Holz als Roh- und Werkstoff 58 (2000) 162–167 © Springer-Verlag 2000

Selecting trees for structural timber

Addis Tsehaye, A. H. Buchanan, J. C. F. Walker

Abstract Twenty-eight cubic metres of timber (i.e. a total of 2248 boards) cut from 108 *Pinus radiata* trees from two 25-year-old plantations from Canterbury and Nelson in the South Island of New Zealand were tested in tension. Within- and between-tree variations of stiffness, strength and density were examined. Comparisons between density and stiffness for selecting trees for structural timber indicated that stiffness is the better parameter for selecting superior trees within the natural population of a forest stand; and the quality and grade recovery of structural timber would be increased significantly if trees were to be selected on the basis of stiffness. These conclusions apply to both stands although regional differences are evident with the Nelson timber being somewhat stiffer.

Auswahl von Bäumen für Bauschnittholz

Zusammenfassung 28 m^3 Schnittholz, entsprechend 2248 Brettern, wurden aus 108 Kiefernstämmen (*P. radiata*) geschnitten. Die Proben, die aus einer 28jährigen Plantage in Neuseeland stammen, wurden auf Zugfestigkeit geprüft. Die Variation von Steifigkeit, Festigkeit und Dichte innerhalb und zwischen den einzelnen Bäumen wurde untersucht. Beim Vergleich von Dichte und Steifigkeit als Parameter zur Auswahl von Schnittholz erwies sich die Steifigkeit als der bessere Parameter, um die besten Bäume eines Standorts auszuwählen. Qualität und Ausbeute an günstigen Güteklassen könnten signifikant ansteigen, wenn Bäume aufgrund ihrer Steifigkeit ausgewählt werden. Dies gilt für beide untersuchten Standorte, wenn auch regionale Unterschiede bestehen; denn die Proben aus Nelson waren durchweg etwas steifer.

Addis Tsehaye
Consultant, 387 Ilam Road, Christchurch, New Zealand

A. H. Buchanan
Department of Civil Engineering, University of Canterbury,
Christchurch, New Zealand

J. C. F. Walker (✉)
School of Forestry, University of Canterbury,
Christchurch, New Zealand

The authors would like to acknowledge the New Zealand Foundation for Research, Science and Technology for support towards this project, and Carter Holt Harvey Forests, Nelson for help in sourcing appropriate logs.

1
Introduction

"Wood quality is defined in terms of attributes that make it valuable for a given end use" (Jozsa & Middleton 1994). Hence, it is not possible to agree on a common, desirable set of wood quality properties for all sectors of the forest products industries as wood quality can have meaning only when the final product is known. Wood quality relates to the cumulative effect of these wood properties on some specific product or products. Further, wood properties should be interpreted in terms of the cellular, anatomical and chemical characteristics of the wood within and among trees.

Density has long been considered the best single index of intrinsic wood quality. However, to the sawmiller wood quality is reflected in the value of mill production and depends on grade outturn and value ($/m^3) for each grade. Again, the structural engineer sees wood quality in terms of strength and stiffness. Finally, consumers measure wood quality in terms of many variables including hardness, appearance, durability etc., depending on the final use for the wood.

Wood density is the index most often used for selecting wood, on the assumption that density is a good indicator of strength, stiffness and other properties. The argument developed in this paper is that if stiffness is desired, then stiffness should be used for selection wherever possible: that includes selection of breeding stock, selection of trees for thinning, selection of logs for sawing and selection of sawn timber. In this paper density and stiffness are compared as indicators for assessing wood quality of young, fast-growing radiata pine for structural timber.

2
Materials and methods

Trees for this study came from two unpruned 25-year old stands, one in the Southern Pigeon Valley, Nelson, and the other near Dunsandel, Canterbury, both in the South Island of New Zealand. These trees were felled and cross-cut to give three or four sawlogs. Each log was identified by tree number and log type (butt, second, third and fourth log).

The Dunsandel stand in Canterbury was chosen because Walford (1985) had identified wood from this area to be amongst the poorest in the country. This stand was taken to represent the lowest possible wood quality base line for subsequent research in other areas within New Zealand. The Nelson site was chosen to represent the typical wood supply for a region identified as producing high density timber according to the New Zealand Forest Research Institute's broad regional classification (Cown & McConchie 1983).

Slower growth on the drier stonier sites around Dunsandel resulted in smaller trees, and these were cross-cut to give three 3.6 m logs, whereas the Nelson trees generally gave four 4.2 m logs. The consequential effect of having timber of different lengths is discussed later. Forty eight trees (144 logs) from Canterbury and sixty trees (240 logs) from Nelson were milled, air dried to 12% moisture content, dressed to 90 × 35 mm and machine stress graded according to the Australian grading rules (SAA 1978a, b).

Milling details have been described in Addis Tsehaye et al. (1995b). All logs were sawn to the pattern shown in Fig. 1. This pattern gave a central cant and one, two or three 40 mm flitches on either side. The flitches were re-cut at the breast bench to yield timber of nominal dimensions 100 × 40 mm. In re-cutting the 100 mm wide cant, the object was to box the pith within a single 100 × 40 mm piece and cut further pieces of the same size by working out symmetrically towards the cambium. In practice the pith wandered and was rarely confined to a single board, and the number of pith-containing pieces within a single log varied from 1 to 3. The position of every board was recorded relative to the pith and numbered from 1 (with-pith) to 4 as shown in Fig. 1.

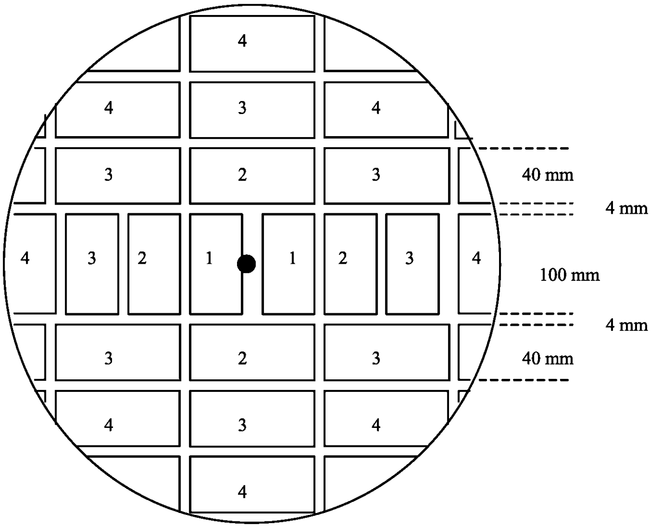

Fig. 1. Sawing pattern, cutting a 100 mm thick central cant and 40 mm wide flitches to give 90 × 35 mm dry, dressed boards
Bild 1. Einschnittplan für 100 mm hohes zentrales Kantholz und 40 mm dicke Seitenbretter. Nach dem Trocknen und Hobeln ergeben sich daraus Bretter der Dimension 90 × 35 mm

In the tensile test each board was clamped with hydraulic pressure between jaws 450 mm long to give a clear span of 3.15 metres for the Nelson timber and 2.6 metres for the Canterbury timber, over which length the modulus of elasticity was measured. The tensile force was applied by a 200 kN capacity hydraulic ram controlled by a manually operated valve. The load cell measuring the applied force was checked at intervals with a standard reference load cell and any drift corrected. Subsequently a clearwood sample adjacent to the failure zone was cut from each board and its unextracted air-dry density (12% M.C.) determined.

3
Results

All boards were graded according to the structural grade values (Table 1) in the Australian grading rules (SAA 1988: AS 1720). The grade recoveries with respect to both the log type and the position of the boards relative to the pith are summarised in Tables 2 and 3.

3.1
Adjusting for the length effect

In the subsequent tables, the results for the Nelson timber are compared with those for the Canterbury timber. As indicated earlier, 2.6 m clear lengths were used for testing the Canterbury timber compared with 3.15 m clear lengths for the Nelson timber. According to the principle of the weakest link (Madsen & Buchanan 1986), differences in span length will have a noticeable effect on the tensile strength values, with larger spans giving lower strength values. Hence, in order to make an appropriate comparison, the tensile strength data for the Canterbury timber have been standardized to 3.15 m span length by applying a length effect parameter, k_1, as recommended in the AS/NZS 4063 (SAA 1992).

$$k_1 = (L_o/L_s)^{c.v.} \tag{1}$$

where: L_o = non-standard span (m); L_s = standard span (m); and c.v. = coefficient of variation.

The length effect in structural timber arises because of within-board variability, which reflects the random distribution of defects along the length of each board. The coefficient of variation used in equation 1 is the particular coefficient of variation (shown below in column 8, Tables 4 and 5 for Canterbury) for between-board variability. This is a measure of the variation in strength at the weakest point for each board in the test population. Equation 1 is based on the assumption that these two sources of variability are the same. This assumption is not necessarily true, but may be reasonably used, given the

Table 1. Characteristic tensile stresses for structural grades and moduli of elasticity for radiata pine (SAA 1988: AS 1720)

	Grade						
	F2	F3	F4	F5	F8	F11	F14
Characteristic Stresses for tensile strength (MPa)	4.0	5.0	6.5	8.2	13.0	16.6	21.1
Moduli of Elasticity (GPa)	4.5	5.2	6.1	6.9	9.1	10.5	12.0

Table 2. Grades of boards according to log type

Source:	Nelson				Canterbury				
Log	Grade distribution (%)				Log	Grade distribution (%)			
	F4 and below	F5	F8 and better	Total # of boards		F4 and below	F5	F8 and better	Total # of boards
Fourth	11.5	41.0	47.5	200	Fourth	n/a	n/a	n/a	n/a
Third	11.2	31.2	57.6	304	Third	60.6	36.2	3.2	221
Second	13.8	26.2	60.0	355	Second	48.1	40.3	11.6	295
Butt	17.5	26.8	55.7	474	Butt	53.9	28.8	17.3	399
All	14.2	29.8	56.0	1333	Total	53.7	34.3	12.0	915

n/a = not applicable because only three logs were cut from the smaller Canterbury trees

Table 3. Grades of boards at different positions from the pith

Source:	Nelson				Canterbury				
Position from pith	Grade distribution (%)				Position from pith	Grade distribution (%)			
	F4 and below	F5	F8 and better	Total # of boards		F4 and below	F5	F8 and better	Total # of boards
1	67.3	32.7	0.0	275	1	95.6	2.5	1.9	206
2	0.6	60.7	38.7	506	2	58.9	36.8	4.3	440
3	0.0	0.3	99.7	394	3	13.6	56.8	29.6	250
4	0.0	0.0	100.0	158	4	5.3	26.3	68.4	19
All	14.2	29.8	56.0	1333	Total	53.7	34.3	12.0	915

difficulty of measuring within-board variability. The effect of this adjustment is to reduce the ultimate tensile strength values for the Canterbury timber (to offset the shorter length being tested).

3.2
Variation in properties with log type

The properties of all boards cut from a particular log type are averaged to provide a mean modulus of elasticity, ultimate tensile strength and density for that log type (Table 4).

3.3
Variation in properties from pith to cambium

The mean modulus of elasticity and ultimate tensile strength values are shown in Table 5 for each position relative to the pith, with all log types aggregated.

3.4
Variation in properties between trees

Differences in the mean modulus of elasticity and ultimate tensile strength between the individual trees were examined by ranking their modulus of elasticity and density values. Using a univariate procedure (SAS 1985), the least stiff and stiffest trees were identified by ranking according to stiffness, while the low density and high density trees were identified by ranking according to density. The trees were divided into three groups. Two groups represented the lowest 10% and the highest 10% within the population and a large third group represented the majority of the trees.

The mean modulus of elasticity, ultimate tensile strength and density for all the three groups of trees ranked according to stiffness are summarised in Table 6, for the butt logs only.

Table 4. Mean values of density, modulus of elasticity and ultimate tensile strength, based on the log types for the Nelson and Canterbury timber

Source:	Nelson				Canterbury			
Log	N	MOE (GPa)	UTS (MPa)	Density (kg/m^3)	N	MOE (GPa)	UTS* (MPa)	Density (kg/m^3)
Fourth	199	9.2 (24)	15.2 (37)	481 (9)	n/a	n/a	n/a	n/a
Third	304	10.1 (31)	17.1 (42)	489 (12)	221	6.6 (26)	14.2 (35)	462 (9)
Second	355	10.2 (33)	18.3 (48)	491 (12)	295	7.0 (24)	16.8 (32)	462 (8)
Butt	473	9.9 (33)	20.3 (52)	506 (12)	399	6.8 (31)	19.4 (40)	492 (8)
All	1331	9.9 (32)	18.3 (47)	495 (12)	915	6.8 (28)	17.3 (39)	475 (9)

Values in parentheses are coefficients of variation (%); n/a = not applicable as only three logs were cut from these trees;
*The Canterbury UTS values have been adjusted to a 3.15 metre span and are lower than the original values, for the 2.6 metre span, previously published in Addis Tsehaye et al. (1995a, b)

Table 5. Mean values of modulus of elasticity and ultimate tensile strength based on relative position to the pith

Source Position from pith	Nelson				Canterbury			
	N	MOE (GPa)	UTS (MPa)	Density (kg/m^3)	N	MOE (GPa)	UTS* (MPa)	Density (kg/m^3)
1	275	6.3 (16)	11.7 (32)	460 (9)	206	5.0 (22)	12.8 (28)	464 (9)
2	506	8.8 (10)	15.1 (32)	477 (9)	440	6.7 (21)	16.7 (32)	470 (9)
3	393	11.9 (10)	22.8 (37)	517 (10)	250	8.5 (18)	21.7 (34)	489 (8)
4	157	15.1 (25)	28.5 (39)	551 (12)	19	9.5 (16)	27.3 (33)	514 (8)
All	1331	9.9 (32)	18.3 (47)	495 (12)	915	6.8 (28)	17.3 (39)	475 (9)

Values in parentheses are coefficients of variation (%)
*The Canterbury UTS values have been adjusted to a 3.15 metre span and are lower than the original values, for the 2.6 metre span, previously published in Addis Tsehaye et al. (1995a, b)

Table 6. Mean modulus of elasticity and ultimate tensile strength for the three groups of trees ranked according to stiffness: data from the butt logs only

Source:	Nelson					Canterbury				
Group	# of trees	# of boards	MOE (GPa)	UTS (MPa)	Density (kg/m^3)	# of trees	# of boards	MOE (GPa)	UTS (MPa)	Density (kg/m^3)
Least stiff trees	6	39	6.9 (11)	13.4 (11)	501 (8)	5	47	4.7 (6)	11.5 (28)	489 (4)
Medium stiffness trees	48	378	9.8 (9)	19.8 (22)	483 (11)	38	311	6.5 (12)	19.7 (13)	486 (6)
Stiffest trees	6	57	12.8 (5)	26.5 (15)	560 (13)	5	41	8.4 (7)	25.5 (4)	527 (5)

Values in parentheses are coefficients of variation (%)

The mean modulus of elasticity, ultimate tensile strength and density for all the three groups of trees ranked according to density are summarised in Table 7, for the butt logs only.

4
Discussion

4.1
Within-tree variation

Table 2 demonstrates that a significant quantity of framing and structural timber can come from the top logs of a young tree from Nelson. Table 3 shows that the proportion of F4 and below grades decreases and the proportion of F5 and better grades increases in moving away from the pith. Again, the recovery of high grade material from Nelson is better compared with that from Canterbury at any one position from the pith.

Table 4 indicates that the mean value for the modulus of elasticity changes little in going from the butt log to the top log, whereas the mean tensile strength decreases steadily from the butt log to the top log. These trends are found in both regions: Nelson and Canterbury. The constant log stiffness values for butt and top logs are a surprise as the proportion of corewood/juvenile wood increases dramatically with height up the stem and conventional analysis would expect a deterioration in log quality with height. The interpretation lies in the abnormally low stiffness of the corewood in the butt log being counterbalanced by very stiff outerwood, whereas the top logs have somewhat stiffer corewood and less stiff wood further from the pith.

The uniformity of the mean stiffness values between logs in a tree is an acceptable outcome for the New Zealand tree growers as it offers a source of structural timber. Walford (1994) noted that the silvicultural treatments generally advocated (early thinning to waste and pruning of the butt log) mean that the more mature timber from the butt logs will be clearwood and destined for high value non-structural uses, while structural timber will have to come from the unpruned upper logs and the knotty corewood of the butt logs.

Table 7. Mean modulus of elasticity and ultimate tensile strength for the three groups of trees ranked according to density: data from the butt logs only

Source:	Nelson					Canterbury				
Group	# of trees	# of boards	MOE (GPa)	UTS (MPa)	Density (kg/m^3)	# of trees	# of boards	MOE (GPa)	UTS (MPa)	Density (kg/m^3)
Low density trees	6	62	9.2 (29)	19.2 (59)	468 (10)	5	42	6.2 (10)	17.8 (6)	450 (1)
Medium density trees	48	350	9.8 (36)	19.5 (50)	505 (11)	38	315	6.9 (17)	19.2 (22)	489 (4)
High density trees	6	62	11.6 (28)	25.6 (45)	558 (14)	5	42	7.0 (25)	19.5 (22)	542 (3)

Values in parentheses are coefficient of variation (%)

The change in the mean stiffness values on going from the pith to the cambium is greatest between positions 1 and 2 (Table 5). For the Nelson timber, moving from position 1 to 2, 2 to 3, and 3 to 4 the percentage increase in stiffness is 40%, 35%, and 27% respectively. The respective changes in stiffness for the Canterbury timber are 34%, 27% and 11%.

The changes in the mean tensile strength values in moving from the pith to the cambium (Table 5) follow a similar pattern to that for stiffness. For the Nelson timber, moving from position 1 to 2, 2 to 3 and 3 to 4 the percentage increase in tensile strength is 29%, 51% and 25% respectively. For the Canterbury timber the change between positions 1 and 2 and positions 2 and 3 is 30% and between positions 3 and 4 is 26%. The rates of change observed in both stiffness and strength are in line with the statement made by Bendetsen (1978) namely, "the rate of change in most properties is very rapid in the first few rings, the later rings gradually assume the character of mature wood".

The magnitude of changes in the mean density (Table 5) on going from the pith to the cambium do not correlate with the changes in the mean stiffness and tensile strength values. The percentage change in the mean density on moving from position 1 to 4 is 20% for the Nelson timber and only 11% for the Canterbury timber. The percentage increases in the mean stiffness and tensile strength between these positions are 140% and 144% respectively for the Nelson timber, and 90% and 113% respectively for the Canterbury timber.

From the perspective of tree improvement, the case is well made for focussing on the corewood properties rather than on the outerwood. The financial return in raising corewood from F4 to F5 grade (an increase in revenue of ca. \$100/m^3) greatly outweighs the benefits of improving outerwood by a grade (an increase in revenue of ca. \$20/m^3).

4.2
Between-tree variation

Table 6 indicates that the potential for selection of trees according to stiffness is considerable. There are large differences between the two extremes, i.e. the stiffest trees for the two stands are 80–85% stiffer and 98–122% stronger than the least stiff trees. In breeding, if one were to select trees having properties corresponding to those of the stiffest 10% of population rather than of the medium stiffness trees, this would improve the out-turn of timber by at least one grade. In sawmilling, if structural lumber mills were able to exclude the poorest 10% of timber from current production, then an improved grade out-turn would result and, as important, less emphasis would need to be placed on reprocessing below-grade lumber. One such tool to achieve this pre-sorting of logs is acoustics: its effectiveness is evaluated in Addis Tsehaye et al. (in press).

Table 7 on the other hand shows that by ranking trees on the basis of density only a modest increase in stiffness and tensile strength between the low density and high density trees is achieved with no significant difference between the medium and high density trees.

The traditional approach to improve wood quality has been to argue in favour of selection on the basis of density. This study and earlier ones (including Addis Tsehaye et al. 1991, 1992, 1995a, b; Hadi 1992) have identified low stiffness – especially in corewood – to be the principal constraint to greater use of radiata pine for structural purposes. Superior density as such does not appear to be the most direct means of achieving superior stiffness and strength. Thus, alternative strategies that approach the problem of low stiffness directly warrant investigation (Cave & Walker 1994).

4.3
Between-site variation

The mean stiffness, tensile strength and density values in the current study (Tables 4 and 5) demonstrate that the Nelson timber is superior (i.e. both within and between logs) to that of the Canterbury timber. However it is important to re-emphasise that the timber from Canterbury was deliberately sought from the poorest location within that province (to establish a "floor" to poor wood properties) so that poor properties reported for this one stand are *not* typical of that region. The differences between the two stands in Canterbury and Nelson are much greater when comparing stiffness (6.8 GPa and 9.9 GPa, a 46% difference) than when comparing strength (17.3 MPa and 18.3 MPa) and density (475 kg/m^3 and 495 kg/m^3). These observations support the previous reports (Cave & Walker 1994; Walker & Butterfield 1996) that density alone cannot account for differences in mechanical properties, particularly stiffness in radiata pine.

5
Conclusions

From the present study the following conclusions are drawn:

Stiffness is better than density for selecting structural timber, especially if sawmill production is marketed on the basis of machine stress grading.

Between-tree variations in wood properties are considerable. If the least stiff logs can be identified at the skid site, then uneconomic processing of those logs having poor quality sawn timber could be avoided.

The mean modulus of elasticity is roughly constant up the height of the tree, suggesting that there are opportunities to produce machine stress graded lumber (of modest stiffness) from the upper logs in the stem.

Considering regional variations, the mean stiffness, tensile strength and density values for the Nelson timber are superior to those for the Canterbury timber from a poor site. The percentage difference between the two regions is much greater in stiffness (46%), but only slight (<6%) in both strength and density.

References

Addis Tsehaye, Buchanan AH, Walker JCF (1991) Characterising boxed-pith of *Pinus radiata*. J Inst Wood Sci 12: 211–6

Addis Tsehaye, Buchanan AH, Walker JCF (1992) The strength of finger jointed boxed-pith timber of *Pinus radiata*. J Inst Wood Sci 12: 285–9

Addis Tsehaye, Buchanan AH, Walker JCF (1995a) A comparison of density and stiffness for predicting wood quality. Or density: the lazy man's guide to wood quality. J Inst Wood Sci 13: 539–43

Addis Tsehaye, Buchanan AH, Walker JCF (1995b) Stiffness and tensile strength variation within and between radiata pine trees. J Inst Wood Sci 13: 513–8

Addis Tsehaye, Buchanan AH, Walker JCF (2000) Sorting logs using acoustics. Wood Sci Technol (in press)

Bendtsen BA (1978) Properties of wood from improved and intensively managed trees. For Prod J 28: 61–72

Cave ID, Walker JCF (1994) Stiffness of wood in fast-grown plantation softwoods: the influence of microfibril angle. For Prod J 44: 43–8

Cown DJ, McConchie DL (1983) Radiata pine wood properties survey (1977–82). New Zealand For Serv, FRI Bull No. 50, Rotorua

Hadi P (1992) Proof testing of radiata pine boxed-pith timber. M.For.Sc. thesis, University of Canterbury

Jozsa LA, Middleton GR (1994) A discussion of wood quality attributes and their practical implications. Forintek Canada Corp. Special Publication No. SP-34, Vancouver

SAS (1985) SAS procedures guide for personal computers version 6 edition. SAS Institute Inc. Cary, North Carolina

SAA (1978a) Rules for mechanical stress grading of timber, AS1749. Standard Association of Australia, North Sydney

SAA (1978b) Specification for mechanically stress graded timber, AS1748. Standard Association of Australia, North Sydney

SAA (1988) Timbers structure code, Part 1 – Design methods, AS 1720. Standard Association of Australia, North Sydney

SAA (1992) Joint Australian and New Zealand Standard, Timber – stress graded – in-grade strength and stiffness evaluation, AS/NZS 4063. Standard Association of Australia, North Sydney

Walford GB (1985) The mechanical properties of New Zealand grown radiata pine for export to Australia. New Zealand For Serv, FRI Bulletin No. 93

Walford GB (1994) Preliminary results of an in-grade evaluation of juvenile radiata pine. Proc. of Pacific Timber Engineering Conf., Gold Coast, Australia. Vol. 2: 725–30

Walker JCF, Butterfield BG (1996) The importance of microfibril angle for the processing industries. New Zealand J For 40: 34–40