Nordic Wood: Reliability of timber structures

Summary report on existing strength data

Alpo Ranta-Maunus, VTT, Finland

1 Modelling strength data for reliability analysis

The purpose of the strength data collection and analysis was to find more information, which is needed in the reliability analysis of timber structures. First, a sensitivity analysis revealed that the calculated reliability is sensitive to the lowest strength values, whereas the values around the mean have no effect. Therefore, in order to get correct information on the reliability of structures, we need an adequate sample size, and the distribution function should fit well to the lowest values in the relevant population. Considering the test data available, a population of 1 000 test data can be considered adequate, and the population can consist of a combination of different test series. Then the distribution functions can be fitted to the lower tail, e.g. 10%, of the values, and used both to determine the characteristic 5th percentile value and to estimate the structural reliability.

In some cases it was observed that machine-graded sawn timber had too low a 5th percentile value, which is supposed to be a signal of an error in grading. This has to be counteracted by improving the calibration of grading machines or grading technology. We do not propose that this kind of error in research equipment functions should be considered in the structural reliability analysis.

2 Summary of strength data

Nordic project partners have collected and analysed such existing strength data of timber materials to which they have access. We have analysed the bending data of sawn and round timber, LVL, glulam, finger joints, I-beams and plywood. The tension strength results of glulam lamellae, and compression data of round timber have also been analysed in the project.

In this summary report, only the results obtained from the largest samples are included. From the sawn timber data, only machine-graded timber with a sample size N > 500 is included, with the exception of a sample of Irish-grown sitka spruce (N = 386), in order to include some results other than Scandinavian. The results of visually graded timber are not included because of the low yield of the method. The largest population of sawn timber we analysed comprised 1 300 specimens.

From Kerto LVL we have nearly 2 000 quality control specimens both in edge-wise and flat-wise bending. From tension tests of glulam lammellae a sample of 1 000 specimens were available, and 600 for bending of finger joints. For small-diameter round timber, about 600 bending and compression test samples have been analysed.

The samples for other materials are unfortunately smaller. Since no other information was available, the following samples are also reported here: plywood (281), glulam (126 + 109), and I-beam (294).

Strength distributions are illustrated on a relative scale in Figure 1, where all strength values are divided by the 5th percentile. For comparison, curves for lognormal distribution with COV = 10, 20 and 30% are shown as well. The upper figure with linear probability scale shows the differences above characteristic value, whereas the smallest strength values can be compared when logarithmic scale is used (lower figure).

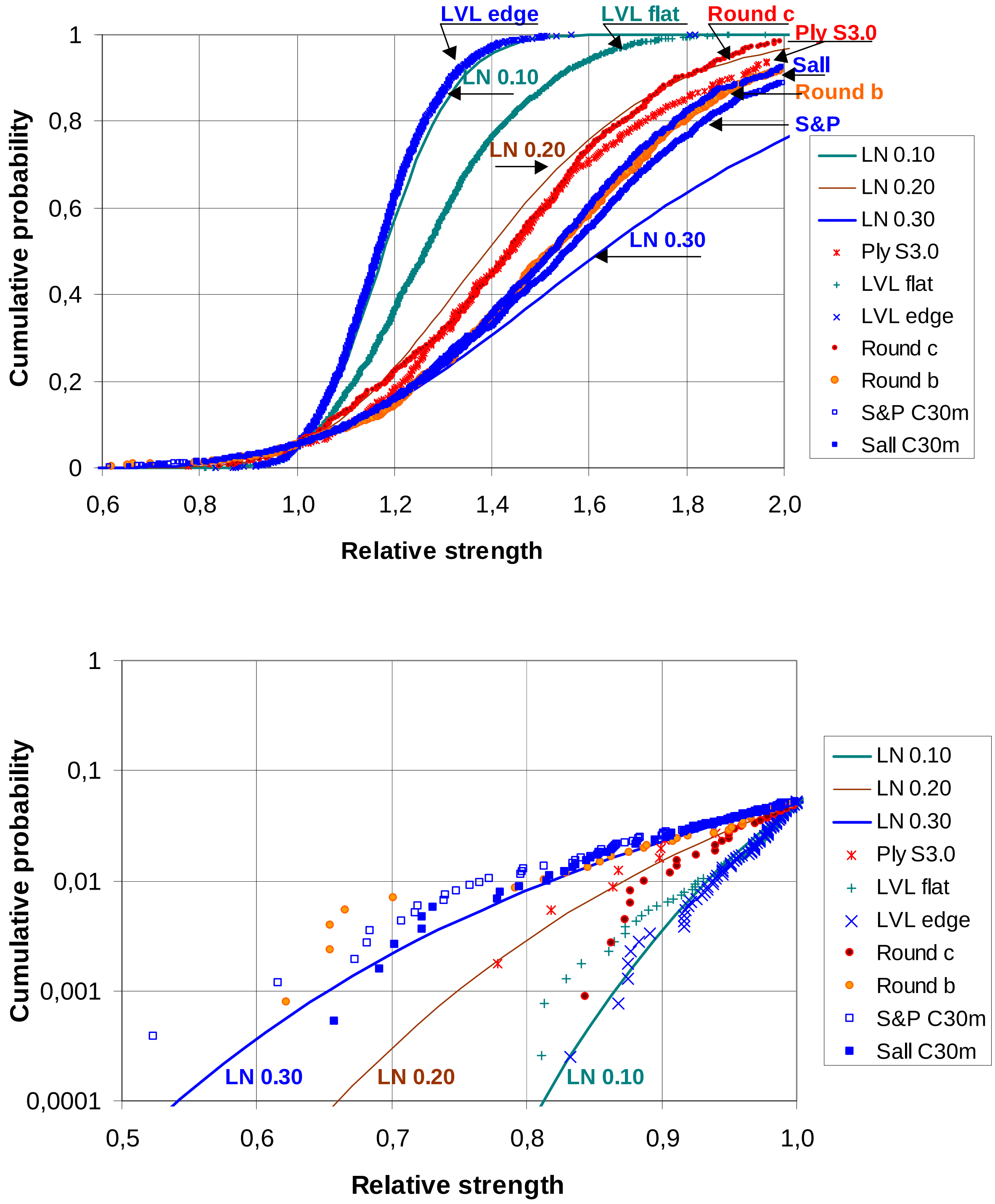

Figure 1. Cumulative probability distributions of relative strength (strength per 5th percentile) of sawn and round timber, LVL and plywood on linear and logarithmic scale as well as lognormal function with COV = 0.1, 0.2, and 0.3.

The results are reported in detail by Ranta-Maunus et al. (2001), Sorensen and Hoffmeyer (2001) and NTI (2001). A summary is provided here concerning:

- how well the samples meet the target characteristic (5 percentile) value, and
- the parameters of distribution functions fitted to the data in terms of COV.

When strength data is used in the reliability analysis, it is essential that the distribution function used fits well with the lower strength values, otherwise the reliability values are misleading. Therefore, we fitted distribution functions separately to all the data and to the lower tail, 10 % in many cases. If both fittings gave nearly the same result, we concluded that this material follows the distribution in question, and we could use the parameters obtained from any of the fittings. For LVL and plywood we obtained nearly the same COV when fitting lognormal distribution to all the data and to the lower tail. On the other hand, the sawn timber results show a flatter tail than that of lognormal distribution, only a little steeper than normal distribution. When we used lognormal distribution to describe this data, we used COV based on the fitting to lower tail.

The results of analysis are shown in Tables 1 (sawn timber) and 2 (others) concerning the 5 percentile value observed versus the target value of the grade, and the COV parameters of normal, lognormal and 2-parameter Weibull distributions fitted to the lower tail data. The 5th percentile value is based to non-parmetric distribution, which is the method used in the EN-standards for sawn timber. In most cases, the 5th percentile is close (a little above) the target value with some exceptions:

- one set of sawn timber data gives 10 % too low a 5th percentile
- two sets of finger joint data give 5 and 17 % too low a value
- two sets of tension lamellae give 3 to 4 % too low a value
- glulam and plywood had a 10% higher 5th percentile than the grade value.

The result is contradictory for glulam: the testing made by its constituents, lamellae and finger joints, suggests that there could be a problem in the strength of glulam, whereas the strength of glulam exceeds the code value. We should obtain more data on glulam in order to be able to draw conclusions on the tail data.

Visually graded sawn timber, which is not reported here, gives normally a higher 5th percentile value than needed for the grade. Therefore, this traditional method can be considered conservative but uneconomic. An other problem associated with the tests of visually graded timber is that the grading is made in the laboratory, indicating the conservatism of the grading rules rather than the high strength of commercially produced material.

When normal, lognormal and 2-parameter Weibull distributions are fitted to the lowest 10% of the results, the COV parameters related to these functions are quite different, as shown in Tables 1 and 2. Sawn timber, which has COV of the whole test data from 21 to 29 %, has the COV parameters of tail-fitted distributions as follows:

Normal distribution:	18 – 24 %
Lognormal distribution	29 – 35 %
2-parameter Weibull	14 – 21 %

Distributions fitted to the lower tail of the tension strength of lamellae, and bending strength of finger joints and round timber have similar COV parameters as sawn timber.

Table 1. Collection of machine-graded sawn timber bending strength distribution data, and bending and compression data of ungraded small-diameter round timber. The type of distribution fitted to the lower tail data is given as well as the COV parameter of the fitted distribution, the tail used for fitting as % of total sample and $f_{0.05}$ based on nonparametric distribution.

Species	Origin	Grade	$f_{0.05}$ [N/mm^2]	Grading method	Sample size	Tail fitted [%]	Distribution type	COV [%]	Reference
Spruce	Finland	M30	30.5	Bending	496	10	Normal Lognormal 2-P Weibull	18 29 14	Ranta-Maunus et al. 2001 S-1 in Table 2.3
Spruce	Finland	M30	31.3	Bending	986	10	Normal Lognormal 2-P Weibull	19 31 15	Ranta-Maunus et al. 2001 S-1 to S-99 in Table 2.7, “Sall” in Figure 1
Spruce and pine	Finland, Sweden	M30	30.6	Bending	1327	10	Normal Lognormal 2-P Weibull	20 35 17	Ranta-Maunus et al. 2001 Table 2.10, “S&P” in Figure 1
Spruce and pine	Sweden and Finland	M24	24.6	Dynamic	819		Normal Lognormal 2-P Weibull	24 35 21	Dalsgaard Sorensen, Hoffmeyer Table 6.11, Series F all
Sitka spruce	Ireland	M30	27.1	Bending	386	30	Normal Lognormal 2-P Weibull	23 34 21	Dalsgaard Sorensen, Hoffmeyer Table 7.2, Series H, Cook Bolinder
Small round timber, bending	Finland, UK, Austria		36.6	None	660	10	Normal Lognormal 2-P Weibull	20 34 16	Ranta-Maunus et al. 2001 Table 2.20, Spruce and pine, “Round b” in Figure 1.
Small round timber, compression	Finland, UK		17.8	None	575	10	Normal Lognormal 2-P Weibull	13 18 9	Ranta-Maunus et al. 2001 Table 2.20, spruce and pine, “Round c” in Figure 1.

Table 2. Collection of EWP (plywood, LVL, I-beam, glulam) strength distribution data together with lamellae tension and finger joint bending results. The type of distribution fitted to the lower tail data is given as well as the CO -parameter of the fitted distribution, the tail used for fitting as % of total sample and $f_{0.05}$ *based on nonparametric distribution. Grade value is the expected* 5th *percentile strength according to the grade.*

Product	Origin	Target $f_{0.05}$ [N/mm^2]	$f_{0.05}$ in test [N/mm^2]	Explanation of test	Sample size	Tail fitted [%]	Fitting distribution	COV [%]	Reference
I-beam	Norway	24	25.8	Tension / compression of flange in standard bending test	294	10	Normal Lognormal	12 17	NTI
Finger joint	Norway	24	22.8	Edgewise bending	620	10	Normal Lognormal	20 33	NTI
Finger joint	Norway	30	24.9	Edgewise bending	220	10	Normal Lognormal	27 57	NTI
Glulam	Norway	30	33.5	Edgewise bending	126	10	Normal Lognormal	11 13	NTI
Glulam	Norway	37	39.9	Edgewise bending	109	10	Normal Lognormal	14 19	NTI
Glulam lamellae	Scandinavia	20	19.2	Tension	1098	30	Normal Lognormal 2-P Weibull	21 30 18	Dalsgaard Sorensen, Hoffmeyer Table 3.15, Cook Bolinder
Glulam lamellae	Scandinavia	20	19.4	Tension	1079	30	Normal Lognormal 2-P Weibull	21 30 18	Dalsgaard Sorensen, Hoffmeyer Table 3.16, Computermatic
Glulam lamellae	Scandinavia	16	17.0	Tension	549	30	Normal Lognormal 2-P Weibull	22 33 20	Dalsgaard Sorensen, Hoffmeyer Table 3.17, Dynadrade
LVL	Spruce, Kerto	50	51.3	Edgewise bending	1968	10	Normal Lognormal 2-P Weibull	8 9 5	Ranta-Maunus et al. Table 2.13, “LVL edge” in Figure 1.
LVL	Spruce, Kerto	50	50.3	Flatwise bending	1963	10	Normal Lognormal 2-P Weibull	10 12 6	Ranta-Maunus et al. Table 2.13, “LVL flat” in Figure 1.
Plywood	Spruce, 3 mm ply	30	33.6	Flatwise bending	281	10	Normal Lognormal 2-P Weibull	16 23 11	Ranta-Maunus et al. Table 2.17, “Ply S3.0” in Figure 1.

Engineered wood products, and round timber in compression had smaller COV values. Ungraded small-diameter round timber, which had a COV of all data of 23 %, obtained a tail-fitted COV parameter of lognormal distribution as low as 18%. In engineered products, the COV of tail-fitted lognormal distribution is close to the COV of the entire data. For LVL we obtained a COV around 10%. For other EWPs the sample size should be larger so that we can draw firm conclusions on the shape of distribution tail.

3 Recommendations

Based on the analyses performed, the following recommendations are made:

The data available suggests that engineered wood products follow well the lognormal distribution, and sawn timber could be better described by normal or Weibull distribution. However, it is suggested that lognormal distribution is used for all timber materials in structural reliability analysis, because it is widely used for other materials and because it seems to be the best for timber materials used for long span structures as well.

When more specific information is unavailable, the COV parameters of lognormal distribution can be taken from Table 3. It has to be observed that the data used in this work was based on the testing of:

- mainly Nordic sawn timber
- Kerto-LVL
- Finnish 3 mm-ply spruce plywood (only 300 specimens)
- Norwegian I-beams (only 300 specimens)
- Norwegian glulam (only 100 + 100 specimens).

It would be valuable, especially for glulam, which is used in long-span structures, if a much bigger population were analysed.

Table 3. Suggested values for COV-parameter of lognormal distribution when used in structural reliability analysis.

Material	COV [%]
Machine graded sawn timber	30
Plywood*)	20
Glulam*), I-beam*)	15
LVL	10

*) inadequate population (N < 300).

References

Dalsgaard Sorensen J., Hoffmeyer P., 2001, Statistical Analysis of Data for Timber Strengths. Manuscript.

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