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ALLOCATION OF CENTRAL EUROPEAN HARDWOODS
INTO EN 1912

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Presented by J Denzler

F Lam commented that in Canada when new grades containing "something and better" is considered, the relative proportion of the grade needs to be considered carefully so that it can be maintained to prevent possibility of taking some of the high grade material away. J Denzler agreed.

JW van de Kuilen received confirmation that normal distribution was used to represent MOE.

Allocation of Central European hardwoods into EN 1912

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1 Introduction

Up to now Central European hardwoods are scarcely used as structural timber. However, due to ecological reasons an increasing amount of hardwoods is being produced in Central European forests. As hardwoods exhibit higher strength and stiffness values they could be used to produce high strength timber products, e.g. glulam.

For long span structures modulus of elasticity is often the limiting factor in design. Therefore, modulus of elasticity is an important material property and it is important that EN 338 reflects the strength-stiffness relationship correctly.

Test results of bending and tension tests of German beech and oak specimens showed that the modulus of elasticity values for given strength levels are higher than those tabled in EN 338. In order to be able to make the best possible use of home grown hardwoods, the strength profiles in EN 338 should be modified.

The aim of this paper is to suggest a more appropriate relationship between strength and stiffness for hardwoods in EN 338 in order to use the full capacity of hardwoods as structural timber of high strength and stiffness.

Moreover, the paper discusses how the characteristic strength and stiffness values of a grade depend on the combination of grades graded in one pass and that this effect has to be taken into account when assigning grades to strength classes.

2 Allocation of Beech (*Fagus sylvatica*) graded according to DIN 4074-5

223 beech scantlings with three different cross sections (35x70, 60x120, 60x180 mm²) and 571 beech boards with six different cross sections (25x100, 25x150, 32x120, 32x165, 35x100, 35x150 mm²) were collected from three different sawmills in Germany (GLOS & NAEHER 2005). The length of the boards and scantlings varied from 4,000 to 5,000 mm. All specimens were kiln-dried to a target moisture content of 12 %.

The specimens were visually graded according to DIN 4074-5 with respect to all relevant parameters. After grading the scantlings were tested in bending and the boards (32x120, 32x165 mm²) were tested in tension according to EN 384 and EN 408. The other boards were tested with a test length less than 9 times the width. Therefore, these results are

indicative only. Moisture content, growth ring orientation and density were measured according to ISO 3131, respectively, using a 2 cm thick defect-free test slice of full cross section cut from the test specimen near the failure zone.

Table 1 (Annex) summarises the test results of 177 beech scantlings of the visual grades LS 10, LS 10 & better and LS 13 (46 specimens did not meet the grade LS 10 and were rejected). According to EN 384 all test values were adjusted to 12% moisture content. Modulus of elasticity was adjusted to a pure bending modulus of elasticity and bending strength to 150 mm height. No length adjustment was applied because the specimens were tested with a span of 18 times the height and a distance between the inner loading points of 6 times the height. All specimens were tested with the critical defect on the tension edge. Therefore, the 7.5th percentile was used to calculate the characteristic bending strength (GLOS & DENZLER 2004).

The visual grade LS 10 includes only 56 specimens. This is not sufficient to establish mechanical properties. The visual grade LS 10 & better includes all specimens which belong to the grades LS 10 and LS 13. Based on their characteristic strength, the visual grades LS 10 & better and LS 13 fit into the strength classes D 35 and D 40 of EN 338 (see Table 2). The modulus of elasticity of these two grades is $E_{m,0,mean} = 15,900 \text{ N/mm}^2$ and $E_{m,0,mean} = 16,100 \text{ N/mm}^2$, respectively. These values are much higher than the values according to strength class D 35 and D 40 (Figure 1). As modulus of elasticity is strongly correlated with density, density shows the same tendency: The density values of the grades LS 10 & better ($\rho_{mean} = 741 \text{ kg/m}^3$, $\rho_k = 683 \text{ kg/m}^3$) and LS 13 ($\rho_{mean} = 738 \text{ kg/m}^3$, $\rho_k = 682 \text{ kg/m}^3$) exceed the values of the strength classes D 35 and D 40, respectively.

Table 2: Stiffness and density values in EN 338.

strength class	[-]	D 30	D 35	D 40	D 50	D 60	D 70
$f_{m,k}$	[N/mm ²]	30	35	40	50	60	70
$f_{t,0,k}$	[N/mm ²]	18	21	24	30	36	42
$E_{0,mean}$	[N/mm ²]	10,000	10,000	11,000	14,000	17,000	20,000
ρ_{mean}	[kg/m ³]	640	670	700	780	840	1080
ρ_k	[kg/m ³]	530	560	590	650	700	900

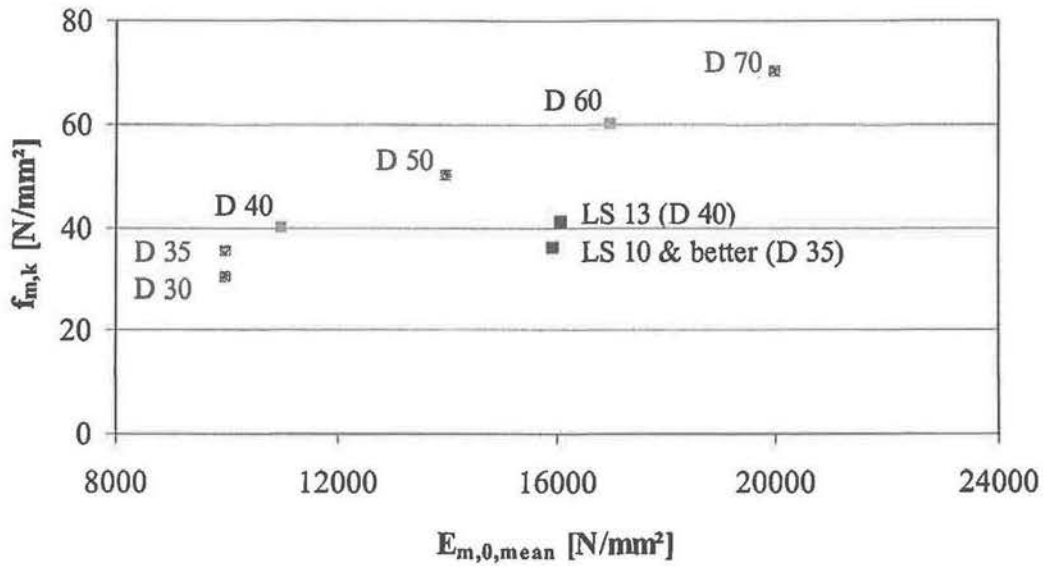


Figure 1: Relationship between $f_{m,k}$ and $E_{m,0,mean}$ given in EN 338 compared with test results for bending tests of beech scantlings.

Table 3 (Annex) summarises the test results of 355 beech boards of the visual grades LS 10, LS 10 & better and LS 13 (216 specimens did not meet the grade LS 10 and were rejected). According to EN 384 all test values were adjusted to 12% moisture content and tension strength was adjusted to 150 mm width. For tension strength no length adjustment factor is given in EN 384. All cross sections not tested with 9 times the height are therefore painted in grey and the results are indicative only.

The visual grade LS 10 includes 75 specimens. This is not regarded to be sufficient to establish mechanical properties. The visual grade LS 10 & better includes all specimens which belong to the grades LS 10 and LS 13 and therefore, contains enough specimens per sample to establish the required characteristic values. These results confirm the allocation of visual grade LS 10 & better to strength class D 35 for Central European beech. Based on its characteristic strength the visual grade LS 13 fits even into strength class D 50.

Modulus of elasticity of the two grades exceeds the required characteristic values of D 35 and D 50, not taking into account the factor of 1.09 between tensile and bending modulus of elasticity (BURGER & GLOS 1995). Moreover, the grade determining defect was always located within the gauge length for the MOE measurement, which probably leads to lower mean values than a random measurement within the specimen length.

The density of the grade LS 10 & better ($\rho_{mean} = 720 \text{ kg/m}^3$, $\rho_k = 656 \text{ kg/m}^3$) exceeds the required density of strength class D 35, the mean density of the grade LS 13 ($\rho_{mean} = 721 \text{ kg/m}^3$) is lower than the mean density of strength class D 50. However, the characteristic density of the grade LS 13 ($\rho_k = 655 \text{ kg/m}^3$) meets the required value of strength class D 50 given in EN 338.

3 Allocation of Oak (*Quercus petraea*, *Quercus robur*) graded according to DIN 4074-5

337 oak scantlings with three different cross sections (40x80, 60x120, 60x180 mm²) were collected from one German sawmill. Their length varied from 3,000 to 4,000 mm. Oak is highly durable and, therefore, often used in outdoor and hence in wet conditions. For this reason the oak specimens were not kiln-dried before testing and had an average moisture content of 32.6%.

The specimens were visually graded according to DIN 4074-5 with respect to all relevant parameters and tested in bending according to EN 384 and EN 408. Moisture content, growth ring orientation and density were measured according to ISO 3131, respectively, using a 2 cm thick defect-free test slice of full cross section cut from the test specimen near the failure zone.

Table 4 (Annex) summarises the test results of 239 oak scantlings of the visual strength class LS 10 & better (98 specimens did not meet the grade LS 10 and were rejected). According to EN 384 all test values were adjusted to $u = 12\%$ moisture content. For specimens with $u > 18\%$ the adjustment was based on a moisture content of $u = 18\%$ to prevent unreliable values for modulus of elasticity. For strength an adjustment factor of 1.16 was used. This factor was based on the following information:

1. From tests with matched specimens with $u = 12\%$ and $u > 20\%$ an adjustment factor of 1.21 was detected (GLOS & LEDERER 2000).
2. According to the German standard DIN 1052-1, 5.1.7, strength values must be reduced by $1/6 = 16\%$ for $u > 18\%$.
3. According to the Eurocode 5 EN 1995-1-1, 3.1.3, the k_{mod} -value of service class 1 ($u = 12\%$) and service class 3 ($u > 20\%$) differs between 16% and 22% depending on the load duration class.

Modulus of elasticity was adjusted to a pure bending modulus of elasticity and the bending strength to 150 mm height. No length adjustment was necessary because the specimens were tested with a span of 18 times the height and a distance between the inner loading points of 6 times the height. All specimens were tested with the critical defect on the tension edge. Therefore, the 7.5th percentile was used to calculate the characteristic bending strength (GLOS & DENZLER 2004).

Based on its characteristic strength Central European oak of the visual grade LS 10 & better fits into strength class D 30. The modulus of elasticity of this grade is $E_{m,0,\text{mean}} = 11,500 \text{ N/mm}^2$. This value is higher than the required modulus of elasticity of strength class D 30. The density values of this grade ($\rho_{\text{mean}} = 715 \text{ kg/m}^3$, $\rho_k = 634 \text{ kg/m}^3$) exceed the required density values of strength class D 30.

4 Relationship between strength and stiffness

The strength-stiffness-relationship of a grade depends on the combination of grades graded in one pass. This influence gets stronger with increasing number of grades to be graded in one pass. This is the case in machine grading as well as in visual grading. To show this influence the database of Holzforschung München was used to simulate mechanical grading of 2343 spruce specimens (*Picea abies*) tested in tension according to EN 384 and EN 408.

Grading was based on size and location of knots, density and cross-sectional dimensions as is the case in existing X-ray grading machines, e.g. the GoldenEye 702. An indicating property was calculated for each test piece and settings were derived so that each grade fulfilled the required characteristic strength values of so called L-classes L 17 to L 40, not taking into account the characteristic value of modulus of elasticity and density of each grade.

Figure 2 shows the relationship between strength and stiffness of each strength class, dependent on the respective grade combination, e.g. L 17, L 17 and L 30, L 17 and L 36 or L 17 and L 40, whereas the yield is optimised in the highest strength classes. For strength class L 17 the modulus of elasticity (tension) varies between 9,200 N/mm² and 11,700 N/mm² depending on the applied grade combination. If more than two grades are graded in one pass the relationship may get even worse. Figure 3 shows the corresponding coefficients of variation (COV) of tensile strength of each strength class, dependent on the respective grade combination. Most of the COV are greater than 30 %. Figure 4 shows the relationship between strength and density, respectively. The effect on characteristic density is not consistent if the assumption of normal distribution is used because the standard deviation may be reduced when more than one grade is graded in one pass leading to higher characteristic values.

In order to specify a relationship between strength and stiffness for one grade it is necessary to either take this effect into account or to restrict the grade to only those specimens within one grade and to exclude all specimens that exceed the upper grade limit.

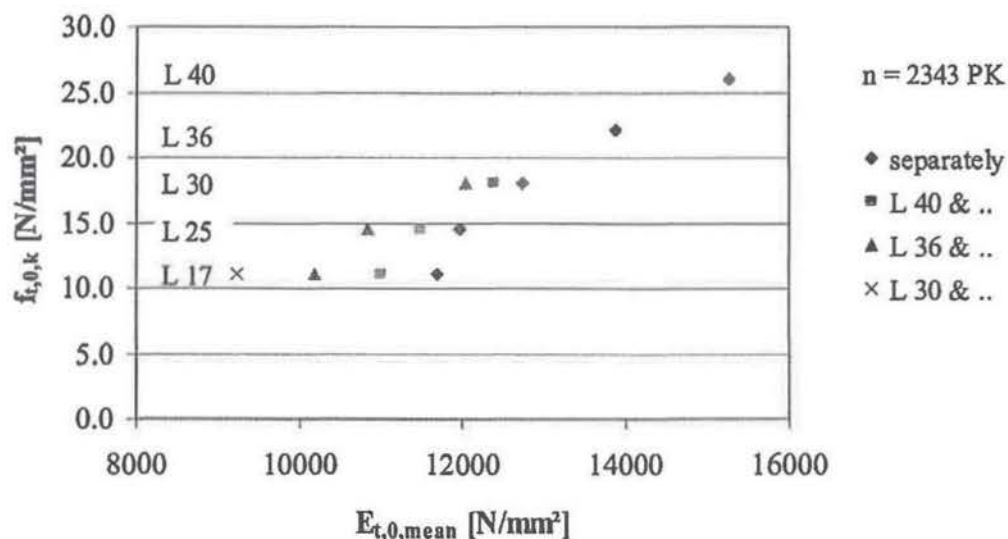
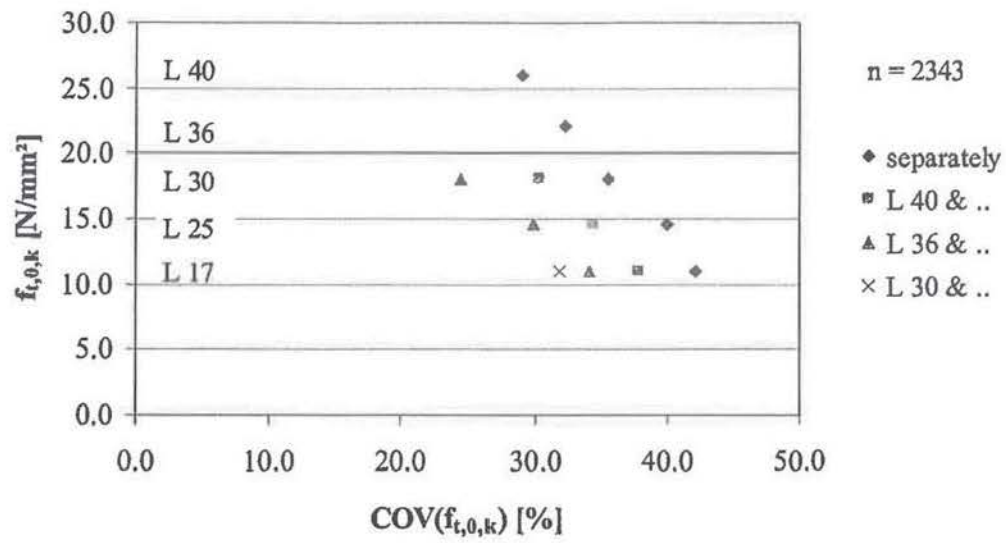


Figure 2: Relationship between $f_{t,0,k}$ and $E_{t,0,mean}$ for different strength classes and strength class combinations.



5 Conclusion

The aim of this paper is to propose a relationship between strength and stiffness for tempered hardwoods in EN 338. In order to be able to use tempered hardwoods efficiently and keeping in mind that in the near future there will be no need for a great variety of different grades for hardwoods it is recommended to accept grades like "LS 10 & better" and define strength profiles in EN 338 based on such grades. Therefore, the following stiffness and density values are proposed for the strength classes in EN 338 (see Table 5).

Table 5: Proposal for modified stiffness and density values in EN 338.

strength class	[-]	D30	D35	D40	D50
$f_{m,k}$	[N/mm ²]	30	35	40	50
$f_{t,0,k}$	[N/mm ²]	18	21	24	30
existing $E_{0,mean}$	[N/mm ²]	10,000	10,000	11,000	14,000
proposed $E_{0,mean}$	[N/mm²]	11,500	14,500	15,500	16,500
existing ρ_{mean}	[kg/m ³]	640	670	700	780
proposed ρ_{mean}	[kg/m³]	710	720	720	720
existing ρ_k	[kg/m ³]	530	560	590	650
proposed ρ_k	[kg/m³]	630	650	650	650

Based on the test results it is proposed to add German beech of the grades LS 10 & better and LS 13 to strength class D 35 and D 40, respectively, in EN 1912. Additionally, German oak of the grade LS 10 & better can be allocated to strength class D 30.

6 Literature

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7 Annex

Table 1: Bending test results of beech scantlings.

species	[-]	Beech (Fagus sylvatica) Germany											
source	[-]												
grade	[-]	LS 10				LS10 & better				LS 13			
n	[-]	9	36	11	56	48	93	36	177	39	57	25	121
thickness	[mm]	35	60	60	all	35	60	60	all	35	60	60	all
height	[mm]	70	120	180	all	70	120	180	all	70	120	180	all
u _{mean}	[%]	11.8	12.0	11.1	11.8	11.5	11.9	11.0	11.6	11.4	11.8	11.0	11.5
SD(u _{mean})	[%]	0.4	0.7	0.3	0.7	0.3	0.7	0.3	0.6	0.3	0.6	0.3	0.6
f _{m,mean}	[N/mm ²]	53.7	70.7	59.4	65.7	74.4	78.6	69.1	75.5	79.2	83.5	73.3	80.0
SD(f _{m,mean})	[N/mm ²]	9.7	22.9	17.2	21.2	17.6	20.9	17.4	19.6	15.5	17.9	16.0	17.1
k _h =(150/h) ^{0.2}	[-]	1.16	1.05	0.96	-	1.16	1.05	0.96	-	1.16	1.05	0.96	-
f _{m,k(5)}	[N/mm ²]	31.9	22.4	37.5	30.4	34.7	37.2	38.9	38.0	43.1	50.3	40.4	44.2
f _{m,k(7.5)}	[N/mm ²]	31.9	33.2	37.5	36.3	41.5	40.8	39.9	41.2	43.5	51.1	43.1	48.5
k _s	[-]	-	-	-	-	-	0.88	-	-	-	0.87	-	-
f _{m,k}	[N/mm ²]	-	-	-	-	-	35.9	-	-	-	40.9	-	-
E _{m,0,mean}	[kN/mm ²]	13.1	16.3	15.4	15.6	14.4	16.7	16.1	15.9	14.7	16.9	16.4	16.1
E _{m,0,mean}	[kN/mm ²]	-	15.6	-	-	-	15.9	-	-	-	16.1	-	-
ρ _{mean}	[kg/m ³]	738	758	718	747	720	754	733	741	715	752	740	738
ρ _{mean}	[kg/m ³]	-	747	-	-	-	741	-	-	-	738	-	-
ρ _k	[kg/m ³]	696	692	659	681	679	686	679	677	677	682	691	675
ρ _k	[kg/m ³]	-	686	-	-	-	683	-	-	-	682	-	-

Table 3: Tension test results of beech boards.

species	[-]	Beech (Fagus sylvatica) Germany																							
		LS 10								LS10 & better								LS 13							
grade	[-]	19	10	13	19	7	7	75		78	63	60	67	43	44	355		59	53	47	48	36	37	280	
n	[-]	25	25	32	32	35	35	all		25	25	32	32	35	35	all		25	25	32	32	35	35	all	
thickness	[mm]	100	150	120	165	100	150	all		100	150	120	165	100	150	all		100	150	120	165	100	150	all	
width	[mm]	11.4	11.6	10.6	9.9	11.2	11.4	10.9		11.3	11.4	10.6	9.9	11.4	11.5	10.9		11.2	11.3	10.5	9.9	11.4	11.5	11.0	
u_{mean}	[%]	0.7	0.6	0.3	0.3	0.3	0.9	0.9		0.7	0.6	0.2	0.3	0.4	0.7	0.8		0.7	0.5	0.2	0.3	0.4	0.7	0.8	
$SD(u_{mean})$	[%]																								
$f_{t,0,mean}$	[N/mm ²]	48.3	42.6	37.8	37.0	51.6	46.3	43.0		84.3	71.5	57.3	55.8	92.6	74.9	71.9		95.9	76.9	62.7	63.2	100.6	80.4	79.7	
$SD(f_{t,0,mean})$	[N/mm ²]	18.2	12.1	15.6	12.9	15.3	11.8	15.4		36.4	32.9	24.4	22.6	31.6	26.7	32.4		33.0	32.8	23.8	21.3	27.5	25.3	31.4	
$k_t=(150/h)^{0.2}$	[-]	1.08	1.00	1.05	0.98	1.08	1.00	-		1.08	1.00	1.05	0.98	1.08	1.00	-		1.08	1.00	1.05	0.98	1.08	1.00	-	
$f_{t,0,k(s)}$	[N/mm ²]	22.6	30.3	19.1	14.8	30.1	33.1	22.4		29.3	30.3	23.2	25.8	35.5	34.1	29.3		40.6	33.2	28.2	32.8	47.6	36.7	34.6	
k_s	[-]	-	-	-	-	-	-	-		1.00						-		1.00						-	
$f_{t,0,k}$	[N/mm ²]	-	-	-	-	-	-	-		27.9						-		33.9						-	
$E_{t,0,mean}$	[kN/mm ²]	11.7	10.3	12.2	12.7	10.8	10.7	11.7		14.1	13.5	13.7	14.5	14.6	13.8	14.0		14.8	14.1	14.1	15.3	15.4	14.4	14.7	
$E_{t,0,mean}$	[kN/mm ²]							-								-								-	
ρ_{mean}	[kg/m ³]	703	710	734	717	712	712	714		714	712	726	721	732	721	720		717	712	724	723	736	723	721	
ρ_{mean}	[kg/m ³]							-								-								-	
ρ_k	[kg/m ³]	652	685	677	642	654	667	657		646	652	655	658	658	672	655		645	648	649	665	660	673	654	
ρ_k	[kg/m ³]							-								-								-	

Table 4: Bending test results of oak scantlings.

species	[-]	Oak (Quercus petraea, Quercus robur)			
source	[-]	Germany			
grade	[-]	LS10 & better			
n	[-]	111	62	66	239
thickness	[mm]	40	60	60	all
height	[mm]	80	120	180	all
u_{mean}	[%]	26.1	34.5	41.8	32.6
$SD(u_{mean})$	[%]	6.7	6.0	8.5	9.7
$f_{m,mean}$	[N/mm ²]	48.9	46.0	41.2	46.0
$SD(f_{m,mean})$	[N/mm ²]	12.3	11.0	8.8	11.5
adj.factor $u^{1)}$	[-]	1/1.16	1/1.16	1/1.16	1/1.16
$k_h=(150/h)^{0.2}$	[-]	1.13	1.05	0.96	-
$f_{m,k(5)}$	[N/mm ²]	28.6	30.4	29.3	30.1
$f_{m,k(7.5)}$	[N/mm ²]	31.6	32.9	33.0	32.2
k_s	[-]	0.93			-
$f_{m,k}$	[N/mm ²]	30.0			-
$E_{m,0,mean}$	[kN/mm ²]	11.1	12.6	11.2	11.5
$E_{m,0,mean}$	[kN/mm ²]	11.5			-
ρ_{mean}	[kg/m ³]	692	741	728	715
ρ_{mean}	[kg/m ³]	715			-
ρ_k	[kg/m ³]	599	677	651	626
ρ_k	[kg/m ³]	634			-

¹⁾ The adjustment factor 1.16 for m/c is based on the following information:

1. From tests with matched specimens with $u=12\%$ and $u>20\%$ an adjustment factor of 1.21 was detected (GLOS & LEDERER 2000).
2. According to the German standard DIN 1052-1, 5.1.7, strength values must be reduced by $1/6 = 16\%$ for $u>18\%$.
3. According to the Eurocode 5 EN 1995-1-1, 3.1.3, the k_{mod} -value of service class 1 ($u=12\%$) and service class 3 ($u>20\%$) differs between 16% and 22% depending on the load duration class.