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Single and Double Step Joints Design

Overview of European standard approaches compared to experimentation

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ABSTRACT

In the field of Built Heritage Restoration, Engineers have to work with old timber trusses made of badly preserved joints, by figuring out how the carpentry connections fail, which geometrical parameters of the joint influence the failure modes and how the internal forces are distributed inside the joint. The present paper overviews two common traditional connections: Single Step Joint (SSJ), and Double Step Joint (DSJ). For both connections, some recommendations about the geometrical parameters and design models are defined by European standards and authors of works. But no one details how to design both Step Joints against the shear crack in the tie beam and the compressive crushing at the front-notch surface. Therefore, the design equations with respect to both failure modes must properly be determined. The reliability of SSJ design equations and the failure modes have been checked by performing several SSJ specimens under monotonic compression test.

1 INTRODUCTION

From the old traditional to contemporary carpentries according to Yeomans (2003), the Single Step Joint (SSJ) and Double Step Joint (DSJ) have often been used in order to connect the rafter with the tie beam, at the foot (also called step) of timber trusses. Over time, both common Step Joints may be subjected to structural damage such as the shear crack in the tie beam and the crushing at the front-notch surface. The former causes the destabilization of the timber truss while the latter generates high deformation inside the connection. Therefore, the present paper aims at determining the design equations in order to prevent both failure modes in Single and Double Step Joints, with respect to their geometrical parameters. To this end, several geometrical recommendations and design models from European standards (e.g. DIN 1052

(2004), Eurocode 5 (2004)) and state-of-the arts (e.g. Siem et al. (2015), Bocquet (2015)) must firstly be overviewed for both traditional connections. In order to check the reliability of design equations and the appearance conditions of both failure modes, several SSJ specimens have been tested under monotonic compression, by modifying their geometrical parameters.

2 SINGLE STEP JOINT DESIGN

2.1 Geometrical parameters

As illustrated in Figure 1, the Single Step Joint (SSJ) is characterized by a single heel, including two contact surfaces, between the rafter and the tie beam. The first contact area called ‘’front-notch surface’’ is located in the front of the joint whereas the last one, called “bottom-notch surface”, is situated at the bottom of the same connection. The front-notch (bottom-notch) surface is inclined under an angle α (γ) to the normal of the grain (parallel to the grain) in the tie beam. The Single Step Joint is also characterized by the heel depth t_v, the shear length l_v, and the rafter skew angle β. Note that the state-of-the art of Siem et al. (2015) can propose some recommendations from European standards about the geometrical SSJ parameters as detailed in Table 1. The recommended values framed in red must be checked for the SSJ geometrical parameters when designing contemporary timber trusses. According to Oslet (1890), all the SSJ geometrical configurations can be gathered from the past until today into three SSJ families, as shown in Figure 1: the Geometrical Configuration Ideal Design (GCID), the Geometrical Configuration Perpendicular to the Tie beam (GCPTB) and the Geometrical Configuration Perpendicular to the Rafter (GCPR). Being the most efficient SSJ due to the ideal inclination of the front-notch surface, the GCID is also the most recent as its geometry requires an accurate timber cutting, using the new technologies (e.g. Computer Numerical Control (CNC)). By opposition, the GCPR and GCPTB are mostly encountered within old timber carpentries.

2.2 Design equation against the shear crack

As show in Figure 2, the design rafter load-bearing capacity, noted $N_{rafter,Rd}$, must be checked by the equation (1) below in order to avoid the shear crack in the tie beam for all the SSJ geometrical configurations, according to Siem et al. (2015) and Bocquet (2015):

$$N_{rafter,Rd} \leq k_{v,red} \cdot f_{v,k} \, \frac{k_{mod}}{\gamma_M} \cdot \frac{b \, . \, k_{cr} \, . \, \min(l_v, 8.t_v)}{\cos\beta} \qquad (1)$$

where: $k_{v,red}$ = reducer coefficient, taking into account the heterogeneous shear stress distribution along the grain in the tie beam ($k_{v,red}$=0.8 conform with the Dutch National Annex from Eurocode 5, according to Siem et al. (2015)); $f_{v,k}$= characteristic shear strength of timber in the tie beam; k_{mod}= modification factor for duration of load and moisture content; γ_M=

partial coefficient of timber material (Eurocode 5 (2004)); γ_M= partial coefficient of the material (Eurocode 5 (2004)); k_{cr}= reducer factor of the tie beam width b, taking into account the influence of cracks on the shear strength along the grain, for timber elements subject to bending (k_{cr}=0.67 for solid timber, from the Amendment 1 of Eurocode 5(2008)); $8.t_v$= maximal value of the shear length according to the heel depth (DIN 1052 (2004)).

2.3 Design equation against the crushing at the front-notch surface

As illustrated in Figure 3, the design rafter load-bearing capacity, noted $N_{rafter,Rd}$, must be checked at the rafter and tie beam side respectively by the equations (2)-(3) and (4)-(5) in order to avoid the crushing at the front-notch surface for the GCID ($\alpha = \beta/2$), according to Siem et al. (2015) and Bocquet (2015). Concerning the GCPTB characterized by an inclination angle of the front-notch surface $\alpha = 0°$, the crushing always occurs at the rafter side as the related compressive strength is lower than that at the tie beam side. Hence, the design rafter load-bearing capacity from the GCPTB, noted $N_{rafter,Rd}$, must be checked only at the rafter side by the equations (2)-(3). In contrast to the GCPTB, the crushing always appears at the tie beam side for the GCPR as this SSJ configuration is featured by an inclination angle of the front-notch surface $\alpha = \beta$. Thereby, the design rafter load-bearing capacity from the GCPR, noted $N_{rafter,Rd}$, must be checked only at the tie beam side by the equations (5)-(6) below.

$$N_{rafter,Rd} \leq k_{c,\beta-\alpha} \cdot f_{c,\beta-\alpha,k} \cdot \frac{k_{mod}}{\gamma_M} \cdot \frac{b.\, t_{ef,rafter} \cdot sin(90+\alpha-\gamma)}{sin(90-\beta+\gamma)} \tag{2}$$

$$t_{ef,rafter} = \frac{t_v}{\cos(\alpha)} + 30\, sin(\beta-\alpha) + 30\sin(\alpha-\gamma) \tag{3}$$

$$N_{rafter,Rd} \leq k_{c,\alpha} \cdot f_{c,\alpha,k} \cdot \frac{k_{mod}}{\gamma_M} \cdot \frac{b.\, t_{ef,tb} \cdot sin(90+\alpha-\gamma)}{sin(90-\beta+\gamma)} \tag{4}$$

$$t_{ef,tb} = \frac{t_v}{cos(\alpha)} + 30\, sin(\alpha) + 30 \tag{5}$$

$$N_{rafter,Rd} \leq k_{c,\alpha} \cdot f_{c,\alpha,k} \cdot \frac{k_{mod}}{\gamma_M} .b \cdot t_{ef,tb} \tag{6}$$

where: $f_{c,\alpha,k}$= characteristic compressive strength of timber at the front-notch surface under an angle α to the grain in the tie beam; $f_{c,\beta-\alpha,k}$= character compressive strength of timber at the front-notch surface under an angle $\beta-\alpha$ to the grain in the rafter; $t_{ef,rafter}$= effective length from the front-notch surface related to the crushing spreading in the rafter; $t_{ef,tb}$= effective length from the front-notch surface related to the crushing spreading in the tie beam; $k_{c,\alpha}$= factor depending on the loading geometrical configuration, and on the spreading of the compressive stress under an angle α to the grain inside timber, conform with Eurocode 5 (2004) and DIN 1052 (2004), ($k_{c,\alpha} = 1$ for carpentry connections, according to Siem et al. (2015)).

3 DOUBLE STEP JOINT DESIGN

3.1 Geometrical parameters

When the maximal limitation of the shear length l_v is too harsh for the Single Step Joint (e.g. architectural geometrical restrictions), the Double Step Joint (DSJ) is only used instead in order to prevent the shear crack in the tie beam. Thanks to the wide foot including both heels between the rafter and the tie beam as shown in Figure 4, the total shear length and the shear strength of the DSJ is higher than in the Single Step Joint (SSJ). However, the DSJ geometrical configurations require accurate timber cutting using new technologies (e.g. CNC) and should then be used only if it is necessary for low rafter skew angle β according to Siem et al. (2015). As illustrated in Figure 4, the "Front Heel" is located in the front whereas the last one called "Rear Heel" is situated in the Rear of the DSJ. Similarly to the SSJ, each heel includes two contact surfaces between the rafter and the tie beam: the front-notch surface which is located in the front, and the bottom-notch surface which is situated in the bottom of each heel. Whereas the inclination angles of the front-notch and bottom-notch surfaces (i.e. α and γ) in the Front heel are identical to the three SSJ families, those in the Rear heel are related to the GCPR (i.e. $\alpha = \gamma = \beta$). In the DSJ, the shear length at the Front Heel depth $t_{v,1}$, noted $l_{v,1}$, is the distance between the top of the Front Heel and the tie beam edge along the grain whereas the shear length at the Rear Heel depth $t_{v,2}$, noted $l_{v,2}$, is the distance between the top of both heels along the tie beam grain. Note that the state-of-the art of Siem et al. (2015) can propose some recommendations from European standards about the DSJ geometrical parameters with values framed in red, as detailed in Table 2.

3.2 Design equation against the shear crack

As shown in Figure 5, the design rafter load-bearing capacity, noted $N_{rafter,i,Rd}$, must be checked by the equation (7), similar to (1) from the SSJ design, in order to avoid the shear crack in the tie beam for each DSJ heel, according to Siem et al. (2015) and Bocquet (2015):

$$N_{rafter,i,Rd} \leq k_{v,red,i} \cdot f_{v,k} \, \frac{k_{mod}}{\gamma_M} \cdot \frac{b \,.\, k_{cr} \,.\, \min(l_{v,i}, 8.t_{v,i})}{\cos\beta} \tag{7}$$

where: i = number of the DSJ heel (i.e. i=1 for the Front heel, i=2 for the Rear heel).

From Bocquet (2015), 2 mm gap is preconized at the front-notch surface in the Front heel to optimize the rafter load-bearing capacity of DSJ against the shear crack. If the geometrical recommendation is checked, the internal forces resolution becomes ideal in the DSJ so that the rafter load-bearing capacities $N_{rafter,i,Rd}$ can reach their maximal values in both heels. Besides, the shear crack may emerge at the Front and Rear Heel depths ($t_{v,1}$ and $t_{v,2}$) along their respective shear length ($l_{v,1}$ and $l_{v,2}$) as illustrated in Figure 5. In order to prevent the shear crack in the tie beam at the Front and Rear Heel depths, the maximal design rafter load-bearing capacity, noted $N_{rafter,max,Rd}$, must be checked such as a sum of design rafter load-bearing capacities related to both heels given by the equation (7).

$$N_{rafter,max,Rd} = N_{rafter,1,Rd} + N_{rafter,2,Rd} \tag{8}$$

If the recommendation from Bocquet (2015) is not checked for the front-notch surface of the Front Heel, the internal forces resolution is then not ideal. Thereby, the rafter load-bearing capacity from the Rear Heel doesn't reach its maximal value and the emergence of shear crack will only occur at the Front Heel depth $t_{v,1}$ in the tie beam. Hence, the total design rafter load-bearing capacity of Double Step Joint (9), noted $N_{rafter,tot,Rd}$, is always between the design rafter load-bearing capacity the Front Heel ($N_{rafter,1,Rd}$) and the maximal design rafter load-bearing capacity ($N_{rafter,max,Rd}$) respectively calculated by equations (7) and (8).

$$N_{rafter,1,Rd} \leq N_{rafter,tot,Rd} \leq N_{rafter,max,Rd} \tag{9}$$

3.3 Design equation against the crushing at the front-notch surface

As illustrated in Figure 6, the design rafter load-bearing capacity against the crushing at the front-notch surface in the Front Heel, noted $N_{rafter,1,Rd}$, must be checked by the equations (2)-(3)-(4)-(5)-(6) with respect to the three SSJ families. The design rafter load-bearing capacity against the crushing at the front-notch surface in the Rear Heel, noted $N_{rafter,2,Rd}$, must be checked by the GCPR design equation (6), based on the effective length $t_{ef,2,tb}$ (10) in the Rear heel of DSJ as shown in Figure 7.

$$t_{ef,2,tb} = \frac{t_{v,2}}{cos(\beta)} + 30\ sin(\beta - \gamma) + 30 \tag{10}$$

From Bocquet (2015), 2 mm gap is also preconized at the front-notch surface in the Front heel to optimize the rafter load-bearing capacity of DSJ against the crushing at the front-notch surface. If the geometrical recommendation is checked, the internal forces resolution becomes ideal inside the DSJ so that the rafter load-bearing capacities (i.e. $N_{rafter,1,Rd}$ and $N_{rafter,2,Rd}$) can reach their maximal values in both heels. In order to prevent the crushing at the front-notch surface, the maximal design rafter load-bearing capacity, noted $N_{rafter,max,Rd}$, must be checked such as a sum of design rafter load-bearing capacities related to the Front and Rear Heels, similarly by the equation (7). If the geometrical recommendation from Bocquet (2015) is not checked, the internal forces resolution is then not ideal. As the Front Heel depth $t_{v,1}$ is inferior to the Rear Heel depth $t_{v,2}$, the rafter load-bearing capacity from the Front Heel will probably reach its maximal value before that from the Rear Heel does. Calculated by the equation (9), the total design rafter load-bearing capacity of DSJ, noted $N_{rafter,tot,Rd}$, is always between the design rafter load-bearing capacity from the Front Heel ($N_{rafter,1,Rd}$) and the maximal design rafter load-bearing capacity ($N_{rafter,max,Rd}$) against the crushing at the front-notch surfaces.

4 EXPERIMENTATION ON SINGLE STEP JOINT

4.1 Experimental process and specimens

As the geometry and design models related to the Single Step Joint (SSJ) are simpler than those from the Double Step Joint (DSJ), the experimentation from Verbist et al. (2017) has firstly been performed on SSJ specimens, to determine their mechanical behaviour (i.e. rafter load-bearing capacity, and the failure modes). By modifying their geometrical parameters, several SSJ configurations have then been tested under normal monotonic compression in the rafter to check the reliability of SSJ design equations and the appearance conditions of both failure modes (i.e. shear crack in the tie beam, and crushing at the front-notch surface).

Because the GCPR and GCPTB are the most encountered SSJ in old traditional carpentries whereas the GCID is only present in new timber trusses, all the three SSJ families have been performed by changing the inclination angle α of the front-notch surface. As the emergence of failure modes is mainly conditioned by the rafter skew angle β with respect to design equations, two values have then been selected: $\beta = 30°$ for the shear crack, $\beta = 45°$ for the crushing. Note that the specimen labelling used for each SSJ geometrical configuration can be described by illustrating the following example: GCTB_30^{o}_tv25_240SL. The first term deals with the three SSJ families (i.e. GCID, GCPR, and GCPTB). The second term is related to the rafter skew angle β [°]. The third term determines the size of the heel depth t_v [mm] while the fourth one defines the size of the shear length l_v [mm].

The *Pinus sylvestris* has been chosen as Wood Species for the experiments on SSJ specimens. According to the mechanical characterization of small timber samples from Verbist et al. (2017), the *Pinus sylvestris* can belong to the wood class C24 (Eurocode 5 sorting of wood) featured by: the characteristic compressive strengths $f_{c,0,k} = 29.4$ MPa, $f_{c,15,k} = 20.7$ MPa, $f_{c,30,k} = 12.9$ MPa, $f_{c,90,k} = 3.7$ MPa (parallel, inclined under 15° and 30° angles, and perpendicular to the grain respectively), and the characteristic shear strength $f_{v,k} = 4$ MPa parallel to the grain. Based on these wood mechanical properties, the theoretical rafter load-bearing capacities ($\mathrm{N}_{\mathrm{rafter,theo}}$) can then be calculated by the SSJ design equations previously defined with respect to both failure modes, as detailed in Table 3.

4.2 Discussion about SSJ design equations

In order to check the reliability of SSJ design equations with respect to the failure modes, both maximum normal loads in the rafter $\mathrm{N}_{\mathrm{rafter,exp}}$ for each SSJ configuration tested can be compared with the theoretical rafter load-bearing capacity ($\mathrm{N}_{\mathrm{rafter,theo}}$) as detailed in Table 3. From the SSJ design equations, the following parameters have been chosen for all the SSJ geometrical configurations: k_{mod}=0,9, γ_M=1,3, $k_{c,\alpha} = 1$ and $k_{v,red}$=0,8. Based on the general formulation $COV = 100. Deviation/Average$, the coefficient of variation COV [%] is defined for the experimental results from a same SSJ geometrical configuration such as $Deviation = |N_{rafter,exp1} - N_{rafter,exp2}|$ and $Average = \left(N_{rafter,exp1} + N_{rafter,exp2}\right)/2$. Besides, the relative variation $\Delta_{\mathrm{rel,rafter}}$ [%] of maximum normal loads in the rafter between the smallest of both experimental results and the theoretical value is determined for each SSJ configuration, according to both failure modes: $\Delta_{\mathrm{rel,rafter}}$=$100. (N_{rafter,expmin} - N_{rafter,theo})/N_{rafter,theo}.$

As illustrated in Figures 2 and 8, the shear crack emerges at the heel depth t_v in the tie beam and spreads along the shear length l_v to the tie beam end. According to the SSJ families and the geometrical proportion l_v/t_v, the shear crack may appear as the final failure mode due to high crushing at the front-notch surface. The SSJ design equations against the shear crack can predict the maximum normal load in the rafter for the majority of β=30° specimens tested, apart from the tv30_160SL specimens and the GCPR for which they are too restrictive ($\Delta_{\mathrm{rel,rafter}}$≅50%). Moreover, the crushing at the front-notch sometimes emerges instead of the shear crack for the GCID and GCPR characterized by high geometrical proportions $l_v/t_v \geq 8$ while the shear crack is more likely to occur for the GCPTB. Hence, the reducer coefficient $k_{v,red}$ taking into account the heterogeneous shear stress in the tie beam (Figure 2) varies according to the geometrical proportion l_v/t_v and to the inclination angle α of the front-notch surface. To simplify these correlations, the reducer coefficient $k_{v,red}$=0.8 can be imposed with safety in the design equations for all the SSJ geometrical configurations including $l_v/t_v \geq 6$ whereas it can be neglected for the others specimens ($k_{v,red}$=1) checking $l_v/t_v < 6$. If further research aims at optimizing the SSJ design equation against the shear crack, the reducer coefficient $k_{v,red}$ should then be calculated by empirical equations such as $k_{v,red}$=$f(\alpha\ , l_v/t_v)$.

As shown in Figure 9, the compressive crushing occurs at the front-notch surface in the rafter and/or the tie beam. Regarding this failure mode, the relevance of design equations depends on the rafter skew angle β and the inclination angle α of the front-notch surface. Concerning the GCID, the design equations can predict the maximum normal load in the rafter although they are quite safe ($\Delta_{\mathrm{rel,rafter}}$≅35%) for the β=45° specimens. This safety may come from the assumption to neglect the friction forces at the contact surfaces of the Single Step Joint in the design equations. Indeed, the higher the rafter skew angle β, the higher the friction forces and thus the rafter load-bearing capacity of the connection. Therefore, the friction forces should be taken into account to design the Single Step Joint characterized by rafter skew angles $\beta \geq 30°$. However, the design equations cannot anticipate the experimental values $\mathrm{N_{rafter,exp}}$ concerning the GCPR and the GCPTB because they are too restrictive ($\Delta_{\mathrm{rel,rafter}} \gg 50\%$) for the $\beta = 45°$ specimens. The underestimation of the rafter load-bearing capacity may come from the low reliability of the criteria from the state-of-the art of Siem et al. (2015) when calculating the characteristic compressive strength $f_{c,a,k}$ under inclination angles $\alpha \geq 30°$ to the grain of timber. Because the loading factor $k_{c,\alpha}$ has been neglected ($k_{c,\alpha} = 1$) in the SSJ design equations, the theoretical approximations of the characteristic compressive strength $f_{c,a,k}$ are too restrictive when the inclination angle α of the loading to the grain is superior to 30°. As the inclination angle $\propto$ of the front-notch surface is equal to the rafter skew angle β for the GCPR at the tie beam side and for the GCPTB at the rafter side, the relative differences $\Delta_{\mathrm{rel,rafter}}$ between $\mathrm{N_{rafter,exp}}$ and $\mathrm{N_{rafter,theo}}$ is higher than those for the GCID specimens featured by a lower inclination angle of compressive loading to the grain : $\propto = \beta/2$. Hence, the factor $k_{c,\alpha}$ should be taken into account in the SSJ design equations ($k_{c,\alpha} > 1$) for the GCPTB and GCPR characterized by a moderate inclination angle of the front-notch surface ($\alpha \geq 30°$).

5 CONCLUSION

Based on geometrical and design recommendations from the European standards and authors of works, the design equations have been determined for the Single Step Joint (SSJ) and Double Step Joint (DSJ) with respect to both failure modes: the shear crack in the tie beam, and the crushing at the front-notch surface. As the Single Step Joints make easier for cutting timber due to their simple geometry, they have then been tested under monotonic compression by modifying the main SSJ geometrical parameters. Thereby, the reliability of SSJ design equations and the emergence conditions of both failure modes have been discussed and checked.

Relating to the shear crack, it has been shown that the reducer coefficient $k_{v,red} = 0.8$ according to the experimental results must be imposed with safety for the SSJ geometrical configurations including the parameter $l_v/t_v \geq 6$ whereas it can be neglected for the other ones ($k_{v,red} = 1$). Following this recommendation, the design equations and the emergence of the shear crack can be checked as the final failure mode in the Single Step Joint whatever the rafter skew angle β. As further research on the heterogeneous shear stress distribution in the tie beam, empirical equations giving $k_{v,red} = f(\alpha\,, l_v/t_v)$ should be determined accurately in order to improve much more the reliability of the SSJ design equations. Thereby, Finite Element Models based on SSJ geometrical configurations tested should be developed in order to predict better the shear crack by determining the reducer coefficient $k_{v,red}$, with respect to the SSJ geometrical parameters and the experimental results.

The reliability of SSJ design equations against the crushing at the front-notch surface have been checked for all the GCID specimens. However, they are too restrictive for the GCPTB and GCPR with the rafter skew angle β=45°, due to the bad theoretical approximation of the characteristic compressive strength $f_{c,a,k}$. For moderated inclination angles of compressive loading to the grain ($\alpha \geq 30°$), the factor $k_{c,\alpha}$ should not be neglected ($k_{c,\alpha} > 1$) in the SSJ design equations when assessing the characteristic compressive strength $f_{c,a,k}$ of timber at the front-notch surface. Besides, the SSJ design equations are also restrictive because the friction inside the connection has been negligible wrongly. Thereby, the friction forces at the contact surfaces of the Single Step Joint should be taken into account in the design equations for rafter skew angles $\beta \geq$30°.

The SSJ design equations and recommendations quoted above could also be applied to design the Front and Rear Heels of the Double Step Joint against the shear crack in the tie beam and the crushing at the front-notch surfaces. Nevertheless, future experimental and numerical assessments on the Double Step Joint are required to check the reliability of design equations and the appearance conditions of both failure modes, by modifying the main DSJ geometrical parameters.

Note that the SSJ specimens tested in laboratory come from young timber. Even if its mechanical properties can be approached with theoretical equations, it is not the case at all for timber from older carpentries. In the field of Built Heritage Restoration, the characterization of the traditional timber joints (e.g. strength, stiffness) can hardly happen without extracting some samples from the remaining structure. Due to the presence of damaged timber elements and joints, it is not possible to predict the emergence of failure modes inside the old carpentries, based only on the design equations previously defined for the sound Single and Double Step Joints. In order to take into account the impact of damage on the mechanical behaviour of old Step Joints, some reducer coefficients should then be introduced in the proposed design equations from the present research.

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REFERENCES

Bocquet, J-F. (2015). Les assemblages de charpentes traditionnelles dans le futur contexte réglementaire. Eurocode 5 : Conception et calcul des structures en bois – Sous-partie : Assemblage – *Formation ENSTIB* – Université de Lorraine, France.

DIN 1052:2004-08, Deutsche Norm (2004). *Design of timber structures - General rules and rules for buildings* - DIN Deutsches Institut für Normung e. V. - Praxishandbouch Holzbau - Edition 2004-08 - August, 2004.

Eurocode 5, NBN EN 1995-1-1 (2004). *Design of timber structures – Part 1-1: General – Common rules and rules for buildings* – CEN, European Standardization Institute – Brussels, Belgium, November 2004.

Eurocode 5, NBN EN 1995-1-1/A1 (2008). *Amendement 1 – Conception et calcul des structures en bois – Part 1-1: Généralité – Règles communes et règles pour les bâtiments* – CEN, Institut Européen de Standardisation, Bruxelles, Belgique.

Oslet, G. (1890). *Traité de charpente en bois, Encyclopédie théorique & pratique des connaissances civiles et militaires. Partie Civile, Cours de construction, Quatrième partie* – Edited by Chairgrasse H. Fils, Paris, France. Digital reproduction.

Siem, J., Jorissen, A. (2015). Can Traditional Carpentry Joints be assessed and designed using modern standards? – *Structural Health Assessment of Timber Structures. Shatis'15: 3rd International Conference on Structural Health Assessment of Timber Structure*, Volume 1 – Edited by Jerzy Jansienko, Tomasz Nowak. Wroclaw – Poland, September 9-11, 2015.

Verbist, M., Branco, J.M., Poletti, E., Descamps, T., Lourenço, P.B. (2017). Single Step Joint: overview of European standardized approaches and experimentations – *Materials and Structures* – DOI 10.1617/s11527-017-1028-4 – March 27, 2017.

Yeomans, D. (2003). *The Repair of Historic Timber Struc*tures - Editor, Thomas Telford Ldt, London - Published by ICE Publishing, United Kingdom - October 10, 2003.