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Technical Report

Creep behavior of cross laminated timber in service class 2

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Abstract

At the University of Applied Sciences in Augsburg the creep behavior of cross laminated timber (CLT) in service class 2 has been investigated during a period of 15 years.

The results indicate that the creep behavior of CLT is more pronounced than for glued laminated timber and therefore higher deformation (creep) factors k_{def} should be used in design.

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1 First investigations

In 1999 a diploma thesis has been performed in cooperation with MERK Timber GmbH, Aichach (Germany). The scope of this thesis was to determine the shear modulus and to estimate the creep behavior of CLT.

The investigations concerning the creep behavior were performed with CLT-members having a width of 300 mm, a depth of 85 mm (5 x 17 mm) and a span of 1530 mm. The boards were produced with relieving grooves and the members were glued in a vacuum process.

Three test series with different loading have been investigated (see **Figure 1**):

- series 1: beam with constant moment-loading
- series 2: beam with third point loading
- series 3: beam with single point loading at mid-span.

Of each test series two specimens have been investigated.

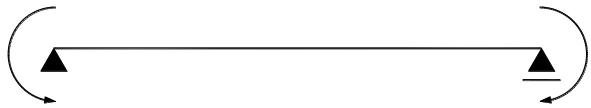
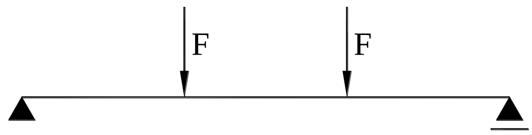
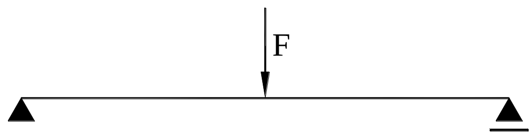
series 1	
series 2	
series 3	

Figure 1 test series

These test series have been designed in order to have different amounts of shear-loading and thus different amounts of shear deflection in relation to the corresponding total deflections.

The loadings were chosen aiming at a tension stress in the outer lamellae of about 10,6 – 10,9 N/mm², which corresponds to the allowable tension stress of the German timber design code at that time (DIN 1052, [3]) for strength Class S 10.

The loadings were applied with weights made from concrete, having a load of 600 to 800 kg depending on the test series.

The test specimens were placed in a specially fabricated roofed "warehouse" (**Figure 2**). In this location the test specimen were widely protected against rainfall, so that this situation may be classified to a "rough" service class 2 according to Eurocode 5. This rating is confirmed by the moisture contents of the test specimens determined after 15 years, showing homogeneous values in the range between 14 – 15%, being typical for timber in service class 2.

In **Figure 3** to **Figure 6** the different test specimens with corresponding loadings are shown.

Figure 2 roofed „warehouse“

Figure 3 test specimen with constant moment-loading (series 1)

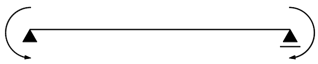
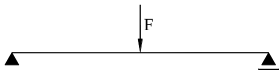
Figure 4 weight made from concrete for test specimens with constant moment-loading (series 1)

Figure 5 test specimen with third point loading (series 2)

Figure 6 test specimens with single point loading (series 3)

The expected elastic deflections were calculated separately for shear and bending. In **Table 1** the expected values are given together with the percentiles referred to the corresponding total deflections.

Table 1 expected elastic deflections

	series 1 		series 2 		series 3 	
	in [mm]	in [%]	in [mm]	in [%]	in [mm]	in [%]
$w_{Q,inst,exp.}$ [1)]	-	-	1,37	19,4%	1,36	23,6%
$w_{M,inst,exp.}$ [2)]	6,85	100%	5,70	80,6%	4,41	76,4%
$w_{inst,exp.}$	6,85	100%	7,07	100%	5,77	100%

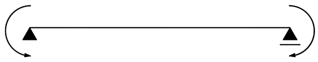
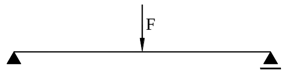
1) calculated assuming:
G = 600 N/mm² for the longitudinal lamellas, G_R = 60 N/mm² (rolling shear modulus) for the cross-wise lamellas,
effective shear stiffness $S = 2{,}225 \cdot 10^6$ N calculated according to [2]

2) calculated according to elastic composite theory assuming:
E = 11.000 N/mm² and $I_{ef} = 12{,}16 \cdot 10^6$ mm^4 taking into account the buildup of the members

Based on this table it can be seen, that the bending members with shear loading (series 2 and 3) show considerable amounts of shear deflections compared to the corresponding total deflections (19,4% for series 2 and 23,6% for series 3). This may be explained by the comparatively low span of the test beams (ℓ = 1,53 m).

Immediately after loading of the beams on 30th of August 1999 the deflections w_{inst} were determined. The measured values are given in **Table 2**.

Table 2 Measured deflections w_{inst} in [mm]

	series 1 		series 2  F F		series 3  F	
	specimen		specimen		specimen	
	PK 1	PK 2	PK 3	PK 4	PK 5	PK 6
gemessen: w_{inst}	4,94	5,18	6,42	9,83	5,54	4,82
Note: The given values are mean values of different measurements and do not indicate an unrealistic accuracy/precision of the measurements						

The deflections have then been continuously determined over a period of the next 4 months (127 days). In the subsequent 1 – 2 years only sporadic measurements have been performed by the staff of MERK Timber GmbH.

Figure 7 shows the increase of deflections referred to the corresponding initial deflections w_{inst} for this first period.

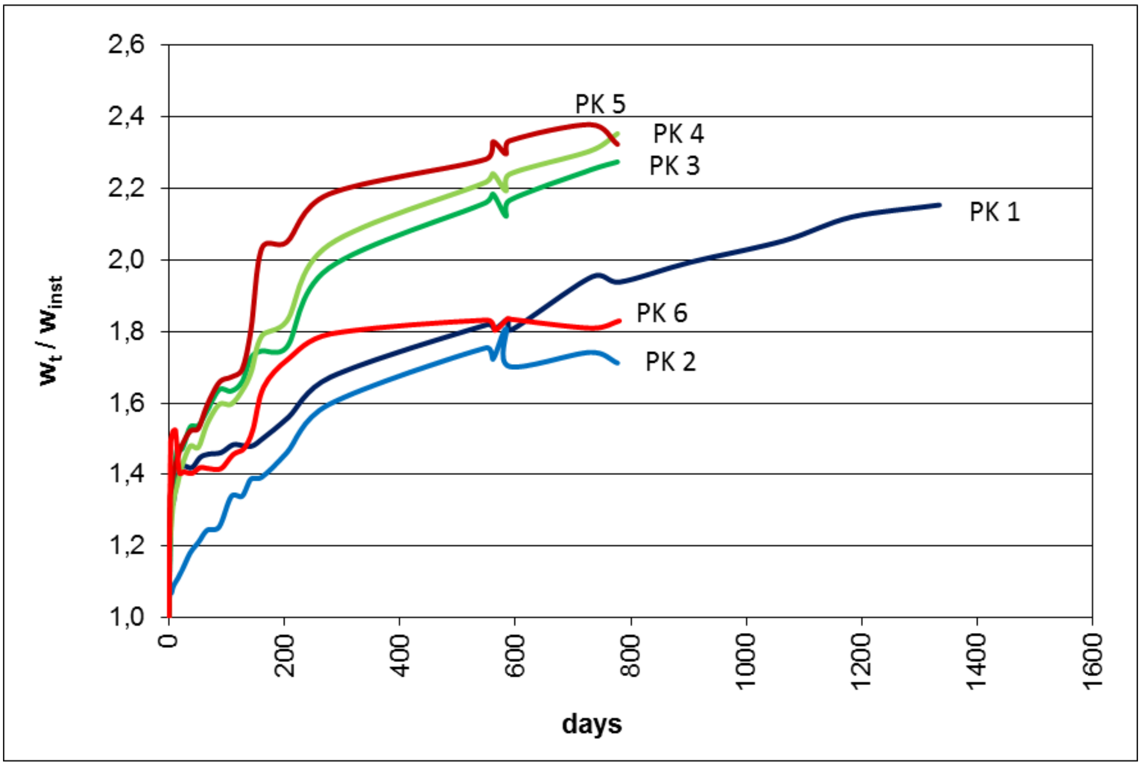


Figure 7 deflection w_t referred to initial deflection w_{inst}

Then the test specimens have been „forgotten“ and no measurements were performed until spring 2014. At that time the test specimen have been finally investigated during a second student’s project. The results of this project are described below.

2 Condition of test specimen

The moisture content of the test specimen were measures at different places. The measured values were in an uniform range between 14 and 15%. This moisture content is typical for timber in service class 2

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3 Deflections after 15 years of loading

The measured deflections after 15 years of loading are shown in **Table 3**.

Table 3 measured deflections w_{15y} in [mm] after 15 years of loading

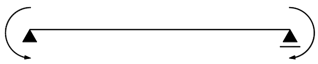
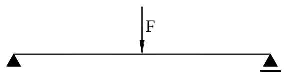
	series 1 		series 2 		series 3 	
	specimen		specimen		specimen	
	PK 1	PK	PK 3	PK 4	PK 5	PK 6
w_{15y}	9,77	8,62	21,81	31,37	16,59	23,74
Note: The given values are mean values of different measurements						

Figure 8 shows the increase of deflections referred to the corresponding initial deflections w_{inst}. In this figure the period between the end of the first measurements and the final measurements is plotted in dashed lines.

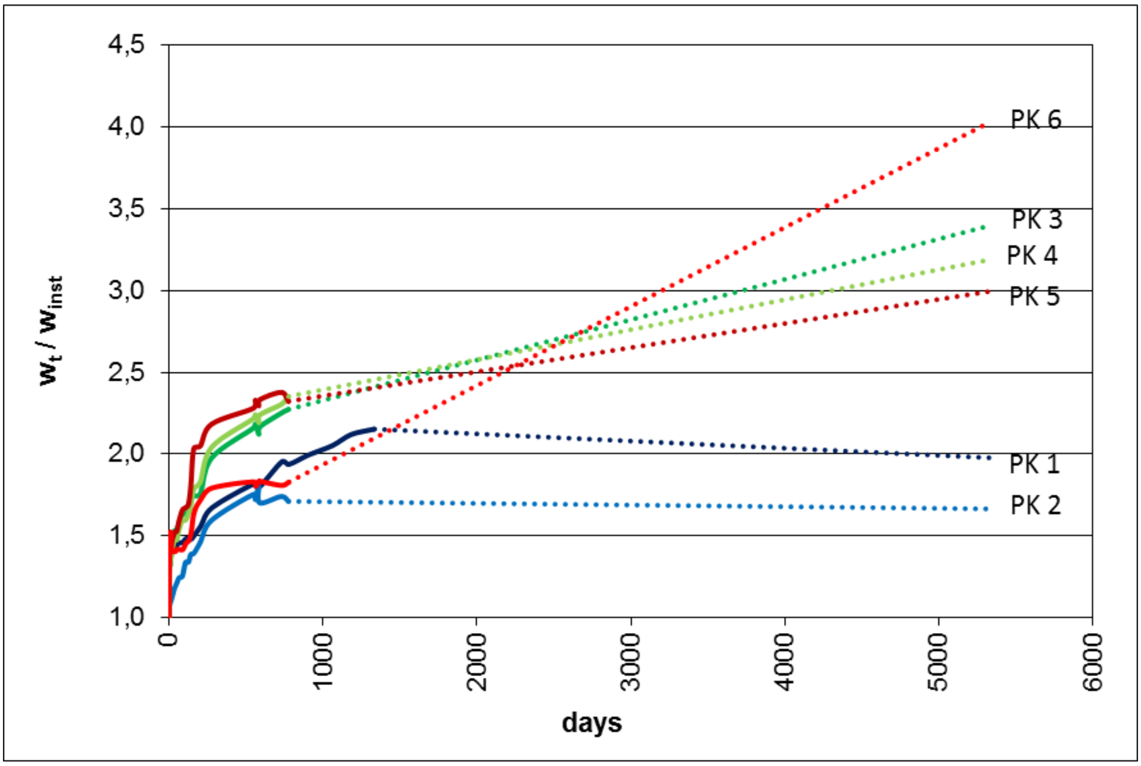


Figure 8 deflection w_t referred to initial deflection w_{inst}

From Figure 8 it can be seen that the specimens with constant moment-loading (PK 1 and PK 2, series 1) do not show any further increase of deflection after the first measuring period.

The other test specimen with shear loading however show significant increases of the deflections. The disproportionate increase of deflection for specimen PK 6 is remarkable, a reason for this could not be found.

Note:	The measuring of the deflections could only be performed with yardstick and caliper gauge. Therefore the apparent decrease of deflections for series (specimen PK 1 and PK 2) should not be overestimated. However the measurements allow a good estimation of tendencies.

4 Estimation of creep factors

4.1 Creep factor for rolling shear

The final deflection of the specimens PK 1 and PK 2 may be calculated as follows:

$$w_{fin} = w_{inst} \cdot (1 + k_{def,M}) \qquad \text{Eq. (1)}$$

with

w_{fin} = final deflection

w_{inst} = instantaneous (elastic) deflection

$k_{def,M}$ = deformation factor (creep factor) for (pure) bending

With Eq. (1) the creep factor $k_{def,M}$ may be determined with the measured deflections as follows:

$$k_{def,M} = \frac{w_{fin}}{w_{inst}} - 1 \qquad \text{Eq. (2)}$$

Based on **Figure 8** the quotient w_{15y} / w_{inst} may be estimated to be in the range of 1,8 approx.. This corresponds to a value of $k_{def,M} \approx 0,8$ after a period of 15 years. This value is in good accordance with the creep factor k_{def} given in Eurocode 5 valid for products made of solid timber in service class 2.

The substantial increase of deflections for the other test specimens of series 2 and 3 can therefore only be explained by additional rolling shear deformations due to creep. Assuming different creep factors for rolling shear and bending the final deflection for the corresponding beams may be calculated as follows:

$$w_{fin} = w_{inst,Q} \cdot (1 + k_{def,Q}) + w_{inst,M} \cdot (1 + k_{def,M}) \qquad \text{Eq. (3)}$$

with

w_{fin} = final deflection

$w_{inst,Q}$ = instantaneous (elastic) deflection due to shear force

$k_{def,Q}$ = creep factor for rolling shear

$w_{inst,M}$ = instantaneous (elastic) deflection due to bending moment

$k_{def,M}$ = creep factor for bending

= 0,8 (see above)

Based on **Table 1** the amount of shear deflection (compared to the total deflection) has been estimated to be 19,4% for series 2 (third point loading) and 23,6% for series 3 (single point loading) approx..

With this Eq. (3) may be transformed into:

series 2: $w_{fin} = 0{,}194 \cdot w_{inst} \cdot (1 + k_{def,Q}) + 0{,}806 \cdot w_{inst} \cdot (1 + k_{def,M})$ Eq. (4a)

series 3: $w_{fin} = 0{,}236 \cdot w_{inst} \cdot (1 + k_{def,Q}) + 0{,}764 \cdot w_{inst} \cdot (1 + k_{def,M})$ Eq. (4b)

In order to determine $k_{def,Q}$ these equations may be transformed into:

series 2: $$k_{def,Q} = \frac{\frac{w_{fin}}{w_{inst}} - 0{,}806 \cdot (1 + k_{def,M})}{0{,}194} - 1$$ Eq. (5a)

series 3: $$k_{def,Q} = \frac{\frac{w_{fin}}{w_{inst}} - 0{,}764 \cdot (1 + k_{def,M})}{0{,}236} - 1$$ Eq. (5b)

The so calculated values for $k_{def,Q}$ are given in **Table 4**.

Table 4 calculated (estimated) creep factors for rolling shear $k_{def,Q}$

	w_{fin} [mm]	w_{inst} [mm]	$k_{def,M}$	$\mathbf{k_{def,Q}}$
PK 3	21,81	6,42	0,8	**9,0**
PK 4	31,37	9,83		**8,0**
PK 5	16,59	5,54		**5,9**
PK 6	23,74	4,82		**14,0**

Table 4 indicates that the creep factors for rolling shear are about 10 times higher than the creep factors for bending.

4.2 Mean/weighted creep factor for floor-elements

The test specimens had short spans and thus had considerable amounts of shear deformations. CLT-elements used as floor elements usually have higher spans and thus lower shear deflections. For these beams the importance of shear deflections is much lower than for the test specimens.

Therefore a “mean” or “weighted” creep factor is derived based on the example of a typical floor element.

Given: Single span element with 5 layers of 27 mm thickness (D = 5·27 = 135 mm) in service class 2. Span ℓ = 4,50 m. Dead load: g_k = 3,0 kN/m²

Calculation values: G = 600 N/mm², G_R = 60 N/mm², E = 11000 N/mm², $I_{ef} = 162{,}385 \cdot 10^6$ mm^4

Deflections: w_Q = 0,64 mm

$\underline{w_M = 8{,}97 \text{ mm}}$

w_{inst} = 9,61 mm (= ℓ/470)

Assuming creep factors for bending of $k_{def,M}$ = 0,8 and for creep of $k_{def,Q}$ = 10·0,8 = 8,0 the final deflection may be calculated according to Eq. (3) to:

$w_{fin} = 0,64 \cdot (1 + 8,0) + 8,97 \cdot (1 + 0,8) = 21,9$ mm (= ℓ/205)

Relating this final deflection w_{fin} to the initial deflection w_{inst} a weighted (mean) creep factor $k_{def,mean}$ may be calculated to

$w_{fin} = w_{inst} \cdot (1 + k_{def,mean}) \rightarrow k_{def,mean} = 1,28$

This estimated mean creep factor is considerably higher than specified in the German Annex to Eurocode 5, where a value of k_{def} = 0,8 is assumed.

The investigations described above confirm the results of JÖBSTL [4] showing, that CLT has a more pronounced creep behavior than glued laminated timber and therefore higher deformation factors should be used in design.

5 References

[1] EN 1995-1-1:2010-12: Eurocode 5: Design of timber structures – Part 1-1: General - Common rules and rules for building.

[2] DIN EN 1995-1-1/NA: National Annex – Nationally determined parameters.

[3] DIN 1052:1988: Holzbauwerke.

[4] Jöbstl, R.A.; Schickhofer, G. 2007: Comparative Examination of Creep of GTL and CLT-Slabs in Bending“, CIB-W18/40-12-3, Bled.

6 Summary

In course of two student's projects at the University of Applied Sciences in Augsburg the deflection behavior of CLT bending elements has been observed during a period of 15 years. A total of 6 specimens with different loading exposed to service class 2 have been investigated. The loading of the specimens was such that the allowable tension stress according to the German timber design code at that time [3] for strength Class S 10 was reached.

Based on the measured deflections it may be assumed that creep due to rolling shear is considerably higher than creep due to bending. The tests indicate a creep factor for rolling shear being approx. 10 times higher than the creep factor for bending (in service class 2).

Transferring this result derived from short span test specimens to typical long span CLT floor elements, a mean/weighted creep factor of $k_{def,mean} \approx 1,2 - 1,3$ may be assumed for CLT elements in service class 2. This value is considerably higher than the creep factor k_{def} = 0,8 specified in [2]. Thus the tests described here indicate a need of modifying the creep factors actually used in design calculations.

The results described above were derived on elements exposed to service class 2 and therefore only allow a tendential statement for floor elements mostly exposed to service class 1.

Furthermore the results have been derived on 5-layer-CLT elements with 17 mm thick boards having relieving grooves. A general transfer to other beam layups with differing layer-thicknesses and without relieving grooves needs further investigations.

7 Acknowledgement

Acknowledgement is given to the following students for their engagement in this project:

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