Compression perpendicular to grain – a Swedish survey

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Abstract

The transition from different design codes and design principles for stresses perpendicular to grain has been a change to strength levels and how to handle the design situation when it comes to design of supports for wood in the Swedish building industry.

A lot of tests and investigations of the strength perpendicular to the grain has been done in the past, some projects are on-going. The defining of a level for rupture is not unambiguous. The level has to be defined in conjunction to some conditions of deformation. The proportional level however can be reasonable defined. A design situation has to consider at least three different details:

Compressions by studs on a sill, compression of a wall plate between two studs or between a support of a beam and a stud, and beam support.

The Swedish former characteristic strength level of 7 MPa seems to be adequate for a stud 45 mm which is compressing a continuously supported 45 mm thick sill and with an acceptable deformation of approximately. For other situations this level is seems to be too high. Especially for multi-story buildings with wood structures.

Key words: Compression, strength, wood, review, Sweden

Preface

On behalf of the Swedish Forest Industries Federation a survey of strength perpendicular to grain has been done in order to investigate the adequate level for use in Swedish design of wood structures.

Contents

1 Introduction and background

Recently the Eurocode was introduced in Sweden as the standards for the verification of building structures replacing Swedish national codes. For timber structures, rules are given in Eurocode 5 (EN 1995-1-1 [1], EN 1995-1-2 [2], EN 1995-2[3]). Contrary to building practice the Swedish forest product industries experienced problems with the design rules regarding the compression perpendicular to grain. Eurocode 5 uses the strength values specified in, among others, EN 338 [4] (for solid timber) and EN 1194 [5] (for glued laminated timber). The latter two standards specify characteristic values based on measurements according to EN 408 [6]. The testing procedure for the determination of the strength perpendicular to grain specified in EN 408 [6] describes the material properties while the boundary conditions (e.g. support conditions, effective depth and width) is to be described by the mechanical model.

Due to the slow growing rate of trees available in Sweden (pine, spruce) the typical dimensions and grade available in Sweden is limited. While different depths are available (95 mm, 120 mm, 145 mm, 195 mm, 220 mm) the normal width of a timber board is 45 mm which results in a limited contact area on e.g. bottom rails.

Industry representatives in Sweden remember characteristic stress values perpendicular to grain, for Swedish Timber of 7 MPa while today's standards specify characteristic values of 2.0 MPa to 2.7 MPa, (C18 to C30).

This study represents a summary of historic Swedish regulations regarding compression perpendicular to grain and gives a survey on research in this field available in Scandinavia. Intention is to deliver input for revised mechanicals models used for verification of compression perpendicular to grain.

1.1 Design approaches in Scandinavia

Deviating for the design approach in [1] in Scandinavia other approaches are recently released. The approaches can be summarized in short:

i. Design approach using loads for SLS, (serviceability limit state), to verify supports where compression perpendicular to grain appear. This approach will be published in 2014 in the glulam guide "Limträhandbok", also available online.
ii. Design rules published by the Norwegian Standard Institute, Standards Norway. The design approach gives guidance on when other values than specified in material standards (EN 338 [4], EN 1194 [5]) can be used for verification purposes.

1.2 Future standardisation

Swedish experts from industry and research expressed the aim that verification of connections where compression perpendicular to grain occur shall be executed with respect to the accepted limit of deformation. Further, the moisture content of the timber members shall be taken into account. The limits for deformation may be clearly restricted when designing multi-storey buildings, but may be for single houses or up to the individual designer. It seems to be practical to have different calculation models in the standard to describe typical loading situations.

2 Abbreviations symbols and units

2.1 Abbreviations

CPG	compression perpendicular to the grain
COV	coefficient of variation
glulam	glued laminated wood
LVL	laminated veneer lumber
MC	moisture content
SLS	service limit state

2.2 Symbols and units

$f_{c,90}$	compression strength perpendicular to grain, in MPa (in diagrams and figure from referenced reports is the older kp/cm^2 often used).
s_i	specific gravity for the moisture content i in kg/m^3.

3 Historic Swedish design codes

A search for how the matter of compression perpendicular to grain (CPG) has been handled in former building codes in Sweden is essential as a background. Before the introduction of the partial safety calculation method, in the late seventies, a method based on a kind of serviceability limit state (SLS) was used. Only values for soft wood is discussed in this survey.

3.1 Tabled strengths values in Swedish building codes

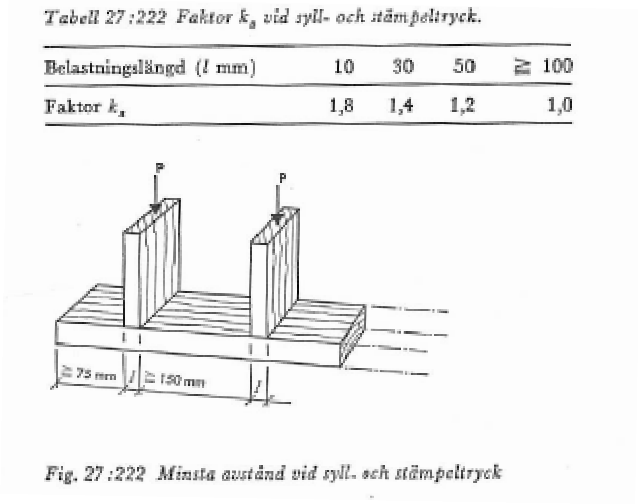
3.1.1 Swedish building code 1967, SBN 67 [7]

The strength values was valid up to 18 % of wood moisture content (MC) without compensation and for exceptional load cases a factor of 1.4 could be used for increasing the strength levels.

Table 1. Comparison of strength classes of EN 338 [4] and strength values specified in SBN 67 [7] with the resulting design values.

Strength class, SBN 67	**Comparable strength class according to EN 338**	**Allowable bending strength edgewise, SBN 67** *[MPa]*	**CPG, SBN 67** *[MPa]*	**Design value for 45 mm on a sill** *[MPa]*
T300	~C30	10.0	2.0	2.5
T200	~C24	8.0	2.0	2.5
Ö-virke	(~C14)	6.0	1.7	2.1

A calculation method for compression on ground sills was given in this code. Under some conditions the strength could be increased with a factor 1.8. With a loading length along the fibres from 10 mm to 50 mm and with a spacing of at least 150 mm gave a factor of 1.8 to 1.2. For 100 mm spacing the factor was 1.0, see figure 1. The distance to the sill end had to be greater than 75 mm. A special note recommended that the designer should be aware of big deformations that could jeopardize the structures safety. For a 45 mm loading length on a sill is the design value determined to 2.5 MPa.



Tabell 27:222 Faktor k_a vid syll- och stämpeltryck.

Belastningslängd (l mm)	10	30	50	≧ 100
Faktor k_a	1,8	1,4	1,2	1,0

Fig. 27:222 Minsta avstånd vid syll- och stämpeltryck

Figure 1. The principles for sill compression and factor k_a for increased CPG [7].

3.1.2 Swedish building code 1980, SBN 80 [8]

The strength values were valid up to climate class 2, corresponding to approximately 16 % MC. With compensation for exceptional load cases a factor of 1.4 could be used for increasing the specified strength levels. (This concerned mainly exceptional snow load which was in the span of 25 to 50 % higher than normal snow load). The same is valid for [7].

Table 2. Comparison of strength classes of EN 338 [4] and strength values specified in SBN 80 [8] with the resulting design values.

Strength class, SBN 80	Comparable strength class according to EN 338	Allowable bending strength, edgewise SBN 80 *[MPa]*	CPG, SBN 80 *[MPa]*	Design value for 45 mm on a sill *[MPa]*
T30	~C30	11.0	2.0	2.7
T20	~C24	9.0	2.0	2.7
T18	~C18	7.5	2.0	2.7
Ö-virke	(~C14)	6.0	2.0	2.7

Also in this code a calculation method for compression on sills was given with similar factors as in SBN 67 [7]. The loading length along the fibres 15 mm to 50 mm with a spacing of at least 150 mm gave a factor of 1.8 to 1.3 (1.2 in SBN 67 [7]). For 100 mm spacing the factor was 1.1 and for 150 it was 1.0. The distance to the sill end had to be greater than 75 mm or 1.5 times the sill height. Also in this code there was a special note recommended that the designer should be aware of big deformations that could jeopardise the structures safety.

3.1.3 Nybyggnadsregler, NR, BFS 1988:18, code 1989 [9]

This code the design rules are based on the limit state concept with the use of partial safety factors. Design values in table 3 is in the ULS. No certain advice for SLS is given for CPG in this code. It should be noted that for CPG a significant higher value, 7 MPa, was introduced for all strength classes.

Table 3. Comparison of strength classes of EN 338 [4] and strength values specified in Nybyggnadsregler NR [9] with the resulting design values.

Strength class, NR	**Comparable strength class according to EN 338**	**Bending strength, edgewise SBN 80** *[MPa]*	**CPG, NR** *[MPa]*	**Design value for 45 mm on a sill1)** *[MPa]*	**Design value for 45 mm on a sill2)**
K30	~C30	30	7.0	5.1	6.9
K24	~C24	24	7.0	5.4	7.3
K18	~C18	18	7.0	5.7	7.7
K12	(~C14)	12	7.0	5.7	7.7

1) In NR 1988:18 there was no special coefficient for compression on sills and no reference to complementary literature was given.

2) However, there was a series of guidance documents, handbooks (*Byggvägledning*, 1990 [10]), which presented a method to calculate the strength for sill compression. The model was similar to the model in SBN 80 [8].

The available *Byggvägledning* [10] can be seen as an answer from the building industry to the lack of design rules by the building authorities. This guidance document was available for timber structures while for steel and concrete structures detailed design rules were available (BSK and BBK, issued by the building authorities).

The presented design values in Table 3 are for safety class 1, climate class 0, 1 and 2 (up to 16 % MC), medium term load, the quotient for permanent and medium-term load is 0.25. In this code there was a procedure described to consider the level of permanent load and the safety class when calculating the partial safety factor for the wood.

3.1.4 BKR 1, 94:1, BFS 1993:58 [12]

This code is the continuation of the use of the partial coefficient method.

Table 4. Comparison of strength classes of EN 338 [4] and strength values specified in BKR 1 [12] with the resulting design values.

Strength class, BKR	**Comparable strength class according to EN 338**	**Bending strength, edgewise BKR 1** *[MPa]*	**CPG, BKR 1** *[MPa]*	**Design value for 45 mm on a sill3)** *[MPa]*	**Design value for 45 mm on a sill4)**
K30	~C30	30	7.0	4.5	6.0
K24	~C24	24	7.0	4.8	6.4
K18	~C18	18	7.0	5.0	6.8
K12	(~C14)	12	7.0	5.0	6.8

3) In BKR 1 [12] there was no special coefficient for compression on sills but no reference to complementary literature was given.

4) As in NR [9] there was a series of guidance documents (*Byggvägledning*, 1996 [11]). However, regarding compression on sills no further guidance documents are specified.

The presented design values in Table 4 are for safety class 1, medium term load, climate class 0, 1, and 2 (16 % MC) The model for sill compression is the same as for NR [9].

3.1.5 BKR 3, BFS 1998:39 [13]

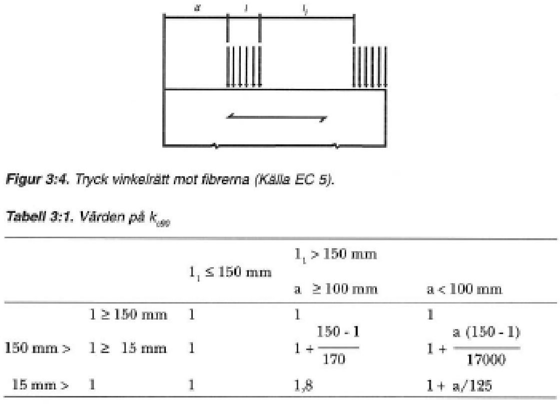
This code is the continuation of the use of the partial coefficient method. In this code a special coefficient κ_{c90} is introduced for calculating CPG. The same coefficient as in ENV 1995-1-1 [14] was used.

Table 5. Comparison of strength classes of EN 338 [4] and strength values specified in BKR 3 [12] with the resulting design values.

Strength class, BKR	**Comparable strength class according to EN 338**	**Bending strength, edgewise BKR 3** *[MPa]*	**CPG** *[MPa]*	**Design value for 45 mm on a sill**[5)] *[MPa]*
K30	~C30	30	7.0	7.2
K24	~C24	24	7.0	7.7
K18	~C18	18	7.0	8.0
K12	(~C14)	12	7.0	8.0

[5)] The model for sill compression is presented in Figure 2. Calculated for this case, comparable to the former tables, is the coefficient 1.6 (the code refer to ENV1995-1-1, 5.1.5).

The presented values in Table 5 are for safety class 1, medium term load, Climate class 0, 1, and 2 (16 % MC).



Figur 3:4. Tryck vinkelrätt mot fibrerna (Källa EC 5).

Tabell 3:1. Värden på k_{c90}

		$l_1 \leq 150$ mm	$l_1 > 150$ mm $a \geq 100$ mm	$a < 100$ mm
	$l \geq 150$ mm	1	1	1
150 mm >	$l \geq 15$ mm	1	$1 + \frac{150 - l}{170}$	$1 + \frac{a(150 - l)}{17000}$
15 mm >	l	1	1,8	$1 + a/125$

Figure 2. Model for calculating sill compression according to ENV 1995-1-1 [14].

4 Danish code

4.1 Dansk ingeniørsföreningens norm for trækonstruktioner, 4. Udgave november 1982. Dansk standard 413 [15]

This code uses a similar approach as the Swedish BKR 3.

Table 6. Comparison of strength classes of EN 338 [4] and strength values specified in with the resulting design values.

Strength class, DS4130	**Comparable strength class according to EN 338**	**Bending strength** *[MPa]*	**CPG** *[MPa]*	**Design value for 45 mm on a sill4)** *[MPa]*
K30	~C30	30	7	4.9
K24	~C24	24	7	4.9
K18	~C18	18	7	4.9

4) The model for sill compression is not presented here. Calculated for this case, comparable increasing factor to the former tables is the coefficient 1.35 (the same as in SBN 80 [8] and BKR). Minor differences of partial coefficients from the Swedish code is the main difference.

The presented values in Table 6 are for low safety class 1.36, medium term load, climate class I and IU (16 % MC).

5 Excerpts from test reports concerning compression perpendicular to the grain

5.1 Höga upplagstryck (SP-AR 1990:51) [16]

This report discusses the new situation with the new high values in NR 1 [9] and focused towards supports for roof trusses and mainly family houses with one story. The codes SBN 67 [7] and SBN 80 [8] were sometimes difficult to fulfil without any extra ordinary steps to distribute the load on the support. With new higher values approximately 60 % smaller support area could be used.

A deformation criterion was set out in the report with respect to the requests by the timber industry. 5 mm could be acceptable (approx. 10 % of a sill or a rail with 45 mm height).

Compression tests of 45 mm × 220 mm (density 332 to530 kg/m^3), 11 to 14 % MC, at three stress levels, 3, 7, and 10 MPa. The deformation is a compression of a top rail, wall plate.

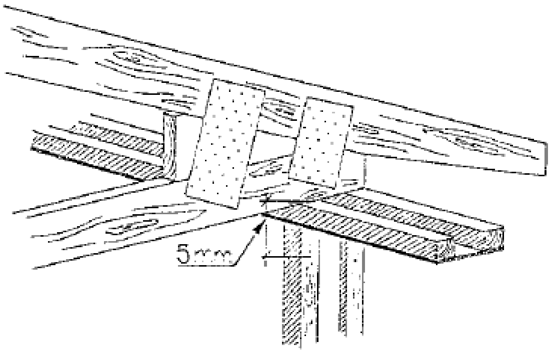
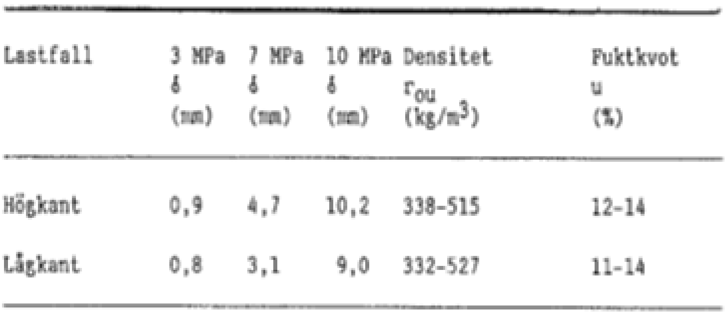


Figure 3. Design detail considered in the report [16].

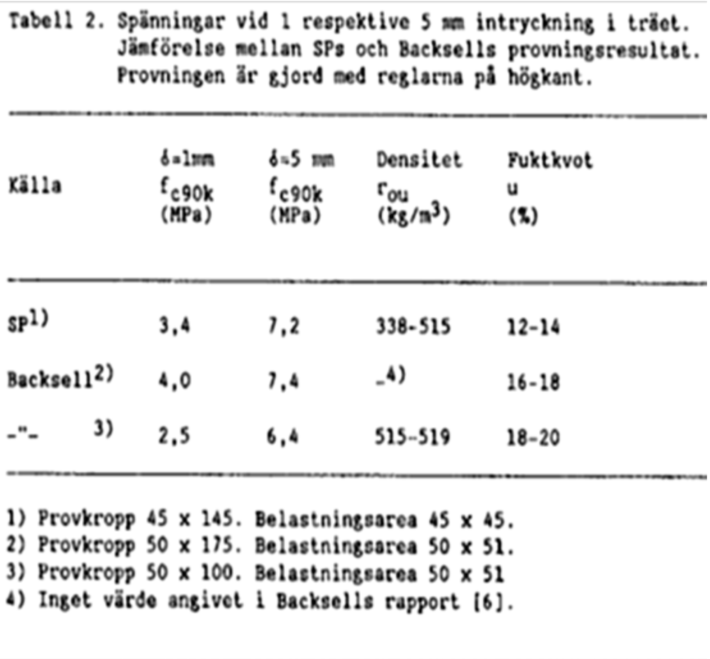


Lastfall	3 MPa δ (mm)	7 MPa δ (mm)	10 MPa δ (mm)	Densitet r_{ou} (kg/m^3)	Fuktkvot u (%)
Högkant	0,9	4,7	10,2	338-515	12-14
Lågkant	0,8	3,1	9,0	332-527	11-14

Figure 4. Values for deformation and stress. "Högkant" means edgewise and "Lågkant" means flatwise [16].

Test results given in Figure 4 show that 7 MPa were reached for edgewise test samples when 4.7 mm deformation was accepted.

Compressions stress at deformation levels 1, 5 and 10 mm for edgewise loaded specimens gave similar results, see Figure 5.



Tabell 2. Spänningar vid 1 respektive 5 mm intryckning i träet. Jämförelse mellan SPs och Backsells provningsresultat. Provningen är gjord med reglarna på högkant.

Källa	δ=1mm f_{c90k} (MPa)	δ≈5 mm f_{c90k} (MPa)	Densitet r_{ou} (kg/m^3)	Fuktkvot u (%)
SP1)	3,4	7,2	338-515	12-14
Backsell2)	4,0	7,4	-4)	16-18
-"- 3)	2,5	6,4	515-519	18-20

1) Provkropp 45 x 145. Belastningsarea 45 x 45.
2) Provkropp 50 x 175. Belastningsarea 50 x 51.
3) Provkropp 50 x 100. Belastningsarea 50 x 51
4) Inget värde angivet i Backsells rapport [6].

4) No value available

Figure 5. Stresses and deformations and comparisons between SP´s test results and Backsell [16].

All values in Figure 4 and Figure 5 can be considered to be of short-term loads.

Test results show that SP tests confirmed 7.2 MPa for edgewise loading on rails when 5 mm deformation is acceptable. For comparison reasons, the value of 7 MPa was specified in NR [9], section compare 3.1.3.

5.2 Tests of nailing plates reinforcement [17]

In ambition to reinforce glulam beams for compression at the support tests were performed to investigate the possibilities to increase the load capacity with nailing plates. Two series of tests without any reinforcement were made perpendicular to the grains:

- Test series 1: 140 mm × 405 mm
- Test series 2: 215 mm × 405 mm

Three test specimens were tested in each test series. The tests were performed according to EN 408 [6]. The evaluation though is modified so that the deformation level of 4 mm is set as rupture level. Picture 3 below shows the test arrangement with nailing plates. When testing, the test specimens had a MC between11 and 13 %.

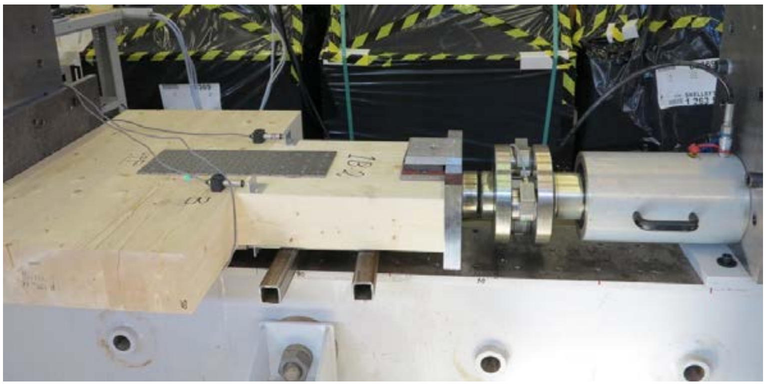


Figure 6. This test set up is showing a nailing plate. The nail plates are symmetrical on both sides [17].

Table 7. Mean values of compression strength at 4 mm deformation without nailing plates [17].

Series	**$f_{c,90}$** *[MPa]*	**Standard deviation** *[MPa]*
1	4.70	0.1
2	5.21	0.57

Table 8. Maximum forces and deformations Mean values of compression strength at 4 mm deformation [17].

Test series	**Maximum force at 4 mm deformation** *[kN]*	**Stresses** *[MPa]*	**Eccentricity, mean** *[mm/mm]*	**Deformation per side d_1/d_2 (mm)** *[mm]*
1A:1	260.5	4.6	0.46	2.55/4.09
1A:2	271.8	4.8	0.06	4.21/4.45
1A:3	268	4.7	0.30	3.64/4.93
2A:1	397	4.6	-0.02	5.82/5.91
2A:2	487	5.6	0.22	6.39/5.14
2A:3	478	5.6	0.11	5.68/5.08

In [17], the eccentricity due to the scatter of material properties in the support area is mentioned as a problem. The differences of density in a piece of wood influence the way the compression force is distributed over the loading surface. A knot or a piece of a knot is harder than the surrounding wood and that can cause eccentricities during loading.

5.3 Timber compression strength perpendicular to the grain [18]

In this study tests perpendicular to grain with supported glulam beams were performed. The support lengths of unreinforced beams are 60, 90 and 120 mm. According to the test results influence the support considerably for CPG. Shorter lengths have higher capacity. The friction between the support surfaces can be of importance. The list below show the difference between a sample made of glulam in comparison to a comparable piece of ordinary wood.

At 2 to 3 millimetre deformation, non-reinforced beams on:

- 60 mm supports yields a 142 – 133 % increase compared to blocks of the same timber,
- 90 mm supports yields a 93 – 85 % increase compared to blocks of the same timber,
- 120 mm supports yields a 87 – 76 % increase compared to blocks of the same timber.

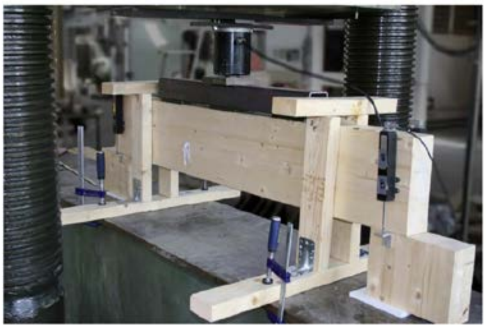
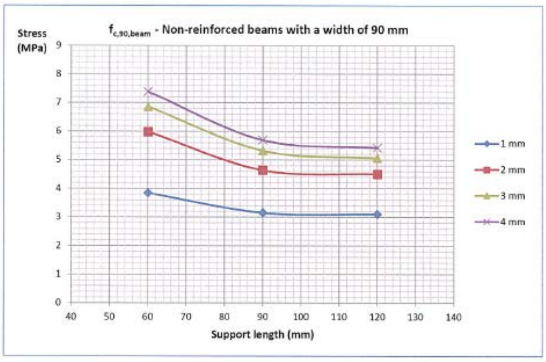
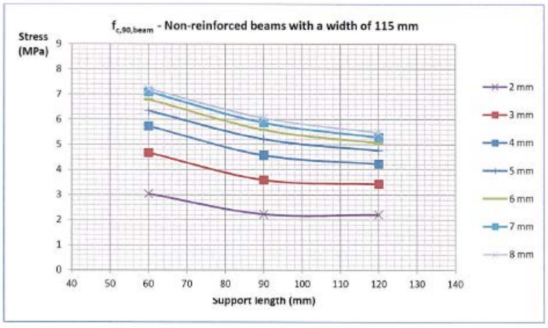


Figure 7. Test set up used in [18].

The test set up was using a 4-point beam supported of columns of glulam.



Graph 6.1 *Deformation / support length – controlled capacity graph for non-reinforced beams with widths of 90 mm (or $f_{c,90,beam}$ – 90 mm width).*



Graph 6.2 *Deformation / support length – controlled capacity graph for non-reinforced beams with widths of 115 mm (or $f_{c,90,beam}$ – 115 mm width).*

Figure 8. Test results with glulam beams 270 mm of height. Mean density 435 to 465 kg/m^3. Shear stress for width 90 mm was calculated to 2.2 to 4.9 MPa and for 115 mm width to 1.2 to 1.8 MPa [18].

The diagrams in Figure 8 shows, in addition to compression and deformation, an influence of volume and the relation between width and support length.

This report gives further information from other references. In the report also figures of compressed wood at rupture are available which unveil the anisotropy and complexity of rupture modes in compression. A diagram slightly different from Figure 9 is included in the report. Figure 9 show the same pattern and illustrates the compressive strength with respect to the anisotropy of the wood.

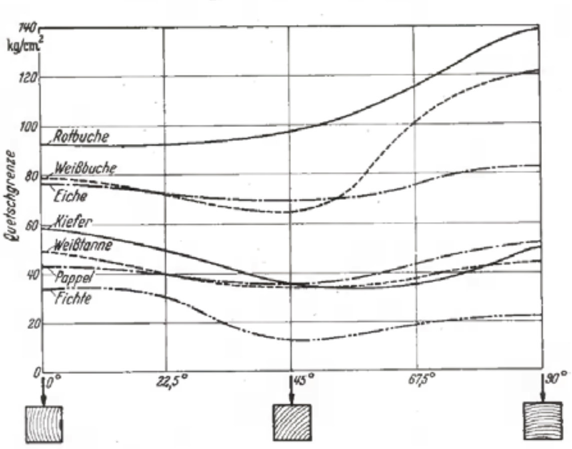


Bild 10. Quetschgrenze bei verschiedener Lage der Jahrringe.

Figure 9. Anisotropy of compression strength according to the macro structure. Gaber (1940) [19]

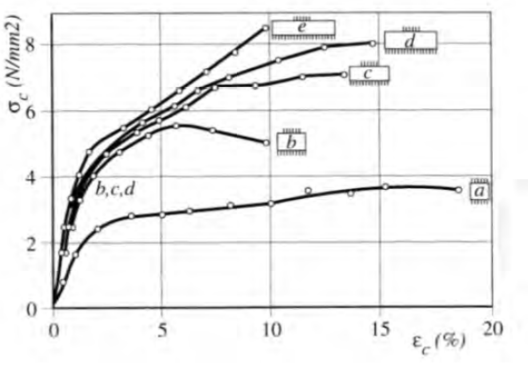
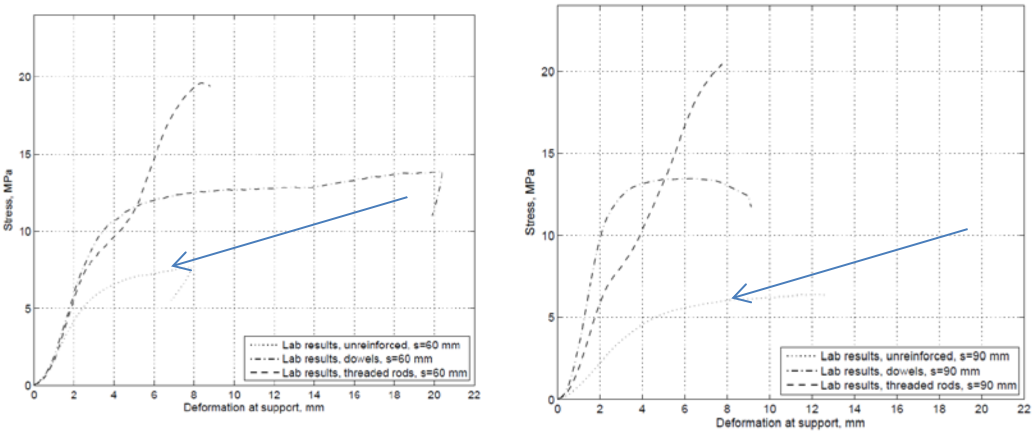


Figure 10. Influence of the loading length along the fibres: a is ratio 1 between loading length and support length, and b, c,d and e are increasing ratios. Suensson 1938 [20].

5.4 Numerical analysis of compression perpendicular to the grain in glulam beams with and without reinforcement [21]

A developed FE-model for unreinforced beam support was verified by means of experiments in the laboratory. The analyse showed that the low values for CPG is motivated when it comes to deformation and at a support length longer than 400 mm. With short support lengths of e.g. 100 mm and 20 mm deformation as acceptable value, the CPG strength could be as high as 8 MPa, and beam dimensions was 115 mm × 630 mm.



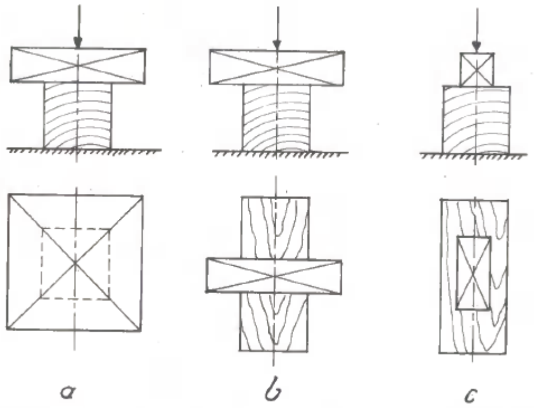
60 mm support length

90 mm support length

Figure 11. Measured deformation and compression stresses for support lengths of 60 and 90 mm [21].

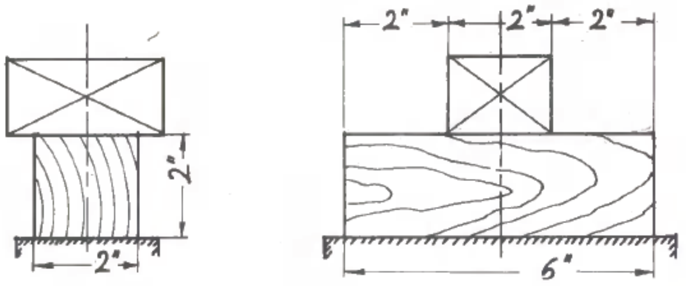
The results confirm the influence of volume and support length.

5.5 Investigation of the strengths properties of wood 1. Test of small clear specimens of Finnish pine (*Pinus Sylvestris*) [22]



Kuva 7. Syitä vastaan kohtisuoran puristuksen erilaiset rasitustavat. a) kokonaispuristus, b) kiskopuristus, c) leimapuristus

Fig. 7. Different loadings in compression perpendicular to the grain. a) entire-compression, b) rail-compression, c) stamp-compression

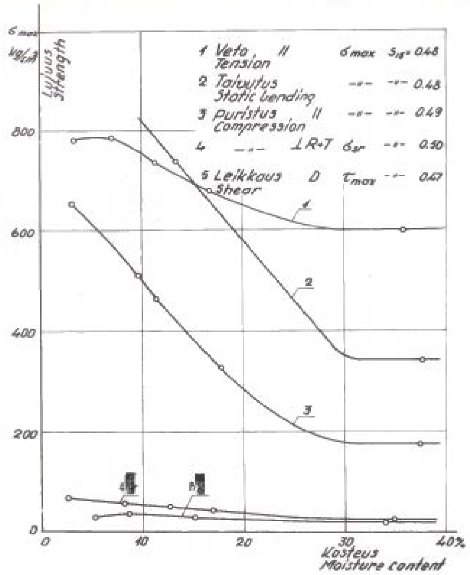


Kuva 8. Kiskopuristuskoe amerikkalaisen menetelmän mukaan

Fig. 8. Sidewise-compression test in accordance with the American method

Figure 12. Different loadings for compression in the report. Tested specimens have always a continuous support [22].

In this report different loading situations and their effects are investigated, see Figure 12.

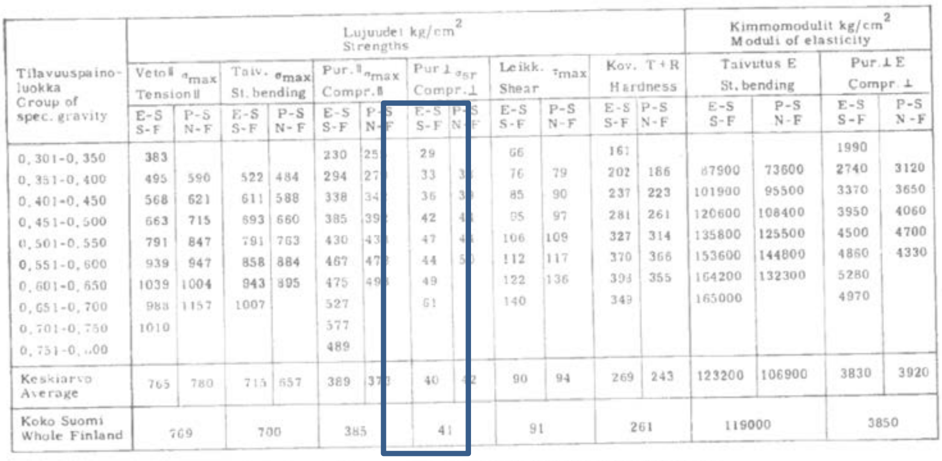


Kuva 32. Kosteuden vaikutus männyn lujuusominaisuuksiin

Fig. 32. Effect of moisture content on the strength properties of pine

Figure 13. Effect of moisture content on the strength properties of pine [22].

Graph 4 in Figure 13 is for CPG and pine. The graph is number 2 from the bottom. The specific gravity $s_{15} = 0.50$ (500 kg/m^3 at 15 % MC). The definition of rupture level has not been identified in the report.

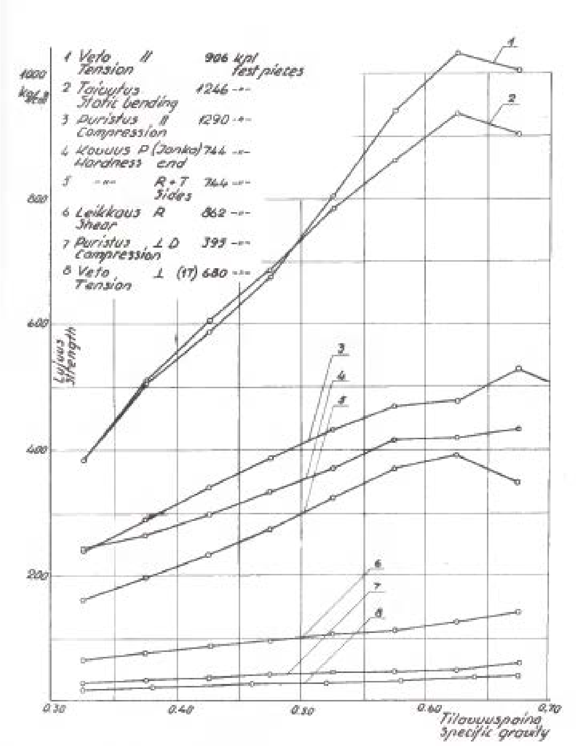


Tilavuuspainoluokka Group of spec. gravity	Lujuudet kg/cm² Strengths												Kimmomodulit kg/cm² Moduli of elasticity			
	Veto∥ σmax Tension∥		Taiv. σmax St. bending		Pur.∥ σmax Compr.∥		Pur.⊥ σsr Compr.⊥		Leikk. τmax Shear		Kov. T+R Hardness		Taivutus E St. bending		Pur.⊥E Compr. ⊥	
	E-S S-F	P-S N-F	E-S S-F	P-S N-F	E-S S-F	P-S N-F	E-S S-F	P-S N-F	E-S S-F	P-S N-F	E-S S-F	P-S N-F	E-S S-F	P-S N-F	E-S S-F	P-S N-F
0,301-0,350	383				230	25[illegible]	29		66		161				1990	
0,351-0,400	495	590	522	484	294	27[illegible]	33	3[illegible]	76	79	202	186	87900	73600	2740	3120
0,401-0,450	568	621	611	588	338	34[illegible]	36	3[illegible]	85	90	237	223	101900	95500	3370	3650
0,451-0,500	663	715	693	660	385	39[illegible]	42	4[illegible]	95	97	281	261	120600	108400	3950	4060
0,501-0,550	791	847	791	763	430	43[illegible]	47	4[illegible]	106	109	327	314	135800	125500	4500	4700
0,551-0,600	939	947	858	884	467	47[illegible]	44	5[illegible]	112	117	370	366	153600	144800	4860	4330
0,601-0,650	1039	1004	943	895	475	49[illegible]	49		122	136	394	355	164200	132300	5280	
0,651-0,700	988	1157	1007		527		51		140		349		165000		4970	
0,701-0,750	1010				577											
0,751-0,..00					489											
Keskiarvo Average	765	780	715	657	389	37[illegible]	40	[illegible]2	90	94	269	243	123200	106900	3830	3920
Koko Suomi Whole Finland	769		700		385		41		91		261		119000		3850	

Taulukko 5. Tilavuuspainon vaikutus mannyn lujuusominaisuuksiin

Table 5. Effect of specific gravity on the strength properties of Finnish pine

Figure 14. Table of strength and density. The mean value is 4.1 MPa, for densities from 300 to 700 kg/m^3 [22].

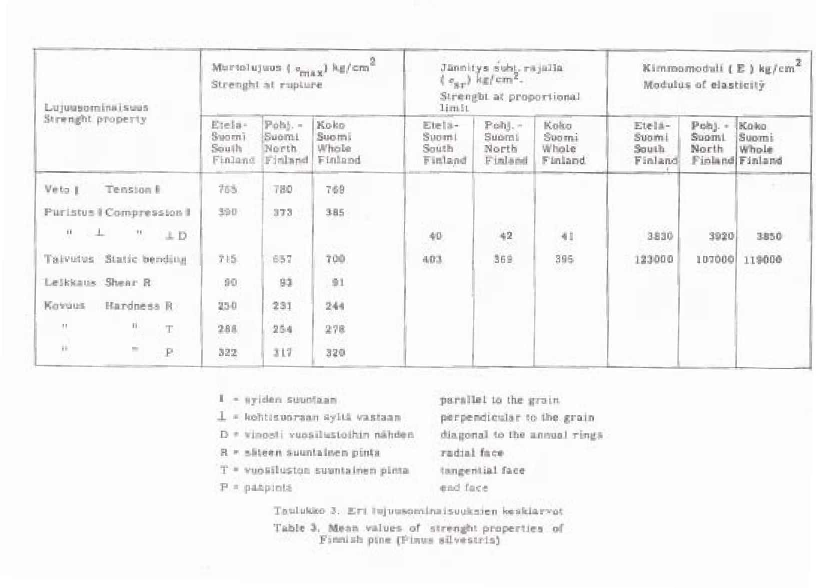


Kuva 29. Tilavuuspainon vaikutus männyn lujuuteen. Koko Suomi. a = 15 %.

Fig. 29. Effect of specific gravity on the strength of pine. Whole Finland. a = 15 %.

Figure 15. Graphs for density and strengths [22].

Graph number 7 in Figure 15 (second from the bottom) shows the link for CPG.



Lujuusominaisuus Strenght property	Murtolujuus (σ_{max}) kg/cm² Strenght at rupture			Jännitys suhl. rajalla (σ_{sr}) kg/cm². Strenght at proportional limit			Kimmomoduli (E) kg/cm² Modulus of elasticity		
	Etelä-Suomi South Finland	Pohj.-Suomi North Finland	Koko Suomi Whole Finland	Etelä-Suomi South Finland	Pohj.-Suomi North Finland	Koko Suomi Whole Finland	Etelä-Suomi South Finland	Pohj.-Suomi North Finland	Koko Suomi Whole Finland
Veto ‖ Tension ‖	765	780	769						
Puristus ‖ Compression ‖	390	373	385						
" ⊥ " ⊥ D				40	42	41	3830	3920	3850
Taivutus Static bending	715	657	700	403	369	395	123000	107000	119000
Leikkaus Shear R	90	93	91						
Kovuus Hardness R	250	231	244						
" " T	288	254	278						
" " P	322	317	320						

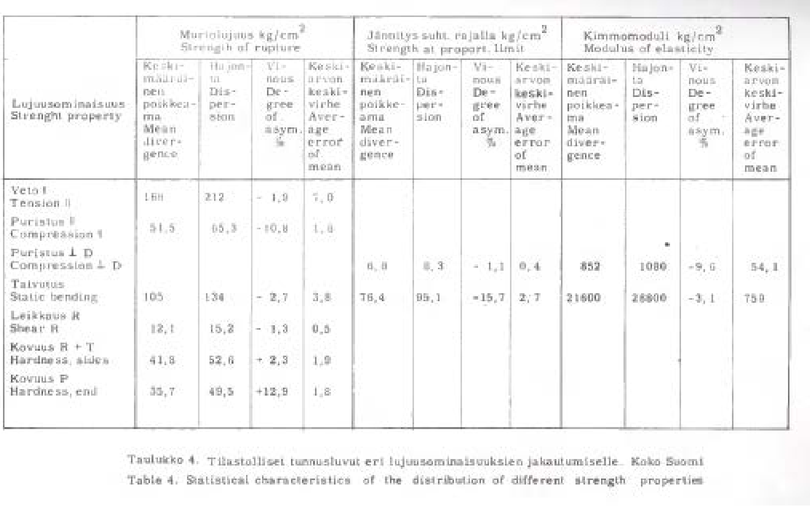
‖ = syiden suuntaan	parallel to the grain
⊥ = kohtisuoraan syitä vastaan	perpendicular to the grain
D = vinosti vuosilustoihin nähden	diagonal to the annual rings
R = säteen suuntainen pinta	radial face
T = vuosiluston suuntainen pinta	tangential face
P = pääpinta	end face

Taulukko 3. Eri lujuusominaisuuksien keskiarvot

Table 3. Mean values of strenght properties of Finnish pine (Pinus silvestris)

Figure 16. Tables for CPG and proportional limit, mean values [22].

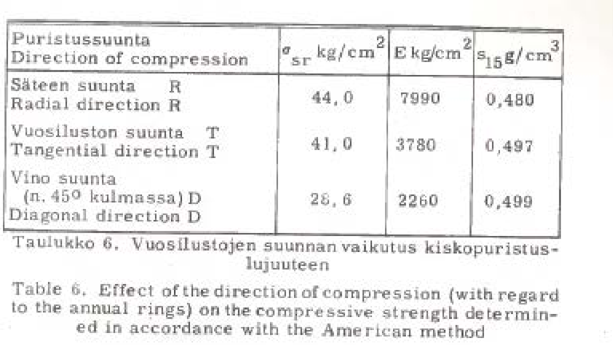
The definition of the proportional limit is not found in the report. Strength at rupture is not given in the table shown in Figure 16.



Lujuusominaisuus Strenght property	Murtolujuus kg/cm^2 Strength of rupture				Jännitys suht. rajalla kg/cm^2 Strength at proport. limit				Kimmomoduli kg/cm^2 Modulus of elasticity			
	Keskimääräinen poikkeama Mean divergence	Hajonta Dispersion	Vinous Degree of asym. %	Keskiarvon keskivirhe Average error of mean	Keskimääräinen poikkeama Mean divergence	Hajonta Dispersion	Vinous Degree of asym. %	Keskiarvon keskivirhe Average error of mean	Keskimääräinen poikkeama Mean divergence	Hajonta Dispersion	Vinous Degree of asym. %	Keskiarvon keskivirhe Average error of mean
Veto ‖ Tension ‖	168	212	- 1,9	7,0								
Puristus ‖ Compression ‖	51,5	65,3	-10,8	1,0								
Puristus ⊥ D Compression ⊥ D					6,8	8,3	- 1,1	0,4	852	1080	-9,6	54,1
Taivutus Static bending	105	134	- 2,7	3,8	76,4	95,1	-15,7	2,7	21600	26800	-3,1	759
Leikkaus R Shear R	12,1	15,2	- 1,3	0,5								
Kovuus R + T Hardness, sides	41,8	52,6	+ 2,3	1,9								
Kovuus P Hardness, end	35,7	49,5	+12,9	1,8								

Taulukko 4. Tilastolliset tunnusluvut eri lujuusominaisuuksien jakautumiselle. Koko Suomi
Table 4. Statistical characteristics of the distribution of different strength properties

Figure 17. Characteristic values of Finnish pine [22].

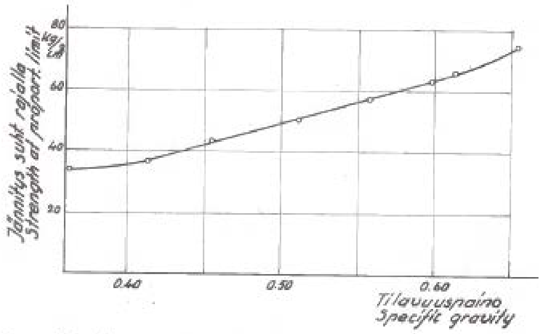


Puristussuunta Direction of compression	σ_{sr} kg/cm^2	E kg/cm^2	s_{15} g/cm^3
Säteen suunta R Radial direction R	44,0	7990	0,480
Vuosiluston suunta T Tangential direction T	41,0	3780	0,497
Vino suunta (n. 45° kulmassa) D Diagonal direction D	28,6	2260	0,499

Taulukko 6. Vuosilustojen suunnan vaikutus kiskopuristuslujuuteen

Table 6. Effect of the direction of compression (with regard to the annual rings) on the compressive strength determined in accordance with the American method

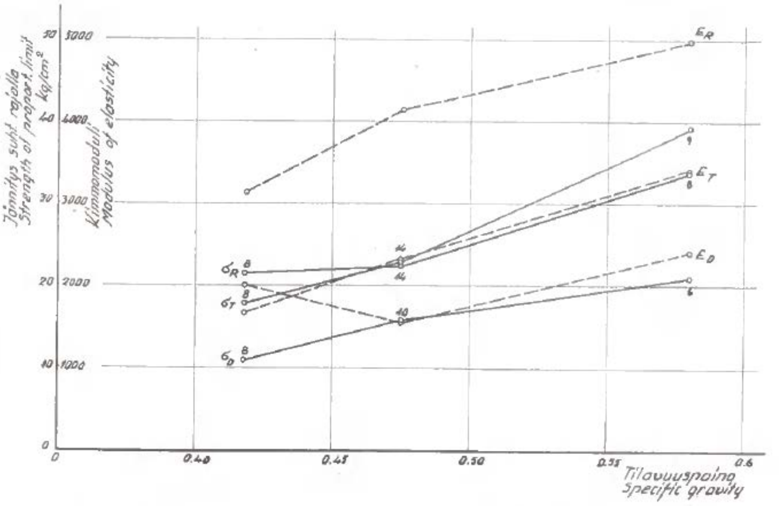
Figure 18. Effect of directions of the annual rings and compression [22].



Kuva 33. Tilavuuspainon vaikutus männyn kiskopuristuslujuuteen. R + T. a = 15 %

Fig. 33. Effect of specific gravity on the sidewise - compression strength of pine (rail compression). R + T. a = 15 %

Figure 19. Sidewise compression and density, rail compression [22].

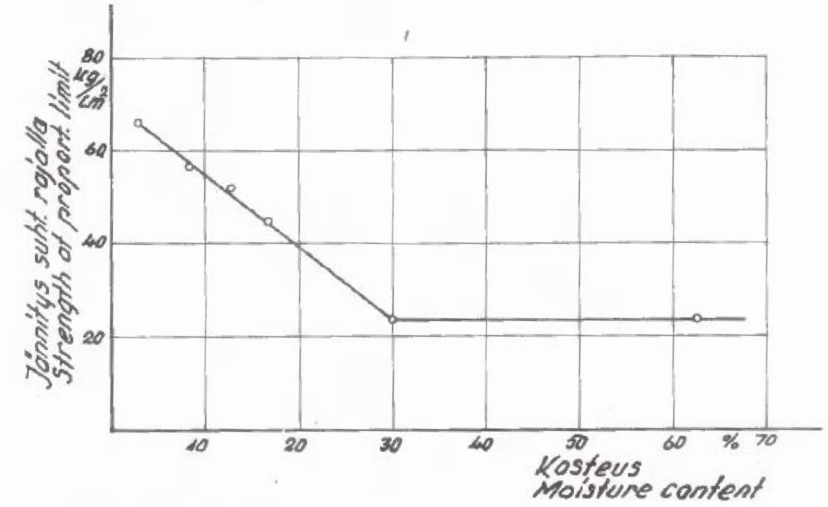


Kuva 35. **Tilavuuspainon vaikutus männyn kokonaispuristuslujuuteen ja kimmomoduliin eri puristussuunnissa.** a = 12 %

Fig. 35. Effect of specific gravity on the entire-compression strength and modulus of elasticity of pine in different compression directions. a = 12 %

Figure 20. Graphs for proportional limits at CPG and 12 % moisture content [22].

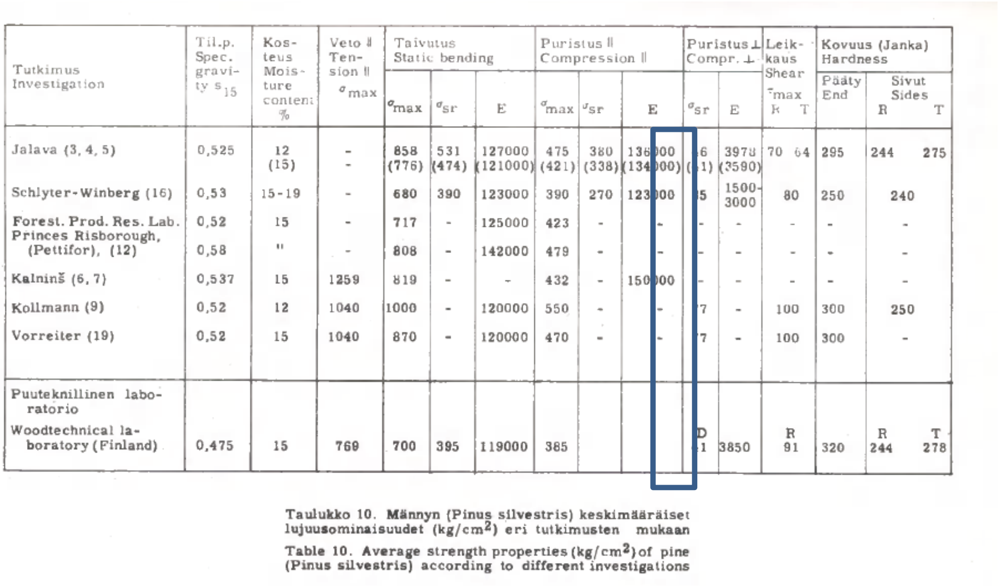
The method used in the tests refer to an American test.



Kuva 34. Kosteuden vaikutus männyn kiskopuristuslujuuteen. R + T. s_{15} = 0, 50

Fig. 34. Effect of moisture content on the sidewise compression strength of pine (rail compression). R + T. s_{15} = 0, 50

Figure 21. Proportional limit for sideways compression [22].



Tutkimus Investigation	Til.p. Spec. gravity s_{15}	Kosteus Moisture content %	Veto ∥ Tension ∥ σ_{max}	Taivutus Static bending			Puristus ∥ Compression ∥			Puristus ⊥ Compr. ⊥		Leikkaus Shear τ_{max}		Kovuus (Janka) Hardness		
				σ_{max}	σ_{sr}	E	σ_{max}	σ_{sr}	E	σ_{sr}	E	R	T	Pääty End	Sivut Sides R	T
Jalava (3, 4, 5)	0,525	12 (15)	- -	858 (776)	531 (474)	127000 (121000)	475 (421)	380 (338)	136[illegible]00 (134[illegible]00)	6 (1)	3978 (3590)	70	64	295	244	275
Schlyter-Winberg (16)	0,53	15-19	-	680	390	123000	390	270	123[illegible]00	5	1500-3000	80		250	240	
Forest. Prod. Res. Lab. Princes Risborough, (Pettifor), (12)	0,52	15	-	717	-	125000	423	-	-	-	-	-		-	-	
	0,58	"	-	808	-	142000	479	-	-	-	-	-		-	-	
Kalninš (6, 7)	0,537	15	1259	819	-	-	432	-	150[illegible]00	-	-	-		-	-	
Kollmann (9)	0,52	12	1040	1000	-	120000	550	-	-	7	-	100		300	250	
Vorreiter (19)	0,52	15	1040	870	-	120000	470	-	-	7	-	100		300	-	
Puuteknillinen laboratorio Woodtechnical laboratory (Finland)	0,475	15	769	700	395	119000	385			D 1	3850	R 91		320	R 244	T 278

Taulukko 10. Männyn (Pinus silvestris) keskimääräiset lujuusominaisuudet (kg/cm^2) eri tutkimusten mukaan

Table 10. Average strength properties (kg/cm^2) of pine (Pinus silvestris) according to different investigations

Figure 22. A synthesis of investigations of wood strengths [22].

5.5.1 Discussion

The conclusion of the report is a proportional limit which could be considered as a SLS limit for tests according to the American method. The proportional limit seems to be in the range of 3.5 to 4.0 MPa. No definition of any rupture level could be found in this report, with reservation for lack of knowledge in Finnish reports.

5.6 Experimental Investigation into Deformations Resulting from Stresses Perpendicular to Grain in Swedish Whitewood and Redwood in Respect of the Dimensioning of Concrete Formwork [23]

In this PhD thesis short term load experiments have been performed. The picture below shows the test set up and values for 5 mm deformation for the tested white wood. The rate of loading is not given. For redwood are the mean values approximately 20 % higher for the edge distances in Picture 20.

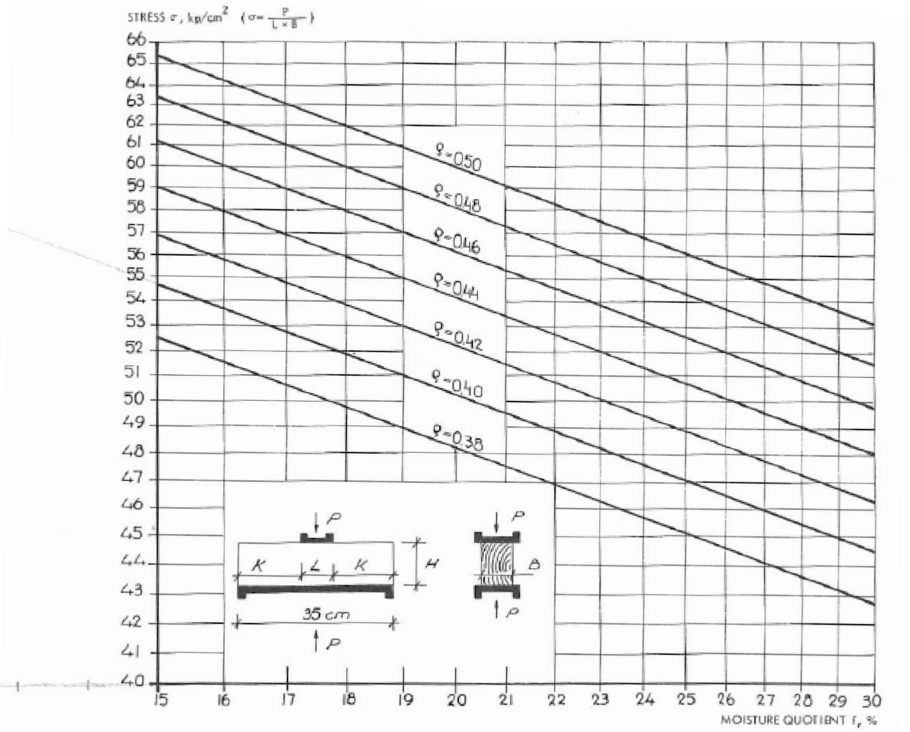


Fig.15 Short-term tests, compression ⊥ to grain, stress σ kp/cm² at deformation δ = 5 mm. Influence of moisture quotient f % and dry volume weight ρ = kg/dm³ at distance to edge K = 12-16 cm and load length L = 2".

Figure 23. Compression of white wood at different densities and moisture content [23].

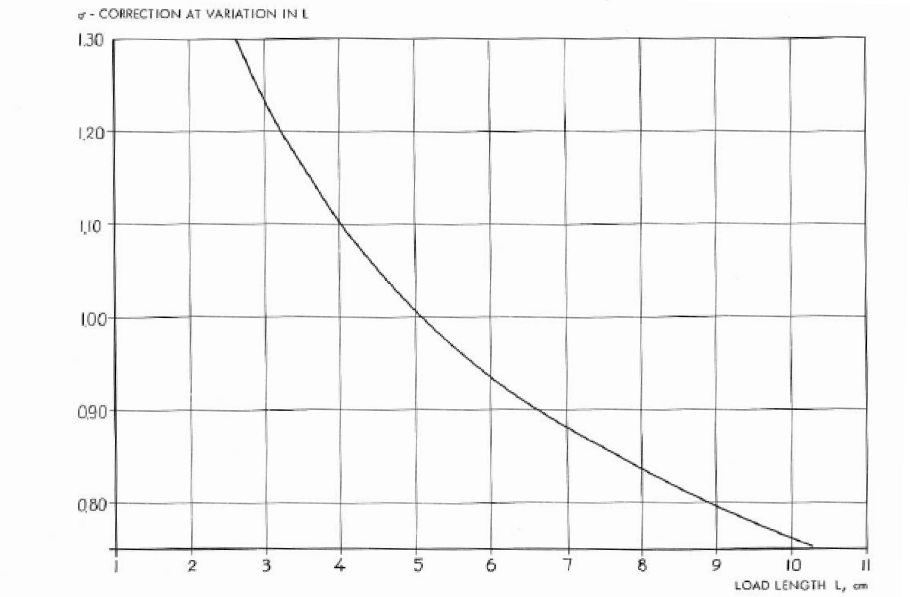


Fig. 16 Correction of stress obtained from above diagram at variation in load length L. 2" (5.08 cm) = 1.00.

Figure 24. Influence of the ratio of loading length and total length [23].

With edge distance K = 0 mm the mean measured values for whitewood and loading length from 1 to 4 inches, 5 mm deformation is 2.33 MPa. For K = 120 to 16 mm the mean value is 5.46 MPa. The MC is within a span of 15 to 23 %. The correction factor is 1.3 at a loading length of 25 mm. Compare to the models given in [7] and [8].

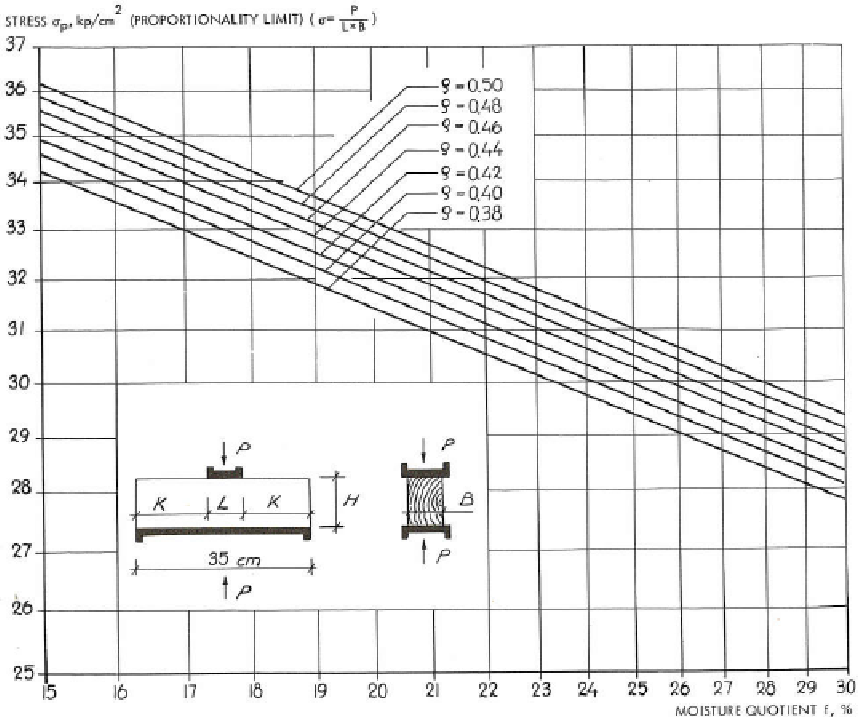


Fig. 19 Short-term tests, compression ⊥ to grain, proportionality limit σ_p kp/cm^2. Influence of moisture quotient f % and dry volume weight ρ kg/dm^3 at distance to edge K = 12-16 cm and load length L = 2".

Figure 25. Proportional limit, density and moisture content [23].

The proportional limit is defined as the point where the stress-deformation graph deviate 0.1 mm from the tangent of the straight line.

5.6.1 Discussion

The thesis suggests ways of calculating stresses and modulus and seems to be a good basis for developing calculations for practical use. The orientation of the annual rings in the tests has to be investigated further. The factors suggested in this theses are used for sill compression pressure in the Swedish codes, SBN [7], [8], NR [9] and BKR [12], [13] and in the Danish code [15].

A quick estimation of the characteristic values in the ultimate limit state for the shortest load length (1") and a estimation of 10 % CoV gives at the best a level of 6 MPa at 5 mm deformation and 120 to 160 mm edge distance. For the proportional limit at a level of 2.0 MPa seems appropriate. 5 mm deformation is clearly above the proportional limit.

A deeper study and investigating of details of the tests could be very useful in the work to develop calculations according to Eurocode. The test results however is just for sill compression and such alike design details.

5.7 Strength of Finnish softwood in compression perpendicular to grain and reinforcement of support areas with nail plates [24]

Quotation: “The density of softwood has a significant effect to the compression strength perpendicular to the grain. The lowest strength values are obtained in the diagonal direction between tangential and radial directions. Usually sawn timber has this weakest direction at support areas in compression perpendicular to the grain. However the strength values of Codes are based on the test results of the main perpendicular directions, and with low-density softwoods. These strength values may be about two times too high for the diagonal direction".

Tests with unreinforced nail plates structures at the supports. Loading width 45 mm and height of the structure element parts for 95 to 220 mm. Finnish spruce with a density span of 350 to 400 kg/m^3 was used.

Quotation: "Some reference tests were done also with the width of 70 mm spruce, with spruce glulam 45 x 225 mm^2 and with Kerto-LVL 39 x 200 mm^2. All specimens were initially conditioned to RH 65 %".

The loading speed was 2 mm/min.

Quation: "The mean strength value of the test results at the deformation 10 mm was 4.9 MPa with average density 395 kg/m^3. Normally the characteristic strengths are calculated from the compression strain of elastic deformation plus 1 %. With this deformation (1.5 mm to 3.0 mm depending of height of the chord) the strength values were at least 30 % lower".

The support length was 100 mm and was a steel block.

The intermediate support had a length of 50 mm. A higher capacity (relatively long distances to the edges) was found. The Finnish Code underestimates the capacity at the intermediate support at densities above 380 kg/m^3. The LVL had approximately 1.9 times higher capacity (density 470 kg/m^3). For glulam the capacity was on the level for ordinary wood (390 kg/m^3).

The cord height had no influence. The deformation was measured over a length of 90 mm from the bottom of the chord.

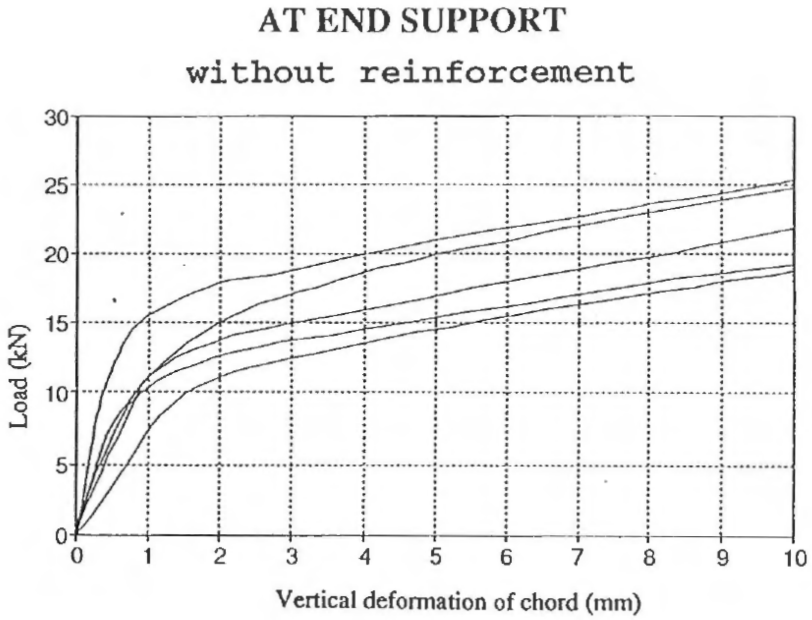


Figure 26. End support, chord 45 mm × 95 mm support length 100 mm. An estimation of stresses at 1 mm deformation gives 3.3 to 1 MPa. At 5 mm deformation the stresses are around 4.7 to 3.3 MPa [24].

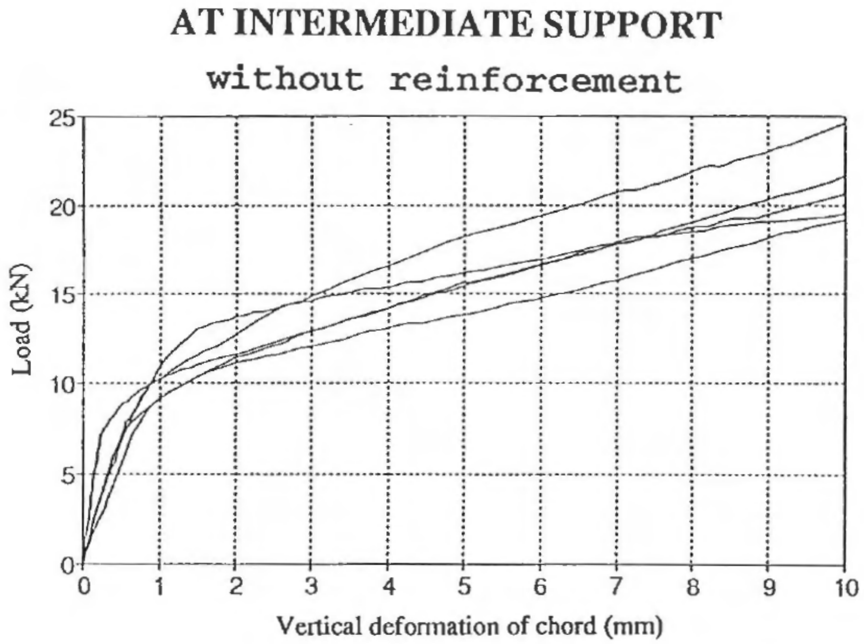


Figure 27. Intermediate support, chord 45 mm × 95 mm support length 50 mm. An estimation of stresses gives at 1 mm deformation 4.9 to 4.0 MPa. At 5 mm deformation the stresses are around 8 to 6.2 MPa [24].

5.8 Analyse of compression strength perpendicular grain in wood, (in Swedish, Analys av träets tryckhållfasthet vinkelrätt fiberriktningen) [25]

In this study two kinds of pieces of glulam were used, beams 77 x 98 x 500 mm^3 (width × height × length), density 525 kg/m^3 and blocks 77 x 98 x 88 mm^3 (width × height × length), 520 kg/m^3. Loading area for the beams and blocks was 77 x 99.6 mm^2 (width × length). The contact area for the load and the support of the blocks covered the total area of wood, similar as the CEN test method, EN 408. The contact area for the load on the beam covered the beams width, similarity to the ASTM D143 method.

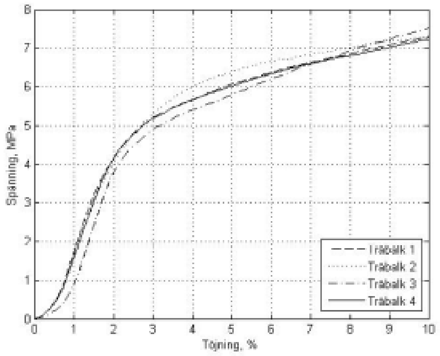


Figure 28. Graphs from the beam loading [25].

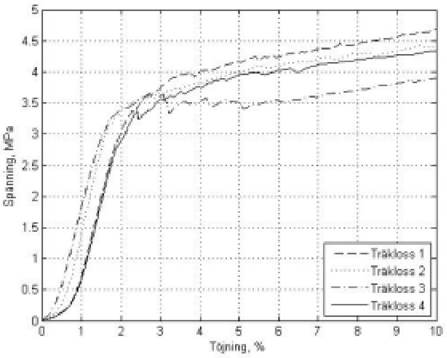
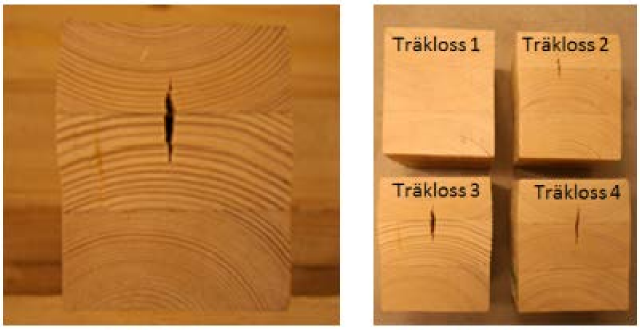


Figure 29. Graphs from the block loading [25].

The compression was mainly in the radial direction. The influence of edge distances is clear. The loading direction, radial direction, the weakest, most ductile direction.



(a) Träkloss 3

(b) Samtliga träklossar

Figur 5.8: Jämförelse mellan provkropparna inom gruppen Träkloss

Figure 30. The compressed blocks of glulam show a kind of rupture. The rupture for the blocks is tension in the centre perpendicular to the load direction [25].

5.8.1 Discussion

A proportional limit at similar level as in other references could be found in this report too.

6 Results of the survey

6.1 General

A proportional limit is identified in several reports referenced here. Strength levels above the proportional level have been set with deformation criteria.

The proportional limits are clearly depending on type of test where the loaded area and the support area are crucial. Influences of volumes are also present.

Tests with glulam members (timber members with large depths) show different failure modes which could be identified as rupture. There is a volume effect not only caused by the higher probability of discontinuities, cracks etc. in a big volume but also due to the actual load distribution in the loaded volume.

The CPG strength given in EN 338 [4] seems to be a proportional limit. Also the level of 2.0 MPa in the historic Swedish codes where allowable stresses were used seem to reflect this.

A model for calculating the increased capacity of sills loaded by studs presented in [7], seems to be relevant, but for other cases new models have to be developed.

Four different design situations seems to be relevant cases for calculations including normal Nordic dimensions:

1. Compression over a complete wood area.
2. Sill compression with adjacent load areas and edge distances, model according to ASTM D143.
3. Compression of a part of a wood volume, for instance a wall plate compressed between a rafter-support and a supporting stud.
4. Beam supports. Beam support can be divided in end support and intermediate support.

For larger volumes of wood, for instance glulam, separate models have be used or developed to reflect the rupture modes.

In each case is MC, density and the direction of the annual rings is influencing the CPG strength and also the load durability. Even the volume effect is present.

The variety of compressive strength within a block of wood can be a risk when the connecting structure parts not can handle eccentricities, for instance buckling due to moment induced by uneven deformation. That is mainly important for single studs acting like columns not embraced by sheets of fibre boards etc.

6.2 Historic Swedish approaches

The transition from allowable stresses to strength at rupture, i.e. the introduction of the partial safety factor method, which resulted in an increase of the CPG from 2 MPa to 7 MPa seems to reflect the change of safety factors used in the method of allowable stresses and the results from [23]. For a one story building and compressions on a sill (normally height 45 mm) which is continuously supported and with an acceptable deformation of approximately 5 mm, apparently 7 MPa could be used. Normally is the deformation distributed by stabilizing sheets and the high load level occurs more seldom, (snow load mostly). In other situations it seems too high for a situation where deformation is crucial and no distribution of deformation is available.

The model for calculating the increasing factor k_a, see Figure 1. The principles for sill compression and factor k_a for increased CPG,[7]., were not really adopted to the ULS principles and was used in the same manner as in the allowable stresses era.

During the time after the introduction of 7 MPa as the strength level for CPG and the entry of Eurocode [1] and EN 338 [4] has no general opinion been outspoken from the building or the design community about a too high CPG level in the code. In Sweden has one story structure been the main part of the buildings with wood structures. The dimensions of studs and sills have grown to larger dimensions due to requirements and ambitions to have a better energy performance. The loads, though, have been almost the same and occasions with ULS is not that common. The ambition to construct multi storey wood structures has brought up the deformation problem arising from a relatively large sum of compressed wood in a multi-story building. In some cases this has been an

evidently problem that has required a change in the arrangement of design details and structures.
During the winter 2009-2010 the snow load touched, and in some cases due to shape-effects, got higher than the designed ULS-level. No obvious causes were linked to high CPG, [26]. The secondary effect of deformation at the supports of a one span supported roof truss could be an unintentional support in the middle of the span due to vertical deformation but the vertical deformation of the truss itself at high load would normally be much higher than the compression of the top rails.

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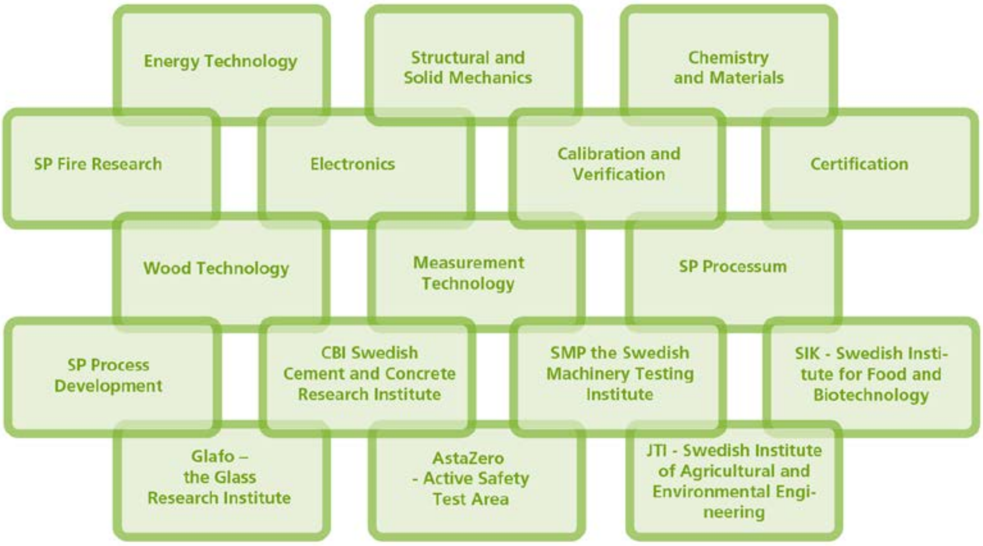

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