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INFLUENCING PARAMETERS ON THE EXPERIMENTAL DETERMINATION OF THE WITHDRAWAL CAPACITY OF SELF-TAPPING SCREWS

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ABSTRACT: Depending on physical and geometrical boundary conditions, withdrawal and/or steel tensile failure govern the structural design of axially loaded self-tapping screws. Therefore needed parameters such as the withdrawal strength f_{ax} or the steel tensile capacity f_{tens} are commonly determined by tests and given in technical approvals and standards. Consequently, it is of major importance to apply a test configuration and procedure guaranteeing a general validity for the broad bandwidth of screw applications. Due to the fact that the mechanical steel behaviour of modern timber screws (i) is comparable with those of similar steel products and (ii) has a typically low dispersion, we concentrate in this paper on effects influencing the withdrawal strength representing the composite behaviour timber-screw. Thus, we show and discuss results of an experimental campaign, aiming to investigate the influence of different load path and supporting conditions as well as of varying loadings rates and sample preparations on the withdrawal performance of self-tapping screws.

KEYWORDS: Axially loaded self-tapping screws; test configurations; load path variation; rate of loading, pre-drilling

1 INTRODUCTION [1]

Self-tapping screws are nowadays commonly used to connect or reinforce linear or laminar structural components out of wood based products such as solid timber (ST), glued-laminated timber (GLT) or cross-laminated timber (CLT). Thereby, inclined or longitudinal positioning relatively to the load direction lead to an optimised way of application reaching the maximum load bearing capacity; see Figure 1. Reason therefore is the resulting primary axial load condition of the screw mainly governed by two failure mechanisms: (a) steel failure in tension and (b) withdrawal failure. For case (b) the characteristic withdrawal capacity (in direction of the screw axis) of the single fastener reachable is given as follows:

$$F_{ax,k} = k_{ax} \cdot f_{ax,k} \cdot d \cdot l_{ef}\,, \tag{1}$$

where k_{ax} considers the effect of insertion angles α of screw axis to grain direction, deviating from 90 °, $f_{ax,k}$ the characteristic withdrawal parameter at α = 90 °, d the diameter and l_{ef} the inserted threaded part of the screw. In addition, there are two main possibilities determining the withdrawal parameter $f_{ax,k}$: (1) by using an empirical regression function, e. g. design equation (8.39) according to EN 1995-1-1 [1], or (2) by using constant values (mainly in dependence of d), referred to a characteristic density ρ_k of 350 kg/m³ and recommended by screw manufacturers in their product related European Technical Assessments (ETAs, formerly known as European Technical Approvals).

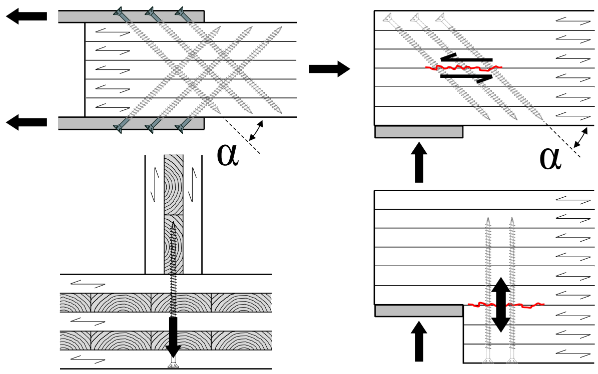

Figure 1: *Common screw applications; left: as connection; right: as reinforcement; above: inclined positioned; below: longitudinally positioned*

Both alternatives principally base on experimental investigations subjected to certain boundary conditions. Especially in case (2), determination of $f_{ax,k}$ values follows an internationally regulated procedure with the aim to avoid irreproducible deviations caused by different test and assessment standards. Thereby, technical guidelines such

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as European Assessment Documents (EADs; for screws Common Understanding of Assessment Procedure, CUAP formerly had to be applied) rule the way (number of tests, which standards have to be considered, etc.), mechanical parameters of e. g. fasteners for use in timber engineering have to be determined. In case of f_{ax} (of self-tapping screws), this document refers to the standard EN 14358 [2] for determination of the characteristic 5 % percentile and especially to EN 1382 [3] for test procedure. Fixed boundary conditions in the latter mentioned document are

i. the position of the fastener relative to the annual ring orientation − at $\alpha = 90\,°$ radial as well as tangential arrangement has to be considered;

ii. the angle ε of the screw axis to the sample's surface − it is fixed to 90 ° (not to be confounded with α);

iii. the distance of the screw axis to the supporting − minimum three times the diameter;

iv. the rate of loading (RoL) − withdrawal failure should appear in 90 ± 30 s with a constant loading velocity v; and

v. the type of loading − monotonic and deviating from EN 26891 [4] without an initial hysteresis.

Subsequently, we may separate those five points in dependence of their impact on the withdrawal capacity as well as their treatment in previous studies. Firstly, it is well known that the type of loading (monotonic or cyclic), doesn't influence the maximum test loads (F_{max} acc. to EN 1382 [3], used to determine f_{ax}) in a major way, see e. g. [5,6]. Secondly, conclusions made in [7,8] indicate that the position of the screw axis to the annual ring orientation at $\alpha = 90\,°$(radial or tangential) has no significant influence on f_{ax}. Thus, the necessity of testing both directions has to be discussed. Thirdly, and with regard to a time to failure area of interest, lasting from 0 s (roughly) to 300 s (as target value for shear strength acc. to EN 408 [9]), but excluding impact impulse loads caused by pendulum impact hammers or drop weight impact testing machines, there are two deviating opinions concerning an RoL related influence existing. On the one hand, Rosowsky and Reinhold (tested small screws and nails both subjected to axial and lateral loads) [10] as well as Aoki and Tsuchimoto (tested bolted timber joints) [11] conclude no (or in special cases just little) impact of RoL on the bearing capacity. On the other hand, Jansson documents in [12] (clear wood bending tests, 'class 1 material') an increase of failure stress by decreasing time to failure of about 13 % between 0.2 s and 60 s. Furthermore, Girhammar and Andersson [13] observe a substantial increase in the 'dynamic strength' (v_{test} = 75 mm/min - 75,000 mm/min) if compared to a reference 'static strength' (v_{test} = 2.0 mm/min) of laterally loaded nailed timber-to-timber connections. Fourthly, investigations, where the angle of the screw axis to the sample's surface or its distance to the supporting have been varied systematically, are hardly to be found.

In addition to these boundary conditions discussed, there are further parameters not ruled in detail in EN 1382 [3] but also probably influencing the bearing resistance of axially loaded self-tapping screws. They are (i) the load and support conditions (push or pull), (ii) the shape and direction of the load path in the sample (push/compression, pull/tension or pile/shear), (iii) the test preparation (with or without pre-drilling) and (iv) the climate conditions (moisture content and temperature) of the sample at time of testing. Concerning point (i) and (ii), previous studies focusing on self-tapping screws are rare again. Bejtka states in [14] that both loading alternatives push and pull lead to the same withdrawal capacities. A very important fact considered in all content-related investigations following on. In contrast to that, Gehri and Haas theoretically assume in [15] significant impacts on f_{ax} caused by compression and shear (push and pile) load path situations in the timber specimen, see Figure 2. This statement is one of the main motivations for carrying out the experimental campaign described in section 2.

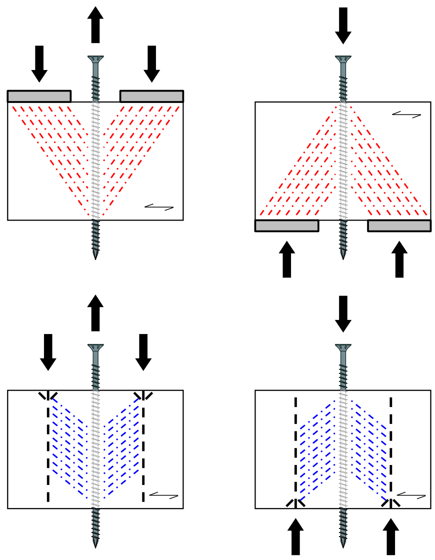

Figure 2: *Different loading and load path situations; left: pull; right: push; above: compression; below: shear; acc. to [15]*

With regard to test preparation (iii), neither in current standards and assessments/approvals (cf. EN 1995-1-1, section 10 [1], e. g. ETA-11/0190 [16]) nor in previous studies also focusing on this topic (ST: [17]; GLT and CLT: [18]) significantly different withdrawal capacities of pre-drilled and not pre-drilled screws have been observed. In addition, in [17] the ST and GLT specimen's temperature (iv) has been varied between -20 °C and 50 °C with no essential influence on f_{ax}, too. In contrast to that the behaviour in dependence of the specimen's moisture content u: Hereby, results of withdrawal tests carried out with different types of timber products indicate a remarkable influence of u on f_{ax}, independently from the product and the way, specimen have been conditioned (reaching target moisture content before or after inserting the screw). Different correction functions for 0 % ≤ u ≤ 20 % are provided in [19] and thus not discussed in detail in the frame of this paper.

In brief: Based on the 'status quo' concerning influencing parameters on the experimental determination of the withdrawal capacity of self-tapping screws, their dependency on varying load path situations, the distance to the supporting, the rate of loading as well as on the angle of the screw axis to the sample's surface is either unknown or different opinions exist regarding these topics. Consequently, in our paper we exactly focus thereon studied in the frame of three experimental campaigns, which are described in section 2 and section 3 more in detail. Finally, in section 4 we summarise our findings related, especially with regard to regulations currently given in EN 1382 [3].

2 MATERIALS AND METHODS

2.1 GENERAL OVERVIEW

As already mentioned in section 1, the test programme being described is separated into three individual series and was carried out at Lignum Test Centre (LTC) at Graz University of Technology. While the first and main series primary focuses on different load path situations (Ia), supporting possibilities (also Ia) and their distance to the screw axis (Ib and Ic), additional series II and III concentrate on different loading rates and surface angles. Furthermore, series I has been carried out in chronological order: After finishing (and based on) data assessment of Ia, series Ib and Ic (α = 90 °) were planned and tested. Thus, only two of four configurations were investigated regarding supporting distances. Table 1 and Figure 3 to Figure 5 give an overview regarding all configurations tested (note: series II configuration is standard push-pull and therefore not shown graphically). For reasons of accuracy, series I screws had been pre-drilled. Although, studies mentioned in section 1 indicate no significant impact, one control-group as part of subseries Ia was conducted without pre-drilling; a comparison is given in section 3.

Table 1: *Overview of test series I-III*

Series	Sub-series	α [°]	ε [°]	d [mm]	d_{PD} [mm]	n* [-]
I	Ia	0 | 90	90	8	- | 6	549
	Ib	0 | 90	90	8	6	160
	Ic	90	90	8	6	469
II		90	90	8	-	99
III		90	45 | 90	6	-	40

* outliers included

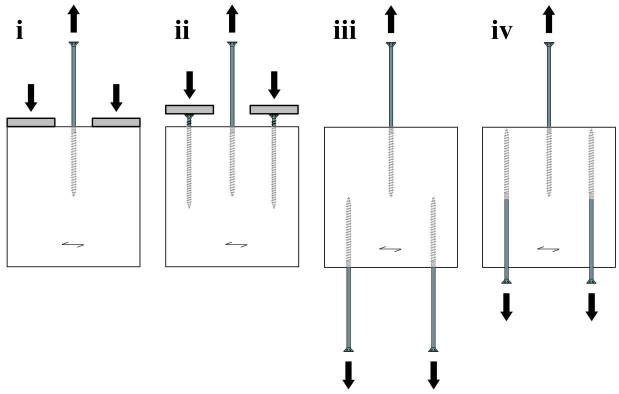

Figure 3: *Test configuration of series Ia: (i) push-pull; (ii) push-pile; (iii) pull-pull; (iv) pull-pile (schematic)*

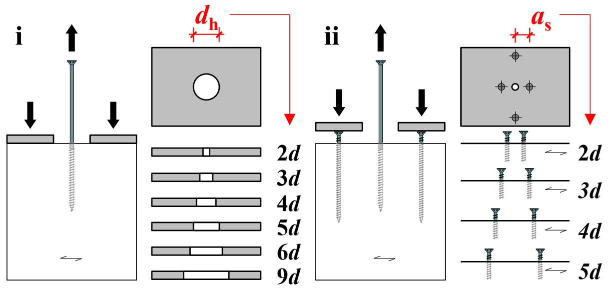

Figure 4: *Test configuration of series Ib (left) and Ic (right)*

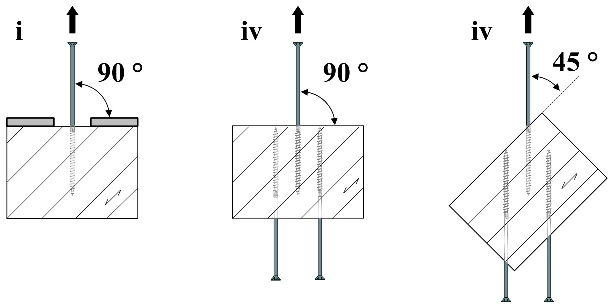

Figure 5: *Test configuration of series III (schematic)*

2.2 MATERIALS

The timber specimen used for the experiments were made out of solid timber (I and II) and GLT (III) beams of Norway spruce (*Picea abies*) with a total length of about 4 m. To achieve homogenous material conditions (location parameters as well as distribution of density ρ, assumed to be normal distributed) for each series, which avoids any density related correction of test result afterwards, the principle of 'matched samples' has been applied in the frame of specimen production.

The self-tapping screws used for the experiments were partially threaded with d = 6 (III) and 8 mm (I and II). Geometrical details are given in Table 2.

Table 2: *Geometrical details of the screws used for the tests*

Diameter d [mm]	Total length [mm]	Thread length [mm]	Effective length l_{ef} [mm]	Technical Approval
6	420	192	107	ETA-12/0373 [20]
8	400	99	90	ETA-11/0190 [16]

2.3 METHODS

The tests determining the withdrawal capacities of series I-III were performed on Allround-Line testing machine by manufacturer Zwick GmbH & Co. KG. The time to failure of all experiments (deformation controlled), except series II, resulted in the range of 90 ± 30 s acc. to EN 1382 [3]. Series II loading protocols are given in Table 3. When tests were finished, $4d$ x $4d$ x l_{ef} clear wood samples were cut out around the screw hole and went to further treatment determining the density by measuring the physical dimensions as well as the moisture content by performing oven dry method. Furthermore, all samples were cut in the middle and observed regarding knots influencing the axial load bearing behaviour and - if they had - thus marked as outliers. Data assessment was carried out by spreadsheets and the software package R [21].

Table 3: *Loading conditions for test series II*

Sub-series	Targeted time to failure [s]	Rate of Loading [mm/min]	n* [-]
1	0	500	20
2	45	4.00	20
3	90	2.20	20
4	135	1.50	20
5	300	0.60	19

* outliers included

3 TEST RESULTS AND DISCUSSION

3.1 GENERAL COMMENTS AND FINDINGS

For a better overview test results and their discussion are thematically divided up into the following subsections. Deviating from EN 1382 [3], withdrawal strength f_{ax} of all results shown in section 3 has been determined by

$$f_{ax} = \frac{F_{ax}}{d \cdot \pi \cdot l_{ef}}, \tag{2}$$

where F_{ax} is the maximum force measured for each test, in (N). Finally, it is worth mentioning, that moisture content of all series varied in a range of max ± 2 % per series.

3.2 STATISTICAL EVALUATION

To find out if a test series' specification essentially influences the withdrawal capacity, we generally tested median values ($f_{ax,med}$) and mean values ($f_{ax,mean}$) for significance deviation using Wilcoxon-Mann-Whitney test and Student's t-Test, which postulates normal distribution (ND) of our results. Test results are shown and compared graphically in form of notched boxplot diagrams (95 % - confidence interval (CI) determined by Wilcoxon-Test) and error bars (95 % - CIs as t-Test results). We assume our data to be lognormal distributed (2pLND), wherefore we tested $\ln(f_{ax,i})$ by applying Shapiro-Wilk-Test (SW) before. In principle, there are two reasons for this assumption: (i) 2pLND constraints only positive data values as they are common for physical and mechanical properties such as strength and stiffness (c. f. [22]), while ND doesn't feature such restrictions; (ii) standard EN 14358 [2] also assumes 2pLND for data assessment. For reasons of general validity (except series III, where test numbers are too small): SW test results indicate that the assumption of 2pLND withdrawal strength is valid for all test results determined (see Table 4 to Table 8). Furthermore, we evaluated the possibility of significantly different deviations by testing the resulting coefficients of variation (CV[$\ln(f_{ax,i})$]) with the modified McKay approach [23].

3.3 IA - LOAD PATH SITUATIONS

3.3.1 Main results

In Figure 6 and Figure 7 as well as in Table 4 location parameters of withdrawal strength are given in dependence of the prevalent load path situation of the test. Additionally, Figure 8 and Figure 9 compare resulting $CV[\ln(f_{ax})]$ of all subgroups. As shown in the corresponding figure, results of test series iii at $\alpha = 90$ ° are plotted with dashed lines, CI error bars are missing here. Reason therefore is the fact that a significant number of screw tests failed by tension perp. to grain instead of withdrawal (c. f. Figure 3). Consequently, this data set has to be seen as right censored. Location parameters $\theta = (\mu_y, \sigma_y)$ were thus determined using maximum-likelihood estimation (rcMLE)

$$\ln\left[L\left(\hat{\theta}|x_i\right)\right] = \max_{\theta}\left[\ln\left[L\left(\theta|x_i\right)\right]\right], \text{ with}$$
$$L\left(\hat{\theta}|x_i\right) = \prod_{i=1}^{n} f_{X_i}\left(x_i|\theta\right)^{d_i} \cdot \left[1 - F_{X_i}\left(x_i|\theta\right)\right]^{1-d_i}, \tag{3}$$

where d_i differs between 1 and 0, which includes whether withdrawal failure has been reached or not. The resulting point estimations for $\ln(f_{ax})$ and $CV[\ln(f_{ax})]$ are drawn as red points without CIs. With regard to all corresponding figures and Table 4, two points are worth to be mentioned: Firstly, the expectations of test series' densities as well as their dispersions ($CV[\rho]$) only vary in the comparatively small scheduled bandwidth, avoiding any correction of withdrawal strength. Secondly and as given by completely overlapping notches and error bars, neither the logarithmic withdrawal strength nor its dispersion are significantly influenced by different test configurations and/or load path situations.

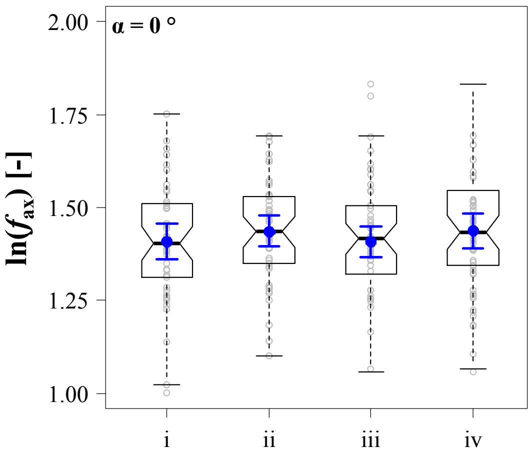

Figure 6: *CIs of logarithmic withdrawal strength; test series Ia, α = 0 °*

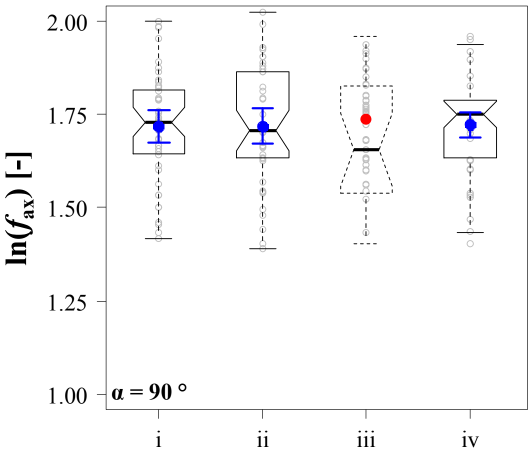

Figure 7: *CIs of logarithmic withdrawal strength; test series Ia, α = 90 °*

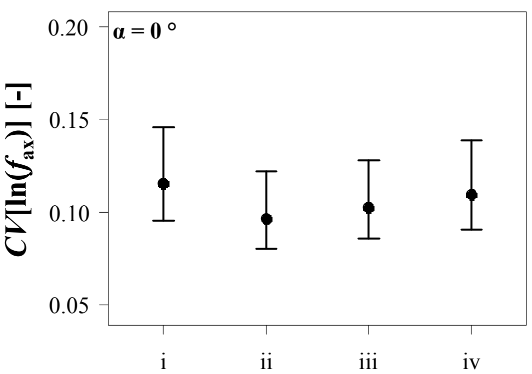

Figure 8: *CIs of CV[ln(f_{ax})]; test series Ia, α = 0 °*

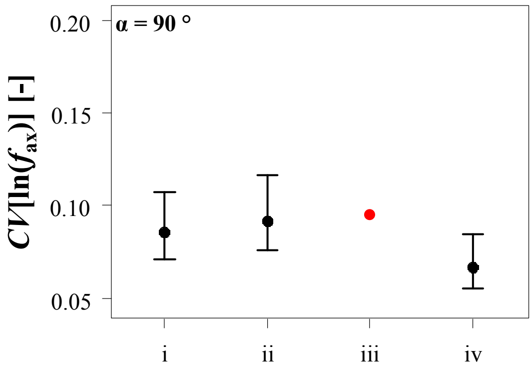

Figure 9: *CIs of CV[ln(f_{ax})]; test series Ia, α = 90 °*

Table 4: *Density and withdrawal strength of series Ia,*

	E[ρ] [kg/m³]	CV[ρ] [%]	E[f_{ax}] [N/mm²]	p* [-]	CV[f_{ax}] [%]	*n* [-]
α = 0 °						
i	408	10.8	4.15	0.72	16.4	46
ii	407	9.68	4.24	0.79	14.0	46
iii	422	10.8	4.13	0.76	14.5	51
iv	416	11.0	4.26	0.87	15.9	46
α = 90 °						
i	402	9.36	5.62	0.34	14.7	47
ii	405	9.62	5.65	0.46	15.9	44
iii	415	14.9	5.77	-	19.4	51
iv	410	7.76	5.63	0.81	11.5	45

* the p-values are the Shaprio-Wilk-Test results for ln(f_{ax})

3.3.2 Pre-drilling

As already mentioned in section 2.1, one control group per α was carried out without pre-drilling. Thus, in Table 5 the location parameters of density and withdrawal strength as well as pairwise statistical test results are given. Again, the expectation as well as the dispersion of density are similar for all series. In case of α = 0 °, Wilcoxon-Test as well as student's t-Test p-values indicate a significantly higher withdrawal strength as consequence of pre-drilling while in case of α = 90 ° differences are negligible. Compared to previous studies (predominately focusing on α = 90 °; only in [17] one ratio for α = 0 ° is given), the result for α = 0 ° was not expected. When considering the 'delicate' situation for this form of application (long-term tests indicate a very poor DoL behaviour of end-grain screwed connections, see [24]) this positive effect of pre-drilling should be focused in future investigations.

Table 5: *Comparison regarding pre-drilling for series Ia*

α [°]		0		90	
pre-drilling	[-]	N	Y	N	Y
E[ρ]	[kg/m³]	402	408	400	402
CV[ρ]	[%]	9.05	10.8	10.0	9.36
E[f_{ax}]	[N/mm²]	3.72	4.15	5.54	5.62
Shapiro-Wilk-Test p-value	[-]	0.11	0.72	0.11	0.34
CV[f_{ax}]	[%]	15.1	16.4	12.4	14.7
n	[-]	48	46	46	47
Wilcoxon-Test p-value	[-]	0.00		0.60	
F-Test p-value	[-]	0.57		0.24	
T-Test p-value	[-]	0.00		0.64	

3.4 IB and IC - SUPPORTING DISTANCES

3.4.1 IB - Varying supporting plates

In this subsection, Figure 10 and Figure 11 as well as Table 6 illustrate the results of withdrawal strength in dependence of a varying hole diameter d_h (of the supporting plate used for common push-pull tests). Again, nearly equal mean densities and *CV*s enable direct comparability of f_{ax}. Congruent to the behaviour observed for different load path situations in section 3.3, α = 90 ° results indicate no significant deviations for different d_h, while at α = 0 ° a non-significant but decreasing trend of withdrawal strengths with decreasing d_h has to be observed.

Since this behaviour can't be explained by mechanical effects (in fact, we exactly assumed the opposite), we additionally evaluate these test results with a prediction model for $f_{ax,pred}$ given in [17] especially for screw axis parallel to grain direction:

$$f_{ax,pred} = 0.00538 \cdot \rho_{exp} - 0.45875 \cdot \left(2.44 \cdot d^{0.572}\right) + 5.92460. \tag{4}$$

When comparing mean values of $\ln(f_{ax,pred})$ (red symbols) with our experimental expectations (blue symbols) in Figure 10, the model values exactly result among the experiments showing that neither bigger subseries results (d_h = 5 and 6 *d*), nor lower ones (d_h = 2 ÷ 4 *d*) significantly deviate from the predictions. To conclude: Also for α = 0 ° an influence of d_h on f_{ax} can be excluded with high reliability.

Moreover and independently from α, a significant influence of d_h on the dispersion of f_{ax} cannot be observed, see Figure 12 and Figure 13.

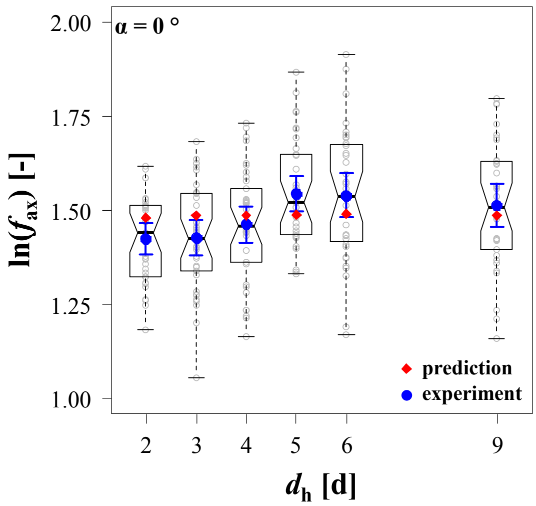

Figure 10: *CIs of logarithmic withdrawal strength and mean model results; test series Ib, α = 0 °*

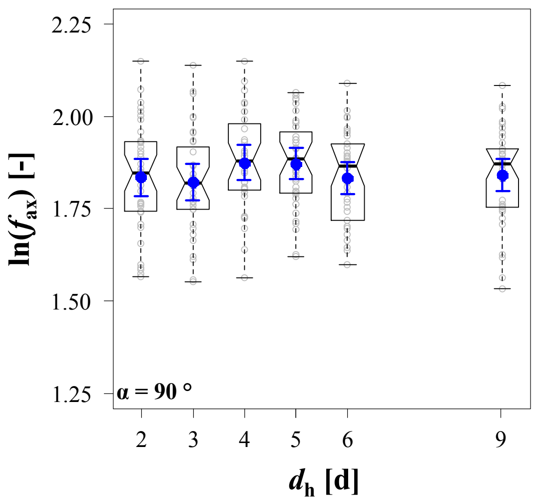

Figure 11: *CIs of logarithmic withdrawal strength; test series Ib, α = 90 °*

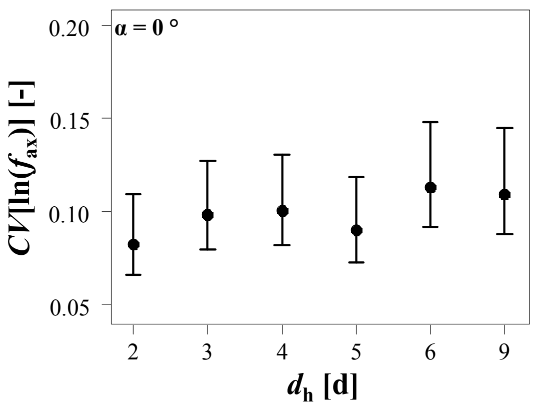

Figure 12: *CIs of CV[ln(f_{ax})]; test series Ib, α = 0 °*

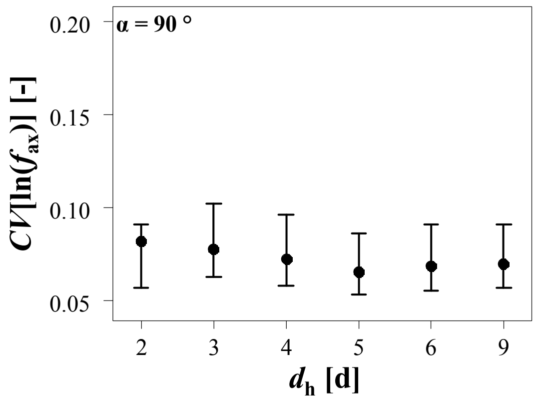

***Figure 13:** CIs of CV[ln(f_{ax})]; test series Ib, α = 90 °*

***Table 6:** Density and withdrawal strength of series Ib,*

d_h [d]	E[ρ] [kg/m³]	CV[ρ] [%]	E[f_{ax}] [N/mm²]	p* [-]	CV[f_{ax}] [%]	n [-]
α = 0 °						
2	398	10.5	4.18	0.16	11.8	33
3	404	12.8	4.21	0.66	14.1	38
4	403	10.6	4.36	0.36	14.8	38
5	405	10.9	4.73	0.14	14.0	35
6	407	10.7	4.73	0.89	17.5	36
9	404	11.8	4.60	0.73	16.7	34
α = 90 °						
2	404	10.3	6.33	0.59	15.1	37
3	406	9.02	6.25	0.93	14.2	35
4	401	10.1	6.58	0.99	13.6	32
5	409	9.59	6.55	0.43	12.3	35
6	406	9.43	6.30	0.49	12.7	34
9	404	9.44	6.36	0.16	12.9	37

* the p-values are the Shaprio-Wilk-Test results for ln(f_{ax})

3.4.2 IC - Varying supporting screws

As demonstrated in Figure 4, not only hole diameters of supporting plates (compression load paths, c. f. Figure 2) but also the distances of the supporting to the test screws (shear load paths) have been varied. In contrast to the campaign shown in section 3.4.1, a fairly smaller program in form of four different distances $a_s = 2 \div 5\ d$ (only in grain direction and for α = 90 °) was executed. Test results shown in Figure 15 and Table 7 indicate constant withdrawal capacities with increasing a_s (which means increasing dimension of the shear field), while those of subseries $a_s = 2\ d$, closest to the test screw, are remarkably smaller than the rest. This effect is easily explained by an already harmed timber-screw composite area. Based on this finding, it is worth mentioning that minimum distances (e. g. acc. to EN 1995-1-1 [1]) should be also considered for fasteners with different 'load-bearing tasks', see Figure 14. Finally and equal to the previous comparisons, a significant influence of d_h on the dispersion of f_{ax} cannot be observed, see Figure 16.

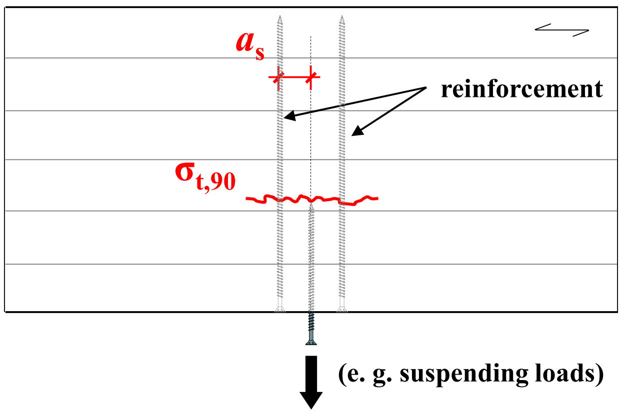

***Figure 14:** Example of different 'load-bearing tasks' in one joint detail*

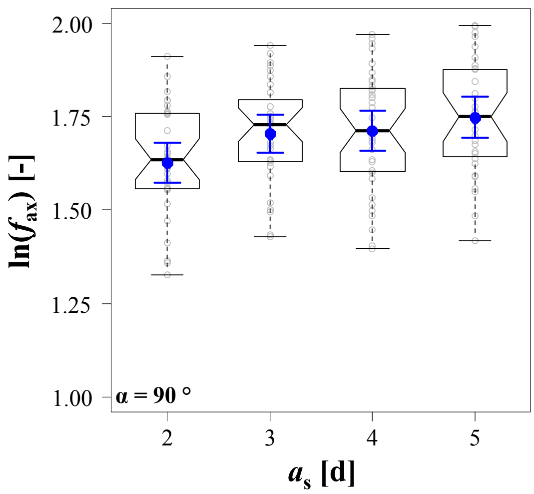

***Figure 15:** CIs of logarithmic withdrawal strength; test series Ic*

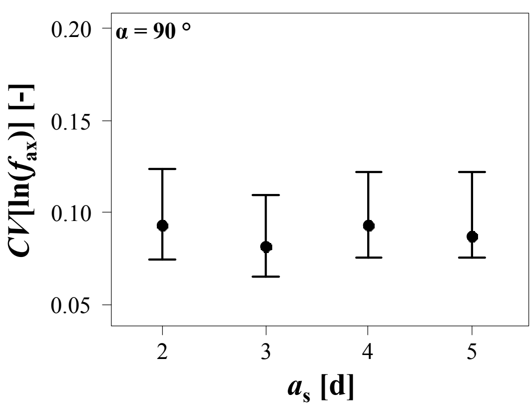

***Figure 16:** CIs of CV[ln(f_{ax})]; test series Ic*

***Table 7:** Density and withdrawal strength of series Ic*

a_s [d]	E[ρ] [kg/m³]	CV[ρ] [%]	E[f_{ax}] [N/mm²]	p* [-]	CV[f_{ax}] [%]	n [-]
2	396	9.99	5.15	0.30	15.2	33
3	393	9.15	5.56	0.49	14.0	31
4	393	9.87	5.61	0.32	16.0	36
5	396	9.50	5.81	0.71	15.3	32

* the p-values are the Shaprio-Wilk-Test results for $\ln(f_{ax})$

3.5 II - RATE OF LOADING

In addition to different conditions for loading and supporting, this section presents the withdrawal strength results in dependence of a varying loading rate. Similar to section 3.4.2, the experimental programme had been reduced to α = 90 °, investigations with screws inserted and loaded parallel to grain are thus seen as a task for the future. Nevertheless, Figure 17 and Table 8 give an overview of the subseries' withdrawal capacities and densities, which again underline the un-necessity of any correction. Back the f_{ax} results, we can notice a remarkable (but non-significant) increase at target time to failure (*ttf*) of ~0 s, while the rest indicates no influence of *ttf* on withdrawal capacity for our field of interest. Once again, Figure 18 demonstrates that $CV[\ln(f_{ax})]$ is not affected by a varying loading rate.

Following previous studies concerning RoL, Figure 19 compares f_{ax} and *ttf* in a semi logarithmic scale, demonstrating that (i) changes of *ttf* with a factor smaller or equal to 10^1 s don't affect the withdrawal capacity in a major way and (ii) an accurate model describing the behaviour of f_{ax} in dependence of RoL needs at least one more sampling point at e. g. *ttf* = 5 s or 10,000 s. Anyway, Equation (5) and Equation (6) propose a first linear approach in dependence of *ttf* (also drawn in Figure 19)

$$\frac{f_{ax,i}}{f_{ax,ref}} = 1.11 - 0.059 \cdot \log_{10}(ttf) \tag{5}$$

and in dependence of v (mm/min)

$$\frac{f_{ax,i}}{f_{ax,ref}} = 0.98 + 0.056 \cdot \log_{10}(v) \text{, (both } R^2 = 0.10\text{).} \tag{6}$$

***Table 8:** Density and withdrawal strength of series II*

	E[ρ] [kg/m³]	CV[ρ] [%]	E[f_{ax}] [N/mm²]	p* [-]	CV[f_{ax}] [%]	n [-]
1	408	12.2	6.32	0.24	20.2	17
2	409	11.0	5.46	0.68	14.3	18
3	415	11.0	5.56	0.34	14.5	20
4	411	11.5	5.56	0.90	16.9	20
5	408	12.5	5.43	0.75	18.2	19

* the p-values are the Shaprio-Wilk-Test results for $\ln(f_{ax})$

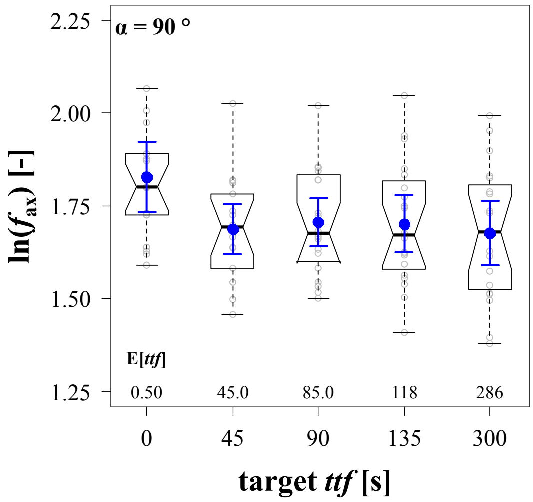

***Figure 17:** CIs of logarithmic withdrawal strength; test series II*

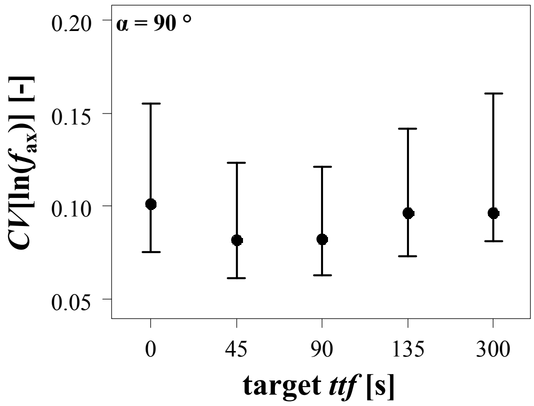

***Figure 18:** CIs of CV[ln(f_{ax})]; test series II*

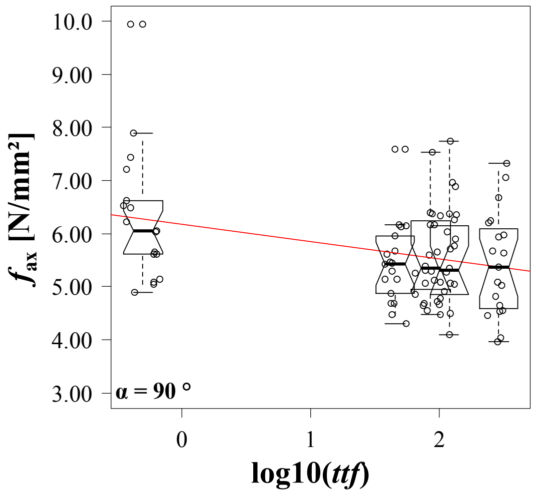

***Figure 19:** Test series II: Withdrawal strength vs. log10(ttf)*

3.6 III - SURFACE ANGLE

The investigation presented in this section was originally carried out as single screw reference test group in the frame of a research project dealing with the axial load bearing behaviour of screwed connections, see [25,26].

As shown in Figure 5, the angle ε of the test specimen's surface to the screw axis has been varied between 90 ° (acc. to EN 1382 [3]) and 45 °, which is a frequently form of application in practise. As consequence of relatively small numbers of tests (see Table 9), an investigation regarding the type of statistical distribution was not performed. Thus, only notched boxplots shown in Figure 20 serve as indicators whether different values of ε influence f_{ax} in major way. Based on the results given, we have to negate this question. In addition, non-significant deviations between load path situations i and iv at α = 45 ° are well in-line with those discussed in section 3.3.1.

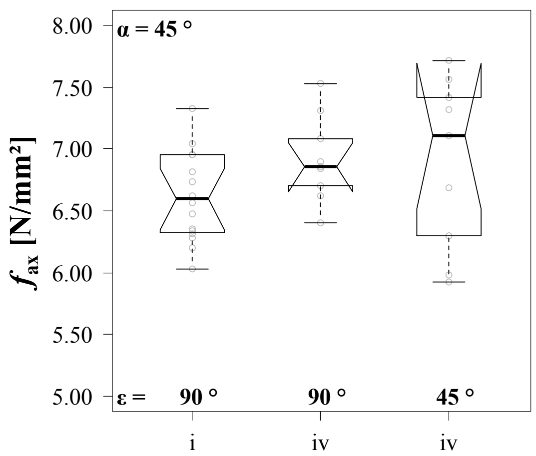

Figure 20: *CIs for withdrawal strength of test series III*

Table 9: *Density and withdrawal strength of series III*

	ε [°]	E[ρ] [kg/m³]	CV[ρ] [%]	E[f_{ax}] [N/mm²]	CV[f_{ax}] [%]	*n* [-]
i	90	430	2.80	6.62	5.49	16
iv	90	439	2.15	6.91	5.02	9
iv	45	448	7.01	6.89	10.0	9

4 SUMMARY, CONCLUSION AND OUTLOOK

In the frame of this paper we showed and discussed the results of a test campaign carried out to evaluate possible effects significantly influencing the experimental determination of the withdrawal parameter of axially loaded self-tapping screws.

Based on the findings of corresponding previous studies, we assumed that especially different load path situations in the timber specimen lead to different withdrawal capacities. Moreover, we executed additional series aiming to investigate further possible effects, such as pre-drilling, the distance of the supporting to the fastener's axis, its angle to the specimen's surface as well as the time to failure (or rate of loading).

Our main interest was to observe the behaviour of expectation and dispersion (in form of the coefficient of variation) of the parameter withdrawal strength in dependence of varying parameters mentioned before. Consequently, we compared test series' results by applying statistical tools for these location parameters such as Wilcoxon-Mann-Whitney-, Student's t-Test and modified McKay approach. The boundary condition of both latter mentioned test procedures is a ND data set, which is convenient for the natural logarithms of f_{ax} when the parameter itself is assumed to follow a 2pLND.

With regard to this evaluation we conclude: If conditions, where too small distances of supporting screws already harm the timber-screw composite area (push-pile), or the screwed connection tested doesn't fail by withdrawal (e. g. pull-pull at α = 90 °), are avoided, different loading and supporting conditions as well as the distance of the screw axis to the supporting won't influence the withdrawal behaviour in a major way. Even though the number of corresponding tests is relatively low, the same findings can be stated for different times to failure and surface angles, postulating that the former mentioned parameter varies in between a practical range (45 s ≤ *ttf* ≤ 450 s). Finally and deviating from the expectation at begin of testing, significant increase of f_{ax} as consequence of pre-drilling was found for α = 0 °.

Beside the latter mentioned observation, which should be focused more in detail in future investigations especially combined with duration of load (DoL) performance, further topics of interest are: The broadening of RoL tests series described in section 3.5 (one or two additional sampling points and the whole test campaign for α = 0 °) to develop an accurate RoL dependent model of f_{ax} as well as a comparison of test results for different load paths with a mechanical model (e. g. Theory of Volkersen [27]).

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