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W-W-W CONNECTIONS IN DOUBLE-SHEAR AT AMBIENT TEMPERATURE: EFFECT OF THE APPLIED TENSILE LOAD AND DOWELS DIAMETER

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ABSTRACT

This work aims to design wood-wood-wood (W-W-W) connections in double-shear, joined by steel dowel pins. Joints with dowels are used in timber construction to transmit high loads. Dowels are economical and easy to produce. The parameters which influence the load-carrying capacity of joints with dowels are: the bending capacity of the dowel (yield moment), the timber embedding strength and the withdrawal strength of the dowel. All calculations presented in this work will be conducted according European standards, namely using the Eurocode 5, part 1-1. This work proposes the determination of the cross-section, number of fasteners and the minimum spacing in edges per each situation in study, using homogeneous glued laminated (glulam) in birch timber materials. The comparison between the multiple outcomes intends to promote the best solution for a particular application.

Keywords: W-W-W connection, wood, steel, dowel, double-shear.

INTRODUCTION

Wood connections have been investigated due their significance in construction and industrial engineering in terms of strength, ductility and all capacity to improve the structural performance in service. In heavy timber structures, double-shear connections, including wood-wood-wood (W-W-W) connections with steel fasteners, are widely used to assembly structural members and transfer loads (Peng, 2011).

The concept of the W-W-W connection is four wood plates joined by steel dowel, with different diameters in each setting. The model will be designed depending on external tensile load in direction parallel to grain (Aissa, 2017), (Abderrahim, 2017).

In this work, a developed spreadsheet illustrates the design of W-W-W connections according standards (CEN, EN1995-1-1) (DIN 6325, EN ISO 8734), considering a homogeneous glued laminated in birch timber, and steel dowels as fasteners. Therefore, the database is elaborated with different variables and parameters, to improve design solutions, and to intent a comparison between all chosen variables. In the developed spreadsheet, different applied loads and dowel diameters will be used, which demonstrate the correlated results for design a safety double-shear W-W-W connection at ambient temperature.

The motivation of this work is to design a connection with resistance to double-shear with safety and appropriate dimensions to transfer the imposed loads in the structural member.

Using different glulam strength classes, the mechanical resistance effect in the W-W-W connection will be discussed. Recently many numerical approaches using the finite element method have been carried out to analyse the behaviour of wooden connections, due the possibility to assess different parameters in conjunction (Aissa, 2017). Few 3D numerical models have been published, the majority publications are based on 2D approach (Eckart Resch, 2012).

W-W-W CONNECTION AT AMBIENT TEMPERATURE IN ACCORDANCE WITH EUROCODE 5

Figure 1 represents a typical W-W-W connection under double-shear with the main dimensions (width, height and thickness of the wood plates, minimum spacing and edge/end distances between the dowels and the wood plate).

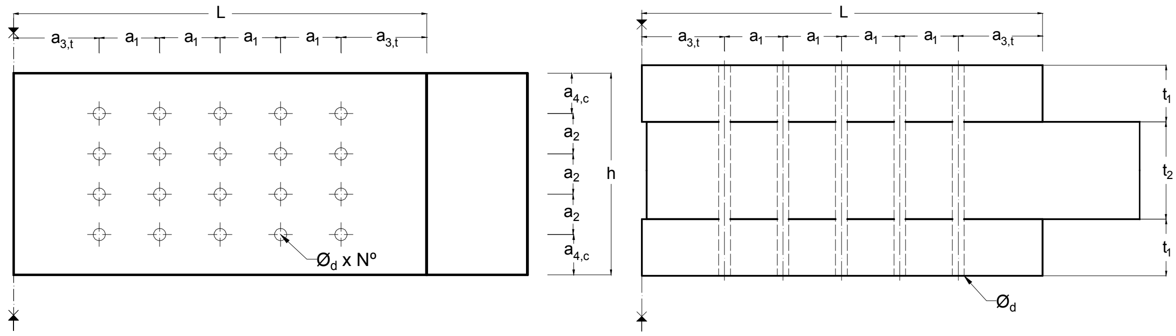

Fig. 1 - Typical W-W-W dimensions.

In order to calculate the shape of the connection, the load was considered as parallel to the grain direction, as well as, the rows of fasteners.

According Eurocode 5 (CEN EN1995-1-1, 2004), the design tensile strength along the grain, $f_{t,0,d}$, must be equal or higher than the design tensile stress along the grain. The tensile strength represents a reduced value of the characteristic tensile strength along the wood grain, due to the application of two safety factors: the modification factor for load duration and moisture content (for short-term equal to 0,9), k_{mod}, and the partial factor for material, γ_M, according equation 1.

$$f_{t,0,d} = \frac{k_{mod}\ x\ f_{t,0,k}}{\gamma_M} \tag{1}$$

Considering E_d as the applied load and A_s the cross-section area of the member, the design tensile stress along the grain, $\sigma_{t,0,d}$, is calculated using the equation 2, Eurocode 5 (CEN EN1995-1-1, 2004).

$$\sigma_{t,0,d} = \frac{E_d}{A_s} \tag{2}$$

Using all proposed simplified equations from Eurocode 5 (CEN EN1995-1-1, 2004) for fasteners in double-shear, the characteristic load-carrying capacity per shear plane and per fastener must be calculated using the equation 3.

$$F_{v,Rk} = min \begin{cases} f_{h,1,k}\, t_1\, d \\ 0{,}5 f_{h,2,k}\, t_2\, d \\ 1{,}05 \dfrac{f_{h,1,k}\, t_1\, d}{2+\beta} \left[\sqrt{2\beta(1+\beta) + \dfrac{4\beta(2+\beta) M_{y,Rk}}{f_{h,1,k}\, d\, t_1^2}} - \beta \right] + \dfrac{F_{\alpha x,Rk}}{4} \\ 1{,}15 \sqrt{\dfrac{2\beta}{1+\beta}} \sqrt{2 M_{y,Rk}\, f_{h,1,k}\, d} + \dfrac{F_{\alpha x,Rk}}{4} \end{cases} \quad (3)$$

where:

t_1 represents the thickness of the wood members;

$f_{h,i,k}$ is the characteristic embedment strength in timber member;

d is the dowel diameter;

$M_{y,Rk}$ is the characteristic yield moment of the fastener;

β the ratio between strength of the members;

$F_{\alpha x,Rk}$ represents the characteristic axial withdrawal capacity of the fastener.

The value of $M_{y,Rk}$ is calculated according the dowel diameter and the bolt material strength $f_{u,k} = 400MPa$, steel S275.

$$M_{y,Rk} = 0{,}3\, f_{u,k}\, d^{2,6} \quad (4)$$

The value of the characteristic embedment strength in timber member, is obtain due to the value of the dowel diameter and the characteristic wood density, ρ_k.

$$f_{h,1,k} = 0{,}082(1 - 0{,}01d)\rho_k \quad (5)$$

With the calculation from $F_{v,Rk}$, it is possible to obtain the number *N* of the bolts, according the design load-carrying fastener capacity calculated $F_{v,Rd}$, equations 6 and 7.

$$F_{v,Rd} = \frac{k_{mod}\, F_{v,Rk}}{\gamma_M} \quad (6)$$

$$N = \frac{E_d}{F_{v,Rd}} \tag{7}$$

The space parallel to grain of fastener and within one row, a_1, perpendicular to grain and between rows, a_2, the distance between fasteners and loaded end, $a_{3,t}$, and unloaded edge, a_4, c, vary in order of the dowel diameter.

W-W-W DESIGNED CONNECTIONS: A DEVELOPED SPREADSHEET

In this work different variables were considered, the dowel diameter (8, 10, 12, 14 and 16mm), the thickness of the wood elements, the material properties and the applied load. The W-W-W designed connection at ambient temperature guarantees the applied load design at 300kN, 200kN, 100kN, 75kN and 30kN.

Different glued laminated timber (glulam) materials were considered for the W-W-W designed connections.

Glulam is manufactured by bonding together individual laminations of solid timber, in rectangular cross-sections and very adaptable in design. (CEN, BS EN 1194, 1999) lists eight glulam strength classes, Table 1.

Table 1 - Grades glulam.

Timber types, (CEN, BS EN 1194, 1999) http://imowood.pt/madeira-lamelada/caracteristicas	Homogeneous Glued Laminated GL24h
	Homogeneous Glued Laminated GL28h
	Homogeneous Glued Laminated GL32h
	Homogeneous Glue Laminated GL36h
	Combined Glue Laminated GL24c
	Combined Glue Laminated GL28c
	Combined Glue Laminated GL32c
	Combined Glue Laminated GL36c

To distinguish them from the solid timber categories, they are designated by GLxh as homogeneous lay-up, meaning that all of the laminations are of the same strength class, or GLxc as combined, where the outer laminations are of a higher strength class.

Table 2 presents all different mechanical properties for each wood glulam grade (all strength and stiffness values).

A spreadsheet was developed, with all applied loads and dowel diameters for the eight glulam strength classes. The results are presented in different tables, according to the parameters combination. Table 3 represents a part of the study and demonstrate some of the correlated results for design a safety double-shear W-W-W connection with GL24h wood glulam.

The results permit to verify the number N of fasteners, the obtained characteristic load-carrying capacity per shear plane and per fastener *Fv,R,k*, and the design load-carrying fastener capacity *Fv,R,d*.

Table 2 - Wood material properties, strength classes.

Material Properties http://imowood.pt/madeira-lamelada/caracteristicas		**Wood Glulam, Grade**							
Parameter	**Designation**	**GL24h**	**GL28h**	**GL32h**	**GL36h**	**GL24c**	**GL28c**	**GL32c**	**GL36c**
Bending strength, MPa	*fm,k*	24	28	32	36	24	28	32	36
Tension parallel to the fibers, MPa	*ft,0,k*	**16,5**	**19,5**	**22,5**	**26**	**14**	**16,5**	**19,5**	**22,5**
Tension perpendicular to the fibers, MPa	*ft,90,k*	0,4	0,45	0,5	0,6	0,35	0,4	0,45	0,5
Compression parallel to the fibers, MPa	*fc,0,k*	24	26,5	29	31	21	24	26,5	29
Compression perpendicular to the fibers, MPa	*fc,90,k*	2,7	3,0	3,3	3,6	2,4	2,7	3,0	3,3
Modulus of elasticity parallel to the fibers, MPa	*E0,mean*	11600	12600	13700	14700	11600	12600	13700	14700
Modulus of elasticity perpendicular to the fibers, MPa	*E90,mean*	390	420	460	490	320	390	420	460
Shear modulus perpendicular to the fibers, MPa	*Gmean*	720	780	850	910	590	720	780	850
Density, kg/m^3	*ρt*	380	410	430	450	350	380	410	430

Table 3 - Designed double-shear W-W-W connections, different dowels diameters and applied loads, GL24h.

Applied Load	**Diameter**	**Strength**	**Minimum Cross-section**	**Choose dimensions**				**Yield moment**	**Embedment strength**	**Characteristic load-carrying capacity**		**N dowels**
Ed	***d***	***ft,0,d***	***As***	***t2***	***t1***	***h***	**Cross-section**	***My,Rk***	***fh,0,k***	***Fv,R,k***	***Fv,R,d***	**Nº**
kN	**mm**	**MPa**	**mm^2**	**mm**			**mm^2**	**kN.m**	**MPa**	**N**	**N**	
300	8	11,9	25253	160	80	295	94400	26743,3	28,67	4028	2900	103
200	8	11,9	16835	140	70	260	72800	26743,3	28,67	4028	2900	69
100	8	11,9	8418	100	50	190	38000	26743,3	28,67	4028	2900	34
75	8	11,9	6313	80	40	155	24800	26743,3	28,67	3878	2792	27
30	8	11,9	2525	50	25	120	12000	26743,3	28,67	3006	2164	14
300	12	11,9	25253	180	90	330	118800	76745,4	27,42	8172,78	5884	51
200	12	11,9	16835	150	75	280	84000	76745,4	27,42	8172,78	5884	34
100	12	11,9	8418	100	50	230	46000	76745,4	27,42	7270,72	5235	19
75	12	11,9	6313	100	50	180	36000	76745,4	27,42	7270,72	5235	14
30	12	11,9	2525	80	40	130	20800	76745,4	27,42	6439,05	4636	6
300	16	11,9	25253	200	100	360	144000	162141,1	26,17	13401,6	9649,2	31
200	16	11,9	16835	170	85	295	100300	162141,1	26,17	13401,6	9649,2	21
100	16	11,9	8418	140	70	230	64400	162141,1	26,17	12563,3	9045,6	11
75	16	11,9	6313	110	55	230	50600	162141,1	26,17	10906,2	7852,5	10
30	16	11,9	2525	80	40	165	26400	162141,1	26,17	9542,1	6870,3	4

All different mechanical properties for the other wood glulam grades were obtained using different spreadsheets. W-W-W designed connection with higher wood material strength (GL36h and GL36c) permits to decrease the cross-section dimension for the same applied load.

Figure 2 represents the behavior between the chosen material strength class and the dimensions for the W-W-W connection. There is a linear correlation between the applied load and the necessary W-W-W dimensions, with a higher increase for lesser strength material.

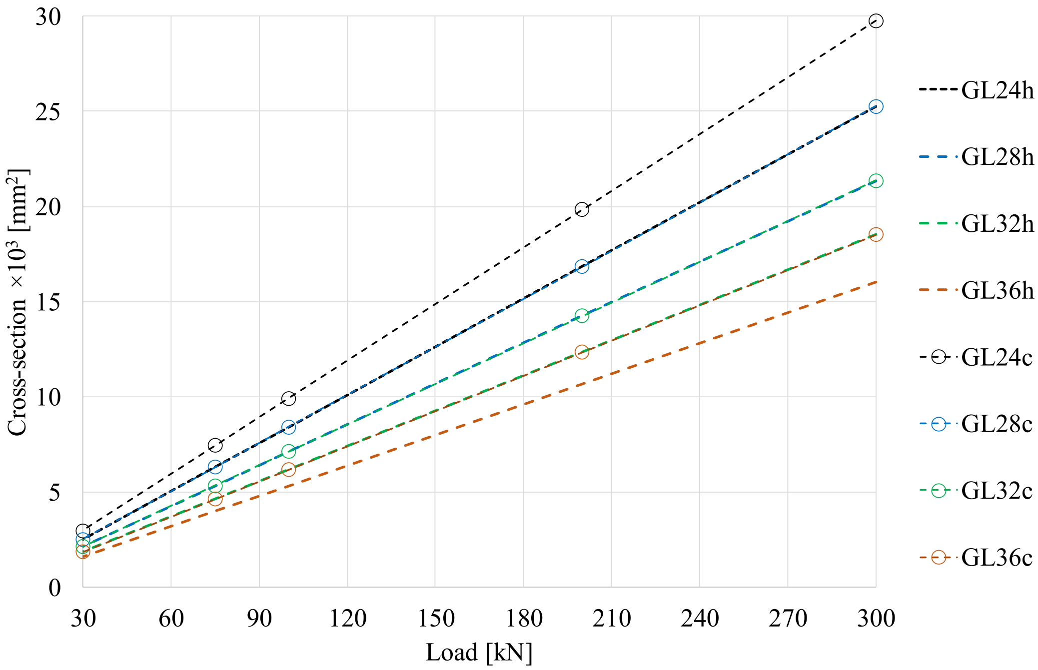

Fig. 2 - Results of the applied load and the obtained cross-section for different wood glulam grades.

Figure 3 and Figure 4 represent the results of the applied load, function of the obtained number of fasteners, for different glulam grades (GLxh and GLxc) according different dowels diameters.

The number of fasteners increase linearly, and with high number for dowels for small diameters. For the minimum spacing and edge/end distances, the variation depends on the loading direction and the dowels diameter obtained during the W-W-W calculations.

For different material strength class there is, in general, a linear correlation between the applied load and the necessary number of fasteners, with a higher increase for lesser strength material.

A little difference is verified between the use of the glulam grades (GLxh or GLxc). Higher material strength reduces lightly the number of the dowels. The most pronounced observation is the relation with the dowel diameter and the number of fasteners. For a diameter equal to 8 mm the number of dowels increases widely when compared with dowels diameter equal 16 mm. The relation also increases when the applied load is higher. Table 4 resumes all the observations relatively to the number of fasteners in W-W-W connections according, dowels diameters, applied load and the used glulam grade.

Table 4 - Number of fasteners, function of dowel diameter, applied load and glulam grade.

d, mm	TIMBER	NUMBER OF FASTENERS, N							
	***Ed*, kN**	**GL24h**	**GL28h**	**GL32h**	**GL36h**	**GL24c**	**GL28c**	**GL32c**	**GL36c**
8	300	103	100	97	95	108	103	100	97
	200	69	66	65	63	72	69	66	65
	100	34	33	32	32	36	34	33	32
	75	27	25	24	24	29	27	25	24
	30	14	13	13	12	15	14	13	13
10	300	70	67	66	64	73	70	67	66
	200	47	45	44	43	49	47	45	44
	100	23	22	22	22	24	23	22	22
	75	17	17	17	17	20	17	18	16
	30	9	8	8	8	9	9	8	8
12	300	51	49	48	47	53	51	49	48
	200	34	33	32	31	35	34	33	32
	100	19	16	17	17	18	19	18	17
	75	14	13	13	12	15	14	13	13
	30	6	6	7	6	7	7	7	7
14	300	39	38	37	36	41	39	38	37
	200	26	25	24	24	27	26	25	24
	100	14	13	13	12	15	14	13	13
	75	12	10	11	11	11	12	12	11
	30	6	5	5	5	6	6	5	5
16	300	31	30	29	29	32	31	30	29
	200	21	20	20	19	22	21	20	20
	100	11	12	12	11	12	11	12	12
	75	10	9	9	8	10	10	9	9
	30	4	4	4	4	5	4	4	4

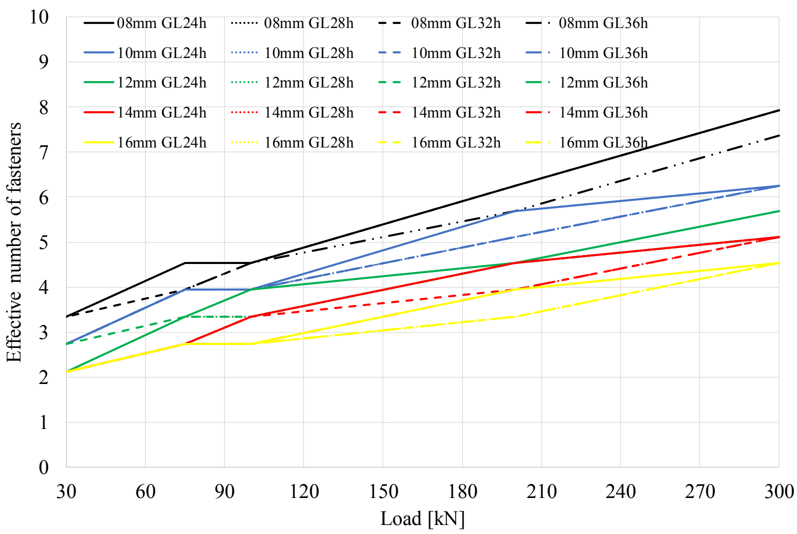

Fig. 3 - Results of the applied load and the obtained number of fasteners for different glulam grades GLxh and dowels diameters.

CONCLUSIONS

A procedure with all analytical and simplified equations was presented to assess a safety cross-section due an applied tensile load in W-W-W connections. The results presented were conducted according the Eurocode 5 (CEN EN1995-1-1, 2004). A worksheet considering all parameters was developed, which permits verify the load-carrying capacity of the connection, the cross-section, the number of fasteners, the minimum spacing in edges, per each situation in study. A developed spreadsheet could promote adequate dimensions for any W-W-W connection to be used. The number of fasteners increases linearly, and with high number for dowels for small diameters. For the minimum spacing and edge/end distances, the variation depends on the loading direction and the dowels diameter. For different material strength classes there is, in general, a linear correlation between the applied load and the necessary number of fasteners, with a higher increase for lesser strength material.

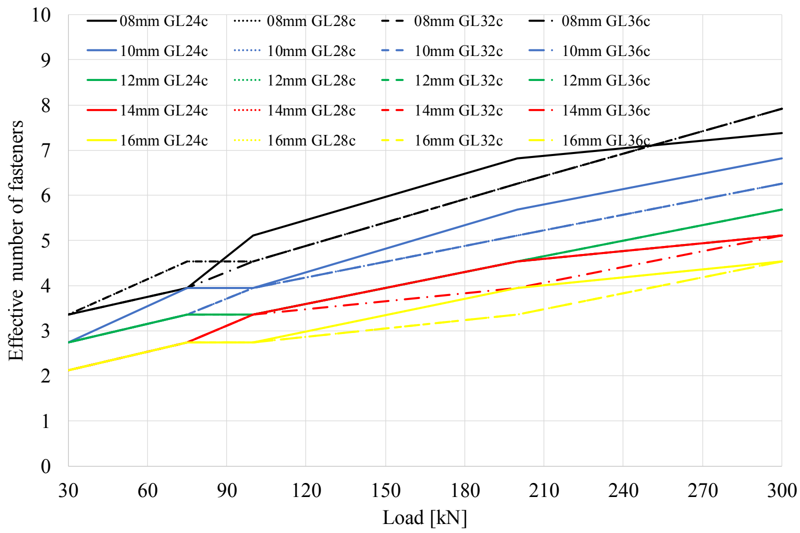

Fig. 4 - Results of the applied load and the obtained number of fasteners for different glulam grades GLxc and dowels diameters.

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