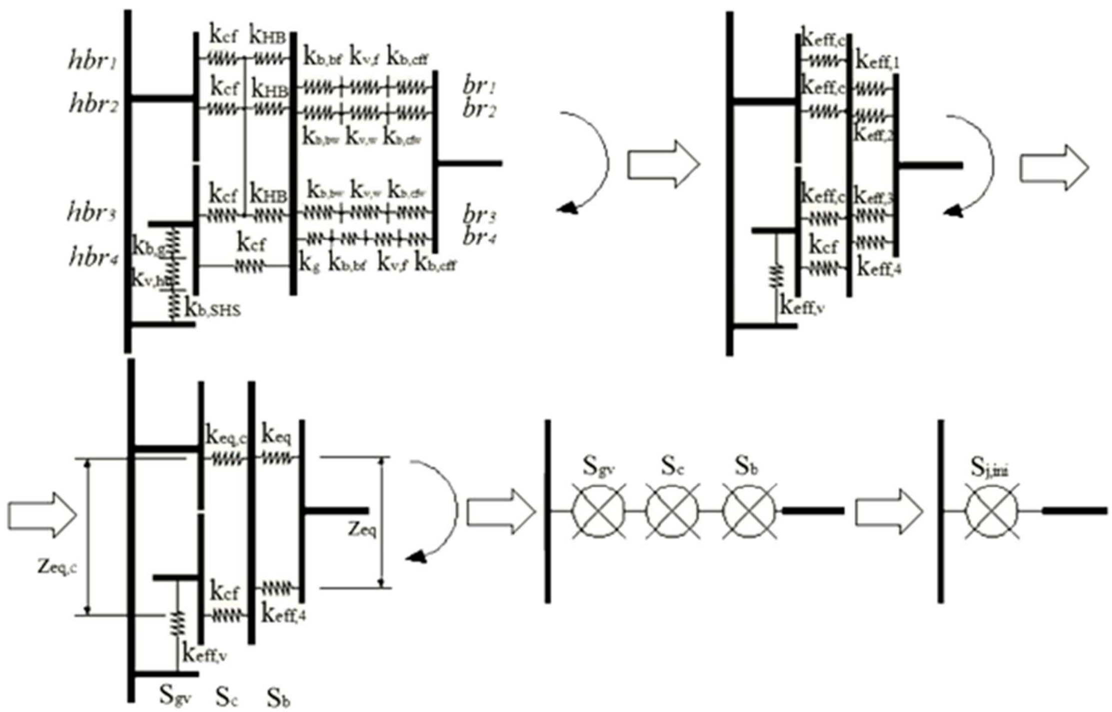


Figure 10: Proposed mechanical model and procedure for evaluating the rotational stiffness.

Figure 11 presents the chord face failure of the SHS section, when the effect is increased 50 times.

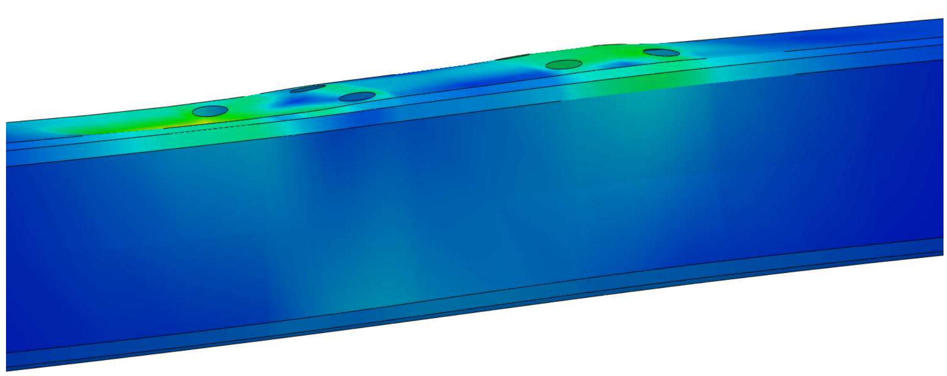


Figure 11: Chord face failure of SHS section (50x).

The stiffness coefficient describing the column face failure is quantified using the analytical method developed by Weynand et al. for beam-SHS column bolted end-plate connections [17]. Equation (9) describes the stiffness coefficient for the SHS column face in tension or in compression.

$$k_{cf} = \frac{t_{SHS}^3}{14.4\ \beta\ L_{stiff}^2} \left(\frac{L_{stiff}^2}{b\ t_{SHS}} \right)^{1.25} \frac{\dfrac{c}{L_{stiff}} + \left(1 - \dfrac{b}{L_{stiff}} \right) \tan\theta}{\left(1 - \dfrac{b}{L_{stiff}} \right)^3 + \dfrac{10.4 \left(k_1 - k_2 \dfrac{b}{L_{stiff}} \right)}{\left(\dfrac{L_{stiff}}{t_{SHS}} \right)^2}} \tag{9}$$

t_{SHS} is the wall thickness of the SHS section;

b is the width of the tension zone: $b=p_2+0.9d_{HB}$

- p_2 is the distance between the hollo-bolts acting in the tension zone;
- d_{HB} is the diameter of the hollo-bolt;

c is the height of the tension/compression zone: $c=0.9d_{HB}$

L_{stiff} is the equivalent yield length for stiffness evaluation: $L_{stiff}=b_{SHS}-2t_{SHS}-r$

- b_{SHS} is the width of the SHS section;
- r is the root radius;

$$\beta = \begin{cases} \left(0.7 + 0.6\dfrac{b+c}{L}\right) & if \quad \dfrac{b+c}{L_{stiff}} \leq 0.5 \\ 1 & if \quad \dfrac{b+c}{L_{stiff}} > 0.5 \end{cases}$$

$$\theta = \begin{cases} \left(35 - 10\dfrac{b}{L_{stiff}}\right) & if \quad \dfrac{b}{L_{stiff}} < 0.7 \\ \left(49 - 30\dfrac{b}{L_{stiff}}\right) & if \quad \dfrac{b}{L_{stiff}} \geq 0.7 \end{cases}$$

$k_1=1.5$;

$k_2=1.6$;

According to Weynand et al. [17] the validity of the stiffness formula k_{cf} requires the following conditions to be satisfied:

$$10 \leq \frac{L_{stiff}}{t_{SHS}} \leq 50$$

$$0.08 \leq \frac{b}{L_{stiff}} \leq 0.75$$

$$0.05 \leq \frac{c}{L_{stiff}} \leq 0.20$$

The width of compression zone was assumed equal to 75% of the equivalent yield length ($L_{stiff,}$), this being limited by one of the conditions presented above.

The stiffness coefficient of the hollo-bolts in tension was also included in the S_c individual rotational stiffness value and it was evaluated by using the experimental load-displacement curves of the M20 hollo-bolts subjected to tension, provided by Lindapter hollo-bolt manufacturer [18]. The obtained stiffness coefficient corresponds to the lower half of the stiffness interval of the hollo-bolts, determined by Lee et al. [19] by experimental testing of hollo-bolts.

Figure 12 depicts the HBBC joint geometry with the SHS face tension/compression zone similarly to Weynand et al. method [17], while figure 13 shows the M20 hollo bolt performance according to Lindapter [18].

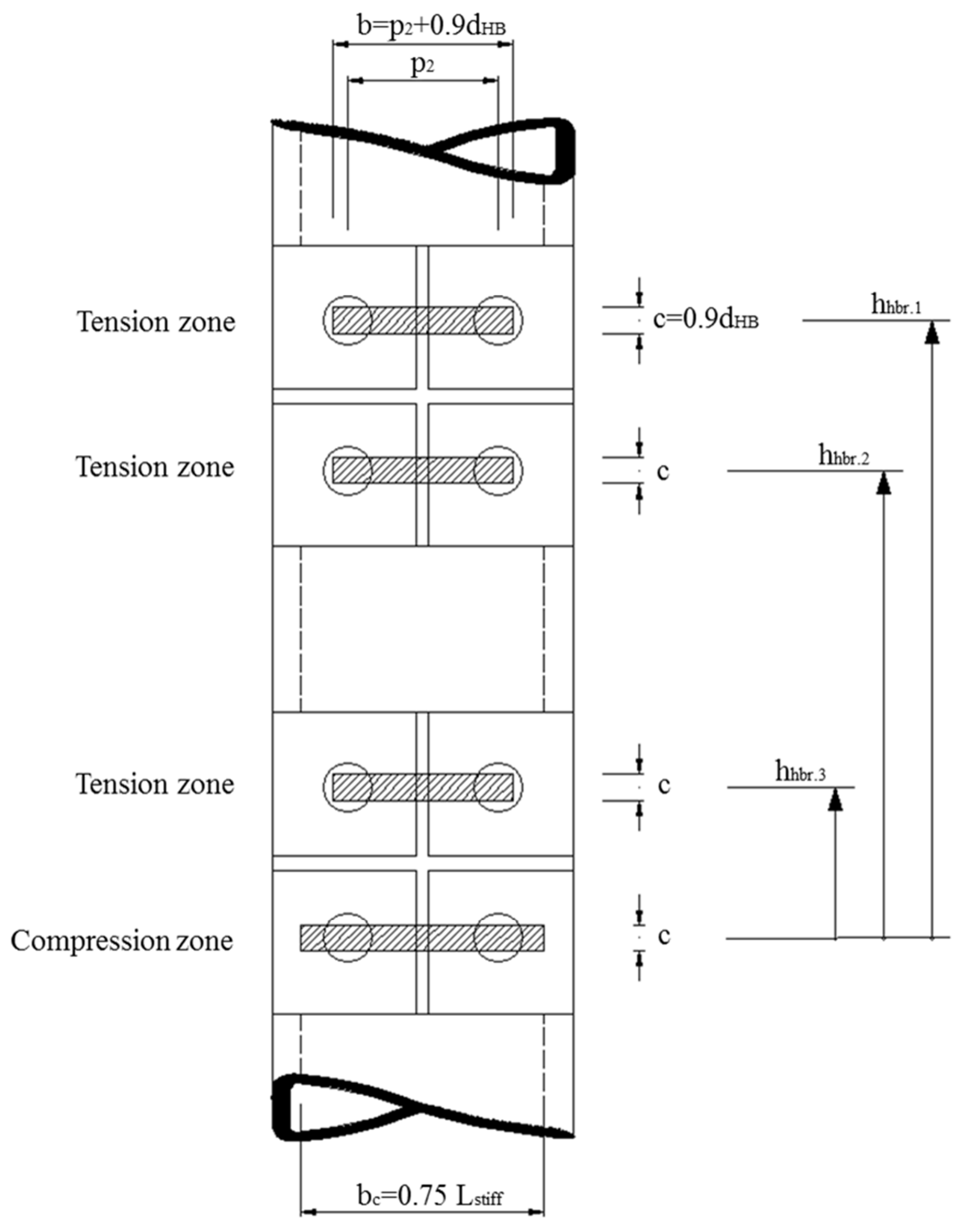


Figure 12: HBBC joint geometry with SHS face tension/compression zone similarly to Weynand et al. method [17].

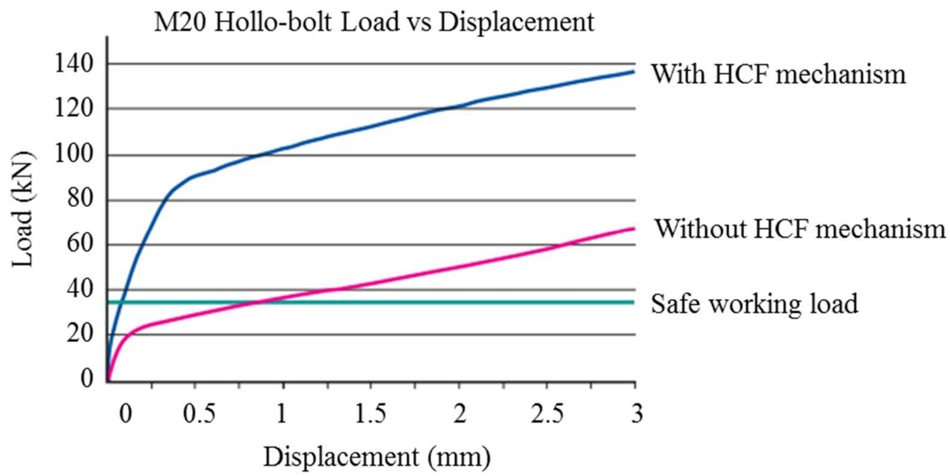


Figure 13: M20 Hollo bolt performance according to Lindapter [18].

Comparing to the previous joint configuration (DCBC), where the gusset plates are welded to the column, in case of those connected with hollo-bolts, the gusset element can move in the direction of the length of the SHS column due to the flexibility of the hollo-bolt connection subjected to shear. This is taken into consideration in the S_{gv} individual rotational stiffness value and the considered components can be seen in figure 14.

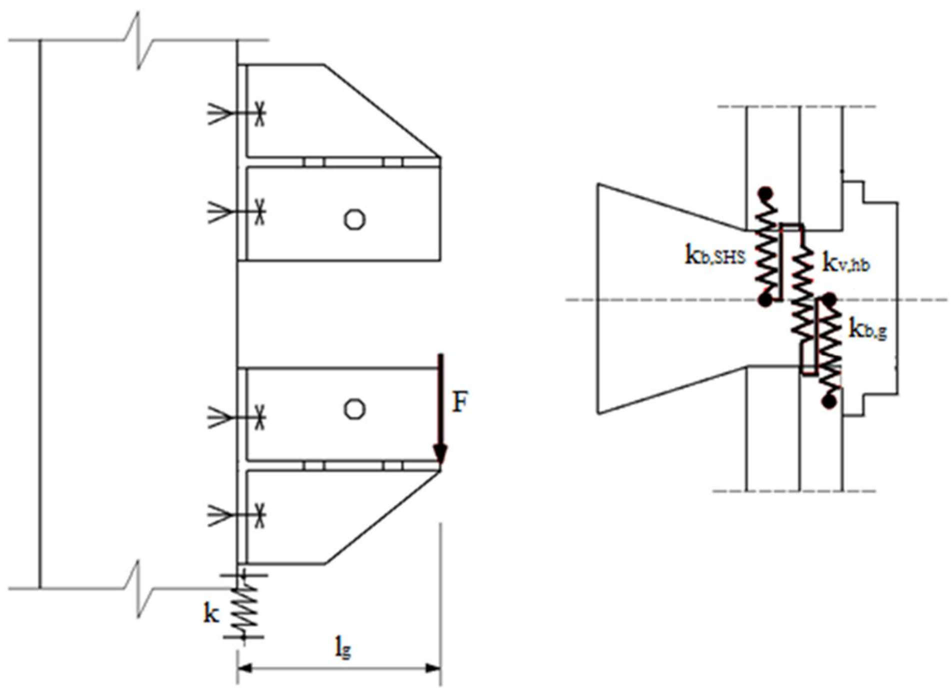


Figure 14: Components considered active in the displacement of the lower gusset due to the shear in the hollo bolt connections.

The individual stiffness coefficients are combined in a vertical row using equation (10), and finally a partial rotation stiffness due to this component is obtained as equation (11) presents:

$$k_{eff,v} = \frac{1}{\frac{1}{k_{b,SHS}} + \frac{1}{k_{v,hb}} + \frac{1}{k_{b,g}}} \tag{10}$$

$$S_{gv} = l_g^2 \ E \ k_{eff,v} \tag{11}$$

$k_{b,SHS}$ is the stiffness coefficient of the hollo-bolt in bearing on the SHS section component;
$k_{v,HB}$ is the stiffness coefficient of the hollo-bolt in shear component;
$k_{b,g}$ is the stiffness coefficient of the hollo-bolt in bearing on the gusset component;
l_g is the length of the gusset element;
S_{gv} is the individual rotational stiffness of the joint, when considering the components presented in figure 13;

Figure.15 shows the displacement of the left bracket due to shear stiffness of the hollo-bolt connections (Δ bracket2), and the bending of the bracket illustrated with the displacement Δ bracket1, when the effect is increased 20 times. The other bracket has similar behavior but with much smaller deformations at elastic level of the joint, and therefore its contribution to the joint stiffness is neglected.

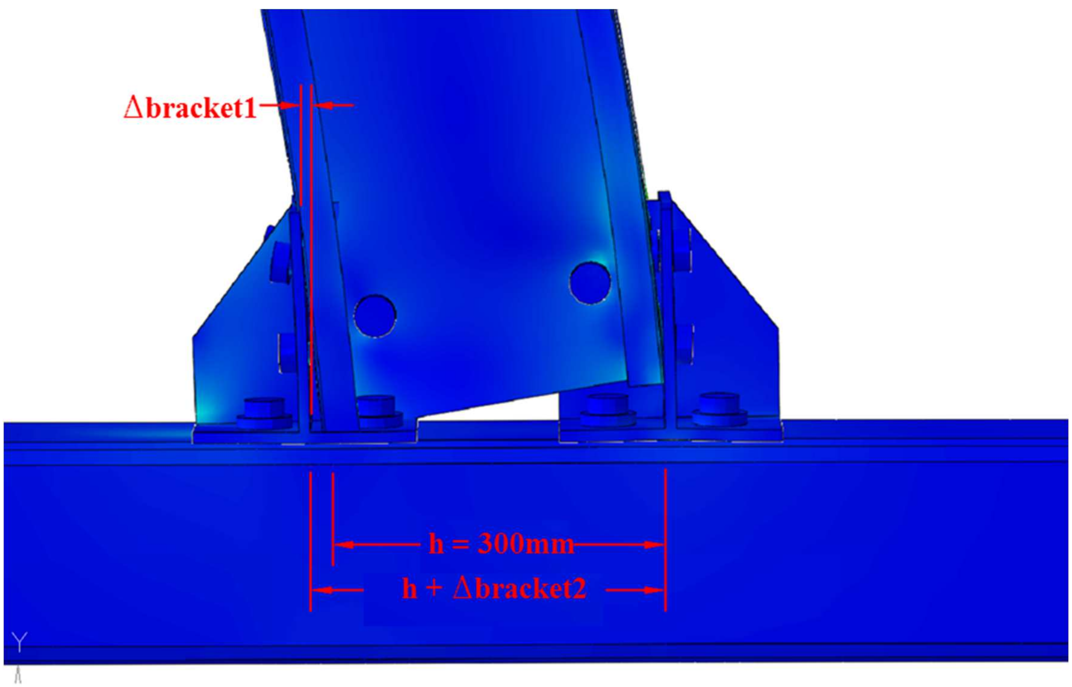


Figure 15: Deformations (20x) due to the shear in the hollo-bolt connection (at elastic region).

The final rotational stiffness of the HBBC joint is determined by using the equation (13).

$$S_{j,ini} = \frac{1}{\frac{1}{S_b} + \frac{1}{S_c} + \frac{1}{S_{gv}}} \tag{13}$$

Table 4 presents the results of application of component method for the HBBC joint, in terms of resistance values of the hollo-bolt connection components.

Table 4: Resistance of hollo-bolted connection components.

Hollo Bolt row	SHS web in shear [kN]	SHS flange in bending [kN]	Hollo bolt Tension [kN]	Bracket Tens/Comp [kN]	Bolt-row resistance [kN]
1	849.5	887.5	248*	528.3	248
2			248*		248
3			248*		248
4	849.5	887.5	248*	528.3	248
$M_{HBC,Rd}$ = 203.36 kNm					

*Tensile resistance value corresponding to 2 hollo-bolts, according to ETA-10/0416 [20]

The stiffness coefficients of the components in the bolted connection and the rotational stiffness of the bolted connection, S_b are presented in table 5.

Table 5: S_b rotational stiffness and the stiffness coefficients of the considered components

Bolt row	Bolts in shear [mm]	Bolts in bearing on the cold-formed member [mm]	Bolts in bearing on the bracket [mm]	Equivalent bracket deflection stiffness k_g [mm]	Bolt-row effective stiffness [mm]
1	3.809	0.860	1.697	-	0.496
2	3.809	0.915	0.771	-	0.377
3	3.809	0.915	0.771	-	0.377
4	3.809	0.860	1.697	0.759	0.300
S_b = 3334.7 kNm/rad					

Table 6 shows the stiffness coefficients taken into account in evaluation of the S_c rotational stiffness and the obtained value.

Table 6: S_c rotational stiffness and the stiffness coefficients of the considered components.

Hollo Bolt row	HB in tension [mm]	SHS Chord face failure [mm]	HB effective stiffness [mm]
1	2.857	1.354	0.919
2	2.857	1.354	0.919
3	2.857	1.354	0.919
4	-	1.578	1.578
S_c = 21790.7 kNm/rad			

The rotational stiffness S_{gv} and the stiffness coefficients of the considered components are shown in table 7.

Table 7: S_{gv} rotational stiffness and the stiffness coefficients of the considered components.

Hollo Bolt row	HB in shear [mm]	HB in bearing on the SHS [mm]	HB in bearing on the bracket [mm]	Effective stiffness [mm]
3-4	3.048	3.074	2.459	0.943
S_{gv} = 8487.7 kNm/rad				

The final HBBC joint moment resistance was determined by being the minimum between the bolted connection moment resistance ($M_{bC,Rd}$), the hollo-bolt connection resistance

($M_{HBC,Rd}$) and the moment resistance of the 2xC profile beam ($M_{beam,Rd}$), as seen in equation (12). The resistance of the bolted connection is the same, as for the DCBC connection (see table 1), as well as the moment resistance of the cold-formed member.

$$M_{C,Rd} = \min\left(M_{bC,Rd}, M_{HBC,Rd}, M_{beam,Rd}\right) \tag{12}$$

Thus, the comparison between the experimental and analytical initial joint stiffness and moment resistance of the HBBC joint is presented in table 8.

Table 8: Overall results of application of component method for the HBBC joint.

	Initial stiffness [kNm/rad]	Moment resistance [kNm
Experimental value	1838	111
Analytical value	2157	121
Deviation [%]	17%	9%

3 DISCUSSIONS

The used formulas for the determination of the rotational stiffness values of the joints showed certain sensitivity to some of the included terms. Thus, the observed sources of sensitivity regarding the obtained values and the justification of the made choices are discussed in the current section.

In the case of the DCBC joint, the final joint stiffness value is influenced by the position choice of the center of compression, which for the presented results was regarded as the contact area between the C profile and the bracket. Another alternative to this would be to consider the center of compression as the center of gravity of the two adjacent elements, which are connected by the bolts, or to take the center of gravity of only the bracket, this way changing the distance between the center of compression and the tension bolt rows and also increasing the overall joint rotational stiffness value.

During the determination of the joint rotational stiffness of the HBBC joint, certain questions arose regarding the applicability of the standard EC3 stiffness coefficient formulas given for basic joint components (bolts in shear, bolts in bearing on the connected elements), which are devised for regular bolts, since half of the joint is composed of hollo-bolts, which need a much larger hole diameter than the same size regular bolt and also have a sleeve (with inferior material properties than the bolt). The sleeve might have an effect on the resistance of the bolt, however it was deemed unreasonable to assume that the hollo bolt, composed of the bolt itself and the sleeve would have the same impact on the joint stiffness as a solid bolt having the diameter equal to the outer diameter of the sleeve. This is due to the fact, that the hollo-bolt is composed of two elements, having different material properties and a certain tolerance between them, making it more flexible than a solid bolt having the same diameter. Thus, in the case of the stiffness coefficient of the hollo-bolt bearing on the connected elements and the hollo-bolt in shear a more conservative approach was followed, according to which the diameter of the hollo-bolt introduced in the formula was equal to the diameter of the bolt itself, namely 20 mm. The variables influencing the non-standard stiffness coefficient formula, for the SHS chord face failure was the considered bolt diameter for the evaluation of tension and compression zone height, and the width of the compression zone. In the current paper the bolt diameter was taken as the outer diameter of the sleeve, while the compression zone width was taken as the maximum allowed by the formula limitations, since the plate applying pressure on the SHS profile has the same width as the SHS profile.

If the hollo bolt diameter would have been taken as the outer diameter of the sleeve (32.75 mm) throughout the joint rotational stiffness evaluation of the HBBC joint, then the final value would have increased with around 10 %, yielding a highly over-estimated rotational stiffness value.

4 CONCLUSIONS

Application of component method implemented in EN 1993-1-8 for the determination of connection behavior of single sided joints consisted of cold-formed build-up beam and SHS column presented in this paper is possible with some adjustments. The basic components are available in EN 1993-1-8 and additionally newly developed and reported components are taken in account to describe the joint rotation stiffness. The components identified as contributing to the strength and stiffness of the connections are: bolts in shear, bolts in bearing on the cold-formed member, bolts in bearing on the bracket and bending of the bracket. In case of connection using hollo-bolts the joint is divided in more components. The additionally required components for this case are: hollo-bolt in tension, chord-face failure of the SHS column in tension, hollo-bolts of the lower bracket in shear and bearing on the SHS column and on the bracket. Using the presented components, the obtained connection characteristics are reasonable in terms of accuracy, yielding deviations under 10% for the DCBC joint and deviations under 20% for the HBBC joint. However, it should be noted, that the applied non-standard stiffness coefficients showed high sensitivity to the introduced data, especially the stiffness coefficient of the SHS chord face failure, which was also limited in terms of compression zone width. The position chosen for the center of compression, as well as the bolt diameter considered for the hollo bolts could also be considered as other sources of sensitivity, considering the final value of the joint rotational stiffness obtained by using the component method.

The analytical evaluation of moment resistance gave the same result for both joint types. This is because the component having the lowest resistance in both joint types is the beam, built up of the same type of C profiles.

The moment resistant joints can be evaluated analytically with the presented design concept. Further research activity will be carried out in order to confirm and extend the applicability of the proposed component method approach, using parametric studies on FEM models.

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