IN-GRADE TESTING OF
NORFOLK ISLAND PINE
(Araucaria heterophylla)
TO ENABLE CHARACTERISATION OF THE TIMBER

A thesis submitted in partial fulfilment
for the Degree of MASTER OF TIMBER TECHNOLOGY,
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Faculty of Engineering
Department of Civil Engineering and Building

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SUMMARY

This report deals with an investigation into the structural properties of the timber species, Norfolk Island pine (Araucaria heterophylla) to enable characterisation of the timber. The various structural properties (bending stress, shear stress, compressive stress, tensile stress and Modulus of Elasticity) are determined by full-scale (in-grade) testing procedures.

Full-size specimens were tested at the University of Central Queensland in Rockhampton and NSW State Forests Research facility at Pennant Hills in Sydney.

The timber is being used on Norfolk Island as a structural and decorative timber. Because it is a limited but renewable resource, optimum use needs to be made of it as a building material to make maximum use of the material. Presently Norfolk Island has an inverse balance of payments with timber products, the vast majority of which is imported New Zealand radiata pine. If this balance of payments is to be reversed, better utilisation needs to be made of the locally produced timber. Implied in this also is improved utilisation of local labour and industry in producing the local product.

No significant testing has been done in the past on Norfolk Island pine. The only technical references to it in the literature appears to be in the botanical and silvicultural context. One author has given the material a provisional grading only (this would be based on small clear specimens, possibly not even produced on Norfolk Island).

It is only with rigorous full-scale testing of the product that its structural properties can be determined with any confidence so as to make better use of it as a building material.

This thesis reports on such testing of full-size, randomly selected, locally-produced specimens. The work is undertaken in accordance with the recent joint AS/NZ Standard AS 4063:1992. It is believed that this is the first work of this type that has been undertaken on this material.

The results are varied, indicating relatively higher shear and compressive strengths but, by comparison, lower bending and tensile strengths and Modulus of Elasticity. Without doubt, the timber is weakest in tension (some 3 grades below its equivalent compression classification). Careful selection will need to be made of the timber for applications where it is in tension.

The relatively close spacing of the knots appears to have strong influence on reduced strength. If the knots can be reduced by improved silvicultural techniques or eliminated in post-harvesting/milling operations, such as excising the knots and re-jointing (eg finger-jointing) then a much improved product could be obtained.

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DECLARATION

The test results and main text material contained in this thesis is the original work of Rex Glencross-Grant. Where material has been used previously, the source is acknowledged and it is referred to accordingly.

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PRINCIPAL NOTATIONS

A	Cross-sectional area
b	breadth of member
d	depth of member
E	Modulus of Elasticity (MoE)
E_{mean}	Mean value of the Modulus of Elasticity of the data, MPa
$E_{0.05}$	Fifth percentile value of the Modulus of Elasticity of the data, MPa
F	Permissible design stress
F'	Basic working stress
F_b	Permissible design stress in bending
F_b'	Basic working stress in bending
F_c	Permissible design stress in compression parallel to grain
F_s	Permissible design stress for shear in beams
F_s'	Basic working stress for beams in shear
$F_R(x)$	Cumulative Distribution function of the strength (R) at the value x
f	Applied nominal stress
f_b	Applied nominal stress in bending
f_c	Applied nominal stress in compression
f_s	Applied nominal stress for shear in beams
f_t	Applied nominal stress for tension parallel to grain
h	depth of test specimen, mm
i	Strength ranking
I	Second moment of area (moment of inertia)
l	structural length or span, mm
l_s	standard length (or test length), mm
M_1	Optimum moisture content (12.5%)
M_2	Specimen moisture content
n	sample size

NOTATIONS (cont.)

N	Axial load, N
P	Applied lateral load, N
R	Strength, MPa
R_k	Characteristic value of R, MPa
$R_{k,norm}$	Normalised characteristic strength, MPa
R_{basic}	Basic working stress, MPa
$R_{0.05}$	Fifth percentile value of R, MPa
V_R, V_E	Coefficient of variation of R and E, MPa
V_{data}	Coefficient of variation computed from data
X_i	data value
X_{mean}	Mean value of data
Δ	increment
δ	Deflection

Chapter 1

INTRODUCTION

1.1 Background

This Project investigates the structural properties of Norfolk Island pine timber (Araucaria heterophylla - variously referred in the past as A. excelsa or A. robusta) through recently developed and standardised in-grade testing techniques (AS/NZ 4063).

Norfolk Island, approximately 1600 km north-east of Sydney, was Australia's first island territory and the site of the second British settlement in the Pacific (settled only a matter of weeks after Sydney Cove). It is a hilly, fertile island, of volcanic origin (forming part of the volcanic Norfolk ridge running deep beneath the sea from the north island of New Zealand through to New Caledonia and even beyond). It is dominated by two peaks (the remnants of a volcanic crater), sheer rugged cliffs and straight towering pines (photos 1 and 2). The Island in size is some 8 km long (from north to south) and 5 km across (east to west).

Norfolk Island pine is perhaps one of the oldest recorded endemic commercial species in Australasia. Captain Cook in the *Resolution* on his second voyage around the world , discovered and landed on Norfolk Island in 1774. He, "*found the Island uninhabited and near akin to New Zealand ... the chief product ....* ***Spruce Pines*** (my emphasis) *which grow here in vast abundance and to a vast size, from two to three feet diameter and upwards, it is of a different sort to those in New Caledonia and also to those in New Zealand and for Masts, Yards &ca superior to both. We cut down one of the smallest trees we could find and cut a length from the upper end to make a Topgt Mast or Yard. My carpenter tells me that the wood is exactly the same nature as the Quebeck Pines. Here then is a nother Isle where Masts for the largest Ships may be had.*" (p 17)[1] . However, his hope for extensive use of the timber as masts proved unfounded due to the weakness induced by the branching knots. Norfolk pine was nevertheless successfully used to build the sloop that Bass and Flinders circumnavigated Tasmania with (p 128)[2] and in many of the buildings in early Sydney town .[3]

Cook mentions that the Norfolk pine is different to the pines in New Caledonia. Contact has been made with the Forestry Service in Noumea, New Caledonia (du Service des Productions Vegetables et des Forests). The Service has provided several papers on the Araucaria species in New Caledonia (including Cherrier, de Laubenfels and Veillon)[4,5,6]. There are some 14 separate species recorded in New Caledonia (Bernieri, Biramulata, Columnaris, Jussieu, Laugenfelsii, Luxurians, Montana, Nemorosa, Rulei, Schmidii, Scopulorum and Subulata) (after de Laubenfels).

Bootle[7] mentions other Araucarias as being used in Australia:

- A. Angustifolia (Parana pine), native to south-east Brazil, Paraguay and Argentina,
- A. Bidwillii (Bunya pine), native to southern Queensland, almost identical to Hoop pine,
- A. Cunninghamii (Hoop pine), native to rainforests of northern NSW, Queensland and the mountains of New Guinea,
- A. Hunsteinii/Klinki (Klinki pine), native to New Guinea. Very similar to Hoop pine.

The Norfolk pine (A. Heterophylla) appears to be unique to Norfolk Island. It has featured prominently in Island life since it was first settled in 1788 by King. It is almost in the category of a "national" icon for the Island and its people - it features on Norfolk's Coat of Arms and holds pride of place in the centre of Norfolk's flag ("Norfolk" green outer vertical panels, a centre white panel with a green Norfolk pine tree emblazoned).

The pine has also figured prominently in the Island's stamps, particularly definitive issues such as the Commemoration of the bi-centenary of Cook's landing on the Island in October 1774.

Little evidence appears thereafter in the literature of any extensive testing of Norfolk Island pine. One of the few references to it is in Bootle (ref 5, p 130), "*It is used as a general purpose timber on Norfolk Island. Its strength grouping is provisionally S6, SD6.*"

The New Zealand Forest Research Institute's Bryan Walford[8] advised recently that , "*I can find no record of any work done on Norfolk pine timber. I do recall having received an enquiry in the past but never any testing.*" The general opinion within the Institute is that, *"Norfolk pine is similar to kauri except that it is full of small knots because it is not usually old enough to have developed significant amounts of clear wood between the knots."* Also that, *"it will probably be difficult to treat, being a refractory species, similar to Douglas fir."*

1.2 Present day

Various economic factors (such as the ever increasing cost of imported radiata pine from NZ, both in terms of the cost of the timber and increasing shipping and handling costs) and environmental considerations (the species has been extensively logged in earlier times and needs to be conserved) have in recent times encouraged the growing of Norfolk pine on Norfolk Island as a plantation species. If the species is to be fully and effectively utilised as a plantation timber then there is a strong need to be cognisant of its full structural capabilities to encourage and enable optimum utilisation. If there are weaknesses in its structure then these need to be overcome or at least minimised to ensure maximum usage with a minimum of wastage of the resource.

Initially the thought of the project was quite daunting logistically because it involved transporting some 70 pieces of timber in 3 metre lengths to both Rockhampton and Sydney.

The reason for different destinations was that not all the testing could be done at the one location. In Rockhampton, the Civil Engineering Department within the School of Engineering of the University of Central Queensland had developed in-grade testing apparatus for bending, shear strength and compression tests. In Sydney, the NSW State Forests' Timber Research Laboratory at Pennant Hills had developed a full-scale tensile testing rig.

As well, it was decided at an early stage that a mixture of CCA treated and untreated timber should be tested to see if there was any significant variation in test results of both types.

The timber was harvested and milled during August/September, 1992. After milling it had to be dimensioned to the specified size as such structural timber is normally only rough sawn on Norfolk Island. The timber to be treated had to be delivered to the Island's Administration operated Tanalith Plant. Because of a back-log of timber awaiting treatment, some delay was encountered. The balance of the untreated timber also had to be treated with methyl bromide to satisfy Australian Quarantine Regulations. Two separate bundles then had to be sorted, strapped, carted, loaded and consigned by ship from Norfolk Island. The timber was loaded in early December, 1992 and arrived in Sydney mid-January, 1993 (after having travelled via Fiji) (photos 3 and 4 refer).

Despite having Quarantine Certificates for the two consignments, they were held in Customs Bond in Sydney for sometime awaiting clearance. Eventually this was obtained and the timber was cleared late in January, 1993.

Arriving in Sydney late in February 1993 it was found that the timber at Pennant Hills (for tensile testing) was far too wet for conditioned testing, with moisture contents well over 20%. Desired optimum levels of moisture content for consistent testing is in the 10 to 15% range. Travel plans then had to be altered to travel to Rockhampton and undertake the testing there first. The timber had earlier arrived in Rockhampton by rail from Sydney. It was in a far more satisfactory condition for testing with moisture contents consistently below 20%.

1.3 Strength and Grade

A strength grouping has applied to both Australian and New Zealand timbers for many years. In more recent times the concept of stress grading has been introduced.

It is both convenient and reasonably efficient to group species having similar properties and regard those in each group as being identical for design purposes and equivalent for commercial purposes. This is particularly so with the large number of species used structurally in Australia.

Generally, a species is allocated to a group if its bending strength, stiffness and other mechanical properties are similar to those of a hypothetical species representing the group. All strength properties used previously in grouping were calculated from laboratory tests on small clear specimens and are not the properties to be assumed for usual commercial grades of timber of structural size.

Strength grouping was originally based on green state of the timber and ranged from groups S1 to S7 (being the lowest). Generally strength properties are proportional to density, with denser timbers being stronger.

However, with increasing popularity and use of seasoned hardwoods and plantation softwoods, it then became necessary to provide similar groupings for seasoned timber. To achieve this (without reference to the green condition) the information on the properties of timber species as determined at 12% moisture content were analysed on their own merit. Strength groups were then designated SD1 to SD8 and once again were proportional to density. "Seasoned" implies that the maximum moisture content anywhere within one piece of timber shall not exceed 15%. Seasoning may be achieved by air drying, kiln drying or any other non-destructive means whereby moisture content could be reduced to this level.

Stress grades have been introduced in recent times into Australian timber standards and is rapidly increasing in importance as more effective use is made of timber, particularly in terms of making optimum use of it as a renewable resource. As well, in view of legislative moves involving both grading and branding and specification within building codes and the Timber Framing Code AS 1684, it has increased in importance. A grading index is necessary to indicate to designers, specifiers and builders the ability of a piece of timber to perform for the purpose which it is intended in its structural capacity.

Stress grade is designated in form such as, "F8", which indicates that for this grade of material the basic working stress in bending is approximately 8 MPa.

The main advantages in using the stress grade system are:

1. Descriptive terms can largely be avoided and thereby confusion as to what is meant is reduced. It also assists buyers, suppliers and specifiers as to what is actually meant,

2. Allows the interlocking or over-lapping of stress grades, visual grades and strength groups.

3. Similar set of stress grades can be used for both green and seasoned timber, thereby avoiding the need for a separate set of stress grades and separate settings for machine grading green and seasoned timber.

Thus, by considering the properties of seasoned timber on their own merits, a number of species whose properties improve considerably after seasoning, can now be utilized more effectively. Some of the softwoods fall into this category.

Much, if not all previous testing work, was undertaken on small clear specimens. In recent years, extensive laboratory and field testing has been undertaken on full-size, mill-graded timber of a variety of species. Quite detailed testing work has been undertaken in particular in Canada and specifically by Western Forest Products Laboratory and Prof. Borg Madsen (University of British Columbia, Civil Engineering Dept). The results of such testing has indicated that the "small clears" approach to testing is not as accurate as it could be for stress grading. Significant changes have therefore been made to allowable working stresses in tension parallel to grain, and other changes recommended for bending stress, Modulus of Elasticity and some other properties.

It is to this end that in-grade testing was undertaken on full-size samples of Norfolk Island pine.

Chapter 2

EXPERIMENTAL PROCEDURE

2.1 In-grade Testing

To enable more extensive characterisation of Norfolk Pine, a standardised series of in-grade tests need to be undertaken on full-size specimens of the timber, these being;

(a) Extreme fibre stress in bending (Modulus of Elasticity, MoE), and bending strength, f_b',

(b) Shear strength perpendicular to grain, f_s'

(c) Compression parallel to grain, f_c' and

(d) Tension parallel to the grain, f_t'.

AS4063[9] notes in discussing application of the Standard that, ***"the standard test configurations to be specified have been chosen to simulate in-service conditions.... typical sizes, spans and loading arrangements are recommended, and the test specimens cut from locations selected at random from within the sticks of timber samples."***

2.2 Sample Size

Clause 7.2 of AS4063 stipulates that, ***"the minimum sample size be not less than 20 pieces for stiffness and not less than 30 pieces for strength."***

The number of specimens tested in each category were:

Bending strength/Modulus of Elasticity:	**39**
Shear strength:	**34**
Compressive strength:	**39**
Tensile strength:	**23**

The lesser number of specimens tested in tension resulted from rejection of a number of specimens as being below standard for on-site sorting processes of visual and bounce tests. Several specimens in the lower end of the fifth-percentile range failed to "fit" a reasonable cumulative distribution curve and were also rejected.

2.3 Test Equipment

The Laboratory staff at the University of Central Queensland manufactured equipment to enable **in-grade bending, shear strength and compression tests** to be undertaken on specified sizes of samples. All equipment used in the project had been designed and manufactured at the Department of Civil Engineering at UCQ in accordance with Draft Australian/NZ Standard AS 4063 (Timber - Stress Graded, In-grade Strength and Stiffness Evaluation). Similarly, the testing work was undertaken in accordance with AS 4063 and ASTM D198 (Static Tests of Timbers in Structural Sizes)[10], D245 (Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber)[11] and D2915 (Evaluating Allowable Properties for Grades of Structural Lumber)[12].

Additionally, equipment for determination of tensile strength had previously been manufactured by NSW State Forests, at its Research Division, Pennant Hills, on the northern outskirts of Sydney.

The standard test configurations for evaluating strength and stiffness properties of the samples follows.

2.3.1 Bending Strength and MOE:

The standard bending test is a two-point load test with equal loads (P/2) being applied at third points. The distance between supports ($3l_S$) to be equivalent to 18 times the height (h) of the specimen (18h). Thus for these specimens:

$$3l_S = 18h = 18x90mm = 1620 \text{ mm}.$$

Once the specimen was supported on two supports of low bearing area, the load application was by way of a short steel splitter-beam of universal section. Load (P) was applied to the mid-point of the splitter beam and this in turn was split to the third-points (l_S) onto the top flange of the 90x45 section by way of approximately 20mm dia bars bearing on flat steel plates on the top flange of the short timber beam (see Diagram 1 and photo 5).

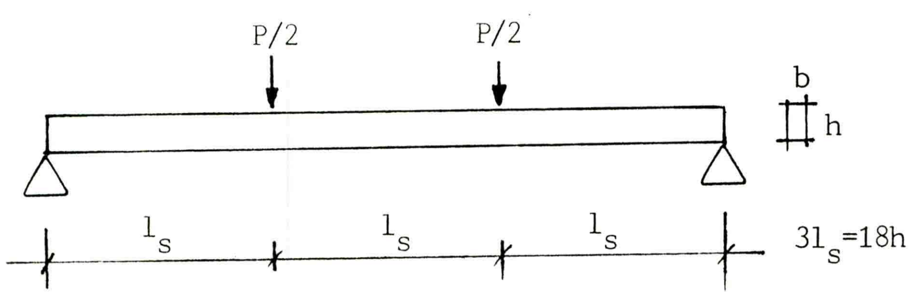

Diagram 1: Standard test configuration for measurement of bending strength and Modulus of Elasticity (after AS 4063).

2.3.2 Shear strength

For shear strength the standard test is a single point load (P) application to the mid-point of the specimen. The spacing of supports ($2l_S$) is to be 6 times the height (h) of the specimen (6h). Thus for these specimens:

$$2l_S = 6h = 6x90 = 540mm.$$

Load was applied through a curved hardwood block onto a flat steel plate on the top flange of the specimen (see Diagram 2 and photo 6).

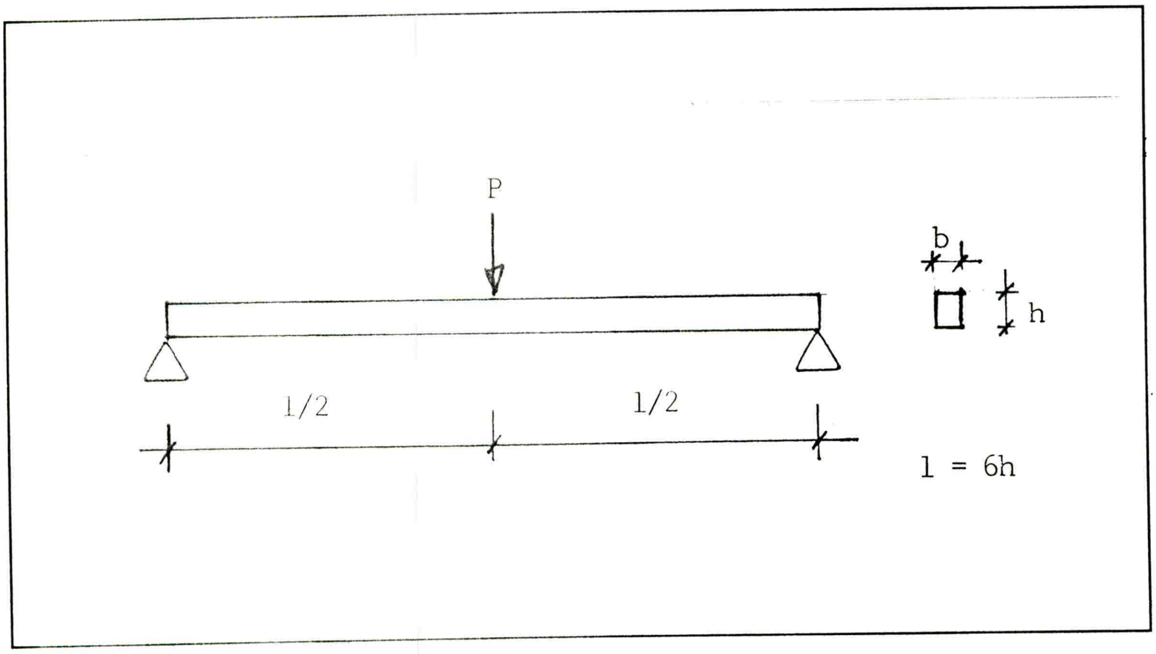

Diagram 2: Standard test configuration for measurement of Shear Strength (after AS 4063)

2.3.3 Compression tests:

For compressive strength measurement the standard test rig consists of two sections of rolled hollow steel section the same width of the specimen, with clamping brackets each side to secure and restrain the specimen (diagram 3 and photo 6). However, care had to be taken to ensure that significant friction did not occur between the specimen and the restraints. To minimise friction, the specimen was isolated from the restraint by using thin plastic membrane, lightly lubricated with petroleum jelly, thus ensuring that the specimen could move freely but still be restrained (or contained within the rig).

The length of specimen (l_S) is to be 30 times the breath (b) of the specimen, thus in this case:

$$l_S = 30b = 30x45 = 1350 \text{ mm.}$$

Load application (N) is by way of direct top end compression loading with the bottom end of the specimen and rig supported on a platen plate of the test rig (see Diagram 3 and photos 7 and 8).

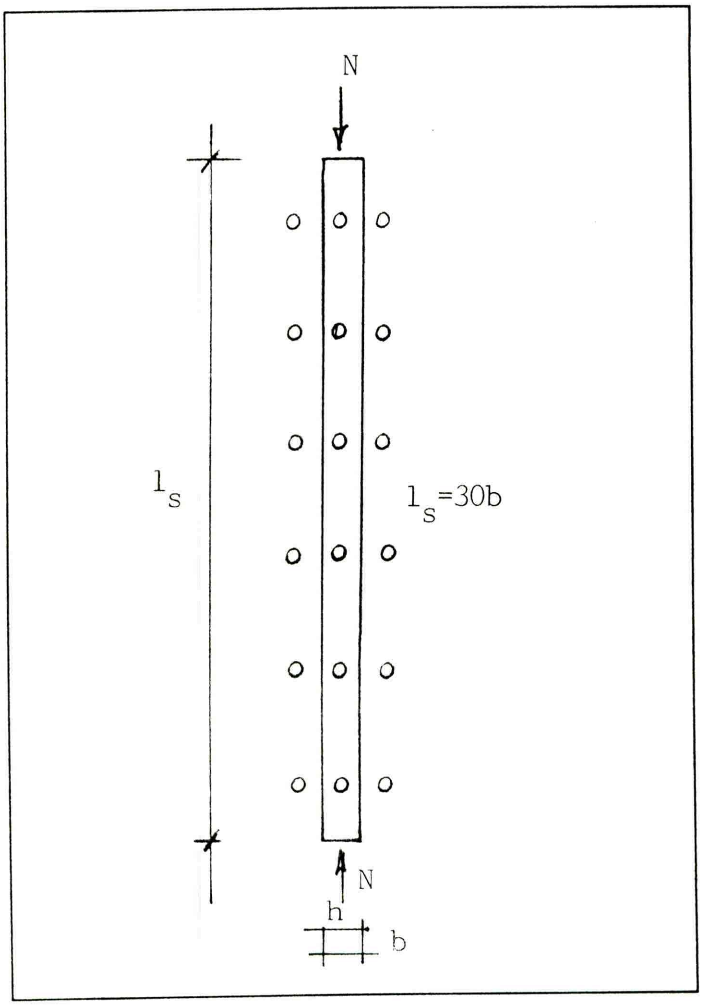

Diagram 3: Standard test configuration for measurement of compressive strength (after AS 4063)

2.3.4 Tension tests:

For determination of tensile strength, the full-size test rig essentially involves clamping a specified length of member at each end and applying a tensile load (N) (see Diagram 4 and photo 10). The clear length between the supports or clamps (l_S) is determined by:

$$l_S = 2250 + 7.5h = 2250 + 7.5x87 = 2903 \text{ mm},$$

but not greater than 30h = 30x87 = 2610 mm

Thus, allowing at least 355 mm for clamping each end, the specimen length needs to be at least 3400 mm.

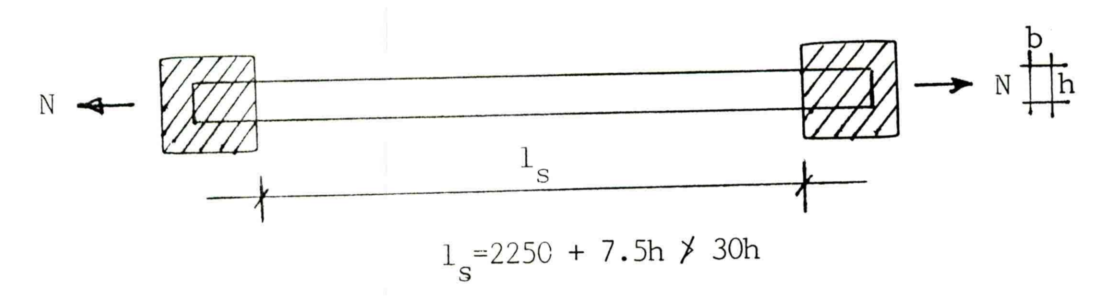

Diagram 4: Standard test configuration for measurement of tensile strength (after AS 4063)

2.4 Testing Procedure

Each nominal 3.6m length of 90x45 Norfolk Island pine was sorted on the basis that a skilled tradesman would sort in the field. The "bounce" and eye tests sorted cracked and unsuitable pieces and these were discarded in preparation for random cutting to prescribed lengths for the following tests:

2.4.1 Extreme Fibre Strength Tests (MOE/MOR):

Firstly some 39 pieces (18 of untreated and 21 CCA treated) of 90x45 were randomly selected and cut into approx 1700 mm lengths. Those with obvious knots were tested with knots uppermost (so that knots were on the compression face rather than the tension face), as indeed they should be placed in a normal construction situation by tradespeople.

Each specimen was numbered, moisture contents measured at 3 consistent positions along the length of the specimen and the readings averaged. Similarly the depths and breadths of each specimen were measured at 3 consistent positions and the measurements averaged.

The specimen was then loaded into the test rig, with supports at 1620 mm apart. The two-point load was applied through a steel beam and cylindrical bearing points 270 mm each side of the mid-point of the specimen on the uppermost edge (photo 5).

The dial gauge was supported in a framed yoke, which in turn was affixed to the neutral axis at each end of the specimen. A flattened pin was fixed to the neutral axis at the centre of the specimen and the dial gauge positioned between the yoke and the pin. Thus, as load was applied, the centre of the beam deflected, thus activating the dial gauge.

A small proving load was applied initially and then relaxed before the load regime was applied in earnest. Load was applied between 0 and 5 kN, the dial gauge removed and then loading continued until failure. Applied load was obtained in the form of voltage from a digital multi-meter. Previously the load cell had been calibrated for applied load against voltage reading (36mV=19.62kN). Dial gauge readings were recorded for each 0.5kN increment of load. From these , the deflection at each load step was calculated. The results of these tests are recorded in Tables 1 and 2.

2.4.2 Shear Strength Tests:

As for Extreme Fibre Stress tests above, 34 pieces of 90x45 were randomly selected and cut into minimum 600mm lengths (14 pieces were untreated Norfolk Island pine and 20 pieces were CCA treated Norfolk Island pine). Those with obvious knots were tested with knots uppermost (so that knots were on the compression face rather than the tension face).

Each specimen was numbered, moisture contents measured at 3 consistent positions along the length of the specimen and the readings averaged. The depths and breadths of each specimen were measured at 3 consistent positions and the measurements averaged.

Each specimen was then loaded into the test rig, with supports at 540 mm apart. The two-point load was applied through a steel beam and a centre cylindrical bearing point at the mid-point of the specimen on the uppermost face (photo 6).

The dial gauge was supported on a framed yoke, which in turn was affixed to the neutral axis at each end of the specimen. A flattened pin was fixed to the neutral axis at the centre of the specimen and the dial gauge positioned between the yoke and the pin. Thus, as load was applied, the centre of the beam deflected, thus activating the dial gauge.

As for Extreme Fibre Stress tests, a small proving load was applied initially and then relaxed before the load regime was applied in earnest. Load was applied between 0 and 5 kN, the dial gauge removed and then loading continued until failure. Applied load was obtained in the form of voltage from a digital multi-meter. Previously the load cell had been calibrated for applied load against voltage reading (36mV=19.2kN). Dial gauge readings were recorded for each 1.0kN increment of load. From these, the deflection at each load step was calculated. These figures are recorded in Table 3.

2.4.3 Compressive Strength Tests:

Firstly, some 39 pieces (16 of untreated and 23 CCA treated) of 90x45 Norfolk Island pine were randomly selected and cut into approx 1350mm lengths.

Each specimen was numbered, moisture contents measured at 3 consistent positions along the length of the specimen and the readings averaged. The depths and breadths of each specimen were measured at 3 consistent positions and the measurements averaged.

Each specimen was loaded into the test rig (photo 7) and the rig lifted into position between the loading platens of the compression machine (photo 8). After locating centrally on the platens, a small proving load was applied to secure the specimen in position and then relaxed before the loading regime was applied in earnest. Specific properties of each specimen such as average breadth and depth of each specimen were inputted into the computer. Load was applied by the computer-controlled loading ram to achieve a displacement of each specimen of 1.5mm/minute. Specimens were loaded at this rate until failure occurred. The computer software recorded the max. axial load achieved, calculated the stress, displacement and strain at max. load (photo 9). These figures are tabulated in Table 4.

2.4.4 Tensile Strength Tests:

Some 23 pieces (14 of untreated and 9 CCA treated) of 90x45 Norfolk Island pine were randomly selected and cut into approx 3400 mm lengths.

Each specimen was numbered, moisture contents measured at 3 consistent positions along the length of the specimen by drop hammer meter and the readings averaged. The depths and breadths of each specimen were measured at 3 consistent positions and the measurements averaged.

Each specimen was loaded into the test rig and clamped with the jaw supports at 3020 mm centre to centre or a clear length between supports of 2666 mm (ls) (photo 10). Specific properties for each specimen such as specimen number, breadth and depth were keyed into the computer (photo 11). Tensile load was then applied by computer-controlled hydraulic ram in the axial line of the specimen at a controlled rate until the specimen failed or the machine reached its mechanical limit (approx. 160 kN). Computer software then calculated the maximum fibre stress and provided a printout of all specimens tested (photo 12). The Tensile Strength results are summarised in Table 5.

Samples later cut from tested specimens were oven dried and their moisture contents calculated. These were tabulated (Table 6) and compared with moisture-meter readings. As can be seen, quite a reasonable correlation exists between moisture meter and oven-dry moisture contents, so therefore there is no need to apply a correction factor to the moisture-meter readings.

Chapter 3

EXPERIMENTAL RESULTS

3.1 Student's t Analysis on Treated-vs-untreated specimens:

It has been a generally held belief amongst local trades people on the Island that CCA treated Norfolk Island pine timber was "stronger" than untreated (natural) timber. As a means of determining the significance of this belief, approximate equal quantities of random samples of both materials were included in the testing programme.

When the results for both types of samples were tabulated, a Student's-t analysis was undertaken to determine whether the results were significantly different or the same at the 5% level of significance. The analysis was based on the null hypothesis, H_0: $\mu_1=\mu_2$. This proved to be valid for all test regimes. The data for both treated and untreated specimens could then be pooled for each test, thereby providing a greater population of specimens to statistically analyse. The resultant pooling of data and analysis of results is shown in Tables 1 to 5 for each of the tests.

It is interesting to note that, of the sectional samples cut in Sydney for comparative oven-dried moisture contents, Chromazurol solution indicator tests were also undertaken (in accordance with AS 1605 - Wood Preservatives and Preservative-Treated Wood) but few of the samples tested actually complied with the Standard required penetration. Thus, it could be concluded that inadequate treatment had been applied to the timber. Indeed, upon returning to the Island, it was found that the treatment plant had previously experienced difficulties with the pump at the plant during the latter half of 1992 and had not been able to reach required vacuum levels for adequate treatment. It is understood that the problem at the plant has now been rectified.

There was no significant variation between treated and untreated specimens on this occasion. Simply, from the Student's t-distribution it can be concluded that in the case of these specimens, there was no significant difference between treated and untreated samples, therefore the results can be pooled to provide a greater population for analysis.

3.2 Cumulative Frequency Distribution for 5 Percentile Values

Calculated strengths for the various test regimes were ranked and an estimate of the cumulative frequency distribution function, $F_R(x)$ determined from:

$$F_R(x_i) = (i-0.5)/n$$

where: i = Strength ranking

n = sample size

This calculation appears in Tables 1 to 5.

The five-percentile (0.05) strength was then determined by interpolation of the Cumulative distribution function in the various Tables. Results are summarised in the box at the foot of each table.

3.3 Modulus of Elasticity (MoE)

Modulus of Elasticity (MoE) was calculated from the slope of the straight line section of the load-vs-displacement plot (2P-vs-δ) to determine $\Delta P/\Delta\delta$, thence E was determined from:

$$E = \frac{(\Delta P).\ l^3}{(\Delta\delta)\ 28.173\ I}$$

this is derived from the standard 4-point load deflection equation:

$$\delta = \frac{Pl^3}{28.173\ EI}$$

Values of E for each specimen are computed in Table 2.

3.4 Analysis of Results

Reliability based working stresses were then determined from the sample test results.

The characteristic value of MoR (R_k) was computed, taking into consideration the coefficient of variation (V_R) and the number of specimens (n) in the sample, from:

$$R_k = (1 - 2.7V_R/n^{½})R_{0.05}$$

Similarly, R_{basic} (the basic working stress) was computed from:

$$R_{basic} = R_k/1.75(1.3 + 0.7V_R)$$

where: $R_{0.05}$ is the five-percentile value of MoR
V_R refers to coefficient of variation of strength data

(after AS/NZS 4063:1992, equation 9.2 (1). AS/NZS 4063 notes that, *"the factor 1.75 is the value of the modifier denoted by 'k1" in AS 1720.1. It is used to define the relationship between the 5 min. design strength and the long-term strength associated with the basic working stress. The true factor is (1.3 + 0.7V_R))."*

In a similar way, the characteristic value of MoE (E_k) was computed, taking into account also the coefficient of variation (V_{data}) and the number of specimens (n) in the sample. The lowest value of E_k will be taken as the reliability-based MoE from:

either $E_k = [1 - 0.7V_E/n^{0.5}]\ E_{mean}$

or $E_k = 1.5[1 - 2.7V_E/n^{0.5}]\ E_{0.05}$

where: E_{mean} refers to average value of MoE

$E_{0.05}$ refers to five-percentile value of MoE

V_E refers to coefficient of variation of data

(after AS/NZS 4063:1992, equations 9.1(3) and 9.1 (4)).

A summary of the basic working stress test results for Norfolk pine are listed in Table 7.

Chapter 4

DISCUSSION OF RESULTS

4.1 Bending Strength (MoR)

Bending strength (MoR) results are tabulated in Table 1 of the Appendix. The basic working stress in bending (f_b') is determined as **6.3 MPa** from the test results. This gives a **stress grading of F5** (min. F_c' being 5.5. MPa) (after AS 1720.1 Table 2.3). Thus the **preliminary classification in bending is F5.**

4.2 Modulus of Elasticity

The Modulus of Elasticity is calculated in Table 2 of the Appendix. By adopting the lesser value of E_k (in accordance with AS/NZ 4063), the adopted value for E becomes **7164 MPa**. Similarly, by consulting Table 2.3 AS 1720.1, this once again gives a **stress of F5** (min. MoE being 6900 MPa).

4.3 Shear Strength

Shear strength is determined in Table 3 of the Appendix. The basic working shear stress is calculated as being **1.17 MPa**. By the same procedure as above this gives a **stress grading of F11** (min. F_s' being 1.05 MPa).

4.4 Compressive Strength

Compressive strength is determined in Table 4 of the Appendix. The basic working strength is calculated as being **6.4 MPa**, thus giving a **stress grade of F7** (min. F_c' being 5.2 MPa, with min. for F8 being 6.6 MPa), so it is a borderline grading, being so close to F8.

4.5 Tensile Strength

Tensile strength results appear in Table 5 of the Appendix. The basic working tensile strength is **2.43 MPa**, giving a comparatively low **stress grade of F3.**

4.6 Determination of Stress Grade

Having derived the basic stress values for Norfolk Island pine, it is now desired to classify the timber into a overall stress grade.

As stated in AS/NZ 4063, *preliminary classifications are first made for each of the individual properties. On the basis of these preliminary classifications, the final classification for the reference population is given in Table 1* (of AS/NZ 4063).

Following the classification procedure in Table 1 of AS/NZ 4063, it is determined that Norfolk pine ranks an F5 classification (see Table 8 of the Appendix). This is as close as can be determined from the information available and is with a cautionary note. Because the timber is comparatively low in tensile strength, it is recommended that only good/clear pieces be used in tension applications.

4.7 The Effect of Knots

From Tables 1 to 5 it will be seen that the predominance of the lower stress figures are due to failure at or close to knots. If the test results of the specimens are culled so that only clear specimen results remain, then an interesting pattern emerges (see Tables 10 to 14) (even though the number of specimens is too low to make any real meaningful statistical analysis). The stress grade for bending strength increases to F8 and for Modulus of Elasticity and compressive strength both increase to F11. Whilst the number of clear specimens remaining in the tension sample is small, nevertheless the increasing trend is evident, with tensile strength increasing to F5 grade . Some of the clear specimens in the tension tests reached the operating capacity of the machine and were not able to be fractured. There is thus an indication that clear specimens are certainly quite a deal stronger in tension than has been determined here. A Summary of indicative strengths expected in clear Norfolk pine are summarised in Table 15.

However, one has to caution, that in the building trade one can't be so selective to use all clear specimens - straight economics, material availability and field convenience tend to prevail. Therefore, if more widespread use is to be made of Norfolk pine as a structural timber, other means have to be investigated as to how to make best use of the product. Such means may include investigation of various jointing systems so that knots can be excised and the timber rejoined. Otherwise, silvicultural techniques may be able to increase the spacing between knots, particularly on the butt end of trees so that longer lengths can be obtained of knot-free material.

Chapter 5

CONCLUSION

Norfolk Island pine timber is an endemic species to Norfolk Island and has played a large part in Island life since initial settlement. It has been used in a variety of applications over the years. Latterly use of it has been largely reserved as a decorative-joinery timber for internal features and some external use, such as cladding. This is essentially because the timber has been in scarce supply. However, numerous plantations have been laid down over the Island and it will once again become a major construction material (given time and the appropriate treatment).

The assessment of the timber's mechanical properties is important in making optimum use of it in future years.

Essentially the material did not test as well as was first anticipated. As has been reported in other literature, it is essentially the closely spaced knots that inhibit the timber from developing higher strengths in full-size specimens. The particular area of weakness was in tension, where only an F2 grade classification was achieved. On the other hand shear and compressive strengths reached the levels initially expected with F11 and F7 grades respectively. Whilst bending strength and Modulus of Elasticity reached F5 grade.

No doubt the extent and proximity of knots largely influenced the results. Indeed it has been shown (albeit with limited results) that stress grade could increase by 3 grades by simply analysing clear specimens only. Whilst it is not a practical solution to use only clear sticks in construction work, it does at least suggest that it is certainly worth modifying the product to substantially improve its strength.

It is hoped that the series of tests undertaken, results obtained, tabulated and analysed in this thesis will provide the ground work for future industry directions, including Government guidance/encouragement and extent of usage of the material, so that far better utilisation is achieved from the timber in the future. It is only through improved utilisation of the product that Norfolk Island's balance of payments imbalance with respect to structural timber can be countered.

APPENDIX

TABLES

TABLE 1 BENDING STRENGTH TEST RESULTS FOR NORFOLK PINE WITH ADJUSTMENTS FOR MOISTURE CONTENT

Length, L 1620 M = PL/3

Test dates: 19/24 February, 1993 Opt m/c %, M1 = 12

University of Central Queensland, Rockhampton. a = 1.75

b = 0.0333

Specimen No.	Max Applied Load, 2P kN	Avg width b, mm	Avg depth d, mm	Section Modulus, bdd/6 Z, cucm	Max. bending stress fb' M/Z, MPa	B stress adj for opt. m/c B2*, MPa	Strength Rank, i	Cumul. Dist'n Function, Fr(x)	Meter moisture content % M2
b6c	2.4	45	89.3	59.81	10.83	12.02	1	0.0139	16.0
b4p	3.96	46.6	89.3	61.94	17.26	19.31	2	0.0417	16.3
b18p	4.9	46.3	90	62.51	21.17	19.62	3	0.0694	8.8
b7c	3.84	45	90.1	60.89	17.03	21.41	4	0.0972	20.3
b1p	4.5	46.3	89.6	61.95	19.61	22.37	5	0.1250	17.0
b22c	5	45.1	90.5	61.56	21.93	25.23	6	0.1528	17.3
b18c	6.22	46.3	89.5	61.81	27.17	27.86	7	0.1806	13.0
b13p	5.4	45	90.2	61.02	23.89	31.30	8	0.2083	21.6
b21c	6.17	46	90	62.10	26.83	33.01	9	0.2361	19.6
b11c	5.74	45.3	90	61.16	25.34	33.20	10	0.2639	21.6
b7p	7.21	40	89.6	53.52	36.37	35.76	11	0.2917	11.3
b14p	7.03	44.6	91	61.56	30.84	36.83	12	0.3194	18.6
b9p	7.7	46.2	89.6	61.82	33.63	38.04	13	0.3472	16.7
b19c	7.56	46.6	90	62.91	32.45	40.42	14	0.3750	20.0
b12p	8.4	45.3	86.6	56.62	40.06	42.13	15	0.4028	14.0
b5c	10.2	46.5	90	62.78	43.87	42.31	16	0.4306	10.5
b8p	9.02	46.6	89.3	61.94	39.32	43.99	17	0.4583	16.3
b3p	7.83	46.2	88.3	60.04	35.21	44.55	18	0.4861	20.5
b16c	8.1	45.3	90	61.16	35.76	45.39	19	0.5139	20.6
b16p	11.6	46.1	90	62.24	50.33	48.30	20	0.5417	10.3
b8c	10.3	46.6	90	62.91	44.21	48.51	21	0.5694	15.6
b10c	7.88	43.6	91	60.18	35.36	49.52	22	0.5972	23.6
b20c	11	44.8	90.3	60.88	48.78	50.40	23	0.6250	13.3
b12c	11.45	44.5	89.6	59.54	51.92	51.04	24	0.6528	11.3
b15p	11.2	45	88.8	59.14	51.13	51.13	25	0.6806	12.0
b5p	11.03	45	89.6	60.21	49.46	51.49	26	0.7083	13.6
b4c	11.2	46	89.5	61.41	49.24	51.80	27	0.7361	14.0
b15c	10.6	44	90	59.40	48.18	52.03	28	0.7639	15.0
b17p	10.9	47	89.8	63.17	46.59	52.12	29	0.7917	16.3
b14c	9.8	43.5	88.6	56.91	46.49	54.57	30	0.8194	18.0
b11p	9.6	42.8	90	57.78	44.86	55.21	31	0.8472	19.6
b6p	12.18	44	89.5	58.74	55.98	55.44	32	0.8750	11.6
b9c	10.8	44.8	90	60.48	48.21	58.80	33	0.9028	19.3
b13c	11.57	46	90.5	62.79	49.75	61.98	34	0.9306	20.0
b10p	12.6	43	88.5	56.13	60.61	62.14	35	0.9583	13.0
b17c	10.23	46.6	90	62.91	43.91	66.06	36	0.9861	25.6
Averages	**8.5**	**45.2**	**89.7**	**60.6**	**37.9**	**42.6**			**16.4**

Standard deviation for fb':	**12.46**	**13.45**	**MPa**
Coefficient of variation, Vr:	**0.33**	**0.32**	
5 percent value MofR (interpolating), R0.05 =		**19.4**	**MPa**
Rk = [1 - 2.7Vr/n**0.5]R0.05 =		16.65	MPa
Rbasic=Rk/[1.75(1.3+0.7VR)] =		**6.26**	MPa

*After ASTM D2915, method of adjustment for moisture content variation:

B2 = B1[(a - bM2)/(a - bM1)]

SPECIMEN NUMBERING SYSTEM:

Prefix b: Denotes bending strength specimens

Suffix p: Denotes "plain" untreated specimens

Suffix c: Denotes CCA treated specimens.

TABLE 2: MODULUS OF ELASTICITY RESULTS FOR NORFOLK PINE WITH MOISTURE CONTENT ADJUSTMENTS

Test dates: 19/24 February, 1993 M/c adj a= 1.44 pt m/c % 12
University of Central Queensland, Rockhamp b= 0.02 (M2)
SPECIMEN LENGTH, L = 1620

Specimen No.	Avg width b, mm	Avg depth d, mm	Moment of Inertia, I bddd/12 I, cm**4	Slope MofE straightline plot/2	E=(5)L**3/ 28.173*(4) E1	E adj for opt m/c E2	Rank	Cumul. Freq Distn Fr(xi)	Meter moisture content % M1	Remarks
Col (1)	Col (2)	Col (3)	Col (4)	Col (5)	Col (6)	Col 6a	Col (7)	Col (8)	Col (9)	Col (10)
b22c	45.1	90.5	278.57	0.0824	4464	4896	1	0.0128	17.3	Failed under knot
b18p	46.3	90	281.27	0.1012	5430	5155	2	0.0385	8.8	Failed next to knot
b1c	42.1	90.1	256.61	0.0910	5352	5498	3	0.0641	13.6	Failed below knot
b4p	46.6	89.3	276.54	0.1179	6434	6930	4	0.0897	16.3	Failed @ knot
b1p	46.3	89.6	277.54	0.1270	6905	7533	5	0.1154	17.0	Failed @ knot
b21c	46	90	279.45	0.1345	7263	8317	6	0.1410	19.6	Failed under knot
b9p	46.2	89.6	276.94	0.1463	7972	8650	7	0.1667	16.7	Failed @ knot
b7p	40	89.6	239.77	0.1420	8937	8834	8	0.1923	11.3	Failed @ knot
b5c	46.5	90	282.49	0.1744	9317	9089	9	0.2179	10.5	Clear failure
b11c	45.3	90	275.20	0.1424	7809	9296	10	0.2436	21.6	Failed @ knot
b3c	41.8	89.6	250.56	0.1537	9257	9462	11	0.2692	13.3	Failed below knot
b16c	45.3	90	275.20	0.1530	8390	9794	12	0.2949	20.6	Failed next to knot
b14p	44.6	91	280.08	0.1710	9214	10352	13	0.3205	18.6	Failed under knot
b19c	46.6	90	283.10	0.1700	9062	10456	14	0.3462	20.0	Failed above knot
b12c	44.5	89.6	266.75	0.1893	10709	10586	15	0.3718	11.3	Clear failure
b18c	46.3	89.5	276.61	0.1940	10584	10763	16	0.3974	13.0	Clear failure
b8c	46.6	90	283.10	0.1922	10245	10899	17	0.4231	15.6	Clear failure
b13p	45	90.2	275.20	0.1682	9223	10980	18	0.4487	21.6	Clear/borer holes
b14c	43.5	88.6	252.12	0.1670	9996	11106	19	0.4744	18.0	Clear failure
b7c	45	90.1	274.29	0.1748	9617	11161	20	0.5000	20.3	Failed under knot
b6c	45	89.3	267.05	0.1848	10443	11189	21	0.5256	16.0	Failed @ knot
b9c	44.8	90	272.16	0.1780	9870	11237	22	0.5513	19.3	Clear failure
b10p	43	88.5	248.38	0.1820	11058	11245	23	0.5769	13.0	Clear
b15c	44	90	267.30	0.1955	11034	11615	24	0.6026	15.0	Failed next to knot
b12p	45.3	86.6	245.17	0.1850	11387	11780	25	0.6282	14.0	Failed under knot
b2c	46.3	89.8	279.40	0.1883	10170	11803	26	0.6538	20.3	Failed below knot
b16p	46.1	90	280.06	0.2255	12151	11816	27	0.6795	10.3	Clear
b10c	43.6	91	273.80	0.1730	9535	11820	28	0.7051	23.6	Clear failure
b20c	44.8	90.3	274.89	0.2130	11693	11952	29	0.7308	13.3	Failed next to knot
b4c	46	89.5	274.82	0.2226	12223	12645	30	0.7564	14.0	Clear failure
b17c	46.6	90	283.10	0.1862	9926	12835	31	0.7821	25.6	Clear failure
b3p	46.2	88.3	265.06	0.1936	11022	12842	32	0.8077	20.5	Clear
b17p	47	89.8	283.63	0.2279	12126	13062	33	0.8333	16.3	Clear
b8p	46.6	89.3	276.54	0.2269	12382	13338	34	0.8590	16.3	Clear/failed
b13c	46	90.5	284.13	0.2224	11812	13629	35	0.8846	20.0	Failed under knot
b15p	45	88.8	262.59	0.2410	13850	13850	36	0.9103	12.0	Failed 'tween knots
b6p	44	89.5	262.87	0.2500	14352	14257	37	0.9359	11.6	Failed @ knot
b5p	45	89.6	269.75	0.2510	14042	14427	38	0.9615	13.6	Failed @ knot
b11p	42.8	90	260.01	0.2440	14162	16216	39	0.9872	19.6	Failed @ knot
Averages	**45.1**	**89.7**	**271.1**	**0.1791**	**9985.1**	**10803.0**			**16.4**	

Standard deviation for MofE:	**2368**	**2508**	
Coefficient of variation, Ve:	**0.24**	**0.23**	
5 percentile MofE, E0.05 (interpolating) =		**5309**	**MPa**
Ek = [1 - .75*Ve/n0.5]Emean =**		**10502**	**MPa**
Ek = 1.5[1 - 2.7*Ve/n0.5]E0.05 =**		**7164**	**MPa**
Adopt lesser Ek =		**7164**	**MPa**

E2 = [(a - bM2)/(a - bM1)] for MoE: a = 1.44, b = 0.02

(after ASTM D2915) 12% for M2 used as optimum m/c

TABLE 3: SHEAR STRENGTH TEST RESULTS FOR NORFOLK PINE

Test date:	**23-25 Feb, 1993**	Max reaction, V = P/2
University of Central Queensland,		Length, L = 540 mm
Rockhampton		Opt m/c, M1% = 12
		a = 1.33
		b = 0.0167

Specimen No.	Max applied Load, P, kN	Avg b mm	Avg d mm	X-sectional area (bxd) A,sqcm	Max shear stress, fs' 3V/2A /sqmm=MP	Fs' adj. for opt. m/c S2*, MPa	Shear stress rank, i	Cumul. Dist'n Function Fr(xi)	Meter moisture content % M2	Remarks
s6c	14.8	44.3	90.0	3987.0	2.78	2.98	1	0.0147	16.5	2x30 knots
s4p	15.6	45.0	87.5	3937.5	2.97	3.09	2	0.0441	14.7	50 knot
s7c	14.0	43.5	89.0	3871.5	2.71	3.18	3	0.0735	22.0	40 knot
s14p	15.9	46.0	88.3	4061.8	2.93	3.20	4	0.1029	17.8	Clear
s12p	16.7	46.3	88.3	4088.3	3.07	3.48	5	0.1324	20.0	Clear
s8c	16.0	45.3	89.5	4054.4	2.96	3.51	6	0.1618	22.6	Clear
s19c	20.0	44.5	90.0	4005.0	3.75	3.94	7	0.1912	15.3	Clear
s8p	18.6	41.8	88.3	3690.9	3.78	4.06	8	0.2206	16.7	Clear
s10p	21.6	46.7	89.7	4189.0	3.86	4.30	9	0.2500	19.0	Clear
s5c	21.8	46.5	88.5	4115.3	3.97	4.36	10	0.2794	18.0	Clear
s18c	19.8	42.2	89.2	3764.2	3.95	4.46	11	0.3088	19.8	50 knot
s17c	21.5	45.0	90.0	4050.0	3.98	4.56	12	0.3382	20.7	Clear
s9p	21.7	44.2	89.7	3964.7	4.10	4.60	13	0.3676	19.3	Clear
s1p	24.3	46.0	88.0	4048.0	4.50	4.64	14	0.3971	14.0	Clear
s14c	24.5	45.8	90.2	4131.2	4.44	4.76	15	0.4265	16.6	Clear
s9c	22.3	44.5	90.0	4005.0	4.18	4.83	16	0.4559	21.0	Clear
s11c	24.4	45.0	88.5	3982.5	4.59	4.94	17	0.4853	16.8	Clear
s3p	27.5	45.0	88.2	3969.0	5.20	5.03	18	0.5147	9.7	Clear
s12c	25.4	44.8	90.0	4032.0	4.72	5.08	19	0.5441	16.8	Clear
s6p	28.0	46.0	88.5	4071.0	5.16	5.26	20	0.5735	13.3	
s2p	29.1	45.2	88.3	3991.2	5.47	5.33	21	0.6029	10.3	Clear
s4c	27.1	46.7	90.0	4203.0	4.83	5.42	22	0.6324	19.3	Clear
s3c	25.6	41.7	89.3	3723.8	5.16	5.59	23	0.6618	17.2	Clear
s2c	29.1	45.7	89.0	4067.3	5.36	5.67	24	0.6912	15.7	Clear
s13p	31.2	45.5	88.5	4026.8	5.81	5.69	25	0.7206	10.6	Clear
s10c	29.9	44.2	90.0	3978.0	5.64	5.92	26	0.7500	15.2	Clear
s13c	30.1	45.8	86.3	3952.5	5.70	6.04	27	0.7794	15.8	Small knot
s20c	27.1	44.3	90.0	3987.0	5.09	6.05	28	0.8088	22.7	Clear
s15c	30.6	46.3	90.0	4167.0	5.51	6.14	29	0.8382	19.0	Clear
s16c	29.9	44.8	89.7	4018.6	5.57	6.30	30	0.8676	19.8	Clear
s5p	32.0	44.7	87.5	3911.3	6.14	6.44	31	0.8971	15.2	Clear
s15p	31.5	42.3	89.5	3785.9	6.24	6.83	32	0.9265	17.8	Clear
s1c	33.4	43.7	89.3	3902.4	6.42	6.86	33	0.9559	16.3	Clear
s11p	35.8	46.5	88.7	4124.6	6.51	6.92	34	0.9853	16.0	Clear
Averages:	**19.5**	**44.9**	**89.0**	**3994.1**	**5.02**	**6.17**			**16.0**	

Standard deviation for fs':	**1.07**	**1.09**	**MPa**
Coefficient of variation, Vr:	**0.16**	**0.16**	
5 percentile value (by interpolation), R0.05=		**3.11**	**MPa**
Rk = [1 - 2.7Vr/n**0.5]R0.05 =		2.88	MPa
Rbasic=Rk/[1.75(1.3+0.7VR)] =		**1.17**	**MPa**

*After ASTM D2915, method of adjustment for moisture content variation:

S2 = S1[(a - bM2)/(a - bM1)]

SPECIMEN NUMBERING SYSTEM:

Prefix s: Denotes shear strength specimen

Suffix p: Denotes "plain" untreated specimen

Suffix c: Denotes CCA treated specimen.

TABLE 4 COMPRESSIVE STREGTH TEST RESULTS FOR NORFOLK PINE WITH ADJUSTMENTS FOR MOISTURE CONTENT

Test dates: 1,2 and 3 March, 1993 Opt m/c %, 12.0
University of Central Qld, Rockhamp M/c adjustment factors for compression (after ASTM D2915)
Temp: 20 deg C a = 2.75
Humidity: 50% b = 0.0833

Specimen No.	Max Comp. Load, C kN	Avg b mm	Avg d mm	X-sectional Area (bxd) A, sqmm	Max comp. stress fc' C/A C1, MPa	fc' adj. for opt m/c C2*, MPa	Comp. stress rank, i	Cumul. Dist'n Function Fr(xi)	Meter Moisture Content % M2	Remarks
c18c	48.33	45.0	90.0	4050.0	11.93	17.81	1	0.0128	19.0	55 knot
c16p	62.67	46.2	88.5	4088.7	15.33	18.13	2	0.0385	15.3	40 knot
c29c	57.88	45.0	90.0	4050.0	14.29	19.04	3	0.0641	17.3	40 knot
c10p	81.90	46.0	86.3	3969.8	20.63	19.84	4	0.0897	11.2	70 knot
c1c	82.12	44.0	89.0	3916.0	20.97	20.16	5	0.1154	11.2	knot
c17c	65.89	46.3	88.7	4106.8	16.04	20.97	6	0.1410	17.0	90 knot
c7c	75.82	40.7	89.3	3634.5	20.86	21.12	7	0.1667	12.3	clear
c31c	72.22	43.8	89.0	3898.2	18.53	22.54	8	0.1923	15.8	80 knot
c3c	77.72	45.0	89.0	4005.0	19.41	22.82	9	0.2179	15.2	70 knot
c2p	79.31	42.5	88.0	3740.0	21.21	24.00	10	0.2436	14.5	40 knot
c3p	90.59	45.0	88.0	3960.0	22.88	24.20	11	0.2692	13.2	60 knot
c1p	84.84	45.2	87.5	3955.0	21.45	24.28	12	0.2949	14.5	35 knot
c22c	63.72	45.7	89.5	4090.2	15.58	24.64	13	0.3205	19.8	95 knot
c23c	70.65	43.8	90.0	3942.0	17.92	25.31	14	0.3462	18.2	100 knot
c24c	68.15	43.3	89.3	3866.7	17.62	25.40	15	0.3718	18.5	100 knot
c21c	71.41	43.2	89.8	3881.2	18.40	25.64	16	0.3974	18.0	40 knot/cut
c9p	110.30	46.7	86.8	4053.6	27.21	25.70	17	0.4231	10.8	clear
c30c	110.40	45.0	90.0	4050.0	27.26	25.74	18	0.4487	10.8	clear
c20c	82.38	41.7	89.3	3723.8	22.12	26.02	19	0.4744	15.2	45 knot
c7p	100.00	45.0	90.0	4050.0	24.69	26.52	20	0.5000	13.5	clear
c15p	102.90	44.8	87.7	3929.0	26.19	28.87	21	0.5256	14.0	clear
c8p	102.70	45.0	88.5	3982.5	25.79	29.99	22	0.5513	15.0	20 knot
c6p	118.20	45.0	87.5	3937.5	30.02	30.24	23	0.5769	12.2	clear
c4p	110.20	45.0	87.5	3937.5	27.99	30.37	24	0.6026	13.7	50 knot
c4c	95.38	45.5	89.0	4049.5	23.55	30.79	25	0.6282	17.0	small nots
c26c	86.39	43.7	88.7	3876.2	22.29	31.06	26	0.6538	18.0	clear
c25c	93.07	45.0	87.8	3951.0	23.56	31.38	27	0.6795	17.3	clear
c27c	87.02	45.3	89.0	4031.7	21.58	32.21	28	0.7051	19.0	40 knot
c19c	92.60	45.3	89.3	4045.3	22.89	32.55	29	0.7308	18.3	50 knot
c14p	111.30	43.7	88.2	3854.3	28.88	32.68	30	0.7564	14.5	clear
c11p	120.00	46.2	89.0	4111.8	29.18	33.21	31	0.7821	14.6	clear
c8c	131.40	45.0	89.0	4005.0	32.81	34.71	32	0.8077	13.2	clear
c5p	131.90	45.8	87.5	4007.5	32.91	36.28	33	0.8333	14.0	40 knot
c6c	109.40	45.0	88.0	3960.0	27.63	37.27	34	0.8590	17.5	clear
c2c	132.70	45.0	89.7	4036.5	32.88	41.19	35	0.8846	16.3	clear
c28c	92.84	45.7	90.0	4113.0	22.57	41.28	36	0.9103	21.6	40 knot
c12p	111.60	44.7	87.7	3920.2	28.47	41.89	37	0.9359	18.8	40 knot
c5c	148.20	44.0	88.0	3872.0	38.27	44.03	38	0.9615	14.8	clear
c13p	122.10	44.7	89.7	4009.6	30.45	48.90	39	0.9872	20.0	clear
Averages	**93.75**	**44.7**	**88.7**	**3965.7**	**23.65**	**28.94**			**15.67**	

Standard deviation, fc':	**5.80**	**7.49**	MPa
Coefficient of variation, Vr:	**0.25**	**0.26**	
5 percentile value (by interpolation), R0.05=		**18.54**	MPa
Rk = [1 - 2.7Vr/n**0.5]R0.05 =		16.47	MPa
Rbasic=Rk/[1.75(1.3+0.7VR)] =		**6.35**	MPa

* After ASTM D2915, method of adjustment for moisture content variation

$$C2 = C1[(a - bM2)/(a - bM1)]$$

SPECIMEN NUMBERING SYSTEM:
Prefix c: Denotes Compressive strength specimens
Suffix p: Denotes "plain" untreated specimens
Suffix c: Denotes CCA treated specimens

TABLE 5 TENSILE STRENGTH TEST RESULTS FOR NORFOLK PINE WITH MOISTURE CONTENT ADJUSTMENTS

Test dates: 26 August, 1993
State Forests of NSW, Pennant Hills, Sydney

Specimen No.	Max Load T, kN	Avg b mm	Avg d mm	X-sectional area,bxd A, sqmm	Max tensile stress ft' T/A, MPa	Tensile Stress rank, i	Cumul. Dist'n Function Fr(xi)	Specimen Moisture Content % M2	Remarks
t5c	31.75	44.2	86.6	3826.4	8.30	1	0.0217	13.3	Failed at knot
t10c	37.75	41.8	87.7	3664.6	10.30	2	0.0652	10.0	Failed at knot
t2c	41.00	45.7	86.4	3951.1	10.38	3	0.1087	11.2	Failed at knot
t1p	46.13	45.5	86.8	3950.2	11.68	4	0.1522	11.2	Knot
t4p	47.88	45.0	87.4	3929.5	12.18	5	0.1957	11.3	Knot
t14c	49.38	44.3	87.2	3866.9	12.77	6	0.2391	9.8	Failed at knot
t1c	57.63	45.8	87.6	4012.4	14.36	7	0.2826	11.0	Clear
t5p	60.50	44.4	86.6	3847.6	15.72	8	0.3261	10.3	Knot
t15p	74.00	44.4	86.3	3833.0	19.31	9	0.3696	9.8	Failed at knot
t3p	75.63	44.1	86.4	3811.5	19.84	10	0.4130	9.7	Clear
t6c	82.25	45.4	86.5	3925.9	20.95	11	0.4565	12.5	Failed at knot
t13c	87.00	43.7	86.9	3795.4	22.92	12	0.5000	9.8	Failed edge jaw
t8p	94.25	44.4	87.7	3893.9	24.20	13	0.5435	11.3	Knot
t4c	120.38	44.3	87.3	3868.7	31.12	14	0.5870	10.0	Clear
t2p	129.25	44.5	87.2	3884.8	33.27	15	0.6304	10.7	Clear
t9p	128.00	43.0	86.9	3738.0	34.24	16	0.6739	9.8	Knot popped
t11p	136.88	44.9	86.8	3893.4	35.16	17	0.7174	10.0	Knot
t14p	139.00	44.7	86.6	3869.8	35.92	18	0.7609	10.8	Failed at knot
t12p	161.38	45.4	87.7	3985.6	40.49	19	0.8043	8.2	Clear
t12c	162.00	45.9	87.1	3993.9	40.56	20	0.8478	12.0	Did not fail
t13p	171.25	46.1	86.7	3992.9	42.89	21	0.8913	9.2	Did not fail
t10p	170.63	44.6	87.1	3886.0	43.91	22	0.9348	10.0	Did not fail
Averages	**95.63**	**44.64**	**86.97**	**3882.79**	**24.57**			**10.54**	

Standard deviation of ft':	**11.77**	
Coefficient of variation, Vr:	**0.48**	
5 percentile value (by interpolation), R0.05=	**9.60**	**MPa**
Rk = [1 - 2.7Vr/n**0.5]R0.05 =	6.95	MPa
Rbasic=Rk/[1.75(1.3+0.7VR)] =	**2.43**	**MPa**

SPECIMEN NUMBERING SYSTEM:
Prefix t: Denotes Tensile strength specimens
Suffix p: Denotes "plain" untreated specimens
Suffix c: Denotes CCA treated specimens.

TABLE 6:
ACTUAL DRY MOISTURE CONTENTS VS METER READING M/C'S

Comparative oven-dry results compared with drop-hammer moisture meter
Pennant Hills, 26 August, 1993:

Sample ID	Wet Weight gms	Dry Weight gms	Wet-dry weight gms	Moisture content meter, %	Moisture content wet-dry %	Dry density, kg/cum.
t1p1	53.8	48.88	4.92	11.0	10.07%	503.4
t1p2	49.11	44.55	4.56	11.0	10.24%	410.3
t3p1	45.56	41.36	4.2	10.0	10.15%	371.41
t3p2	48.53	44.05	4.48	10.0	10.17%	420.66
t5p1	54.2	49.18	5.02	10.0	10.21%	441.71
t5p2	54.3	49.28	5.02	10.0	10.19%	458
t7p1	42.25	38.17	4.08	9.0	10.69%	341.52
t7p2	47.24	42.74	4.5	9.0	10.53%	436.04
t15p1	53.89	48.69	5.2	11.0	10.68%	476.94
t15p2	54.28	49.1	5.18	11.0	10.55%	460.83
t2c1	55.55	50.76	4.79	11.0	9.44%	539.43
t2c2	50.1	45.76	4.34	11.0	9.48%	421.55
t3c1	45.35	41.06	4.29	11.0	10.45%	368.01
t3c2	45.61	41.27	4.34	11.0	10.52%	387.11
t6c1	46.45	41.97	4.48	11.5	10.67%	350.31
t6c2	54.56	49.32	5.24	11.5	10.62%	493.51
t8c1	42.44	38.53	3.91	11.0	10.15%	323.44
t8c2	49.9	45.31	4.59	11.0	10.13%	453.47
t10c1	43.22	39.02	4.2	10.0	10.76%	347.18
t10c2	45.41	41	4.41	10.0	10.76%	390.87
Averages				**10.6**	**10.32%**	**419.8** kg/cum.

SPECIMEN NUMBERING SYSTEM:
Prefix t: Denotes tensile strength spceimens
No. prefix Denotes specimen identifying number
Suffix p: Denotes "plain" untreated specimens
Suffix c: Denotes CCA treated specimens

Mechanical Property	Basic Working Stress (MPa)	Equivalent F-grading (after AS1720.1 Table 2.3)
Bending strength, fb'	6.24	F5
Modulus of Elasticity, MoE:	7164	F5
Shear strength, fs'	1.17	F11
Compressive strength, fc'	6.34	F7
Tensile strength, ft'	2.43	F3

TABLE 7: SUMMARY OF BASIC WORKING STRESSES FOR NORFOLK ISLAND PINE

(after adjustment to moisture content at 12%)

	Preliminary Classification			Resultant Stress Grade for Reference Population	
	Bending Strength	Tension Strength	Modulus of Elasticity		
	F	F	F	F	
	F	F+1	F-1	F	
	F	**F-1**	**F+2**	**F**	Closest
	F-1	F+1	F+2	F	
Norfolk pine	**F5**	**F3**	**F5**	**F5**	

(after AS/NZ 4063)

Make preliminary classification as F5, but that only good pieces be used in tension applications.

TABLE 8: F-GRADE CLASSIFICATION FOR NORFOLK ISLAND PINE

TABLE 9:

COMPARATIVE MECHANICAL PROPERTIES *(after Bootle Appendix 3)*

SPECIES	DENSITY		MODULUS OF ELASTICITY		MAX CRUSHING STRENGTH		STRENGTH GROUP	
	Green kg/cu.m	Dry MPa	Green GPa	Dry GPa	Green MPa	Dry	Green	Dry
A. Angustifolia (Parana pine)		530	9	11	28	54	S5	SD6
A. Bidwillii (Bunya ppine)		460	12	13	22	45	S6	SD5
A. Cunninghamii (Hoop pine)	680	530	10	13	28	53	S6	SD5
A. Heterophylla (Norfolk pine)	**420#**	**560***		**7.2**			**S6** (provisional only)	**SD6**
A. Hunsteinii (Klinki pine)		450	10	12	22	44	S6	SD6
Pinus Radiat, NZ	930	480	7.3	9.1	18	41	S6	SD6
Pinus Radiata, SA/Vic	800	500	8.1	10	19	42	S6	SD6

#After NSW State Forests

* After Lane-Poole

Note:

Whilst Bootle does not say, no doubt his tabulated results are based on small clear specimens.

The results for Norfolk pine are based on in-grade (full-size) tests.

TABLE 10:
BENDING STRENGTH TEST RESULTS FOR CLEAR NORFOLK PINE

	Length, L	1620	M = PL/3
Test dates: 19/24 February, 1993	Opt m/c %, M1 =	12	
University of Central Queensland, Rockhampto	a =	1.75	
	b =	0.0333	

Specimen No.	Max Applied Load, 2P kN	Avg width b, mm	Avg depth d, mm	Section Modulus, bdd/6 Z, cucm	Max. bending stress fb' M/Z, MPa	fb' adj for opt. m/c B2*, MPa	Strength Rank, i	Cumul. Dist'n Function, Fr(x)	Meter moisture content % M2
b18c	6.22	46.3	89.5	61.81	27.17	27.86	1	0.0139	13.0
b13p	5.4	45	90.2	61.02	23.89	31.30	2	0.0417	21.6
b5c	10.2	46.5	90	62.78	43.87	42.31	3	0.0694	10.5
b8p	9.02	46.6	89.3	61.94	39.32	43.99	4	0.0972	16.3
b3p	7.83	46.2	88.3	60.04	35.21	44.55	5	0.1250	20.5
b16p	11.6	46.1	90	62.24	50.33	48.30	6	0.1528	10.3
b8c	10.3	46.6	90	62.91	44.21	48.51	7	0.1806	15.6
b10c	7.88	43.6	91	60.18	35.36	49.52	8	0.2083	23.6
b12c	11.45	44.5	89.6	59.54	51.92	51.04	9	0.2361	11.3
b4c	11.2	46	89.5	61.41	49.24	51.80	10	0.2639	14.0
b17p	10.9	47	89.8	63.17	46.59	52.12	11	0.2917	16.3
b14c	9.8	43.5	88.6	56.91	46.49	54.57	12	0.3194	18.0
b9c	10.8	44.8	90	60.48	48.21	58.80	13	0.3472	19.3
b10p	12.6	43	88.5	56.13	60.61	62.14	14	0.3750	13.0
b17c	10.23	46.6	90	62.91	43.91	66.06	15	0.4028	25.6
Averages	**9.7**	**45.5**	**89.6**	**60.9**	**43.1**	**48.9**			**16.6**

Standard deviation for fb':	**26.37**	**18.22**	**MPa**
Coefficient of variation, Vr:	**0.61**	**0.37**	
5 percent value MofR (interpolating), R0.05 =		**34.6**	**MPa**
Rk = [1 - 2.7Vr/n**0.5]R0.05 =		25.61	MPa
Rbasic=Rk/[1.75(1.3+0.7VR)] =		**9.37**	MPa

*After ASTM D2915, method of adjustment for moisture content variation:

B2 = B1[(a - bM2)/(a - bM1)]

SPECIMEN NUMBERING SYSTEM:

Prefix b: Denotes bending strength specimens

Suffix p: Denotes "plain" untreated specimens

Suffix c: Denotes CCA treated specimens.

TABLE 11:
MODULUS OF ELASTICITY RESULTS FOR CLEAR NORFOLK PINE

Test dates: 19/24 February, 1993 M/c adj a= 1.44 pt m/c % 12
University of Central Queensland, Rockhamp b= 0.02 (M2)
SPECIMEN LENGTH, L = 1620

Specimen No.	Avg width b, mm	Avg depth d, mm	Moment of Inertia, I bddd/12 I, cm**4	Slope MofE straightline plot/2	E=(5)L**3/ 28.173*(4) E1	E adj for opt m/c E2	Rank	Cumul. Freq Distn Fr(xi)	Meter moisture content % M1	Remarks
Col (1)	Col (2)	Col (3)	Col (4)	Col (5)	Col (6)	Col 6a	Col (7)	Col (8)	Col (9)	Col (10)
b5c	46.5	90	282.49	0.1744	9317	9089	1	0.0128	10.5	Clear failure
b12c	44.5	89.6	266.75	0.1893	10709	10586	2	0.0385	11.3	Clear failure
b18c	46.3	89.5	276.61	0.1940	10584	10763	3	0.0641	13.0	Clear failure
b8c	46.6	90	283.10	0.1922	10245	10899	4	0.0897	15.6	Clear failure
b13p	45	90.2	275.20	0.1682	9223	10980	5	0.1154	21.6	Clear/borer holes
b14c	43.5	88.6	252.12	0.1670	9996	11106	6	0.1410	18.0	Clear failure
b9c	44.8	90	272.16	0.1780	9870	11237	7	0.1667	19.3	Clear failure
b10p	43	88.5	248.38	0.1820	11058	11245	8	0.1923	13.0	Clear
b16p	46.1	90	280.06	0.2255	12151	11816	9	0.2179	10.3	Clear
b10c	43.6	91	273.80	0.1730	9535	11820	10	0.2436	23.6	Clear failure
b4c	46	89.5	274.82	0.2226	12223	12645	11	0.2692	14.0	Clear failure
b17c	46.6	90	283.10	0.1862	9926	12835	12	0.2949	25.6	Clear failure
b3p	46.2	88.3	265.06	0.1936	11022	12842	13	0.3205	20.5	Clear
b17p	47	89.8	283.63	0.2279	12126	13062	14	0.3462	16.3	Clear
b8p	46.6	89.3	276.54	0.2269	12382	13338	15	0.3718	16.3	Clear/failed
Averages	45.49	89.62	272.92	0.19	10691	11618			16.59	

Standard deviation for MofE:	**1064**	**1120**	
Coefficient of variation, Ve:	**0.10**	**0.10**	
5 percentile MofE, E0.05 (interpolating) =		**10666**	**MPa**
Ek = [1 - .75*Ve/n0.5]Emean =**		**11401**	**MPa**
Ek = 1.5[1 - 2.7*Ve/n0.5]E0.05 =**		**14924**	**MPa**
Adopt lesser Ek =		**11401**	**MPa**

E2 = [(a - bM2)/(a - bM1)]MoE: a = 1.44, b = 0.02
(after ASTM D29 12% for M2 used as optimum m/c

TABLE 12:
SHEAR STRENGTH TEST RESULTS FOR CLEAR NORFOLK PINE

Max reaction, V = P/2

Test dat 23, 24 and 25 February, 1993 Length, L = 540 mm

University of Central Queensland, Rockhampt Opt m/c %, M 12

a = 1.33

b = 0.0167

Spec. No.	Max. Load, P, kN	Avg b mm	Avg d mm	X-sectional area (bxd) A,sqcm	Max shear stress, fs' 3V/2A N/sqmm=MPa	fs' adj. for opt. m/c S2*, MPa	Shear stress rank, i	Cumul. Dist'n Function Fr(xi)	Meter moisture content %	Remarks
s14p	15.9	46.0	88.3	4061.8	2.93	3.20	1	0.0147	17.8	Clear
s12p	16.7	46.3	88.3	4088.3	3.07	3.48	2	0.0441	20.0	Clear
s8c	16.0	45.3	89.5	4054.4	2.96	3.51	3	0.0735	22.6	Clear
s19c	20.0	44.5	90.0	4005.0	3.75	3.94	4	0.1029	15.3	Clear
s8p	18.6	41.8	88.3	3690.9	3.78	4.06	5	0.1324	16.7	Clear
s10p	21.6	46.7	89.7	4189.0	3.86	4.30	6	0.1618	19.0	Clear
s5c	21.8	46.5	88.5	4115.3	3.97	4.36	7	0.1912	18.0	Clear
s17c	21.5	45.0	90.0	4050.0	3.98	4.56	8	0.2206	20.7	Clear
s9p	21.7	44.2	89.7	3964.7	4.10	4.60	9	0.2500	19.3	Clear
s1p	24.3	46.0	88.0	4048.0	4.50	4.64	10	0.2794	14.0	Clear
s14c	24.5	45.8	90.2	4131.2	4.44	4.76	11	0.3088	16.6	Clear
s9c	22.3	44.5	90.0	4005.0	4.18	4.83	12	0.3382	21.0	Clear
s11c	24.4	45.0	88.5	3982.5	4.59	4.94	13	0.3676	16.8	Clear
s3p	27.5	45.0	88.2	3969.0	5.20	5.03	14	0.3971	9.7	Clear
s12c	25.4	44.8	90.0	4032.0	4.72	5.08	15	0.4265	16.8	Clear
s6p	28.0	46.0	88.5	4071.0	5.16	5.26	16	0.4559	13.3	
s2p	29.1	45.2	88.3	3991.2	5.47	5.33	17	0.4853	10.3	Clear
s4c	27.1	46.7	90.0	4203.0	4.83	5.42	18	0.5147	19.3	Clear
s3c	25.6	41.7	89.3	3723.8	5.16	5.59	19	0.5441	17.2	Clear
s2c	29.1	45.7	89.0	4067.3	5.36	5.67	20	0.5735	15.7	Clear
s13p	31.2	45.5	88.5	4026.8	5.81	5.69	21	0.6029	10.6	Clear
s10c	29.9	44.2	90.0	3978.0	5.64	5.92	22	0.6324	15.2	Clear
s20c	27.1	44.3	90.0	3987.0	5.09	6.05	23	0.6618	22.7	Clear
s15c	30.6	46.3	90.0	4167.0	5.51	6.14	24	0.6912	19.0	Clear
s16c	29.9	44.8	89.7	4018.6	5.57	6.30	25	0.7206	19.8	Clear
s5p	32.0	44.7	87.5	3911.3	6.14	6.44	26	0.7500	15.2	Clear
s15p	31.5	42.3	89.5	3785.9	6.24	6.83	27	0.7794	17.8	Clear
s1c	33.4	43.7	89.3	3902.4	6.42	6.86	28	0.8088	16.3	Clear
s11p	35.8	46.5	88.7	4124.6	6.51	6.92	29	0.8382	16.0	Clear
Averages:	**25.6**	**45.0**	**89.2**	**4011.9**	**4.8**	**5.2**	**15.0**	**0.4**	**17.0**	

Standard deviation for fs':	**1.00**	**1.01**	**MPa**
Coefficient of variation, Vr:	**0.15**	**0.15**	
5 percentile value (by interpolation), R0.05=		**3.49**	**MPa**
Rk = [1 - 2.7Vr/n**0.5]R0.05 =		3.23	MPa
Rbasic=Rk/[1.75(1.3+0.7VR)] =		**1.32**	**MPa**

*After ASTM D2915, method of adjustment for moisture content variation:

$$S2 = S1[(a - bM2)/(a - bM1)]$$

SPECIMEN NUMBERING SYSTEM:

Prefix s: Denotes shear strength specimen

Suffix p: Denotes "plain" untreated specimen

Suffix c: Denotes CCA treated specimen.

TABLE 13:

COMPRESSIVE STRENGTH TEST RESULTS FOR CLEAR NORFOLK PINE

Test dates 1,2 and 3 March, 1993 Opt m/c %, 12.0
University of Central Qld, Rockha M/c adjustment factors for compression (after ASTM D2915)
Temp: 20 deg C a = 2.75
Humidity: 50% b = 0.0833

Spec. No.	Max Comp. Load, C kN	Avg b mm	Avg d mm	X-sectional Area (bxd) A, sqmm	Max comp. stress fc' C/A C1, MPa	fc' adj for opt m/c C2*, MPa	Adj. Comp. stress Rank, i	Cumul. Dist'n Function Fr(xi)	Meter Moisture Content % M2	Remarks
c7c	75.82	40.7	89.3	3634.5	20.86	21.12	1	0.0128	12.3	clear
c9p	110.30	46.7	86.8	4053.6	27.21	25.70	2	0.0385	10.8	clear
c30c	110.40	45.0	90.0	4050.0	27.26	25.74	3	0.0641	10.8	clear
c7p	100.00	45.0	90.0	4050.0	24.69	26.52	4	0.0897	13.5	clear
c15p	102.90	44.8	87.7	3929.0	26.19	28.87	5	0.1154	14.0	clear
c6p	118.20	45.0	87.5	3937.5	30.02	30.24	6	0.1410	12.2	clear
c26c	86.39	43.7	88.7	3876.2	22.29	31.06	7	0.1667	18.0	clear
c25c	93.07	45.0	87.8	3951.0	23.56	31.38	8	0.1923	17.3	clear
c14p	111.30	43.7	88.2	3854.3	28.88	32.68	9	0.2179	14.5	clear
c11p	120.00	46.2	89.0	4111.8	29.18	33.21	10	0.2436	14.6	clear
c8c	131.40	45.0	89.0	4005.0	32.81	34.71	11	0.2692	13.2	clear
c6c	109.40	45.0	88.0	3960.0	27.63	37.27	12	0.2949	17.5	clear
c2c	132.70	45.0	89.7	4036.5	32.88	41.19	13	0.3205	16.3	clear
c5c	148.20	44.0	88.0	3872.0	38.27	44.03	14	0.3462	14.8	clear
c13p	122.10	44.7	89.7	4009.6	30.45	48.90	15	0.3718	20.0	clear
Averages	**111.5**	**44.6**	**88.6**	**3955.4**	**28.1**	**32.8**			**14.7**	

Standard deviation, fc':	**4.35**	**7.22**	MPa
Coefficient of variation, Vr:	**0.15**	**0.22**	
5 percentile value (by interpolation), R0.05=		**25.72**	**MPa**
Rk = [1 - 2.7Vr/n**0.5]R0.05 =		21.78	MPa
Rbasic=Rk/[1.75(1.3+0.7VR)] =		**8.56**	MPa

* After ASTM D2915, method of adjustment for moisture content variation

$$C2 = C1[(a - bM2)/(a - bM1)]$$

SPECIMEN NUMBERING SYSTEM:
Prefix c: Denotes Compressive strength specimens
Suffix p: Denotes "plain" untreated specimens
Suffix c: Denotes CCA treated specimens

TABLE 14:
TENSILE STRENGTH TEST RESULTS FOR CLEAR NORFOLK PINE

Test date: **26 Aug, 1993**
State Forests of NSW, Pennant Hills, Sydney

Specimen No.	Max Load T, kN	Avg b mm	Avg d mm	X-sectional area,bxd A, sqmm	Max tensile stress ft' T/A, MPa	Tensile Stress rank, i	Cumul. Dist'n Function Fr(xi)	Specimen Moisture Content % M2	Remarks
t1c	57.63	45.8	87.6	4012.4	14.36	1	0.0217	11.0	Clear
t3p	75.63	44.1	86.4	3811.5	19.84	2	0.0652	9.7	Clear
t13c	87.00	43.7	86.9	3795.4	22.92	3	0.1087	9.8	Failed edge jaw
t4c	120.38	44.3	87.3	3868.7	31.12	4	0.1522	10.0	Clear
t2p	129.25	44.5	87.2	3884.8	33.27	5	0.1957	10.7	Clear
t12p	161.38	45.4	87.7	3985.6	40.49	6	0.2391	8.2	Clear
t12c	162.00	45.9	87.1	3993.9	40.56	7	0.2826	12.0	Did not fail
t13p	171.25	46.1	86.7	3992.9	42.89	8	0.3261	9.2	Did not fail
t10p	170.63	44.6	87.1	3886.0	43.91	9	0.3696	10.0	Did not fail
Averages	**126.1**	**44.9**	**87.1**	**3914.6**	**32.2**			**10.1**	

Standard deviation of ft':	**10.27**	
Coefficient of variation, Vr:	**0.32**	
5 percentile value (by interpolation), R	**14.36**	**MPa**
Rk = [1 - 2.7Vr/n**0.5]R0.05 =	10.23	MPa
Rbasic=Rk/[1.75(1.3+0.7VR)]	**3.84**	**MPa**

SPECIMEN NUMBERING SYSTEM:
Prefix t: Denotes Tensile strength specimens
Suffix p: Denotes "plain" untreated specimens
Suffix c: Denotes CCA treated specimens.

TABLE 15:

SUMMARY OF BASIC WORKING STRESSES FOR CLEAR NORFOLK PINE

(after adjustment to optimum moisture content at 12%).

Material Property	Basic Working Stress (MPa)	Equivalent F-grading (after AS1720.1 Table 2.3)
Bending strength, fb'	9.37	F8
Modulus of Elasticity, MoE:	11401	F11
Shear strength, fs'	1.32	F14
Compressive strength, fc'	8.56	F11
Tensile strength, ft'	3.84	F5

Note: This preliminary classification is based on a limited number of results and interpretation should be treated with caution.

	Preliminary Classification			Resultant Stress Grade for Reference Population	
	Bending Strength	Tension Strength	Modulus of Elasticity		
	F	F	F	F	
	F	F+1	F-1	F	
	F	F-1	F+2	F	Closest
	F-1	F+1	F+2	F	
Clear Norfolk pine	F8	F4	F11	F8	

(after AS/NZ 4063)

Note: Make preliminary clear classifcation as: F8
with caution that tension applications be viewed closely.

TABLE 16: F-GRADE CLASSIFICATION FOR CLEAR NORFOLK ISLAND PINE

PHOTOGRAPHS

Photo 1: Sheer, rugged cliffs at Cascade jetty, typical of the Island's rugged coastline (1668/24)

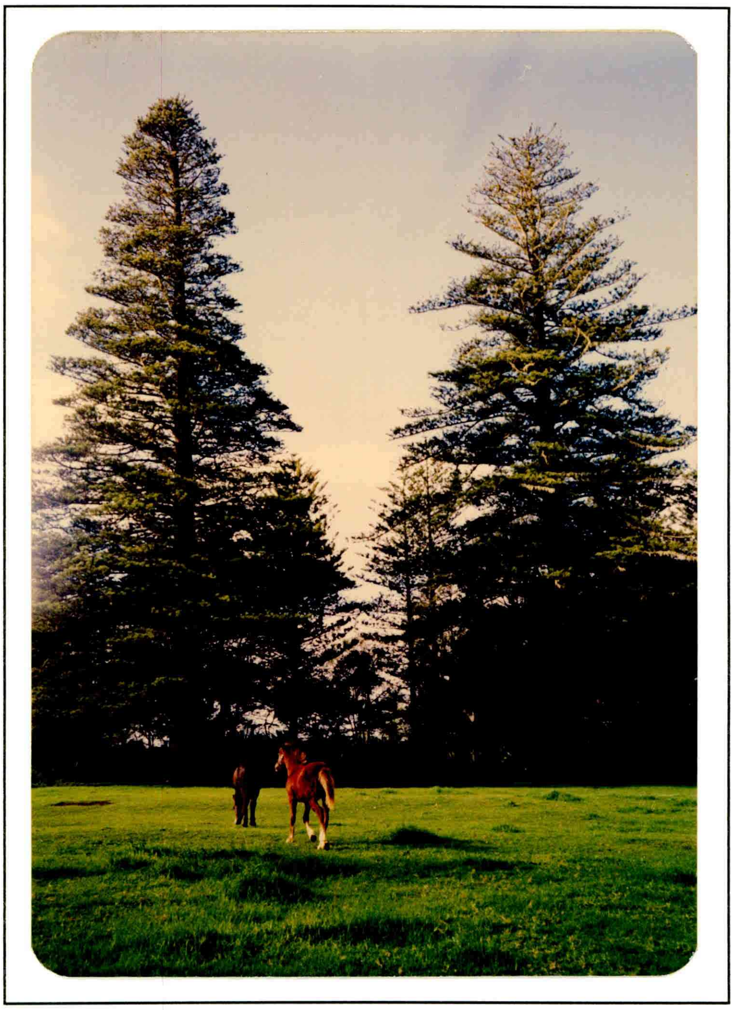

Photo 2: Norfolk pine in its natural environment (0552/0)

Photo 3: 2 bundles of timber at wharf awaiting shipment.
One bundle for Forest Research Institute at Pennant Hills,
other bundle for University of Central Queensland, Rockhampton
(1668/13)

Photo 4: Bundled timber loaded on lighter for transfer to awaiting ship (1668/20)

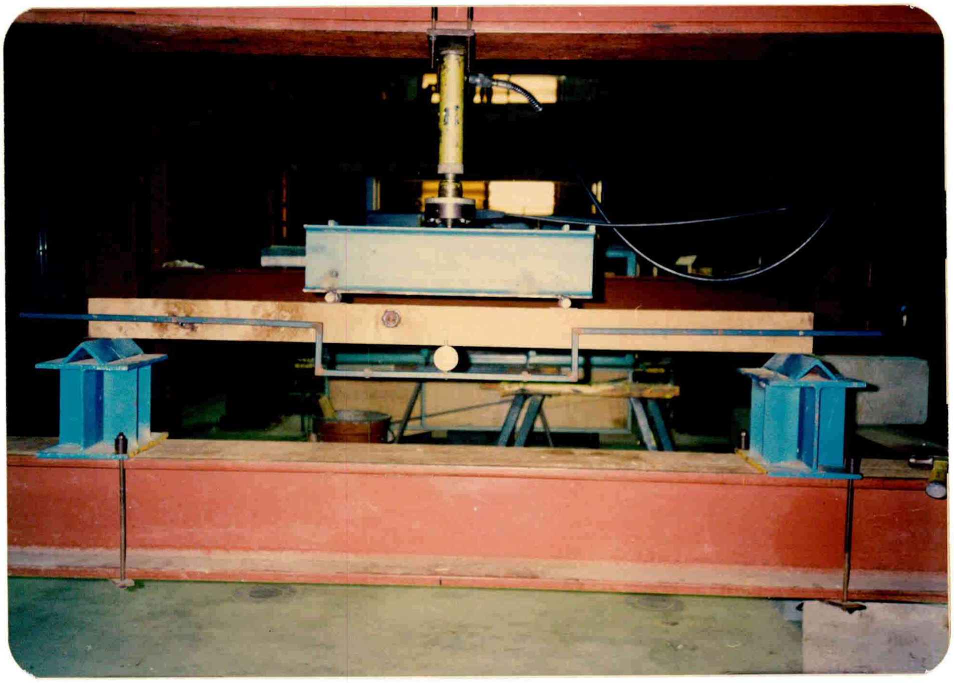

Photo 5: Extreme Fibre Stress (MOE/MOR) testing rig (Y002/7)

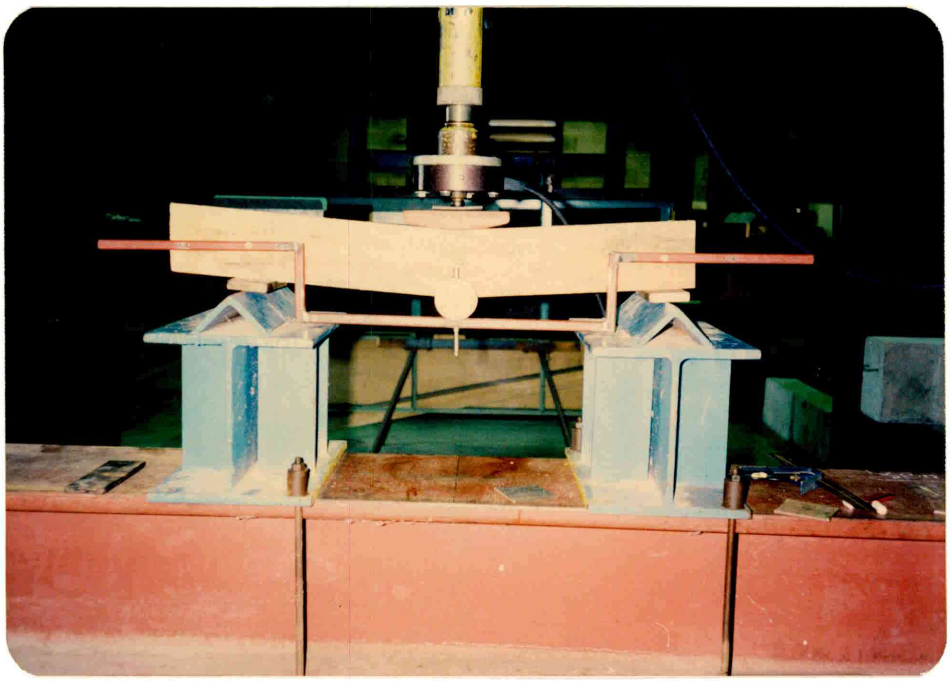

Photo 6: Standard test rig for measurement of shear strength perpendicular to grain (Y002/12)

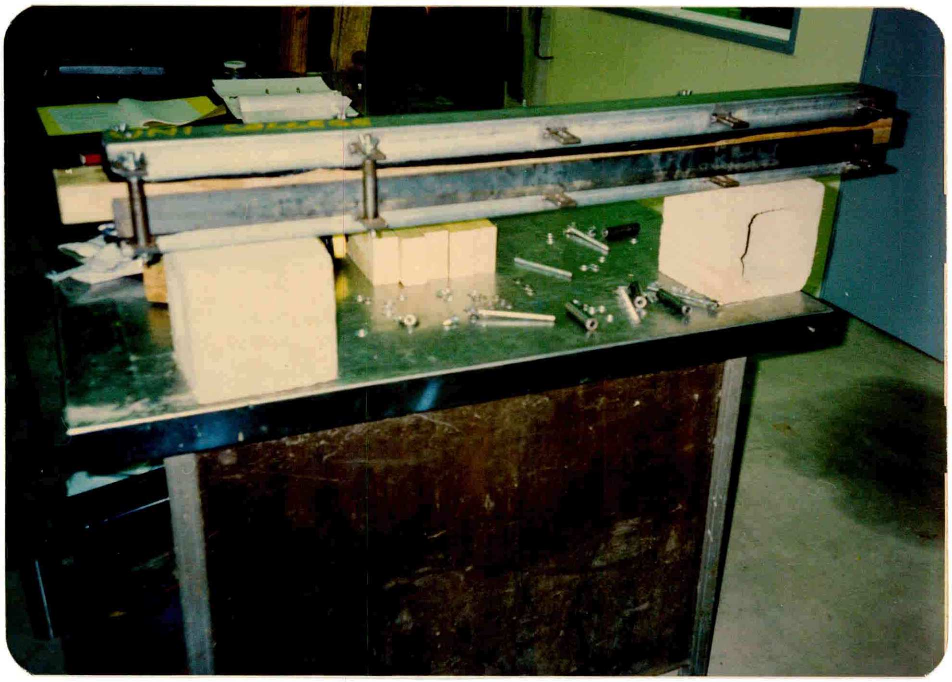

Photo 7: Compressive Strength Test rig and specimen (9934/4)

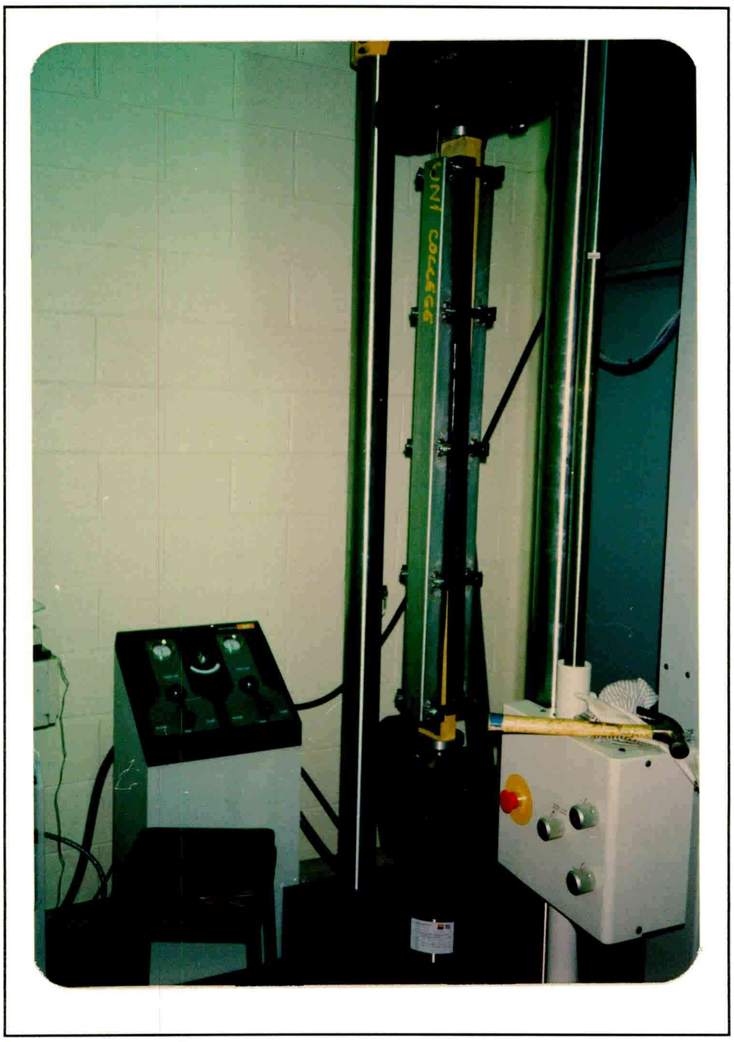

Photo 8: Instrumentation and equipment associated with compressive strength testing (9934/6)

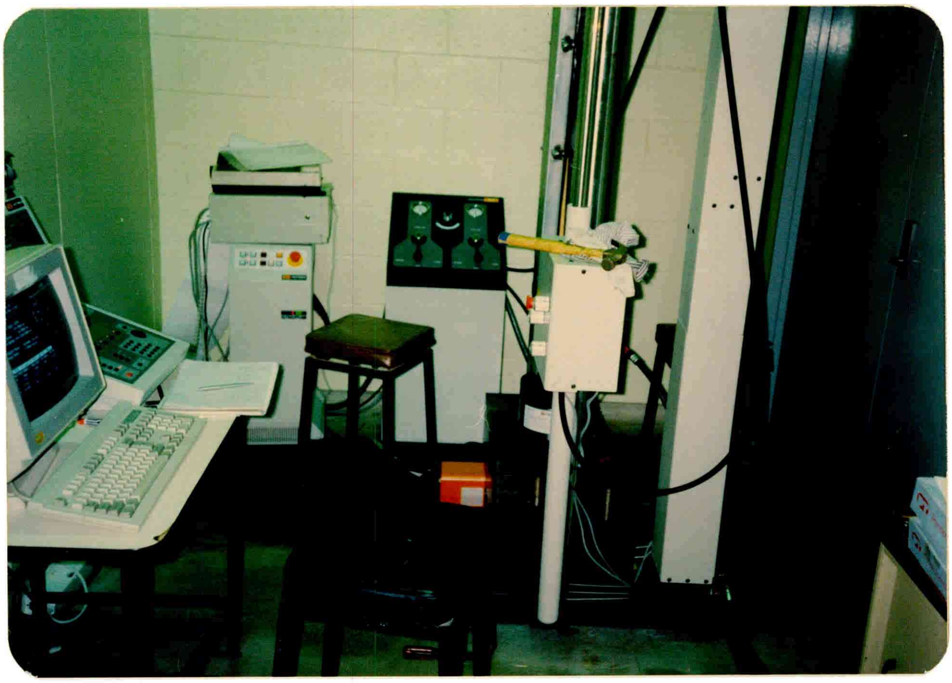

Photo 9: Computer terminal controls for compression loading (9934/5)

Photo 10: Tensile testing rig at NSW State Forest's Research Division, Pennant Hills (460366/27)

Photo 11: Specimen clamped in tensile test rig at Pennant Hills (460366/24)

Photo 12: Instrumentation and controls for tensile test rig at Pennant Hills (460366/26)

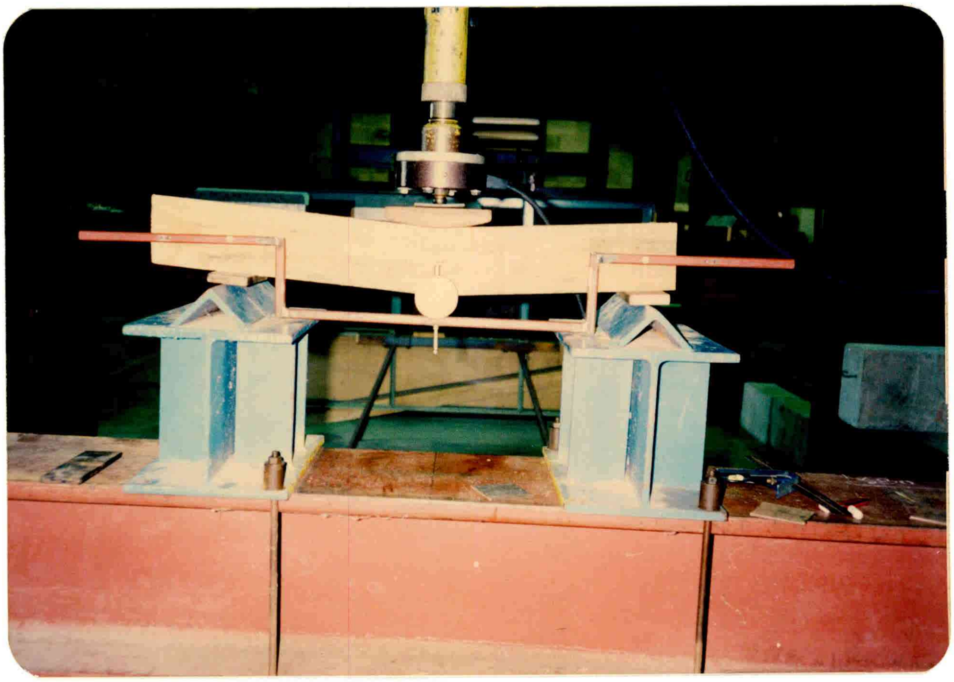

Photo 13: Shear strength testing rig, Feb 1993 (9934/2)

Photo 14: Shear strength tests (s1p to s15p, untreated) Feb 1993 (9934/0)

Photo 15: Shear strength tests (s1c to s13c, treated) Feb 1993 (9934/1)

Photo 16: Shear strength tests (s13c to s20c, treated) Feb 1993 (9934/3)

Photo 17: Bending strength tests (b1p to b18p, untreated) Feb 1993 (Y002/3)

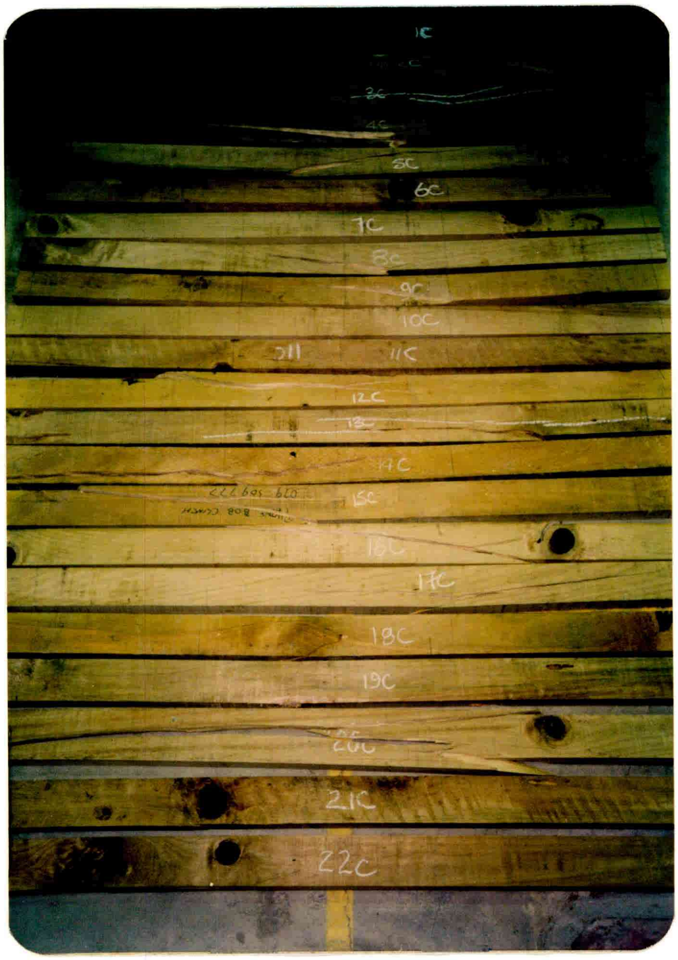

Photo 18: Bending strength tests (b1c to b22c, treated) Feb 1993 (Y002/11)

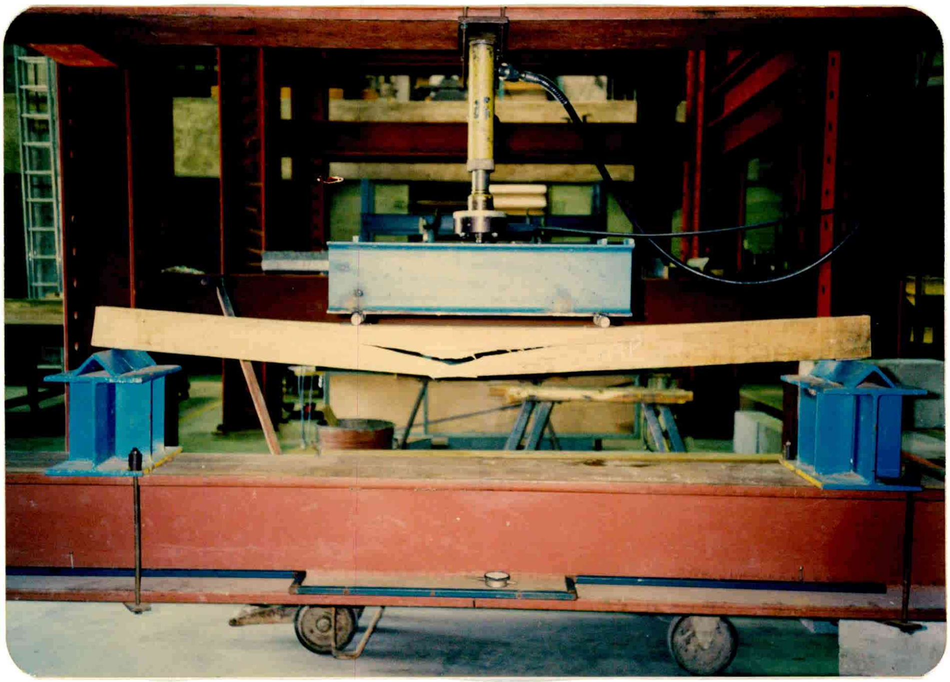

Photo 19: Example of failure under bending (sample 17p), Feb 1993 (Y002/2)

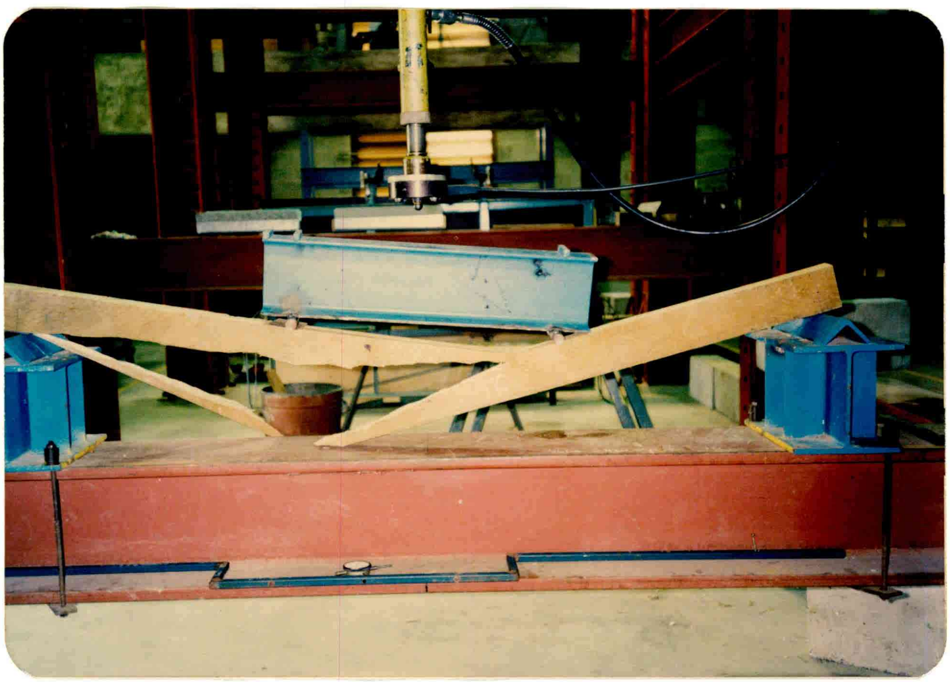

Photo 20: Example of bending failure (sample 14c), Feb 1993 (Y002/6)

Photo 21: Compressive strength failures (c1c to c8c, treated), Mar 1993 (9934/12)

Photo 22: Compressive strength failures (c17c to c24c, treated), Mar 1993 (9934/9)

<u>Photo 23:</u> Compressive strength failures (c1p-c8p untreated), Mar 1993 (9934/13)

<u>Photo 24:</u> Compressive strength failures (c9p to c16p, untreated), Mar 1993 (9934/10)

Photo 25: Compressive strength failures (c25c-c31c treated), Mar 1993 (9934/16)

Photo 26: Tensile strength failures (t1p to t15p, untreated), Aug 1993 (1694/0)

Photo 27: Tensile strength failures (t1c to t14c, treated), Aug 1993 (1694/3)

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