Steel-to-Timber and Timber-to-Timber Simple Shear Connections

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Abstract: - The main objective of this manuscript is to present an analytical procedure of steel-to-timber and timber-to-timber connections in simple shear, related to the calculated number of dowels needed. These types of connections need to be assembled by dowel–type fasteners, such as nails, screws, bolts, and dowels. In this work, the connections are fixed with steel dowels. Timber connections made with dowels are a good choice, they look great when compared to screw connections and are rigid because have a tight fit while screws have a loose fit in the hole. Different simplified equations were used to calculate the characteristic load-carrying capacity in simple shear per fastener. These equations are useful in designing connections in simple shear when loaded in tensile and allow calculating the number of dowels needed. To obtain the results for discussion, different parameters were considered: three steel dowel diameters, three applied tensile loads, and three species in homogeneous glued laminated timber, each one with different densities. The discussion of the results shows that the number of dowels increases when the diameter decreases, and the material properties have a lesser dependence on this calculation. Using these simplified equations provides a better and easier understanding of the factors that can affect the behavior of steel-to-timber and timber-to-timber connections in simple shear. The key connection point is the shear capacity and ductility behavior of the screw and or dowel element, as presented in this work.

Key-Words: - Eurocode 5, timber connections, steel dowels, simplified equations, load capacity, strength material.

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1 Introduction

The load-carrying capacity of the connections can be described by the European Yield Model based on a plastic limit state analysis. The first researcher working in this area assumes this model has an ideal rigid-plastic behavior of the timber and steel dowel, [1]. This method predicts the strength of a two or three-member dowel type connection, [2].

Timber-steel connections are fragile members of structural construction, and the possibility of brittle failures cannot be avoided in many situations. Both steel and timber materials behave differently and the interaction between the elements is even more complex to analyze.

Many works are presented by some researchers to study different connections and their capacity due to different applied boundary conditions. Among others, some researchers present a numerical methodology to study an asymmetric multi-bolted connection preloaded and cyclically exposed to normal and tangential loads, [3]. Another study by [4] presents experimental tests about the behavior of simple supported composite steel-concrete beams exposed to bending using shear connections, focused on the use of fiber-reinforced concrete to reduce the percentage of additional reinforcement in the concrete dowels.

With the growth concern about climate change, the use of timber in building construction presents itself as a solution to this problem. Timber is a sustainable material when compared with the use of other materials, requiring only minimum processing when compared with materials like steel, concrete, or aluminum. The major justification is related to the positive contribution to the carbon cycle and the lowest used energy through its whole process. In addition, timber can present good mechanical characteristics, such as strength and density properties.

Connections have been reported as many problems as possible in structures related to the collapse, involving connections dowel-type, [5], [6]. However, most failures occur due to human errors [5], [6]. Another important issue related to the physical properties of timber which affects some failures and consecutively its strength, deformation, and durability is the moisture content, [7]. The effect of moisture content on the load-carrying capacity and stiffness of connections has been demonstrated by researchers, [7], [8], [9].

The main goal of this work is to present analytical methodologies to predict the safety of connections in simple shear, determining the load-carrying capacity and the number of needed dowels for the connection.

Different constructive connections in a simple shear, joined by steel dowels will be calculated. This study brings results to the previous investigations by the authors [10], looking for the effect of steel dowels and different materials. The designed connections were evaluated for different applied tensile loads parallel to the grain, different dowel diameters, and different timber material densities.

2 Materials and Methods

The geometric model of the steel-to-timber and timber-to-timber connections under study will be calculated according to Eurocode 5, part 1-1, [11], as represented in Figure 1 and Figure 2. To obtain the dimensions of the connections it was used the material properties involved in the study. The main dimensions of the connection are the width (*L*), height (*H*), the depth (*W*) obtained by the thickness of the timber (t_1 or t_2) and steel plates (t_s), the minimum spacing, and edge/end distances between the dowels and the plates (a_1, a_2, a_3, and $a_{4,t}$).

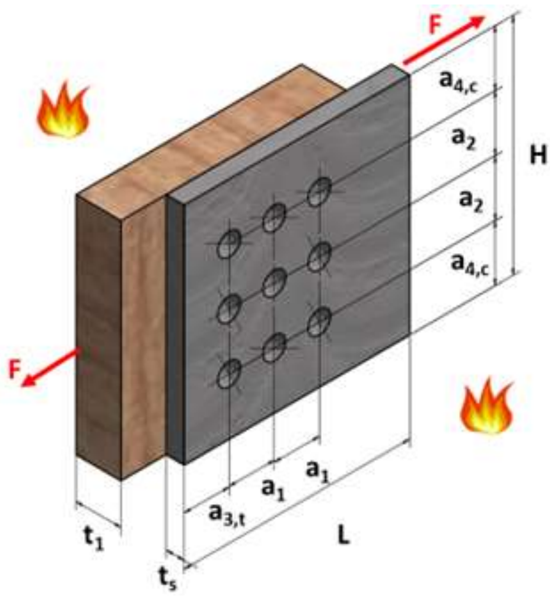

Fig. 1: Steel-to-timber connection

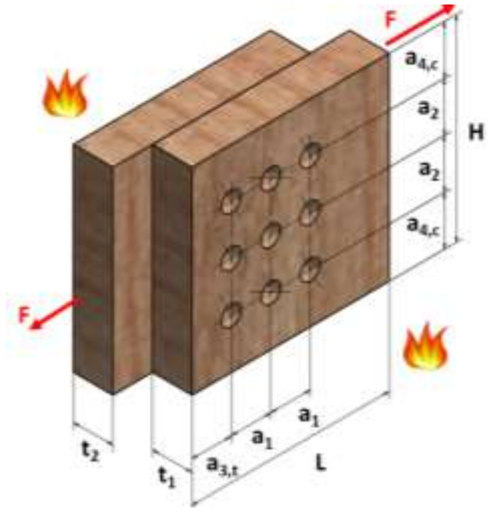

Fig. 2: Timber-to-timber connection

Mechanical properties of timber and steel were considered for the dimensioning. For timber members, homogeneous glued laminated specimens were considered GL24h, GL28h, and GL32h, [9], [10].

According to the minimum spacing and edge and end distances given with symbols illustrated in Figure 1, Table 1 shows the equations that allow the calculation of these variables. The angle between the direction of the tensile load and the loaded edge (or end) is α in the equations presented in Table 1.

Table 1. Calculation of the spacing or edge/end distance

Spacing or edge/end distance	Angle	Minimum spacing or edge/end distance
a_1	$0° \leq \alpha \leq 360°$	$(3+2+\|\cos \alpha\|)\ d$
a_2	$0° \leq \alpha \leq 360°$	$3d$
$a_{3,t}$	$-90° \leq \alpha \leq 90°$	Max($7d$; 80 mm)
$a_{4,c}$	$180° \leq \alpha \leq 360°$	$3d$

3 Characteristic Load-Carrying Capacity Calculation

As reported by some authors, dowelled connections loaded in tension can fail in different modes: bearing failure, net tension failure, the split of wood, shear-out, and group shear-out failure, [12], [13].

These failure mode types depend on joints, fastener configurations, and the connection geometry, [12], [13].

In this manuscript, different connections were designed using the simplified equations from Eurocode 5, part 1-1 [11] and Eurocode 3, part 1-1, [14]. To reduce the risk of failure modes, a minimum edge distance, and end spacing criteria for the connections, using different dowel diameters, were considered.

According to the simplified equations from Eurocode 5, part 1-1 [11], the characteristic load-carrying capacity per shear plane per fastener, $F_{v,Rk}$, is determined according to equations (1) to (3).

In these equations, the main variables are related as follows:
$F_{v,Rk}$ is the characteristic load-carrying capacity in a simple shear plane per fastener;
$f_{h,i,k}$ is the characteristic embedment strength in the timber member (i=1, 2);
t_i represents the thickness of the timber member (i=1, 2), respectively the smaller and the middle timber side member;
d is the dowel or fastener diameter;
$M_{y,Rk}$ is the characteristic yield moment of the fastener, calculated according to the dowel diameter and the material strength;
β is the ratio between the embedment strength of the members;
$F_{\alpha x,Rk}$ represents the characteristic axial withdrawal capacity of the fastener.

Equation 1 is only used for timber-to-timber connections and fasteners in single shear.

$$F_{v,Rk} = min \left\{ \begin{array}{c} f_{h,1,k}\, t_1\, d \\ f_{h,2,k}\, t_2\, d \\ \frac{f_{h,1,k}\, t_1\, d}{1+\beta} \left[\sqrt{\beta + 2\beta^2 \left[1 + \frac{t_2}{t_1} + \left(\frac{t_2}{t_1}\right)^2 \right] + \beta^3 \left(\frac{t_2}{t_1}\right)^2} - \beta \left(1 + \frac{t_2}{t_1}\right) \right] + \frac{F_{\alpha x,Rk}}{4} \\ 1{,}05\, \frac{f_{h,1,k}\, t_1\, d}{2+\beta} \left[\sqrt{2\beta(1+\beta) + \frac{4\beta(2+\beta) M_{y,Rk}}{f_{h,1,k}\, d\, t_1^{\,2}}} - \beta \right] + \frac{F_{\alpha x,Rk}}{4} \\ 1{,}05\, \frac{f_{h,1,k}\, t_2\, d}{1+2\beta} \left[\sqrt{2\beta^2(1+\beta) + \frac{4\beta(1+2\beta) M_{y,Rk}}{f_{h,1,k}\, d\, t_2^{\,2}}} - \beta \right] + \frac{F_{\alpha x,Rk}}{4} \\ 1{,}15 \sqrt{\frac{2\beta}{1+\beta}}\, \sqrt{2\, M_{y,Rk}\, f_{h,1,k}\, d} + \frac{F_{\alpha x,Rk}}{4} \end{array} \right\} \quad (1)$$

Equation 2 is used for steel-to-timber connections in single shear and a thin steel plate as the outer member.

$$F_{v,Rk} = min \left\{ \begin{array}{c} 0{,}4\, f_{h,1,k}\, t_1\, d \\ 1{,}15\, \sqrt{2\, M_{y,Rk}\, f_{h,1,k}\, d} + \frac{F_{\alpha x,Rk}}{4} \end{array} \right\} \quad (2)$$

Equation 3 is used for steel-to-timber connections and a thick steel plate in single shear.

$$F_{v,Rk} = min \left\{ \begin{array}{c} f_{h,1,k}\, d \left[\sqrt{2 + \frac{4 M_{y,Rk}}{f_{h,1,k}\, d\, t_1^{\,2}}} - 1 \right] + \frac{F_{\alpha x,Rk}}{4} \\ 2{,}3\, \sqrt{M_{y,Rk}\, f_{h,1,k}\, d} + \frac{F_{\alpha x,Rk}}{4} \\ f_{h,1,k}\, t_1\, d \end{array} \right\} \quad (3)$$

In the study, different parameters were considered: three dowel diameters (6, 8, and 10 mm), three applied tensile loads F_d (10, 15, and 20 kN), and three materials (GL24h, GL28h, and GL32h), each one with different densities (370, 420 and 480 kg/m^3, respectively).

After the calculated value of $F_{v,Rk}$, it is required to determine the design value of the characteristic load-carrying capacity $F_{v,Rd}$, which is obtained from equation (4).

$$F_{v,Rd} = \frac{F_{v,Rk}\, k_{mod}}{\gamma_M} \quad (4)$$

In this equation, two safety factors are introduced, defined according to Eurocode 5 part 1-1 [11]. The partial factor for the material property γ_M is equal to 1.25 for glued laminated timber. The modification factor, considering the load duration and moisture content effect k_{mod} was considered equal to 0.6 for glued laminated timber. With the obtained design value of the characteristic load-carrying capacity $F_{v,Rd}$ it is possible to determine the number of dowels N according to the applied load design, using equation (5).

The arrangement of the dowels will be in lines and columns. The layout between dowels corresponds to the calculated spacing, resulting from the equations, according to Eurocode 5 part 1-1, [11].

$$N \geq \frac{F_d}{F_{v,Rd}} \quad (5)$$

4 Results and Discussion

The results are presented in Figure 3, Figure 4 and Figure 5, which represent the relation between the number of dowels depending on the applied load and the dowel diameter for each type of connection.

For connections timber-to-timber in Figure 3, there is not a large variation in the number of dowels for connections with large diameters and any wood material density. When the use of dowels decreases in diameter, the variation in the number of dowels increases.

Figure 4 shows the results for connections steel-to-timber with thin steel plate, and dowels diameters 8 and 10 mm, the several dowels are very close. The same behavior is obtained when the steel plate is thick, Figure 5. For small dowels diameter, in these connections, a linear increase is verified, also in all different materials densities used.

In general, the density material does not affect so much the number of dowels when compared with the effect of dowel diameter. Nevertheless, the better the wood, the stronger and stiffer the connections. The same conclusions were reported by the authors of this work in previous publications about connections in double shear, [9], [10]. The increase in several dowels is significantly pronounced in connections with small dowel diameters. Comparing all types of connections, steel-to-timber with a thick steel plate needs a higher number of dowels for any type of timber density. Always for any connection, timber with high density combined with a higher dowel diameter needs a lesser number of dowels.

In doweled connection, and according to Eurocode 5, part 1-1 [11], the dowel diameter should be greater than 6 mm and less than 30 mm. This rule does not allow the higher slope to be verified in the number of dowels when the size diameter decreases.

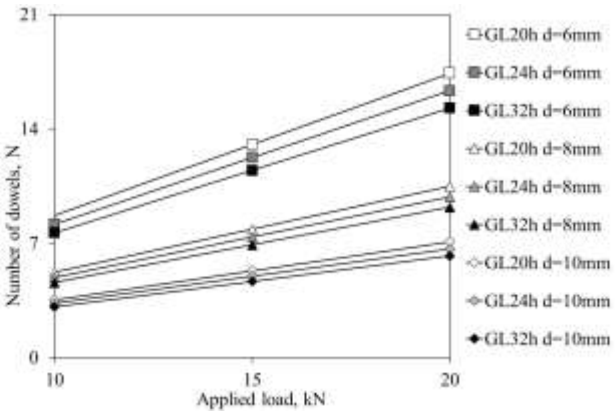

Fig. 3: Dowels depend on the applied load in connections timber-to-timber

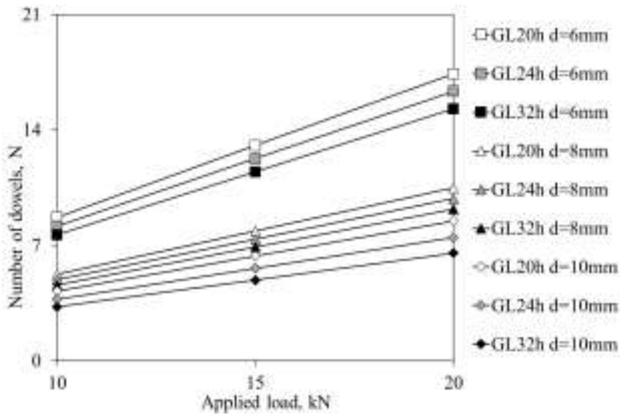

Fig. 4: Dowels depend on the applied load in connections steel-to-timber with a thin steel plate

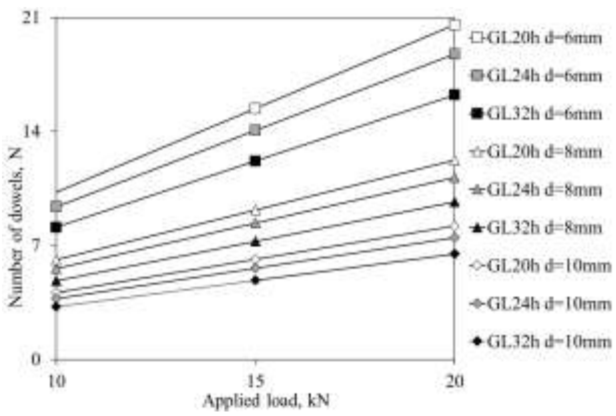

Fig. 5: Dowels depend on the applied load in connections steel-to-timber with a thick steel plate

5 Conclusion

A procedure with simplified equations from Eurocode 5 was presented to assess the dimensions and the number of dowels of the connections in simple shear for any applied tensile load.

The main conclusions are listed as follows:

-The number of fasteners increases with load, according to the use of standards.

-A lower dowel diameter has a higher pronounced effect on the required number of fasteners.

-The mechanical effect due to the strength of the material and its density for GL24h, GL28h, and GL32h implies the verification that when the better the wood, the stronger and stiffer the connections.

Although the current results show interesting tendencies, further studies are required before useful outcomes for the implementation. Recommendations include different load effects and strength material, and experimental tests to carry out the same behavior.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

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Conflict of Interest

The authors have no conflicts of interest to declare.