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Abstract

The use of small-diameter timber in construction has been investigated. The aim of the work is to increase the use of the wood harvested in forest thinning in construction applications. The work has covered a wide range of aspects, from availability of the material to design of the structures. This publication summarizes the results in following areas: availability, dimensions and quality of conifers harvested in forest thinning, cost of harvesting and woodworking, comparison of drying methods: seasoning, warm-temperature and high-temperature kiln-drying, improving durability, strength of round small-diameter conifers, potential types of structures to be built from round timber and new mechanical joints.

The tree species that were included in the study are Scots pine, Norway spruce, Sitka spruce, Larch and Douglas fir.

The main reasons why round timber is rarely used in construction can be summarized as: the material is not available via the normal commercial routes, the roundness requires special methods and systems that are not known by architects and carpenters, the strength values of timber connections are not available for engineers, the lack of standards and models.

This research aims to produce information needed in the use of small roundwood in load-bearing structures in order to remove the obstacles mentioned above.

Results concerning availability of construction-quality round timber in the first commercial thinning reveal that the resource itself is vast: millions of cubic meters in Finland alone. The yield per hectare is, however, limited and dependent on the dimensions required. When the diameter of the final product is

adequate at less than 100 mm, the first commercial thinning is also economic for the harvesting of construction timber. The economics of manual and mechanical harvesting have been compared. When larger dimensions are needed, the second thinning is more likely to produce the required material.

The cost of producting round timber is primarily dependent on the surface quality needed: timber peeled cylindrical is twice as expensive as material that is only debarked. Both of these have their own market. The cost of construction is dependent on labour costs, which at the moment is higher for round timber than for sawn timber because conventional systems are not suited for the use of round timber. Additional costs may arise from the deviations of cylindrical form.

Drying is a critical phase of production, which determines how much checking is observed. In this respect, high-temperature drying gives much better quality than normal, commercial warm-temperature kiln-drying or natural seasoning. Accordingly, the drying method should be chosen based on the surface requirements. End-cracking also affects the capacity of joints.

The strength of small-diameter timber was observed to be higher than expected. Characteristic values are presented as well as a proposal for visual strength-grading. A method for non-destructive mechanical strength-grading based on X-ray is also proposed. A statistical analysis is presented which indicates the dependence of strength and stiffness on different factors such as density, knots, moisture content, diameter and age.

New mechanical connections have been designed and tested. For engineered structures, a round form enables the use of steel lacing around the wood, which considerably increases the load capacity of the joints.

The largest quantities of round timber are used, and can be used, in non-structural applications and in small, traditional-type buildings. Smaller in volume but important for the image of roundwood is its application in the architecture of medium-sized leisure industry buildings in which the load-bearing structure is visible. As part of the project, designs for a footbridge and a watchtower have been made.

Preface

The project "Round small-diameter timber for construction" is part of the EC´s 4th framework programme (FAIR-CT95-0091), which was completed by the end of 1998. The EC contact person was Dr A. Arabatzis. The project participants are listed below as follows:

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This publication is the final report of the project, which summarizes the main research results. The report has been writen by the editor with the help of all the participating teams. Major contributions from the following persons are acknowledged:
Mr Jukka Pietilä (MTT) for Chapters 2.1 and 2.2 on harvesting; Mr Antti Nurmi (VTT) for Chapter 2.4 on oil impregnation; Mr Hannu Boren (MTT) for the analysis of mechanical and physical properties of Finnish timber; Dr Caspar

Groot (TUDelft) for Chapter 4 on mechanical connections, and Dr Robert Griffiths (U Surrey) for Chapter 5 on roundwood structures.

More detailed results are published in the papers given in the references. The main documents for facilitating building design are the design guidelines for round timber structures, which have been made separately for engineered (Groot 1999) and non-engineered structures (Griffits et al. 1999).

I would like to express my sincere thanks to all persons involved for their commitment to the work.

Espoo June 1, 1999

Alpo Ranta-Maunus

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1. Introduction

Small-diameter roundwood was traditionally used in construction in olden times. It is still used though to small extent in areas where wood, as a building material is common. Often, roundwood is used by do-it-yourself men in rural areas. The commercial construction business very seldom uses small-diameter round timber. On the other hand, small-diameter wood is available from forest thinning, which provides a surplus of such material. Good management of forests cannot be performed without proper thinning. Delayed thinning is a common problem in Europe, because of the lack of demand, and the low price. Such wood can also be used for energy production, but at the moment it is not competitive with other energy sources. As a result, new uses of timber are being sought in the construction industry, which would make forest thinning economical. As building material, round timber is considered environmentally friendly, especially if processing and transportation are minimal.

The objective of this research was to study how small-diameter timber could be used in construction. The work includes critical issues of material production, such as harvesting, processing, drying, strength and durability. Issues related to structural development are also focused upon: feasible types of buildings that can be built from round timber, the development of mechanical connections, and the drafting of design guidelines for roundwood structures. The content of the work reported in this publication is summarized in Table 1.1.

The aim in harvesting research is to find out what the harvesting costs are of structural quality small-diameter timber when manual or mechanical harvesting is used. One problem to be dealt with is related to the fact that only a part of the timber harvested in the first commercial thinning is suitable for construction. The required quality is characterized in terms of dimensions, straightness and knots. A draft for visual strength-grading has been produced. Non-destructive methods have also been studied to determine whether they can be used for strength-grading.

Natural seasoning is the traditional method of wood drying. The quality and final moisture content of seasoned roundwood have been studied and compared with available industrial kiln-drying methods. The important issues in wood drying are the moisture content and checking of wood, which is important for visual appearance, durability and strength of the mechanical connections.

Table 1.1. Work content.

Task	Objective
Material production and research	
Harvesting	Assessment of economic harvesting methods and roundwood resources available. Harvesting of material for experiments.
Quality characterization	Measurement of the quality of roundwood harvested, and estimation of the availability of the structural quality of roundwood. Quality classification system.
Drying	Comparison of the quality of kiln-dried and seasoned roundwood. Schedules for kiln-drying.
Strength	Characteristic strength values needed in design of buildings.
Development of structures	
Market study	Estimation of the potential types of buildings for the use of roundwood, and estimation of the roundwood market.
Structural systems and details	Structural systems and details for buildings. Theoretical models for connections. Design rules for connections and details.
Design guidelines	Design guidelines in relation to Eurocode 5 including strength-grading system for round timber.
Buildings	Model drawings and demonstration building to be built.

Today, roundwood is mainly used outdoors, exposed to rain, in non-structural applications. Often, natural durability is not adequate and it is improved by impregnation with preservatives. The trend is to avoid toxic preservatives, and therefore there has been another EU-funded project on the use of natural preservatives (FAIR-CT95-0089). Some results on oil impregnation are summarized in this report.

The strength of small-diameter round timber has not previously been tested. It is thought that the strength of small wood might be low for two reasons. Firstly, it is to large extent juvenile wood, and the knot sizes can be relatively large. On the other hand, it is known that the bending strength of adult round timber is higher than that of sawn timber of a similar cross-section size, and small cross-sections are known to have higher strength than large ones based on the Weibull theory. The objective of strength testing is to find out which of these effects is strongest, and to determine characteristic values for the species and grades studied.

Potential types of structures that can be built from round timber have been determined. Design guidelines have been written both for engineered structures in conjunction with Eurocode 5, and for simpler non-engineered structures. In this publication the use of small-diameter roundwood in structures is illustrated, and the design guidelines have been produced separately. A key-issue in engineered structures is the connections. The work includes the development of new types of joints applicable for round timber.

2. Harvesting, quality and manufacturing

2.1 Economy of harvesting

The main sources for the results presented in this chapter are taken from Mr Henrik Heräjärvi's thesis for the master of forestry degree (Heräjärvi 1998). The information on harvesting economy in Austria and UK is based on the work of the project partners. Mr Jukka Pietilä made the roundwood production cost calculations and he also combined and modified the aforementioned texts.

Most of the work is focused on Finland because we have a bigger study in which we compared different kinds of harvesting methods in the same stand. In Austria and in the UK our results are based on one harvest case where we harvested strength sample trees. However, we believe those results are based on up-to-date technology and they are rather average ones. In addition, as seen later, the main results do not differ too much in other countries. The conditions differ between countries, but so they do within one country and therefore we always have to adapt our results, conclusions, rules and advice to meet local circumstances and needs.

2.1.1 Introduction

Harvesting construction timber

The first step in round construction timber production is gaining the raw material for roundwood. A large and under-utilized resource for construction timber is derived from the first commercial thinnings of forests, which were selected as the scope of this study. Thinning is one of the normal processes carried out during forestry management since it allows the better quality trees to grow for later use. Choosing the most suitable felling method is dependent on various parameters (Barnard 1997, Heräjärvi 1998), which include:

- terrain
- accessibility to the forest
- distance to roadside for collection
- volume of timber to be felled
- location of forest in relation to other felling operations

- scale of operation
- experience of the logger
- density of the stand
- amount of undergrowth.

For example, in Austria, Scotland and Wales the main factor in determining the choice of felling operation method is the terrain. The cut-to-length method is widely used on low lands, and in Finland nearly exclusively. In this method, tree stems are cut for pulpwood and construction timber lengths are already cut in the forest during felling. A logger or harvester may perform this harvesting. For large stands a harvester and forwarder would be the most likely method chosen. Harvesters are now being developed to operate on difficult terrain, so their use on steep sites is becoming more widespread. Commercially, most softwood felling operations are now carried out using a harvester, although in certain situations manual felling may be used.

For sites where the topography makes mechanical harvesting impossible manual methods are used. In this situation, the logs are either transported off the hillside using cables and winches or by a forwarder if access roads have been made into the forest.

Transportation of the roundwood can increase the costs if accessibility to the site is difficult and the distance to the roadside from the felling area involves long transport times to deliver the logs. The distance that the logs have to be transported by the forwarder should be considered, since long distances will add time and costs to the operation. The preferred option is for the collection points to be accessible for the haulage lorries, and for a short distance from the felling area to the roadside.

A further consideration in determining which harvesting method to use is the quantity of timber to be felled. For large operations it is commercially viable to use a harvester and forwarder; however, if the stand of timber is small and access to the site for large plant is difficult, then it may be more practical to harvest the timber manually. This practice is common if the stand or amount of harvested trees is small. Additionally the competitiveness of manual harvesting compared to using a harvester increases when the size of stems to be removed is smaller.

Harvesting small roundwood for construction does not require the development of any new harvesting technology. Tree felling can be carried out as part of the normal harvesting process. Similarly, no changes are needed to transport the logs. The main differences lie in the method of selecting the timber and how this can be integrated with existing harvesting methods.

When using cut-to-length method, there are two main strategies. The first is to select timber from harvested pulpwood, and the second is to harvest the roundwood specifically for roundwood construction timber. Both strategies have their advantages and disadvantages and they both have different methods of implementation. They both affect the costs and benefits and that is why both methods were tested.

In the selection method, the potential construction timbers are graded bolt by bolt from a pulpwood pile and those bolts which best fulfil the quality and dimension demands are selected. In the harvesting method, the construction timber is harvested as one specific assortment, e.g. pine pulpwood. Harvesting includes selecting and felling the trees, cutting them into suitable length-diameter -combinations and then transporting them to the roadside.

Nearly all of the small-diameter construction timber is harvested in the first commercial thinnings. The quality demands concerning, e.g. straightness and wood quality, set on that timber are higher than those for pulpwood. For construction timber harvesting, the problem when harvesting the first thinnings is in leaving the best quality stems to grow. The future quality of the forests must not be jeopardized and a quality-thinning principle must be followed by leaving the best trees. Thus, the raw material for construction timber is taken from the best stems of the removed ones.

It is important to separate pulpwood and construction timber already during the forest operations in order to achieve the best economical efficiency. Later separation of the pulpwood and construction timber material will cause extra work and costs. The problems have been in not having studies on this kind of integrated harvesting pulpwood and construction timber are harvested together. However, there has been plenty of research work concerning integrated pulp and fuel-wood harvesting, e.g. Imponen (1995), Hakkila et al. (1995), Mäkelä & Ryynänen (1994). During this work it has been possible to compare our results with those concerning time consumption, productivity and costs of pulpwood harvesting e.g. Imponen & Kuitto (1986), Kuitto et al. (1994), Lilleberg (1990), Liikkanen (1992), Mäkelä (1989 and 1990). But construction timber harvesting differs from pulpwood harvesting especially in felling, with construction timber harvesting we have to observe the quality demands, which debase productivity.

Up to now, entrepreneurs have bought all the pulpwood coming from one stand and they have subsequently sorted the trees into pulpwood and construction timber. This has caused extra work and a problem for pulpwood marketing. Thus, it has reduced the economical profitability of roundwood constructions.

Aim of the study

The aim of this study is to introduce a harvesting method for integrated construction timber and pulpwood harvesting. The idea is that the trees are sorted during harvesting in the forest into pulpwood and construction timber.

During this work we developed and studied four cut-to-length harvesting systems for integrated pulp and construction timber harvesting. These were manual harvesting, manual pre-harvesting of mechanical harvesting and mechanical harvesting. The fourth method was selecting pulpwood and construction timber on a roadside. We also studied how well these different methods could meet the quality demands set on construction timber.

The productivity and costs for these four methods were measured and analyzed, and the productivity of the harvesting work was calculated as a function of tree size. In addition, calculations and estimations were made of the production costs for small-diameter construction timber, debarked and peeled.

Concepts

A construction timber stem is a tree stem whose quality and dimensions are suitable for cutting at least one construction timber bolt.

A pulpwood stem is a tree stem whose quality or dimension is suitable only for pulpwood.

A construction timber is a debarked or peeled construction product that is round and dimensioned.

With time-study data the working times (W_0) (effective time + breaks + auxiliary time) and effective times needed were calculated. In the time-studies, the most commonly effective time (E_0) and operating time (E_{15}) were used. With operating time means working times without breaks longer than 15 minutes, effective time is working time without breaks (Harstela 1991). When estimating productivity in forestry operations, operating times are usually used (e.g. Brunberg 1988, Kuitto et al. 1994, Asikainen 1995) but also effective time is used (e.g. Sirén 1990, Kuitto et al. 1994, Nurmi 1994). In this study, working times and effective times have been used because the amount of small breaks was so small.

Felling means felling, debranching and cutting a stem for timber assortments. Forwarding means transportation of the timber to the roadside. Harvesting is felling and forwarding together.

2.1.2 Material and methods of time and productivity study

Harvesting methods

In the Finnish time-study the logger, forwarder and harvester operators were professional and used to harvesting work. Because they were not used to the harvesting method employed in this study they trained on one plot, which was similar to those used in the time-study. The forwarder and harvester were medium-size ones that are commonly used in harvesting work. Both logger and machines worked on a piecework wage according to which their work was measured.

The harvested pulpwood bolts fulfilled the usual pulpwood quality demands. The top diameter for a pulpwood stem was 7 cm. For construction timber stems the quality demands were (Borén 1999):

- maximum knot diameter 3 cm,
- minimum distance of two knot whorls at least 15 cm and
- the stems should not have curving, scar, or fissures.

The following harvesting methods were used in the study:

1) Manual harvesting. Logger and forwarder. The logger harvested using an ordinary manual-thinning work method. If he noticed that the pulpwood stem fulfilled the construction timber quality demands, he performed a clean delimbing and cut the stem into construction timber lengths, and then piled it separate from the pulpwood. The forwarder transported the bolts on separate sides of a load bunk (Figure 2.1).

2) Manual pre-harvesting of mechanical-harvesting. Logger, harvester and forwarder. With manual pre-harvesting we tried to improve the productivity of mechanical harvesting. In this method, the logger cut undersized trees and he harvested for pulpwood or construction timber from all the removed trees whose breast-height diameter was less than 10 cm. He also planned and marked the carriage roads. After that the harvester cut the trees on the carriage roads and other trees by making two assortments. The haulage was done with a forwarder.

3) Mechanized harvesting. Harvester and forwarder. The harvester harvested both the construction timber and pulpwood at the same time, but put them in separate piles for hauling. The most important factor distinguishing the two assortments was the different length of construction timber (3 m) compared to pulpwood (2.9, 3.7 and 4.7 m). Forest forwarding as in 2).

4) Selecting construction timber on a roadside. The harvester felled the pulpwood. From these bolts, the forwarder operator selected those logs whose quality was suitable for construction purposes. The selection took place either when
a) loading, by loading the logs on different sides of a load bunk or
b) while unloading on a roadside.

After forwarding, on a roadside, the construction timber selection quality of each method was studied. The aim of this evaluation was to find out if the qualities of construction timber fulfilled the demands and whether there were bolts in the wrong piles.

Figure 2.1. Manual logging and timber on roadside.

Stand

The data for this work-study was collected from the first commercial thinning of a mixed Norway spruce and Scots pine stand in which spruce was dominant. Only spruce was harvested for construction timber, and pine was harvested for pulpwood. Before harvesting preliminary estimations were made about the volume of trees.

When the cost calculations were made, it was assumed that the logger cost was 16.7 euro/h, the machine cost for the harvester was 66.7 euro/h, and for the forwarder 37.5 euro/h (note that these are derived from piecework wages). In this paper, the harvesting times also includes the harvesting time for pine. The costs were divided for timber assortments according to the formula (Oijala & Terävä 1994):

$$CA = \frac{STa}{SOa} TC \tag{2.1}$$

where CA = harvesting cost of assortment (euro/m^3)
STa = assortment's share of total harvesting time (%)
SOa = assortment's share of out turn (%)
TC = total cost (euro/m^3).

Table 2.1 shows the number of harvested construction timber and pulpwood stems per plot. The share of construction timber stems is also shown. Out of all the harvested stems, the share of construction timber stems was 25 %.

Table 2.1. Number of harvested stems per each plot and share of construction timber.

Method	Number of pulpwood stems	Number of construction stems	Share of construction timber (%)
Manual	208	75	22.9
Manual pre-harv.	209	95	23.3
Mechanized	215	68	25.9

2.1.3 Results

Productivity and costs

The felling productivity and costs are given in Table 2.2. If the share of those stems which did not fulfil the quality demands of construction timber are taken into account, the costs of manual pre-harvesting and mechanized harvesting of construction timber will increase by 20 %.

Table 2.2. Productivity of felling on effective time (E_0) basis and felling costs by assortments with various harvesting methods.

Method	Productivity, (m^3/E_0)		Costs (euro/m^3)	
	Pulpwood	Construction	Pulpwood	Construction
Manually	1.35	0.40	6.9	14.1
Pre-harvest	2.34	0.71	10.4	16.1
Mechanized	3.31	1.16	9.3	11.7

In Austria, felling costs were about 18 euro/m^3. The main reason for this was the hilly terrain.

The costs for the harvesting (felling and forwarding) are given in Table 2.3. If the costs alone are taken into account, the most profitable logging method for construction timber is by selecting from roadside piles.

Table 2.3. Harvesting costs by logging method.

Method	Costs (euro/m^3)
Manually	16.6
Pre-harvesting	17.2
Mechanized	15.7
Selection by road a/b	14.6/13.4

For tree delivery of small entrepreneur or private use, also the harvesting costs per meter and per bolt were calculated. The results are shown in Table 2.4.

Table 2.4. Harvesting costs per construction timber bolt and meter.

Method	Harvesting costs (euro/bolt)	Harvesting costs (euro/m)
Manually	1.1	0.23
Pre-harvesting	1.1	0.27
Mechanized	1.0	0.28
Selection by road a/b	0.95/0.87	0.27/0.23

If the bolt volume increased by 10 dm^3, the logging costs increased by about 0.17 euro. The trend was the same as the volume decreased. With increased bolt volume the relative productivity of harvesting work decreased. The reason for this is, e.g. close delimbing which is needed for construction timber.

Results by methods/Method 1: Manual harvesting

Table 2.5 gives the mean breast-height diameters and the volumes of pulpwood and construction timber stems.

Table 2.5. Average breast-height diameters and volumes of pulpwood and construction timber stems.

	Pulpwood	Construction timber
Breast-height diameter, cm	11.7	13.5
Mean volume, dm^3	65	95

Every construction timber bolt that was logger-felled fulfilled the quality demands for construction timber. Felling a construction timber stem took about 20 % more time compared with a pulpwood stem. This was because of the stem size. Stage delimbing and bucking took clearly longer for construction timber than for pulpwood. The relative difference was about 40 %. This arises from the need for the exact measuring of bolt dimensions and close delimbing. Transition times between the stems were 15 to 20 s. Figure 2.2 shows regression between stem diameter and harvesting time.

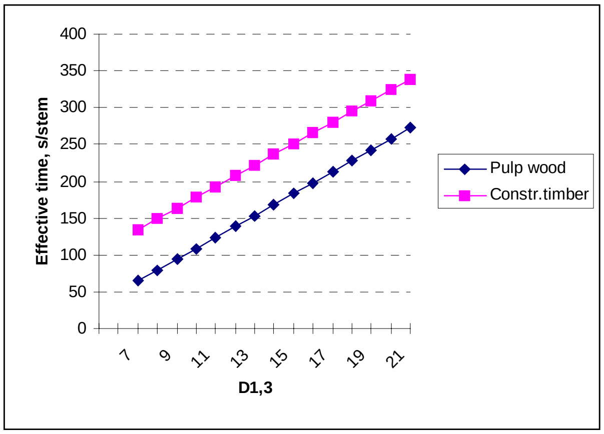


Figure 2.2. Harvesting time dependence on breast-height diameter $d_{1,3}$ in manual harvesting.

Method 2: Manual pre-harvesting

In manual pre-harvesting, the transition times of the logger were long. On average it took 47 s to move from one felled tree to another. Table 2.6 gives the mean diameters and volumes of the trees which the harvester felled in method 2.

Table 2.6. Average breast-height diameters and volumes of pulpwood and construction timber stems, which the harvester felled in the manual pre-harvesting method.

	Pulpwood	Construction timber
Breast-height diameter, cm	12	13
Mean volume, dm^3	67	81
Time consumption (s/stem)	38	49

Concerning time consumption, felling a construction timber stem took about 1.3 times longer than felling a pulpwood stem. Figure 2.3 shows the regression between the stem diameter and harvesting time.

The construction timber bolts, that were logger-felled, fulfilled the quality demands, but with the harvester 20 % of the bolts did not. The main reasons were the vertical branches that the harvester operator did not see.

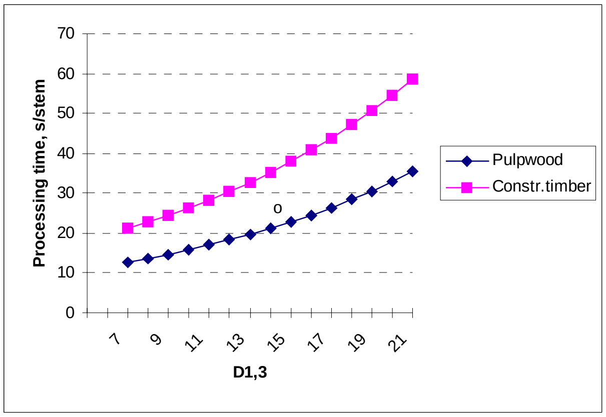


Figure 2.3. Harvester's felling time dependence on breast-height diameter $d_{1,3}$ with manual pre-harvesting.

Method 3: Mechanized harvesting

Table 2.7 gives the mean values of the trees harvested on the mechanized harvesting plot. The construction timber stems were bigger than the pulpwood stems and that is reason for the longer time consumption.

Table 2.7. Mean values of pulpwood and construction timber stems that were harvested with the harvester.

Method	Pulpwood	Construction timber
Breast-height diameter, cm	11	14
Mean volume, dm^3	47	91
Time consumption (s/stem)	34	48

On average it took 12 % longer to harvest a construction timber stem than to harvest a pulpwood stem. Figure 2.4 shows the regression between stem diameter and felling time. The variation between felling times was greater than with the pre-harvesting method because there were smaller stems.

Again, 20 % of the construction timber bolts did not fulfil the quality demands. The main reasons were again the vertical branches, which were not seen, but also branches and twist were defects. In addition the harvester's head rollers had spoiled the bolts.

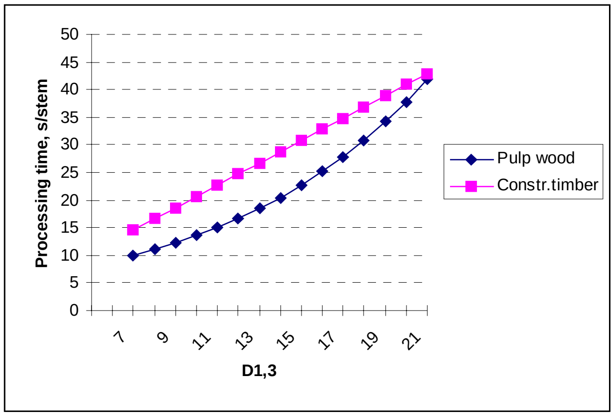


Figure 2.4. Felling time dependence on breast-height diameter $d_{1,3}$ in mechanized harvesting.

Forwarding with methods 1, 2 and 3

Between the methods, there were no big differences in transportation, loading and unloading times when forwarding construction timber. In general, the forwarding time increased slightly compared to pulpwood forwarding because construction timber and pulpwood had to be separated during unloading. The productivity and costs of forwarding are shown in Table 2.8. In manual harvesting, the plot productivity was better because the bolts were longer than in other plots.

Table 2.8. Productivity and costs of forwarding by plot.

Method	Productivity (m^3/h)	Costs ($euro/m^3$)
Manually	10.0	3.8
Pre-harvesting	8.7	4.3
Mechanized	8.3	4.5

In Austria, on more hilly terrain, the forwarding costs after harvesting were 8.6 euro.

The forwarder operator's mistakes during unloading are given in Table 2.9. The percentages show how well an operator managed to keep the bolts, which had been grouped by the feller, separate. The figures do not include those bolts, that did not fulfil the quality demands after harvesting.

Table 2.9. Mistakes in sorting the bolts when unloading the forwarder.

Method	Construction timber in pulpwood pile (%)	Pulpwood in construction timber pile (%)
Manually	17	7
Pre-harvesting	12	0
Mechanized	6	0

Method 4: Road side selection of construction timber

With both methods the problem was that it was mentally very hard to separate the bolts one by one with a crane. With sorting method a) it took about 2 min/m^3 to unload, compared to 1.2 min/m^3 with method b). Sorting timber when loading, as in method b), did not increase the loading time compared to the time consumption of one assortment loading. With method a), the result was better, as can be seen from Table 2.10.

Table 2.10. Quality of construction timber sorting with method 4.

Method	Construction timber in pulpwood pile (%)	Pulpwood in construction timber pile (%)
When unloading	3	3
When loading	6	8

In method 4 only extra costs compared to pulpwood forwarding are caused by the sorting work when unloading. Table 2.11 shows the productivity and costs of sorting method.

Table 2.11. Productivity and costs producing construction timber by sorting at the road- side.

Method	Productivity (m^3/h)	Costs (euro/m)
When unloading	11.5	6.4
When loading	14.0	5.1

2.1.4 Conclusions

Harvested plots

Small-diameter construction timber should be harvested during other thinning operations, because it is not economically or biologically profitable to harvest only construction timber alone.

It is important to pre-estimate the potential of a construction timber yield from a plot. There is no use in harvesting construction timber from plots where there is not enough construction timber. Of course, situations vary from plot to plot and it is difficult to set limits on what the yield per hectare should be, for instance. It was found difficult to estimate construction timber yields. It is difficult to estimate the timber quality from standing trees and, on the other hand, from construction timber bolts from whose upper parts of the stem are hidden before felling.

Comparing results with earlier research

In general, the harvesting costs of our study were about the same magnitude as determined in previous studies. Logger-felling costs in our study were about the same as the average in Finnish pulpwood first thinnings (Mattila 1995). The real felling and forwarding costs were also compared with simulated ones (Oijala & Örn 1995). The deviations in harvesting costs were very small, although the forwarding costs were smaller in this study.

Harvesting methods

It is difficult to say which method is best for construction timber harvesting because the best solution varies from case to case.

If we select the suitable trees from pulpwood piles, our costs are lower than with other methods and quality-price ratio is good. Harvesting costs are the same than for pulpwood and only extra cost is bolt selection. On the other hand we cannot produce special dimensions and lengths. This is not a problem if our dimension demand is about the same than pulpwood dimensions. When selecting, we have also to handle a lot of bolts that may be mentally and physically hard work at least if we have a lot of selection work to do.

With manual harvesting the harvesting costs are the highest but also the bolt quality is the best. Nearly every bolt fulfilled the quality demand. With manual harvesting it is also possible to grade the timber already when felling with simple grading rules concerning knot size and radial growth. In order to prevent pulpwood and construction timber from being mixed during transportation construction timber bolts should be marked on both ends, e.g. with chalk.

Manual pre-harvesting turned out to be unsuccessful according to this study. The reason for this was that, in the sample plot, there were not that many under-growing small trees that pre-harvesting would have been profitably. It also turned out that the method in which all construction timber is felled by a logger and pulpwood by the harvester is unsure. The reason is that, before felling, it is difficult to estimate whether the stem is construction timber quality or not.

If only the yields and costs are taken into account, mechanized harvesting seems to be the most profitable way to harvest pulpwood and construction timber integrally. But if good selection of construction timber is one criterion, the case is different. Less than 80 % of the bolts fulfilled quality demands, which increased the price of suitable trees. The reason for the rejections was that the harvester operator could not see the tree quality from the cabin. Additionally, the tree-moving rollers of the harvester head destroyed the bolts. Pile selection may, of course, be done for mechanically harvested bolts.

2.2 Yield and quality in the first thinning

2.2.1 Introduction

Harvesting first thinnings is important but it has also encountered problems (Hakkila 1996, Heräjärvi 1998, Lämsä et al. 1990, Maa- ja metsätalous-ministeriö 1988, Vuokila 1976). Using pulpwood also for other products than pulp may increase the profitability of first thinning. This may increase forest owners' willingness to harvest in their own forests. The problem with mechanical exploitation of pulpwood is that the selection for raw material must be made from the removed trees, whose quality is often bad.

The aim of this study is to find out how much small-diameter construction timber is available from first commercial thinnings in Finland. The tree species studied were Scots pine *(Pinus sylvestris)* and Norway spruce *(Picea abies)*.

When estimating the construction timber yield, the minimum length for the timber was 2.4 m and the minimum diameter 5 cm. In addition, the stem had to look straight. No rot, scars or vertical branches were allowed. For construction timber, the maximum diameter for knots was 30 mm and the minimum distance between knot whorls should be at least 15 cm.

This study is based on Ms Reeta Stöd's report submittted for her master's thesis at the University of Joensuu. Mr Jukka Pietilä reviewed the report and translated it into English.

2.2.2 Material

Field inventory

We did our inventory in Southern-, Eastern- and Western-Finland. There are about 56 % of young thinning stands in Finland and about 65 % of their volume. In each part we measured 20 stands, 60 all together. We carried out the field inventory in autumn 1997.

Our presumption was that the dominant tree species and ground fertility effect the construction timber yield. Thus, we partitioned young thinning stands into sub-groups with the dominant tree species on the plot (pine or spruce) and the fertility division of Finnish forest tax-classes. The tax-classes are IA, IB, II, III and IV. In class IA sites fertility and tree growths are best and in class IV site the poorest. In sampling we put classes IA and IB together into one fertility group and the rest of the classes into another group. Based on this division, we made relative sampling of the sample plots in each region, according to Pahkinen and Lehtonen (1989).

Plot measurements

Primarily we selected plots for measurements with data from forestry management plans. The minimum area for a measured compartment was 0.5 hectare. A main criterion was the need for first commercial thinning. We inventoried only those compartments where there was a biological need for thinning.

Figure 2.5 shows the sample tree specia distribution of our field inventory.

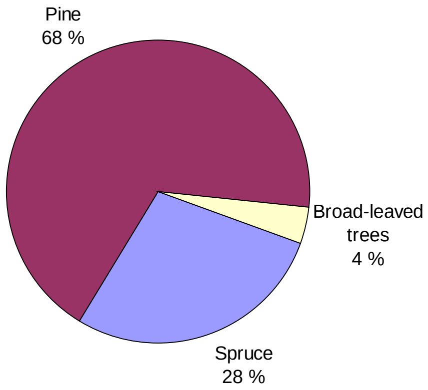


Figure 2.5. Sample tree-species distribution.

In addition, we tried to select those compartments where the volume share of the dominant tree species was as high as possible.

We measured 3–8 sample plots in each compartment. The distance between the plots was 20 m. The sample plot was circular with a radius 3.99 m and area of thus 50 m^2. If the sample plot was treeless, broad-leaf dominant, rocky or otherwise unordinary for the site, the sample plot was deviated from as little as possible.

All the stands we measured in Eastern-Finland were young thinning stands. Three of the stands in Southern-Finland were advanced thinning stands but they were not thinned during past times. In Western-Finland we measured one mature stand whose tree stand was dense and diameter small and it had not been thinned. In order to estimate the construction timber yield and quality, all pines and spruces on the sample plots, whose breast-height diameter was 7 cm of more, were measured and estimated. The measured and estimated properties were

- breast-height diameter (diameter on 1.3 m high)
- tree length
- diameter of thickest knot

- quality of thickest knot
- length of stem part suitable for construction timber
- length of tree crown
- height of lowest dead branch
- heights for defect beginning and end.

In addition we measured defects, and their heights, which have an effect on the technical quality of the stem. These are listed below:

- twist
- crook
- corkscrew
- vertical branches
- rot
- scar
- knot whorls whose distance is less than 15 cm.

The length of stem twist was recorded. If the stem had small branch angles or other defects than mentioned before, they were written down. In order to help the further analysis of tree quality data, we recorded those trees, which should be felled during harvesting for quality reasons.

2.2.3 Methods

Thinning of sample plots

With the data we collected during the inventory, we selected those trees that should be removed in an ordinary first thinning. Thus, we did not carry out the thinnings in reality. During thinning we did not try to maximize the yield of the construction timber, but the removed trees were selected as in an ordinary first thinning. Because we did not measure the trees' co-ordinates on sample plots we could not identify their locations respective of each other during our theoretical thinning. Into the inventory results we marked those trees, that were in dense groups, so we could remove some of them in our theoretical thinning.

We selected the trees for thinning according to the quality-thinning principle. Whereby the trees removed should be not only the smallest ones but also trees with big knots and low stem quality. In quality thinning, we did not pay too much attention to yield but we tried to improve the quality of the stand for the future (Niemistö 1994, Lilleberg 1995).

Thinning model

We thinned our sample plots theoretically with thinning models presented by Niemistö (1992). In the thinning models, which are based on stem number as in Niemistö (1992), the mean diameter is the mean diameter of the stems remaining after thinning. Because that was difficult to estimate before thinning, we harvested in several stages. After each stage we estimated whether the number of remaining trees fulfilled the thinning model demand or not.

In the first stage we harvested those trees that should be harvested for some major defect found in the field inventory. In the next stage we harvested stems for minor quality reasons and we paid attention to the combination of defects like straightness, twisted butt and crook. Because the aim was quality thinning we tried to leave those trees that had small branches growing.

If the two first stages were not enough to achieve the stem number of the thinning model, in the third stage we removed so many minor trees that the stem number was low enough.

Scaling of felled trees for cross-cutting and yield estimating

The heights of the 5, 7 and 9-cm top-diameter points were estimated from all the harvested stems with the taper curve of Laasasenaho (1982). The curve is based on the breast-height diameter and tree length.

With crosscutting points and defect heights, we estimated those parts of the stems, that fulfilled the quality and dimensional demands of construction timber. If the construction timber was longer than the minimum 2.4-m length, we increased its length by steps of 0.3 m if possible. Thus, possible bolt lengths were 2.7, 3.0, 3.3-m etc. In this stage we tried to achieve a maximum yield for construction timber. Bolts other than construction timber bolts were graded for pulpwood if they fulfilled pulpwood quality and dimension demands, according to Tapion Taskukirja (1997).

All the stem parts, that fulfilled the construction timber quality demands were included in the construction timber yield. We estimated the yield by compartments and by tree species in cubic metres per hectare. The yield in cubic metres was estimated with the volume estimates of Laasasenaho (1982). The pulpwood yield was estimated in the same way. In the results we also show the yield for construction timber bolts whose lengths were 3, 4, 5 and 6 m, per hectare.

Total amount of construction timber

We estimated the total yield of construction timber by multiplying the area of young thinning stands by the estimated yield per hectare. These calculations were based on the dominant tree species and region. The Finnish Forest Research Institute calculated the area of young thinning stands that should be harvested during the next 10 years. Their calculation is based on the national forest inventories.

2.2.4 Results

Thinning grade and quality of removed trees

In all the stands we obtained the stem numbers and mean diameters of the harvesting models. Before harvesting, the average stem number per hectare was 2 000. In the south, the density was 2 000 stem/ha on average, in the east 2 200, and in the west 1 600 stem/ha. During harvesting we removed on average 800 stems per hectare, in the south 1 000, in the east 1 200 and in the west 600 stems per hectare.

Table 2.12 gives mean volumes and their minimum and maximum values of unthinned compartments and also the volumes of unharvested and remaining trees with their minimum and maximum values.

Table 2.12. Tree volume of compartments before thinning, yield and volume of remaining trees (m^3/ha) mean/ minimum/ maximum by dominant tree species, tax-class, geographically and by regeneration method.

	Before thinning	Yield	Remaining trees
Pine	166.7 / 75.8 / 299.6	64.3 / 8.9 / 149.6	102.4 / 37.6 / 152.1
Spruce	212.0 / 89.7 / 353.0	85.0 / 0.0 / 187.0	127.0 / 84.4 / 196.5
IA-IB	202.3 / 83.3 / 353.0	85.2 / 0.0 / 186.8	117.1 / 37.6 / 196.5
II-IV	165.4 / 75.8 / 299.6	60.9 / 7.5 / 147.6	104.5 / 52.8 / 152.1
South	202.1 / 75.8 / 353.0	85.0 / 12.5 / 187.0	117.1 / 63.2 / 196.5
East	195.9 / 83.3 / 299.6	88.4 / 31.9 / 150.7	107.5 / 37.6 / 152.1
West	139.1 / 80.8 / 195.8	35.9 / 0.0 / 82.9	103.2 / 52.8 / 146.7
Cultivation	176.6 / 75.8 / 353.0	68.9 / 8.9 / 187.0	107.8 / 37.6 / 166.1
Natural	183.8 / 80.8 / 330.8	72.1 / 0.0 / 147.6	111.7 / 52.8 / 196.5
Total	179.3 / 75.8 / 353.0	70.1 / 0.0 / 187.0	109.2 / 37.6 / 196.5

Yield of round construction timber

All samples

34 % of sample trees had a stem-part whose quality was suitable for construction timber. 23 % of removed trees fulfilled both the quality and dimensional demands for at least one construction timber bolt. Only from very few, 0.7 % of stems, was it possible to harvest two construction timber bolts.

The following tables show the results from all compartments. Tables 2.14–2.19 show the yield of round construction timber by dominant tree species (pine, spruce), regeneration method (sawing, natural regeneration), tax-class (IA–IB, II–IV) and by region (South-, East- and West-Finland, see Figure 2.6). Tables

2.13 and 2.14 show the average share of construction timber yields from total tree harvest and their minimum and maximum values.

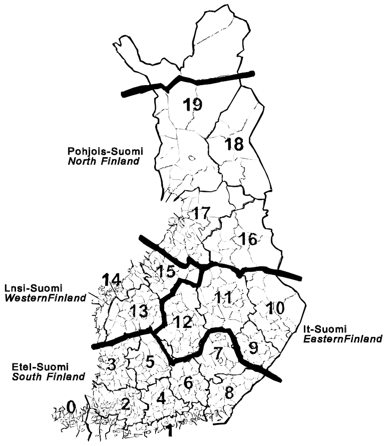


Figure 2.6. Division of Finland into South-, West-, East- and North-Finland.

Table 2.13. Average yields of round construction timber (m³/ha) and their minimum and maximum values by dominant tree species; the minimum diameters for construction timber are 5, 7 and 9 cm.

	Pine			Spruce		
	Av.	Minimum	Maximum	Av.	Minimum	Maximum
5 cm	9.1	0	49.3	12.7	0	32.7
7 cm	7.9	0	54.0	11.2	0	38.9
9 cm	6.2	0	55.3	8.6	0	43.8

Table 2.14. Share of round construction timber (%) from total harvest yield (mean/ maximum/ minimum) by tax-class, regeneration method, dominant tree species and region. Minimum diameter for construction timber is 9 cm.

	Pine	Spruce	Total
IA-IB	3.7 / 0.0 / 23.7	10.5 / 0.0 / 31.0	7.1 / 0.0 / 31.0
II-IV	10.3 / 0.0 / 39.7	4.4 / 0.0 / 12.4	9.5 / 0.0 / 39.7
South Finland	9.3 / 0.0 / 35.9	9.4 / 0.0 / 17.5	9.3 / 0.0 / 35.9
East Finland	5.9 / 0.0 / 23.7	5.3 / 0.0 / 16.7	5.7 / 0.0 / 23.7
West Finland	10.6 / 0.0 / 39.7	15.5 / 0.0 / 31.0	11.1 / 0.0 / 39.7
Cultivated	7.3 / 0.0 / 39.7	8.1 / 0.0 / 17.5	7.5 / 0.0 / 39.7
Natural	11.4 / 0.0 / 35.9	9.1 / 0.0 / 31.0	10.6 / 0.0 / 35.9
Total	8.6 / 0.0 / 39.7	8.6 / 0.0 / 31.0	8.6 / 0.0 / 39.7

The main reason for the unsuitability of the removed spruce stems for construction timber was butt sweep. This defect was found in 35 % of the removed spruce stems. For pine stems one individual defect was not that dominant.

The effect of site fertility and regeneration method on the yield was also analyzed. Average yields (m^3/ha) and standard errors for round construction timber by site fertility, regeneration method and volume (m^3/ha) are illustrated in Figures 2.7–2.9 for all samples, but separately for pine and spruce. For pine the best yields of round construction timber was gained from poor fertility and - naturally regenerated stands, where the volume was over 150 (m^3/ha). For spruce, the regeneration method does not have such a significant effect on the yield of round construction timber. The best yield of round spruce construction timber was found from a stand with rich fertility site and a high volume of timber (> 200 m^3/ha).

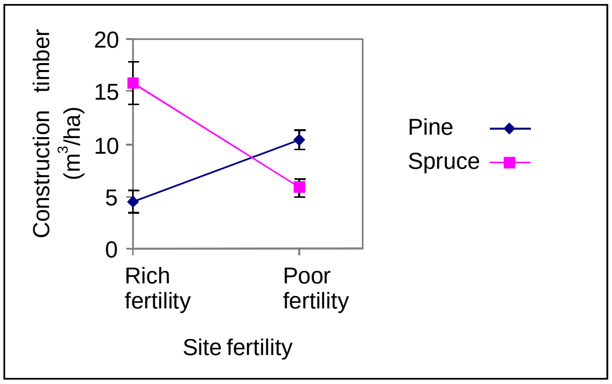


Figure 2.7. The effect of site fertility on yields of round construction timber.

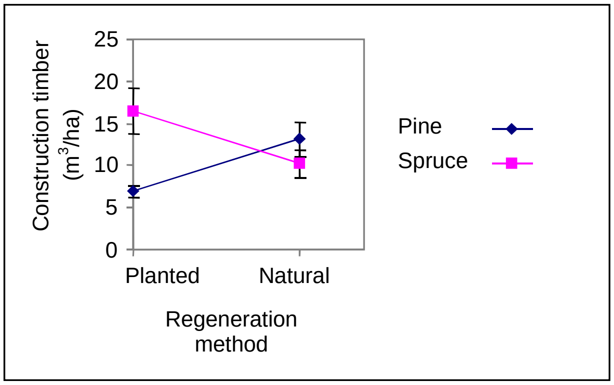


Figure 2.8. The effect of regeneration on yields of round construction timber.

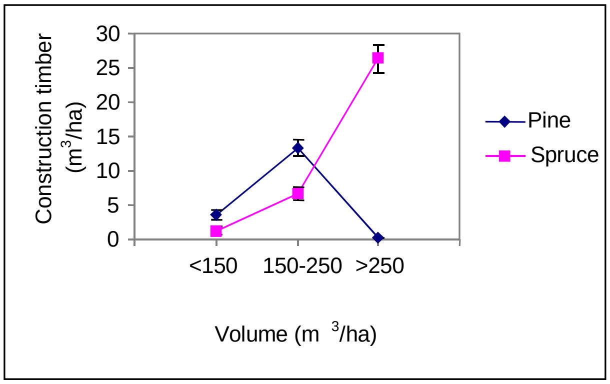


Figure 2.9. The effect of volume of stand on yields of round construction timber.

Yield from best quarter of compartments

We grouped the inventoried compartments into four groups according to their construction timber yield. We took the best quarter for further estimations. In the best compartments, the average share of construction timber was 32 % of total yield, with a variation of between 16–82 %. The average tree volume on those compartments was 221.9 m^3/ha (variation 80.8–353.0 m^3/ha) prior to harvest, the harvest yield was 101.9 m^3/ha (variation 28.0–187.0 m^3/ha) on average, and after harvesting the tree volume was 125.3 m^3/ha (variation 52.8–196.5 m^3/ha).

Table 2.15 presents the construction timber yield in the best quarter of compartments (stem/ha) with three different minimum diameters. The table shows how yield varies with changing minimum diameters.

Table 2.15. Average yield of construction timber in the best compartments (bolt/ha) with each length-diameter combination; minimum bolt diameter is 9 cm.

Length, m	Diameter, mm					
	50	75	100	125	150	175
2	0	17	6	2	0	0
3	0	56	25	9	17	0
4	0	31	3	0	0	3
5	0	22	0	0	0	0
6	0	18	9	0	0	0
7	0	29	7	2	0	0
8	0	8	0	0	0	0
9	0	9	3	0	0	0
10	0	2	3	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0

Total amount of construction timber

Table 2.16 presents the total estimates for construction timber, which is available in Finland, excluding Lapland.

Table 2.16. Estimate for construction timber yield from Finnish young thinning stands (excluding Lapland). Grouping by region, dominant tree species and tax-class. Minimum diameter 5 cm. Values are in 1 000 cubic metres.

	IA–IB		II–IV	
	Pine	Spruce	Pine	Spruce
South	494.7	2135.4	1561.6	285.5
East	176.7	692.3	1453.1	64.0
West	33.1	113.2	727.0	16.5

Thus, the total amount of construction timber is about 7.7 million m^3, 4.4 million m^3 pine, and 3.3 million m^3 spruce with 5 cm minimum diameter. For a minimum diameter of 7 cm, these yields will decrease by about 15 %, that is, to 3.7 million m^3 for pine and to 2.8 million m^3 with spruce. Further more, if we assumed that only the best quarter of compartments was worth harvesting, the corresponding figures would be about 1.2 million m^3 for pine and 0.9 million m^3 for spruce.

2.2.5 Discussion

On average, the largest construction timber yields are found in compartments, in Southern-Finland on fresh mineral soil forest sites, where spruce is dominant and which are naturally regenerated. But most of the compartments, which belonged to the best quarter concerning construction timber yield, were found on poor mineral soils where pine was the dominant tree species. Concerning tax-classes, on sites IA–IB the yield was better on spruce-dominant sites and on sites II–IV on pine-dominant sites.

The technical quality of construction timber in tax classes II–IV was better than in the other tax class. From compartments where natural regeneration has taken place, we get better quality construction timber. The best stocks of construction timber were found on spruce stands on luxuriant mineral soils and pine stands on oligotropic mineral soils, which are naturally suitable for these tree species. When comparing these naturally suitable stands, the yield from spruce stands is bigger compared with pine but there is a great risk of defects, like crooks and butt twist. With pine stands on naturally suitable soil, the share of seriously defected, e.g. crooks and butt twist, stems is lower. Stand selecting has a great effect on construction timber yield. In the best stands, our average construction timber yield is double compared with average yield. The problem is that we could not find any good factors to determine the best ones, e.g. from forestry plans. The best way to determine the best ones is through some kind of field inventory.

We presume the estimated yield of construction timber to be about 8 million m^3. We do not know how much of this is available when we also take into account the economic and logistic factors, but it is at least over 2 million m^3 if we assume that the best quarter is worth harvesting.

With regard to the design of roundwood constructions, we favour the use of bolts whose lengths are 3 m with a diameter of 10, 12.5 or 15 cm. If a span of 4 m is needed, then the maximum diameters could be 10 or 12.5 cm. From the results it seems that there are also some bolts available, whose diameter is 10 cm and length even 7 m available. These could be used for special purposes. These dimension combinations are naturally available without delivery problems.

2.3 Drying

The objective of drying research is to determine how adequate drying can be achieved, and what is the quality of dried wood. Experimental wood-drying research was carried out in Austria (spruce) and Finland (spruce and pine). Natural seasoning and kiln-drying at two different temperatures were tested. In addition, other participants made observations concerning drying when preparing material for strength testing. Traditional techniques to determine the location of check by sawing a slit was used, but not as a research topic. Twisting was measured on seasoned logs.

2.3.1 Seasoning

Finnish pine and spruce logs were harvested in April 1996 and piled in stacks at VAKOLA in an open place. The stacks were clear of the ground (first logs about 50 cm above the ground). The logs were piled crosswise in layers and about 5–10 cm apart from each other.

It was expected that the seasoning of thicker logs (140 mm < D < 160 mm) to 18 % MC would be completed in August, and the seasoning of thinner logs (80 < D < 100 mm) at end of June. Because of the exceptionally wet summer until the middle of July, the MC in most logs was over 20 % at the end of July. Therefore, the scheduled seasoning period was extended. August was warm and dry in Finland (the driest August for 160 years), and most of the logs had a moisture content of below 18 % at the end of August (26.8.96). Finally the logs were conditioned to the target moisture content.

All the logs had a wide crack (min. 5 mm) all along the length of the pole.

In Austria 150 spruce logs were seasoned, and finally stored inside a building for 2 months in order to achieve the target moisture content of 10 %. The results are discussed in relation to high-temperature drying (Section 2.3.3).

Twisting

The Finnish logs were marked with parallel lines at both ends before drying, and the twisting angle was measured after drying and conditioning.

Figure 2.10 shows the mean and standard error values for twisting (°/m) calculated for age-classes within samples separately for Norway spruce and Scots pine. In addition, the mean moisture content of the sample is presented. Within the presented samples, the moisture content is constant along the age distribution. Figure 2.10 clearly shows that twisting in older specimens is smaller both for Norway spruce and Scots pine. The data of Norway spruce samples 1–150, with two moisture content levels (u = 14.8 % and 19.4 %), specially indicates that moisture content has a significant effect on twisting, i.e. a lower moisture content increases twisting.

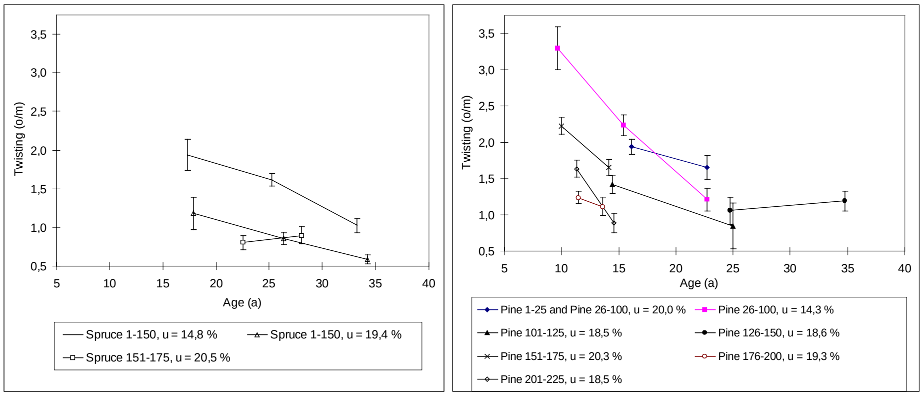


Figure 2.10. Mean and standard error values for twisting (in degrees per meter) calculated for age classes within samples of Norway spruce (left) and Scots pine (right)(Boren 1999).

The hypothesis for statistical analysis is that twisting is induced by both a young age and a low moisture content. Regression models for twisting were made separately for Norway spruce and Scots pine. As a result, it is concluded that form, processing method or origin of specimen do not have an effect on the twisting, but as expected, age, grossgrain and moisture content do influence twisting. The variables used were:

- a = age (a)
- G = gross grain (mm/m)
- T = twisting (^{o}/m)
- u = moisture content (%)

The linear regression model for Norway spruce is:

$$\lg(T+1) = 0.253 + 0.007604(G+1)(28-u)/a \qquad (2.2)$$

The multiple coefficient of determination for the model (adjusted R^2) is 0.20 and the standard error (s) = 0.18.

The linear regression model for Scots pine is:

$$\begin{aligned}\lg(T+1) = {} & 0.926 - 0.226\lg a + 0.116\lg(G+1) + 0.000774\rho_{12} \\ & - 0.576\lg u\end{aligned} \qquad (2.3)$$

The multiple coefficient of determination for the model (adjusted R^2) is 0.26 and the standard error (s) 0.18.

Below is shown the effect of age, gross grain and moisture content on twisting for Norway spruce and Scots pine calculated by model (2.2) and (2.3), respectively.

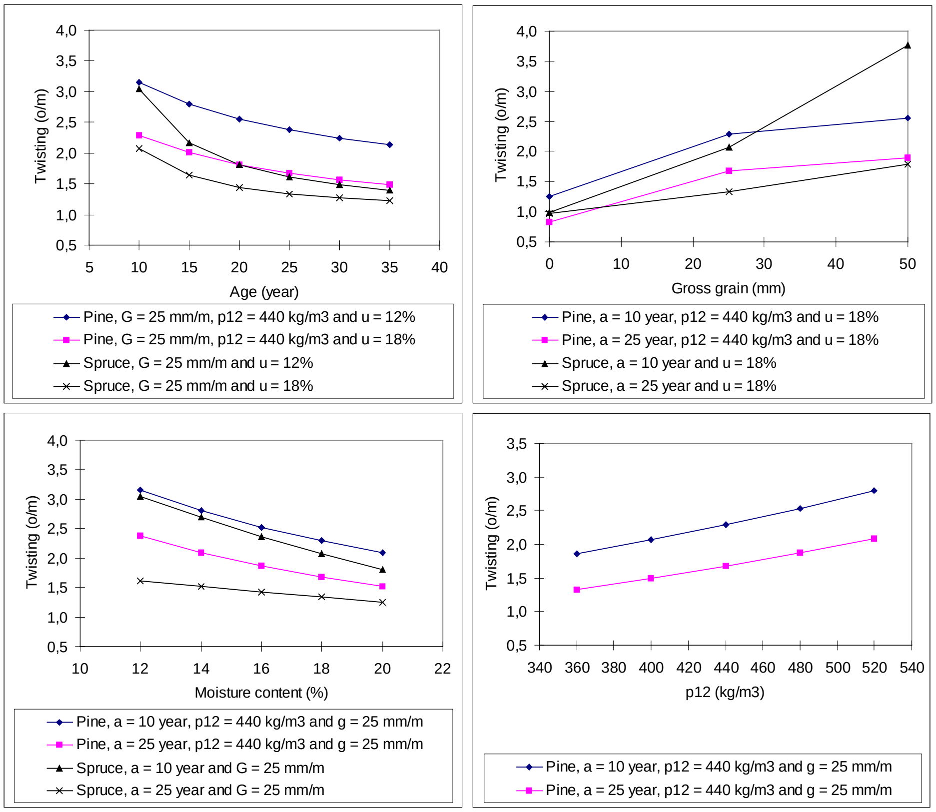


Figure 2.11. The effect of age, density, gross grain and moisture content on twisting of pine and spruce calculated by Eqns.(2.3) and (2.2) respectively (Boren 1999).

2.3.2 Kiln-drying at 70°C

For Finnish kiln-drying tests, the harvested pine and spruce logs were 1.2 m long. The density (dry mass / green volume) of the pine logs in the drying tests was low (370 kg/m^3) but the density of spruce (380 kg/m^3) was near the average in Finland. The logs were barked manually with barking knives and stored in a freezer before the drying tests. The ends of the logs were closed with polyurethane sealant (Sikaflex) to avoid moisture evaporation at the ends.

For measuring the twisting of the logs in drying both ends were marked with pins and parallel lines before drying. After drying the twisting angle was measured.

After drying the number and length of cracks were measured. The cracks were classified according to the width: less than 1 mm, 1–3 mm, 3–5 mm and over 5 mm. The purpose was to convert the visual appearance of the logs into a numerical form.

In the first 2 tests, (Table 2.17) the aim was to completely avoid cracking with a mild drying at the stage when the surface moisture content had reached the fibre saturation point. The schedules were based on optimizing the drying stresses with a drying simulation model so that creep would keep the drying stress below the strength of the surface. The result was less good: cracking could not be avoided at this temperature.

In the last 4 tests, the idea was to dry rapidly, especially in the beginning and thus cause a large number of small cracks. For this purpose, it is advantageous that the logs are as cold as possible at the beginning of the drying (wintertime).

Table 2.17. Principal differences used in drying schedules.

Test number	Principle of the schedule
1	Mild drying until the MC is below FSP then fast drying
2	Fast drying at beginning and mild when MC of surface near FSP
3	At beginning low temperature and RH for achieving micro cracks; fast drying at 67 °C; mild drying to let the surface creep (minimizing crack width)
4	Fast drying at 70 °C with low RH at beginning for achieving micro cracks; mild drying to let the surface creep; fast drying
5	Fast drying
6	Fast drying; slower drying; conditioning

Quality of kiln-dried logs

The average twist varied between 1.4 and 6.7 °/m when dried from green to end moisture content (Table 2.19). The length reduction in kiln-drying to 12 % MC after two weeks air seasoning was 0.5 mm/m for spruce logs and 0.7 mm/m for pine logs.

The end cracking does not differ from cracking in the middle of the logs, probably because of the protection of the ends with polyurethane sealant. The measured properties of the logs before (diameter, density, initial MC) and after drying (MC, twisting and cracking) are summarized in Tables 2.18 and 2.19.

Table 2.18. Measured properties of the logs before drying tests and moisture contents after drying.

Test	Species	D mm	Drying time h	Density kg/m3	Initial MC %	End MC %	Surface MC %	Centre MC %
1	Pine	145	258	353	139	15.3	9.7	20.8
	Pine	175	400	386	136	13.1	9.8	17.2
2	Pine	141	162	358	110	21.0	15.9	28.3
	Spruce	152	162	370	106	20.5	14.3	26.9
3	Pine	152	213	360	132	27.2	18.7	30.9
	Spruce	161	213	377	100	20.0	13.7	27.0
4	Pine	100	94	384	110	17.8	11.9	24.4
	Spruce	94	94	373	73	15.0	10.3	19.7
5	Pine	111	137		~50	11.9	9.9	15.0
	Spruce	99	137		~40	11.1	8.8	12.0
6	Pine	105	192 + 10	374	114	10.4	10.3	11.0
	Spruce	96	192 + 10	394	81	10.3	9.3	10.3

Table 2.19. Twisting and cracking in drying tests.

Test	Species	D mm	End MC %	Twist ° / m	Percentage of logs with crack width			
					>5mm	3–5 mm	1–3 mm	<1 mm
1	Pine	145	15.3		50	25	13	0
	Pine	175	13.1		75	13	25	13
2	Pine	141	21.0	2 - 2.8 - 4	50	25	63	50
	Spruce	152	20.5	0 - 3.8 - 12	50	38	38	38
3	Pine	152	27.2	2 - 6.7 - 9	0	8	38	88
	Spruce	161	20.0	1 - 5.0 - 10	63	88	100	88
4	Pine	100	17.8		25	100	100	88
	Spruce	94	15.0		0	75	100	88
5	Pine	111	11.9	0 - 1.7 - 3	13	50	100	100
	Spruce	99	11.1	0 - 1.4 - 2	50	100	100	100
6	Pine	105	10.4	1.6 - 4.2 - 7.3	38	88	100	90
	Spruce	96	10.3	1.4 - 4.4 - 5.8	36	100	88	100

Mild kiln-drying schedules resulted in some logs completely without cracks, but most of the logs included at least one large crack. The visual appearance was not what was aimed at.

Rapid kiln-drying schedules resulted in many small cracks and the visual appearance was acceptable. Other advantages of these schedules were short the drying time and low total costs. Also, by rapid kiln-drying, some logs developed one or two large cracks. To avoid these, it is recommended to slow down the drying rate after a rapid beginning so that the surface has time to creep. This partly diminishes the widening of the cracks. An effective conditioning period after the drying phase does narrow the cracks.

Compared to seasoning in open air in springtime, the kiln-drying is normally quite mild, i.e. the relative drying stresses are lower than in open air. Based on this fact, in the fifth test the logs were firstly seasoned after debarking in open air in a windy and sunny location until the desired micro cracking of the surface had taken place. After that, the drying was continued in the drying kiln to achieve an acceptable total drying time and a low moisture content.

Kiln-drying at 110°C

About 150 spruce logs, harvested in Austria in February 1997, were used for high-temperature drying according to the drying schedules, as specified in Table 2.20. The number and size of cracks were recorded before and after kiln-drying and the result is compared with natural seasoning.

The logs had then been stacked into 4 steel-devices that offered a safe piling system. Between every layer stickers made of steel or wood were used. One stack was put on a load cell, to control the loss of water according to the loss of weight.

Table 2.20. Drying schedule in high-temperature drying.

Drying phase	Temperature	Equilibrium moisture content (EMC)	Drying gradient
Until fibre saturation point (FSP)	110°C	6 %	5
Under FSP	110°C	5 %	6
Under 20 % EMC	110°C	4.5 %	

Sensors were installed for measuring and logging the temperature inside the logs (20 mm, 60 mm), on the surface, the air temperature of the chamber and the temperature of the distance sensor. Also the relative air humidity and the moisture content of 9 logs at various depths were measured.

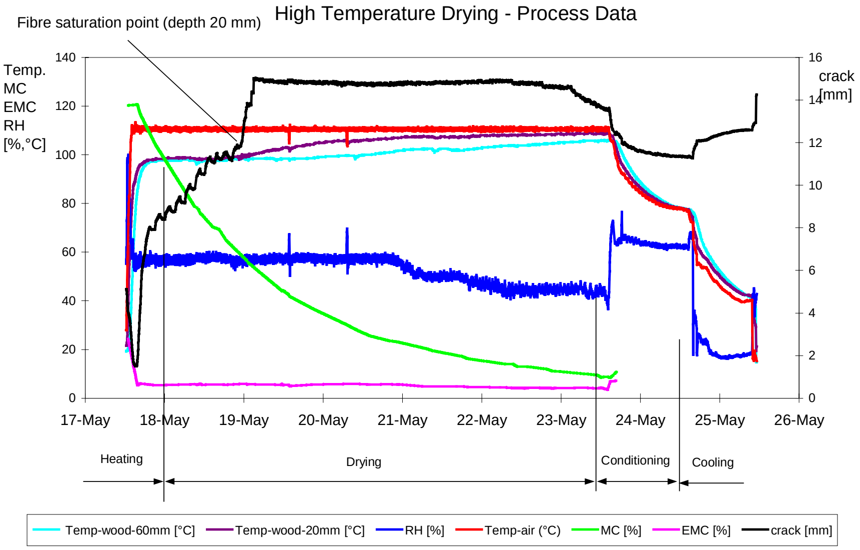


Figure 2.12. Measurements in a log during high-temperature drying.

The target moisture content was 10 %. The complete kiln run (including heating, drying, conditioning, cooling) lasted exactly 8 days. Two critical stages could be identified during the drying process:

- Reaching of Fibre Saturation Point:
  This is the moment, when the stresses get too high for the material and the first checks appear or existing checks become deeper and wider.
- Cooling phase:
  The wood is still at a high-temperature, while the surrounding air is cooling down. On the contact surface between the air and wood, the air begins to reheat. It is now able to take up humidity again. This causes a postdrying effect, i.e. after reaching the planned moisture content, the wood dries again. This was the reason why the final moisture content in the experiment is lower than the target (average 7.6 vs. 10 %).

In high-temperature drying there is a practical problem concerning stickers: steel stickers penetrate into the logs, while wooden stickers last only one kiln run, because they become plastic and deform.

Comparison of the quality of seasoned and kiln-dried wood

An obvious difference caused by a high drying temperature is the change of colour: high-temperature dried logs are darker. The most important difference is that the number and dimensions of the cracks are very small in comparison to seasoned logs. Comparing the percentage of cracks before and after high-temperature drying, it was found, that the number of checks wider than 0.2 mm did not increase on a large scale.

The size of cracks after high-temperature drying differs clearly from the size of cracks after seasoning, which included also 2 months' indoor storage. Seasoning caused at least one big crack (~ 6 mm) along the log, accompanied by on average 6 cracks > 0.2 mm. On the other hand, high-temperature drying only caused cracks not larger than 1.7 mm. On average, less than 4 cracks, larger than 0.2 mm in size, developed per log.

The bending strength of high-temperature-dried logs is about 10 % lower than that of seasoned logs, but this did not change the proposed strength class according to EN 338.

2.3.3 Discussion on drying

Natural seasoning can be recommended as a drying method when there are no precise quality requirements concerning final moisture content and cracking. It should also be noticed that drying cracks did not affect the bending strength of the timber.

The results clearly indicate that cracking during drying can be minimized by the use of high-temperature drying. When drying at temperatures between 60–70 °C, checking can be reduced a little from that during natural seasoning, but not as much as by the use of higher temperatures. The numerical results on the cracking of Austrian spruce at 110 °C are summarized in Table 2.21. The Finnish results for seasoning are quite similar, even if the final moisture content was higher. It can be concluded that the total width of drying cracks around the girth can be reduced from 3 % to 1 % of the girth circumference, and the maximum crack width decreases even more when high-temperature drying is used and the final moisture content is around 10 %.

It was observed during the high-temperature tests that the cracks had already been initiated before kiln-drying and that the number of cracks did not increase significantly during high-temperature drying, but the size of the cracks increased. This suggests that even less cracking on the surface of round timber might occur, if the high-temperature drying started before the first cracks had appeared in seasoning while waiting for kiln-drying.

Table 2.21. Comparison of seasoning and high-temperature drying of Austrian spruce.

Drying method	Final MC (%)	Average diameter (mm)	Average maximum crack width (mm)	Total cracks / girth (%)
Seasoning	9	120	5	2.9
	10	150	7	3.2
Kiln 110 °C	6	120	1	0.7
	9	165	2	1.2

Proposal for drying schedules

When high temperature drying cannot be used, some drying schedule suggestions are presented as follows on the basis of the test dryings. The main principal steps in the drying schedules are:

1. very fast drying at the beginning to achieve very many micro cracks
2. mild drying to allow the surface to creep
3. effective drying
4. conditioning with high RH.

Suggested air velocity through the stack > 3 m/s. Examples of suggested schedules are given in Table 2.22.

Table 2.22. Drying schedule suggestions for small-round timber.

Diameter ~ 100 mm

Time, h	T, °C	WBD, °C	RH, %
0	ambient	ambient	60
10	70	25	25
20	70	25	25
30	70	10	62
42	70	10	62
48	70	15	47
192	70	15	47
196	70	2	91
204	70	2	91
End MC:	Pine	12 %	
	Spruce	10 %	

Diameter ~ 150 mm

Time, h	T, °C	WBD, °C	RH, %
0	ambient	ambient	60
10	70	25	25
30	70	25	25
40	70	10	62
64	70	10	62
70	70	15	47
450	70	15	47
460	70	2	91
480	70	2	91
End MC:	Pine	12 %	
	Spruce	10 %	

Diameter ~ 100 mm

Time, h	T, °C	WBD, °C	RH, %
0	ambient	ambient	60
10	70	25	25
20	70	25	25
30	70	10	62
42	70	10	62
48	70	15	47
100	70	15	47
106	70	2	91
118	70	2	91
End MC:	Pine	18 %	
	Spruce	16 %	

Diameter ~ 150 mm

Time, h	T, °C	WBD, °C	RH, %
0	ambient	ambient	60
10	70	25	25
30	70	25	25
40	70	10	62
64	70	10	62
70	70	15	47
260	70	15	47
266	70	2	91
280	70	2	91
End MC:	Pine	18 %	
	Spruce	16 %	

WBD = Wet Bulb Depression

2.4 Oil impregnation and drying

Introduction

In order to find methods to improve surface quality of round timber after drying in terms of checking, drying in hot oil was seen as potential. In addition, oil impregnation can improve durability in external use. Therefore, experiments with oil were started. Earlier treatment trials with small and large-size sawn wood dimensions showed, that Tall oil-based resins can penetrate into wood quite easily when mixed with organic solvents, such as turpentine or mineral oil-based "white spirit". However, such solvents are not favoured by the wood-treating industry and may cause environmental problems. In addition, the European VOC directive sets new requirements for such impregnation plants, including solvent recovery, etc.

Hot-oil treatments, such as Boultonizing, patented by Sir Boulton in 1879, gave an opportunity to utilize non-volatile Talloil-based compounds without organic solvent. At elevated temperature, the viscosity of resin compounds is lowered and penetration into wood can be considerably improved. A process of this type avoids the need for air- or kiln-drying, and is applicable to wet or green timber too.

Material and methods

Round small-diameter green timber was chosen for the trials. Both Scots pine and Norway spruce timber species were included in the trials. The diameter of the wood was chosen to be around 10 cm with a round-piled surface quality in order to detect the drying defects.

The initial and final moisture contents as well as retention of oil after impregnation were determined by the toluene extraction method. The temperature in oil and in timber was measured.

After drying, air pressure was applied to the treatment cylinder to force the oil to penetrate deeper into the wood. After 1 h, working pressure, the oil was evacuated from the cylinder and 0.5 h final vacuum was drawn to improve the surface dryness of the wood. The apparatus is shown in Figure 2.13.

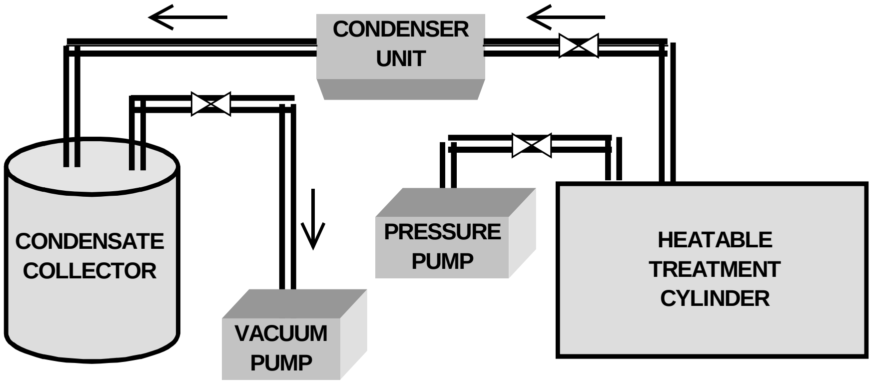


Figure 2.13. Schematic drawing showing the function of drying and treatment apparatus.

Most oils with boiling points above 150 ^{0}C and which do not distil together with water are suitable for the Boultonizing process. From several Tall oil candidates, PS 046 H (modified TOR+ ester mixture) was selected for scaling up. Primarily the selection was based on its liquid nature and secondly on the test results of biological screening. Its boiling point is above 200 ^{0}C and it holds the original viscosity very well after several heating cycles.

Results and discussion

Optimized drying schedules are given in Figure 2.14.

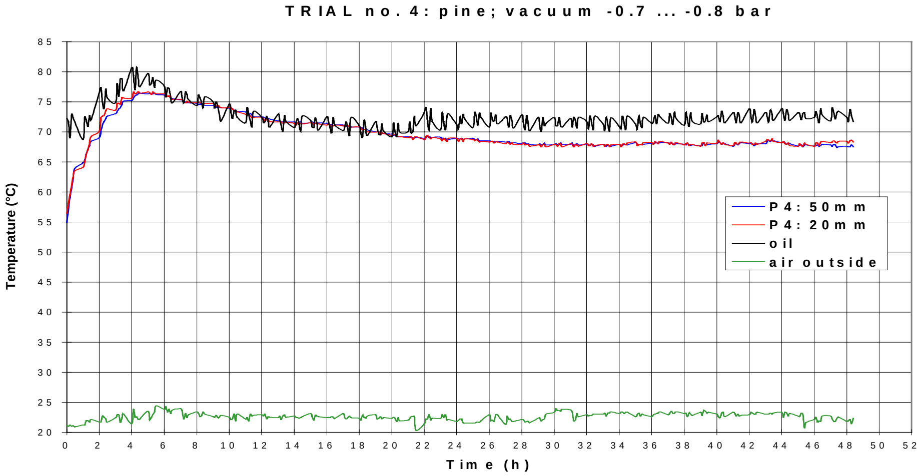


Figure 2.14. Optimized drying schedule for round small-diameter Scots pine.

In the drying experiments the variables studied were the height of the vacuum, temperature in the drying oil and drying time. The studied parameters were adjusted to meet the boiling point of water. A high vacuum/low temperature did not result in very good surface quality. Longitudinal, sometimes quite deep checks appeared on the surface in most of the blocks. On the other hand, in experiments with a lower vacuum/higher temperature the surface quality of most blocks was excellent and without cracks.

Optimum results were obtained in a vacuum of -0.7...-0.8 bar and in an oil temperature of +75...+80 ^{0}C (see Figure 2.14). The oven-dry density and moisture content of the blocks before and after drying are given in Table 2.23.

Table 2.23. Moisture content, heartwood proportion of pine and specific gravity of blocks.

Wood species	Log no.	Heartwood area (%)	Density owen-dry (kg/m3)	Drying time (h)	Initial moisture content (%)	Final moisture content[1)] (%)
pine	2	18	442	19	96	59
pine	10	19	424	19	81	-
spruce	12	-	494	19	66	-
spruce	20	-	419	19	65	20
pine	3	18	406	25	104	69
pine	9	6	401	25	98	38
spruce	13	-	391	25	43	20
spruce	19	-	425	25	103	29
pine	4	4	384	48	107	14
pine	7	20	416	48	114	21
pine	8	19	372	48	119	18
spruce	14	-	449	48	56	17
spruce	15	-	344	48	68	18
spruce	16	-	432	48	40	13

[1)] by means of extraction with toluene

During the drying, the oil penetrated only to the surface of timber.

Pressure treatment trials were carried out in order to get deeper penetration in the wood. Trials showed that Scots pine could easily be treated through the sapwood zone. In the case of Norway spruce only very limited penetration could be achieved. The retention of oil in Scots pine after a typical full cell process varied from 340 to 480 kg/m^3. The retention level of treatment oil is directly dependent on treatment process. Using Rüping or Lowry processes will cut the retention, which is generally known and used by the impregnation industry. Figure 2.15 shows the quality of treatments achieved by hot-oil drying followed by normal vacuum/pressure treatment.

Figure 2.15. Scots pine after drying and treatment process.

Conclusions

The combination of drying and impregnation with hot oils resulted in round timber with outstanding quality. Drying defects could be avoided almost totally and the process resulted in Scots pine rounds with full sapwood penetration. However, Norway spruce did not show good treatability.

3. Strength of small-diameter timber

Small-diameter round timber contains a large proportion of juvenile wood and knots, and has not been tested widely. These are the basic reasons why 1400 bending tests and a smaller number of compression and tension tests have been undertaken in this research. The objective of the work was to determine the characteristic values needed in the design of load-bearing structures, to study the feasibility of non-destructive methods in strength-grading, and to initiate a process for developing international standards for visual strength-grading of round timber for structural use.

Special attention was given to the applicability of CEN standards, written for sawn timber, to round timber. The issues to be discussed include the strength-testing methods, strength classes and grading. Of particular interest is the effect of size on strength: a high proportion of juvenile wood in smaller sections suggests that strength could be lower when diameter is smaller, which is contrary to the EN384 -size adjustment for sawn timber.

The research is summarized here. More detailed descriptions of the methods and results can be found in other publications (Boren 1999, Boren & Barnard 1999, Gard et al. 1998, de Vries 1998, Patzelt 1998, Ranta-Maunus et al. 1998).

3.1 Testing methods

The strength test procedures were based as closely as practicable on EN 408: 1995, which is intended for testing sawn timber. Some deviations from the standard had to be adopted because of the round form and in some cases variable diameter. With experience the test methods have been modified, and a proposal for the testing standard of round timber has been drafted (Appendix A). In the actual testing there were minor differences in the methods used by the different participants. These differences are not believed to have significantly influenced the results presented here and they are not detailed in this summary.

3.1.1 Bending tests

A four-point bending test was used to determine the modulus of elasticity (E) and the bending strength (f_m) (Figure 3.2). In principle, the span was 18 times the diameter and the distance between two symmetrical loads was 6d. Local deflection between the loads was measured for determining E. Some participants also measured global deflection to compare the values obtained for global and local E (Figure 3.1). Local E values are given in the results if not otherwise stated. The average diameter was used for the calculation of E. For strength determination the minimum diameter close to the failure location was used for calculating of the bending stress.

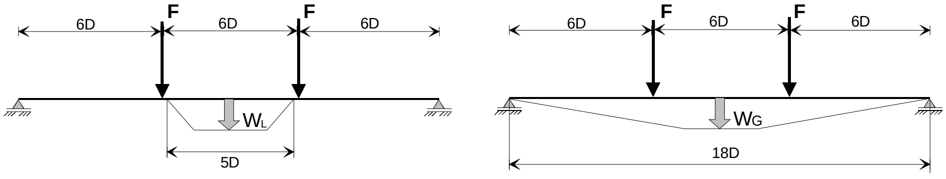


Figure 3.1. Schematic of bending test. Left: local E, right: global E determination.

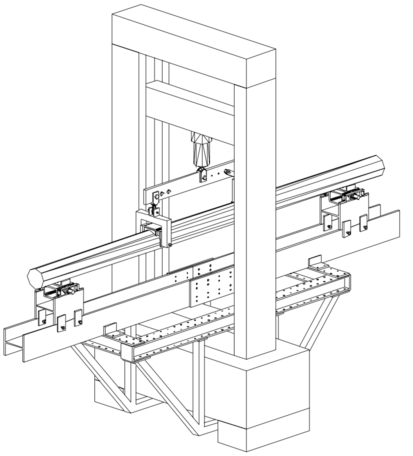


Figure 3.2. Bending set-up.

3.1.2 Compression test

The compression test was also carried out in accordance with EN 408:1995, and a schematic layout is shown in Figure 3.3. Deformations for the determination of E were measured using two LVDTs placed either side of the specimen in a centroidal plane. Two gauges were used in order that the centroidal movement could be found in case of uneven load take-up or minor buckling.

The heavy loading equipment is shown in Figure 3.4. For determining the compression strength, the load was increased until it started to drop. Often the failure mode was local crushing, as illustrated in Figure 3.5.

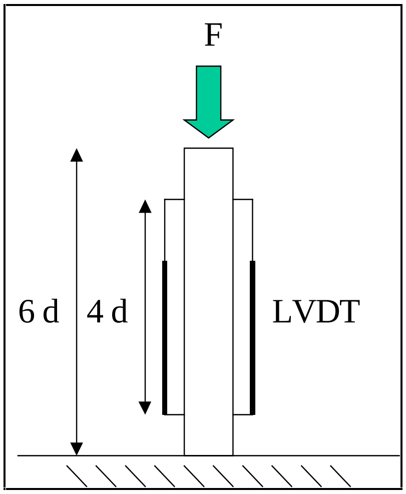


Figure 3.3. Schematic view of compression test.

Figure 3.4. Heavy loading equipment is needed in compression tests.

Figure 3.5. Local crushing in compression.

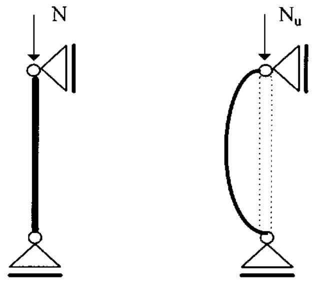
3.1.3 Buckling test

When a slender column is loaded axially, there is a tendency for it to deflect sideways. This type of instability is called flexural buckling. The strength of slender members depends not only on the strength of the material but also on the stiffness and initial curving of the column.

The buckling tests performed by CTBA aimed to verify whether the calculation method proposed by EC5 can be directly applied to roundwood.

In order to maintain an axial load during the test and to reach as far as possible the ideal case of a two-hinged column, a mechanical system was used to force the timber pole ends in a one degree of freedom displacement: axial displacement of the machine. This mechanical system can be described as two boundary holders, see Figure 3.6.

When using such a system, the considered length of a pole for buckling calculations is equal to its real length l_0 reduced by (2×150 mm). In fact, the equivalent length of a corresponding ideal two-hinged column is between l_0 and $(l_0 - 2\times150 \text{ mm})$.



Example of a Two-hinged column

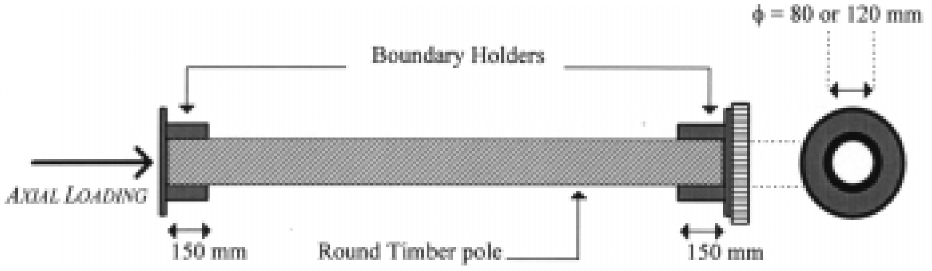


Figure 3.6. Principle of the mechanical arrangements for buckling tests.

For cylindrical logs, three lengths were used: 1500 – 2000 mm and 3000 mm, and at least six logs for each group of (length, diameter) were tested. A total of 48 pieces were tested.

Buckling tests were performed at a constant displacement rate and during 400 seconds at least before the logs broke. The load (stress) versus time curve was recorded. The critical (or buckling) stress corresponds to the point where this curve starts to decrease.

3.1.4 Tension test

The test pieces were of full structural cross-section and of sufficient length to provide a test length clear of the testing machine grips of at least 9 times the largest cross-sectional dimension. The critical points were marked on each pole based on NDT measurements (see section 3.1.6). CTBA then positioned this location, when possible, in the centre of the tested length. Special grips were designed for this test, an illustration of which is shown in Figure 3.7. The grips were especially designed for use with cylindrical specimens. The principle of gripping consists of increasing the grips pressure on the round timber as the tensile load increases. This ensures that no slipping appears during the test until the piece breaks.

The tensile strength and modulus of elasticity were calculated using the same principles as proposed for the compression tests in EN408.

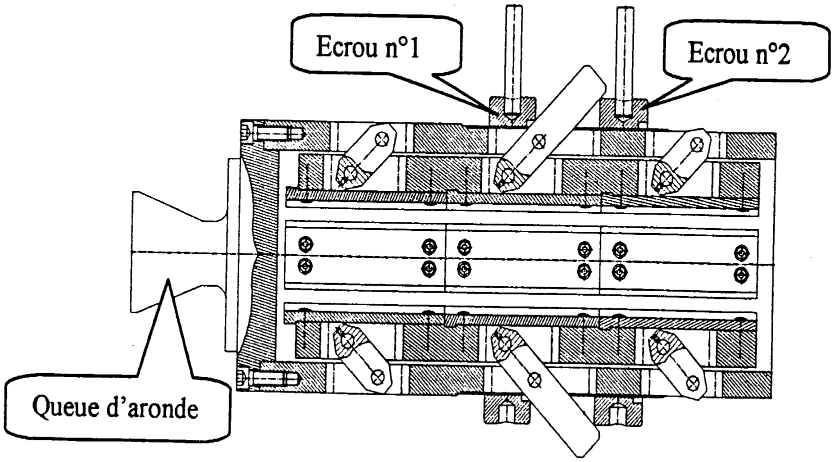


Figure 3.7. Illustration of the grips for tension tests by CTBA.

3.1.5 Dynamic modulus of elasticity

Most of the machine-graded timber available today is graded from bending stiffness. The timber is centrally loaded between supports to cause a deformation from which the stiffness of the cross-section is calculated and used as a grading parameter. An alternative way to determine the stiffness is based on the relationship between the frequency of a freely vibrating piece of timber and its modulus of elasticity. Since this method is independent of specific geometry problems such as curvature and taper it may prove to be a suitable method for the grading of small-diameter roundwood (de Vries 1998).

A relatively cheap and quick way of measuring the stiffness of timber is based on the relationship between the eigenfrequency for the free-free condition of a specimen and its elasticity. A lot of research work has already been done in this area (Görlacher 1984, Hearmon 1966, Hu and Hsu 1996, Perstorper 1994). This method is based on the Euler beam theory for free flexural vibrations of prismatic beams. The eigenfrequency of a material specimen is the basic vibration of the whole specimen at normal mode. The vibration can be initiated by a longitudinal or transverse impact. Due to the geometry and mass of the samples and test arrangement considered, the longitudinal vibration method was applied (Figure 3.8). Longitudinal vibrations of beams with small cross-sections with respect to length are not significantly influenced by shear and torsion deformations.

The fundamental relationship is given by the differential equation

$$\rho \frac{\partial^2 u}{\partial t^2} = E \frac{\partial^2 u}{\partial x^2} \tag{3.1}$$

where u is longitudinal displacement, E the modulus of elasticity and ρ the density.

The modulus of elasticity may then be derived to be:

$$E_{dyn} = 4l^2 f^2 \rho \tag{3.2}$$

where *l* is the length of specimen and *f* the eigenfrequency.

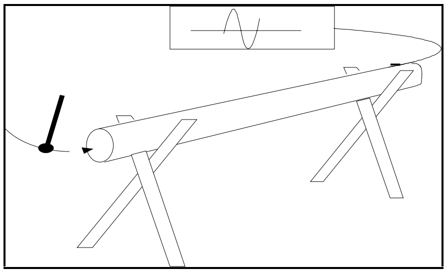


Figure 3.8. E_{dyn} test arrangement.

High correlation between E_{dyn} and E_{stat} has been established for sawn timber (r=0.93) on the laboratory scale (Görlacher 1984). When applying the vibration method under industrial conditions the correlation coefficient obtained is lower (Blass et al. 1995, Gard 1996). This method was used by TU Delft to larch poles as reported in Chapter 3.4.2.

3.1.6 X-ray density measurement

As part of a previous project, CTBA developed a continuous measurement system in order to grade structural sawn wood by means of an X-ray density measurement along with a grading software (Figure 3.9). A high speed of grading (upto 200 m/min) can be achieved by this method. In this project, the equipment was used to grade small-diameter round timber and the software was accordingly modified. The method is based on the accurate measurement of local density: the end-resolution is ≈ 5 mm^2 for a single data value.

The knots can be detected by this method since the knot density has an average value of 2.5 higher than clear wood.

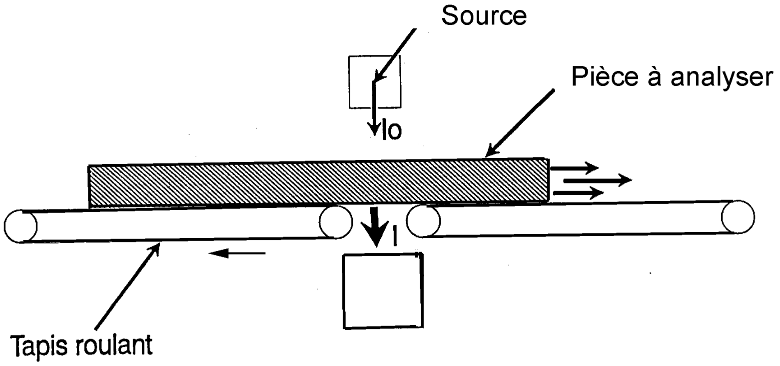


Figure 3.9. Device of the X-ray equipment.

The X-ray densimeter sets up a bi-dimensional cartography of a timber (Figure 3.10) which allows the calculation of its density point by point. With this cartography, a program calculates the densities and numbers of knots. In a first stage, a nodosity parameter allows us to assess the location of the more likely bending breaking point. With this calculation the software forecasts the location of the centre of the bending trial.

The set of measured parameters allows us to assess the bending strength and stiffness of the beam by means of a correlation set up with the 1500 sawn timber beams tested in an earlier project.

The sampling was composed of cylindrical Douglas fir poles from trees of an age from 10 to 17 years. Two diameters were studied : 80 and 120 mm, of 4 m length. The X-ray machine performs a numerical radiography of the wood, so it provides a cartography in which each point is linked to the wood mass for this co-ordinate.

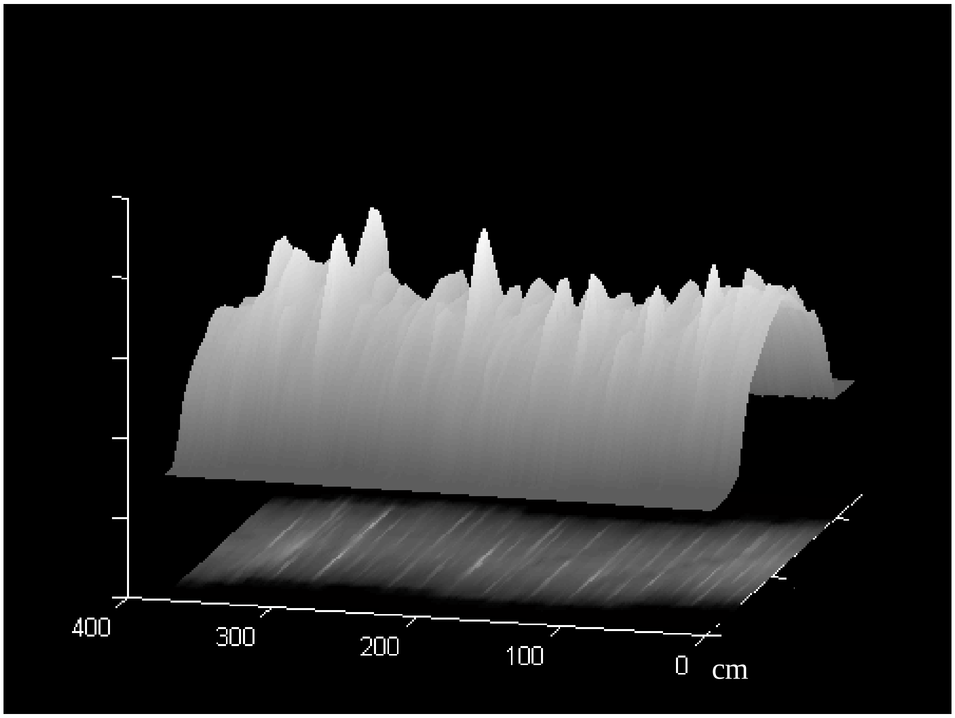


Figure 3.10. Map of the roundwood density.

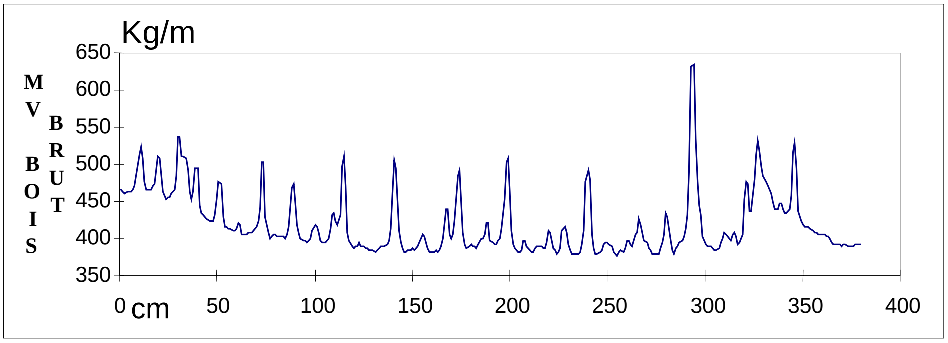


Figure 3.11. Mean density along the beam for a roundwood.

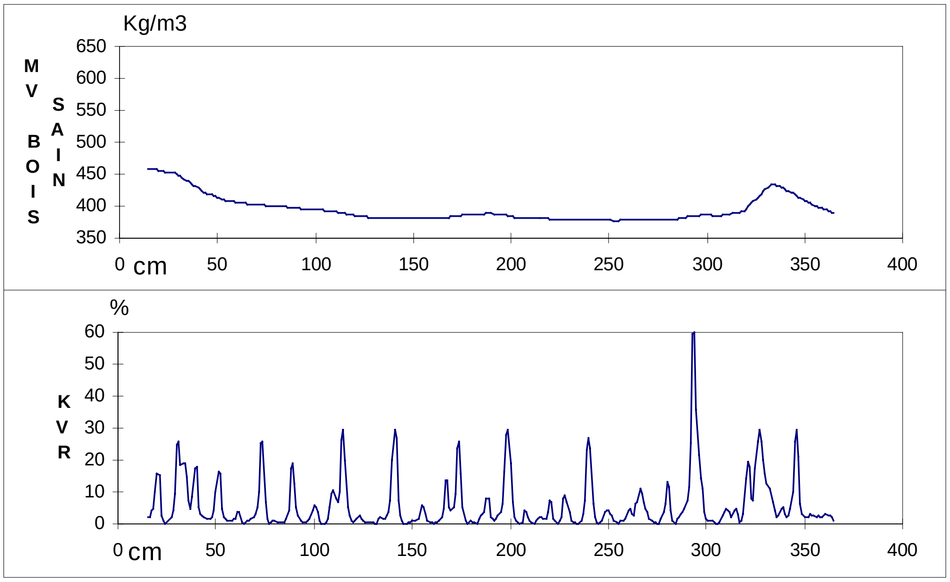


Figure 3.12. Variation of the density of clear wood and KVR parameter along the roundwood log.

The cartography allows us to produce a curve of wood density centimetre by centimetre, as if the log had been cut into discs of 1 cm in length and as if the density of each slice was measured (Figure 3.11). Based on this curve, the density information can be divided into two components: the clear wood density (without knots) and the additional density caused by knots, which is used to calculate the KVR (Knot Volume Ratio), the ratio of the volume of knots to the total wood volume, as illustrated in Figure 3.12. This method was applied by CTBA to Douglas fir (Chapter 3.4.3).

3.2 Materials and statistical methods

3.2.1 Sampling

Norway spruce (*Picea abies*), Sitka spruce (*Picea sitchensis*), Scots pine (*Pinus sylvestris*), Larch *(Larix kaempferi*) and Douglas fir (*Pseudotsuga menziesii F.*), harvested in different countries and locations, were tested for the determination of characteristic strength values. In Finland, Norway spruce samples were harvested from two stands (fertile soils) located in Southern and Eastern Finland. Scots pine samples were harvested from four stands in Southern and Eastern Finland covering poor and fertile soils. In Holland, Larch was harvested at a location in the eastern part of the Netherlands. In the UK Scots pine was harvested near Windsor; the sample is slightly atypical because the quality of the stems is particularly good. Sitka spruce was harvested from the Kielder Valley, close to the Scottish border and this sample is considered typical of the UK. In Austria, Norway spruce was harvested at two locations: in an alpine area (Salzkammergut, 650–850 m above sea level) and from a plain area (Innviertel, 350–400 m). In France Douglas fir was harvested in the Limousin area (Platateau des Millevaches) 700 m above sea level.

From each stem, after debarking, milling and drying, a specimen for strength testing was prepared. When the length of stems allowed, bending and compression specimens were made from the same stem. The numbers of round-pole specimens used for the bending, compression, buckling and tension tests are given in Table 3.1.

Table 3.1. Total number of round-pole specimens in strength tests.

	Finland	Holland	UK	Austria*	France**
Bending					
Norway spruce	200			300	
Sitka spruce			100		
Scots pine	175		100		
Larch		185			
Douglas					360
Compression					
Norway spruce	200				
Sitka spruce			100		
Scots pine	175		100		
Larch		60			190
Douglas					
Tension					
Douglas					50
Buckling					
Douglas					50

* Only naturally dried specimens are included the statistical analysis presented in this paper.
** French strength-testing material is not included in the statistical analysis presented in this paper.

3.2.2 Measured features of material

The quality of the tested timber was characterized by measurements. Such variables were recorded that could possibly affect the strength. These included the diameter, density, moisture content and several knot-related parameters. The following notations were used for the variables in the analysis:

- *a* = age (years), measured at or close to the failure point
- *c* = circumference of the specimen (mm), measured at or close to the failure point
- *d* = diameter of the specimen (mm), measured at or close to the failure point
- *m* = machine-processed timber surface (mm)
- *ks* = knot sum (mm), measured at or close to the failure point
- *ks/c* = KAR= knot sum per circumference (%), measured at or close to the failure point
- *ks/d* = knot sum per diameter (%), measured at or close to the failure point
- *mk* = max. knot (mm), measured at or close to the failure point; measurement method is shown in Figure 3.13.
- *mk/d* = max. knot per diameter (%), measured at or close to the failure point
- *o* = origin/species

- *ob* = over bark
- ρ_{12} = density at 12 % moisture content (kg/m^3) at or close to the failure point
- $\rho_{12,\ 0.05}$ = 5-percentile value of the sample for density at 12 % moisture content (kg/m^3)
- $\rho_{12,\ k}$ = characteristic value of the population for density at 12 % moisture content (kg/m^3) in accordance with CEN 384.
- *p* = processing method
- *r* = ring width (mm), measured at or close to the failure point
- *s* = length of sawn circumference (mm), measured at or close to the failure point
- *s/c* = length of sawn circumference per total circumference, measured at or close to the failure point
- *ss* = sawn (plane) surface in compression and tension zone
- *t* = average taper (mm/m), tapering (to measure conical shape of specimen) only for bending specimens
- *u* = moisture content, mass of water per dry mass (%), measured at or close to the failure point
- *ub* = under bark, i.e. after processing.

For the calculated strength and stiffness values, the notations are used as follows:

- $E_{c,\ 0}$ = modulus of elasticity in compression parallel to the grain (kN/mm^2)
- $E_{c,\ 0,\ mean}$ = mean value of the population for the modulus of elasticity in compression parallel to the grain (kN/mm^2)
- E_m = modulus of elasticity in bending (kN/mm^2)
- $E_{m,\ mean}$ = mean value of the population for the modulus of elasticity in bending (kN/mm^2)
- $f_{c,\ 0}$ = compression strength parallel to the grain (N/mm^2)
- $f_{c,\ 0,\ 0.05}$ = 5-percentile value of the sample for compression strength parallel to the grain (N/mm^2)
- $f_{c,\ 0,\ k}$ = characteristic value of the population for compression strength parallel to the grain (N/mm^2)
- f_m = bending strength (N/mm^2)
- $f_{m,\ 0.05}$ = 5-percentile value of the sample for the bending strength (N/mm^2)
- $f_{m,\ k}$ = characteristic value of the population for the bending strength (N/mm^2).

The diameter of the knots was measured around the circumference of the log i.e. at right-angles to the longitudinal direction of the specimen (Figure 3.13). Table 3.2 summarizes the variables and values measured in the tested bending and compression material. For Douglas fir, mainly X-ray measurements were made, and most of the features in Table 3.2 are not available.

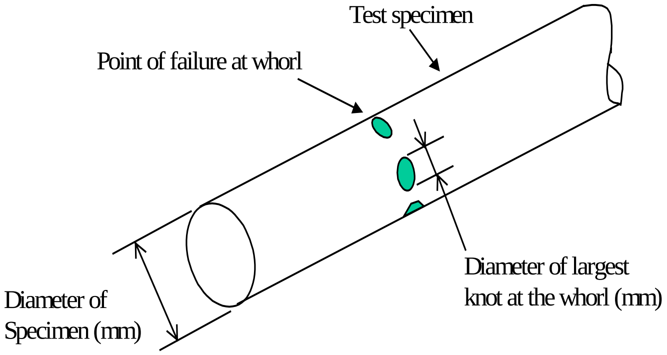


Figure 3.13. Method used to measure knot diameter.

Table 3.2. Means and standard deviations of the property values in round bending material.

Bending material Mean / st. d.						
	Austria	Finland		Holland	UK	
	spruce	pine	spruce	larch	pine	Sitka
N	85	175	200	185	100	100
a		20 / 4	28 / 9	41 / 7	33 / 6	19 / 4
d	134 / 20	125 / 22	113 / 21	121 / 16	529 / 41	126 / 12
ks	20 / 13	76 / 26	47 / 25	28 / 17	75 / 39	77 / 27
ks/d	16 / 10	62 / 20	41 / 19	23 / 15	60 / 31	62 / 22
mk		19 / 6	13 / 6	17 / 7	23 / 13	19 / 5
p_{12}	450 / 49	470 / 38	434 / 67	577 / 46	529 / 41	478 / 40
r		3.3 / 0.7	2.3 / 1	2.1 / 0.6	2.0 / 0.4	3.7 / 0.9
t		4 / 4	3 / 2	6 / 2	3 / 1	3 / 1
u		15.9 / 3.2	15.6 / 2.3	14.8 / 0.9	18.9 / 1.9	18.3 / 2.2
Compression material Mean / st. d.						
	Austria	Finland		Holland	UK	
	spruce	pine	spruce	larch	pine	Sitka
N	0	175	200	61	100	100
a		19 / 6	24 / 7	43 / 5	33 / 6	19 / 4
d		117 / 22	107 / 23	118 / 17	126 / 11	124 / 14
ks		80 / 39	52 / 25		57 / 47	73 / 27
ks/d		71 / 37	50 / 21		45 / 37	56 / 27
mk		19 / 6	15 / 6		18 / 15	19 / 6
p_{12}		472 / 42	426 / 57	582 / 40	539 / 48	476 / 37
r		3.4 / 1.2	2.4 / 0.9	2.1 / 0.6	2.0 / 0.4	3.7 / 0.9
u		15.3 / 3.7	15.7 / 2.1	14.5 / 0.6	17.3 / 1.8	17.3 / 1.9

The cumulative frequencies of the most important physical features for the bending and compression material are illustrated in Figures 3.14 and 3.15, respectively, in order to compare the tree species samples. Between the tree species there is a large variation both in their mechanical and physical properties. In addition, a variation within the tree species samples is not equal. Even 5-percentile or mean values are not equal in most cases. Therefore, any broad conclusions about similarities or differences between tree species cannot be determined without proper statistical analysis. The Finnish material, both Norway spruce and Scots pine, seems to be the most comprehensive covering a large range and variation of the physical properties and including twice as many specimens as the others.

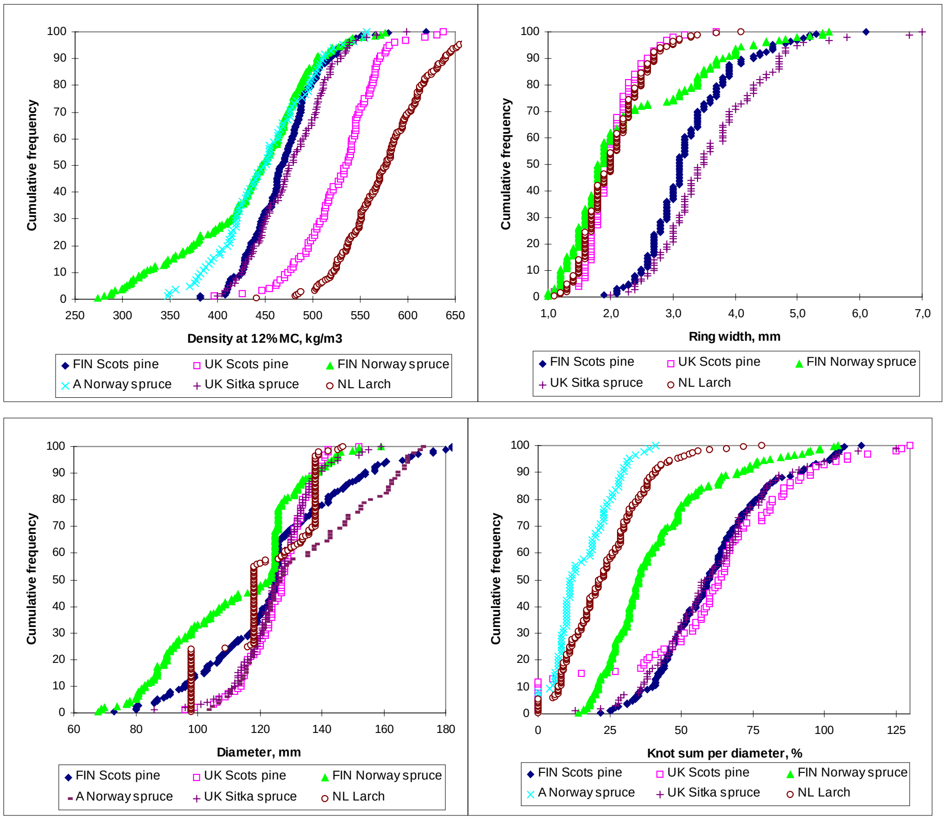


Figure 3.14. Cumulative frequencies of round bending material by species.

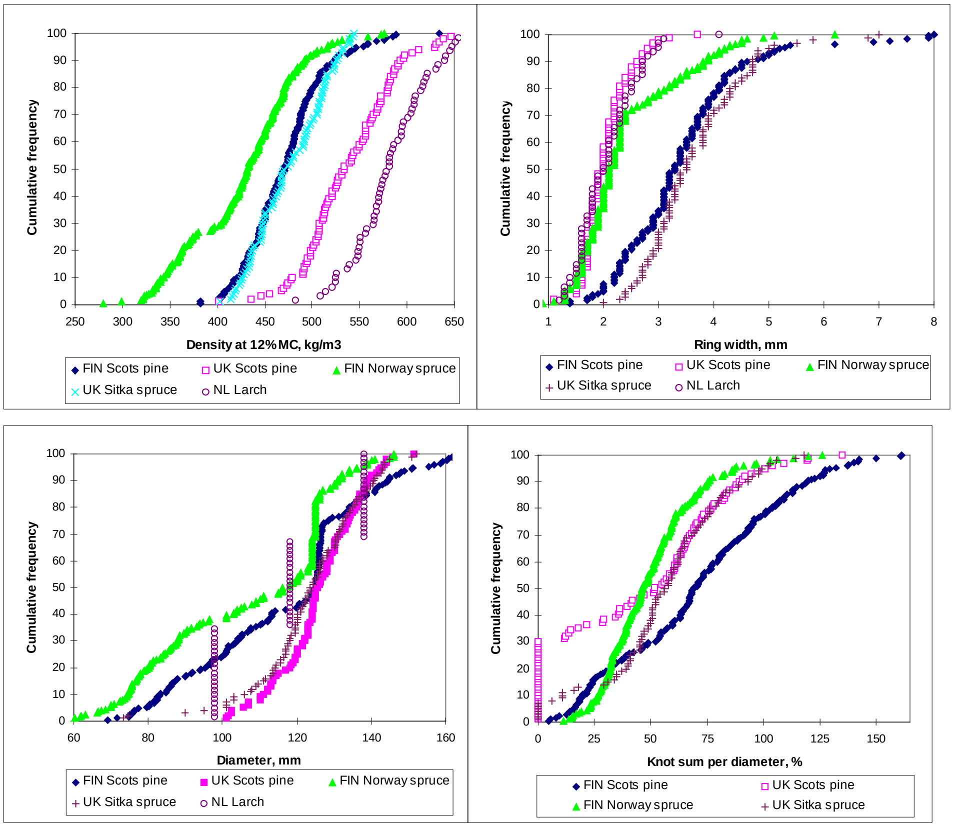


Figure 3.15. Cumulative frequencies of round compression material by species.

3.2.3 Statistical methods

The main statistical method is regression analysis. Because a regression model is not supposed to contain independent variables, which are strongly correlated to each other (Bowerman and O’Connell 1990), a correlation analysis was performed before a linear regression analysis.

The standard, EN 384 (1995), states adjustment factors for the properties $E_{c,0}$, E_m, $f_{c,0}$ and f_m with regard to moisture content and size, assuming no other information is available. To validate these factors and to study the significance of the various features for strength and stiffness of round timber, they have been analyzed by multiple regression analysis. This information was used as a basis for visual strength-grading. In the multiple regression analysis $E_{c,0}$, E_m, $f_{c,0}$ and f_m were used as dependent variables. In addition, the multiple regression technique was used to study if there is an interaction between the variables, such as timber size and the knots.

Linear regression analysis was performed in general such that the regression equation was of the form

$$y = c + \sum c_i x_i \tag{3.3}$$

where y is the dependent variable, x_i are the independent variables, c is the constant of the model and c_i are the multipliers of the independent variables. In some cases it was observed that taking a logarithm of the dependent variable improved the homoscedasticity of the model (Bowerman and O´Connell 1990). Accordingly, a second type of regression equation studied was

$$\log_{10} y = c + \sum c_i x_i \tag{3.4}$$

When predicting values by the logarithmic model, the factor ε was added to the constant c such that:

$$\varepsilon = 0.5\times(s^2\times\ln(10)) \tag{3.5}$$

where s = the standard error of the logarithmic model. This improves the accuracy of the model and eliminates possible systematic error (Meyer 1941).

As an example, the analysis of similarity of the bending strength of different species is presented here in detail. Other statistical analyses have been made in a similar way, and only the models are summarized in Chapter 3.3. More details can be found in the paper by Boren (1999).

From strength testing material it was tested whether tree species had differences in their mechanical properties, when physical properties are similar, the hypothesis being that there are no differences; H_0: multiplier for variable tree species (o) is zero.

H_0 can be tested by normal t-test. The effect of o was tested by the multiple regression analysis for $E_{c,0}$, E_m, $f_{c,0}$ and f_m, results for f_m being as follows:

$$f_m = B - 0.104\frac{ks}{d} - 30.5\lg r - 0.63u \qquad (3.6)$$

where

B= 99.2 for larch
86.3 for Norway and Sitka spruce
81.9 for Scots pine

The F-value of Model is 222.5. The multiple coefficient of determination for the model (adjusted R^2) is 0.60 and the standard error (s) 9.826. All the multipliers included in the model are significant and the basic statistical assumptions behind the regression model are fulfilled. The regression model characteristics are given in Table 3.3, and residual picture is shown in Figure 3.16.

Table 3.3. Regression model characteristics for bending strength.

					95 % Confidence interval for B	
Variable	B	Std. Error	t	Sig.	Lower Bound	Upper Bound
constant	99.2	2.4	41.7	.000	94.5	103.8
ks/d	-0.104	0.019	-5.5	.000	-0.141	-0.067
lg r	-30.5	2.617	-11.7	.000	-35.6	-25.4
pine	-17.3	1.169	-14.8	.000	-19.6	-15.0
spruce	-12.9	1.036	-12.4	.000	-15.0	-10.9
u	-0.63	0.146	-4.3	.000	-0.916	-0.344

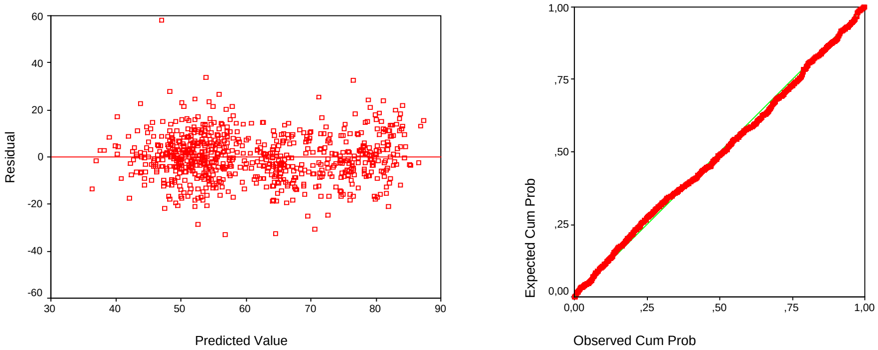


Figure 3.16. Residual picture and normal probability plot for model f_m.

3.2.4 Hypotheses of the mechanical properties of round timber

The hypotheses to be tested in statistical analysis are as follows:

1. Mechanical properties and relations of different mechanical properties of small-diameter round timber (pith included) are comparable to sawn timber. Therefore the same strength-related EN standards could be applied to the round timber as to the sawn timber.

2. When keeping the round shape in processing instead of rectangular, the knot angle (angle between specimens surface and knot) is optimum, so that the knot area is minimized on the specimen's surface. Therefore, round timber has a lower KAR on average than the sawn timber.

3. Because of the round form, the bending strength of round timber should be higher than that of sawn timber. Also, because of the unprocessed wood, hand-debarked timber should have better mechanical properties than machine-processed timber.

4. Regardless of species (conifer family), round timbers have similar mechanical properties, whilst their physical properties are the same.

5. Because of the large extent of juvenile wood, there is no negative size effect on the bending strength in small-diameter round timber. For the same reason,

age especially has an effect on the compression strength.

6. Strength-grading is possible to carry out by visually assessing the knot-related parameters and ring width.

The hypotheses have been verified by actual measured results of physical and mechanical properties and by statistical methods.

3.3 Strength results

3.3.1 Overview of results

The strength and stiffness values obtained in the bending and compression tests are summarized in Table 3.4, where the mean values and standard deviations are given. Cumulative distributions are shown in Figures 3.17 and 3.18. Bending strengths are high, lower 5th percentile ranging from 35 to 60 N/mm^2, all the mean values exceeding 50 N/mm^2. Tension tests were made only for Douglas fir. The 50 tension tests resulted in a mean value of 29 N/mm^2 and a 5th percentile value of 16 N/mm^2. There is strong evidence that the NL larch has the best mechanical properties among the tested material.

Table 3.4. Means and standard deviations of bending and compression values of tested round timber at test moisture content.

Species/country	f_m	$f_{c,0}$	E_m	$E_{c,0}$
Scots pine				
FIN	50.3 / 11.2	26.2 / 8.2	10.9 / 2.4	9.4 / 2.0
UK	53.8 / 9.3	28.4 / 4.9	13.1 / 4.1	12.2 / 2.8
Norway spruce				
A[1]	61.7 / 11.6		13.0 / 1.9	
FIN	59.8 / 12.5	27.8 / 5.6	12.1 / 2.6	10.7 / 3.4
Sitka spruce				
UK	57.5 / 10.1	24.7 / 3.6	13.9 / 4.4	11.6 / 2.9
Larch				
NL	78.3 / 12.7	41.4 / 3.7	13.6 / 2.5	
Douglas				
F	52 / 9.9[2]	33/-	11.1 / 2.4[2]	11.0/-

1) Naturally seasoned material
2) Cylindrical specimens, d = 120 mm

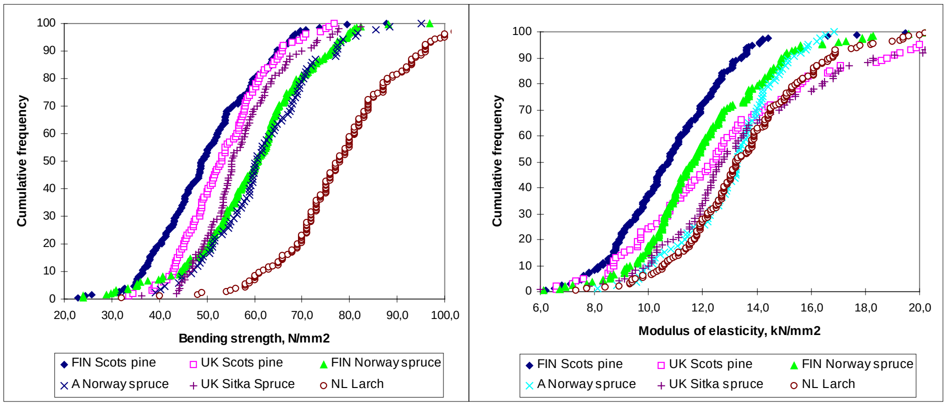


Figure 3.17. Cumulative frequencies of bending strength and modulus of elasticity by species at test moisture content.

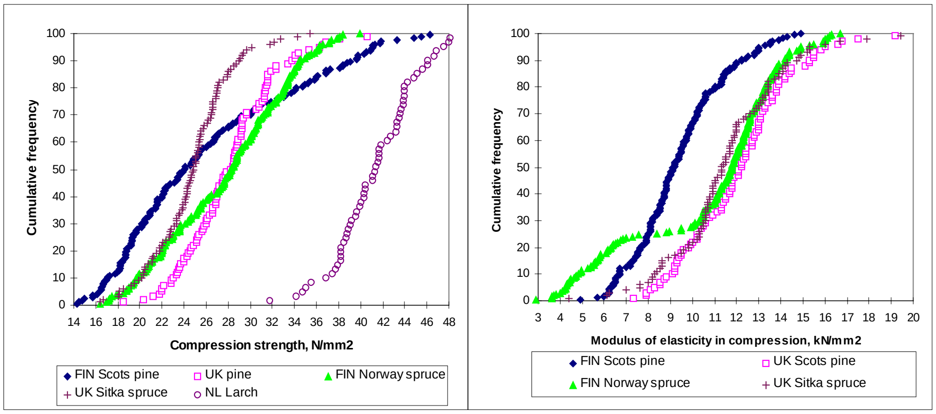


Figure 3.18. Cumulative frequencies of compression strength and modulus of elasticity by species at test moisture content.

The moisture content in the the tests was mainly in the range from 10 to 20 %. The obtained values were adjusted to 12 % moisture content in accordance with standard EN384: f_c values were adjusted by 3 % and E by 2 % for every percentage point difference in moisture content. No size adjustment was made. The lower fifth percentile values for strength were determined by the ranking method. The lower fifth percentile for density was determined based on normal distribution.

The characteristic values were first calculated for all the tested material of all species and later (3.4.1.2) for the graded samples. The characteristic values for unsorted material are given in Tables 3.5 and 3.6.

The strength values are higher than were expected before testing. In particular, bending strength is considerably higher than would be obtained from unsorted sawn timber.

Table 3.5. Bending characteristics adjusted to 12 % MC in accordance with EN 384. Size adjustment not used.

Species (country)	Sample size	ρ_{mean} [kg/m^3]	ρ_{05} [kg/m^3]	$f_{m,mean}$ [N/mm^2]	$f_{m,05}$ [N/mm^2] by rank	$E_{m,mean}$ [kN/m^2]
Scots pine (FIN)	175	470	407	50	35	11.9
Scots pine (UK)	100	529	461	54	39	14.9
Scots pine (FIN+UK)$^{3)}$	250	492	427	52	37	12.9
spruce (FIN)	200	434	323	60	35	12.9
spruce (A) $^{1)}$	143	451	360	61	36	12.9
larch (NL)	178	580	509	85	63	14.3
Douglas (F)$^{2)}$	180	442	367	52	37	11.1
Sitka spruce (UK)	100	478	392	58	44	16.1

1) Drying by seasoning
2) D = 120 mm, cylindrical, KAR 24 %
3) Combined British and Finnish machine rounded.

Table 3.6. Compression and tension characteristics adjusted to 12 % MC in accordance with EN 384. Size adjustment not used.

Species (country)	Sample size	$f_{c,mean}$ [N/mm^2]	$f_{c,05}$ [N/mm^2]	$f_{t,mean}$ [N/mm^2]	$f_{t,05}$ [N/mm^2]
Scots pine (FIN)	175	28.0	19.7		
Scots pine (UK)	100	32.8	25.9		
pine (FIN+UK)	250	30.2	24		
spruce (FIN)	200	30.7	20.8		
larch (NL)	58	45	38		
Douglas (F)	190	33	26		
Douglas (F)	50			29	16
Sitka spruce (UK)	100	28.6	21.7		

3.3.2 Correlation analysis

The correlation analysis was performed for all test results (at test moisture content) with pine (FIN, UK), spruce (A, FIN, UK) and larch (NL) for bending and compression material indicating that the mechanical properties and knot related properties have a moderate negative correlation (Tables 3.7 and 3.8). Age (*a)* and density (ρ_{12}) have a strong positive correlation with mechanical properties, and they both have a strong negative correlation with ring width (*r*). Moisture content (*u*) has a negative influence on strength properties, especially on compression strength ($f_{c,\,0}$). The size of timber (*d*) does not seem to have any correlation with the mechanical properties. Timber size and moisture content correlate positively with the knot-related properties, which causes interpretation problems of effects of these properties. However, the conclusion is that, regardless of tree species, knot-related properties and ring width could be used as a basis for the visual strength-grading of round timber.

Table 3.7. Correlation coefficients in whole bending material (Boren 1999).

	E_m	f_m	*a*	*d*	*ks*	*ks/d*	mk	ρ_{12}	*r*	*t*	*u*
E_m	1.00	.57	.28	-.02	-.28	-.27	-.22	.40	-.25	-.07	.06
f_m		1.00	.64	-.16	-.59	-.56	-.39	.64	-.55	.11	-.28
a			1.00	.001	-.58	-.61	-.24	.71	-.78	.26	-.12
d				1.00	.18	-.06	.29	-.02	.31	-.02	.08
ks					1.00	.96	.71	-.30	.57	-.06	.03
ks/d						1.00	.65	-.30	.51	-.07	.36
mk							1.00	-.11	.36	.13	.15
ρ_{12}								1.00	-.50	.25	.08
r									1.00	-.07	.10
t										1.00	.03
u											1.00

Table 3.8. Correlation coefficients in whole compression material.

	$E_{c,0}$	$f_{c,0}$	*a*	*d*	*ks*	*ks/d*	mk	ρ_{12}	*r*	*u*
$E_{c,0}$	1.00	.67	.52	-.08	-.46	-.45	-.34	.59	-.50	-.07
$f_{c,0}$		1.00	.70	.02	-.56	-.56	-.43	.61	-.54	-.59
a			1.00	.22	-.37	-.46	-.22	.67	-.71	-.14
d				1.00	.19	-.19	.19	.13	.13	-.01
ks					1.00	.92	.83	-.20	.47	.25
ks/d						1.00	.74	-.23	.42	.25
mk							1.00	-.09	.33	.22
ρ_{12}								1.00	-.41	-.05
r									1.00	.13
u										1.00

For sawn timber, the correlation coefficient between f_m and E_m is of interest, because mechanical strength-grading machines are based on that relationship. Although strength-grading machines do not exist for the round timber correlation between f_m and lg E_m for the whole tested material was calculated. The correlation coefficient is low (r^2 = 0.38) compared to the correlation obtained for sawn timber (usually r^2 = 0.6 - 0.8). A linear model between f_m and E_m has a little lower correlation (r^2 = 0.32). These low correlations are influenced by mixed species, and also by the variability of test moisture content and the inaccuracies of the dimensions of non-cylindrical specimens. The correlation is higher for cylindrical, calibrated round specimens.

Figure 3.19 shows the scatter plot of density and ring width for the Finnish material, and a fitted polynomial regression curve as a function of ring width separately for pine and spruce. When the ring width is higher than 5 mm the density does not seem to decrease any more. At a ring width 3 mm, the mean density at MC 12 % is 480 kg/m^3 for pine and 394 kg/m^3 for spruce i.e. the difference is 86 kg/m^3. At a ring width 5 mm, the mean density at MC 12 % is 431 kg/m^3 for pine and 329 kg/m^3 for spruce, i.e. the difference is about 102 kg/m^3.

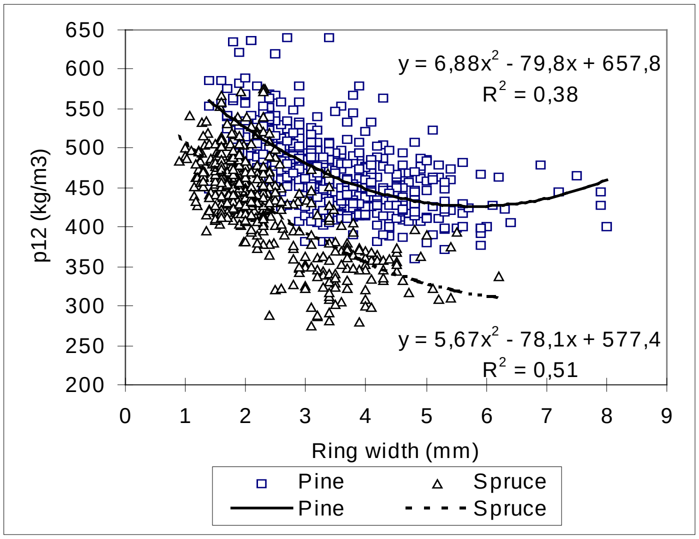


Figure 3.19. The correlation between ρ_{12} and ring width for all tested Finnish material separately for pine and spruce.

3.3.3 Effect of machine rounding and sawing

The effect of machine rounding and sawing on the mechanical properties were studied from the Finnish material, Scots pine and Norway spruce. The models presented in this chapter cannot be used for prediction, because of the small variation of properties and small sample size (only a part of the Finnish material was convenient for this statistical analysis).

As a first step it was analyzed how visible knot dimensions change when a stem with bark is turned into a pole or sawn at least partly. A linear regression model for Scots pine and Norway spruce revealed that the change of KAR due to machining (ΔKAR) depends on the relative change of circumference X_1(%) and on the proportion of sawn circumference from the total final circumference X_2(%). The regression models for Norway spruce (3.7) and Scots (3.8) pine are as follows**:**

$$\Delta KAR(\%) = 10^{0.988+0.005405X_1+0.0000155X_1X_2} - 10 \tag{3.7}$$

$$\Delta KAR(\%) = 10^{1.034+0.006366X_1+0.001104X_2} - 10 \tag{3.8}$$

The multiple coefficient of determination for the models (adjusted R^2) is 0.25 and 0.33, respectively.

The result is illustrated in Table 3.9, where it is shown that sawing results in higher KAR than turning round, which corresponds to the expectations.

Table 3.9. The effect of machine rounding and sawing on KAR of Norway spruce and Scots pine.

c_{ob}	c_{ub}	S	ΔKAR (%) for pine	ΔKAR (%) for spruce	Form
500	400	0	4.5	2.5	Round
500	400	200	6.5		Partly sawn
500	400	400	8.7	3.4	Squared sawn

The change in the knot quality measured from dry, rotten or black knots over the bark to sound knots measured after processing for round timber is dependent on knot diameter, change of diameter of timber and rate of growth.

The effect of machine surface processing (machine debarking, sawing) in comparison to hand debarking was tested by multiple regression analysis for f_m. The new variables used were:

- c = circumference at or close to the failure point (mm).
- h = height (mm).
- m = machine-processed circumference at or close to the failure point (mm).
- KAR_m = knot sum of machine-processed surface per total circumference (hand debarked: $KAR_m = 0$).
- ss = sawn surface in compression and tension zone (round: ss = 0 and sawn: $ss = 1$).
- S = 1 for spruce, 0 for pine.

The model and result are shown below. Machine processing interacts with *KAR*, i.e. increasing the knot sum increases the negative effect of machine processing. The form of the specimen has affects the bending strength:

$$\lg f_m = 1.84 - 0.000874h - 0.00262KAR_m - 0.032r - 0.06238ss - 0.008378u / \lg a - 0.0004686\rho_{12} + 0.0000519\rho_{12}S \quad (3.9)$$

The F-value of the model is 159.5 and the multiple coefficient of determination (adjusted R^2) is 0.70 .

Table 3.10 illustrates the effect of the form of the specimen, processing method and tree species on the mechanical properties, when the same log is turned from a hand-debarked pole to squared sawn timber. Virtually, pine and spruce have a different density at similar ring widths. Therefore, the effects of form, processing method and tree species are presented for pine and spruce at the same ring width value and different density (lower for spruce). The table indicates that, at the same ring width, spruce is weaker because spruce has a lower density.

Table 3.10. The effect of processing method and form of specimen on the bending strength (r = 3 mm and u=18 %) according to Eqn (3.9).

a	h	Total c	Total ks	KAR_m	Pine f_m ρ_{12}=440 kg/m^3	Pine f_m ρ_{12}=480 kg/m^3	Spruce f_m ρ_{12}=440 kg/m^3	Spruce f_m ρ_{12}=390 kg/m^3	
20	150	471	60	0.0	49.9	52.1			Hand debarked
20	150	393	60	7.6	47.7	49.8			Partly sawn and hand debarked in tension zone
16	125	393	60	15.3	46.8	48.9	49.3	46.4	Machine round
12	100	393	60	7.6	43.1	45.0			Partly sawn in tension zone and hand debarked
12	100	400	60	15.0	41.2	43.0	43.4	40.9	Squared sawn

The bending strength and stiffness of round Finnish spruce (N=200) was also compared to sawn timber (Norway spruce 42 x 145) as tested in a Nordic Industry Fund project. Here, the sample size was about 600, covering all of Finland. For testing and analysis, EN 338, EN 384, EN 408 and EN 518 were applied. The cumulative distributions of bending strength, modulus of elasticity and density are given in Figure 3.20. The density distributions are similar except the lower 30 % of round timber, which clearly has a lower density than sawn timber, the lower 5th percentiles of the distributions being 306 and 376 kg/m^3, respectively. However, the modulus of elasticity of these two sets of material are fairly similar, and the bending strength of round timber is higher, the lower 5th percentiles being 35.4 and 27.7 N/mm^2. If the low density material of round timber is disregarded so that the density distributions of sawn and round timber are similar, then the 5th percentile value of bending strength for round spruce is double the value of sawn spruce.

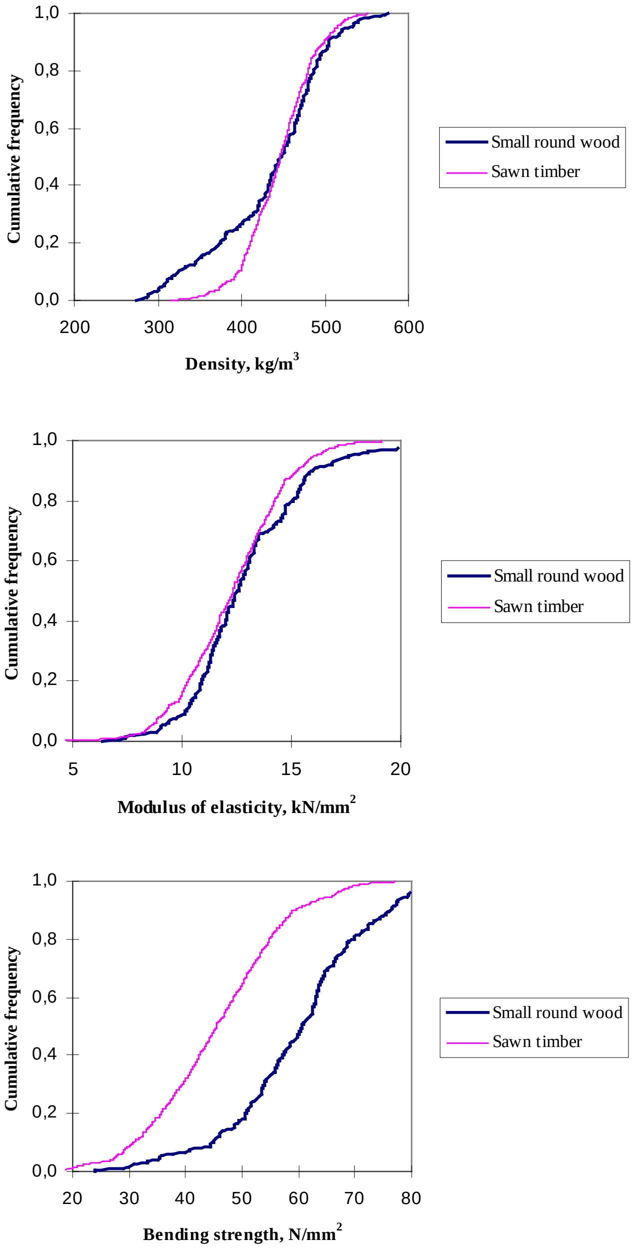


Figure 3.20. Comparison of bending strength, stiffness and density of round and sawn Finnish unsorted spruce timber.

3.3.4 Differences between species

It was tested, whether the tree species had differences in their mechanical properties when their physical properties were similar, as described in Chapter 3.2.2. The multipliers of the regression models are summarized in Table 3.11. The models for E_m and f_m cover larch, Scots pine, Norway spruce and Sitka spruce, indicating that the bending strength of larch is 13 to 17 MPa higher than that of spruce or pine when the knot area ratio and annual ring width are similar. The models for $E_{c,\,0}$ and $f_{c,\,0}$ cover Scots pine, Norway spruce and Sitka spruce. In compression, spruce is stronger than pine when density, knot area ratio and annual ring width are similar (see Figure 3.21).

Table 3.11. Multipliers for regression models including different species.

Variable	f_m	lg E_m	lg $f_{c,\,0}$	$E_{c,\,0}$
Constant	99.2	1.168	1.56	-0.606
KAR	-0.327	-0.00222	-0.002107	-0.0543
lg r	-30.5	-0.104	-0.169	-4.077
pine	-17.3	-0.0276		
spruce	-12.9			
spruce* ρ_{12}			0.0000654	0.00428
ρ_{12}			0.0005936	0.02788
u	-0.63		-0.02	
R^2	0.60	0.13	0.78	0.59

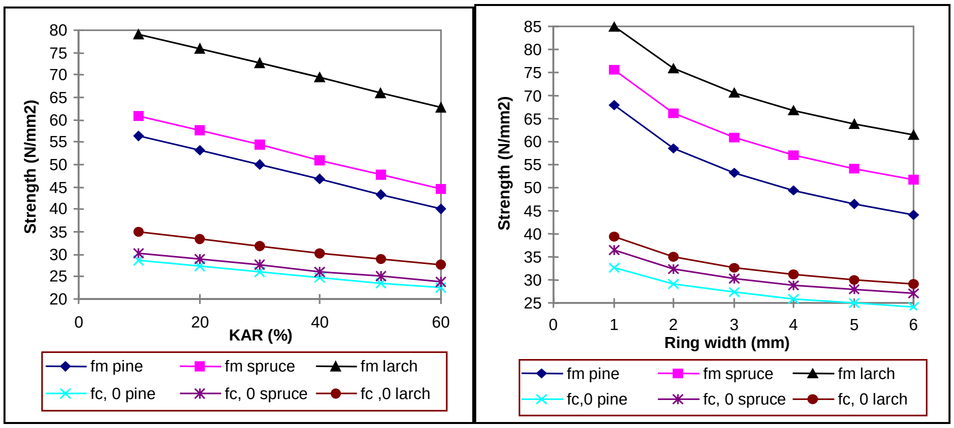


Figure 3.21. Illustration of the effect of KAR and ring width on the bending and compression strength of species when u = 12 %, p_{12}= 400 kg/m^3 for pine and spruce and 500 kg/m^3 larch, r = 2 mm for larch and 3 mm for pine and spruce or KAR = 10 % for larch and spruce, and 20 % for pine.

3.3.5 Effect of diameter

The effect of diameter is also analyzed in tabulated form (Tables 3.12 and 3.13) in bending and compression. The mechanical properties are adjusted to 12 % moisture content in accordance with the EN 384 standard. For E_m a clear positive trend was observed, i.e. the values increase with the increasing diameter of round timber. For other mechanical properties, no positive or negative size effect was observed, even when other physical properties were also taken into account. The results of Douglas fir, not included in the statistical analysis, clearly show that bending strength and stiffness increases with increasing diameter from 80 to 130 mm.

Table 3.12. The effect of diameter on the E_m and f_m (adjusted to 12 % MC) of round timber.

	d	*d*	f_m	$f_{m,\,0,05}$	E_m	*u*	ρ_{12}	*ks*
	mm	mm	N/mm^2	N/mm^2	kN/mm^2	%	kg/m^3	%
	range	mean	mean	by rank	mean	mean	mean	mean
Scots pine UK+FIN								
n = 27	...100	91	48.6	34.0	12.8	16.8	472	67
n = 58	100...130	120	54.4	35.1	12.7	16.5	495	71
n = 90	130...	144	47.4	31.5	12.9	18.1	492	87
Spruce A+FIN+UK								
n = 68	...100	87	66.7	52.0	13.3	15.5	465	32
n = 204	100...130	120	57.5	41.5	13.5	15.3	435	54
n = 113	130...	143	59.1	45.7	14.2	15.9	467	49
Larch								
n = 44	...100	98	76.0	51.0	13.4	14.4	573	30
n = 71	100...130	119	79.9	59.0	14.5	14.5	582	28
n = 70	130...	138	78.1	59.5	14.7	15.4	576	26
Douglas								
n = 60	80	80	48	32.5	7.0		460	
n = 29	...100...	100	82	34.4	11.0		442	
n = 180	120	120	52	36.8	11.1		442	
n = 120	...135...	135	58	37.2	16.8		430	

Table 3.13. The effect of diameter on the $E_{c,0}$ and $f_{c,0}$ of round timber.

N	d mm range	d mm mean	$f_{c,0}$ N/mm^2 mean	$f_{c,0,0,05}$ N/mm^2 by rank	$E_{c,0}$ kN/mm^2 mean	u % mean	ρ_{12} kg/m^3 mean	ks % mean
Scots pine								
42	...100	86	23.8	17.9	9.0	17.3	457	84
157	100...130	120	32.0	23.7	11.7	15.2	509	61
75	130...	142	28.5	19.9	11.4	17.0	493	86
Spruce								
80	...100	80	32.2	25.1	13.4	16.1	449	42
163	100...130	120	28.5	20.3	10.9	15.9	431	66
57	130...	137	31.0	25.5	12.9	17.3	468	63
Larch								
21	...100	98	44.1	32.9		14.2	573	
20	100...130	118	43.8	37.0		14.4	583	
20	130...	138	45.8	37.3		15.0	592	
Douglas								
34	80	80	30	25	11.9			
40	80...	95	39.1	31.9	11.5			
60	120	118	31	25.4	10.9			
39	...120...	130	31.4	25.1	9.5			

The effects of age, diameter, knots, ring width and moisture content on the mechanical properties of machine round timber were analyzed separately for Finnish material by regression analysis (Boren 1999). Figure 3.22 shows the effect of density on the mechanical properties in bending and compression for machine-rounded pine and spruce for different ring widths.

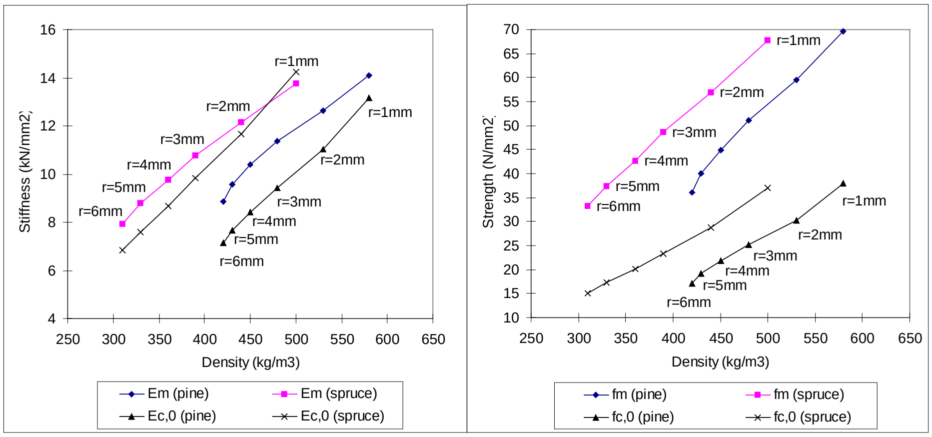


Figure 3.22. The effect of density on the mechanical properties in bending and compression for machine round pine and spruce at diameter 125 mm, KAR is 23.9 % and moisture content 12 %.

The effect of diameter could not be observed, because the effects of growth rate and diameter are interrelated. Therefore, the effect of age was studied separately. The effect on the characteristic compression strength for the Finnish material is illustrated in Figure 3.23, which clearly shows that a higher age gives higher characteristic compression strength.

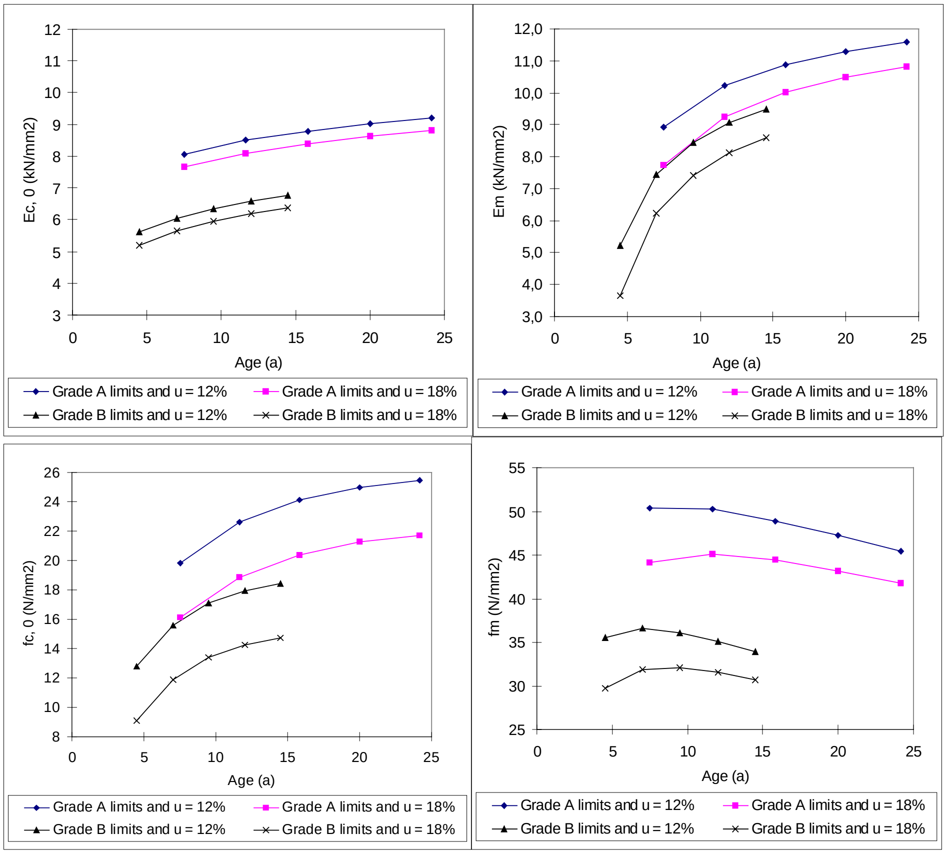


Figure 3.23. The effect of age on strength and stiffness calculated by regression models for machine rounded pine. For both grades grade A and B limits are used for ring width and knots, density is 440 kg/m^3 and diameter ranged 75…175 mm.

The figure indicates a clear age dependence on compression properties and modulus of elasticity. Effect on bending strength is not so obvious.

3.3.6 Buckling strength

The buckling test results for French Douglas Fir species were compared to the design equation

$$\sigma_{c,crit} = \pi^2 * E_{0.05} / \lambda_y{}^2 \qquad (3.10\ )$$

with the slenderness ratio $\lambda_y = \lambda_z = \left(l_0 - 2*150mm\right)/\rho$ and *the radius of gyration* $\rho = \left(\pi * \phi^4 / 64\right)^{1/2} / \left(\pi * \phi^2 / 4\right)^{1/2} = \phi / 4$.

48 tests with cylindrical specimens were carried out. Experimental values of the compression and buckling tests, as a function of the slenderness ratio, were compared to the calculated buckling stress as follows:

1- Buckling strength is calculated based on values of strength class C24: $E_{0.05}$ = 7400 N/mm^2. If the predicted value of $\sigma_{c,crit}$ exceeds $f_{c,0,k}$ for the C24 strength class, this later value is retained ($f_{c,0,k}$ = 21 N/mm^2).

2- Buckling strength is calculated also based on the material values obtained in this research: $f_{c,0,k}$ = 25.1 N/mm^2 and $E_{0.05}$ = 7700 N/mm^2.

A comparison of these three cases is illustrated in Figure 3.24, which shows that the predicted values of the critical stresses are conservative. The figure indicates that the safety of slender round compression members is higher than the safety of members where buckling is prevented.

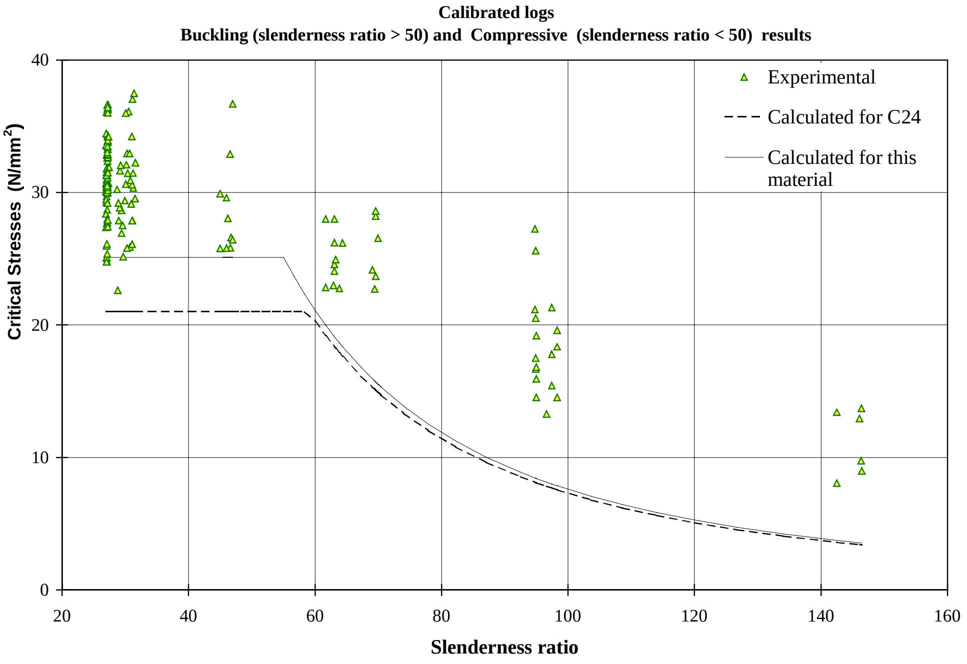


Figure 3.24. Results of buckling tests and calculated buckling stresses.

3.4 Strength-grading

During the last 10 years grading systems for sawn timber have been developed and improved in order to increase the yield with respect to strength. A reasonable relationship has been found between the modulus of elasticity, some visual features (knots, growth ring data) and the bending strength. Both visual and machine strength-grading are established in the wood industry, and the trend is now towards machine strength-grading.

Clearly, for small-diameter roundwood visual strength-grading systems need to be established first. This is because visual grading is the cheapest method and less investment is needed, which is essential for when starting small businesses. Machine grading becomes possible for small-diameter roundwood, when its use as load-bearing material has increased and enterprises exist who are willing to invest in order to increase the yield of their production.

In this research, both short-term and long-term objectives have been focused upon. As a short-term objective, simple visual rules have been developed in order to enhance the commercial use of small-diameter round timber as building material. As a long-term objective, NDT methods have been studied, and it has been shown that NDT is especially applicable for grading round timber.

3.4.1 Visual grading

In principle, every visible timber property or feature is suitable for strength-grading, provided that a relationship exists between the property and the strength and stiffness. Some examples are: slope of grain, annual ring width, knots, wane, distortions and decay caused by micro-organisms.

Grading rules that apply limits to visible properties enable the prediction of the strength of a piece of timber based on established relationships between the visible features and the member strength. Visual strength-grading is therefore defined as classifying timber according to its strength, based on statistical relationships between visible features and the load-carrying capacity.

Based on the experience with sawn timber, there are some disadvantages in visual grading (Blass et al. 1995), for instance, the relatively weak relationship between the measured parameters and the strength, e.g. correlation (r-value) factors for knots about 0.5, ring width 0.4 (Görlacher 1990). Extensive research is necessary to determine visual grading parameters that will enable the wood industry to classify small-diameter roundwood. Different species are likely to need different limits for grading parameters.

3.4.1.1 Determination of visual grades

Based on the statistical analysis of strength data performed by the different participants, a selection of visual strength-grading parameters was made: maximum knot-size per diameter, knot sum per diameter and maximum growth ring width, and preliminary limits for these parameters were set. A synopsis of the grading criteria based on this research is given in Table 3.14. A proposal for a grading standard was drafted and is published as Appendix B.

Table 3.14. Preliminary values for main strength-grading criteria of round Scots pine, Norway spruce and larch timber.

Strength-grading criteria	Grade A	Grade B	Larch Grade A
Knot sum per diameter ks/d [%]	75	100	65
Max. knot per diameter mk/d [%]	25	30	35
Ring width r [mm]	3	5	4
(mk/d) * r [mm]			0.8

3.4.1.2 Characteristic values for grades and species

The grading criteria specified above were applied to the tested samples of Scots pine and Finnish Norway spruce. Norway spruce had an initial sample size 200, of which 143 bending specimens and 149 compression specimens fulfilled the limits of grade A. The unsorted material met strength class C30 requirements except for density, which met C18. Obviously, density is the critical factor which determines the strength class. This material was divided into 3 samples according to the moisture content of specimens. In Table 3.15 the results are summarized: number of specimens meeting grading criteria, and mechanical characteristics of the sample. Because so many specimens passed grade A limit, sorting was not carried out for grade B.

UK Scots pine material had 100 specimens in bending and compression. Finnish Scots pine material had 150 machine-debarked specimens in bending and compression. The unsorted material suggested that C30 is possible but compression strength is difficult to achieve. Of this material, 70 UK and 52 Finnish bending specimens, and 73 UK and 47 Finnish compression specimens passed the limits of grade A, and 127 Finnish bending specimens and 119 compression specimens passed the limits of grade B given in Table 3.14.

The 5-percentile values of the samples are determined by the following methods:

- For strength properties $f_{c,0}$ and f_m a non-parametric method is used, i.e. it is a test value for which 5 % of the values are lower. If this was not an actual test value, then interpolation between two adjacent values was permitted.

- For ρ it was calculated from a normal distribution: ρ_{05} = (Mean ρ_{12} - 1.65*s), where s is standard deviation for the sample.

Table 3.15. 5-percentile values of graded round-pole samples in ***bending****, adjusted to 12 % MC in accordance with EN 384 except for size adjustment.*

Grade	Sample	Mean *d* [mm]	Mean MC [%]	Sample size	ρ_{05} [kg/m^3]	$f_{m,05}$ [N/mm^2] by rank	$E_{m,mean}$ [kN/mm^2]
A	FIN spruce 1	100	13.5	47	394	45.0	12.9
A	FIN spruce 2	117	14.6	48	368	52.5	12.8
A	FIN spruce 3	115	19.2	47	411	46.2	14.1
A	FIN pine	117	14.7	52	433	38.3	12.5
A	UK pine	127	19.1	70	466	41.9	15.4
B	FIN pine	126	15.2	127	416	35.2	11.8

Table 3.16. 5-percentile values of graded round-pole ***compression*** *samples, adjusted to 12 % MC in accordance with EN 384 except for size adjustment.*

Grade	Sample	Mean *d* [mm]	Mean MC [%]	Sample size	ρ_{05} [kg/m^3]	$f_{c,05}$ [N/mm^2] by rank
A	FIN spruce 1	100	13.8	49	381	28.2
A	FIN spruce 2	100	14.6	50	389	29.6
A	FIN spruce 3	108	18.7	50	362	25.1
A	FIN pine	124	11.1	47	434	28.6
A	UK pine	126	17.4	73	462	26.8
B	FIN pine	123	13.8	119	404	21.7

3.4.1.3 Strength classes for grades

The equivalence between the visual grades and strength classes is considered on the basis of the results summarized in Tables 3.15 and 3.16. The requirements for European C-strength classes (EN 338) are summarized in Table 3.17 below for poplar and conifer species. A timber population may be assigned to a strength class, when characteristic values of E_m, f_m and ρ at 12 % moisture content are greater or equal to the limits given in Table 3.17. Compression strength is also included in Table 3.17, since it has been considered as a strength classification criterion, in addition to the requirements of CEN 384. As a result, it is concluded that grade A Scots pine and Norway spruce meet the requirements of C30 and grade B Scots pine C18 (Table 3.18).

The characteristic value of strength for a population in a grade, f_k , is calculated in accordance with CEN 384 to be:

$$f_k = f_{05} k_s k_v \tag{3.11}$$

where f_{05} is the weighted mean of the sample's fifth percentile values, k_s is a factor relative to the number of samples and their size, and k_v = 1 for visual grading.

The characteristic value of ρ is calculated as the mean of the sample's fifth percentile values weighted by sample sizes, and the mean value of E is the mean of the sample's mean values weighted by sample sizes, without consideration of Eqn (3.11).

Table 3.17. CEN-strength classes and some of the characteristic values for poplar and conifer species according to the EN 338 standard.

	C14	C16	C18	C22	C24	C27	C30	C35	C40
$f_{m,\,k}$ [N/mm^2]	14	16	18	22	24	27	30	35	40
$f_{c,\,0,\,k}$ [N/mm^2]	16	17	18	20	21	22	23	25	26
$E_{m,\,mean}$ [kN/mm^2]	7	8	9	10	11	12	12	13	14
$\rho_{12,\,k}$ [kg/m^3]	290	310	320	340	350	370	380	400	420

Table 3.18. Characteristic values of graded populations and location according to strength classes.

Species country	Grade	k_s	$f_{m,k}$ [N/mm^2]	$f_{c,k}$ [N/mm^2]	$E_{m,mean}$ [kN/mm^2]	ρ_k [kg/m^3]	Strength class
Norway spruce (FIN)	A	0.91	43.6	25.1	13.3	384	C30
Scots pine (FIN, UK)	A	0.84	33.9	23.1	14.0	450	C30
Scots pine (FIN)	B	0.86	30.2	18.7	11.8	411	C18

3.4.2 Dynamic modulus of elasticity as a grading parameter

A closer correlation between the strength and grading parameters produces a lower variation within a timber grade and consequently gives a better yield for the grades. Most of the machines used for grading sawn timber are based on stiffness measurements, using the close relationship between the stiffness or the modulus of elasticity of a piece of timber and its strength. The correlation between E and f_m is about 0.7–0.8 (r-value) for sawn timber, and is similar for the round timber in this study.

In order to determine a strength-grading system, the measured features and properties, including E_{dyn}, were correlated with f_m. The results for Larch are presented in Table 3.19.

Table 3.19. Correlation coefficients (r) between significant parameters for Larch (Gard et al. 1998).

	f_m	ρ_0	$E_{m\ dyn}$	$E_{m\ global}$	$E_{m\ local}$	knot	growth ring
f_m	1.00						
ρ_0	0.65	1.00					
$E_{m\ dyn}$	0.76	0.75	1.00				
$E_{m\ stat\ global}$	0.76	0.66	0.85	1.00			
$E_{m\ stat\ local}$	0.72	0.64	0.82	0.91	1.00		
knot value	-0.64	-0.45	-0.61	-0.56	-0.53	1.00	
growth ring value	-0.56	-0.34	-0.52	-0.52	-0.43	0.55	1.00

Table 3.19 shows the strongest single correlation with f_m to be obtained from $E_{m\ dyn}$ and $E_{m\ stat\ global}$. Even higher correlation values can be obtained by applying strength models with multiple parameters, which were analyzed by multiple regression analyses. The results are shown in Table 3.20, in which the different parameters considered in the model are marked.

Table 3.20. Correlation coefficients (r) between f_m and parameters involved in the model (Gard et al. 1998).

Model	Correlation coefficient (r)	Model parameters				
		$E_{m\ dyn}$	$E_{m\ stat\ global}$	Density	Knots	Growth ring
1	0.76	x				
2	0.77	x		x		
3	0.79	x			x	
4	0.79	x				x
5	0.76		x			
6	0.79		x	x		
7	0.80		x		x	
8	0.79		x			x
9	0.81	x		x	x	x
10	0.80	x		x	x	
11	0.82		x	x	x	x
12	0.82		x	x	x	
13	0.70				x	x

The best result for the prediction of bending strength (f_m) was obtained with model 12, linking static bending stiffness with density and knot size.

Grading system for roundwood

One of the key strength properties concerning the strength classes is the bending strength. From the results obtained, the following conclusions can be drawn:

- The correlation coefficients of the regression models for larch roundwood correspond very well with the models used for sawn timber in the wood industry (Blass et al. 1995).

- Visual features such as knots and growth rings have a lower correlation with strength than with the modulus of elasticity.

- The highest correlation can be achieved by models in which information on the modulus of elasticity, knots and density is combined.

- Where roundwood is used in construction as an engineering material, it could be economical to develop a grading machine. The particular problems of a roundwood bending-test arrangement suggest that the vibration measurement apparatus to determine modulus of elasticity will be of great value.

3.4.3 Grading by X-ray

Linear regression analysis was used to analyze the feasibility of an X-ray method as a strength-grading machine for round Douglas fir. Material characteristics are given in Table 3.21. The methods compared included an X-ray method comprising 10 measured parameters, an ultrasonic (Sylvatest) method (12 parameters), annual ring widths and a knot criteria method. The Sylvatest measures only the speed of ultrasonic wave propagation in the wood. These speeds measured at different points constitute a first family of parameters.

A theoretical formula provides the relationship between density, modulus of elasticity and the speed of ultrasonic waves. Therefore a second family of parameters corresponds to the modulus of elasticity, assessed with the formula below:

$$E = \rho v_{us}^2 \tag{3.12}$$

where v_{us} is the velocity of ultrasonic wave.

This second family is, generally speaking, better related to the modulus of elasticity, but it requires the knowledge of density, which means that another machine is necessary for its measurement.

X-ray and Sylvatest give practically the same accuracy for the prediction of bending strength ($R^2 = 0.3$) as indicated in Table 3.22.

Table 3.21. Characteristics of Douglas fir used for grading study (N=180, d=120 mm).

	f_m MPa	local E GPa	global E GPa	KAR %	Moisture content %	ρ kg/m ^{3}
Mean	52.5	11.1	9.4	24.0	12	442
5% value	36.8	7.7	7.3	12.0	10.3	367
st. dev.	9.9	2.5	1.3	8.7	1.1	51

Table 3.22. Comparison of grading methods applied to Douglas fir.

Source of parameters	Number of parameters	R² for f_m prediction	R² for global E prediction
X-ray	10	0.28	0.51
Sylvatest	12	0.29	0.65
Anual rings	2	0.046	0.025
Knots (KAR/KVR)	5	0.21	0.40
All	30	0.45	0.76

X-rays grading benefits from several advantages in comparison with visual grading:

- Measurement of the density is more precise (medium value of error 4 kg/m^3).
- The whole calculation is quicker than the measurement and location of KAR.
- The location of the main defect is reliable (the location of bending failure is predicted for 96 % of cases in a maximal nodosity location).
- X-ray grading allows the grading to be automated and increases the productivity.

4. Mechanical connections

4.1 Potential roundwood connections

The project focused its attention on a selected range of pole diameters: 8–16 cm: thin roundwood. For structural purposes, nominal values of pole diameters were applied: the lower boundary of a selected range of pole diameters. The applied nominal values are 75, 100, 125, 150 and 175 mm.

An important aspect in the use of roundwood is its behaviour with respect to drying. Roundwood shows a greater amount of shrinkage in the circumferential (tangential) direction than in the radial direction. Tangential shrinkage usually leads to the formation of cracks and radial shrinkage often has the effect that connectors (bolts or lacings) can become loose after some time.

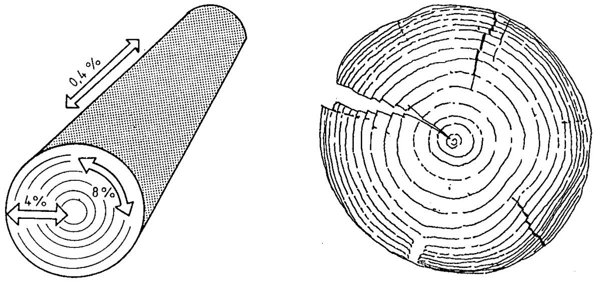


Figure 4.1. Shrinkage and cracking of roundwood due to drying.

The axial crack formation may cause special problems in the application of thin roundwood, since fasteners in the connections may coincide with the cracks (see Figure 4.1). That is why special attention must be paid to this problem of securing the safety of thin roundwood structures. As shown in Chapter 2.3, cracking can be minimized by selection of the drying method.

4.2 Laced joints

4.2.1 Description of laced joints

At the TUDelft, extensive research has been carried out on structural applications of roundwood timber. This research resulted in the execution of various structures. In this work, experimental and practical experience was obtained with the development and behaviour of connections in roundwood. The developed connections represent a special type since, apart from dowels lacings were used to reinforce the connections.

During the project period, the experience gained with laced connections was analyzed and evaluated to formulate design rules for this type of roundwood connections. To this end, first the strength test results of roundwood connections using dowel-like fasteners supported by wire lacings were analyzed. Subsequently, the results were compared with theoretically determined strength capacity values using Johansen's equations. Finally, the structural design of these roundwood connections was related to the dimensioning methods used for rectangular sawn wood, as prescribed in Eurocode 5.

Many tests were carried out at the Delft University of Technology on wire-laced dowel connections. In principle two types were developed.

- Type one (see Figure 4.2):

  A pole is slotted along a diameter line to allow insertion of a (galvanised) steel plate. Two hollow dowels are inserted through pre-drilled holes in the wood pole and steel plate. The end-distance is 4.4 to 4.7 x dowel diameter and dowel spacing is 4.7 to 5.8 x dowel diameter. The connection is secured by 2 or 4 wire bindings, 4–5 mm thick, on each dowel. Two wires are laced around the half pole section perimeter and through the hollow dowels. The other two wires are laced in a similar manner on the remaining half-perimeter of the pole. A fifth wire is sometimes added around the full-pole diameter without routing through the hollow dowel hole.

- Type two (see Figure 4.3):

A pole is slotted along a diameter line to allow insertion of a (galvanized) steel plate. Two bolts are inserted through pre-drilled holes in the wood pole and steel plate. The end-distance and bolt spacing are 7 x hole diameter. The connection is secured by 4 wire bindings, 4–5 mm thick, on each bolt. The wires are laced around the full-pole diameter without routing through the bolt hole.

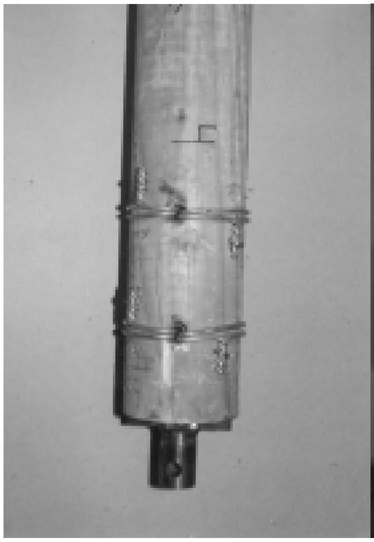


Figure 4.2. Connection with hollow dowels.

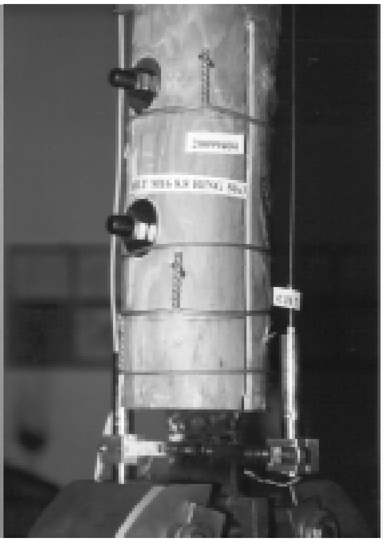


Figure 4.3. Connection with bolts.

Tests were carried out to determine the design loads of these connections, which were used in several space frames. Comparable tests were carried out by an English research institute, the Timber Research and Development Association (TRADA). These test data were also used to analyze the wire-laced dowel-type connection.

4.2.2 Estimation of load capacity of wire-laced joints

The estimation of the load-carrying capacity of wire-laced dowel joints is based on the European yield theory adopted in EC 5. The test results of roundwood joints show values that differ from the values obtained by the yield theory. They provide information about the maximum strength of the connection and about the failure mode that occurs.

In two steps the test results are compared to the calculation procedures for connections applied in EC 5. In step 1 the mean results of the different test series are compared with the estimation of the failure strength using the European yield theory. In step 2 a statistical analysis is applied to evaluate the findings of step 1. To this end, the embedment strengths that occur during testing are compared with the prescribed values in EC 5.

Failure Modes

Generally, the wire-laced dowel joint showed a similar failure behaviour as described by the yield theory. However the mechanical behaviour of the connections was influenced by the presence of the lacings: the lacings prevented the wood from splitting. It may be assumed that the lacings introduced a friction into the connection which contributed to a higher load-carrying capacity of the connection. This assumption was confirmed by the test results.

Failure modes which may occur:

1. Failure on embedment strength.
2. Failure of the dowel with one plastic hinge and failure of the wood, partially on maximum embedding strength.
3. Failure of the dowel with three plastic hinges and failure of the wood partially on maximum embedding strength.
4. Failure on shear strength of the piece of wood under the dowel.
5. Failure on tensile strength of the net cross-section.
6. A new or old crack could not be kept closed by the lacings impairing the force transfer from dowel to wood.

The first 3 failure modes correspond to the modes described by the yield theory. The failure modes 4 and 5 may occur if the connection layout design is wrong. It is clear that these failure modes represent cases of undesired failure behaviour and, consequently, should be avoided. Failure mode 6 is a specific problem of roundwood. If the lacings are properly applied, this will not be a restrictive failure mode.

Assumptions

For the estimation of the strength of the joint the following assumptions were applied:

- The values used for the estimation were average values, as the number of tests was too small to derive 5th percentile values. An approximation of the 5th percentile values was found through the application of a statistical analysis.

- The prescribed end-distances were not observed. Since no shear or tensile failure occurred during testing but a regular failure mode 2, according to EC 5, it may be assumed the end distances were sufficient for the development of the maximum embedment strength in the connection.

- The pole diameter was considered as the width of the connection. The reason was that the dowels traversed the centre of the pole and thus had the length of the pole diameter. The development of the embedment strength took place under the dowel. The lack of surrounding wood was compensated by the lacings.

- A distinction was made between one and two wires *per* dowel. As most of the connections made use of 2 dowels, 2 and 4 lacings per connection were used. The bolted connections always had two wires per bolt.

- The formula specified in EC 5 for dowel-type connections was used for the calculation of the embedment strength.

Estimation

The characteristic data of the test series are collected in Table 4.1. The number of specimens in each test series is in the range from 4 to 16. Three main groups of connections can be distinguished:

group 1: connections with 2 wires per dowel
group 2: connections with 1 wire per dowel
group 3: connections with 2 wires per bolt

Step 1

In this section the lowest values of the yield theory are compared with the mean values of the test results. Failure modes 1, 2 and 3 correspond with those mentioned in part 4.2.

Table 4.1. Comparison of test results and Yield Theory.

Test series	Wood-type	No. dowel	ø dowel	No. wire	ø pole	Wood density	Mean test value	Yield theory failure mode 1	Yield theory failure mode 2	Yield theory failure mode 3
			mm		mm	kg/m^3	kN	kN	**kN**	kN
P1	Scotch P	2	17	4	100	estim.	71.11	91.1	**55.5**	69.2
P2	Scotch P	2	17	4	100	known	68.9	91.1	**51.4**	60.3
L2	Larch	2	21.3	4	120	known	124.6	154.5	**94.9**	119.0
L6	Larch	4	21.3	8	200	average	281.3	*417.5*	***214.3***	222.6
RVS-4	Larch	2	17	4	120	known	75.3	133.9	**63.2**	72.9
Galv-4	Larch	2	17	4	120	known	71.8	108.6	**60.8**	70.8
P3	Scotch P	2	17	2	100	known	58.4	84.6	**48.7**	58.1
L3	Larch	2	21.3	2	120	known	107.42	153.9	**94.7**	118.8
Galv-2	Larch	2	17	2	120	known	69.4	111.2	**61.7**	71.0
L4	Larch	2	16	4	150	average	151.99	140.7	***90.3***	116.1
L5	Larch	2	16	4	120	average	135.94	114.4	***85.5***	116.1
L7	Larch	4	16	8	200	average	311.1	338.7	***194.7***	232.3

According to EC 5, the lowest value of failure mode 1, 2 or 3 is restrictive. The calculations show that failure mode 2 is always restrictive. The tests showed (see Figures 4.4 and 4.5), that failure indeed occurs according to failure mode 2.

A first impression is (see Table 4.4, failure mode 2) that the calculated values represent a conservative approximation of the test values. The difference between test result and the lowest yield theory value (failure mode 2) is rather small for the dowel connections. This is, however, not the case for the bolted connections (L4, L5, L7).

Figure 4.4. Failure mode 2.

Figure 4.5. Failure mode 2.

Step 2

To give an indication of the safety interval of the connections, a statistical analysis was done. The analysis was focused on the comparison of the occurring maximum embedment strength during testing and the prescribed embedment strength of EC 5. To this end, the embedment strength, $f_{h,1,d}$, occurring in the connection during testing, was calculated by means of the yield theory, taking into account that failure mode 2 is applicable:

$$R_d = f_{h,1,d} t_1 d \left[\sqrt{2 + \frac{4M_{y,d}}{f_{h,1,d} d t_1^2}} - 1 \right] \qquad (4.1)$$

The value of $f_{h,1,d}$ is, subsequently, compared with the embedment strength formula, figuring in EC 5, assuming γ=1 and k_{mod}=1 which gives $f_{h,1,d} = f_{h,k}$:

$$f_{h,k} = 0.082(1\text{-}0.01d)\rho_k. \qquad (4.2)$$

A linear regression analysis was performed on the relation between the embedment strength derived from the test values and the density of the wood. As not all the wood densities were known per test specimen, only those series were analyzed from which information was available.

The embedment strength, derived from the test series ($f_{h,\ test}$), was considered as the dependent variable. The independent variables were the wood density and the dowel diameter. The dowel diameter is a constant coefficient and is therefore combined with the wood density resulting in the independent variable ρ_v. So the following relationship was analyzed:

$$f_{h,1,d} = f_{h,test} = C\ (1\text{-}0.01d)\rho_v \qquad (4.3)$$

Hence, C can be compared with the value 0.082 of Equation (4.2).

Group 1: P2, L2, RVS-4, Galv-4 (2 dowels, 4 wires)

From the first group of test results, the connection with 4 lacings, 4 of the 6 test series were sufficiently documented to be used. In total, 55 test values were available.

From the second group of test results all the data sets were used, in total 17 test values.

The bolt test series were not sufficiently documented to be used for a regression analysis. At the moment, a new test series is being prepared to establish an embedment formula for laced-bolted connections.

To give an indication of the $f_{h,1,d}$ value, the average values were used and a 5th percentile values were estimated. Table 4.2 shows the results of the statistical analysis.

Table 4.2. Statistical analysis.

Group 1	**C**	Stand. Deviation	Lower limit	Upper limit
P2	0.113	0.007	0.098	0.129
L2	0.112	0.006	0.098	0.126
RVS-4	0.097	0.003	0.091	0.103
Galv-4	0.094	0.004	0.085	0.104
Total	0.103	0.003	0.098	0.109
Group 2	**C**	Std. deviation	Lower limit	Upper limit
P3	0.092	0.004	0.085	0.104
L3	0.097	0.006	0.084	0.111
Galv-2	0.092	0.004	0.085	0.104
Total	0.097	0.003	0.090	0.104
Group 3	average $f_{h,test}$	**C**	st. deviation	**C** 5th %
L4+L5+L7	62.65	0.1545	0.0314	0.103

Comparing the C-values with the 0.082 EC 5 value, they are always higher (see Table 4.3).

Table 4.3. Lower 5th percentile C-values as a function of connection type.

	Group 1 2 dowels, 4 wires	**Group 2** 2 dowels, 2 wires	**Group 3** bolts
C-value	0.098	0.090	0.103

It may be concluded that the C-values are a function of the type of connection. The separate evaluation of the three groups provides some insight into the efficiency of the various connection methods.

Especially the bolted connection shows a large deviation in strength from the yield theory values. Therefore some additional tests were performed to investigate deeper the influence of the lacings. To this end, embedding-strength tests were performed with the exception that one plastic hinge in the dowel was consented. The occurring embedment strength was derived from the test result in a similar way as described in part 4.3 step 2.

There were 3 groups of tests done. Group L8 had one belt and one dowel and a diameter of 115 mm. L9 was similar but had a diameter of 135 mm. L10 was similar to L8 but did not have a belt. The results are listed in Table 4.4.

Table 4.4. Results of embedment tests.

Test series	Wood-type	No. dowel	ø dowel	No. belts	ø pole	Wood density	Mean test value	Yield theory failure mode 2
			mm		mm	kg/m³	kN	kN
L8	Larch	1	16	1	115	known	66.3	67.1
L9	Larch	1	16	1	135	known	71.7	70.2
L10	Larch	1	16	0	115	known	59.2	65.6

A statistical analysis was carried out in a similar way as for Table 4.2. The results are shown in Table 4.5.

Table 4.5. Statistical analysis.

Group 1	**C**	Stand. Deviation	Lower limit	Upper limit
L8	0.082	0.003	0.073	0.087
L9	0.086	0.006	0.069	0.103
total	0.082	0.003	0.076	0.088
L10	0.067	0.007	0.047	0.087

From the results, it can be seen that the test result comes very close to the estimated values (Table 4.1). There is also very little deviation in the results. When no belts are applied the results are lower than the estimated values. It can be concluded that, when hollow dowels with wires or bolts with nuts are employed, there is no extra strength effect due to friction. The use of the connections is illustrated in Figure 4.6.

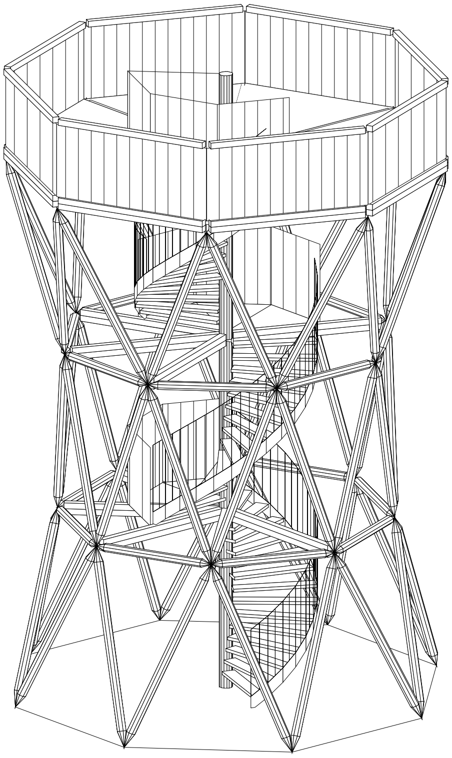


Figure 4.6. Watch-tower project in which strapped bolt connections are applied.

4.3 The Block Joint

4.3.1 Description of the joint

From a market survey that was held amongst architects and construction designers, it was found that one of the reasons for not using roundwood as a structural material was the aesthetics of the connections so far used. In their opinion, the connections using wire straps around the poles are aesthetically unattractive; furthermore, the manufacture of this connection is generally rather time-consuming and therefore expensive; a general complaint is that, for roundwood connections, no calculation methods are available to dimension them adequately.

Additionally, there is the problem of cracks that influence the strength of the joint. The existing joints all use dowel-type fasteners; for small-diameters the dowel is necessarily placed axially, while cracks may occur axially as well. A loss of connection strength may be assumed if the dowel is placed over a crack.

With the above-mentioned points in mind, a new type of joint was developed and tested. The description of the joint, the tests carried out, and the design rules that follow from these tests are reported.

Different parts of the joint

The joint is fixed to a roundwood pole with a milled slot at about 200 mm from the end. From the head of the pole to this slot a hole is drilled into the longitudinal direction. To enable the joint to transfer tension forces, a steel block is placed in the milled slot. Then a steel rod is placed into the drilled hole and screwed into the steel block (Figure 4.8).

On top of the beam, a round steel disc is screwed onto the rod. This disc positions the steel block inside the beam. Furthermore, it ensures an even distribution of the stresses in case of compression forces. The last part of the connection consists of a hexagonal hollow bar with a screw thread on one side and a cover plate with a small hole in it on the other side. The screw-threaded side is screwed to the rod in order to secure the fixing of the disc and to transfer the tension forces into the rod.

Before fixing the hexagonal bar to the rod, a bolt is placed into the hollow section in such a way that it sticks out of the cover plate. By adding two small steel elements, the bolt can now easily be connected to a node. In this way, the connection is very similar to the well-known and often used MERO-connection (Figure 4.7).

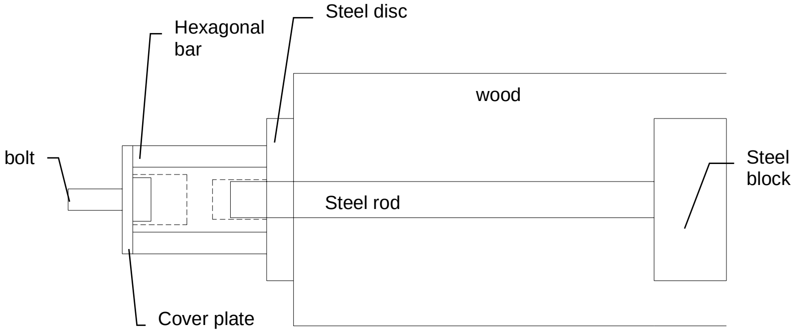


Figure 4.7. Cross-section of the block-joint connection.

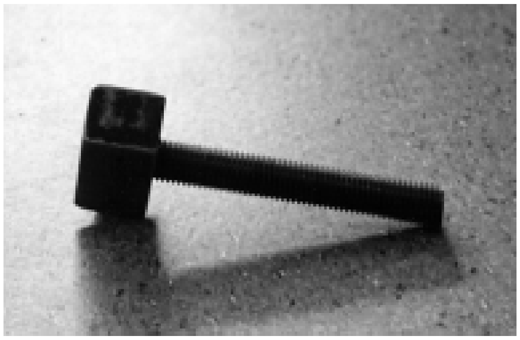


Figure 4.8. Steel block attached to steel rod .

During the test series, the dimensions of the different parts of the joint were varied in order to optimize the strength of the connection itself. This resulted in roughly the following dimensions for the different pole diameters, as given in Table 4.6.

Table 4.6. Dimensions of the different parts of the connection.

Part of the connection	Pole diameter 140 mm	Pole diameter 100 mm
Steel block dimensions	85 x 40 x 40 mm^2	75 x 30 x 30 mm^2
Steel rod diameter	M20	M16
End distance	250 mm	180 mm
Disc thickness	15 mm	12 mm
End bolt	M14	M12

Testing

When used in trusses, the joint has to be able to transfer both tension and compression forces. First, testing was focused on the tension testing of the joint, as in this way it would allow a comparison to be made of the strength and stiffness of the joint with known alternative solutions. In a later stage of the project, some compression tests on the complete joint were carried out.

All the tests were carried out on poles with diameters of 100 and 140 mm. The applied wood species was Japanese Larch with a density varying from approximately 400 to 550 kg/m^3 (the wood can be classified as C40). The moisture contents of the wood varied from 12 to 15 %.

All tests were carried out on a test bench with a maximum test capacity in tension of 15 tons. As the 140 mm joint sometimes appeared to be stronger than 15 tons, the various dimensions of the joint were in some cases different from the values given in Table 4.6. Varying the dimensions also gave much more insight into the behaviour of the joint and made it possible to optimize the joint by evaluating the different failure modes.

Failure modes

As stated before, testing was focused on the tension strength of the joint. Next to that, a few simple tests were carried out to obtain information on the compression strength of the joint.

If the joint was loaded in tension, five different failure modes may occur. In Figure 4.9, the stresses critical for different failure modes are presented.

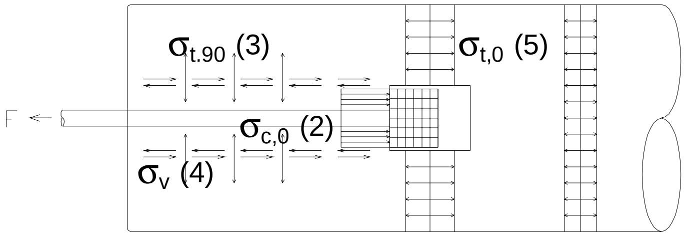


Figure 4.9. Occurring stresses in the connection.

Failure mode 1, Strength and stiffness of the steel block.

The tension forces in the steel rod are transferred to the wood by the steel block. Consequently, the wood underneath the steel block is loaded in compression. The block at the end of the rod must have sufficient stiffness in order to enable a uniform repartition of the compression stresses on the wood.

It goes without saying that, next to stiffness, the rod and the block must have enough strength to transfer the tension forces.

This failure mode turned out to be plastic. The stiffness of the steel block was tested by means of 2 test specimens. From the results the dimensions of the steel block were determined.

Failure mode 2, Embedment strength of the wood underneath the steel block

The wood is subjected to compression stresses that are introduced by the steel block. It is common for dowel-type joints that the combined effects of both the compression strength of the wood and the shape of the dowel, expressed in the embedment strength, are determined. If the dowel is flat, it is obvious that the embedment strength, found during testing, is almost equal to the compression strength of the wood itself. In this case the failure mode is plastic as well.

This type of failure was first tested in standardized tension tests. In order to calculate the embedment strength according to the standard procedure, an additional 40 pieces were tested in compression. In these tests, only the last part of the joint was taken into consideration.

Failure mode 3, Splitting of wood

The compression stresses underneath the steel block are transferred into tension stresses in the reduced cross-section area beside the slot. This is possible by a reversal of the force direction occurring in the end area of the pole (see Figure 4.9) facilitated through a complex combination of tension forces perpendicular to the grain and shear forces. The tension forces perpendicular to the grain may cause a splitting failure of the wood. As this failure mode is very brittle, such behaviour has to be prevented (Figure 4.10). By placing a steel strap around the beam at approximately a distance of half the beam width from the slot, splitting will not occur.

This type of failure was tested in the normal test set-up. The (four) test specimens were not secured with lacings and all failed as a result of splitting.

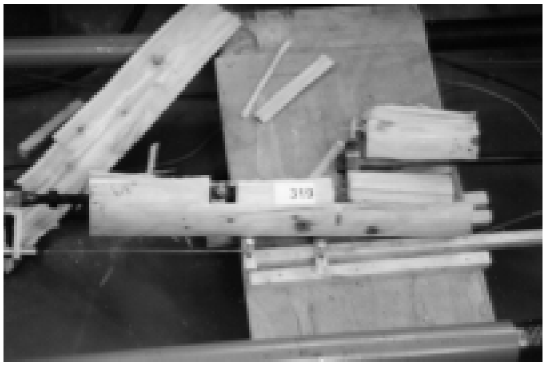


Figure 4.10. Failure through splitting.

Failure mode 4, Shear failure of the wood

The compression stresses underneath the steel block are transferred into tension stresses in the reduced cross-section area beside the slot. This is possible by a reversal of the force direction occurring in the end area of the pole (see Figure 4.9) facilitated through a complex combination of tension forces perpendicular to the grain and shear forces. Applying a strap the connection may fail in shear; in this case the shear strength of the wood is exceeded and a part of the pole is pushed out. This type of failure is brittle as well (Figure 4.11).

Tests were carried out on about 35 pieces in the standardized tension test.

Figure 4.11. Typical shear failure.

Failure mode 5, Tension failure in the reduced net cross-area

Finally, the pole itself was subjected to tension stresses. As a part of the wood is milled away in order to insert the steel block, the net cross-area is reduced. Tension stresses will be highest at this cross-section and the pole may fail under tension. This type of failure is once again brittle. The tension failure was tested by means of 20 poles with a diameter of 100 mm.

Failure of the joint loaded in compression

If the joint is loaded in compression, the covering steel plate will be pressed into the wood. Failure will occur if the embedment strength (=compression strength) of the wood is exceeded. This failure mode is plastic. Two tests were carried out as the maximum capacity of the bench was only 15 tons.

4.3.2 Test results

For the different failure modes, the test results are discussed.

Failure mode 1, Strength and stiffness of the steel

After the second test, the stiffness of the block was increased in order to enable a uniform distribution of the compression stresses. In order to make sure that the stiffness of the rods would not influence the stiffness of the joint too significantly, a rod with a bigger diameter was chosen. No further investigation has been done on the steel parts in the joint.

Failure mode 2, Embedment strength of the wood

A series of embedment tests was carried out according to a standardized testing procedure. It turned out to be difficult to determine the stiffness of the connection from these tests as the stiffness of the rod had to be taken into account as well. Furthermore, tension tests are not described for embedment strength testing. For this reason a series of supplementary tests was carried out.

These tests made it clear that this type of failure shows a very plastic failure behaviour and the strength is almost equal to the compression strength of the wood. The slot in the middle of the pole did not influence the strength at all. In order to protect the compression testing-bench from shear forces, the tests were stopped before a displacement of 15 mm was reached. However, tests were always run until the moment that the compression force was already decreasing for more than 1 minute.

Failure mode 3, Splitting of the beam

All poles tested without steel straps around them failed due to splitting of the pole. This happened with a lot of energy, causing pieces of wood to detach from the pole. The strength found for the joint (without straps) was about 60 % of the strength determined in the tests where a strap was applied. As the deviation in the test results was higher as well, no further tests without straps were carried out.

Failure mode 4, Shear failure of the beam

The shear strength of the wood depends on many parameters. First, as there are tension forces perpendicular to the grain as well, the strength will be lower than when tested in shear only. Then, there is the influence of cracks, knots and the geometry of the joint. And, last but not least, the cross-area over which shear will take place is very difficult to define. Therefore, one cannot compare the shear strength found in the tests with the strength given in the codes. The shear values found in the test series turned out to be approximately 50 % lower than expected from the standard values.

The influence of the shear area was also difficult to determine. If the shear failure of the joint is compared with that of a ring shear connector, a decrease in strength may be expected with increasing shear area (Figure 4.12). However, such a tendency could not be found in these test series.

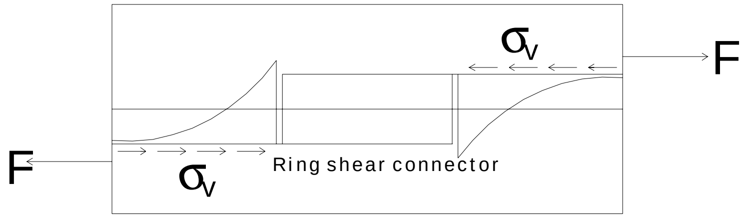


Figure 4.12. Shear strength of a ring shear connector.

Failure mode 5, Tension strength of the wood

The tension strength found in the test series is probably equal to the tension strength of the wood if knots and other small imperfections are taken into account. The tension strength was only tested for beams with a diameter of 100 mm, as the remaining cross-area for the beams with diameter 140 mm was too big. The forces would be higher than the maximum capacity of the bench.

Failure of the joint loaded in compression

Tests were carried out to determine the load-bearing capacity of the covering steel plate (Figure 4.13). The load-bearing capacity exceeded that of the testing bench (150 kN) and can be estimated (through evaluation of the contact area and the known compression strength of the material) to a value of 250 kN.

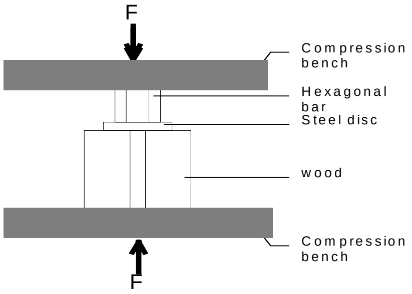


Figure 4.13. The joint tested in compression.

The compilation of test results is given in Table 4.7.

Table 4.7. Test results.

Failure mechanism		Pole diameter (mm)	No of tests	Mean (N/mm^2)	Minimum (N/mm^2)
Embedment	[f_h]	140	60	45.9	37.8
Splitting		140	2		
Shear	[f_v]	140/100	30	2.7	2.5
Tension	[f_t]	100	17	23.8	21.9

4.3.3 Design criteria for the joint

If the dimensions given in Table 4.6 are observed, and Japanese Larch of the same quality (see section ‘Testing of the Joint’) as used in testing is applied, the joint is able to transfer tension forces up to 110 kN (characteristic value) and compression forces up to 250 kN.

From the test results it was concluded that, taking into account

(i) certain joint detailing recommendations for compression, and

(ii) the necessary prevention of the splitting failure mode (via the application of a steel strap is placed around the pole),

three tension failure modes have to be checked, and the following equations are proposed:

Embedment underneath the steel block:

$$\sigma_{c,0} = \frac{F}{A_{block,net}} \leq f_{h,d} = 0.9 f_{c,0,d} \qquad (4.4)$$

Shear strength of the wood:

$$\sigma_{v} = \frac{F}{A_{shear}} \leq 0.4 f_{v,d} \qquad (4.5)$$

Tension strength of the wood:

$$\sigma_{t,0} = \frac{F}{A_{wood,net}} \leq 0.6 f_{t,0,d} \qquad (4.6)$$

4.4 Forced plate joint

4.4.1 Introduction

Forced plates provide a simple and practical solution for connecting round timber. The joints are easy to construct and various plate sizes are available. The plates are galvanized and pressed into different pre-formed shapes to enable different joint configurations to be produced; the plates are also pre-drilled for nailing. Ring nails are used to connect the plates to the timber and it is recommended that all the nail holes be used. The forced plates are manufactured in Germany (Rudolf Feicht gmbh. Metallverarbeitung, Arnstorfer Str. 10, 84326 Zell, Germany). Various configurations are available for building different structural forms and five plate sizes are offered for different diameter logs. Typical dimensions of one plate are shown in Figure 4.14. In this example, a plate for a 13–17 cm diameter log is used.

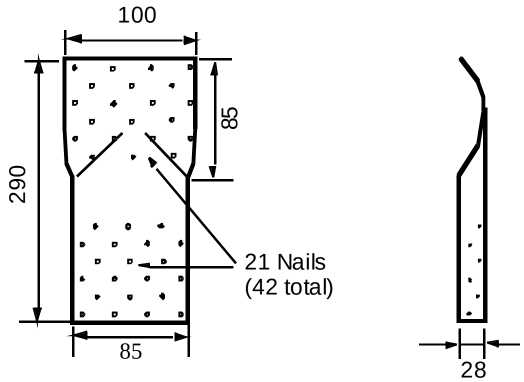


Plate thickness = 1.5mm
Nail = 60mm ringed shank (penetration = 57mm)
Nominal diameter = 3.5mm
Nails to comply with DIN1052
(Note: The dimensions shown are measurements from a plate)

Figure 4.14. Typical plate dimensions (ref 13–17 cm).

4.4.2 Calculation

Calculations may be based on the equations given in Eurocode 5: Design of Timber Structures (1994). Here, a calculation example is shown and the assumptions made are as follows:

- Plates fully nailed
- Loads acting axially
- No pre-drilled holes
- No bending moment introduced into the joint
- Timber is Sitka spruce (*Picea sitchensis*) C30 ; $\rho_k = 380$ kg/m^3
- Joint slip not considered Plate Details

Nails are ring-shanked, 3.5 mm diameter, 60 mm long
Service class 2, load duration permanent: modification factor $k_{mod} = 0.6$
Partial safety coefficients:
Steel (γ_m) = 1.1, timber (γ_m) = 1.3
Embedding strength ($f_{h,k}$):

$$f_{h,k} = 0.082\rho_k d^{-0.3} \tag{4.7}$$

$$f_{h,k} = 0.082 \times 380 \times 3.5^{-0.3} = 21.4 N / mm^2$$

Fastener design yield moment ($M_{y,k}$):

$$M_{y,k} = 180 d^{2.6} Nmm \qquad (4.8)$$

$$M_{y,k} = 180 \times 3.5^{2.6} = 4675 Nmm$$

Design embedding strength ($f_{h,d}$):

$$f_{h,d} = \frac{k_{\text{mod}} f_{h,k}}{\gamma_m} = \frac{0.6 \times 21.4}{1.3} = 9.9 N / mm^2 \qquad (4.9)$$

Design value for nail yield moment ($M_{y,d}$):

$$M_{y,d} = \frac{4675}{1.1} = 4250 Nmm \qquad (4.10)$$

Nails in single shear
Minimum nail penetration = 6d
Actual penetration = 57 mm > 6 × 3.5 = 21 mm
Check using Equations 4.11 and 4.12 for minimum value of R_d:

$$R_d = 0.4 f_{h,d} t_1 d = 0.4 \times 9.9 \times 57 \times 3.5 = 790 N \qquad (4.11)$$

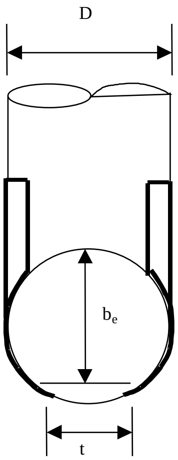
$$R_d = 1.1 \sqrt{M_{y,d} f_{h,d} d} = 1.1 \sqrt{2 \times 4675 \times 9.9 \times 3.5} = 626 N \qquad (4.12)$$

Minimum value = 626N

Design load = Design resistance per nail × Number of nails × Number of plates
= 626 x 21 x 2 = 26.3 *kN*.

Check joint for tension perpendicular to the grain:

$b_e \geq 0.5$ h = 0.5 × D = 70 mm



Dimensions:
D = 140 mm
b$_e$ = 125 mm (furthest nail)
t = (0.8D) = 112 mm (cl 3.2.1.2.1)

Figure 4.15. Joint dimensions.

Shear strength

$f_{v,k} = 3.0\ N/mm^2$
according to Table 1. pr EN 338:1994.

Design shear strength

$$f_{v,d} = \frac{3.0 \times 0.6}{1.3} = 1.38 N / mm^2$$

Design shear force

$$V_d \leq \frac{2 f_{v,d} b_e t}{3} = \frac{2 \times 1.38 \times 125 \times 112}{3} = 12.9 kN \qquad (4.13)$$

$$F_{90,d} = 2V_d \leq 2 \times 12.9 = 25.8 kN$$

Therefore minimum load is due to tension perpendicular to the grain where Design failure load = 25.8 *kN*.

5. Roundwood Structures

5.1 Introduction

This chapter of the report looks at the opportunities for round-pole construction in Europe. It covers buildings from simple cowsheds and barns designed and built by local craftsman (Figure 5.1), to highly prestigious statement structures designed by architects and engineers where the small-diameter poles of this investigation may only be an appropriate and complementary part of the whole, in conjunction with other materials that facilitate a much greater scale of structure (Figure 5.2).

Figure 5.1. Portal frame details from a pole barn in Austria.

Figure 5.2. Two views of the Efteling building at Kaatsheuvel in Holland.

The areas of the project covered by this chapter include:

- The market study undertaken at the start of the project by each partner and drawn together by VTT in Finland.
- The non-engineered guidelines, identified as essential to the development of the volume use of round-pole structures. The guidelines cover smaller buildings and structures suitable for construction by builders, farmers and craftsmen requiring no more than local authority approval. The complete document identifies the opportunities and gives guidance on standard techniques for design and construction. The booklet is richly illustrated with examples and ideas as an appropriate communication to the end-user.
- The engineered guidelines, which look to the development of new uses for round-poles in construction and enables poles to compete with other structural materials in higher technology buildings and structures. This booklet brings together the research on material and joint properties and is written to provide factual information for engineers, architects and planning authorities.
- Site visits. As part of the programme of meetings during the project, visits were arranged by the participating countries to projects of significant interest to enable the researchers to view first hand the very different approaches and techniques involving the use of round-poles in different countries, but likely to be of value throughout Europe.

The output from these areas of the project work are, principally, three major documents suitable for widespread publication in Europe, namely:

- Round small-diameter timber for construction: Market Summary edited by Anna-Leena Perälä (1997)
- The Non-Engineering Guidelines (Griffits et al. 1999)
- The Engineering Guidelines (Groot 1999).

Further dissemination of this part of the work is planned through articles in the architectural and construction press, through agricultural media and at international conferences focusing on structural uses of timber.

In preparing this report, the help given by an internal project group report prepared by Dr Pieter Huybers of the Delft University of Technology in the Netherlands is gratefully acknowledged (Figure 5.3).

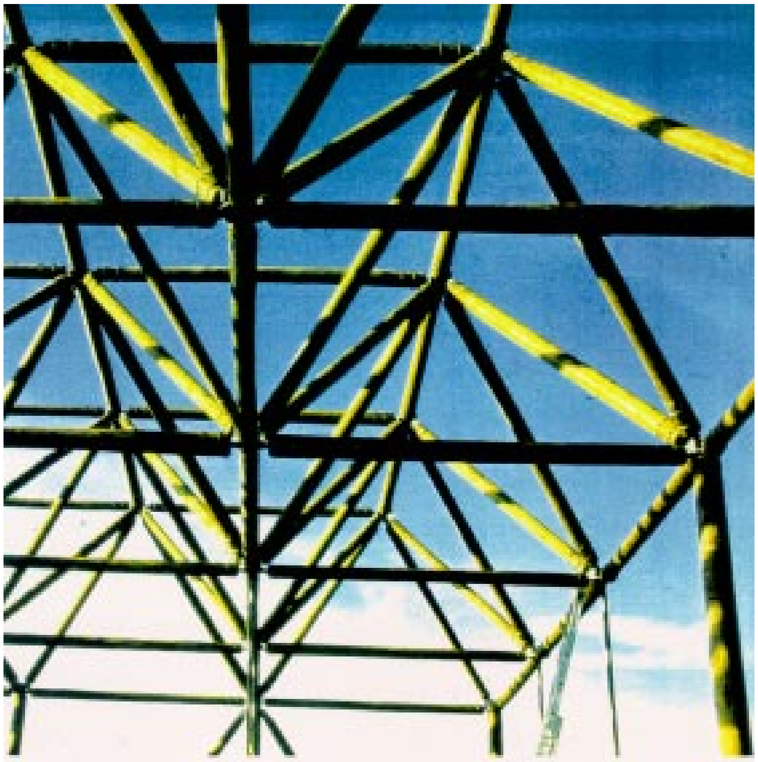


Figure 5.3. Research notes presented by Dr Pieter Huybers showing one of his round-pole space structures.

5.2 Historical influences

Roundwood has always been a very common building material. It was, and is, available throughout the world. As a source of material it is self-replenishing over a much shorter period of time than that needed for sawn timber. It is therefore understandable that roundwood has remained very popular in many developing countries. However, in Europe the changes in the building industry related to available materials, planning and technical requirements, and commercial expediency has meant that roundwood has often been ignored in the twentieth century.

Recently, as a result of changes in forestry management, a quality and predictable resource of small-diameter roundwood is available. There is commercial value in seeking to use it in higher value-added end-uses as principal structural members within the construction industry and to develop its volume use in local rural industry.

In olden times when timber was more plentiful and the overall volume of construction was very much smaller, small-diameter round-poles would be used for their convenience in size, related to handling and transportation, and where quality might be of secondary importance. This would lead to end-uses in more temporary constructions and in lower value buildings such as barns, animal shelters and artisan houses. Illustrating these themes, Figures 5.4 and 5.5 show a reconstruction of a Roman camp and fortification, which included an enormous volume of small-diameter, minimally prepared roundwood. Figure 5.6 illustrates an old French barn and workers' accommodation, now used as a craft shop where the round-pole rafters are of very poor quality by today's standards in terms of straightness, but yet have survived over a long period of time.

Figure 5.4. Two views of a modern reconstruction of a Roman fortification.

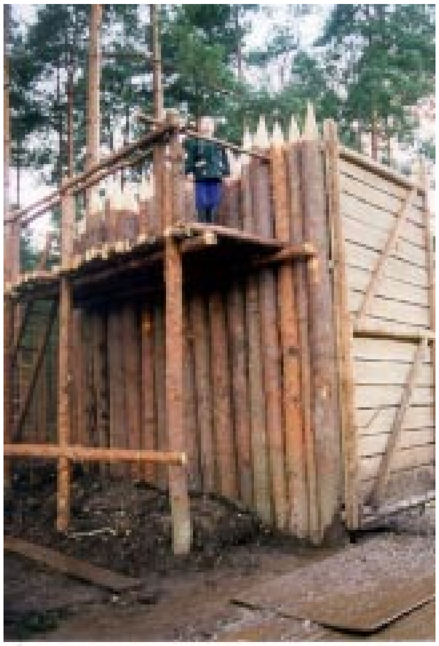


Figure 5.5. Round-pole ramparts and wall in f film set for a Roman fort.

Figure 5.6. Round-pole rafters in a French barn now used as a craft shop.

Figures 5.7 and 5.8 show more formal uses of roundwood, which might relate to larger more prestigious structures in developing countries where the ability to use small-diameter roundwood, without any form of high-technology, greatly increases its potential. The buildings are in fact in Holland and are relatively modern if less permanent structures, but their design must be based on structural forms found in Dutch protectorates in Africa or the East Indies.

Figure 5.7. Restaurant roof in woodland park near Apeldoorn in Holland.

Figure 5.8. Tea-room at Apeldoorn. Both Figures 5.7 and 5.8 show adaptations of designs from traditional buildings in Dutch colonies in the Far East.

More recently, round-pole use has been restricted to agricultural and rural end-use, mainly in the more forested areas of Europe. Unless there is a strong tradition for the use of wood, the structures are often ill-considered and lacking in reliability. This is apparent from:

- Lack of stability in the structure as a whole or in the meeting of elements.
- Poor or inappropriate connections. The elements are often just bolted together such that drying cracks in the wood run through the holes because the wood shrinks around the bolts and meets considerable resistance to its contraction.
- Supporting poles being dug into the ground or cast into concrete footings without the ability to drain water. Moisture content in the poles then increases making them vulnerable to rot and premature failure.
- Poles expected to support unduly high bending moments, which leads to unacceptably high deflections, increasing the rustic nature of the building, and possibly leading to early failure of the structure.

Where the tradition for use of wood is greater, and experience of timber avoids the elementary problems noted above, it is instead common that the use of timber has not developed to meet the challenges of today, inspired by modern living requirements, changes in architectural philosophy and competition from other materials.

5.3 The present situation

Changes in the forestry industry and the challenges of commercialism have identified the need to get maximum value out of all the forestry output including what has often been considered a secondary by-product - forest thinnings. Throughout Europe there is a vast resource of such thinnings, which, due to the nature of their cultivation and growth make them more suited to constructional end-uses than had been previously envisaged. Quality, in terms of strength and straightness is essential. Practicality in terms of available length and proportion of timbers meeting acceptable specification is also necessary. Changes in perception and use of timber are also important. Very small 5–8 cm diameter poles are commercially available throughout Europe, mostly in a peeled and concentric form for use in garden landscaping. The leisure industry and access to the countryside have grown enormously and developments associated with these changes have to be environmentally acceptable and appropriate to the location. This has created a totally new market for buildings portraying a more rustic and traditional image but still incorporating high technology and high quality.

Round-poles are ideal for meeting this demand, either in debarked form where the priority is on rustic appearance or in peeled form if it is important to demonstrate the twentieth century influence on an old technology.

Familiarity with such modern structures, through their use by visitors more aware of an urban landscape, creates further uses for round-poles, bringing them into the urban environment to reduce the harshness of the landscape and create a more relaxed and tranquil and environmentally healthy image. This area has grown from playground equipment to cover inner-city farms and zoos, towers and footbridges in urban parks as well as visitor centres, restaurants and maintenance facilities within such parks.

In the countryside, the new uses of roundwood have benefited its volume of use in farm buildings and landscaping. Proprietary fixing systems are more readily available along with the staple material and there is an increased enthusiasm for the use of roundwood in comparison with the more recent competition of steel and concrete. Again, environmental concerns and the desire to use appropriate technology benefit the acceptance of roundwood structures by the planning authorities.

It is with this background that this project was started in 1996. Material was available, interest had been generated but support information was lacking. Before that information could be properly provided it was important to identify the current situation and the potential market. This would determine the main objectives of the project in addition to the classification of the timber source within the needs and scope of EC5, the European Code for timber design.

5.4 Market study

5.4.1 Overview

The five countries involved in the project had widely different experience in the use of roundwood, and hence in their visions of potential and possible use. Each country produced its own market study and these were edited and summarized by a specialist in the field of market studies, Anna-Leena Perälä of VTT in Finland (1997). She noted the following: "The measure of forest and the use of wooden products vary in different countries. The resource of forests per capita and the use of wooden buildings are significant in Finland and in Austria. Wooden structures are not so common in the United Kingdom, France and the Netherlands. Presently small roundwood (dia. 8–15 cm) is used for firewood, paper industry pulp or on a limited scale as sawn goods, primarily in the countryside and yards. The purpose of this sub-project is to seek potential and interesting markets for the products in construction in participant countries in the future.

The main results indicate that potential markets could be both in small buildings and large engineered structures. It seems that the work will include:

- the development of small buildings with traditional structural systems to be built in rural areas, including agricultural buildings.

- the development of systems for larger buildings, which could be attractive when combined with unique architecture, especially in the leisure industry.

Larger volumes come from small buildings and simple structures. The key buildings could be log cabins, small storage buildings and agricultural buildings. Such buildings could also be larger architectural buildings, for instance in woodlands. In the civil engineering area small bridges (footbridges, light vehicle access bridges), sound barriers and landscaping could be developed.

The essential material properties for small roundwood are its straightness, taper, durability, strength properties and joining methods. Architects and structural designers would appreciate products that are also readily available, standardized, slightly processed and used locally. Treatment is also important.

Small roundwood is most often seen as a competitor of sawn goods, but the structures could be developed with new ideas. The product must be priced competitively and easy to install. Now, there is too little experience. Good showcase projects and instructions will promote the use of the product since end-users and designers have to be convinced of a product's advantages."

5.4.2 Results by country

(i) United Kingdom

The UK has a small forest area (10.5 % of total land), large imports (90 % of sawn timber), uses 10 Mm^3/year of sawn timber, 43 % in construction. Roundwood use very small; 80 % for paper and boards, 20 % for fuel, fencing, leisure products and construction. Although the volume is low-use, there are many examples of pole-use from small barns to highly engineered buildings. As the country is moving to a more environmentally concerned attitude, the potential for roundwood in leisure and agriculture (buildings), transportation (cycle routes) and landscape and gardening is opening. Figure 5.9 shows how these uses are of greatest importance in woodland, farming and rural areas.

(ii) France

France is 27 % forested. It uses 15 Mm^3/year in construction, which is 25 % of total consumption. There is little use of timber in building and round-poles are mainly used as telegraph poles and for urban furniture (sound barriers, retaining walls, crash barriers, snow fences). The perceived obstacles to the use of roundwood are shown in Figure 5.10.

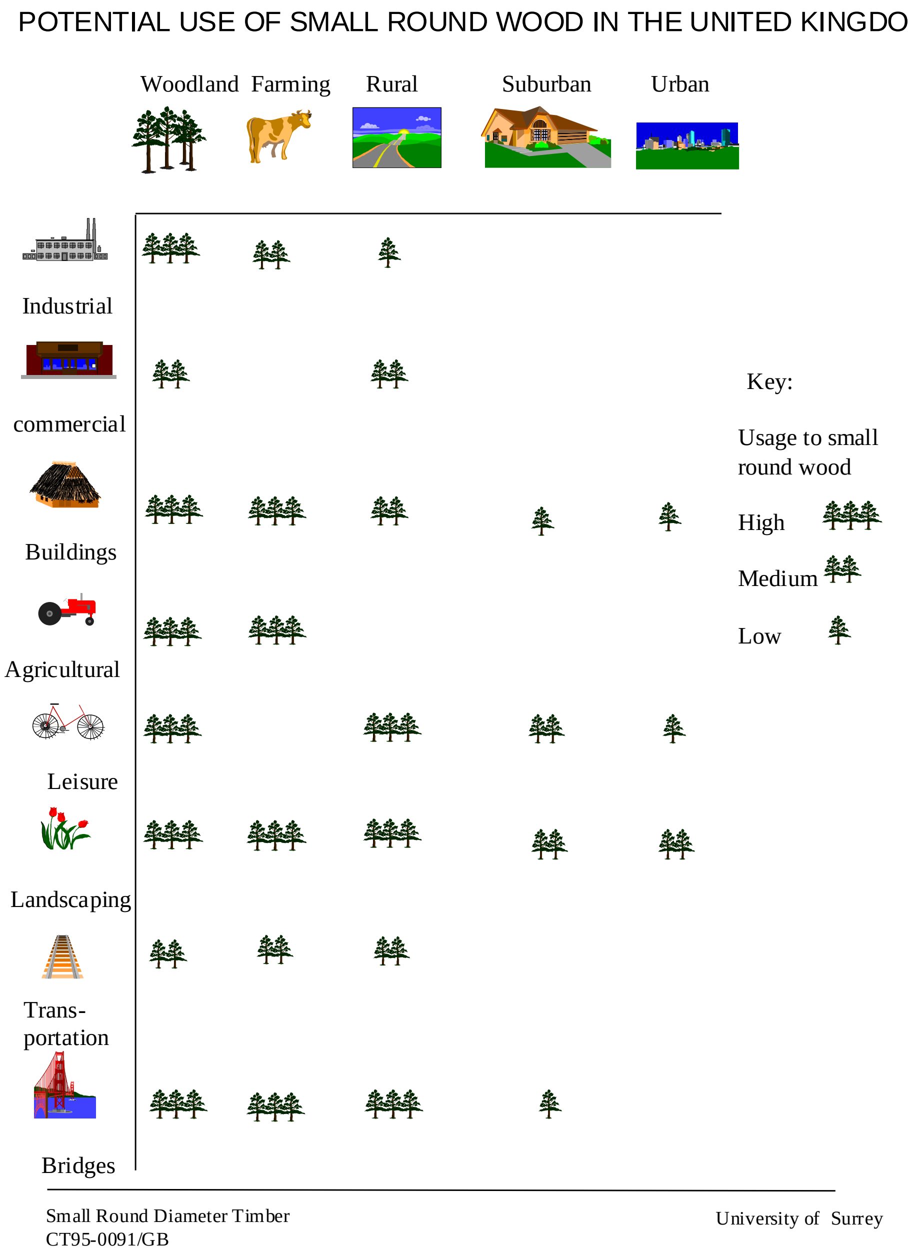
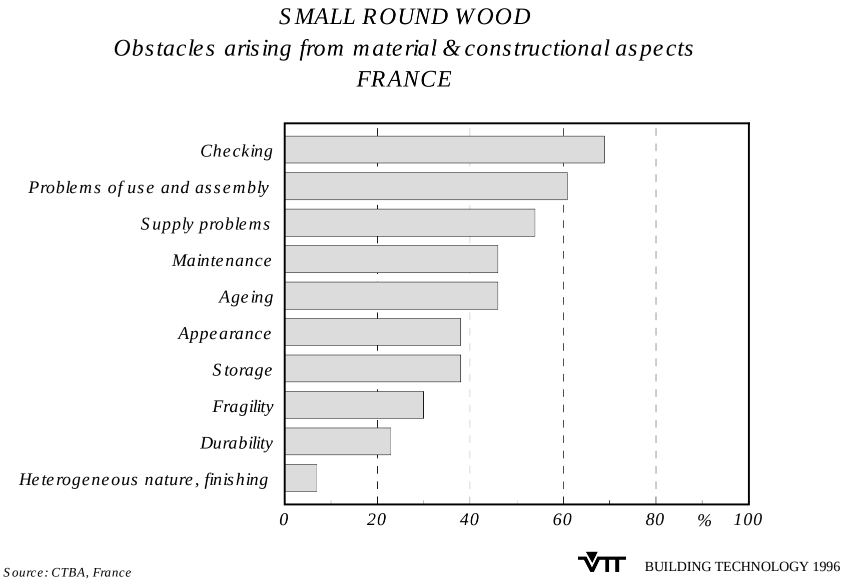


Figure 5.9. Results of the UK Survey.



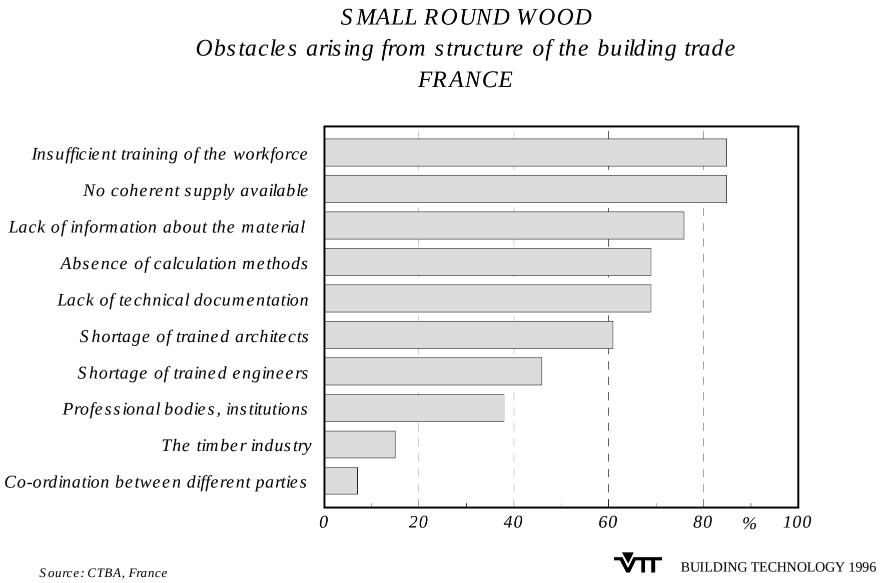
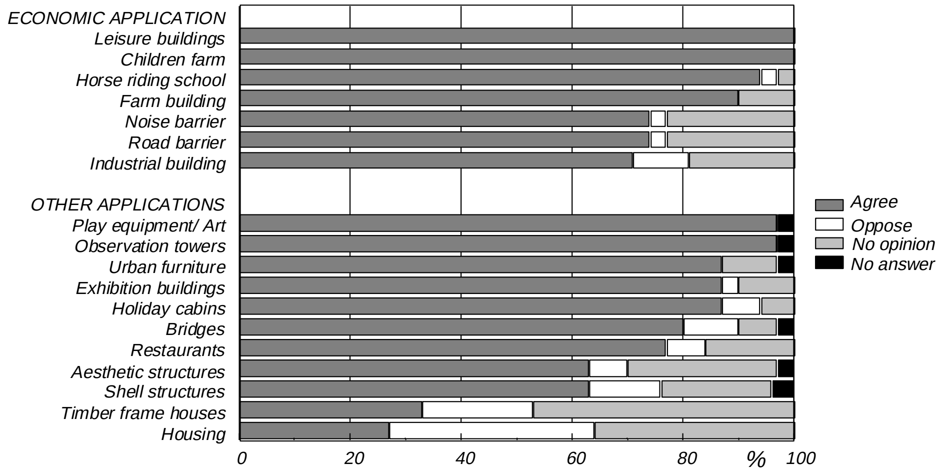


Figure 5.10. Perceived obstacles to roundwood from the French Survey.

(iii) The Netherlands

The Netherlands is 10 % forested, and 90 % of wood is imported. For thinnings 0.7 Mm^3/year is available, with 30 % going to paper and board. There is evidence of interest in round-pole use for leisure buildings (children's farms, riding schools) and farm buildings. Problems are due to the lack of architectural tradition and poor image, but the government is targeting these problems and there is a keenness to go "back to basics" in construction forms. The results of the Dutch survey are shown in Figure 5.11.

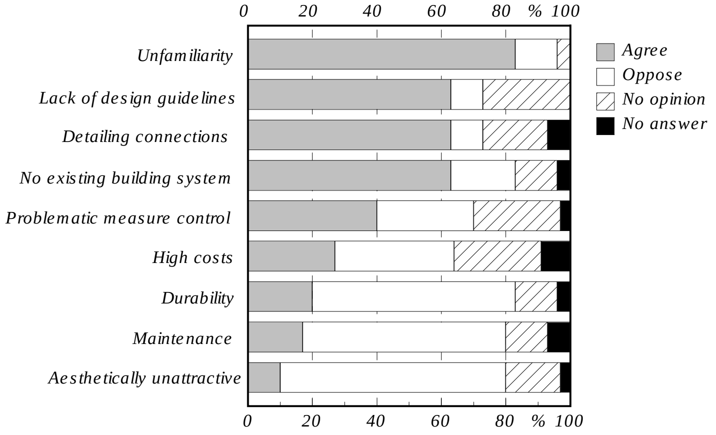
Potential use of small round wood in the Netherlands



Source: VTT, Building Technology

VTT BUILDING TECHNOLOGY 1996

Obstructions to use small round wood in the Netherlands



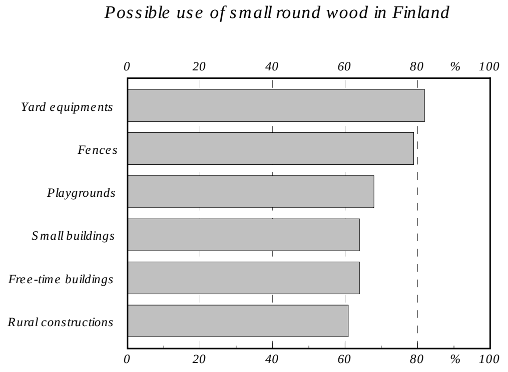
Source: TUDelft 1996

VTT BUILDING TECHNOLOGY 1996

Figure 5.11. Output from the Dutch Survey.

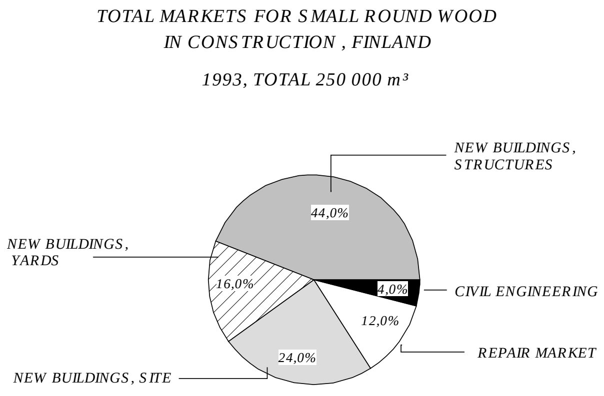
(iv) Finland

Finland has a large forest area (15 % of total in Europe), with 1.8 Mm^3/year harvest potential for small construction roundwood; 0.25 Mm^3/year could be used for construction in Finland. Timber is heavily used in the building industry but very little of this is roundwood. The greatest potential is for buildings under 200 m^2, summer-houses, farm buildings and in frame systems for low cost halls. Tourism, related to the natural environment, could increase the potential market. The results from the Finnish survey of engineers and architects are shown in Figure 5.12.



Source: VTT, Building Technology

VTT BUILDING TECHNOLOGY 1996



VTT BUILDING TECHNOLOGY 1996

Figure 5.12. Results of the Finnish Survey.

(v) Austria

Austria is a major producer and user of timber (31 Mm^3 per year, 6 % small roundwood). The use of roundwood is essential to farmers, etc. who are unable to recover the cost of thinning operations. At present, architects show a low interest in roundwood and are hampered by a lack of experience in engineering structures. Farmers, however, are keen to see developments and have the skills to design and build their own structures.

5.4.3 Conclusions

The market situation of small-diameter roundwood is different for each of the participating countries, which is partly due to their different traditions. Austria and Finland are more rural in character and better accustomed to rustic timber structures, whereas France, and particularly the Netherlands and the United Kingdom are more urbanized countries and consequently have a higher resistance to the use of wood as a building material. However, it can be seen that there are several similarities in the results collected from the different countries. These concern the potential uses of roundwood and obstacles that would need to be removed before roundwood can be utilized in construction projects.

For all the countries, it was clear that the potential market for round timber would be for buildings located in rural areas. The buildings would generally be related to the leisure and recreational industries (for example, cottages, holiday homes, bridges, children’s farms, equestrian buildings, towers) and agriculture. In such areas, round-pole construction will often be regarded by architects as appropriate technology enabling it to be used in larger and more prestigious constructions. Currently, the most common use of roundwood is in landscaping and gardening where the wood is used for noise walls, various barriers and fences, urban furniture, playground structures and pergolas.

In the countries where there is a good supply of timber, such as Finland and Austria, small-diameter roundwood structures can be built at competitively low prices, particularly, when the building owner is carrying out the work himself. This includes simple small-scale structures, for example, multifunctional sheds, etc., which can be built on-site or delivered as a prefabricated package. These structures could still be aesthetically pleasing.

Typical reasons why roundwood is seldom used when it would be perfectly suitable are as follows:

- The material is not generally available to sell via normal commercial channels.

- Architects, engineers and carpenters are not familiar with the strength or jointing characteristics of roundwood, nor do they have adequate design guidelines.

The material's structural characteristics, which include straightness, taper, surface quality and moisture content, are important areas and will need to be considered as part of the project. It can be concluded that one of the aims of this project is to remove the obstacles that currently limit the use of roundwood as a building material. The most important and challenging task is to get the market to work for roundwood by increasing the supply and demand together. The results from this project will provide valuable information to help increase people's awareness of roundwood. The marketing of round-pole structures can be expected to improve as more demonstration buildings are constructed.

It is important to direct further work as follows (Figure 5.13):

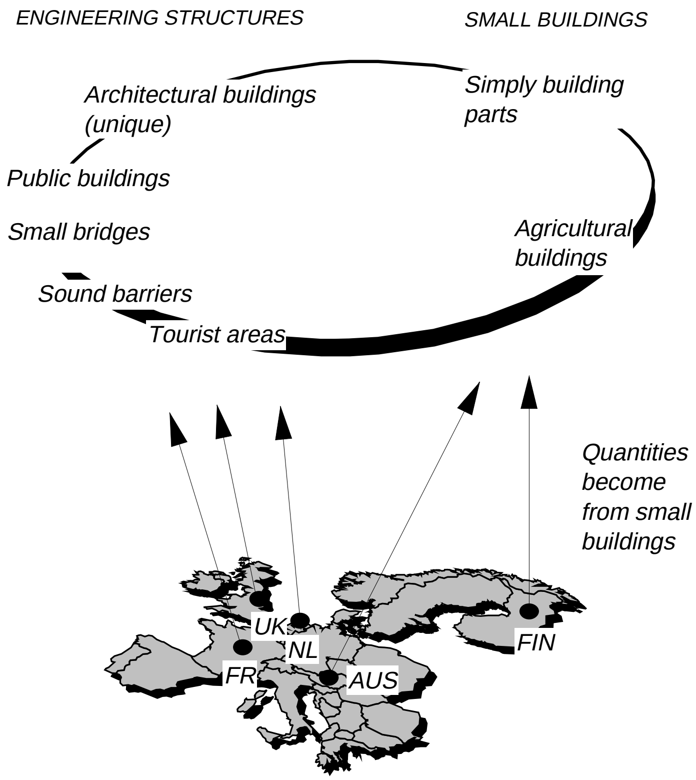


Figure 5.13. Conclusions for further work.

1. The main volume of the use of small-diameter roundwood will be in non-structural use and in small traditional-type buildings. The project does not, however, include landscaping, urban furniture or other non-structural uses. Also those uses will benefit indirectly due to the improved availability of the material. In this project, it is essential to design models for relatively small buildings including the design of a total building: foundation, walls and roof. In most cases these structures do not require new innovations for a load bearing frame. The structural development work includes simple connections and safe span tables for these buildings. The types of structures to be developed include:

- Agricultural and rural buildings: cattle sheds, machinery stores, feeding sheds, drying sheds, storage buildings, garages, including the use with other building materials.

- Footbridges, small vehicular bridges and bridge elements.
- Noise walls and retaining walls on roads.
- Rural vernacular structures.

2. Small in volume but important for the image of roundwood is the use for architectural medium-size buildings for the leisure industry in which the load-bearing structure is visible. These buildings typically include a large room (restaurant, hotel lobby, or exhibition hall). Structural systems with load-bearing joints for these structures will be developed.

5.5 Structure of programme

The work within the market study has thus identified two different end-users for the work of the project. Firstly, a non-technical group, which required information on the design and ability to build simple structures where the requirement for detailed calculations to demonstrate the acceptability of structures would be minimal. For them the guidelines for architects and builders were drafted. This booklet overviewed the use of roundwood and showed, by example, the scope of use and details providing solutions to typical challenges.

Secondly, the engineering body including architectural engineers who would expect to have detailed design information for the available roundwoods and the more common jointing techniques enabling them to incorporate roundwoods into the standard design procedures of EC5. This guideline would be very much more technical and direct in its presentation but would also use case studies to demonstrate the new-found versatility of roundwood.

Two further factors were identified:

- the overlap in the type, and sometimes scale of the structures between the two guidelines.
- the interest in peeled, concentric poles which had not been fully appreciated at the start of the project.
- the need to limit the work of the project to solutions and forms suited to more standard (and thereby volume) use.

- the importance of appreciating small-diameter roundwoods as appropriate components within larger structures incorporating other materials rather than limiting the study to structures composed wholly or substantially of the roundwood sizes covered by the programme.

Figure 5.14 shows the table of end-uses suggested for round-poles and it is included in the non-engineered guidelines.

	URBAN CITY	RURAL	FARMING	FORESTRY REMOTE
COMMON USES **Landscaping** **Minor Structures**	Playground equipment Plant containers	Exercise routes Summerhouses / Patios	Fencing Feed boxes	Adventure trails Road edging Signs Information points Hides & Shelters
NON-ENGINEERED USES: **Buildings** **Structures**	Park kiosks Market stalls	Sheds / Workshops Bus shelters Paths, Cycle tracks Retaining walls	Open barns Animal houses Storage sheds Silos Eqestrian centres	Covered stores Temporary industrial workplaces Holiday cottages Small visitor centres
ENGINEERED USES: **Buildings** **Structures**	Urban farms and zoos Sport pavillions in parks Footpath and cycle way bridges Noise barriers	Houses, domestic and small commercial units Larger clear span and more complex agricultural uses	Farm access bridges Larger retainig walls	Visitor centres and offices Restaurants Retail outlets Vehicle bridges Lookout and communication towers
SUMMARY	Common and non-engineered uses increase in more rural and forested areas			

Figure 5.14. Usage of round-poles in construction.

5.6 Overview of uses

5.6.1 Playground and leisure equipment

One of the most common uses of roundwoods which demonstrates the possibilities of the material to a much wider audience, is in playground furniture. In all types of environment, roundwood has become the number-one material for climbing frames, swing structures and other structures for the larger more complex and often theme playgrounds. Here the wood is used in a harsh environment and very heavy expectations are put on it in terms of limiting cracking and splintering.

An advance, both technically and in size, leads to adventure trails, exercise routes, play forts, elevated woodland walks etc. Whereas the quality playground furniture is mainly prepared from concentric poles, here the members are more likely to be debarked poles. Some examples are shown in Figures 5.15 and 5.16 taken from Moors Valley Country Park in the South of England. Here the use of round-poles within a woodland area is aesthetically essential but the examples demonstrate the reduced formality of the material which makes it ideal for leisure projects where a more rural appearance and feel is important to combat the harshness and rush of urban life.

Figure 5.15. Playground fort from West Moors Country Park in England.

Figure 5.16. Bridge forming part of a tree top trail at West Moors.

Other examples of use for round-poles in this area cover:

- Landscaping; such as kerb lines and retaining walls in forests and country parks
- Signing and small shelters for public notices
- Fencing and retainers used to delineate areas, particularly in playgrounds where short lengths of round-poles placed vertically can also act as a container for the soft wood chips needed in the play area for safety.
- Garden toys, planters, summerhouses and even patios
- Landscaping and terracing of ponds and pools.

5.6.2 Commercial landscaping

A little different from the artistic structures of the leisure industry are the larger structures used commercially such as noise barriers, heavy-duty fencing, retaining walls and loading platforms and retaining walls for storage pits. Here the appearance will not match that of pre-formed materials but round-poles may be used as a result of cost, availability and appropriateness to the environment. Figures 5.17 and 5.18 show examples.

Figure 5.17. Specialist fencing application in Finland.

Figure 5.18. Storage bins combining round-poles and steel with added protection for machine loading operations.

5.6.3 Loghouses

Loghouses have a great tradition in forested countries and are now seen more commonly in less likely environments such as the UK. They can vary from small storage buildings, allowing natural ventilation, to large visitor centres but the most common use is in small holiday chalets and summer homes. Some examples of loghouses are shown in Figures 5.19, 5.20 and 5.21.

Figure 5.19. An open log house storage building in Finland.

Figure 5.20. A large log house used as an exhibition centre in Wales, note also the use of round-poles in the entrance walkway.

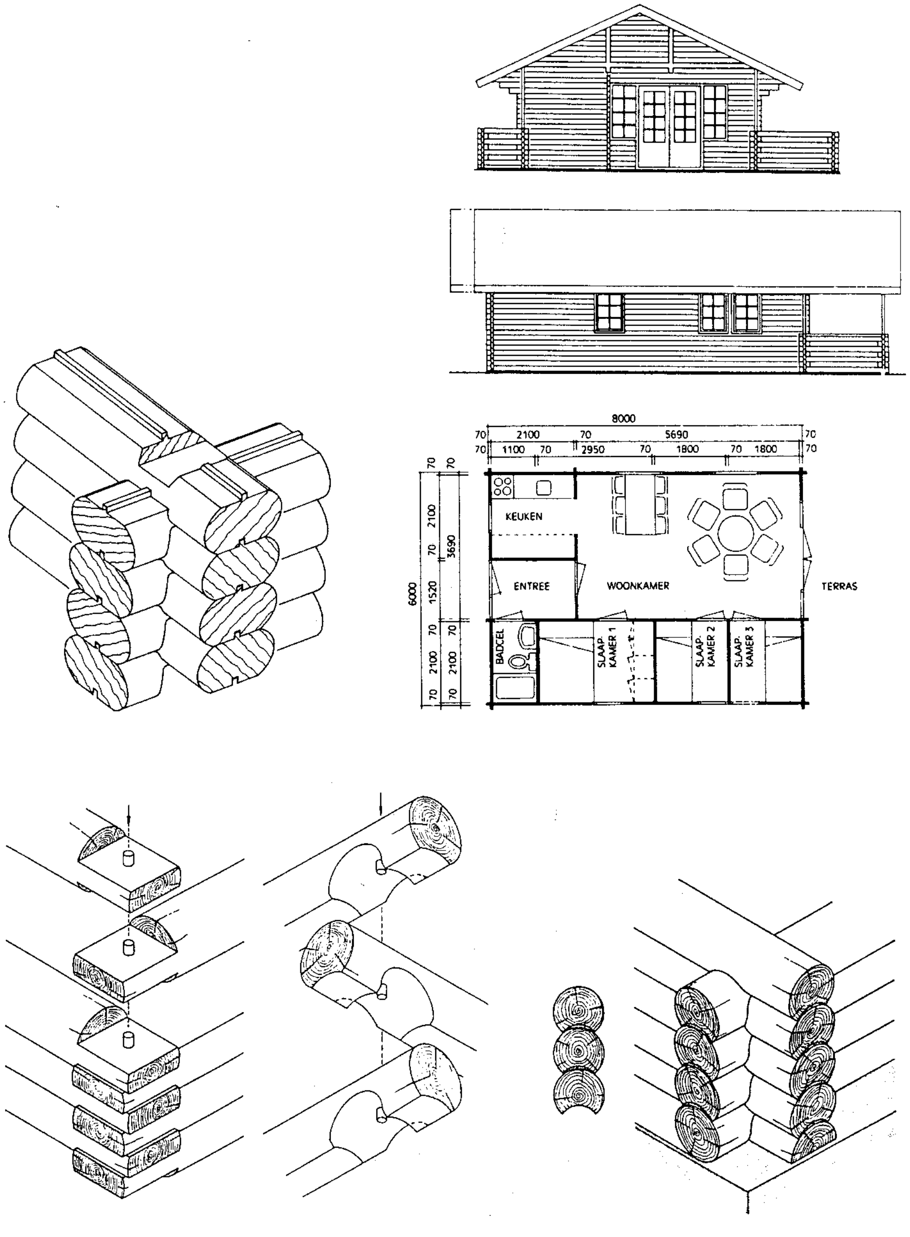


Figure 5.21. Typical details of log house construction.

5.6.4 Pole buildings and pole barns

Pole buildings are very popular, in particular for low-cost self-build construction. Traditionally fully enclosed and insulated buildings would be smaller structures, perhaps limiting roundwood to the main vertical members and secondary horizontals and using sawn timbers for principal beams and finishes. Larger structures would then cover barns, animal houses and other semi-industrial buildings. The size of roundwood would increase but so too would the use, due to the reduced formality of the building. Smaller diameters would be used in bracing, roof units and even claddings. The two forms are combined in the increasingly common commercial buildings used as visitor centres, parkland cafes, shops and garden centre offices, etc.

Details can vary depending on use and tradition. Poles may be sunk into the ground, inserted into concrete bases or built off low walls. Floors may be at ground level or built off the ground and roofs may take many different forms but are mainly exposed on their underside to give height and character to the building.

Examples are shown in Figures 5.22, 5.23 and 5.24 and an extreme version is illustrated in Figure 5.25.

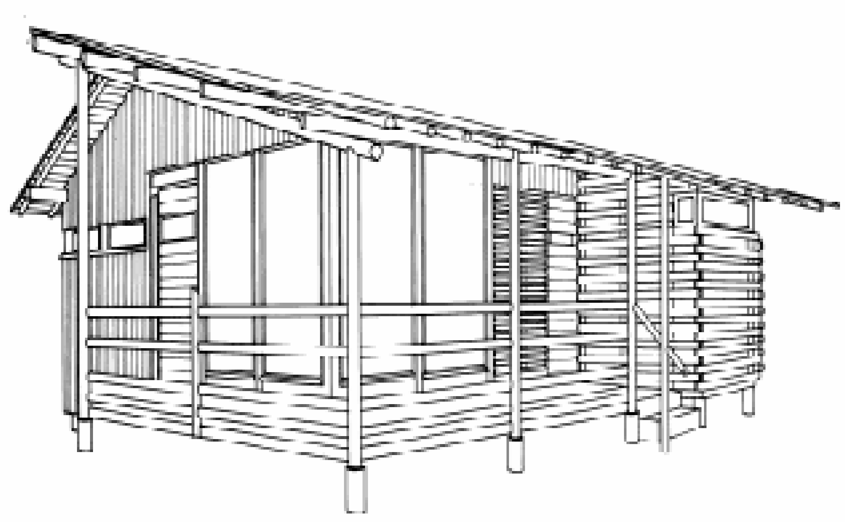


Figure 5.22. Architects view of a small round-pole construction (by Rolf Keränen).

Figure 5.23. A very simple open barn round-pole structures used for drying fence posts in Wales.

Figure 5.24. A visitor centre in Wales making good use of round-poles of different diameters.

Figure 5.25. An extreme form of pole structure house built 6 m above ground level in France such that the floor is then above sea level.

5.6.5 Space frame and specialist roofs

Round-poles are perhaps less suited to trussed structures in roofs and will only compete where trussed rafters are less available or a special roof is needed. Round-poles are, however, very suited for use in three-dimensional space structures, where a short length and small cross-section are an advantage and the use of a whole cross-section reduces problems from natural timber weaknesses. Much work in this field has been undertaken by the Dutch partner, Pieter Huybers' and is illustrated in Figure 5.26 and Figures 5.27 to 5.30.

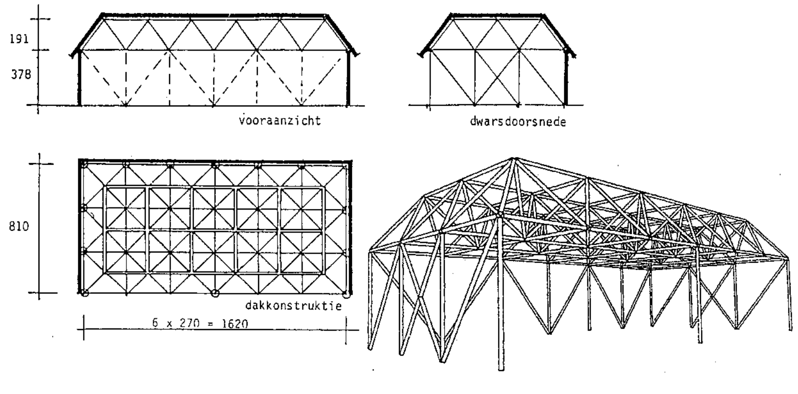


Figure 5.26. Framework for a timber shed in Holland featuring a space frame roof.

Figure 5.27. Space frame roof in barn in England.

Figure 5.28. External space frame with bird houses in a children's zoo in Holland.

Figure 5.29. Huyber's space frame joint detail.

Figure 5.30. Space frame type roof for a training centre in England.

The success of these structures commercially, aesthetically and structurally lies in the joint-linking members and in the connection of this joint with the roundwood. A significant part of the Guidelines for Engineers and Designers is linked to this work but is of much wider use due to the importance of the need for a high-strength but low-cost in-line end connection. The poles themselves are rarely the critical function in the design. Strength will be lost in the connector and particularly when eccentricities are induced.

Other systems have been reviewed including one that relies on end-tube-shaped sleeve connectors and often uses wire pre-stressing to achieve rigidity (Figure 5.31).

Figure 5.31. Poles fitted into endcaps and prestressed to give building rigidity.

5.6.6 Towers and domes

The work on space structure roofs has expanded to other three-dimensional forms, such as towers and domes where the jointing needs are similar. A particularly fine example of a tower at Apeldoorn in Holland is illustrated in the next section, whilst a small dome which can easily be erected and dismantled for exhibition use, is illustrated in Figure 5.32.

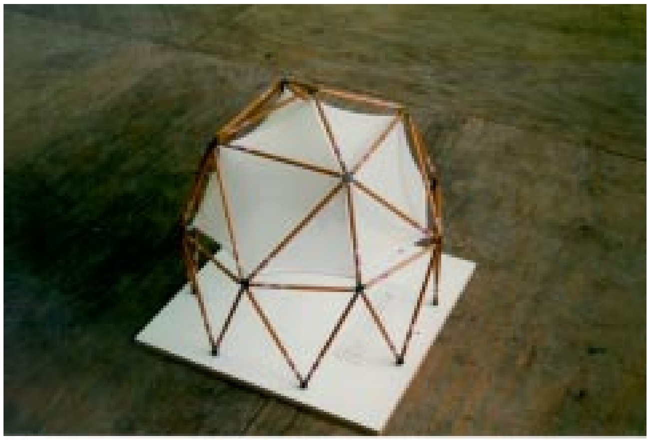


Figure 5.32. Model of a 6 m high pole dome constructed in Holland for exhibition use.

The scope for these structural forms is vast and 50-m span flat domes here have been shown to be fully feasible (Figure 5.33).

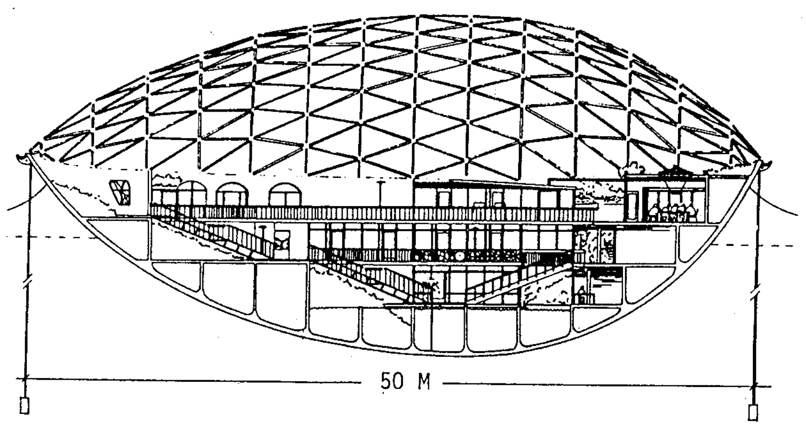


Figure 5.33. Design for a 50 m dome to cover the CICAT centre in Holland.

5.6.7 Bridges

The use of round-poles in bridges is varied in both structural form and size/end-use. Simple forms using poles as principal spanning members are common and appropriate for woodland walkways and cycle paths (Figure 5.34). Larger spans require more complex forms. The solution in Figure 5.35 keeps the main members and joints in compression, thus giving rigidity to the structure. The size of pole will determine the span but for the small-diameters associated with this project spans of up to 15 m can easily be achieved.

Figure 5.34. A simple footbridge at Castell Henllys in Wales using round-poles, main girders and hand rails.

Figure 5.35. A round-pole "arch type structure" bridge in Norway.

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Roundwood can also be used for secondary parts of the structure such as handrails and braces. Intermediate spans are available using A-frames and Figure 5.36 shows a much more complex example that served a long working life under heavy traffic loads in Finland.

Figure 5.36. A Finnish example of a round-pole bridge carrying highway loading.

Multi-span bridges are illustrated in their simplest form in the tree-top trail (Figure 5.34), whereas the higher technology form will probably be based on the space structure relying on the joints detailed in Chapter 4.

5.7 Case studies related to round-pole group visits

5.7.1 Holland

The tour of round-pole structures organized by Delft University of Technology took in the following:

- An animal farm at Rotterdam featuring a space frame roof, which allowed the party to view the form of construction in detail since externally there was an open framework used mainly as an architectural feature. Internally, it was possible to walk through the roof structure itself and see the performance of Huybers' laced joint after a few years' service.

- The entrance pavilion to the Efteling theme park at Kaatsheuvel designed by Ton Van der Ven with structural advice from Hans Roosen. The building features thatch-covered tent-shaped roofs with three 40-m high peaks over an open building 60 m wide. The largest poles are 40-m long, 0.65 m in diameter but many of the poles branching from these main trunks are much smaller. The whole building demonstrates a fantastic use of round-pole technology, very highly engineered to extremely precise tolerances but giving the essential magical fairytale feel required for the building which could not have been achieved in any other material. Efteling is illustrated in Figure 5.37 and Figure 5.38.

Figure 5.37. Two views of the Efteling structure in Holland showing the use of roundwood with other materials.

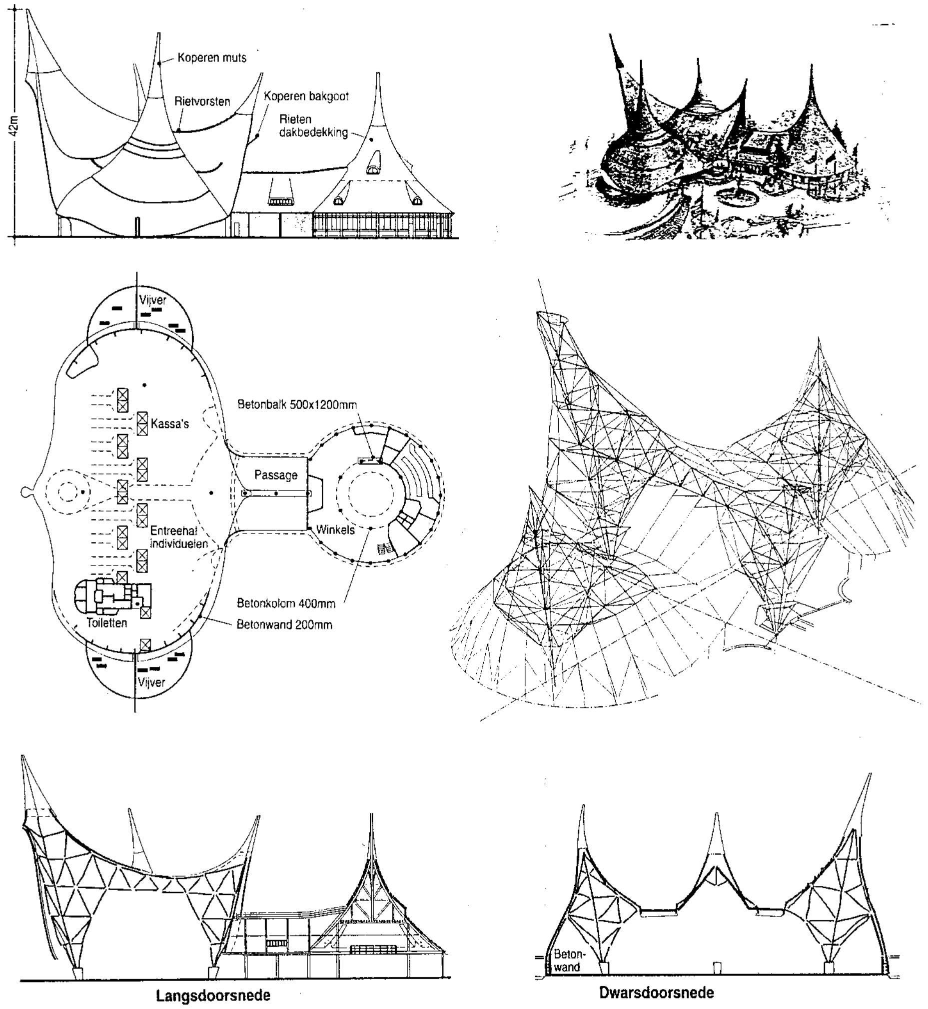
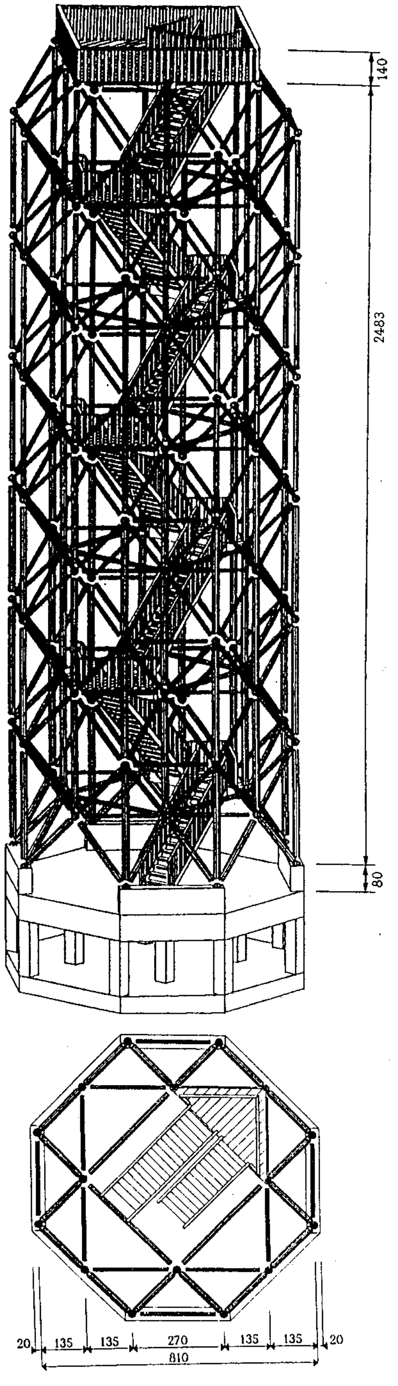
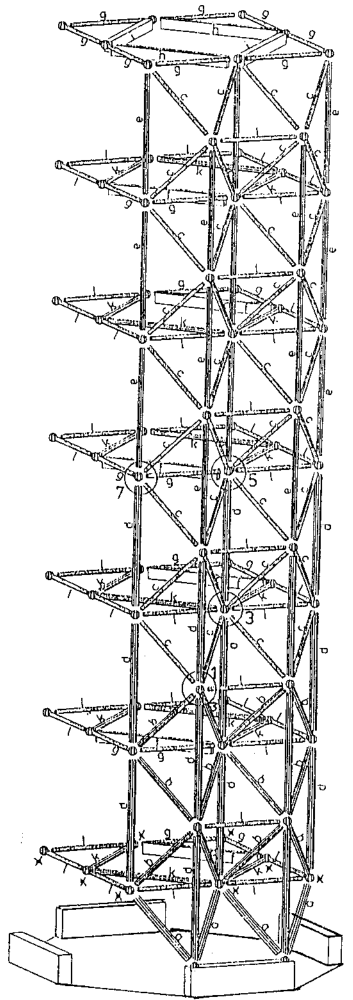


Figure 5.38. Plans and elevation of the Efteling structure.

- The Acacia Hall and the Teahouse at Apeldoorn. Illustrated earlier in Figures 5.7 and 5.8, these buildings showed the use of round-poles in traditional-type structures of the Dutch East Indies. Simple roof forms provided an exciting open solution to these buildings in the middle of a large woodland park.

- The Observation Tower at Apeldoorn. When viewed this was one of the most recent of Huybers' space frame structures. The lookout tower illustrated in Figures 5.39, 5.40 and 5.41 is 27.0-m high with a base 8.1 m x 8.1 m. All the joints are bolted with 16mm diameter high-strength bolts and wire lacing is incorporated to reduce the effects of splitting in the round-poles. Debarked larch is used and the principal members are 2.5-m and 3.6-m long, 12, 15 and 20 cm in diameter.





Legend of poles:

a	inclined diagonal	Ø200	2700	16
b	inclined diagonal	Ø150	2700	48
c	inclined diagonal	Ø120	2700	144
d	vertical	Ø200	3818	48
e	vertical	Ø150	3818	48
f	staircase support	120x350	3378	6
g	landing support	100x165	2260	20
h	platform support	150x350	3378	2
i	platform	112x250	3378	2
k	horizontal diagonal	Ø150	3818	18
l	horizontal	Ø120	2700	60
Total number				412

Figure 5.39. Details of Huyber's tower at Apeldoorn in Holland.

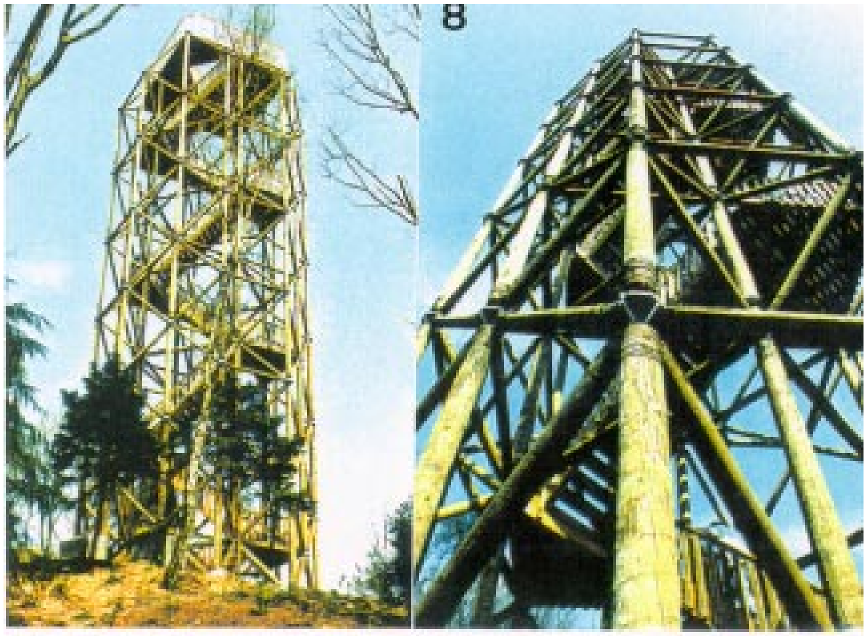


Figure 5.40. Two views of the Apeldoorn tower.

Figure 5.41. Pole joint in the Apeldoorn tower.

5.7.2 England

The UK visit to the University of Surrey concentrated on a tour of Hooke Park in Dorset, where John Makepeace of the Parnham Trust had set up a school for woodland industry. All the buildings and structures for the school, situated deep in woodland, featured round-pole technology. The buildings are an interesting combination of forestry thinnings with very high-tech ideas carefully engineered by Buro Happold in Bath. They demonstrate ideas of what can be achieved with round-poles particularly when reliance can be placed on epoxy gluing. However, they were seen by the project team to be one-off developmental structures, with only limited relevance to the low-cost higher volume uses required for the round-pole project. The following buildings were viewed:

- The Prototype House. The single storey domestic building shown in Figure 5.42 and Figure 5.43 has a size of 11.2 m by 8.5 m. The material used was Norway Spruce. Two A-frames support a doubly curved roof structure using 5.5-m long, 6 to 9-cm diameter hanging poles with an initial sag of 20 cm. Thus the roof load is carried in tension and taken out of the poles by epoxy threaded 12-mm steel rods connected to tension eyes.

Figure 5.42. Interior A frame and rafters in prototype house at Hooke Park.

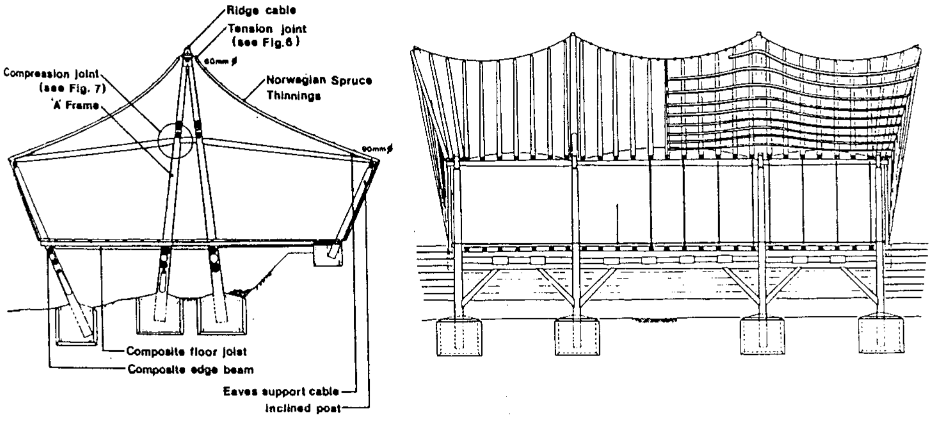
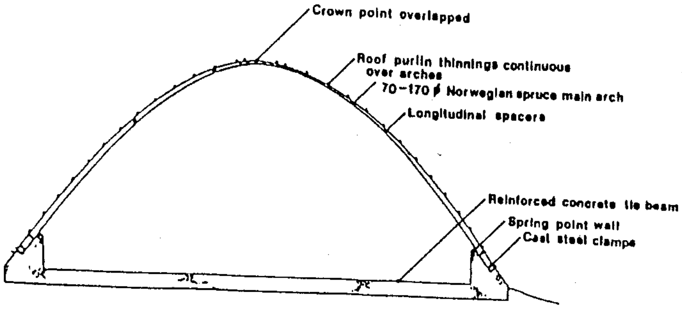


Figure 5.43. The prototype house at Hooke Park in England.

The Workshop Building. This is a 15-m span vault roof using Norwegian Spruce poles 10.5-m long tapering from 18 cm to 7 cm. A crown section of two poles was used to connect the bent poles through lapping bolted joints. At the base, the rods were fixed to concrete walls using grouted-in bolts. Details are given in Figure 5.44 and Figure 5.45.



Structural cross-section through the
Workshop Building

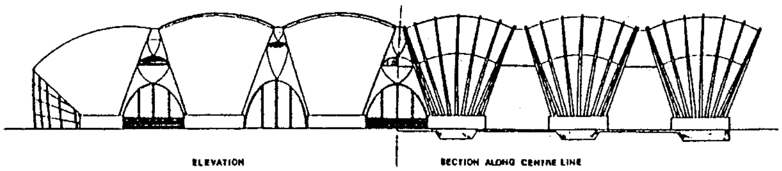


Figure 5.44. Structural details of the Woodland School of Industry at Hooke Park.

Figure 5.45. External and internal views of the workshop building at Hooke Park.

- The Westminster Lodge, architect Ted Cullen, is for student accommodation. The floor is raised above sloping ground and the load-bearing walls are made from clad roundwood. The main feature is the two-way spanning Vierendeel truss roof which required eight 3-m long poles to be spliced together to form the top chord. The poles were approximately 100 mm in diameter and were used in four layers to span the 8.4 m in two principal directions. Blocking pieces provided shear connections between the top and bottom layers adding stiffness in the central part of the span. See details in Figure 5.46.

Figure 5.46. Support system and internal roof structure of scarf jointed poles for the Westminster Lodge at Hooke Park.

5.7.3 Finland

The visit organised by VTT included a visit to children’s playground and harbour area in Lahti, a log-house exhibition in Järvenpää and a pole bridge in Nurmijärvi. In Lahti, impregnated small poles are widely used in a children's park (Launeen perhepäiväpuisto, Figure 5.47). Log-houses are normally used as summer cottages, but also about 1000 log-homes are built annually. The exhibition area consisted of products of several manufacturers. The dimensions used in log- houses are normally larger than would be considered by a small-diameter timber project.

Figure 5.47. Children's park in Lahti.

The bridge (Figure 5.36) has total length of 51 m, maximum span of 16 m and net width 6 m. The estimated load-carrying capacity corresponds to 32-ton vehicles with a 13-ton bogie unit. It was built in the mid-1960s and is still in good condition.

Due to distances, more northern places were not visited, where a new and growing activity is to build cow-sheds from round timber (Figure 5.48).

Figure 5.48 An uninsulated cow-shed in Viitasaari, 25 x 40 m.

5.7.4 Austria

The visit organised by BOKU in Austria took in the main factory for Wolf System at Sharnstein and the small workshops of Herr Zopf together with nearby examples of his cowshed buildings. At Wolf, the team were shown materials and modules for a housing system using slabbed round-poles (see Figure 5.49). Herr Zopf manufactured industrial sheds and other commercial structures in roundwood using forced metal connector plates. Local timber, often owned by the client, was used and some large portal framed structures were very effectively achieved and are detailed in Figures 5.1 and 5.50.

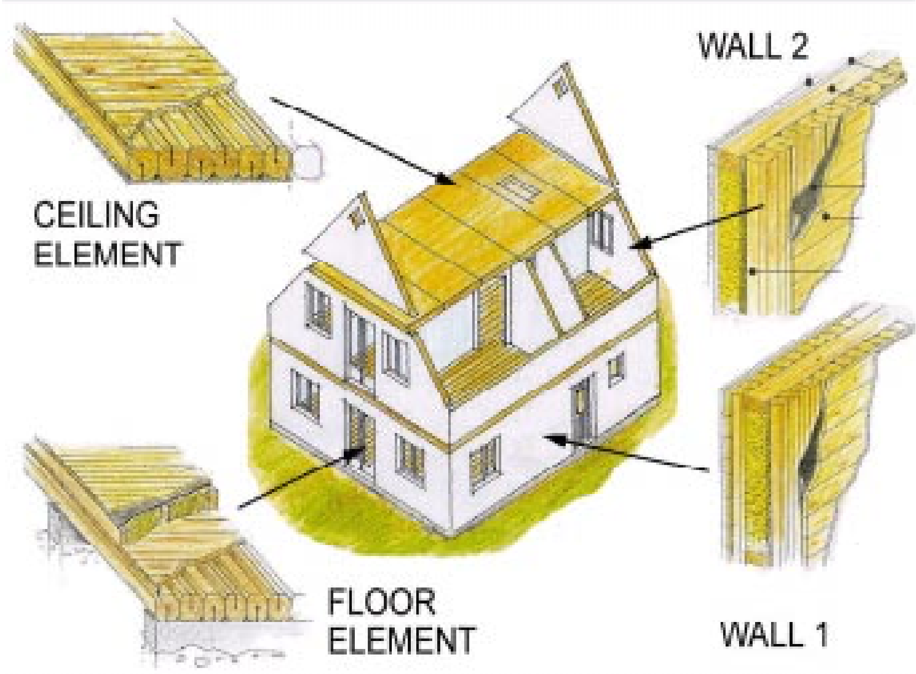


Figure 5.49. Austrian modular housing system using slabbed round-poles.

Figure 5.50. Details of the Zopf system using forced metal plates.

6. Summary

The work covered the economy of harvesting and manufacturing of small-diameter round timber, strength testing and grading of the material, feasible structures to be built in roundwood and the development for jointing technologies.

The resource available for the production of small-diameter structural timber has been studied in detail based on the first commercial thinning in Finland. The result was that the total resource is large. If only the best quarter of compartments is considered worth harvesting, 2.1 million m^3 are available with a minimum diameter of 7 cm. However, the yield per hectare is variable and very much dependent on the dimensions needed. When a diameter of 100 mm or less is adequate, the material can be harvested in the first commercial thinning in an economic way. Larger diameters are also available but the yield is normally small, a few bolts per hectare. Figure 6.1 illustrates the yield per hectare in the best compartments as a function of the diameter of the final product, assumed to be 25 mm less than the diameter of raw material.

For load-bearing structures, diameters such as 150 mm are usually needed. These are available from the second commercial thinning. This material has better quality and a higher price. However, the raw material price is only a minor part of the production cost of finalized products, and will not jeopardize the economy of round timber as building material.

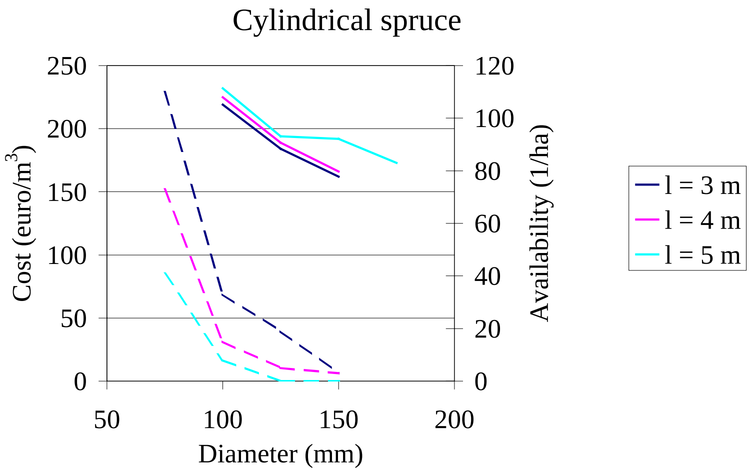


Figure 6.1. Cost of Finnish roundwood milled cylindrically (e/m^3) and availability of the raw material in the first commercial thinning on the best quarter of forest compartments (pieces per ha). Diameter means the size of final product, row material is presumed to be 25 mm larger in diameter.

Production costs are estimated for products with different surface qualities: bark removed only or machined cylindrical. The cost components are given in Table 6.1. There are two production cases analyzed based on 3-m-long bolts and 100-mm top diameter of final product:

- In case (1) the trees are harvested and debarked manually, and natural seasoning is used for drying. Top diameter of the bolts is 130 mm, volume 39 l, ordinary quality.

- In case (2) mechanical harvesting and cylindrical peeling is used with drying in an industrial kiln to 12 % moisture content. The top diameter of the bolts is 150 mm, volume 53 l, selected quality.

Figure 6.2. Photo of manually debarked and peeled timber.

Table 6.1. Example of production cost breakdown of roundwood for 2 quality classes. Yield in debarking is assumed to be 0.6 (cylinder with top diameter effective) and in cylindrical peeling 0.55, d = 100 mm, l = 3m, 5 % overhead included.

	Case 1: manual, low cost		Case 2: technical, high quality	
	Euro / m^3	Euro / m	Euro / m^3	Euro / m
Stumbage price	24.4	0.19	28.4	0.22
Harvesting	27.0	0.21	41.4	0.25
Transportation for debarking or peeling	16.9	0.13	19.7	0.15
Debarking/peeling	44.6	0.35	105.7	0.83
Cost of drying	0	0	25.0	0.20
Total production cost	112.9	0.88	220.2	1.73

The main reason for the higher prices of peeled products is the low yield of peeling. Because only half of the volume of raw material is possible to sell as the product, it will more than double the price of raw material.

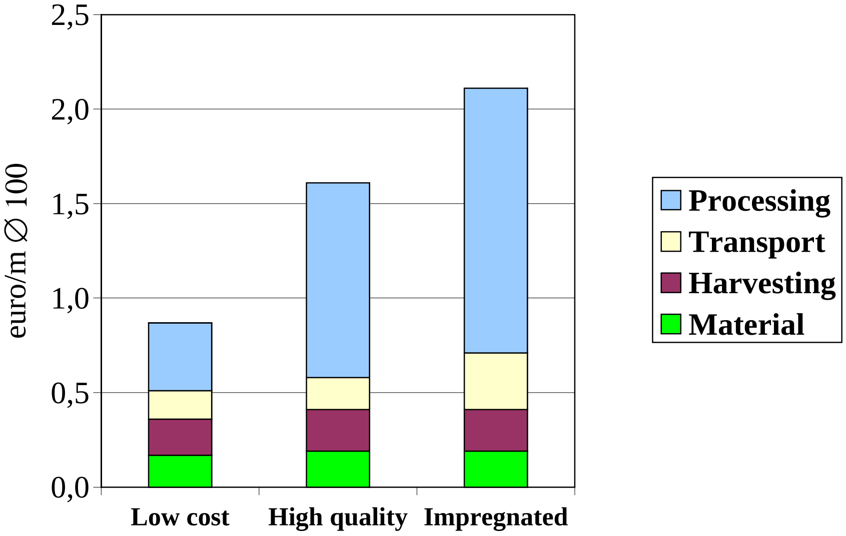


Figure 6.3. Cost breakdown of low cost (Case 1 in Table 6.1), high quality (Case 2) and impregnated high-quality round timber per meter when diameter is 100 mm.

The production cost of cylindrical round timber per cubic meter seems to be close to the cost of sawn timber. Accordingly, the reason to use high-quality round timber is not the low cost, but the required round form. This product is for structures where the round form is visible and the customer wants to have it. Cylindrical round timber can be cheaper, if the side product of rotary peeling can be sold at a fair price.

The cost of debarked round timber is clearly lower than that of sawn timber, roughly half of it. It has high strength and the environmental characteristics are top class. The disadvantage is the natural, irregular form, making it not easy to use in normal construction. It is best suited for buildings in which the appearance is not important.

In practice, the important qualities are those between the two extremes described above. Two options are frequently used: conical peeling as traditional poles in electricity lines, or sawing partly (vane allowed) to have 1 to 4 straight surfaces as needed. The cost of these is expected to be analyzed between the two cases.

When used out-of-doors, exposed to rain, as in a park and garden for small structures and for furniture, the material harvested from the first commercial thinning is of the right size, but it should be protected against biological deterioration. Traditionally, CCA treatment has been used and it offers a good protection. For environmental reasons, new less toxic methods are needed and have also been developed. Roundwood is a well-suited material for external structures and fences. It can be made more attractive by developing drying methods that produce round timber without checking. Round surface without cracks is also more durable, because water cannot enter the material though cracks or remain on horizontal surfaces.

The strength of small-diameter round timber was found to be relatively high: higher than can be obtained for sawn timber made from the same logs (Figure 6.4). The characteristic bending strength of unsorted material may be even double the value of sawn timber.

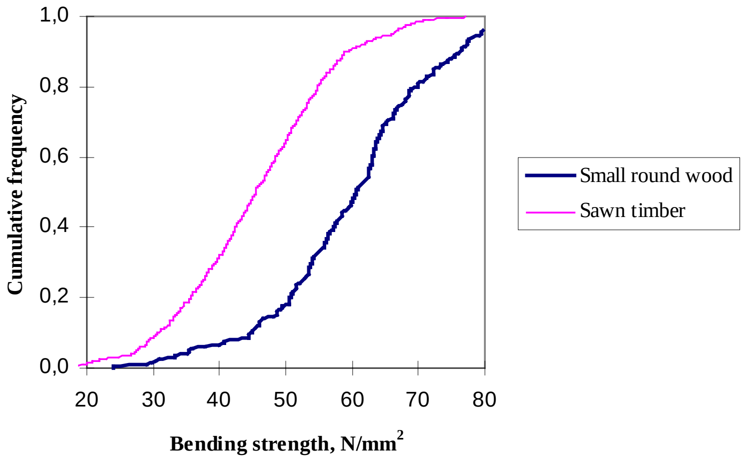


Figure 6.4. Cumulative distribution of bending strength of round and sawn spruce based on 600 specimens of sawn timber and 200 round-timber specimens in Finland.

It is concluded that the same CEN strength classes that are used for sawn timber can be used for small-diameter round timber for structural use. A proposal is made for a visual grading system and the equivalence to CEN strength classes is analyzed.

The correlation of visual grading parameters with strength is not any better than has been observed for sawn timber. However, visual grading is feasible for round timber: the yield of normal strength classes is high because of high strength.

Non-destructive methods (X-ray, ultrasonic, E_{dyn}) are promising for the grading of round timber in the future. The bending test on round timber is more problematic than that on sawn timber. Therefore, non-destructive methods are a more promising alternative for future grading of round timber than traditional grading machines based on bending.

The methods for determination of modulus of elasticity were compared for Douglas fir and larch (Gard et al. 1998):

- vibration measurements (E_{dyn})
- bending method: measurement reference points in middle section and on both ends of the specimens ($E_{m\ stat\ global}$), see Figure 3.1
- bending method: measurement reference points according to EN 408 ($E_{m\ stat\ local}$).

The correlation coefficients between various *E* values are shown in Table 6.2.

It is concluded that the measurement of $E_{m\ stat\ global}$ is more reliable than $E_{m\ stat\ local}$ in the case where the wood has large and variable knot sizes. Therefore the measurement of $E_{m\ stat\ global}$ is seen preferable when a static bending test is carried out. A proposal for a testing method is presented in the Appendix A.

Because of practical problems in performing the bending test, and inaccuracies where the diameter of pole is variable, it is suggested that determination of $E_{m\ dyn}$ should be developed and adopted as a basic method for determination of the modulus of elasticity of round timber. It would be useful as a laboratory tool, but also a possible basis for strength-grading.

Table 6.2. Correlation coefficients between moduli of elasticity.

	Douglas	Larch
$E_{m\ stat\ local} / E_{dyn}$	0.59	0.82
$E_{m\ stat\ global} / E_{dyn}$	0.87	0.85
$E_{m\ stat\ local} / E_{m\ stat\ global}$	0.74	0.91

The load-bearing capacity of the evaluated roundwood **connections** seems to be comparable with that of rectangular sections (the wood thickness being the diameter of the roundwood pole), when applying the EC 5 procedures. An essential condition is that failure mode 2 (see 4.2.2) indeed occurs in practice and wood splitting can be avoided. The executed embedment tests show a significant influence of the application of lacings with hollow dowels or bolts. When only dowels and one belt are applied, the test results duly approach the estimated values.

Therefore, it seems to be sound to recommend that the calculation of wire-laced dowel joints, as evaluated in this paper, follow the EC5 procedures for rectangular sections. Since the condition has to be fulfilled, that failure mode 2 will indeed occur in practice, appropriate dowel/pole stiffness ratios have to be followed.

A new type of joint, block shear joint was developed and tested. When splitting failure mode is avoided, e.g. by the use of lacing, the application of a steel strap around the pole, large forces can be transferred. In testing, characteristic values up to 110 kN in tension and up to 250 kN in compression were obtained.

Round-timber can be used in a variety of **buildings** as presented in great detail in Chapter 5. This project mainly collected information on the existing uses, but also developed new designs. The cover of this publication shows the model of a watch tower developed by the Dutch team. A number of these towers are planned to be built in Holland. Figure 6.5 illustrates a British design for a foot-bridge which is planned to be built in the campus area of Surrey University. Both of these are engineered structures for which round timber is well suited. Still more of round-wood can be used in small buildings for which guidelines are to be published in a separate booklet (Griffiths et al. 1999).

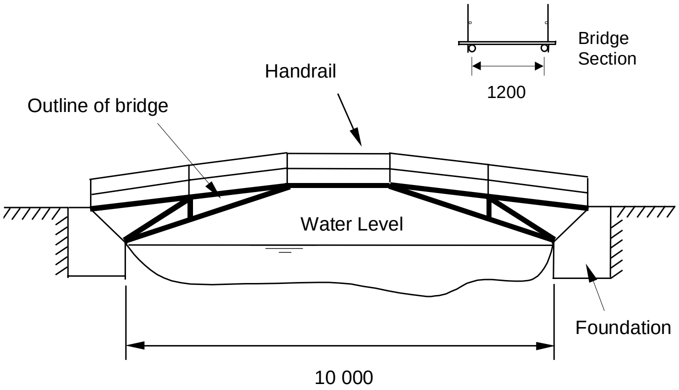


Figure 6.5. A round pole foot-bridge design.

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APPENDIX A

Voluntary Product Standard VPS-SRT-1 Draft 1999-02-01

Structural round timber - Determination of bending and compression characteristics

1. Scope

This standard specifies the test methods for determining the following properties of the structural round timber: modulus of elasticity in bending, bending strength, the modulus of elasticity in compression parallel to the grain, and compression strength parallel to the grain.

This standard is applicable for cylindrical shapes or for tapered shapes of round structural timber, or when the shape is partially cylindrical and partially tapered, and including oval cross-sections.

Where this standard does not describe a test method for a type of test the method from EN 408 can be applied.

2. Normative references

EN 408	Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties
VPS-SRT-3	Structural round timber - Sizes, permissible deviations

3. Symbols

A	cross-sectional area, in square millimetres
a	distance between loading position and nearest support in bending test, in millimetres
d	diameter of round timber, in millimetres
d_1	diameter of round timber at or close to the failure
d_n	diameter of round timber perpendicular to the direction of load at he midspan, in millimetres
d_v	diameter of round timber in the direction of load measured at the mid span, in millimetres
$E_{c,0}$	modulus of elasticity parallel to the grain, in newtons per square millimetre
E_m	modulus of elasticity in bending, in newtons per square millimetre
$E_{m,global}$	modulus of elasticity in bending over the total span, in newtons per square millimetre
F	load, in newtons
F_{max}	maximum load, in newtons
$f_{c,0}$	compressive strength parallel to the grain, in newtons per square millimetre
f_m	bending strength, in newtons per square millimetre
I	second moment of area, in millimetres to the fourth power $I = \pi \cdot d_{v1}^{3} \cdot d_{h1} /64$
l	span in the bending, or the length of the piece between the loading plates in the compression test, in millimetres
l_1	gauge length for the determination of modulus of elasticity, in millimetres
W	section modulus, in millimetres in the third power
w	deflection or displacement in compression, in millimetres.

4. Determination of dimensions of test piece

The dimensions shall be measured to an accuracy of 1 %. All the measurements shall be made when the test pieces are conditioned as specified in clause 7.

5. Determination of the moisture content of test pieces

The moisture content of the test piece shall be determined on a section taken from the test piece. For structural round timber, the section shall be of full cross-section, free from knots and resin pockets.

In the strength test, the section shall be cut as close as possible to the failure.

6. Determination of density of test pieces

The density is measured from a disk, taken close to the point of failure. The immersion method is recommended.

7. Conditioning of test pieces

The test pieces should be conditioned at +20 ^{o}C, 65 % RH to a constant weight, which is considered to be attained when the results of two successive weightings, carried out at an interval of 6 h, do not differ by more than 0.1 % of the mass of the test piece.

8. Bending test

8.1 Test piece

The test piece shall have a minimum length of 19 times the diameter of the round timber. For conical shapes see the span table in the next paragraph. Where this is not possible, the length of the timber shall be reported.

8.2. Procedure

The test piece shall be symmetrically loaded at two points over a span of 15 to 21 times the minimum diameter of the round timber. The loading heads shall be placed at the third points of the span as shown in Figures 1 and 2.

Where the diameter of the round timber is cylindrically processed to a target size, the span should be 18 times that target size. Where the actual diameter is not processed to a target value, the span corresponding to the top diameter of the timber can be taken from the following table:

Top diameter range	Nominal diameter (VPS-SRT-3)	Span
75 to 99 mm	75 mm	1500 mm
100 to 124 mm	100 mm	1950 mm
125 to 149 mm	125 mm	2400 mm
150 to 174 mm	150 mm	2850 mm
175 to 199 mm	175 mm	3300 mm
200 to 224 mm	200 mm	3750 mm
225 to 249 mm	225 mm	4200 mm
250 to 275 mm	250 mm	4650 mm

If the test piece or the equipment does not permit these conditions to be achieved exactly, the distance between the load points and the supports may be changed by an amount not greater than 1.5 times the diameter of the round timber and the span and the test piece length may be changed by an amount not greater than three times the diameter of the timber, while maintaining the symmetry of the test set-up.

The test piece should be placed in a random position with regard to loading direction. However, for practical reasons it is recommended to place the sweep in the direction of loading or opposite to it.

The test piece shall be simply supported.

> Note: Shaped wooden blocks of length not greater than the diameter of the round timber may be inserted between the piece and the loading heads or supports to minimize local indentation. The blocks under the loading heads may have different heights to take into account the possible tapering of the wood.

The test arrangement shall maintain the loading forces equal.

Load shall be applied at a constant rate. The rate of movement of the loading heads shall be not greater than 0.003 *d* mm/s, and so adjusted that the maximum load is reached within (300 ±120) s in case of determining bending strength.

The loading equipment used shall be capable of measuring the load to an accuracy of 1 % of the load applied to the test piece, for loads less than 10 % of the maximum applied load, and with the accuracy of 0.1 % of the maximum applied load.

Deformations shall be determined with an accuracy of 1 % or, for deformations less than 2 mm, with an accuracy of 0.02 mm. The rotation of the test piece during the test shall be considered and taken into account.

The diameters in the direction of the load, d_v, and perpendicular to the load, d_h, are measured at the mid-span.

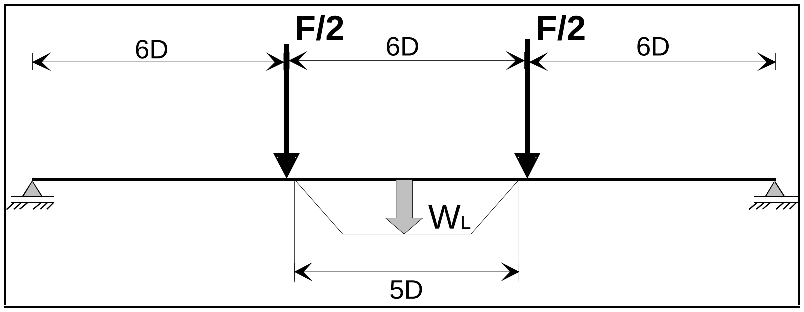

Figure 1. Bending test and measurement of local deflection w_L determination of modulus of elasticity.

8.3 Expression of test results

The local modulus of elasticity in bending E_m (Figure 1) is given by the equation

$$E_m = \frac{a\ l_1^2\ (F_2 - F_1)}{16\ I\ (w_{L2} - w_{L1})}$$

where

$F_2 - F_1$ is an increment of the load on the straight-line portion of the load deformation curve, in newtons
Note: F_1 and F_2 should be taken as 10 % and 50 %, respectively, of the maximum load.

$w_{L2} - w_{L1}$ is the increment of local deflection corresponding to $F_2 - F_1$, in millimetres, having been measured at the centre of a central gauge length of about five times the diameter of the round timber.

Alternatively, the global modulus of elasticity in bending $E_{m,global}$ (Figure 2) can be calculated, which is given by the equation

$$E_{m,global} = \frac{a\ (3l^2 - 4a^2)\,(F_2 - F_1)}{48\,I\,(w_{G2} - w_{G1})}$$

where

$w_{G2} - w_{G1}$ is the increment of total deflection at the centre of beam, corresponding to $F_2 - F_1$, in millimetres

a is the shorter distance between the loading position and the support.

The modulus of elasticity shall be calculated to an accuracy of 1 %.

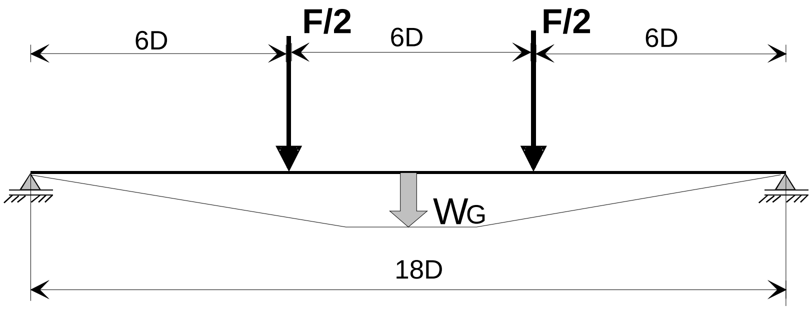

Figure 2. Bending test and measurement of global deflection w_G for determination of modulus of elasticity.

The bending strength f_m is given by the equation

$$f_m = \frac{16 F_{\max} a}{\pi d_h d_v^2}$$

The strength shall be calculated to the accuracy of 0.1 N/mm^2.

Note: The accuracy of determination of modulus of elasticity depends on the material characteristics as knots. Global modulus of elasticity is less sensitive to the effect of large knots and can be recommended especially for cylindrical poles.

9. Compression test parallel to the grain

9.1 Test piece

The test piece shall be of full cross-section, and shall have a length of six times the diameter of the round timber. The end surfaces shall be accurately prepared to ensure that they are plane and parallel to one other and perpendicular to the axis of the piece.

9.2 Procedure

The test piece shall be loaded concentrically. The load shall be applied at a constant rate. The rate of movement of the loading head shall not be greater than 0.00005 l mm/s. The maximum load should be reached within (300±120) s. The time to failure of each test piece shall be recorded and its average reported. Any single piece diverging more than 120 s from the target of 300 s shall be reported.

9.3 Expression of test results

The modulus of elasticity in compression is given by the equation

$$E_{c,0} = \frac{l_1 (F_2 - F_1)}{A(w_2 - w_1)}$$

The compressive strength is given by the equation

$$f_{c,0} = \frac{F_{\max}}{A}$$

The cross-sectional area $A = \pi d_1 d_2 / 4$. The diameters in two perpendicular directions, d_1 and d_2, are measured at or close to the fracture.

The mode of fracture and growth characteristics at the fracture section of each test peace shall be reported.

APPENDIX B

Voluntary Product Standard VPS-SRT-2 Draft 1998-10-28

Structural round timber - grading - requirements for visual strength-grading standards

Foreword

This standard has been prepared as part of the EU/FAIR research project “Round small-diameter timber for construction” (1996-1998). Small-diameter means that all the tested timbers in the project had a diameter of between 50 and 200 mm, the main part of test specimens being in the range of 100 to 150 mm.

Introduction

Strength-grading rules exist for the overhead transmission poles. While the transmission poles are mainly designed for the ground level bending strength, the structural round timber may be used as, e.g. compression members (studs) or as beams. Consequently, the grading rules may differ from the pole-grading rules. Different species grow differently and may need different grading rules, which can yield in different strength classes.

This standard proposes that strength classes for structural timber as given in EN 338 may be used also for round structural timber and the characteristic values will be determined in accordance with the principles of EN 384.

1. Scope

This standard gives basic principles for visual strength-grading standards. In Appendix A, strength-grading standards for two different species are presented.

2. Normative references

This standard incorporates dated or undated references. For undated references the latest edition of the publication referred to applies.

EN 338 Structural Timber - Strength Classes

EN 384 Structural Timber - Determination of characteristic values of mechanical properties and density

EN 844 Round and sawn timber - Terminology

EN1310 Measurement of features.

3. Definitions

For the purposes of this standard the following definitions apply:

3.1 Spiral grain: The apparent deviation of the grain orientation on the surface of the round timber from the orientation of the longitudinal axis of the timber. The grain deviation may in the clockwise or in the anticlockwise direction.

3.2 Grading diameter: the diameter of the round wood, which is measured at or above the knot, not including the knot butts.

4. Requirements for the standards on visual strength-grading of round structural timber

The grading standard shall include limits for the characteristics and their methods of measurement given in the clauses 5 to 7.

If grading is restricted to a special use, e.g. compression, this shall be clearly stated.

If there are any restrictions or additional criteria with regard to the application of the rules, they shall be stated in the standard. Such criteria shall relate to the strength or constructional use of the timber.

Unless otherwise stated, 20 % moisture content shall be taken as the reference point for all measurements.

Limits of reduction in size shall be stated beyond which reprocessing invalidates the grading.

5. Strength reducing characteristics

5.1 Knots

Maximum diameter of the knots or the knot hole, measured along the girth of the round timber, shall be specified.

The knot grouping, over a length of 150 mm shall be specified.

5.2 Spiral grain

The standard shall have a definition of slope of grain, a method for its measurement and limitations on the spiral grain for each grade specified.

5.3 Rate of growth

The grading standard shall contain a requirement for the rate of growth, its method of measurement and limits for it.

5.4 Cracks

The maximum length and the sum of the depths of the radial cracks at a cross-section should be defined.

5.5 Reaction wood

The relative amount of reaction wood in a cross-section should be defined.

6. Geometrical characteristics

6.1 Ovality

The maximum deviation of roundness, its method of measurement and the limits shall be defined.

6.2 Sweep

The maximum continuous or abrupt curvature as a deviation of the straight line shall be defined, as well as its method of measurement and the limits shall be defined.

6.3 Machining defects

The maximum extent of machining defects, like cuts and hairy grain, shall be defined.

7. Biological characteristics

7.1 Bark

The requirement for the inclusion of bark and/or cambium should be defined.

7.2 Fungal and insect damage

The standard shall include requirements that limit fungal and insect damage to round timber, and which prohibit round timber under live insect damage.

8. Other characteristics

The standard may include requirements that limit the presence of oil, mud and other discolouring substances on the surfaces.

9. Marking

Each graded piece shall be marked. A description of the marking shall be given. The marking shall as a minimum give the following information:

a) strength class and/or grade
b) species or species combination
c) producer
d) the standard to which it is graded.

Annex A to VPS-SRT-2

Strength-grading standard for round structural timber - Norway Spruce (Picea abies) and Scots Pine (Pinus sylvestris)

1. Scope

This standard covers the visual strength-grading of structural round timber of spruce grown in the Scandinavian countries based on the EU/FAIR research project “Round Small-diameter Timber for Construction” (1996-1998) in which testing was limited to diameters below 200 mm. This standard can be applied to round timber with different surface qualities: cylindrical or conical machine rounded or debarked timber.

2. Grading limitations

The grading should take place after surface machining of the timber (debarking, lathe work) and after drying to a moisture content less than the fibre saturation point. Surface smoothing is not considered to change the grade. Some of the characteristics, like cracks, vary in size according to the moisture content, and their size may differ at the time of grading from those at the MC of 20 %.

3. The measurement of the strength reducing characteristics

3.1 Knots

The knots are measured along the girth, not including the callus. The diameter of the knot is limited in relation to the grading diameter. The limits are in Table 1.

3.2 Knot groupings

The sum of the knots of a knot grouping is related to the grading diameter. In a cluster, all the knots within a longitudinal distance of 150 mm are included. The limits of the knot groupings are in Table 1.

3.3 Top defect

Top defect is not allowed in structural round timber. Double pith is not allowed.

3.4 Spiral grain

Spiral grain is measured as a deviation of the grain from the longitudinal line and it is measured along the girth. The spiral grain is expressed as 1 to x (1:x), where x is the number of the units in the longitudinal direction when the deviation is one unit. The limits of the spiral grain are in Table 1.

3.5 Rate of the growth

The average rate of growth is measured at the top end of the round timber. The measuring takes place along the radial line through the pith, where the distance from the pith to the surface is the maximum. The number of growth rings is counted starting at 25 mm from the pith and ending at the outer circumference. The rate of growth is expressed as the average of annual ring widths. The upper limits of the rate of the growth are in Table 1.

3.6 Cracks

Cracks other than in the radial plane are not allowed. No radial crack may pass the pith. Two radial cracks at a cross-section are allowed only if the less deep crack has the depth of less than a half of the radius of the round timber. The limits for the depth and for the length of the cracks are in Table 1.

3.7 Reaction wood

Reaction wood is measured as a percentage of the cross-section. The limit of the amount is in Table 1.

4. Limitations for geometrical characteristics

4.1 Ovality

The difference between the maximum and the minimum diameter at any cross-section in relation to the maximum diameter is defined as the ovality. The limits for the ovality are in Table 1.

4.2 Sweep

The maximum height of the arch on the concave side of the round timber is measured over the span of 2 meters. The limits of the sweep are in Table 1.

4.3 Machining defects

The maximum depth of cuts is limited as in Table 1. The length of the cuts is limited to 25 % of the length of the structural round timber.

5. Biological characteristics

5.1 Bark

The bark is not allowed, except in bark pockets or in bark ringed knots. The cambium is evaluated over the length of 1 metre and is expressed as the percentage of the cambium-covered surface to the surface of that 1-m-length. The limits of the cambium are in the Table 1.

5.2 Fungal and insect damage

No decay is allowed. The blue stain is allowed. The insect holes are allowed only in the kiln-dried round timber.

6. Surface cleanness

The surface of the round timber should be free from soil and oil.

7. Allowable characteristics

Table 1. Limits of the characteristics.

Characteristic		**Grade "A"**	**Grade "B"**
Size of the knot in relation to the grading diameter, mm		25 %	30 %
Sum of knots, in relation to the grading diameter		75 %	100 %
Spiral grain		1:10	1:7
Rate of the growth, mm		3	5
Single crack, depth in relation to the grading diameter		50 %	50 %
Single crack, length		not limited	not limited
Sum of any two cracks at a cross-section, in relation to the diameter		75 %	75 %
Reaction wood, ratio to the cross-section		10 %	10 %
Tapering, mm/m	unmachined	5	10
	machined	3	5
Ovality	unmachined	10 %	20 %
	machined	5 %	10 %
Sweep, over 2 meters		5 mm	10 mm
Machining defects, maximum depth		5 mm	5 mm
Cambium		10 %	10 %
Insect holes		not permitted in the air-dried timber	not permitted in the air-dried timber

8. Marking

The round structural timber is marked at the butt end or on the surface close to the butt end. The marking shall give the following information:

a) Grade "A" or "B"
b) Species ER = European Redwood, EW = European Whitewood
c) Producer
d) The number of this standard, e.g. VPS-SRT-2:A
e) The size according to the standard VPS-SRT-3
f) "KD", if the timber is kiln-dried.

APPENDIX C

Voluntary Product Standard VPS-SRT-3 Draft 1998-10-27

Structural round timber - Sizes, permissible deviations

1. Scope

This standard defines the sizes of the structural round timber and the permissible deviations.

2. Normative references

This standard incorporates dated or undated reference. For undated references the latest edition of the publication referred to applies.

VPS-SRT-2, draft	Voluntary Product Standard, Structural round timber - grading - requirements for visual strength grading standards

3. Method of measuring

The length of the structural timber is the minimum distance between the full circumferences at the top and at the butt. Thus the inclined cross cuttings are ignored. The diameter of the of the round timber is the minimum diameter at the top end of the round timber. If the moisture content at the time of measurement deviates from 20 %, the measured size of the diameter can be adjusted by increasing it by 0.25 % for difference in moisture content short of 20 %, or decreasing it by 0.25 % for difference in moisture content in excess of 20 % and up to 28 %.

4. Timber diameters

The size of the round timber is expressed as the next fulfilling size in series of 75 to 200 mm, in steps of 25 mm.

> Note: If the minimum diameter is measured as 89 mm, the size of the round timber is 75 mm.

By the agreement between the producer and the client, the timber sizes may be defined differently.

5. Deviations

The size of the timber is, by definition, within tolerances of -0, +25 mm.

In the case of cylindrically shaped structural round timber, an unmachined, but debarked area of a maximum length of 500 mm and not covering more than 25 % of the circumference and not reducing the diameter by more than 5 mm is considered to meet the size.

The length of the timber is expressed in fulfilling multiples of 300 mm, or it shall meet the requirements of the client with tolerances -0, +50 mm.