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EXPERIMENTAL INVESTIGATIONS ON THE STIFFNESS OF STEEL-TIMBER DOWEL-TYPE CONNECTIONS IN BEECH LVL

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ABSTRACT: With the increasing complexity of timber structures, accurate computational prediction of the load-deformation behaviour of joints is becoming more important for design. In particular, the initial stiffness is a relevant parameter. Therefore, a detailed knowledge of the parameters influencing the connection stiffness is required, but is currently not available for hardwoods. A comprehensive database on the load-deformation behaviour of steel-timber dowel-type connections in beech LVL is being developed on the basis of experimental tests currently being carried out at the University of Stuttgart. The aim is to enable the efficient use of hardwoods in high-performance yet easy-to-manufacture connections by realistically predicting connection stiffness. This paper will give an overview on the first results.

KEYWORDS: Steel-timber dowel-type connections, connection stiffness, beech LVL, experimental testing

1 INTRODUCTION

In times of climate change, timber structures are coming under increasing political and social focus as a sustainable and resource-efficient construction method. At the same time, the forest structure in Germany is changing due to extended drought, with the high proportion of spruce being replaced mainly by beech. As a result, beech will have to be increasingly used in construction practice. The prerequisite for this is a reliable and economical design, also for hardwoods. In particular, the prediction of the load-deformation behaviour of high-performance joints is crucial for the design of complex timber structures. However, the current database on the connection stiffness in hardwoods is far too small to derive reliable predictions.

Therefore, the research project "Innovative timber joints by modelling the stiffness for high-performance timber structures made of hard- and softwood" [1] was started at the Institute of Structural Design at the University of Stuttgart in 2021. The aim is to increase the database of stiffness values of steel-timber dowel-type connections in beech laminated veneer lumber (beech LVL) through experimental investigations. This will enable more accurate predictions in order to provide design recommendations for the new version of Eurocode 5 [2].

This paper deals with the first results of these experimental investigations. After an overview of the current normative regulations for stiffness calculation and the state of the art, the test programme and setup as well as the geometry and the material of the above-mentioned tests are described. Afterwards, the first experimental results are presented and discussed.

2 STATE OF THE ART

For the determination of the slip modulus K_{ser} for steel-timber dowel-type connections in the serviceability limit state (SLS), Equation (1) is given in Eurocode 5 [2]. Thus, the slip modulus depends only on the timber density ρ and the fastener diameter d. Other influencing factors such as the load-to-grain angle, the number of fasteners and the slenderness of the connection (failure mode) are not considered.

$$K_{ser,EC5} = \frac{2}{23} \cdot \rho_m^{1.5} \cdot d \quad (1)$$

In comparison, the Swiss standard SIA 265 [3] defines the above-mentioned slip modulus K_{ser} according to Equations (2) and (3). Unlike Eurocode 5, a distinction is made between fasteners loaded parallel and perpendicular to the grain.

$$K_{ser,0,SIA} = 6 \cdot \rho_k^{0.5} \cdot d^{1.7} \quad (2)$$

$$K_{ser,90,SIA} = 3 \cdot \rho_k^{0.5} \cdot d^{1.7} \quad (3)$$

Several studies (see [4]-[9]) have shown that the stiffness calculated according to Eurocode 5 [2] is quite inadequate, even for softwood connections. First experimental investigations on steel-timber dowel-type connections in beech glulam and LVL mainly examined the load-bearing capacity (see [10]-[12]). This is underestimated by approximately 33 % for connections in beech glulam [10]. Kobel et al. [12] have shown that veneer cross-layers have a positive effect on the load-bearing capacity of connections in beech LVL by preventing the timber from

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Table 1: Load-bearing capacity F_{max}, initial stiffness K_{ser} and reloading stiffness K_e from tensile tests on steel-timber dowel-type connections (d = 16 mm) [4]

Series	Mean values			COV [%]		
	F_{max} [kN] (F_{test} / F_{EC5})	K_{ser} [kN/mm] (K_{test} / K_{EC5})	K_e [kN/mm] (K_{test} / K_{EC5})	F_{max}	K_{ser}	K_e
G-SD16 11 0 1_**GL 24h**	47.9 (114 %)	33.0 (138 %)	57.7 (175 %)	4.54	33.1	20.4
G-SD16 11 0 1_**GL 75**	89.4 (154 %)	55.5 (88 %)	88.7 (160 %)	1.49	25.5	18.4

splitting. As a result, higher loads can be achieved with significantly improved ductile behaviour. The aim of the research project presented in this paper [1],[13] is therefore to verify the positive influence of cross-layers on the stiffness. Initial investigations on the stiffness of steel-timber dowel-type connections in beech LVL have already been carried out by Misconel et al [14]. According to this, the formula for stiffness calculation in Eurocode 5 [2] is insufficient for connections in beech LVL. Comparable results were obtained in tests carried out at the University of Stuttgart as part of IGF project no. 20625 N [4]. In addition to a large number of tests on steel-timber dowel-type connections in spruce glulam (GL 24h and GL 28h), tests were also carried out on 12 connections in beech LVL. Table 1 shows the results of two series of tests on spruce glulam and beech LVL and compares them with the corresponding values determined according to Eurocode 5 [2]. The average load-bearing capacity F_{max} of the connection in beech LVL is underestimated by 54 %. This tendency is also in line with the results of Franke & Franke [10]. It is also shown that the initial stiffness K_{ser} is better represented normatively than the reloading stiffness K_e, which is underestimated by 60 % in beech LVL. However, the large scatter of the test results with coefficients of variation (COV) of around 25 % and the small number of tests do not yet allow any precise recommendations to be made with regard to the computational prediction of the connection stiffness in beech LVL. Fundamental investigations of the stiffness of steel-timber dowel-type connections in beech LVL are therefore necessary and are being carried out in an ongoing research project at the University of Stuttgart [1]. The first results of these investigations are presented in this paper.

3 EXPERIMENTAL RESEARCH

3.1 TEST PROGRAMME AND SETUP

Based on a completed research project at the Institute of Structural Design [4],[5], which mainly investigated the stiffness of dowel-type connections in glulam made of spruce, a further 172 tensile tests are carried out on steel-timber dowel-type connections in beech LVL. The aim is to obtain a comprehensive database on the load-deformation behaviour of dowel-type connections. Figure 1 shows the test setup for the single fastener specimens with a load-to-grain angle α of 0° (top) and 90° (bottom). All tensile tests with grain parallel loading are double symmetric, allowing two connections to be tested simultaneously. Therefore, a total of four displacement transducers per specimen (two per connection) were applied. Only two displacement transducers are used for the tensile tests with a load perpendicular to the grain, as the modified test setup tests a single connection. The displacement transducers measure the relative deformation between the slotted-in steel plate and the timber at the level of the centre line of the dowel.

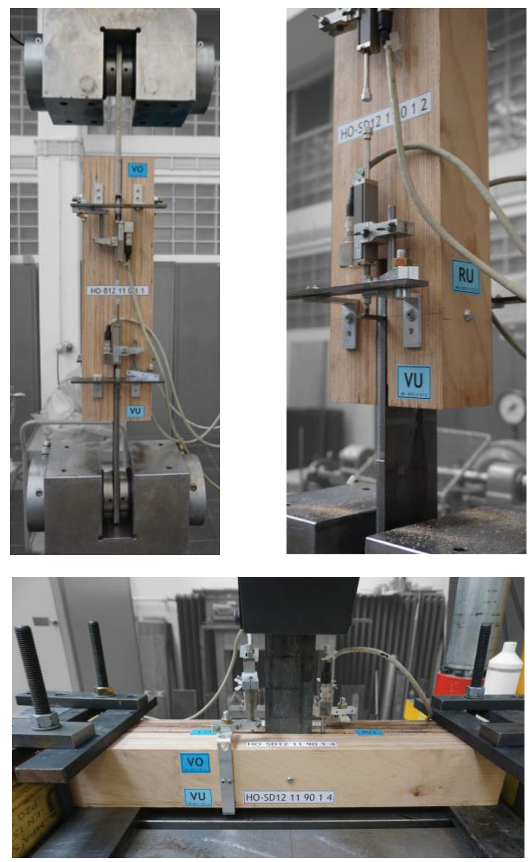

***Figure 1:** Test setup for the specimens with a single fastener and load parallel to the grain (top) and with a load-to-grain angle α = 90° (bottom)*

The experimental programme is given in Table 3. In addition to the number of fasteners, the type and diameter Ø of the fasteners, the load-to-grain angle α, the type of reinforcement of the timber element and the side member thickness $t_{1\text{-}3}$ are varied. The reinforcement of the timber is partly achieved by fully threaded screws and partly by internal reinforcement using veneer cross-layers (GL 60Q). The designation of the test specimens is designed as:

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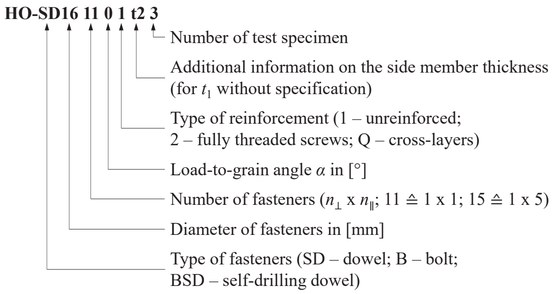

The different side member thicknesses $t_{1\text{-}3}$ are intended to induce all three possible European Yield Model (EYM) failure modes according to Eurocode 5 [2] in the tests. For this purpose, preliminary numerical investigations were carried out using a Beam-on-Foundation (BoF) model already implemented in RFEM (Dlubal) (see [4]-[6]). Figure 2 shows as an example the numerically calculated deformation of the dowel with a diameter of 16 mm plotted over the width of the test specimen for different side member thicknesses with a maximum deformation of the connection of 4 mm.

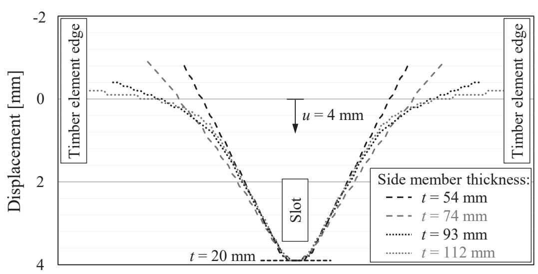

Figure 2: *Deformation of the dowel (Ø = 16 mm) calculated with RFEM plotted over the width of the test specimen for various side member thicknesses (connection deformation 4 mm)*

Using the BoF model, a side member thickness of 20 mm leads to embedment failure in timber (t_1). As the side member thickness increases, the transition from initially one (t_2) to two (t_3) plastic hinges per shear plane can be observed. The BoF model was also used to estimate the load-bearing capacity F_{est} of the connections, which is required for the loading and evaluation according to EN 26891 [15]. The tests were carried out displacement-controlled.

3.2 GEOMETRY AND MATERIAL

An example of a tensile test specimen parallel to the grain with 1 x 5 fasteners per connection and reinforcement with fully threaded screws is shown in Figure 3. Due to the symmetrical design, there are two sets of data for each specimen for the evaluation of the connection stiffness. The *timber elements* with a grade of GL75 and GL 60Q were prefabricated with a fully automated joinery machine. The slots for the slotted-in steel plates were made with a width of 14 mm. Fastener holes were pre-drilled to the appropriate nominal diameter from both sides of the timber member. ASSYplus VG 4 CSMP (countersunk head) type screws according to ETA-11/0190 [16] with diameters of 6 mm and 8 mm were partially used for reinforcement. The fully threaded screws were also pre-drilled with diameters of 5 mm and 7 mm to facilitate insertion. For technical reasons, the diameter of the boreholes was slightly larger than recommended in [16]. In addition to screw reinforcements, some specimens were also reinforced with veneer cross-layers. For this purpose, standard Q-boards in beech LVL were produced with a thickness of 42 mm and a cross-layer content of 14 %. Several Q-boards were glued with melamine to the required cross sections.

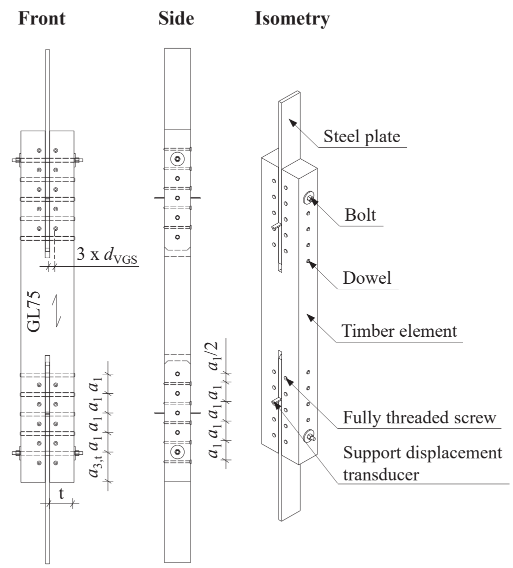

Figure 3: *Example of a tensile test parallel to the grain specimen with 1 x 5 fasteners per connection and screw reinforcement*

The *steel plates* with a grade of S355J2 were manufactured with a thickness of 12 mm. The *fasteners* ordered in S235JR (electrolytically galvanised) steel were made from cold drawn bars. Tensile tests were carried out according to EN ISO 6892-1 [17] on five to six randomly selected samples for each diameter to determine the material properties of the fasteners. The results are summarised in Table 2. Due to the cold forming process of the steel, the technical elastic limit of 0.2 % was taken as yield strength. Compared to the normative values according to EN 1993-1-1 [18], there is a clear overstrength of the steel, where the experimental tensile strength is up to 690 N/mm². This overstrength is also described in the literature (see [4],[5],[19]-[21]).

Table 2: *Mean values of fastener material properties from tensile tests according to EN ISO 6892-1 [17]*

Diameter ***d*** [mm]	**Yield strength** $R_{p0.2}$ [N/mm²]	**Tensile strength** R_m [N/mm²]	**MOE** [N/mm²]
8	588.1	627.0	208,540
12	668.6	689.8	210,550
16	568.5	598.0	209,560
20	444.2	500.5	208,500

Table 3: Experimental programme of tensile tests on steel-timber dowel-type connections in beech LVL

Fastener	Ø [mm]	$n_\perp$ x $n_\parallel$	α [°]	Reinforcement	Timber grade	Side member thickness
Single, dowel	8 12 16 20	1 x 1	0 90	- Fully threaded screws Veneer cross-layers	GL75 GL 60Q	t_1 t_2 t_3
Single, bolt	8 12 16 20	1 x 1	0	-	GL75	t_1
Group, mixed*	8 12 16 20	1 x 3 1 x 5 2 x 3	0	- Fully threaded screws Veneer cross-layers	GL75 GL 60Q	t_1
Self-drilling dowel*	7	1 x 3	0	-	GL75	t_1

** Not content of this paper*

4 RESULTS OF THE CONDUCTED TENSILE TESTS

4.1 GENERAL OVERVIEW

Currently (February 2023), 112 out of 172 planned tests have been carried out. The tests of connections with groups of fasteners are planned to be conducted in spring 2023. Table 4 summarises the already experimentally determined initial stiffnesses $K_{ser,test}$ for connections with single fasteners and compares them with the stiffnesses calculated according to Eurocode 5 [2].

4.2 FAILURE MODES

The failure mode of the connections depends, on one hand, on the side member thickness (EYM). On the other hand, the type of fastener (dowel or bolt), the load-to-grain angle α and the timber reinforcement also influence the load-displacement behaviour in the range of the ultimate limit state (ULS).

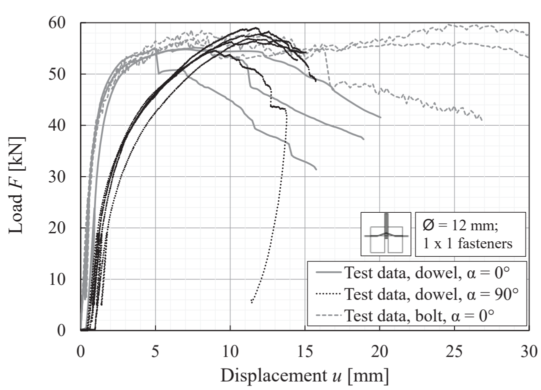

Figure 4: Load-displacement curves for connections with single fasteners (dowels and bolts) of 12 mm diameter and loading parallel and perpendicular to the grain

Figure 4 shows the load-displacement curves for connections with single fasteners (dowels and bolts) of 12 mm diameter and loading parallel and perpendicular to the grain. The load-bearing capacity is in a similar range for all of the connections. However, there is a pronounced plastic plateau for connections loaded parallel to the grain rather than perpendicular to the grain. This applies in particular to connections using bolts due to the rope effect.

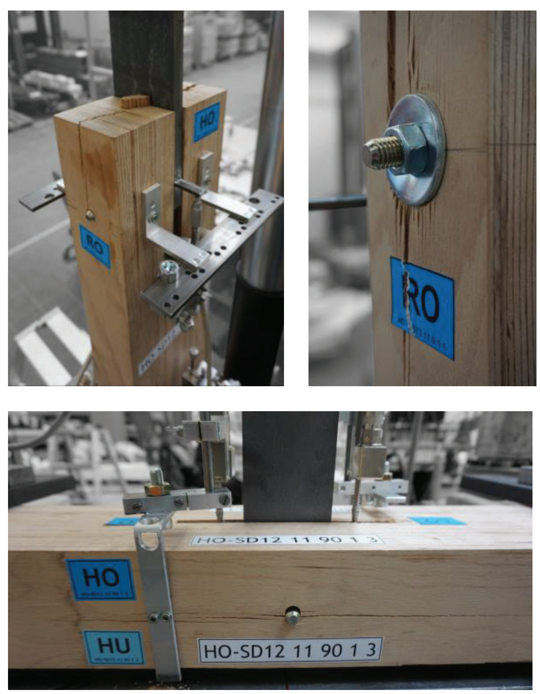

Figure 5: Top left: Splitting of the timber after ductile deformation of the dowel (α = 0°); Top right: Deformation of a bolt and the washer (α = 0°); Bottom: Lateral splitting of the timber after ductile deformation of the dowel (α = 90°)

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The failure modes associated with the load-displacement curves (Figure 4) are shown in Figure 5. The washer of the bolt is deformed and slightly pressed into the timber (Figure 5, top right). Compared to the failure of bolted connections in spruce glulam due to head pull-through (see [22]), the deformations at the washer in beech LVL are significantly smaller. The splitting and partial block shear failure of the timber occurs after the formation of plastic hinges in the dowel (Figure 5, top left) as well as in the bolt for large side member thicknesses and loading

Table 4: Initial stiffness $K_{ser,test}$ and comparison with Eurocode 5 [2] for connections with single fasteners

Series	**Mean** [kN/mm] ($K_{ser,test}$ / K_{EC5})	**SD** [kN/mm]	**COV** [%]
HO-SD8 11 0 1	26.9 (85 %)	6.3	23.4
HO-B8 11 0 1	30.8 (98 %)	7.4	24.2
HO-SD8 11 0 1 t2	22.8 (72 %)	4.4	19.5
HO-SD8 11 0 1 t3	19.5 (62 %)	4.6	23.5
HO-SD8 11 0 1 2	22.0 (70 %)	6.0	27.2
HO-SD8 11 0 Q	17.0 (54 %)	3.3	19.1
HO-SD8 11 90 1	12.9 (41 %)	2.5	19.3
HO-SD8 11 90 Q	12.5 (40 %)	2.1	16.6
HO-SD12 11 0 1	48.2 (102 %)	3.7	7.7
HO-B12 11 0 1	49.9 (106 %)	4.0	8.0
HO-SD12 11 0 1 t2	52.3 (111 %)	9.5	18.2
HO-SD12 11 0 1 t3	45.5 (96 %)	7.6	16.6
HO-SD12 11 0 1 2	40.6 (86 %)	3.4	8.5
HO-SD12 11 0 Q	49.0 (104 %)	8.5	17.4
HO-SD12 11 90 1	24.9 (53 %)	1.8	7.1
HO-SD12 11 90 Q	26.4 (56 %)	2.8	10.6
HO-SD16 11 0 1	76.0 (121 %)	3.4	4.5
HO-B16 11 0 1	74.7 (119 %)	4.7	6.3
HO-SD16 11 0 1 t2	84.9 (135 %)	7.7	9.1
HO-SD16 11 0 1 t3	71.3 (113 %)	4.9	6.9
HO-SD16 11 0 1 2	68.8 (109 %)	10.4	15.2
HO-SD16 11 0 Q	70.7 (112 %)	2.5	3.5
HO-SD16 11 90 1	32.8 (52 %)	8.6	26.1
HO-SD16 11 90 Q	37.0 (59 %)	6.3	17.1
HO-SD20 11 0 1	74.8 (95 %)	7.1	9.4
HO-B20 11 0 1	83.4 (106 %)	12.2	14.7
HO-SD20 11 0 1 t2	104.1 (132 %)	6.3	6.0
HO-SD20 11 0 1 t3	89.6 (114 %)	9.0	10.0
HO-SD20 11 0 1 2	81.3 (103 %)	7.6	9.3
HO-SD20 11 0 Q	121.1 (154 %)	5.1	4.2
HO-SD20 11 90 1	46.9 (60 %)	3.0	6.3
HO-SD20 11 90 Q	62.4 (79 %)	7.7	12.4

Figure 6: Deformation figure of a dowel after testing (specimen HO-SD20 11 0 Q 3 Top)

parallel to the grain. Figure 6 shows the deformation figure of a dowel after these tests. Two plastic hinges occured per shear plane. There is also a clear indentation in the area of the steel plate. Shearing-off of the dowels, as observed by Franke & Franke [11], did not occur in any of the tests. In contrast, the connections loaded perpendicular to the grain showed lateral splitting of the timber (Figure 5, bottom). This results in a relatively brittle failure after about 11 mm of deformation at the dowel. The splitting of the timber can be prevented by reinforcing the timber with screws or veneer cross-layers. Often no cracks were externally visible, especially on specimens with cross-layers. Plastic deformations of up to 18 mm were achieved in these tests with a 12 mm diameter fastener.

4.3 FACTORS INFLUENCING THE INITIAL STIFFNESS

4.3.1 Diameter

The diameter of the fasteners is already included as an important parameter in the Equations for determining the slip modulus according to Eurocode 5 [2] as well as to SIA 265 [3]. Figure 7 shows the initial stiffness K_{ser} plotted against the fastener diameter d. The test data of the connections loaded parallel to the grain and for all three different types of reinforcement are represented by black crosses (test series for connections with single fasteners). It is worth noting that the connections using fasteners of 20 mm diameter and reinforced with cross-layers achieved significantly higher stiffnesses compared to the other tests. While the dashed black trend line is derived from the data points of all the tests mentioned, the solid trend line is derived by neglecting the circled data points of the connections reinforced with cross-layers. These trend lines are compared with the results obtained from

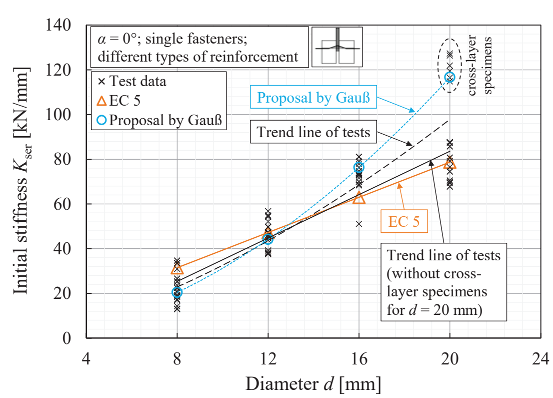

Figure 7: Influence of the fastener diameter d on the initial stiffness K_{ser} and comparison of the test data with stiffnesses according to Eurocode 5 and to a proposal by Gauß [5],[6]

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the calculated stiffness values according to Eurocode 5 [2] for the corresponding diameters (orange line). The results of Eurocode 5 [2] agree relatively well with the solid trend line of the test data without the circled data points. However, if these data points are included in the trend line, the initial stiffness K_{ser} is underestimated for the tests with a fastener diameter of 16 mm and 20 mm. For this reason, a second comparison with the Equation according to Eurocode 5 [2] modified by Gauß [5],[6] (blue dotted line) is shown. In tests on steel-timber dowel-type connections in spruce glulam, Gauß [5],[6] showed that there is more a quadratic rather than a linear effect of fastener diameter on initial stiffness. For this context, the following proposal for the calculation of the stiffness of steel-timber dowel-type connections based on the Equation according to Eurocode 5 [2] is given by Gauß in [5],[6]:

$$K_{ser,proposal,Gauß} = \frac{2}{230} \cdot \rho_m^{1.5} \cdot d^{1.9} \tag{4}$$

For this approach, the increase in stiffness as the diameter increases can be better described by a trend line which is a power law of the form $y = cx^b$ (blue dotted line). A comparison of the stiffnesses calculated by this approach for the corresponding diameters with the test data in Figure 7 (incl. circled data points) shows, that the curve progression fits well for fastener diameters smaller than or equal to 12 mm. For larger diameters, the proposal according to Gauß [5],[6] overestimates the mean values of the stiffnesses derived from the tests. Maybe an independent treatment of cross-layer specimen should be considered.

4.3.2 Load-to-grain angle

The load-to-grain angle α is not yet considered in the calculation of the slip modulus K_{ser} according to Eurocode 5 [2]. However, tests on steel-timber dowel-type connections in spruce glulam carried out by Kuhlmann & Gauß [5] have shown that there is a non-negligible influence on the stiffness of the connection. For a load perpendicular to the grain, these results suggest that the stiffness is only half of that for a load parallel to the grain, as already considered in the SIA 265 [3]. This relationship is now to be verified for the connections in beech LVL as well. Table 5 indicates the ratios of the initial stiffness K_{ser} for load-to-grain angles of 90° and 0° for all the diameters investigated. A distinction is made between unreinforced connections and connections reinforced with cross-layers. It becomes apparent that for most of the test series the stiffness decreases by about 50 % for a load perpendicular to the grain as compared to a parallel loading. The higher ratios of the 8 mm diameter reinforced series and the 20 mm diameter unreinforced series can be explained by the fact that the mean stiffness values of the respective tests with a load-to-grain angle of 0° are lower than expected. It is also worth mentioning that the decrease in stiffness applies equally to both the unreinforced series as well as the series reinforced with cross-layers. Therefore, a reduction of the initial stiffness by 50 % for a load perpendicular to the grain should also be discussed for connections in hardwood.

Table 5: *Ratios of initial stiffness K_{ser} for load-to-grain angles $\alpha = 90°$ and $\alpha = 0°$ for unreinforced connections and connections with cross-layers*

Diameter	**Unreinforced**	**Cross-layers**
d [mm]	$K_{ser,90}/K_{ser,0}$	$K_{ser,90}/K_{ser,0}$
8	0.48	0.74
12	0.52	0.54
16	0.43	0.52
20	0.63	0.52

4.3.3 Side member thickness

Figure 8 illustrates the load-displacement curves of connections with a single dowel of 8 mm diameter and a load parallel to the grain for all three side member thicknesses $t_{1\text{-}3}$ tested. The three different failure modes for steel-timber dowel-type connections can be clearly identified in the load-deformation behaviour. There is a brittle behaviour due to embedment failure and splitting in timber with small side member thicknesses. As the side member thickness increases and plastic hinges are formed in the dowel, a plastic plateau developed and a ductile load-bearing behaviour was achieved. It is noticeable that especially for the large side member thickness t_1 the load can be increased even further in the area of the plastic plateau. This is a typical behaviour for dowel-type connections in hardwood and was also observed by Kuhlmann & Gauß [4].

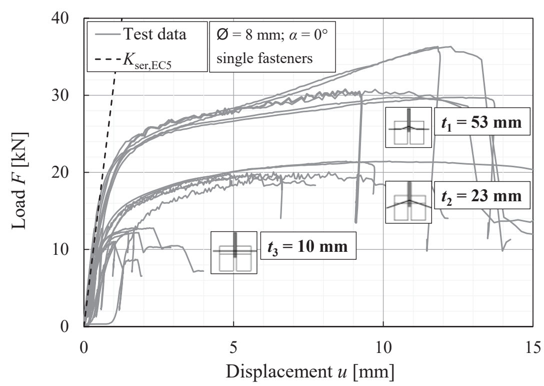

Figure 8: *Load-displacement curves of connections with a single fastener of 8 mm diameter and a load-to-grain angle α of 0° for various side member thicknesses $t_{1\text{-}3}$*

The effect of the side member thickness on the load-displacement behaviour in the range of the SLS is significantly smaller. However, as shown in Table 4, there is a tendency for the initial stiffness to decrease with decreasing side member thickness.

4.3.4 Type of fastener

In addition to connections with dowels, connections with bolts were also tested. Table 4 shows that there is a trend towards a slight increase in initial stiffness for connections using bolts. Nevertheless, the effect of the different types of fasteners is almost negligible. Similar to the side member thickness, the type of fastener has a greater effect on the load-displacement behaviour in the area of the plastic plateau due to the rope effect.

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4.3.5 Reinforcement

Unreinforced connections, connections reinforced with fully threaded screws as well as with veneer cross-layers were tested. It was expected that the reinforcement methods would lead to an increase in stiffness. However, the results according to Table 4 do not show a clear relationship between the reinforcement and the initial stiffness. In some cases, even higher stiffnesses were achieved for unreinforced connections. There is currently no explanation for this unexpected effect. However, the progression of the load-displacement curve in the service load range for connections with cross-layers differs from that of unreinforced connections. Figure 9 shows the load-displacement curve of one of the specimens with cross-layers.

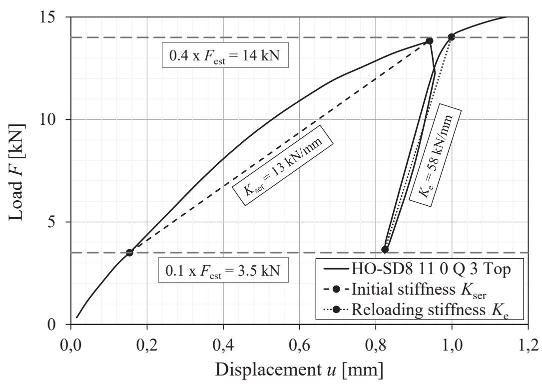

Figure 9: *Load-displacement curve in the service load range and evaluation of the stiffnesses K_{ser} and K_e for the test HO-SD8 11 0 Q 3 Top*

The initial stiffness K_{ser} is evaluated according to EN 26891 [15] by the slope of the curve between 10 % and 40 % of the estimated maximum load F_{est}. It is noticeable that for some connections with cross-layers, the load-displacement curve in this area is not linear but has a convex shape. As a result, the stiffness of these connections is clearly higher in the range between 10 % and 30 % of F_{est} (not shown in Figure 9). However, this cannot be taken into account in the evaluation.

5 CONCLUSIONS

Accurate computational prediction of the load-deformation behaviour of joints in timber is becoming increasingly important for the economic design of complex timber structures. In particular, the connection stiffness is a relevant parameter. Therefore, a detailed knowledge of the parameters influencing the connection stiffness is required, but is currently not available for hardwoods. In this paper, first investigations of a large number of tests on steel-timber dowel-type connections in beech LVL are evaluated and discussed regarding the initial stiffness K_{ser}. An overview of the Equations given in Eurocode 5 [2] and SIA 265 [3] for the calculation of the slip modulus shows that the Equations depend on only a few parameters, such as the timber density and the fastener diameter. In addition, the Swiss standard [3] distinguishes between loading parallel and perpendicular to the grain. This paper summarises several studies indicating that the stiffness calculated according to Eurocode 5 [2] is relatively deficient, even for softwood connections. Recommendations from these studies suggest that additional factors should be considered, such as load-to-grain angle and group effect.

The aim of the investigations presented in this paper is thus to determine the factors influencing the stiffness of connections in beech LVL and to compare the results with the Equation according to Eurocode 5 and with the recommendations given in the literature. The test results indicate, in line with other studies, that there is a large effect of the load-to-grain angle. For most of the test series, the stiffness is reduced by approximately 50 % for a load perpendicular to the grain as compared to a parallel load. Therefore, the implementation of a reduction factor as in SIA 265 [3] of about 0.5 for a load perpendicular to the grain should also be discussed for connections in hardwood. Furthermore, the fastener diameter is an important parameter whose effect on the stiffness tends to be normatively (according to Eurocode 5 [2]) underestimated in the tests, especially for larger diameters. A possibility to better represent the influence of the diameter is to modify the Equation in the Eurocode 5 [2], as proposed by Gauß [5],[6]. The exact value of the exponent implemented in this proposal for the diameter should be investigated in more detail by comparing a large number of experimental data with connections in soft- and hardwoods. For the other parameters investigated, the changes in stiffness did not have a clear trend. For example, there was no clear relationship between the reinforcement and the initial stiffness. In some cases, contrary to expectations, even higher stiffnesses were achieved for unreinforced connections. The type of fastener and the side member thickness have little effect on stiffness, but a greater effect on the development of the plastic plateau and the ductility of the connection.

Within the framework of the current research project, additional tests with groups of fasteners will be carried out in order to be able to estimate the influence of a possible group effect on the stiffness. Furthermore, all test results should also be evaluated in terms of the reloading stiffness K_e, as this may also be relevant for practical applications. The test results will therefore help to increase the data base on the stiffness of dowel-type connections, particularly for hardwoods, and thus enable their efficient use.

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